Evaluating the Impacts of Transit Signal Priority Strategies on Traffic Flow Characteristics:
Case Study along U.S.1, Fairfax County, Virginia

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(ABSTRACT)

Transportation engineers and planners worldwide are faced with the challenge of improving transit services in urban areas using low cost means. Transit signal priority is considered to be an effective way to improve transit service reliability and efficiency. In light of the interest in testing and deploying transit signal priority on a major arterial in Northern Virginia, this research focuses on the impacts of transit signal priority in the U.S.1 corridor in Fairfax County in terms of benefits to transit and impacts on other traffic. Using a simulation tool, VISSIM, these impacts were assessed considering a ten second green extension priority strategy.

The results of the simulation analysis indicated that the Fairfax Connector buses benefit from the green extension strategy with little to no impact on the other non-transit traffic. Overall, improvements of 3.61% were found for bus service reliability and 2.64% for bus efficiency, while negative impacts were found in the form of increases in queue lengths on side streets by a maximum value of approximately one vehicle.

Because this research has provided a foundation for the evaluation of transit signal priority for VDOT and Fairfax County engineers and planners, future research can build upon this effort. Areas identified for future research include the provision of priority for the entire bus route; combination of emergency preemption and transit priority strategies; evaluation of other priority strategies using system- wide priority concepts; and the impacts of priority strategies in monetary terms.

DEDICATION

I would like to dedicate this work to my mother, Vibhavari Deshpande, for all the sacrifices she made to ensure I had a good education.

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Chapter 1 : INTRODUCTION

Transportation engineers worldwide are faced with the challenge of providing more reliable and efficient transportation system. Given the ongoing growth in travel demand and constraints surrounding traditional ways to enhance carrying capacity, attention is being given to potential cost effective alternatives to increase system efficiency without major infrastructure investments. Such transportation system management strategies have evolved over the years as potential cost effective alternatives to sustain the immense pressure over the transportation system, especially in the urban areas. A strategy currently being considered to enhance the efficiency of public transport service reliability is transit signal priority.

The inefficiency of urban bus systems can be attributed in part to the delay experienced at signalized intersections. Past research shows that the stopped delay at intersections comprises about 20 percent of overall transit delay (Zhang, 2001). With rapid development in communication technology, more and more jurisdictions are considering advanced signal control systems and priority strategies. An advantage of such control systems is that they can accommodate changing demands in traffic. Such systems can also perform better under varying demand levels and can be designed to identify a particular type of vehicle such as transit vehicles to provide some form of priority control.

For more than two decades, transit operators and traffic engineers have implemented and evaluated traffic signal priority systems for transit with varying degrees of success. Research has shown that priority strategies may contribute to increase in the quality of transit service but at the same time it is also important to note the potential negative impacts on the other facility users. Research efforts underway around the world reflect the interest among the professionals to examine the potential benefits and to quantify the impacts of these strategies on the total transportation system.

1.1 Problem Statement

The Virginia Department of Transportation (VDOT) together with Fairfax County is performing an operational field test of transit priority strategies along U.S.1 in Northern Virginia. A primary objective of the field test is to enhance the performance of the Fairfax Connector buses along U.S.1 without having substantial negative impacts on other non-transit traffic. In light of the interest in testing and deploying the priority system, there is a need for an evaluation framework and measures in order to determine the impacts associated with these priority strategies as applied to transit as well as overall traffic flow characteristics. An evaluation framework and measures would provide an approach for local stakeholders to examine the likely impacts of the potential deployment to assess the degree to which the deployment achieves its desired objectives. In particular, this research focuses on determining the extent to which traffic signal priority strategies might improve the service reliability of Fairfax Connector buses in the corridor and associated impacts on other traffic.

1.2 Research Goal and Objectives

The overall goal of the research is to evaluate the impacts of traffic signal priority systems on the traffic flow characteristics along U.S.1 in terms of benefits to transit and impacts on other non-transit traffic. This research intends to address two major objectives.

The first objective is to identify a set of performance measures to assess the impacts of traffic signal priority system deployment on U.S.1 in Northern Virginia. These measures focus on the problems and objectives stakeholders hope to address by deploying the proposed system. These measures will help both traffic and the transit operators identify the consequences of transit priority systems.

The second objective is to illustrate the use of measures identified above to evaluate the impacts of transit priority on U.S.1. These measures are used with data collected in the field and with VISSIM, a simulation model.

1.3 Scope Of Research

To improve our understanding about the issues related to the assessment of traffic signal priority systems, a thorough literature review was presented. The literature review will help identify and synthesize appropriate references of research projects involving the deployment of traffic signal priority systems. In particular the focus provides background on the objectives of signal priority; discusses the various technologies used; and summarizes prior experiences in U.S.

An evaluation framework is presented to address the expectations of the stakeholders. This framework is primarily based on the findings of research conducted at Virginia Tech (Chang, 2002). The research herein identifies the appropriate measures from the evaluation framework to test transit signal priority on U.S.1. A primary aim here is to help VDOT and Fairfax County assess the performance of the traffic signal priority system in terms of the extent to which the stated objectives are met and various impacts are realized, along U.S.1 in Northern Virginia.

The next step involved collecting data to use the appropriate measures in the evaluation framework. This consisted of field study performed by a team of researchers. A subsequent step was to select a simulation approach. The review of existing simulation models (Ova, Smadi) showed that VISSIM was a good candidate. VISSIM is a microscopic model similar to CORSIM in display but capable of detailed consideration of the roadway, traffic, and passenger effects on transit performance. VISSIM provided the level of fidelity required to incorporate the level of detail required to complement a field study. The use of VISSIM gives an additional advantage of combining the benefits of both approaches namely field study and simulation-based studies. It also gives an opportunity to conduct a comparative study between predicted impacts by VISSIM and actual observations on the field in the 'after' case, once the system is deployed on U.S.1.

In the end, conclusions and recommendations will describe the major findings of the research.

1.4 Thesis Contribution

This research is significant in several ways. First, it focuses on the first operational deployment of a traffic signal priority system in the Northern Virginia region. Secondly, the results are very important for the transportation community because of increasing interest in the impacts of such priority systems on the total transportation system. Thirdly, this research provides the basis for a comparison of the simulation results reported herein and the "before" and "after" field study currently in progress. Finally, this is the first activity at Virginia Tech to use VISSIM to model transit priority, and thus is paving the way for future research to evaluate the impacts of transit priority.

1.5 Thesis Organization

This thesis is consists of six chapters. Following this chapter, Chapter 2 reviews the work that has been done in the area of signal priority systems and includes a review of different strategies used for traffic signal priority; different detection technologies; the impacts of priority on the transportation system; and actual signal priority experiences in the United States as well as in other parts of the world.

Chapter 3 introduces the research approach and the evaluation framework to assess the priority deployment on U.S.1 in Northern Virginia. The framework includes different measures and the data collection methods required to evaluate priority strategies.

Chapter 4 describes the U.S.1 case study corridor and the traffic flow and transit characteristics in the corridor.

Chapter 5 describes VISSIM, the simulation model used to evaluate the impacts of signal priority in the U.S.1 corridor. General overview of VISSIM is performed along with the data requirements and the calibration method.

Chapter 6 reviews the results based on VISSIM simulations. This chapter also summarizes the major conclusions of the research and identifies the areas for future research.

Chapter 2 : LITERATURE REVIEW

The first step in the research for traffic signal priority systems is to study the vast amount of literature available in this subject. This enables the author to understand the state-of-art traffic signal priority systems and findings in previous studies. It is important to understand the different approaches taken by various researchers in the past with respect to their objectives, in order to formulate an approach for study that will cover all the aspects related to the deployment and the analysis in this research. The literature review also presents evidence that supports or rejects the theory and hypotheses to be posited in this research.

This Chapter also reviews traffic signal priority fundamentals including the objectives of the priority strategies, different strategies and technologies used and summarizes the results and findings in past studies.

2.1 Overview of Traffic Signal Priority Systems

Traffic Signal priority (TSP) has been deployed for more than three decades to facilitate the movement of in-service transit vehicles, either buses or streetcars, through traffic-signal controlled intersections by reducing the time that transit vehicles spend delayed at intersection queues(Chang, 2002). TSP can reduce transit delay and travel time to improve transit reliability, thereby increasing the quality of the transit service. It also has the potential of reducing overall delay at the intersection on a per-person basis. TSP is a tool, effectively used to improve the overall efficiency of the transportation system through basic transportation principles and advanced technological solutions. At the same time, it is essential to understand its potential impacts on other facility users, keeping them to the minimum to achieve maximum benefits with acceptable amount of side effects.

2.2 Priority vs. Preemption

Before discussing the strategies used to implement TSP, it is important to revisit the definition of priority and how it differs from preemption. Priority and preemption are often used synonymously, when in fact they are different systems (Chang, 2002). These two systems may use similar technologies, which are implemented in identical fashion. However, signal priority modifies the normal signal operation to better accommodate the transit vehicles, while preemption interrupts the normal operation for special events (e.g. emergency vehicle responding to emergency call).

Preemption is traditionally used at railroad crossings and at signalized intersections for emergency vehicles where a high degree of priority is warranted for safety and performance reasons. The granting of preemption typically has minimal restrictions, owing to the importance afforded to safety of public emergency workers and response to individuals in need. When a traffic signal is preempted then there is no consideration for maintaining the existing signal-timing plan such that the coordination can be maintained between adjacent traffic signals. Preemption uses a special signal timing plan, requiring the traffic signal controller to transition out of and back into the coordinated operation of normal signal timing plan.

Traffic signal priority attempts to provide some priority service opportunities within the coordinated operation of traffic signal. This allows reduced delay but not elimination of delay, to transit vehicles without significantly impacting the other traffic. Since transit service is typically much more frequent than rail or emergency vehicles service, this allows the system to maintain a better level of performance. It should be noted that preemption could be applied to the transit buses but the impacts of this action must be carefully considered. The application of priority is often subjected to conditions and criteria, mostly to limit the impacts on the other traffic.

Objectives of preemption and priority are quite different (Chang, 2002), though the system architecture in implementation may appear similar. The objectives of priority will be studied in detail later in this chapter. Commonly sighted objectives of emergency vehicle preemption are:

- The system shall significantly reduce response time to emergencies.
- The system shall significantly improve the safety and health of emergency personnel by reducing accidents, relieving stress or both.
- The system shall reduce accidents between non-emergency vehicles related to responding emergency units at intersections where it is installed.

2.3 Objectives of Priority

The primary objective of a traffic signal priority system is to improve the public transit system by reducing the delay it incurs at the signalized intersections. In the U.S. 1 case study the following objectives were established by the stakeholders including the Virginia Department of Transportation (VDOT) and Fairfax County.

1. the system should be deployed to improve bus service reliability for Fairfax Connector buses along the corridor;
2. the system should also improve the bus efficiency at which the Fairfax Connector buses operate in the corridor;
3. the system should have minimal impacts on the other facility users including traffic on side streets; and,
4. the priority system should be a part of larger ITS system that includes preemption system for emergency vehicles, providing a safer interaction between buses and emergency vehicles; this is very important considering high frequency bus service along the main line during rush hours and emergency vehicle entering from the side street.

These objectives form the basis for the evaluation framework and selected measures and that are presented in this research.

2.4 Design Implementation Issues- Traffic Signal Priority Systems

Before presenting details about various strategies and technologies used for traffic signal priority systems, it is essential to study the components that make the traffic priority signal system. This section reviews the overall structure of the traffic signal priority systems at a higher level and introduces the different challenges faced by transportation engineers in successful planning and deployment of traffic signal priority system. The information in this section is based on the knowledge obtained from the literature review of past work (Gifford, Pelletiere, and Collura, 2002) and well supplemented by the author's academic background.

There are many factors that affect implementation of traffic signal priority systems (ITS America, 2002). They can be categorized in two major categories: traffic related factors and transit related factors. Over the years, traffic and transit engineers have had tough times to agree on the purpose and value of traffic signal priority systems. Many times it has been a challenge to get all the stakeholders at the same table to discuss possible use of traffic signal priority systems, due to their conflicting views. There have been different opinions among the professionals about potential benefits of the deployment of traffic signal priority system as against the large amount of money invested. The case study orientation of this research concentrates more on the planning and design implementation issues.

2.4.1 Traffic Signal Related Issues

2.4.1.1 Roadway Geometry

Roadway geometry is one of the most critical factors for the operation of any traffic signal priority system as it directly dictates the capability of the system and types of possible operations. Roadway geometry is impacted by the surrounding land development, which dictates the number and location of the intersections and the transit stops. Roadway geometry offers challenges such as plane of vision e.g. (horizontal and vertical line of sight) for the detection technologies.

2.4.1.2 Traffic Volumes

Traffic volumes are a crucial factor because they change with time for any given intersection or segment of the road. During peak hours the network is often operating under constrained conditions with higher volumes of general-purpose traffic and transit as well. It is crucial for the transit operators to achieve the maximum benefits from the traffic signal priority systems during peak hours, as there is a higher transit usage at this time. The impacts of traffic signal priority systems primarily depend on the volume of traffic in the direction of the transit route as well as the volume conflicting with the transit route.

2.4.1.2 Traffic Signal System including Hardware and Software

This is an operating factor and relates to the extent to which the traffic signal priority system is able to achieve the desired results. For example, it is critical that the signal hardware and software can deploy intended priority strategies and can store and transfer the data in the required format.

2.4.1.3 Pedestrians

Pedestrians have an influence on the operation of the traffic signal priority systems. In most instances, the time required for a pedestrian to safely cross the street at a signalized intersections limits the time available for the signal priority. Also, pedestrians are often the transit customers hence they may require the service at the same time as the transit vehicles.

2.4.1.4 Adjacent Intersection Operations

Adjacent intersection operations are very important to understand in order to achieve the progression for the transit vehicles. This is very crucial in the case of closely spaced intersections. This is a crucial factor in this research as the study corridor consists of 7 intersections in a stretch of 1.3 mile. It is very important to maintain coordination to the extent possible and consider this prior to deployment of the priority system.

2.4.2 Transit Related Issues

2.4.2.1 Type of Transit System

This has an impact on the traffic signal priority system, as it will be easier to implement the system for rail-based than for road-based transit. Rail systems are generally on exclusive (or semi exclusive) right of ways and so prediction of vehicle arrival times at the intersections where they intersect with normal traffic, tend to be more accurate than the bus system because of the traffic impacts. Dwell time is also a major contributor to the uncertainty in arrival to the intersection and is in part why express bus services benefit more form traffic priority system.

2.4.2.2 Transit Stops

The location of transit stops relative to a signalized intersection may impact the effectiveness of the traffic signal priority system. Studies have shown that the far side stops are more compatible with priority systems than near side stops as discussed below.

Near side stops present some additional challenges related to where the transit vehicle should be detected. If the transit vehicle is detected upstream of the transit stop then the dwell time at that near side stop needs to be considered. This dwell time can be variable. Near side stops provide a challenging situation often referred as triple-stop-point, where a queue of vehicles waiting at the intersection makes the transit vehicle stop at the back of the queue, then stopping again at the stop to pick up the passengers, and again at the intersection. Researchers have proposed some solutions to this problem. For example, requiring the driver to shut down the emitter when the vehicle approaches the near side stop; however this adds to the driver’s stress, Connecting the power to the emitter to the door of the transit vehicle in order to turn the emitter off when the door is open may be a strategy to consider.

Far side stops are more compatible with the traffic signal priority system, but they may be unsafe and lead to rear end accidents.

2.5 Priority Strategies

Research on traffic signal priority systems has been conducted worldwide over last three decades. There have been many research attempts in urban areas all over the United States and also in Canada, Japan and Europe. Vehicle signal priority has been used with light rail transit, express bus services, and /or regular transit services. In general, signal priority strategies can be classified in to three major categories: passive priority, active priority and real time/adaptive priority strategies (ITS America, 2002).

2.5.1 Passive Priority Strategies

Passive priority strategies attempt to favor routes with significant transit use in the system wide traffic signal timing schemes, giving consideration to factors such as timing coordinated signals at average transit vehicle speed instead of average automobile speed, reducing the cycle length to reduce delay. This approach tries to better accommodate the transit vehicles while balancing the auto-favored system with basic traffic engineering principles. In general, when transit operations are predictable (e.g. consistent dwell times), transit frequencies are high, and traffic volumes are low, passive priority strategies can perform efficiently. It includes providing progression for transit vehicles adjusting the offsets according to average operating speed of transit buses, providing phase sequence designed to more frequently serve a phase that has high transit demand, or by providing transit by-pass at metering locations. The following are commonly used passive priority strategies.

- Adjustment of Cycle Length

Shortening the cycle length at intersections along the transit route helps to reduce transit vehicle delay, but it also reduces the capacity of the intersection. So the benefits to the transit vehicles must be weighted against the cost associated with the reduction in capacity resulting from the shorter cycle lengths. This approach can be efficient where we have low traffic volumes and high frequency of transit buses.

- Area-wide Timing Plans.

Area wide timing plans is set such that they favor transit bus progression through the network. There are two different approaches to how these plans can be generated. First, allocating the green time based on the number of passengers, rather than vehicles, which pass through the network. This basically favors the high occupancy transit vehicles over single occupancy automobiles increasing the person throughput of the network. To use this technique, vehicle occupancies must be known to allow average passenger delays to be minimized. For this purpose automatic passenger counters can be installed on the transit buses. Secondly, area-wide timing plans can also be designed to give priority to transit vehicles by coordinating intersection signal plans to allow transit vehicle progression through the network. The effectiveness of this technique is highly dependent on the ability to forecast the bus travel times between the network intersections, due to the large variability in dwell times. As a result, this technique is best suited for the express transit routes, because these routes are less prone to variability in travel times between intersections.

- Phase Splitting

Phase splitting refers to splitting priority phases in to multiple phases and repeating these phases within the same cycle. Although the cycle length is not changed in these strategies, they reduce the capacity of the intersection.

- Metering Vehicles

Metering a signal phase can restrict the flow of vehicles entering a designated roadway in a network. This kind of metering reduces the flow downstream of the bottleneck. Transit signal priority in this case can allow transit buses to by-pass the metered signal phases, thus providing a smoother flow for transit vehicles.

2.5.2 Active Priority Strategies

Active priority strategies involve detecting the presence of the transit vehicles, and depending on the system logic and traffic conditions, provide special treatment for them. This relies on the advanced communication technologies to both detect the presence of a transit vehicle, and predict its arrival time at the intersection. There is a need for communication link between signal controller and the transit vehicles. As a result, initial capital investment and periodic maintenance costs are required to operate these strategies. The following are commonly used active priority strategies.

- Phase Extension (Green Extension)

Green extension strategy extends the green time for transit vehicle movement when such vehicle is approaching the intersection. This strategy only applies when the signal is green for approaching transit vehicle. This is an effective strategy as it reduces the delay for the transit vehicle substantially by accommodating it in the same cycle and thus not making it wait for another complete cycle to get the green. The impacts on the other traffic are also less as it does not change or disrupt the phasing.

- Early Green (Red truncation)

Early green strategy shortens the green time of crossing traffic or conflicting phases to expedite the return to green (i.e. red truncation) for the movement where transit vehicle has been detected. Additional green time is allocated to the beginning of the transit vehicles normal green phase to reduce delay. This applies when the signal is red for the transit vehicle movement when the vehicle is detected.

- Actuated Transit Phase (Red interruption)

Actuated transit phases are only displayed only when a transit vehicle is detected at the intersection. An example could be an exclusive left turn phase for the transit vehicle. The left turn is only displayed when the transit vehicle is detected in that lane. Another example would be the use of queue jump phase that will allow the transit vehicle to enter the downstream link ahead of the normal traffic stream.

- Phase Insertion

This is basically an insertion of a special phase for the transit vehicle. A short green phase on the transit vehicles is added in to its normal red phase while conflicting approaches are forced to stop. The phase is only inserted when a transit vehicle is detected and it requests the priority.

- Green Truncation

If the transit vehicle is detected far from the intersection, truncating the transit vehicles green would increase the probability of the transit vehicle to receive a green during next cycle as it arrives at the intersection. Delay to cross street may be reduced through the green truncation. The additional green given to the transit vehicle is truncated once the transit vehicle has passed through the intersection.

- Phase Rotation

The order of signal phases can be rotated to provide the priority to the transit vehicle. For example, a northbound left turn could always be a lagging phase, meaning it follows the opposite through signal. A left turning bus, requesting priority that arrives before the green signal for the through phase begins could request the left turn phase. With the phase rotation concept, the left turn phase could be served as a leading phase in order to expedite the passage of the transit vehicle.

Active priority measures are broadly classified in to two main categories: unconditional priority and conditional priority. In the former approach, the priority is granted whenever the transit vehicle is detected at the intersection. This approach is similar to the preemption where the priority is always granted, subject to safety considerations including the minimum clearance intervals. In the later approach the priority is only granted if predefined conditions are satisfied. Typically these conditions will include the considerations for the saturation on the side streets, the schedule adherence of the transit vehicle and/or the transit rider ship. Conditional priority is used more often at locations within a network of closely spaced traffic signals, because intersections do not operate independently in this environment.

2.5.3 Adaptive/ Real Time Strategies

Adaptive/real time strategies provide priority while simultaneously trying to optimize some given performance criteria. The criteria may include person delay, transit vehicle delay, automobile delay, and/or combination of these criteria. These strategies continuously optimize the effective timing plan based on real time, observed data. They typically require early detection of transit vehicles in order to provide more time to adjust the signals to provide priority while minimizing the impacts. These systems also often require the ability to update the transit vehicles arrival time, which can vary according to number of stops and traffic conditions. The updated arrival time can then provide feedback in to the process of adjusting the signal timings.

2.6 Detection Technologies

Detection technology forms an important component of overall traffic signal priority system architecture. It forms the communication link between the approaching transit vehicle and the traffic signal controller. For active priority to be effective it is very important to detect the approaching transit vehicle and accordingly adjust the signal phasing system to provide the priority to the transit vehicle.

In simple form, detection technology consists of a message conveyer, which is installed on the transit vehicle and a receiver, which is installed in the signal controller. There are different types of media to carry this messages to the signal controller namely light, sound, radio frequencies, etc. There has been extensive research performed at Virginia Tech to study different technologies, system requirements and past deployments (Collura, Chang, Willhaus, and Gifford, 2000). Researchers have studied different types of detection technologies according to their functionality, strengths, and limitations. These technologies have been used by different vendors in different fashions. So the different vendor implementations were studied individually. This section mentions the findings from previous research in brief in order to provide the sufficient knowledge about this important aspect of the traffic signal priority system architecture.

Table 1: Detection Technologies used for Transit Signal Priority

Media And Vendor.	Components	Activation	Strengths	Limitations	Special Feature or Notes
Light (Infrared light) 3M	• Infrared strobe emitters. • Infrared detectors. • Phase selector card	By a switch or automatic mechanism.	Popular technology, Readily available, Separate high and low priorities for emergency and non-emergency vehicles. Individual vehicle logging	Dependent on good visibility conditions, Possibility of interference with neighboring intersections, limited transfer capability	Optional conformation light, Vehicle identification numbers are coded in the message for particular emitter.
Light (Infrared light) Optronics/Tomar Strobecom	• Infrared strobe emitters. • Infrared detector. • Interface device.	By switch or automatic mechanism.	Compatibility with Opticom Vehicle level control, used for different vehicle classes.	Performance hampered by visibility issues, low data transfer potential.	Optional Confirmation light, Vehicle identification numbers are coded in the message for particular emitter.

Light (Infrared light) Novax Bus System.	• Infrared transceiver(“VTM”) • Detection modules (“VDMs”) • Receiver unit (“VIL”).	By a switch or automatic mechanism.	No wiring required from the detector to controller. Infrared technology is resistant to RF and EMI interference.	Receiver needs an RF antenna. Getting AC power for detector is difficult.	Uses “Sidefire” configurati--on with curbside detectors.
Sound. Sonem 2000	• Directional microphone array. • Controller card	By sirens of different types, frequencies and periods.	Does not depend on visibility, No additional equipment on transit vehicle, facilitates interjurisdictional deployment.	Does need some audible signal form the vehicle. Susceptible to false alarms.	Conformation light, operates on sirens in yelp, wail, or hi-lo frequencies.
Sound. EPS-II	• Digital sound wave recognition system. • Phase selector unit.	Special siren emitters or electronic sirens.	Does not depend on line of sight or visibility issues. No modifications needed for emergency	No data transfer capability. Susceptible to false alarms.	

			systems.		
Loop-detector. IDC Loopcom.	• Low frequency transponders • Standard pavement loops connected to a special amplifier.	Pavement Loops.	Does not depend on line of sight or visibility issues. Can be used for high and low priority.	Depends on the performance of appropriately placed loops.	
Push-button.	• Push-button activation device.	By a button.	No additional equipment on the vehicles. Simple and reliable hardware. Performs in all whether.	No remote activation is possible. Human activation dependent. May be untimely due to travel time to the intersection.	Can only be used for Emergency vehicles.
Radio. TOTE	• RF tag readers. • Amtech AVI185 read/write tags	By radio frequency tags.	Does not depend on line of sight or visibility issues. Can be used for high and low priority.	No phase selector functionality. All tags need suitable mounting location, power, and communicat	

				ions capability.	
Radio. Econolite EMTRAC	• Intersection-mounted antenna. • Receiver. • Bus-mounted spread spectrum transmitter.	Transmitter.	Individual logging possible. Can be used for high and low priority.	Non-directional nature requires vehicle to provide approach direction. Potential for malfunction due to compass failures.	
Radio / GPS-AVL. Priority One.	• Radio transmitters placed on vehicles. • Radio receivers at intersection. • The GPS-AVL component	Radio transmitter.	Predetermin ation of intersections is possible.	Susceptible to accuracy issues. Not good for closely spaced intersections.	
Orbtrac 300	• Complete bus management system.	Relays or On-bus processors.	Does not depend on line of sight or visibility issues.	Central management system is needed.	

2.7 Traffic Simulation Tools

Traffic simulation tools model the dynamic flow of vehicles along a roadway. There are essentially three main categories of traffic simulation models: macroscopic, mesoscopic, and microscopic. Macroscopic simulation tools do not model individual vehicles but instead model traffic flow using aggregate traffic speed, flow, and density relationships. Mesoscopic simulation tools do track individual vehicles, however the movement of these individual vehicles are governed by similar traffic speed, flow, and density relationships. Microscopic simulation tools, on the other hand, track individual vehicles whose movement is governed by individual driver behavior models (e.g., car following models and lane changing models). Historically, macroscopic tools have been used to model larger transportation networks because they require less computing resources as compared to microscopic models. Mesoscopic tools are the most recent of the types of models and strive to incorporate the strengths of both the macroscopic and microscopic approaches. For purposes of this research, references to traffic simulation models and tools will be focused primarily on microscopic models (Louisell, 2002).

Traffic simulation analysis is particularly useful for conducting “what if” scenarios in a simulated environment prior to field implementation (Louisell, 2002). These “what if” scenarios could be related to changes in roadway geometric features, lane configuration, traffic signal timing, transit routes, or any number of other traffic operational strategies or alternatives.

Highway capacity analysis and traffic signal optimization are typically conducted prior to simulation analysis to assist in the development of appropriate operational alternatives. Some of the strengths of traffic simulation analysis include its ability to model traffic control devices and individual vehicles on a time step (usually one second) basis and the ability to model uncertainty through stochastic processes.

There are several different traffic simulation tools available and there have been some recent assessments of these tools. Skabardonis conducted an assessment study for the

Washington State Department of Transportation where he identified over a dozen simulation models and conducted a detailed assessment of the following five: CORSIM, INTEGRATION, MITSIM, PARAMICS, and VISSIM (Skabardonis, 1999). In addition, Skabadonis provides an extensive bibliography of recent research related to traffic simulation analysis. The Institute of Transport Studies at the University of Leeds also conducted a thorough review of microscopic traffic simulation models (Institute of Transport Studies, 1997). Since the strengths and weaknesses of these simulation models vary, it is important to choose a model that is appropriate for the analysis at hand. There have also been some recent studies on strengths and limitations of these models (Choa, Milan, Stanek, 2001). As this research involved modeling of a signalized corridor for traffic signal priority systems, VISSIM was selected because of its capability to provide detailed information on the MOE identified; it has a strong emphasis on modeling transit, and it allows the user to evaluate traffic signals through fixed time controllers or through explicitly defined controller logic (Ova, Smadi). Also, this research is the first effort at Virginia Tech to use VISSIM to program traffic signal priority systems using Vehicle Actuated Programming, making it a significant contribution to the research tools at Virginia Tech.

2.8 Deployments/Results and Lessons Learned - Traffic Signal Priority Systems

Traffic signal priority systems have been deployed and tested in various urban areas around the United States. It has also been widely applied in Canada, Japan and Europe. There have been research efforts in the past at Virginia Tech to review selected experiences in U.S. (Collura, Chang, and Gifford, 2000). In this section results of the major studies are presented including the study findings and the conclusions. Information is gathered through published as well as non-published literature, journals and technological magazines and worldwide web pages. First, the U.S. experiences are presented followed by the other international experiences. These experiences are classified in two major categories: field studies and simulation studies.

2.8.1 Field Studies in the U.S.

2.8.1.1 Portland, Oregon

An operational test was carried out at four intersections on Powell Boulevard, Portland in 1994(Kloos, Danaher, and Hunter-Zaworski, 1994). It is a five-lane arterial with three bus stations located at far side and one is at near side. The strategies used were green extension/early green (red truncation) and queue jump with shared right turn lanes. The extensions or early green was allowed up to 10 second in off-peak periods and up to 20 seconds during peak-periods. Portland tested both TOTE and LoopComm detection systems along with 170 Type controllers with Wapiti IKS firmware. The performance measures included bus travel time, delay to non-transit vehicles and person delay at four intersections. Data collected showed 6 minutes reduction in bus travel time during peak-hours and no significant impact on average vehicle or person delay was noticed.

2.8.1.2 Louisiana Avenue, Minnesota

This project relates to research reported herein very closely as it is also characterized by closely spaced intersections and heavy traffic volumes (Westwood Professional Services, Inc., 1995). Opticom was tested at a diamond interchange for through traffic signals; different detectors were used for left turn and through lanes. Econolite ASC-8000 ASC/2 controllers were used in the test. Three levels of priority, low, medium and high were tested as against the base case of no priority. Low, provided extended green while remaining in coordination; medium, provided longer extended green while remaining in coordination; high, provided preemption. The high priority reduced bus travel time by 38%, while the medium and low priority did not reduce bus travel time. Medium and low priority did not increase auto-stopped time, but high priority increased it by 4.4 sec (23%). The investigator concluded that priority treatment within coordinate operation is a viable strategy.

2.8.1.3 San Diego, CA

Passive priority to trolleys in downtown San Diego was deployed in Celniker in 1992 (Celniker, Wayne Terry, 1992). The high frequency of trolleys was a major challenge and brought lengthy delays through the former preemption system. So area wide planning of active priority system was planned to give a progression to the trolleys. The drivers were asked to wait for the fresh green and were assured progression to the next station as long as they departed within first 3 seconds of green. About 2-3 minutes of travel time reduction was achieved over a section of 4.8 km.

2.8.1.4 Miami, Florida

Miami tested a bus preemption system and other priority measures in 1973 along a 16 km section of I95 and Northwest Seventh Avenue corridor of an express bus route, the Orange Streaker (Wattleworth, Courage, Wallace, 1977). The priority strategies included reversible, exclusive lane, preemption, and a coordinated signal system for bus progression. These were addressed by five scenarios: 1- no priority, 2- signal preemption for buses, 3- preemption for buses and exclusive lanes, 4- signal progression and exclusive lane and 5- signal preemption, signal progression, exclusive bus lane. The most effective treatment for reducing bus delays and travel time was found to be bus lanes, followed by preemption, and then progression. Preemption was found to not be as effective as progression in maintaining schedule adherence. Traffic impacts were found to be minimal, and influenced more by signal control parameters (fully actuated vs. coordinated actuated and pretimed vs. coordinated-actuated) than the preemption.

2.8.1.5 Charlotte, NC

Charlotte deployed signal priority along a radial corridor for express buses. Opticom emitters were installed on the buses. The deployment showed an average of 4% savings on travel time for the buses. On the operation side, the vehicles showed reduced wear and tear decreasing the maintenance and less vehicular emissions. The study showed a great success on an overall basis as it was very well accepted by public and was seen as a positive solution for growing congestion problems. There were no significant negative impacts on other traffic.

2.8.1.6 Chicago, Illinois

Chicago found the loop detector based system to be simple and reliable (Collura, Chang, Willhaus, and Gifford, 2000). About 2-3 minutes were saved on the travel time on a bus run of 13-17 minutes, and the impact to traffic was minimal. The system also showed that these were the results of providing the priority to only 30% buses as 70% of the buses arrived during the normal green phase.

2.8.2 Simulation Studies

2.8.2.1 Baltimore, Maryland

Kuah (Kuah, 1992) investigated signal progression for light rail transit (LRT) in downtown Baltimore in 1992. The corridor was along Howard Street and was 2.4 km long. The time space diagram for the Central Light Rail Line (CLRL) was proposed using following assumptions: constant dwell time of 30 sec., 7.5 minutes bi-directional headway, cruise speeds of 40-48km/hr on straight tracks and 24-32 on curved tracks and acceleration rates of 0.84 and 0.76 m/s^2, respectively. The simulation software used was TRANSYT and was applied in two scenarios: with and without CLRL for the year 1992. Results showed no degradation in LOS with introduction of CLRL. However, for one intersection LOS degraded from B to F. Individual vehicle delay was predicted to increase 14% and average transit operating speeds were predicted to decrease by 7 % with the introduction of CLRL.

2.8.2.2 Austin, Texas

Garrow and Michemehl (Garrow, Michemehl, 1997) conducted a priority simulation along a 4.1 km arterial having 11 intersections in Austin, Texas in 1997. The simulation was done using TRAF-Netsim to get three models: peak-period local bus, off-peak period local bus, and off-peak period express bus. The results were as follows.

- Shortening cycle lengths may be useful during off-peak hours. If the reduction is limited then it may help both the transit vehicles as well as the other vehicles along the arterial and cross streets by reducing delays
- Unconditional priority offers good potential during off-peak hours. It is recommended to limit the length of green extension or red truncation at major intersections. It is very important to consider the saturation levels at the cross street before taking out the green from them. For example, removing 5-10 seconds green at intersections having saturation levels of 0.8 to 0.9 can cause signal plan failure
- Far side bus stops are more favorable for traffic signal priority systems than the near side stops
- Signal priority does not affect the overall average person travel time at intersections with significant cross street saturation levels

2.8.2.3 Chicago, Illinois

Bauer, Medema, and Subbarao (1995) reported using simulation for providing priority to LRT vehicles in downtown Chicago (Chicago Central Area Circulator). It was for the proposed project of the Central Area Circulation (CAC), which has an exclusive lane. TransSim II and TRAF-Netsim were used in the simulation. The simulated priority strategies included: 1) Fixed time controllers at intersection and semi-actuated controllers at junctions to give progression to LRT vehicles; 2) red truncation or green extension; 3) delay of LRT is minimized through the use of interactive communication between LRT vehicles and the signal controller, which allows the LRT arrival times at intersections to be predictable.

The results showed that the third strategy led to higher average speed for the LRT. Strategy 1 produced minimal system wide-delay and strategies 2 and 3 yielded similar system wide delays.

2.8.2.4 Seattle, Washington

Jacobson, and Brinckerhoff (1993) reported a study of signal priority given to buses in Seattle area in 1993. There were two different strategies used namely HOV-weighted OPAC strategy and lift strategy. In the former strategy the number of people or vehicles through the intersection were maximized by using a dynamic programming algorithm. It was evident from the study that this algorithm outperforms the conventional signal timing method. In the latter strategy, upstream loop detectors identified the presence of buses; the signal design assumes all the other non-concurrent approaches are not there (lifted) for a given amount of time. The operating parameters were the detector locations and the time during which the traffic is lifted.

TRAF-Netsim was used for the simulation. The 'lift' strategy showed a 33% decrease in bus delay and minimal impacts to the private vehicles. When this strategy was simulated on three adjacent intersections the benefits to the buses were marginal and negative impacts to private vehicles increased. This strategy does not work well with closely spaced intersections.

2.8.2.5 College Station, Texas

Development and laboratory testing of an intelligent concept for providing priority to buses at signalized intersections without disrupting progression was tested in Texas (Balke, Dudek, Urbanik, 2000). The concept used bus position information to predict when in the cycle a bus would arrive at the bus stop and stop line of a signalized intersection and to determine whether a bus needs priority. The strategy used to provide priority was selected on the basis of the estimated arrival time of the bus at the stop line. Priority was provided by using phase extension, phase insertion, and early return strategies without causing the controller to drop from coordination. Implementation of the strategies was accomplished through normal traffic-signal controller commands (such as Ring Force Offs and Phase Holds). Hardware-in-the-loop simulation studies were performed to evaluate the effectiveness of the concept with real traffic-signal controllers. The performance of the intelligent bus priority approach was examined at three volume-to-capacity levels: 0.5, 0.8, and 0.95. Significant reductions in bus travel times were achieved at all three volume-to-capacity levels by using the intelligent bus priority approach. Use of the intelligent bus priority approach resulted in only minor increases in total system stop delay and individual approach stop delays at volume-to-capacity levels of 0.5 and 0.8. The results of the simulation studies performed as part of this study suggested to the researchers that the intelligent bus priority approach could be used at moderate traffic levels (up to volume-to-capacity levels of 0.9 or less) without significantly affecting cross-street delays.

2.8.3 Field Studies in Canada, Europe & the Pacific Rim Experiences

2.8.3.1 Vicenza, Italy

Vinceza Public Transportation Company studied the deployment of the 3M-priority control system (Collura, Chang, and Gifford, 2000). The study included five intersections and 18 buses. Tracking of travel times by day of week and by hour of day for one week before and on week after the deployment of Opticom system showed an average reduction of 23.8% of bus travel times through the center of the city. Results also indicated an average travel speed increase of 5 Km/hr, which represents a 30% increase.

2.8.3.2 Swansea, England

Swansea reported a traffic signal priority study in 1994 (Eavns, 1994). Exclusive bus lanes with both active and passive priority for buses were deployed. The passive priority was implemented through SCOOT system while active priority included green extension, red truncation and transit phase insertion.

The results showed a two percent decrease in travel time with the passive priority and an increase by 17% on other approaches. Green extension or red truncation achieved savings in bus travel times up to 11% in peak hours at the cost of a 7% increase in delay to private vehicles. While green extension showed no reduction in travel times and the delay to other vehicles increased by 15%.

2.8.3.3 Stuttgart, Germany

Three priority levels were developed in Stuttgart to provide priority to a light rail transit system (Nelson, 1993). The first level was called ‘limited preferential system’ and allowed green extension only when required. The second level allows both extensions and recalls while third level provides absolute priority, also known as preemption. ‘Limited preferential treatment’ reduced the transit delays by 50% with minimal extra delay to private vehicles.

2.8.3.4 Brisbane, Australia

Brisbane City Council developed an active bus priority system called RAPID bus priority system, based around its own Urban Traffic and Control system known as BLISS (Brisbane Linked Intersection Signal System). The priority system was deployed at 14 traffic signals on Waterworks Road in Brisbane (Peterson, 1994). The literature indicates that the system was successful and was implemented nation wide.

2.8.3.5 Lyon & Toulouse, France

Lyon developed a bus priority method called CELTIC, which provided a conditional priority to the transit buses (Farges, Henry, 1994). A conditional priority strategy was developed incorporating state estimation and optimization at each intersection over a 50 second horizon. Various criteria are used for the conditional priority including the minimization of the delay to public vehicles.

The field test was carried out in Toulouse. The field test showed that statistically significant reductions in transit travel time in the range of 11 to 14 % with no significant changes in general traffic travel times.

2.8.3.6 Strasbourg, France

Strasbourg and few other French cities tested a traffic signal priority system prepared by a company called CGA (Laurence, 1994). The system uses a beacon-based approach where the system communicates with the transit vehicles before selecting the strategy. The study showed system wide reductions in transit travel times in the range of 4-5%.

2.8.3.7 Zurich, Switzerland

Zurich has very high standards for the public transportation system with the aim of zero delay at signalized intersections (Bishop, 1994). It carries high annual trips in the range of 490 per person, which compares with 131 for Manchester and 290 for England. On detection of a public transport system the controller makes sure that it receives a green at upcoming intersection and the information is also passed on to the successive intersections to achieve local optimization. Metering is also done to keep the transit routes congestion free. It is claimed that at 90% of the signalized intersections have zero waiting time for transit buses.

2.8.3.8 Toronto, Canada

Toronto deployed a non-optimizing signal priority strategy for streetcars on a 1.6 km section of Queen Street (Municipality of Metropolitan Toronto, 1991). The headway for streetcars is 4 minutes in rush hours and 5-6 minutes during non-rush hours. The strategies used were green extension and red truncation. The study showed that the green extension was much more effective than the red truncation, as only 12% of the red truncation were fully used by the streetcars. In this study, the provision of priority disrupted the coordination with successive signal and then the simultaneous provision of priority as considered. The provision of priority decreased the travel times and the delays for the streetcar. This resulted in large reduction in average passenger delay due to high occupancy of transit vehicles.

2.8.3.9 Eindhoven, Netherlands

A conditional bus priority implementation in Eindhoven, the Netherlands, was studied using varying levels of provision of priority (Furth, Muller, 2000). Conditional priority for buses at signalized intersections means that late buses are given priority and early buses are not. This scheme is a method of operational control that improves service quality by keeping buses on schedule. Results showed the strong improvement in schedule adherence compared with a no-priority situation. Traffic impacts at an intersection were studied for three scenarios-no priority, absolute priority, and conditional priority. Compared with no priority, absolute priority increased delays significantly while conditional priority had almost no impact.

2.8.3.10 London, United Kingdom

Use of Automatic Vehicle Location (AVL) for provision of priority to transit buses in London and Southampton was studied (Hounsell, McLeod, 1998). The use of AVL in applications for bus priority at traffic signals is described, including a comparative review of different architectures and techniques that have emerged. Results of a feasibility study for the use of AVL in this context in London are presented. This study indicated that using AVL to target high-occupancy, high-headway buses with higher levels of priority could provide economic benefits for buses and passengers up to twice those achieved with current operations, where priority is equally available to all buses; Deployment details of this application, related to COUNTDOWN, are described

2.9 Conclusion

This Chapter reviewed the vast amount of literature available related to traffic signal priority. Different technologies were presented and the challenges these technologies offer were assessed. The chapter also presents some of the results and findings of prior research efforts in U.S as well as in allover the world.

A traffic signal priority system has the potential to serve as a part of the solution to ever-increasing congestion issues by increasing the overall efficiency of public transport service. Careful planning and design must precede deployment. Moreover, the literature shows that the traffic signal priority systems can enhance the public transportation systems in terms of improved schedule reliability, reduced operating cost and increased operating efficiency. There are many influencing factors, which play an important role in the effectiveness of the priority system and its impacts on the other facility users. It should also be noted that a traffic signal priority system may serve more effectively if it is implemented as a part of a larger ITS system.

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Chapter 3 : RESEARCH APPROACH AND EVALUATION PLAN

3.1 Research Approach

This chapter will present the research approach and the evaluation plan used for this research. This provides framework in which this research was carried out and presented to the stakeholders. The knowledge gained form the literature review and the past research carried out in the field of transit priority at Virginia Tech by Dr. John Collura and James Chang (Chang, 2002), forms the building block for this evaluation framework. This chapter concentrates on synthesizing that knowledge to formulate a framework for the U.S.1 project.

The evaluation framework establishes an appropriate context in which the deployment of the traffic signal priority system was examined on U.S.1. This evaluation framework and plan can provide objective basis for local stakeholders to examine the likely impacts of the potential deployment and to assess the degree to which the deployment achieves the desired objectives. The evaluation framework provides an important foundation for determining whether a project or an individual strategy meets the intended objectives. Without a framework, there is a risk of attempting to justify the worthwhileness of a project without systematic evidence. Almost all potential projects have some merits. However, when considering whether a project should be developed or deployed, the planning process should consider to what extent the stated objectives would be met and what negative impacts would be realized, relative to other alternatives. In particular, the work focuses on the extent to which traffic signal priority strategies can improve the on time performance of Fairfax Connector buses in the corridor and the extent to which deployment of traffic signal priority system affects the overall traffic flow characteristics in the corridor.

The overall concept of the evaluation framework is explained in the following diagram, which is an outcome of the past research done by James Chang (Chang, May 2002) at Virginia Tech. This diagram relates the different aspects of the deployment to the objectives of the stakeholders. The evaluation framework considers the environment surrounding the deployment of the traffic signal priority systems in order to summarize the positive and negative impacts on the traffic flow characteristics along the study corridor.

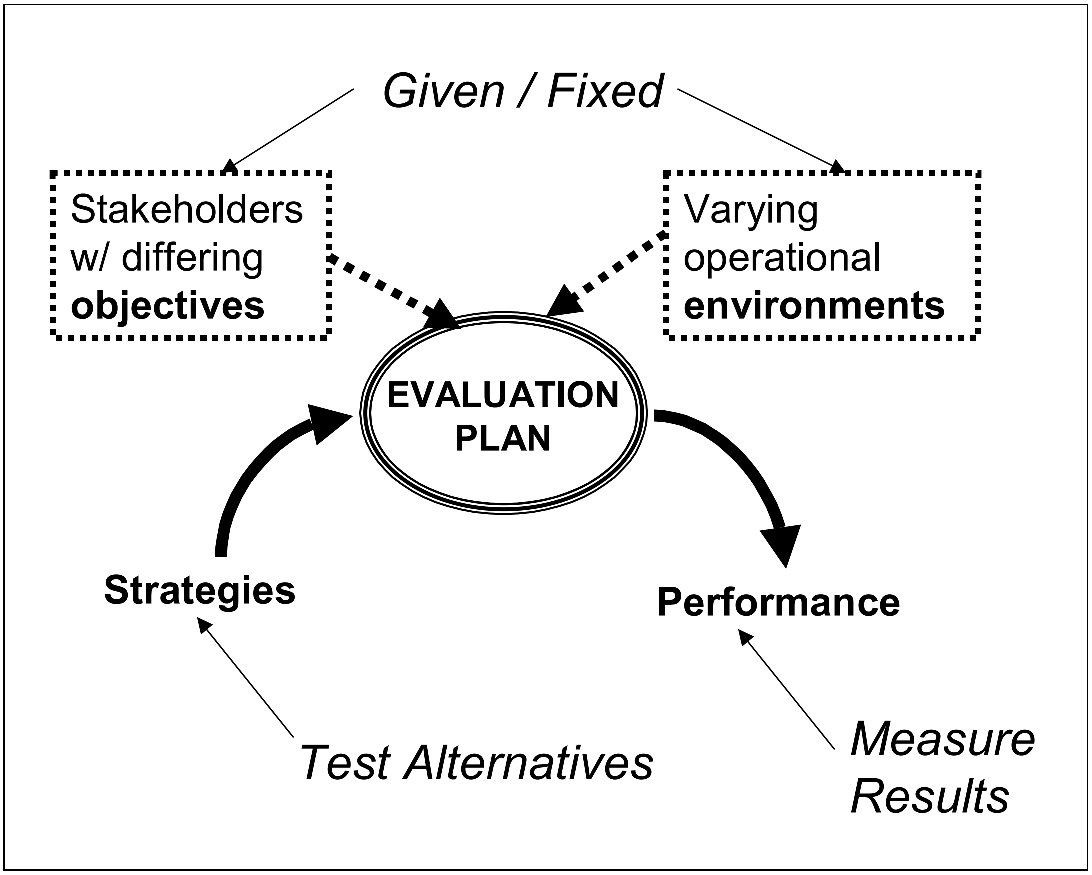


Figure 1: **Framework Concept**

As it can be seen from the figure, the evaluation framework intends to assess the deployment strategies in context to various operational environments and various objectives stakeholders hope to address. In order to assess the performance of a chosen strategy as 'input' the objectives and the operating environment are taken as 'given/fixed' and is evaluated to get the impacts on the present scenario as an 'output'.

The evaluation framework helps in establishing the measures to be taken in order to evaluate all the objectives so as to what data is to be collected and when. This is the primary step in formulation of the evaluation framework. As we are doing this, the current operational environment i.e. various signal timing plans, traffic flow characteristics and transit scheduling, etc, are taken as given and the strategies are formulated according to that. The central element of the framework, the evaluation plan, specifies how the performance of each strategy in terms of meeting stated objectives in the specific environment would be quantified.

In case of U.S.1, two major stakeholders are Virginia Department of Transportation (VDOT) and Fairfax County. VDOT is responsible for the traffic operational behavior i.e. traffic flows, signal timings, etc. while Fairfax County provides local public transit service through Fairfax Connector. As both try to use the same facility to achieve individual goals it is quite understandable that they have different objectives behind the deployment of the traffic signal priority along U.S.1. In order to formulate the evaluation framework it is very important to understand their individual concerns and objectives behind the deployment.

U.S.1 or Richmond Highway is a major arterial in Northern Virginia. The study corridor comprises of seven signalized intersections in a span of 1.3 miles between Popkins Lane on the southern side and North Kings Highway/Shields Avenue on north. This facility is used as an access to the capital belt way and the Washington Metro. Due to heavy traffic volumes and very closely spaced signalized intersections, the operational skills of traffic engineers are at highest demand in peak hours. Also, there is a centrally located fire station, which uses the facility to serve the adjoining areas.

As VDOT tries to accommodate these various facility users they have their specific objectives and concerns behind the deployment of traffic signal priority systems. First as objectives, they hope that the deployment will help in facilitating uniform traffic flow behavior thorough the corridor minimizing the differential operating speed between automobiles and transit buses. Also, if highly occupied transit buses are accommodated in normal traffic flow then higher person throughput can be achieved and person delay can be minimized along the main line. Usually transit buses fall away from the normal progressing traffic due to their low operating speed and dwell times, if the offsets can be accommodative enough then the number of stops and intersection delay for the buses can be reduced making them a part of the progressing traffic. Also, the deployment of traffic signal preemption and priority will improve safety aspect of the corridor allowing emergency vehicles a right of way over transit as well as other vehicles. At the same time they have their own concerns so as not to adversely affect the traffic operations in the corridor. The deployment may increase the person delay and queue lengths on the cross streets. It may also disturb the synchronized operations of the signal timing plans for all theses intersections, this is very important aspect as all the intersections are very closely spaced along the main line. Secondly, operational limitations of priority systems due to issues like near side and far side bus stops and geometric demands can be subject to debate due to their detrimental effect on the signal operations. So it is quite understandable that VDOT has a conservative approach towards the deployment strategy. This is a pilot project evaluated by Virginia Tech to help VDOT address all their objectives.

Fairfax County provides the local public transit system through Fairfax Connector. Three of their major service routes use the selected corridor to serve the residential areas on the southern side with an access to the Washington Metro at Huntington metro station. Being primary stakeholders in the project, they also have their own objectives and concerns behind deployment of the traffic signal priority system. As objectives, they hope to improve the service reliability and efficiency along the corridor. Also, if the average operating speed along the corridor is increased then it is easier to maintain the constant headway and achieve higher operating efficiency. If the number of stops at the intersections is minimized then it can increase the fuel efficiency while reducing the operating costs. A Traffic signal priority system will also help in achieving improved total travel times and will increase the customer satisfaction.

As can be seen, there may be many different dimensions to a single objective. Selection of an appropriate perspective and corresponding measures can be facilitated by a systematic evaluation plan. The following section will further examine the evaluation plan and how it can be tailored to the objectives and environment.

3.2 Evaluation Plan

As discussed previously, the evaluation plan embodies the evaluation objective, in this case the measurement of performance impacts resulting from various traffic signal priority strategies. Appropriate measures of effectiveness, both quantitative and qualitative, can be established for each system objective to be assessed in the evaluation. The following table shows all the objectives and the different measures used to quantify them (Chang, 2002). Depending on the particular environment and objectives, the most appropriate measures of effectiveness are chosen from the proposed measures.

Objective	Measure	Measurement
1.0 Bus Service Reliability (transit schedule adherence)	*1.1* On Time Performance	% of arrivals in on-time window at timepoint(s)
	1.2 Time Reliability	Standard deviation of elapsed time between timepoints / endpoints
	1.3 Perceived OTP	Survey measure of rider opinion
	1.4 Spacing	Maximum headway measured at timepoint(s)
	1.5 Arrival Reliability	Standard deviation of delta (actual time vs. scheduled) at timepoint(s)
2.0 Bus Efficiency (transit travel time savings)	*2.1* Run Time	Elapsed time(mean) between start and end points
	2.2 95%-ile RT	95%-ile elapsed time between start and end points
	2.3 Trip Time	Weighted passenger time on board / in-vehicle
	2.4 Perceived Travel Time	Survey of change in riders' opinions before & after
3.0 Other Traffic-Related Impacts	*3.1* Overall Delay	Delay by [corridor/intersection], [person/vehicle]
	3.2 # of stops	Stops by [corridor/intersection], [person/vehicle]
	3.3 Mainline Travel Time	%-ile / average operating speed
	3.4 Cross Street Delay	Maximum / 95%-ile delay, average delay
	3.5 Fuel Consumption / Emissions	Model output for corridor, average per vehicle
	3.6 Overall System Efficiency	Throughput achieved vehicles per hour, persons per hour
	3.7 Intersection Safety	Red light running / accident frequency

Table 2: Evaluation Measures

This evaluation plan addresses the different objectives and measures them quantitatively. The data needed for this evaluation plan is collected on the field by a team of research students form Virginia Tech. This evaluation plan will be implemented through simulation using VISSIM as a simulation tool.

3.2.1 Application to the Objectives

Building on prior discussion about the evaluation plan and framework, it is now important to apply this evaluation plan to various objectives to state the hypothesis that we intend to examine in this research. This application will be studied in two major categories: transit related and other traffic related.

3.2.1.1 Application to Transit Related Objectives

The framework and plan will be applied to the evaluation of bus service reliability impacts resulting from various traffic signal priority strategies. A theory is posited by Chang (Chang, 2002) which establishes bus transit reliability as a function of four major factors; this theory attempts to apply the insights of Markowitz (Markowitz, 1959) in Modern Portfolio Theory to analysis and optimization of transit reliability (Chang, 2002). So these objectives are addressed in two major categories: Bus service reliability and Bus efficiency.

This framework presents these two as a function of several factors mentioned as different measures in the table. As far as service reliability is considered, factors take in account the waiting time for the passengers at the bus stops and the schedule adherence of the transit buses. This has a direct effect on the quality of the transit service as perceived by the riders. These factors also account for the spacing and the schedule adherence of the bus. In case of the bus efficiency, the factors concentrate on the total travel time for a passenger for a single trip measuring the travel time between end points.

The selection of these measures under the given conditions on the U.S.1 corridor lead to the following hypotheses to be examined

Hypothesis #1

Provision of priority to Fairfax Connector buses will be associated with higher bus service reliability.

Hypothesis #2

Provision of priority to Fairfax Connector buses will be associated with higher bus service efficiency.

3.2.1.2 Application to Other Traffic Related Objectives

The framework presents other traffic related impacts as a function of several factors including the delays to mainline as well as side streets. These factors concentrate on intersection delays and person delays. This includes the average operating speed and number of stops on the main line and delays and increase in queue lengths on the side streets. This evaluates impacts on the other traffic as a result of deployment of traffic signal priority system along U.S.1.

The selection of these measures under the given conditions on the U.S.1 corridor gives rise to the following hypotheses to be examined: -

Hypothesis #3

Provision of priority to Fairfax Connector buses will be associated with little to no impact on the other traffic conditions such as increased queue lengths on side streets.

3.3 Summary

This chapter has presented the evaluation framework and evaluation plan, which will be implemented using the data collected on the field and VISSIM as a simulation tool. The following chapter describes the data collection, operational environment and the strategies of deployment.

Chapter 4 : U.S.1 TRAFFIC FLOW CHARACTERISTICS

The purpose of this chapter is to describe the study corridor and to explain the existing traffic conditions. It is very important to study the traffic characteristics before the traffic signal priority system is deployed to better understand the impacts of the deployment. This chapter will focus on the 'before' data collection and analysis which provides the foundation and framework for 'after' data collection, once the system is deployed on U.S1.

4.1 Location

The study corridor is located in Northern Virginia near Huntington Metro Station. It is a stretch of Richmond Hwy, which connects Fort Belvoir to the Capital Beltway on the northern side of the section. The following map shows the geographic location of the study section on Richmond Highway (North pointing up).

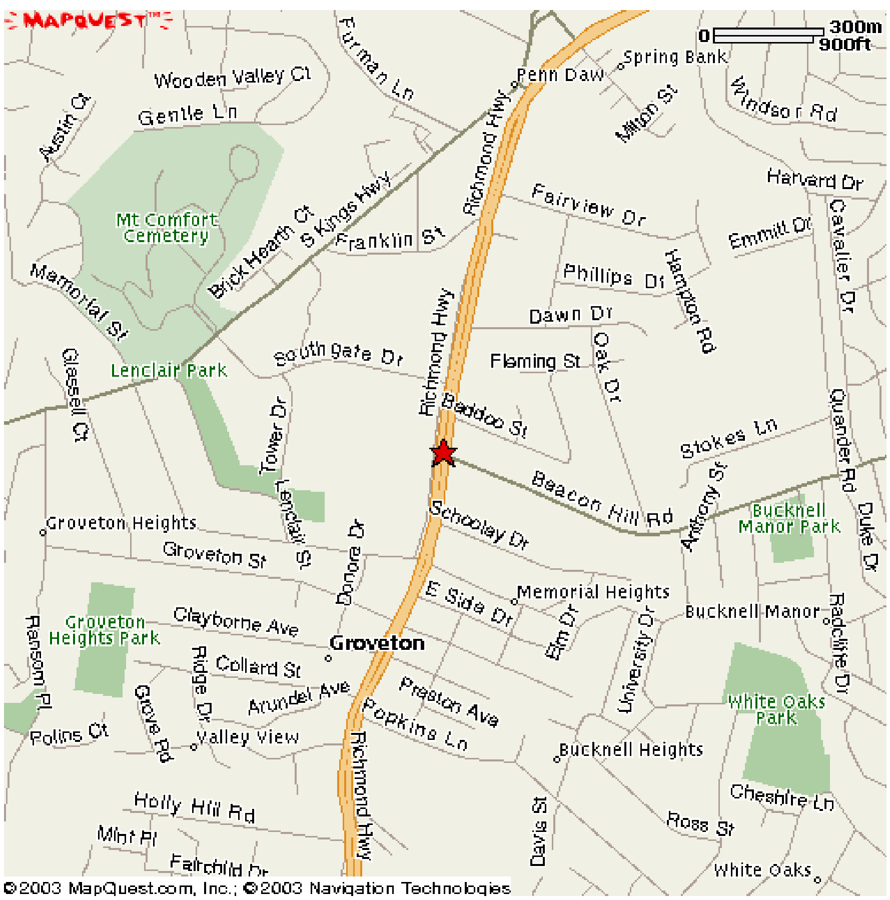


Figure 2: Roadmap showing U.S.1 Study Corridor

The above map shows 1.3-mile section starting form the Popkins Lane (just below Groveton on the map) to the North Kings Hwy/Shields Avenue Intersection (just adjacent to the Penn Daw on the map). This study section has seven closely spaced signalized intersections, which are listed below going from south to north.

1. Popkins Lane @ U.S. 1
2. Collard Street @ U.S. 1
3. Memorial Drive @ U.S. 1
4. Beacon Hill Road @ U.S. 1
5. Southgate Drive @ U.S. 1
6. South Kings Highway @ U.S. 1
7. North Kings Highway/ Shields Avenue @ U.S. 1. The following figure shows the study segment and all the seven intersection in the Synchro file.

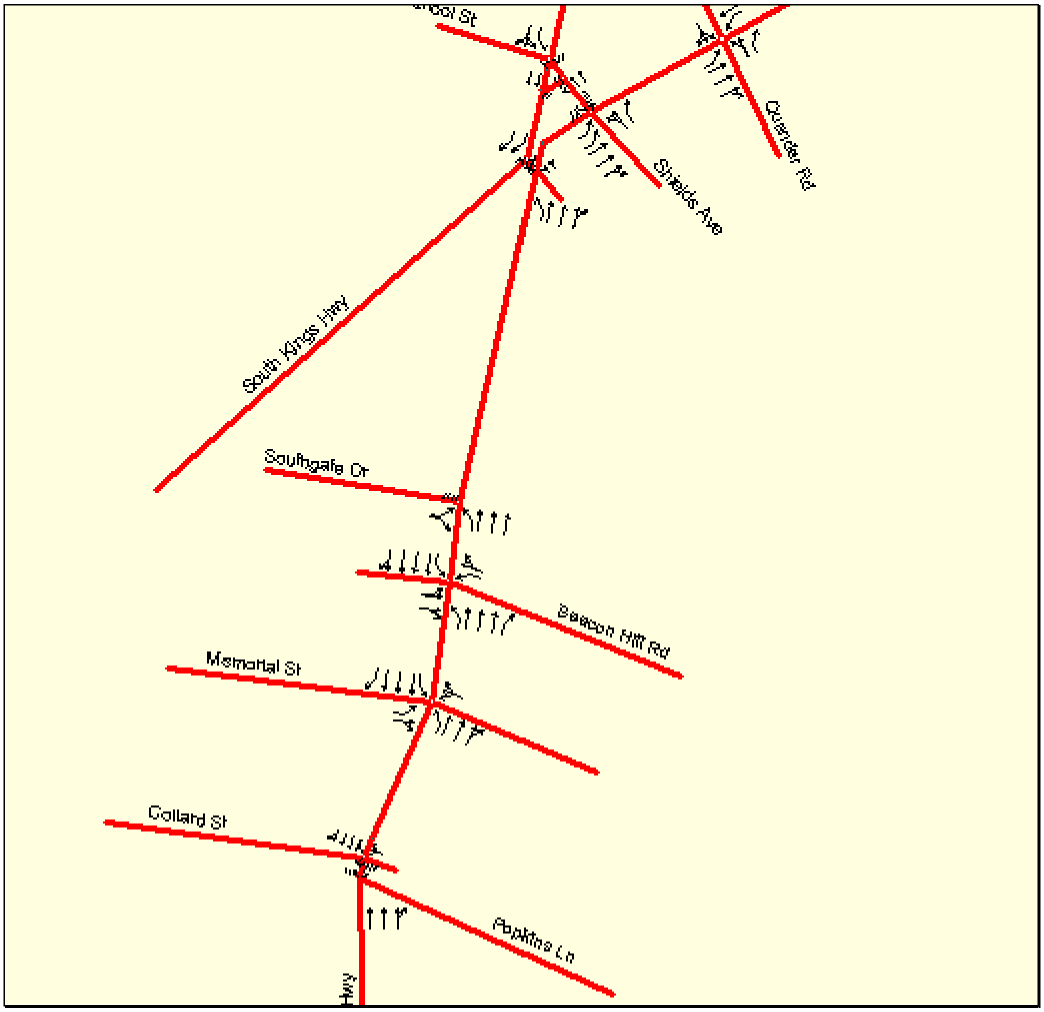


Figure 3: Study segment in Synchro file

4.2 Data Collection

The purpose of data collection is to develop an understanding of the traffic flow characteristics along the study corridor. In order to evaluate the impacts of traffic signal priority systems, it is very important to understand the existing traffic behavior along the corridor. The data collection effort feeds into the evaluation framework described in the previous chapter and provides the complete picture of existing conditions on U.S.1

In this research, the field study was done for following objectives:

- To collect 'before' data for the field study as a part of U.S.1 Traffic Signal Preemption and Priority Project
- To provide a framework for field data collection for 'after' data collection, when the system is deployed.
- To use a simulation model (VISSIM) with actual field data to calibrate the model.

Data collection was done in March and April 2002 by a team of researchers at Virginia Tech involving four graduate students under guidance of the principal investigator. Data was collected and analyzed in two parts namely 'Traffic Characteristics Analysis – U.S.1: Base Case' and 'Transit Impact Evaluation – U.S.1'

4.2.1 Traffic Characteristics Analysis – U.S.1: Base Case

This part of data collection was done in order to examine the existing situation or base case before the effects of priority are analyzed. Table 3 shows the framework used for this part of data collection in terms of data elements and data collection. Table 4 shows data collection time periods.

Measure	Data Elements	Data Sources	Before Collection	Analysis
Mainline Travel Time & Number of Automobile Stops (Platoon w/o bus)	Run time between Popkins Lane & Shields (North Kings Hwy)	Field observations on U.S.1 (Stop Watch)	Complete	Complete
Mainline Travel Time & Number of Automobile Stops (Platoon with bus)	Run time between Popkins Lane & Shields (North Kings Hwy) (Comparative data profiles for Bus and Auto under similar Traffic Scenario)	Field observations on U.S.1 (Stop Watch)	Complete	Complete
Cross –Street Delay	1.Average Queue Lengths	Field observations on U.S.1 (Stop Watch)	Complete	Complete

Table 3: Traffic Characteristics Analysis – U.S.1: Base Case

AM Peak Period	7 to 9 AM
Midday Peak Period	12 to 2 PM
PM Peak Period	4 to 6 PM

Table 4: Data Collection Time Periods

4.2.1.1 Mainline Travel Time (Only Automobiles)

This part of field data collection examines the average operating speeds of automobiles on U.S.1, Number of stops for a platoon, total control delay and total travel time along the corridor were tabulated. Data collection was done based on a ‘floating car’ methodology by having a team of researchers riding an automobile along the corridor being a part of normal traffic stream, while, data was collected manually using a stopwatch and paper-pencil. Following table shows the field observation run scenarios,

Time	Direction Of Travel	Number of Runs
Morning Peak AM	North bound	10
	South bound	10
Evening Peak PM	North bound	10
	South bound	10

Table 5: Data Collection Scenarios for Mainline Travel Time

As depicted in above table, data collection was done in peak periods in both directions along U.S.1. Tables 6,7,8 & 9 depict run summaries in AM and PM Peak periods for the base case.

Run No.	Total Travel Time	Number of Stops	Control Delay	Total Run Time	Avg. Run Speed	Avg. route Operating Speed
	(sec)		(sec)	(sec)	mph	mph
1	140	1	3	137	34.10	33.42
2	179	2	33	146	32.05	26.14
3	257	2	77	180	26	18.21
4	161	1	23	138	33.91	29.06
5	164	2	17	147	31.83	28.53
6	149	2	8	141	33.19	31.40
7	196	3	47	149	31.40	23.87
8	140	1	10	130	36	33.42
9	215	1	64	151	30.99	21.76
10	142	0	0	142	32.95	32.95

Table 6: Northbound Run Summaries in AM Peak Period

Observations: -

- In the AM peak period, the north-bound direction is the peak direction of travel as commuters travel to work north-bound to take Beltway (I-495) or Washington Metro Rail at Huntington Station 3 miles north of the study corridor
- Average operating speed for automobiles is 27.88 mph (average of averages)
- North-bound traffic is heavy due to higher volumes

Run No.	Total Travel Time	Number of Stops	Control Delay	Total Run Time	Avg. Run Speed	Avg. route Operating Speed
	(sec)		(sec)	(sec)	mph	mph
1	130	0	0	130	36	36
2	244	2	113	131	35.72	19.18
3	250	3	101	149	31.40	18.72
4	114	0	0	114	41.05	41.05
5	150	1	16	134	34.92	31.2
6	120	0	0	120	39	39
7	238	1	109	149	31.40	19.66
8	140	1	31	109	42.93	33.42
9	112	0	0	112	41.78	41.78
10	120	0	0	142	32.95	39

Table 7: Southbound Run Summary-AM Peak Period

Observations: -

- In the AM peak period, south-bound traffic is less heavy as compared to north-bound traffic
- Average operating speed is 31.90 mph (average of averages)

Run No.	Total Travel Time	Number of Stops	Control Delay	Total Run Time	Avg. Run Speed	Avg. route Operating Speed
	(sec)		(sec)	(sec)	mph	mph
1	135	0	0	135	34.66	34.66
2	231	2	81	150	31.2	20.25
3	160	2	9	151	30.99	29.25
4	211	1	48	163	28.71	22.18
5	236	2	77	159	29.43	19.83
6	226	2	79	147	31.83	20.70
7	138	0	0	149	31.40	33.91
8	195	2	44	151	30.99	24
9	203	1	51	152	30.78	23.05
10	222	1	76	142	32.95	21.08

Table 8: Southbound Run Summary-PM Peak Period

Observations: -

- In the PM peak period, the south-bound direction is peak travel direction as commuters travel back from work
- In the PM peak period, directional distribution is more balanced as commercial development around study corridor comes in to play
- Average operating speed is 24.89 mph (overall average)
- Average operating speed is lower due to heavy traffic volumes

Run No.	Total Travel Time	Number of Stops	Control Delay	Total Run Time	Avg. Run Speed	Avg. route Operating Speed
	(sec)		(sec)	(sec)	mph	mph
1	294	3	134	160	29.25	15.91
2	216	2	28	188	24.89	21.66
3	128	0	0	128	36.56	36.56
4	143	1	5	138	33.91	32.72
5	275	3	61	214	21.86	17.01
6	163	2	14	149	31.40	28.71
7	155	2	13	149	31.40	30.19
8	142	0	0	142	32.95	32.95
9	159	1	10	149	31.40	29.43
10	180	2	38	142	32.95	26

Table 9: Northbound Run Summary-PM Peak Period

Observations: -

- In PM peak period, directional distribution is more balanced than in AM peak period
- Average operating speed is 27.11 mph (overall average)

4.2.1.2 Mainline Travel Time (Platoon with Bus)

Traffic signal priority system for transit vehicles is a technique to adjust the signal timings to accommodate the transit vehicles in order to reduce the signal delay for the targeted vehicles. In simple words it's a priority given to targeted vehicles when they arrive at a signalized intersection. The level of priority may vary according to the objectives and the policies of the stakeholders. As we prepare to deploy traffic signal priority systems for public transit buses, it is very important to understand the theoretical background of this concept of signal priority. As discussed in the first chapter, transit buses fail to be a part of progressing platoon through a signalized corridor due to their frequent dwelling stops and lower operating speeds. This creates a significant difference between average operating speeds of automobiles as compared to those of buses. Due to this difference buses cannot fit in to the offset plans designed for smooth automobile progression along a signalized corridor, making them suffer excessive control delays and conclusively increasing the average speed difference. Traffic signal priority systems are aimed to address this issue by trying to accommodate transit buses in current signal offset plan, giving them a priority at signalized intersection using different strategies. Therefore, as a part of field study, it is very important to study relative speed profiles of buses and automobiles under similar traffic conditions. In order to achieve better operating speeds for buses we have to try and minimize this speed difference using appropriate traffic signal priority strategies. This section depicts observation scenarios for comparative runs of an automobile and a bus under similar traffic conditions entering the corridor at the same time.

Before we look at the comparative speed profiles, it is necessary to mention that this research proposes '**peak period-peak direction**' transit buses to be prioritized. All transit routes under consideration serve as feeders for the Huntington Metro Station on the northern end of the route, as large residential population uses these Fairfax Connector routes (Rt.105, 106,107) to get to the Metro Station. Therefore, in AM peak period northbound direction is peak transit travel direction and in PM peak period southbound direction is peak transit travel direction. As a result of this, priority will be provided for northbound buses in the morning peak period and for southbound buses in evening peak period.

Tables 10 and 11 show comparative travel characteristics for a transit and non-transit vehicle under similar traffic conditions: -

	Run 1		Run 2		Run 3		Run 4		Run 5	
	Transit	Non-Transit	Transit	Non-Transit	Transit	Non-Transit	Transit	Non-Transit	Transit	Non-Transit
Parameter	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle
Total Travel Time(sec)	302	210	392	200	345	148	305	123	278	120
Number of Stops	7	2	7	2	6	1	6	0	4	0
Control Delay(sec)	31	87	40	64	48	17	35	0	53	0
Total Dwell Time(sec)	77	NA	91	NA	104	NA	1	NA	65	NA
Total Delay	108	87	131	64	152	17	36	0	118	0
Total Run Time	194	123	261	136	193	131	269	123	160	120
Avg. Run Speed(mph)	24.1237113	38.04878	17.931034	34.411765	24.248705	35.725191	17.39777	38.0487805	29.25	39
Avg. route Operating Speed(mph)	15.4966887	22.285714	11.938776	23.4	13.565217	31.621622	15.344262	38.0487805	16.834532	39

Table 10: Comparative Travel Characteristics-NB-AM Peak Period

	Run 1		Run 2		Run 3		Run 4		Run 5	
	Transit	Non-Transit	Transit	Non-Transit	Transit	Non-Transit	Transit	Non-Transit	Transit	Non-Transit
Parameter	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle	Vehicle
Total Travel Time(sec)	370	150	325	156	431	225	302	215	361	165
Number of Stops	5	0	7	0	6	1	4	1	4	0
Control Delay(sec)	22	0	52	0	170	25	56	17	158	40
Total Dwell Time(sec)	90	NA	62	NA	50	NA	40	NA	56	NA
Total Delay	112	87	114	64	220	17	96	0	214	0
Total Run Time	258	63	211	92	211	208	206	215	147	165
Avg. Run Speed(mph)	18.1395349	74.285714	22.180095	50.869565	22.180095	22.5	22.718447	21.7674419	31.836735	28.363636
Avg. route Operating Speed(mph)	12.6486486	31.2	14.4	30	10.858469	20.8	15.496689	21.7674419	12.963989	28.363636

Table 11 : Comparative Travel Characteristics-SB-PM Peak Period

Observations: -

- Average Operating Speed for Transit Vehicles is 13.9 mph
- Average Operating Speed for Non-Transit Vehicles is 28.7 mph

4.2.1.3 Side Street Delay

One of the primary concerns of VDOT upon deployment of signal priority on U.S.1 is the potential negative impact on non-transit traffic, especially on the side streets. This data collection element concentrates on negative impacts of provision of priority to transit buses on other vehicles on Side Streets, as the green extension will take some part of their green time-share in the signal timing plan.

In order to measure the Side Street delay the parameter used in this research is measurement of queue lengths on the Side Streets. For this purpose, according to the volume counts and based on field observations specific intersections were identified as critical intersections at particular times of day. The following observations were considered in choosing the critical intersection. In simulation, queue lengths on all side streets are measured.

- South Kings Highway and U.S. 1 is a critical intersection in AM peak period due to its heavy traffic volumes from South Kings Highway turning onto U.S.1
- North Kings Highway and U.S.1 is a critical intersection in PM peak period due to heavy traffic turning onto U.S.1 from North Kings Highway
- Memorial Drive and U.S.1 is a critical intersection in the AM peak based on the field observations
- Beacon Hill Road and U.S.1, being a commercial activity center, is critical in Mid-day and PM peak period

Figures 4 to 11 show the intersection queue lengths at these critical intersections over the period of 11 consecutive signal cycles.

A) South Kings Highway- AM Peak Period

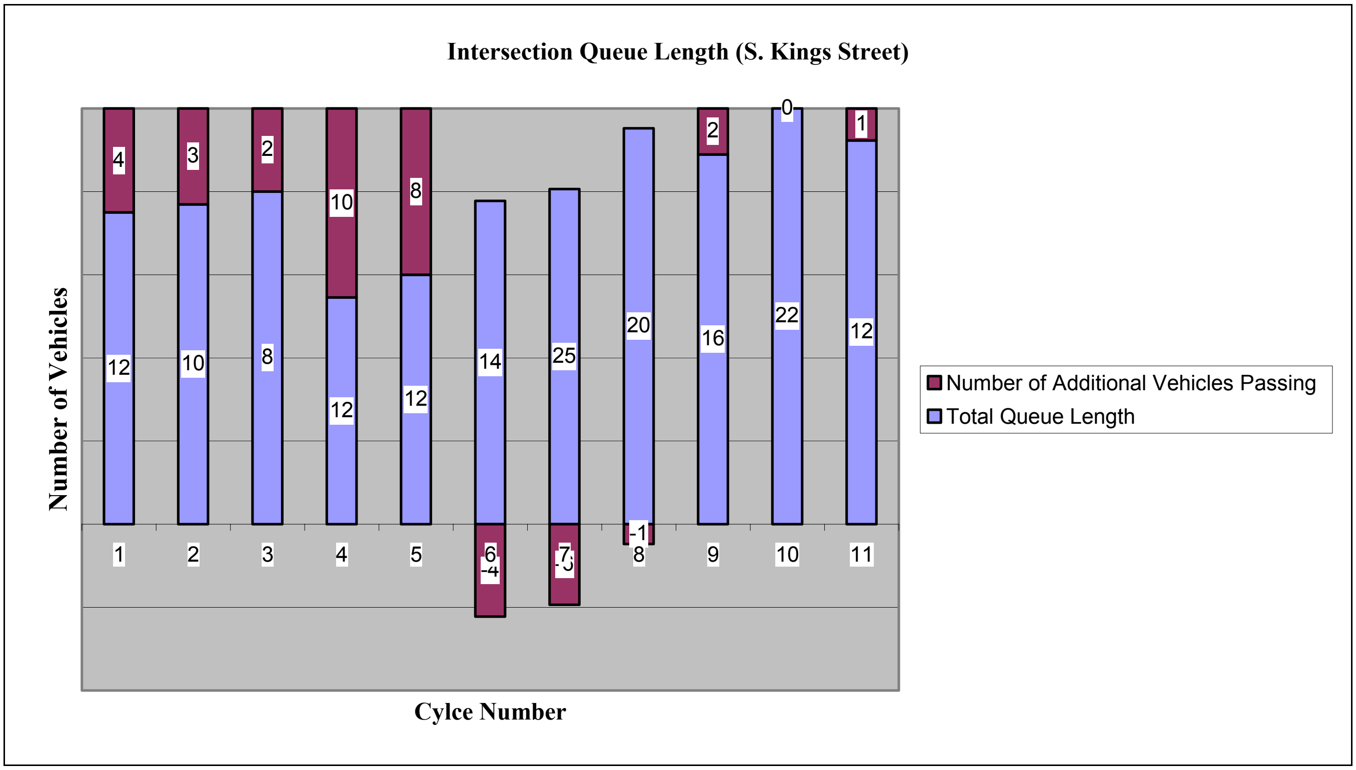


Figure 4: Queue Length on South Kings Highway- AM Peak Period

Observations: -

- Figure 4 shows the queue lengths on South Kings Highway at U.S. 1 over a period of 11 signal cycles.
- Blue portion of bars represent the queue which was present before the light turned green for South Kings Highway traffic.
- Red portion of bars represent the additional vehicles which were able to pass through the intersection in the same cycle and were not a part of the original queue.
- There were three observations when the cycle failed to serve the entire queue, representing the remaining vehicles with negative sign.
- These observations form a part of 'before' data collection and can be compared to similar observations in 'after' case once the system is deployed on U.S.1.

B) Memorial Drive- AM Peak Period

In order to consider the vehicles turning right on red, it is necessary to consider a queue length based on lane groups because right turn on red is a function of acceptable gap on the main street and it can vary according to time of the day. Figure 5 and 6 show queue lengths observed on Memorial Drive in two lane groups.

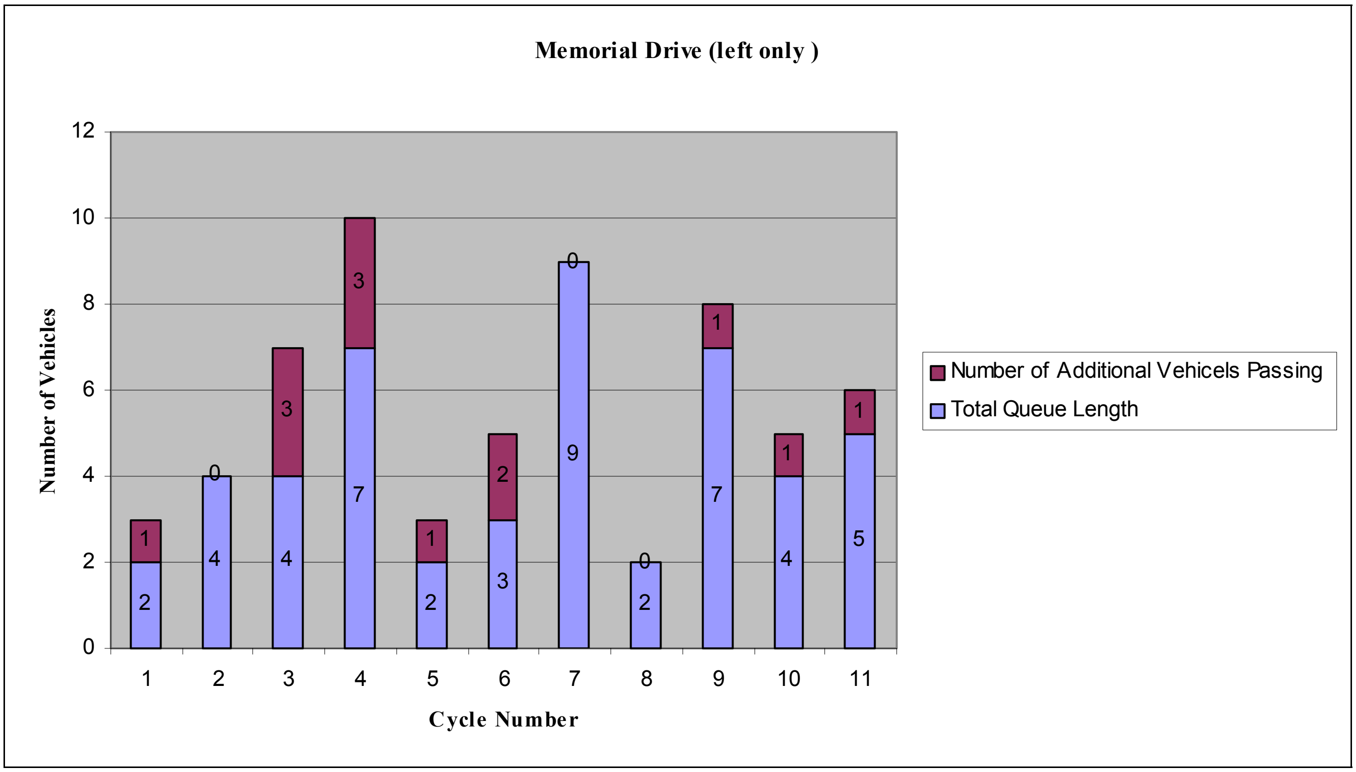


Figure 5: Queue Length on Memorial Drive- AM Peak Period

Observations: -

- Above graph shows the queue length on Memorial Drive (eastbound left turn only lane) onto U.S. 1 over a period of 11 signal cycles
- Blue portion of bars represent the queue which was present before the light turned green for South Kings Highway traffic
- Red portion of bars represent the additional vehicles which were able to pass through the intersection in the same cycle and were not a part of the original queue

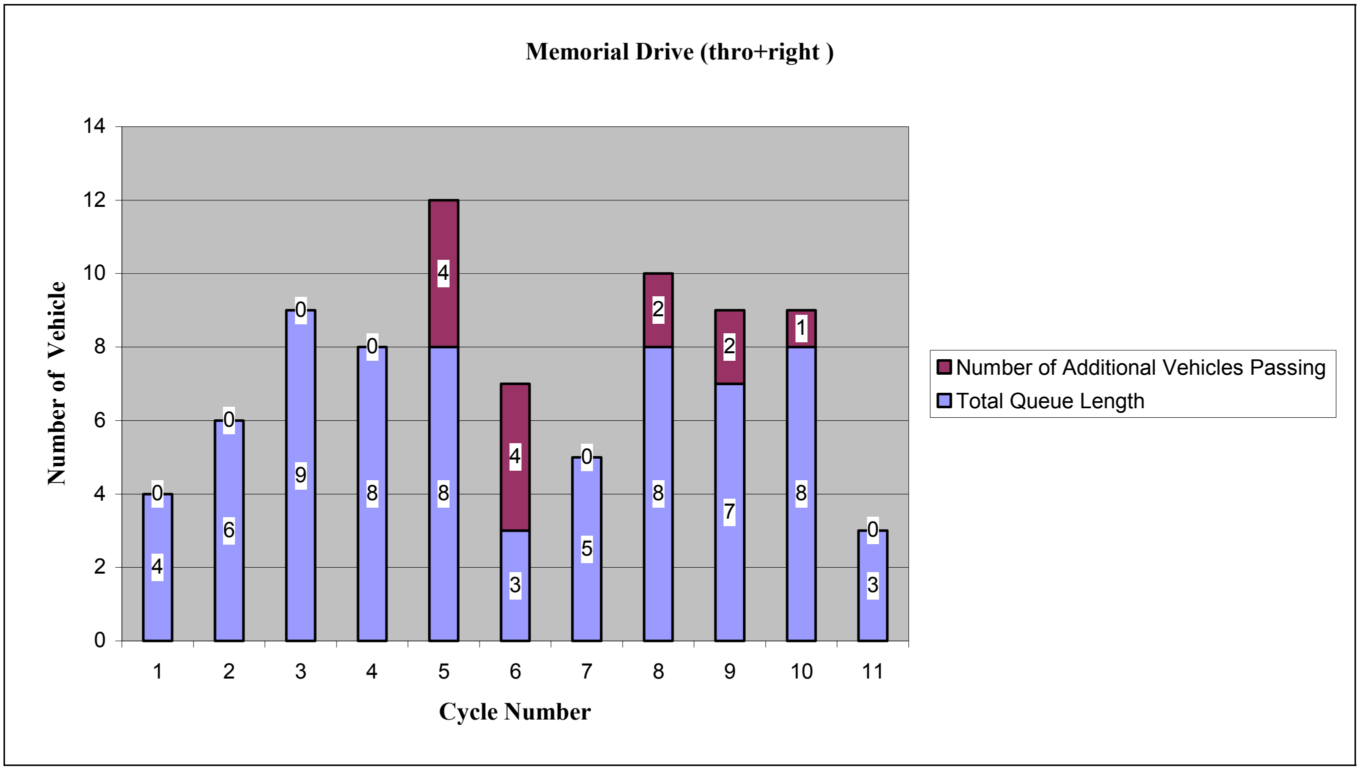


Figure 6: Queue Length on Memorial Drive- AM Peak Period

Observations: -

- Figure 6 shows the queue length on Memorial Drive (eastbound through+right turn lane) to get on to U.S. 1 over a period of 11 signal cycles
- Blue portion of bars represent the queue which was present before the light turned green for Memorial Drive traffic
- Red portion of bars represent the additional vehicles which were able to pass through the intersection in the same cycle and were not a part of the original queue

C) North Kings Highway/Shields Avenue- PM Peak Period

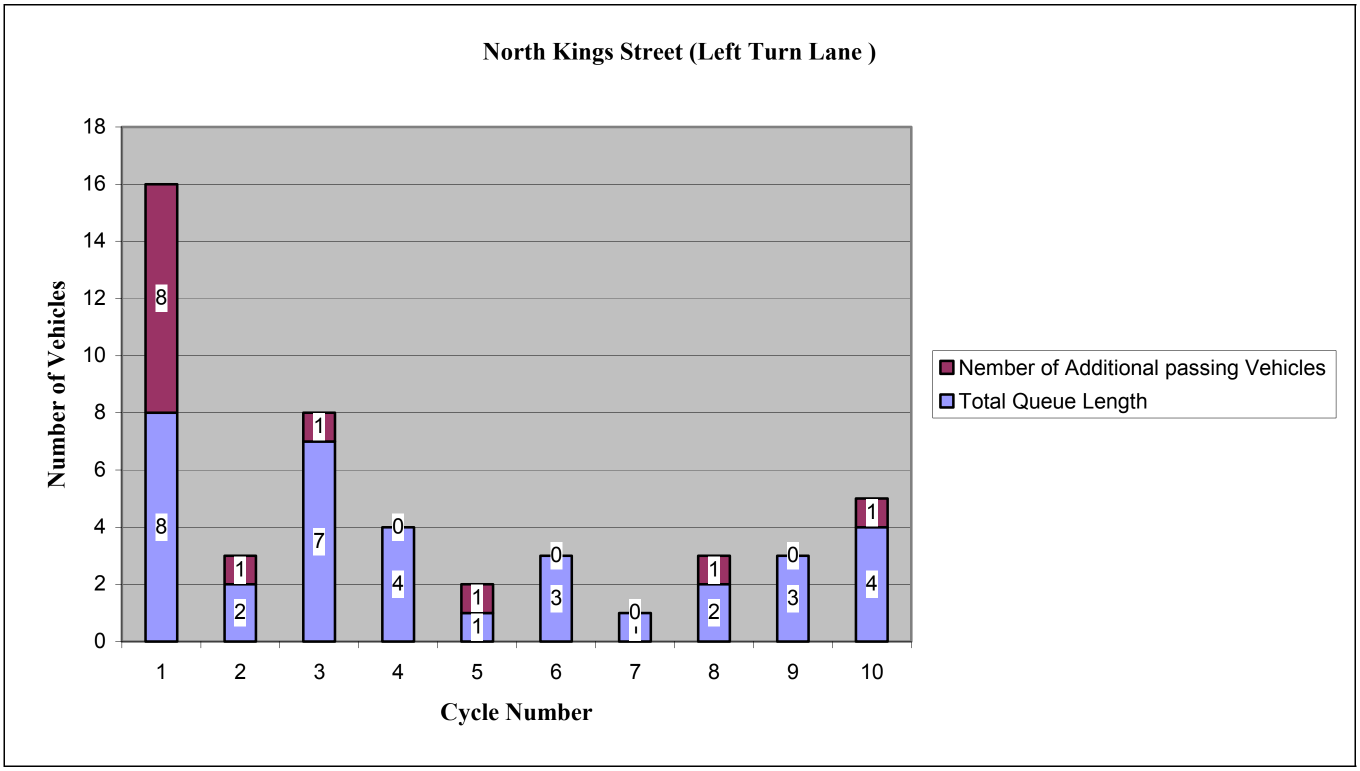


Figure 7: Queue Length on Shields Avenue - PM Peak Period

Observations: -

- Figure 7 shows the queue length on Shields Avenue (left only) to get on to U.S. 1 over a period of 11 signal cycles
- Blue portion of bars represent the queue which was present before the light turned green for Memorial Drive traffic
- Red portion of bars represent the additional vehicles which were able to pass through the intersection in the same cycle and were not a part of the original queue

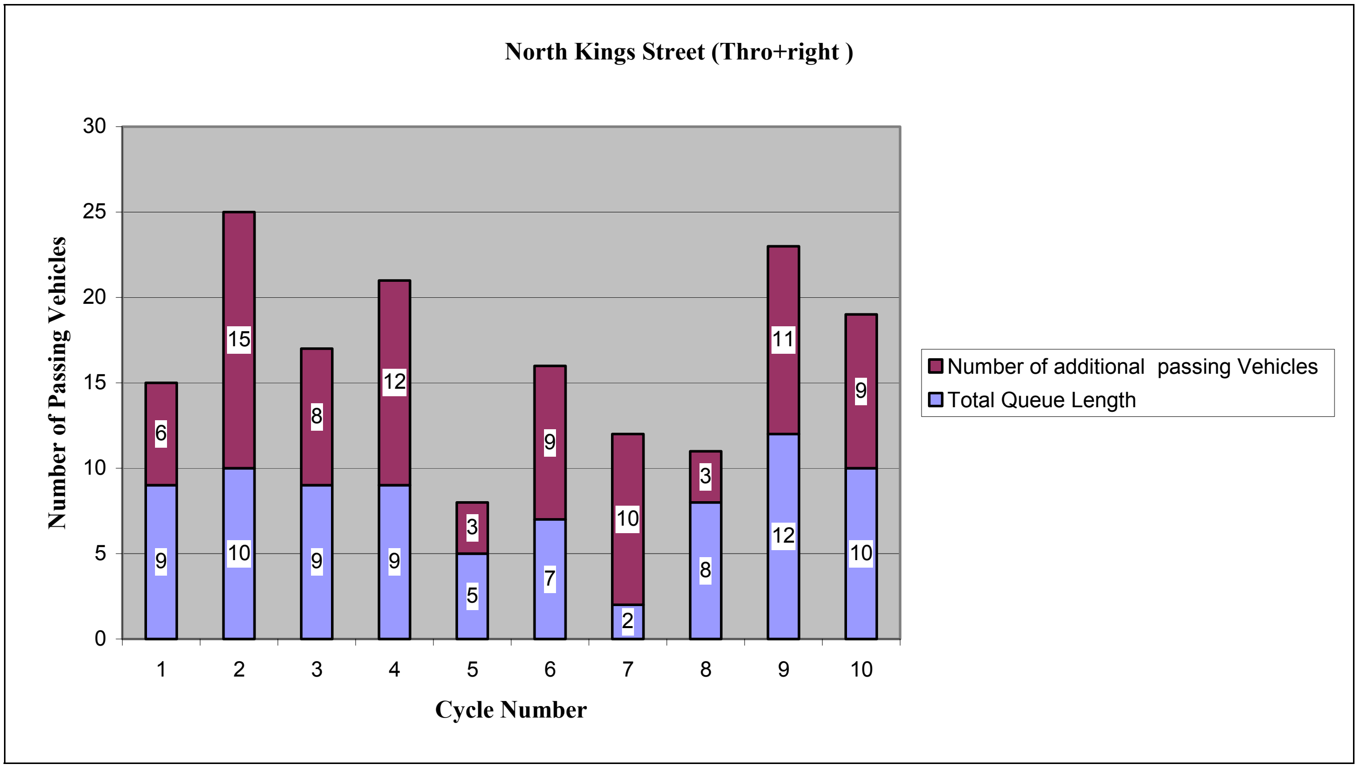


Figure 8: Queue Length on Shields Avenue - PM Peak Period

Observations: -

- Figure 8 shows the queue length on North Kings/Shields Avenue (through+right) to get on to U.S. 1 over a period of 11 signal cycles
- Blue portion of bars represent the queue which was present before the light turned green for Memorial Drive traffic
- Red portion of bars represent the additional vehicles which were able to pass through the intersection in the same cycle and were not a part of the original queue

D) Beacon Hill Road –PM Peak Period

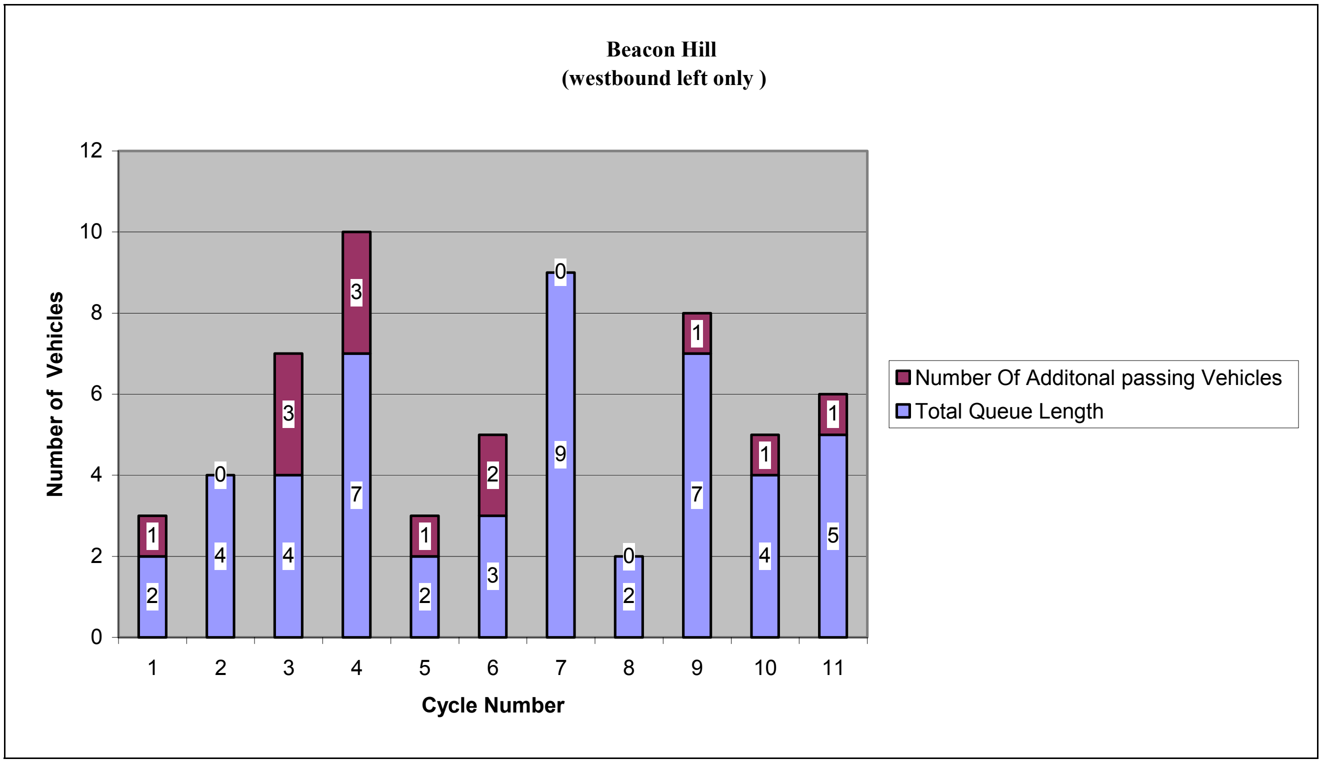


Figure 9: Queue Length on Beacon Hill Road - PM Peak Period

Observations: -

- Figure 9 shows the queue length on Beacon Hill Road (left only) to get on to U.S. 1 over a period of 11 signal cycles
- Blue portion of bars represent the queue which was present before the light turned green for Memorial Drive traffic
- Red portion of bars represent the additional vehicles which were able to pass through the intersection in the same cycle and were not a part of the original queue

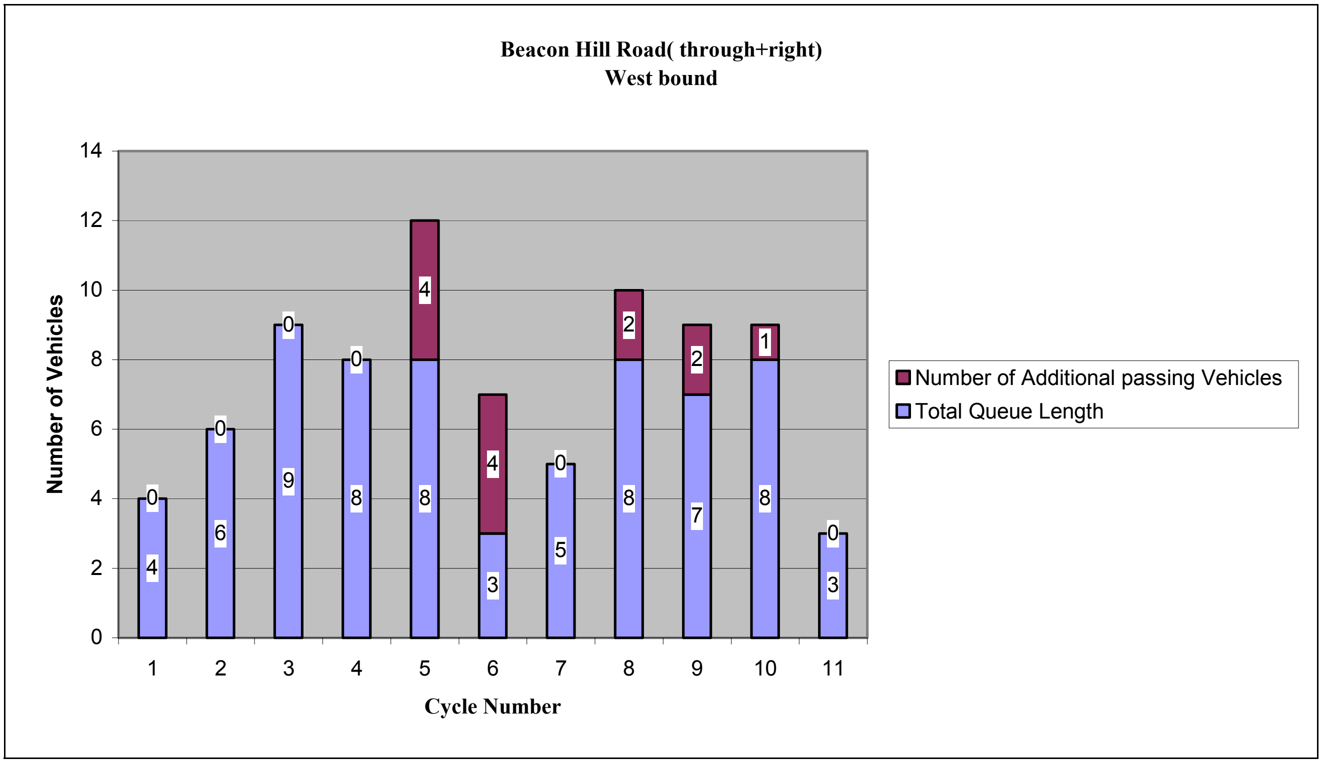


Figure 10: Queue Length on Beacon Hill Road - PM Peak Period

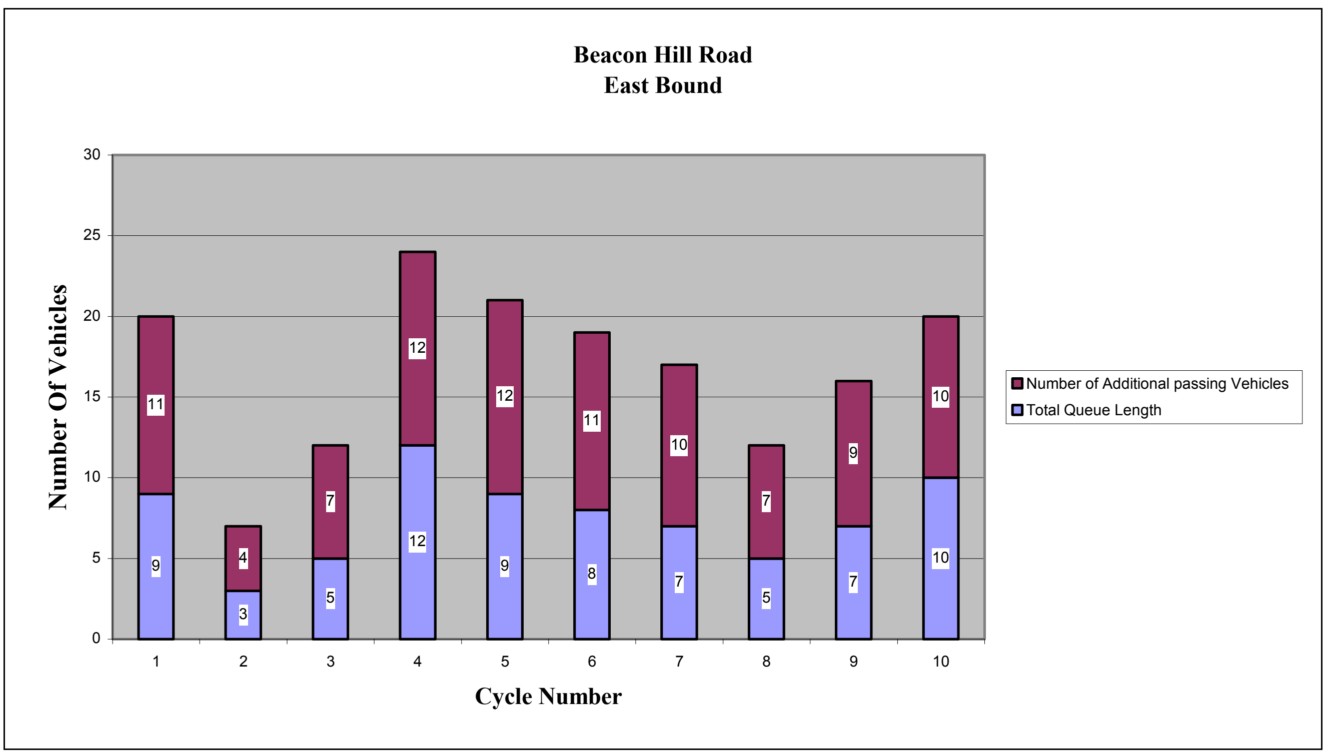


Figure 11: Queue Length on Beacon Hill Road - PM Peak Period

4.2.2 Transit Impact Evaluation

In order to model the transit service accurately, it is necessary to have an understanding about transit network and its characteristics.

Table 12 shows the data collection framework used for transit data collection in terms of data element measures and their sources.

Measure	Data Elements	Data Sources	Field Study		*Simulation Model
			Before Collection	After Collection	
Total Corridor Travel Time	Run time between Popkins Lane & Shields (North Kings Hwy)	1.Field Observations on U.S.1	Complete	To be Completed	VISSIM
On Time Performance at Scheduled time checks	Schedule Deviance at Beacon Hill Road.	1.Fairfax Connector Bus Schedules 2. Field Observations on U.S.1	Complete	To be Completed	VISSIM
Weighted Passenger Time in the Corridor	On-Off Counts on observed bus runs	1.Field observations on U.S.1	Complete	To be Completed	VISSIM
Cross-Street Delay (Non-Transit Vehicles)	Queue Lengths on side streets at major Intersections	1.Field observations on U.S.1	Complete	To be Completed	VISSIM

Table 12: Transit Impact Evaluation

Comments: -

- As shown in above table all the before data collection has been done and that provides an excellent framework for after data collection, once the system is deployed in U.S.1
- This research uses simulation tool VISSIM
- All the measures shown in this table have been explained in the earlier section in comparative data collection for transit and non-transit vehicles except for weighted passenger time in the corridor.

4.2.2.1 Weighted Passenger Time

One of the primary reasons to provide transit buses with priority at signalized intersections is that if transit vehicles, with much higher occupancy than passenger cars, are given preferential treatment under such strategies, the person throughput as well as the fuel efficiency of the system can improve substantially. Therefore, it is very important to make sure that we provide priority to buses traveling in peak direction and having occupancy above a minimum threshold value in order to justify priority. As mentioned in section 4.3.1.2, this research proposes signal priority for '**Peak period -Peak direction**' buses only. So, priority is proposed for northbound buses in AM peak period and southbound buses in PM peak period.

The study corridor consists of three Fairfax Connector routes (105,106,107). Following tables show the on-off counts collected on the field which support the above said notion of 'Peak period-Peak Direction'

Route 105 (Pole Road to Huntington Metro)

Northbound in AM Peak Period

Name of the stop	Initial No. of Passengers	Stop time	Go time	On Count	Off Count	Schedule Time	Deviance	Occupancy
Pole Road	1		7:39:40			7:37:00	0:02:40	1
1		7:40:25	7:40:59	5	0			
2		7:41:25	7:41:42	3	0			
Sacrmento Drive		7:42:15	7:42:30	2	0	7:39:00	0:03:15	11
1		7:43:30	7:43:38	1	0			
2		7:44:05	7:44:20	2	0			
Plantation Drive		7:45:00	7:45:08	1	0	7:44:00	0:01:00	15
1		7:46:40	7:46:51	2	0			
2				0	0			
3		7:47:51	7:48:00	1	0			
4		7:48:51	7:48:42	3	0			
5		7:49:10	7:49:20	2	0			
Russel Road		7:50:40	7:50:48	1	0	7:50:00	0:00:40	24
1		7:51:15	7:51:40	2	0			
2		7:52:32	7:52:40	0	2			
3		7:52:50	7:53:02	1	0			
4		7:53:30	7:53:45	0	3			
5		7:54:00	7:54:30	7	0			
6		7:55:25	7:55:40	3	0			
7		7:56:10		0	0			
8		7:56:30		0	0			
9		7:59:30	7:59:48	1	0			
Ladson Road		8:00:30	8:00:35		2	7:57:00	0:03:35	31
1		8:01:35	8:01:42	1	0			
2		8:02:20	8:02:35	1	2			
3		8:03:35		0	0			
4		8:04:20		0	0			
5		8:04:50		0	0			
6		8:05:20	8:02:41	0	3			
7		8:06:20		0	0			
Beacon Hill Road		8:06:55	8:07:05	2	0			30
1		8:07:45		0	0			
2				0	0			
3		8:09:25	8:09:40	0	3			
4		8:10:35		0	0			
5		8:11:15		0	0			
6		8:16:45	8:17:10	0	2			
7		8:18:00		0	0			
8		8:18:10		0	0			
Huntington Metro		8:19:15		0	22	8:15:00	0:04:15	22

Table 13: Occupancy Data for Rt.105 -NB-AM Peak Period

Comments: -

- Study Corridor starts just after Ladson Road as shown in blue in above table
- Occupancy through study corridor is 30 which is 60% (Bus Capacity = 50)
- Table also shows schedule deviance
- Bus is 215 seconds behind schedule before entering the corridor

Southbound in PM Peak Period

Name of the stop	Initial No. of Passengers	Stop time	Go time	On Count	Off Count	Schedule Time	Deviance	Occupancy
Huntington Metro	49	0:00:00	05:15:00			5:13:00	0:02:00	49
1		5:16:45	5:16:50	1	0			
2		5:18:10	5:18:20	1	0			
3		5:20:00	5:20:25	1	0			
Becon Hill Road		5:23:45	5:24:00	0	3	5:22:00	0:01:45	
1		5:25:45	5:25:55	0	1			50
2		5:28:10	5:28:20	0	1			
3		5:29:00	5:29:35	2	2			
4		5:31:25	5:31:40	2	1			
5		5:32:20	5:32:50	0	2			
6		5:33:25	5:34:05	1	2			
7		5:35:25	5:35:40	1	1			
8		5:36:15	5:36:40	2	6			
9		5:38:10	5:38:45	5	4			
Ladson Lane		5:39:25	5:39:42	0	3	5:31:00	0:08:25	
1		5:40:25	5:40:30	0	1			
2		5:40:55	5:41:10	0	2			
3		5:42:00	5:42:30	0	8			
4		5:43:05	5:43:17	0	2			
5		5:43:45	5:44:00	2	1			
6		5:44:20	5:44:27	0	1			
7		5:45:20	5:45:40	0	7			
8		5:46:07	5:46:15	1	0			
Russel Road						5:39:00		
1		5:40:25	5:40:30	0	1			
2		5:40:55	5:41:10	0	2			
3		5:42:00	5:42:30	0	8			
4		5:43:05	5:43:17	0	2			
5		5:43:45	5:44:00	2	1			
6		5:44:20	5:44:27	0	1			
7		5:45:20	5:45:40	0	7			
8		5:46:07	5:46:15	1	0			
9								
10								
Sacremento Drive						5:48:00		

Table 14: Occupancy Data for Rt.105 -SB-PM Peak Period

Comments: -

- Study Corridor starts just after Huntington Metro as shown in blue in above table
- Occupancy through study corridor is 50 which is 100% (Bus Capacity = 50)
- Table also shows schedule deviance
- Bus is 105 seconds behind schedule before entering the corridor

Route 106 (Mt.Vernon Hospital to Huntington Metro)

Northbound in AM Peak Period

Name of the stop	Initial No. of passengers	Stop time	Go time	On count	Off count	Schedule Time	Deviance	Occupancy
Mt.Vernon hospital	3		8:08:15	0	1	8:05:00	0:03:15	3
1		8:13:55	8:14:00	1	0			
2		8:14:48	8:15:00	5	0			
3		8:15:10	8:15:40	5	0			
4		8:15:50	8:15:50	4				
Mt Vernon Sq .Apt		8:16:05	8:16:20	1	0	8:12:00	0:04:05	19
1		8:17:00	8:17:05	1	0			
2		8:17:50	8:17:56	1	0			
At Signal		8:19:10	8:19:20	1	0			
3		8:20:25	8:20:35	6	2			
4		8:21:13	8:21:20	1	0			
5		8:23:00	8:23:15	1	1			
Beacon Hill Road		8:24:10	8:24:26	4	0	8:19:00	0:08:10	31
1		8:25:25	8:25:47	0	2			
2		8:27:56	8:28:05	0	1			
3		8:28:35	8:28:46	1	0			
Huntington Metro		8:38:25				8:29:00	0:09:25	29

Table 15: Occupancy Data for Rt.106 -NB-AM Peak Period

Comments: -

- Study Corridor starts just after Mt.Vernon Sq. Apt. as shown in blue in above table
- Occupancy through study corridor is 31 which is 61% (Bus Capacity = 50)
- Table also shows schedule deviance
- Bus is 480 seconds behind schedule before entering the corridor

Southbound in PM Peak Period

Name of the stop	Initial No. of Passengers	Stop time	Go time	On Count	Off Count	Schedule Time	Deviance	Occupancy
Huntington Metro	35	0:00:00	5:13:00			5:10:00	0:03:00	35
1		5:16:40	5:17:00	1	0			
2		5:17:30	5:17:45	0	1			
3		5:18:20	5:18:35	0	1			
4		5:19:00	5:19:20	4	0			
5		5:21:00	5:21:20	0	2			
6		5:22:00	5:22:45	1	1			
7		5:23:40	5:23:45	0	4			
8		5:25:35	5:25:50	1	1			
9		5:27:25	5:27:35	0	1			
Beacon Hill Road		5:28:50	5:29:10	3	1	5:19:00	0:09:50	
1		5:29:55	5:30:00	0	2			33
2		5:32:10	5:32:15	0	1			
3		5:33:00	5:33:10	0	1			
4		5:35:00	5:35:20	1	3			
Mt. Vernon Sq.Apt		5:36:25	5:36:35	0	1	5:27:00	0:09:25	
1		5:37:10	5:37:25	0	6			
2		5:38:00	5:38:10	0	3			
3		5:38:40	5:38:55	0	2			
4		5:39:50	5:40:00	0	3			
5		5:41:00	5:41:15	0	1			
6		5:45:20	5:45:45	1	2			
7		5:46:35	5:46:40	0	1			
8		5:48:50	5:48:55	0	1			
9		5:50:40	5:50:55	0	1			
Mt. Vernon Hospital		5:52:50				5:37:00	0:15:50	

Table 16: Occupancy Data for Rt.106 -SB-PM Peak Period

Comments: -

- Study Corridor starts just after Huntington Metro shown in blue in above table
- Occupancy through study corridor is 33 which is 65% (Bus Capacity = 50)
- Table also shows schedule deviance
- Bus is 540 seconds behind schedule before entering the corridor out of which 180 seconds is due to dispatch issues

4.3 Traffic Signal Timing Data

Traffic signal data used in this research is obtained from the VDOT's database maintained in Synchro. Appendix C shows the Synchro inputs for signal timings and traffic volumes.

4.4 Priority Strategy

As mentioned previously, priority strategy used in this research is 10 seconds green extension. The provision of priority is based on local detection at every intersection using 3M Opticom emitter systems.

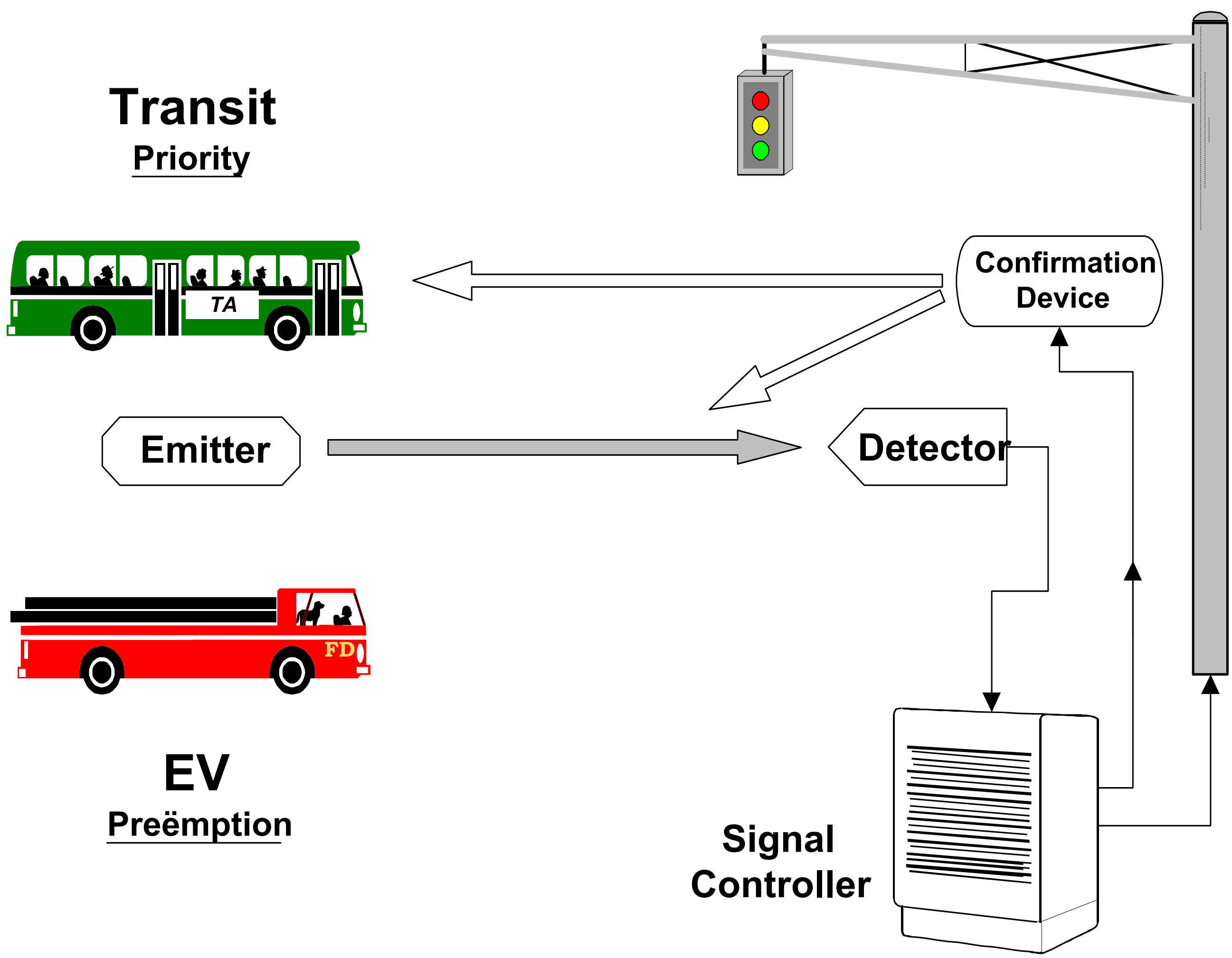


Figure 12 : System Architecture for 3M Opticom Emitter Detection System

Figure 12 shows the system architecture of the detection system used for this research. Figures 13 and 14 show the actual photographs of these elements installed on the field.

Figure 13: Photographs showing 3M Opticom Emitters

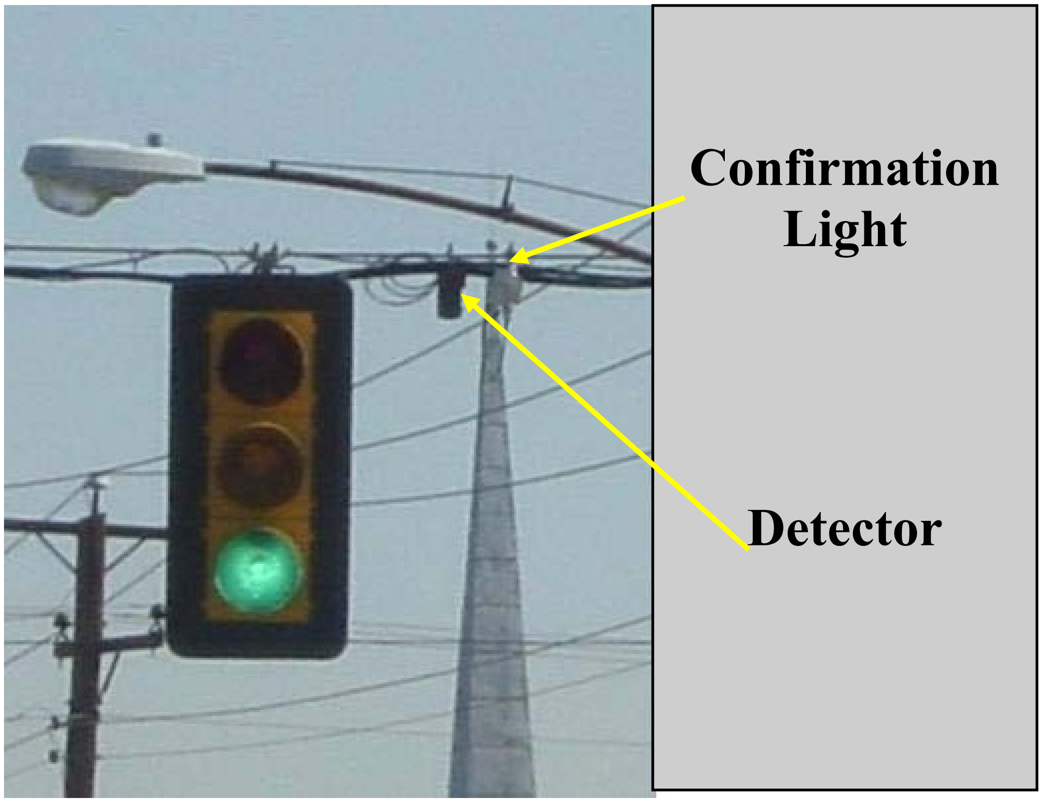


Figure 14: 3M Detector and Confirmation Light

Chapter 5 : MODELLING IN VISSIM

The VISSIM microscopic simulation model was used for this research. VISSIM was selected because of its capability to provide detailed information on the MOEs identified in Chapter 3.VISSIM has a strong emphasis on modeling transit, and it allows the user to evaluate traffic signals through fixed time controllers or through explicitly defined controller logic (Ova, Smadi). Also, this is the first effort at Virginia Tech to use VISSIM to model priority, making it a significant contribution in research tools at the University. This section will give a general overview of the characteristics of the model, its data requirements, and the calibration method.

VISSIM was developed in Germany through research originating at the University of Karlsrhue, Karlsrhue, Germany. VISSIM, a German acronym for "traffic in towns - simulation" is a stochastic microscopic simulation model. There are two main components of the VISSIM model: a traffic simulator and a signal state generator. The traffic simulator model primarily consists of a car following and a lane changing logic. This model uses a psychophysical driver behavior model developed by Wiedemann (1974) (ITC, 2000b).

Basically, this model uses perception thresholds for drivers approaching a moving vehicle and the reaction of the driver once a reaction must be taken. This reaction is then an iterative process of acceleration and deceleration of the vehicle until passing of the vehicle takes place or the paths of the two vehicles diverge (ITC, 2000b). The model can process vehicle locations up to 10 time steps per second.

The signal state generator operates by acquiring detector information and signal head status from the traffic simulator, processes the data, and then returns a new value for a signal head (i.e., green, yellow, or red). This process allows for greater flexibility when creating simulation networks. The signal state generator uses a language called VAP, an English acronym for Vehicle Actuated Program. This language is similar to BASIC in using an IF-THEN logic structure. The VAP polls information and returns signal status to the traffic simulator once per second.

The data requirements of the model consist of mainly four categories: **geometric, traffic characteristics, traffic signal control, and transit information**. Signal control data include parameters such as green times, clearance intervals, maximum and minimum green times, offsets, and permissive periods. Traffic characteristics include parameters such as speed distributions, volumes, turning percentages, percentage of heavy vehicles, vehicle classifications, acceleration/deceleration distributions, etc. Examples of geometric and traffic control data are number of lanes, grades, reduced speed areas, pavement markings, detector locations, yield areas, stop signs, and parking areas. Finally, transit information includes routes, schedule, ridership levels, transit vehicle characteristics, and bus dwell times. Table 17 shows the sources used for all these data elements in this research

Data Element	Source
Geometric Characteristics	Synchro file from VDOT
Traffic Characteristics	Synchro file from VDOT & Field Observations
Traffic Signal Control	Synchro file from VDOT
Transit Information	Fairfax Connector Bus Schedules &Field Observations

Table 17: Data Resources for VISSIM modeling

5.1 Network Modeling

The 1.3-mile section of U.S.1 was modeled with VISSIM using the data obtained from data sources in Table 17. Figure 15 shows a snapshot of the entire network in VISSIM starting from Shields Avenue being north end of the corridor at the top of the graphic Popkins Lane on the south end (North pointed upwards).

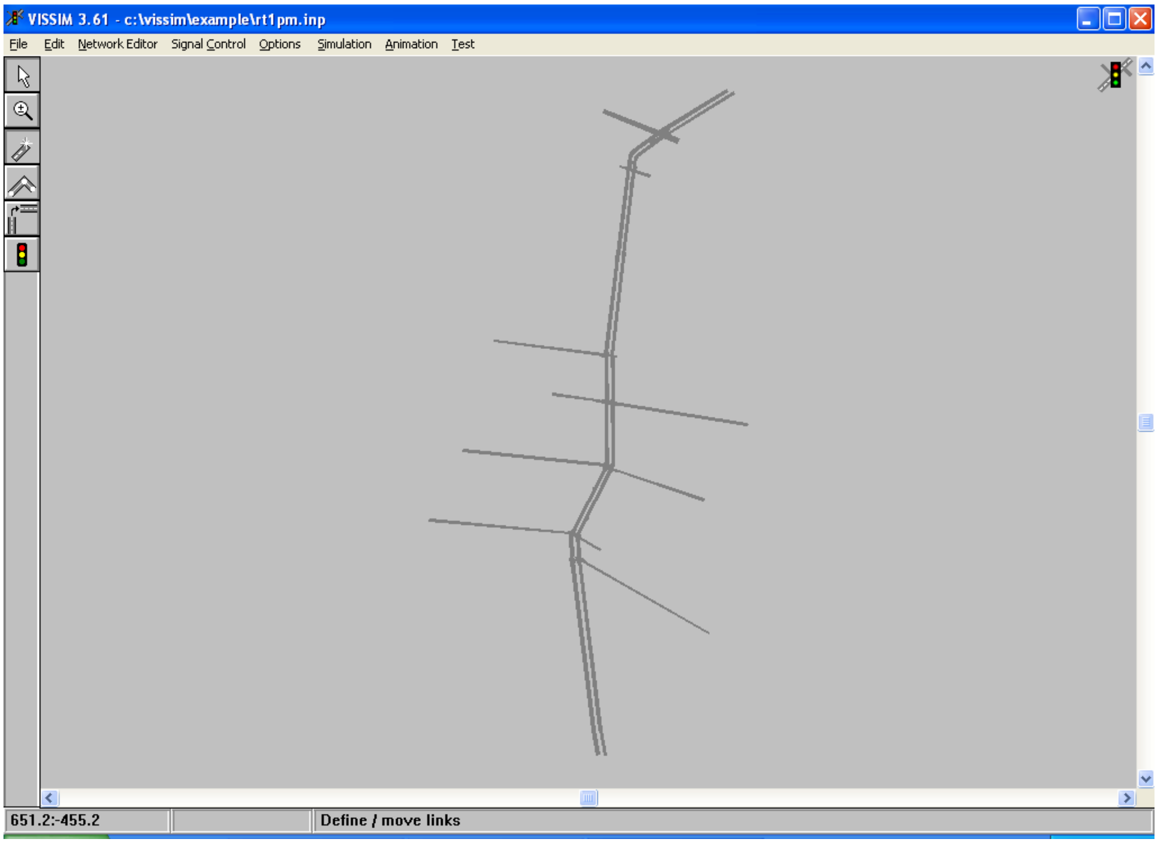


Figure 15: Study Corridor Modeled in VISSIM

5.2 Traffic Signal Control

Modeling traffic signal control to emulate the 'before' case and to deploy a 'green extension' priority logic to give the 'after' case is the heart of this research. Therefore, it was very important to the maximum extent possible to emulate the signal control data and to program the model to deploy priority strategy.

In this research, Signal Control Junction (SCJ) based approach was chosen to model seven intersections in VISSIM. One signalized intersection forms one SCJ that includes different signal head groups attributed to different lane groups. Figure 16 shows a snapshot of entire network with all seven SCJ shown in red color.

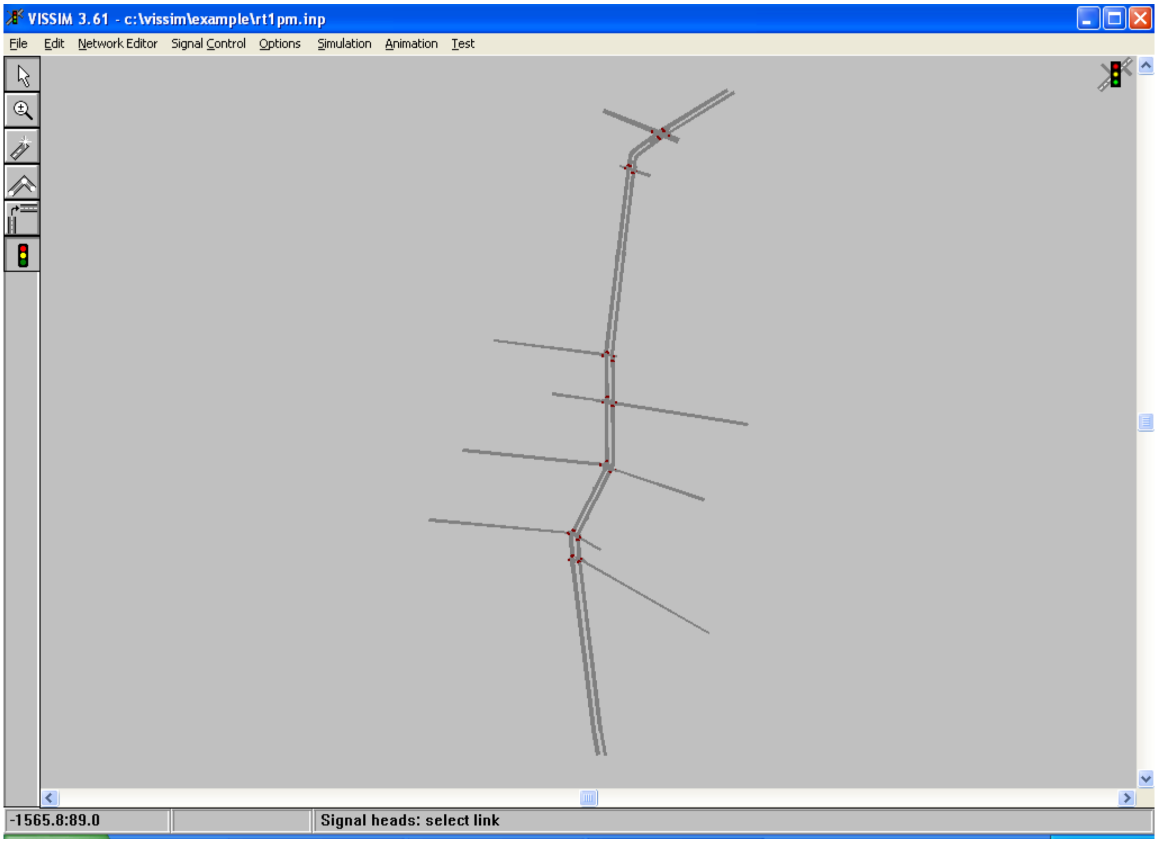


Figure 16: Study Corridor with 7 Signalized Intersections

5.2.1 Signal Controller Logic

In order to program actuated – coordinated signal logic, the signal state generator uses a language called VAP, an English acronym for Vehicle Actuated Program. This language is similar to BASIC in using an IF-THEN logic structure. The VAP polls information and returns signal status to the traffic simulator once per second.

The VAP works on subroutine based programming for individual intersections. This research makes a significant contribution in acquiring these programming capabilities at

Virginia Tech. The VAP being a latest technology, very few attempts have been made in this area before (ITC-World Website), this forms an important aspect of this research.

All seven intersections were programmed and these VAP programs can be found in the Appendix B.

5.2.2 Signal Priority Logic

The literature review summarized in Chapter 2 identified the most common TSP strategies used throughout the country. The review showed that early green and extended green TSP strategies were the most commonly used methods. These strategies were also tailored to meet agencies' preferences, implementation requirements, and location restrictions. In this research primary emphasis was on minimum disruption of coordinated traffic signal operations. This feature was especially important to the case study area, where the main corridor is a major arterial carrying heavy traffic volumes in peak hours. Also, deployment is planned for only green extension. So this research modeled only a 10 second green extension.

As mentioned before, this research applies priority based on individual detection prior to every intersection. Therefore, the priority logic in VAP is based on 'Check-In and Check Out' detectors. These are the detectors in VISSIM, which work the same as the 3M emitter and the detector operate in the field. After a bus requests a priority the actual green times in the original logic are replaced by temporary green times which allow the 10 second green extension for main line travel and takes that time from side streets to be distributed locally over the same cycle. The following program shows the signal priority subroutine used for this model,

Program for Transit Priority

```
/*********************************/
/**** TRANSIT SIGNAL PRIORITY ****/
/*********************************/


SUBROUTINE TransitPriority1;


IF BusDetector1 THEN
   IF presence(BusDetector1) THEN
         CheckIn:=TRUE;
   END;
END;


IF BusDetector2 THEN
   IF presence(BusDetector2) THEN
         CheckIn:=FALSE;
   END;
END;


/**** TEMPORARILY MODIFY MAXGREEN VALUES ****/


IF CheckIn THEN
      TempMaxGreen[1]:=Factor1*MaxGreen[1];
      TempMaxGreen[2]:=Factor2*MaxGreen[2];
      TempMaxGreen[4]:=Factor1*MaxGreen[4];
```

```
        TempMaxGreen[5]:=Factor1*MaxGreen[5];
        TempMaxGreen[6]:=Factor2*MaxGreen[6];
        TempMaxGreen[8]:=Factor1*MaxGreen[8];
ELSE
        TempMaxGreen[1]:=MaxGreen[1];
        TempMaxGreen[2]:=MaxGreen[2];
        TempMaxGreen[4]:=MaxGreen[4];
        TempMaxGreen[5]:=MaxGreen[5];
        TempMaxGreen[6]:=MaxGreen[6];
        TempMaxGreen[8]:=MaxGreen[8];
END.


/**** PREVENT PHASES 2 AND 6 FROM GAPPING OUT ****/


SUBROUTINE TransitPriority2;
IF CheckIn THEN
        GapOut2:=FALSE;
        GapOut6:=FALSE;
        GapOut26:=FALSE;
END.
```

As described above, factors 1 & 2 in TempMaxGreen calculation take care of the 10 second green extension and prevent mainline phases (2&6) from gapping out providing bus with green extension.

5.3 Calibration of Model

The calibration of the model is an important process in the methodology because it provides credibility to the results by closely representing the actual conditions. Typical calibration measures consist of volume, delay, and travel speeds. In this research, average operating speed is used as a calibration measure for the transit network. Also, this research differs from conventional calibration process as most of the model inputs are obtained form the field data collection described in Chapter 4.

Average operating speed of transit buses from field observations (Chapter 4) is 13.4 mph. VISSIM allows the operating speed of particular class of vehicles to be controlled by the simulator. To be in synch with the field data the desired average operating speed was chosen in the range of 12.4 to 15. 5 mph. Also, the signal time distributions seen from the VISSIM output are similar to their inputs from Synchro files, which provides further support for the signal control programming done using Vehicle Actuated Programming. Appendix C shows an example of this green time distribution file from VISSIM.

5.4 Simulation Scenarios

Simulation scenarios are groupings of simulation runs that can be distinguished by certain characteristics being simulated. There are essentially four distinguishing characteristics (or

Table 18: Distinguishing Characteristics of Simulation Runs

Distinguishing Characteristics of Simulation Runs		
Distinguishing Characteristic	**Possible Values**	**Number of Possible Values**
Traffic volume	**Low, Medium, High**	**3**
Priority Capability	**YES or NO**	**2**
Peak Period	**AM, PM**	**2**
Random Runs	**5 random number seeds**	**5**
		Total Runs= 60

factors) that pertain to the simulation scenarios used for this research. These four characteristics are shown in Table 18.

5.5 Summary

This section provided a brief overview of the simulation model, the components of the model, and the data requirements for proper model development. It provided an understanding of the capabilities of this model when applied to the methodology. However, for a detailed description of the simulation model used, readers are encouraged to refer to the VISSIM User Manual (ITC, 2000b).

Chapter 6 : RESULTS, CONCLUSIONS AND RECOMMENDATIONS

This chapter focuses on presenting the results of the simulation analysis and in addition results will be related to the hypotheses presented earlier. Also, major conclusions from this research will be presented along with recommendations for future research.

6.1 Bus Service Reliability – Time Reliability

As the study corridor is a small section of a long transit route, schedule deviance is not a good measure to evaluate results since provision of priority in the study corridor will have no control on what happens along the entire route. Also, the priority strategy is not related to lateness of the transit bus as it is assumed to be the driver's responsibility to make sure that bus never runs ahead of the schedule. Furthermore, it has been seen from field observations that buses were often behind schedule before entering the study corridor.
So in this research, the measure for bus service reliability is 'Time Reliability' (measure 1.2 in the evaluation framework). Provision of priority to a late bus will assist the bus to adhere to on the schedule via savings in travel time.

6.1.1 Bus Service Reliability – Hypothesis #1

In order to test Hypothesis # 1 the measure used is time reliability as a standard deviation of elapsed time between end points of the study corridor (measure 1.2 from table 2). Two travel time data collection points were established on either side of the study corridor. The resulting values for the 15 pairs of simulation runs in AM as well as PM peak period, without and with priority are shown in the figures 17 & 18.

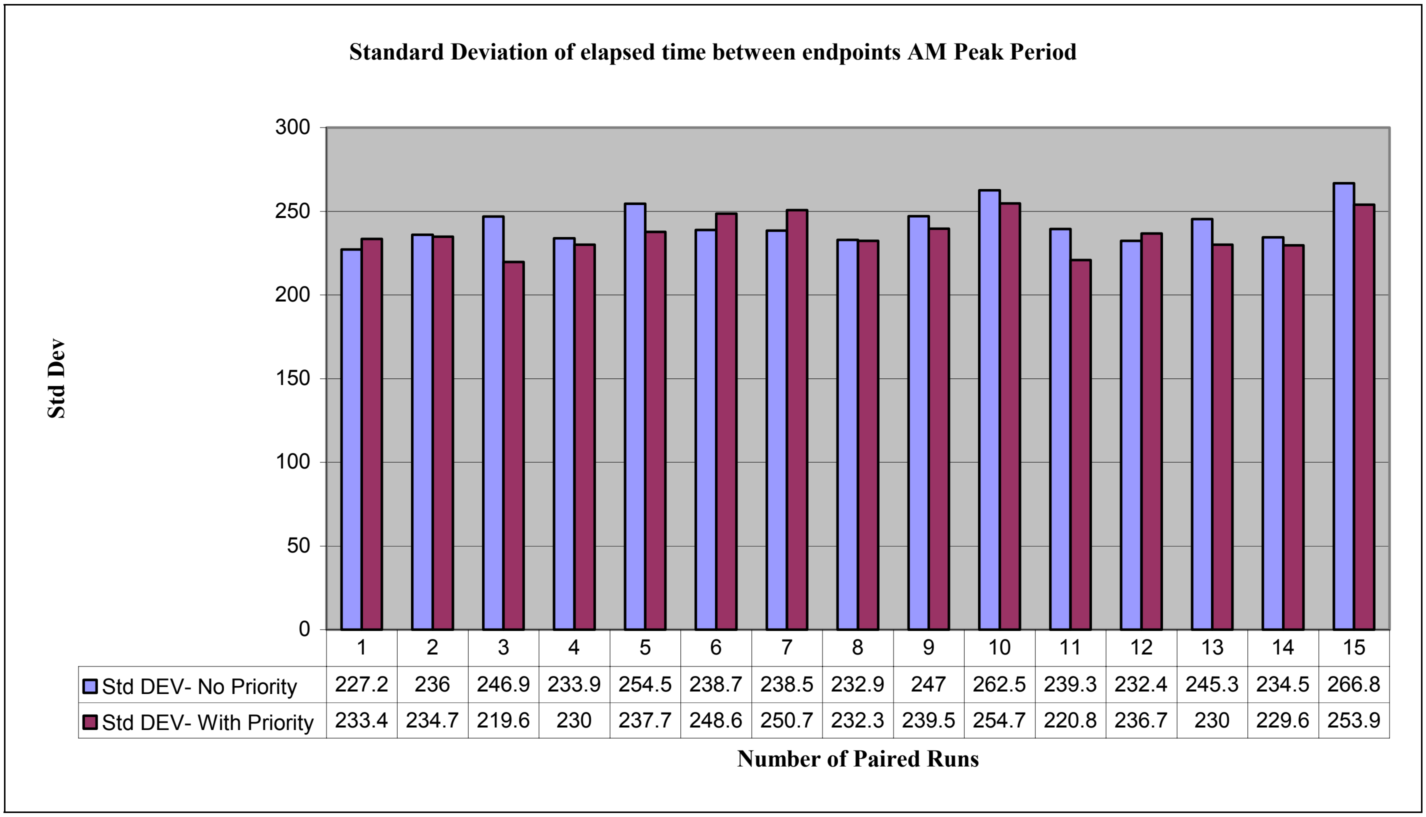


Figure 17: Standard Deviation of elapsed time between endpoints- AM Peak Period

Comments: -

- In 11 out of 15 in AM Peak period, the provision of priority resulted in a lower standard deviation, representing greater bus service reliability.
- Overall there was an average decrease of 2.32 % in the standard deviation of travel time data between end points.
- Standard deviation values represent standard deviation of seven travel time values for elapsed time between end points. These seven values are for seven buses passing through the corridor in the one-hour simulation run, which is in sync with the frequency of Fairfax Connector buses in peak hours. It is acknowledged that a higher number of observations can be obtained by increasing the simulation duration or increasing the frequency of transit bus operation; however, this research focuses on emulating the field conditions resulting in 30 paired runs.

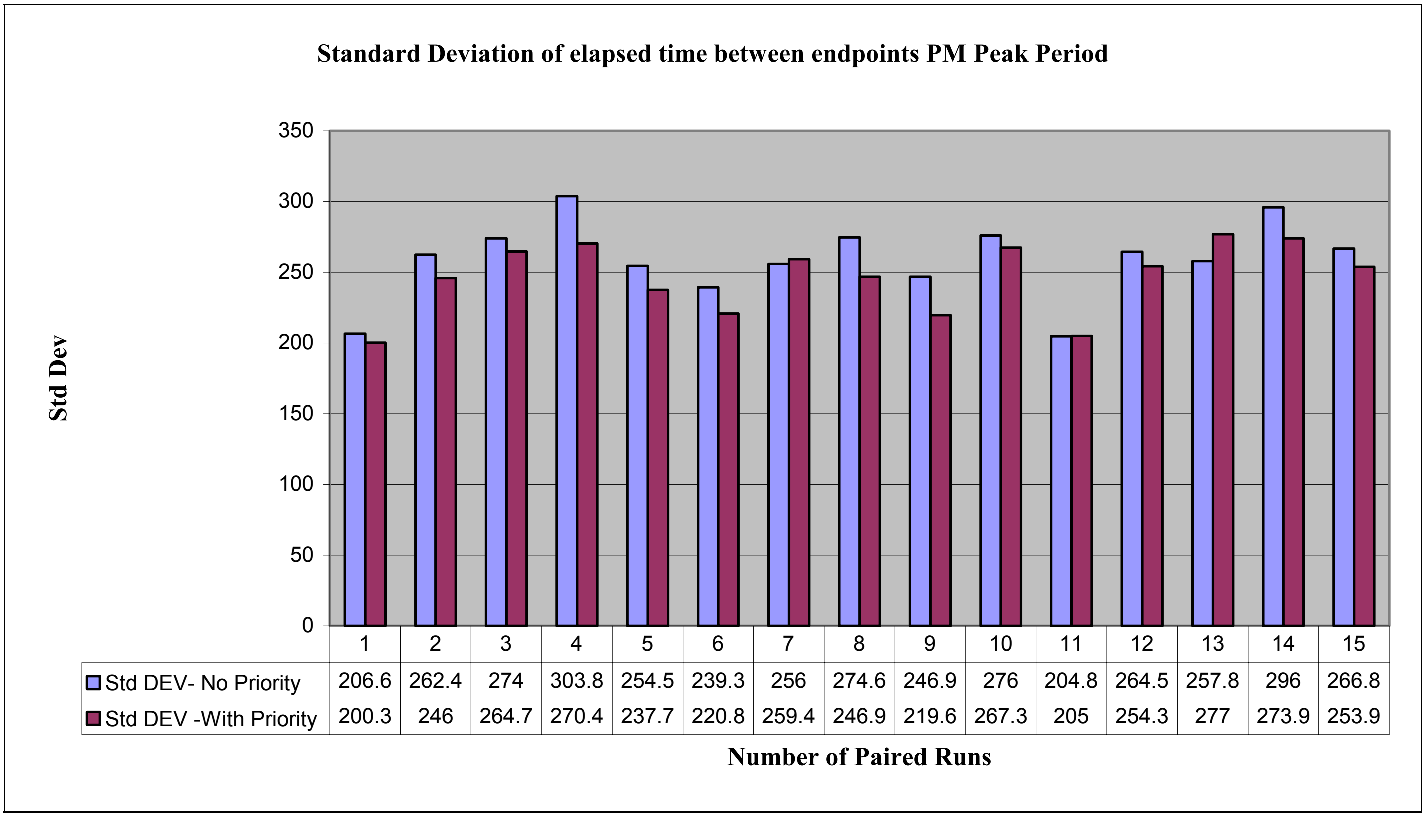


Figure 18: Standard Deviation of elapsed time between endpoints- PM Peak Period

Comments: -

- In 12 out of 15 in PM Peak period, the provision of priority resulted in a lower standard deviation, representing greater bus service reliability.
- Overall there was an average decrease of 4.81 % in the standard deviation of travel time data between end points.

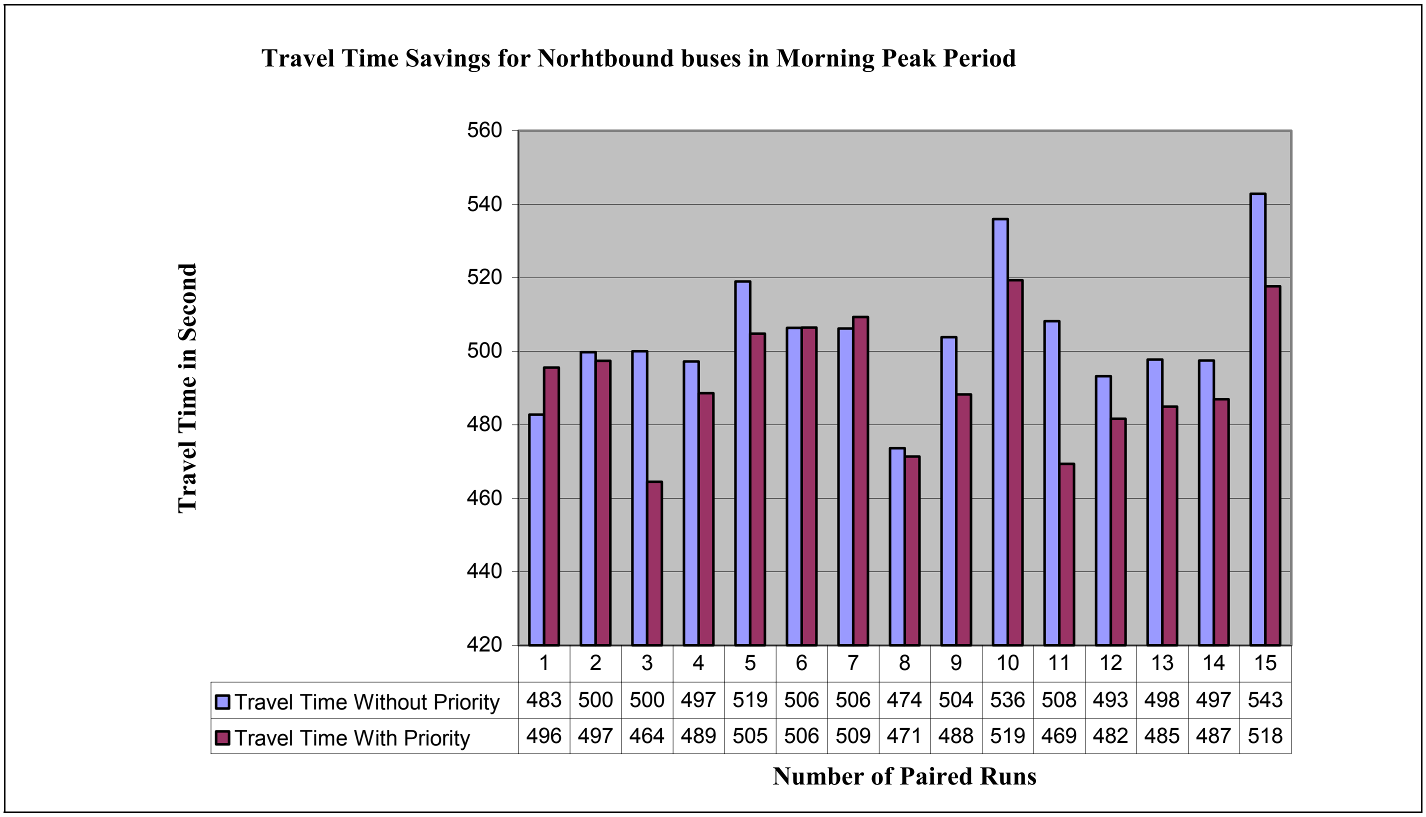
Overall, in 23 of the 30 paired simulation runs, the provision of priority resulted in a lower standard deviation, representing greater bus service reliability. Overall there was an average decrease of 3.61% in the standard deviation of travel time between end points. This indicates that the time reliability is higher with conditional priority than with no priority, affirming Hypothesis #1, which suggests that the provision of priority will be associated with higher bus service reliability. While values of standard deviation decreased when priority was provided one must be cautious to draw conclusions about the statistical significance of the difference in standard deviation values before and after provision of priority. While paired two-sample t test for means showed the difference to be significant, the Kolmogorov-Smirnov (K-S test Data Entry Website) test showed otherwise. Additional observations may assist in exploring these results further.

6.2 Bus Efficiency

As indicated in the evaluation framework, bus efficiency is a measure of travel time savings for transit buses due to the provision of priority. In order to evaluate travel time savings 'Average Run Time' (measure 2.1) is used.

6.2.1 Bus Efficiency– Hypothesis #2

Two travel time data collection points were established on either side of the study corridor. The resulting values for the 15 pairs of simulation runs in AM as well as PM peak period, without and with priority are shown in the Figures 19 and 20.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Travel Time Without Priority	483	500	500	497	519	506	506	474	504	536	508	493	498	497	543
Travel Time With Priority	496	497	464	489	505	506	509	471	488	519	469	482	485	487	518

Figure 19: Travel Time Savings for Northbound Buses - AM Peak Period

Comments: -

- In 12 out of 15 in AM Peak period, the provision of priority resulted in a lower average run time, representing greater bus efficiency
- Overall there was an average decrease of 2.35 % in the average run time data between end points
- Each of the 30 travel time values represent the average of seven travel time values for elapsed time between end points. These seven values are for seven buses passing through the corridor in one-hour simulation run, which is in sync with the frequency of Fairfax Connector buses in peak hours. It is acknowledged that additional observations can be obtained by increasing the simulation duration or increasing the frequency of transit bus operation; however, this research focuses on emulating the field conditions resulting in 30 paired runs.

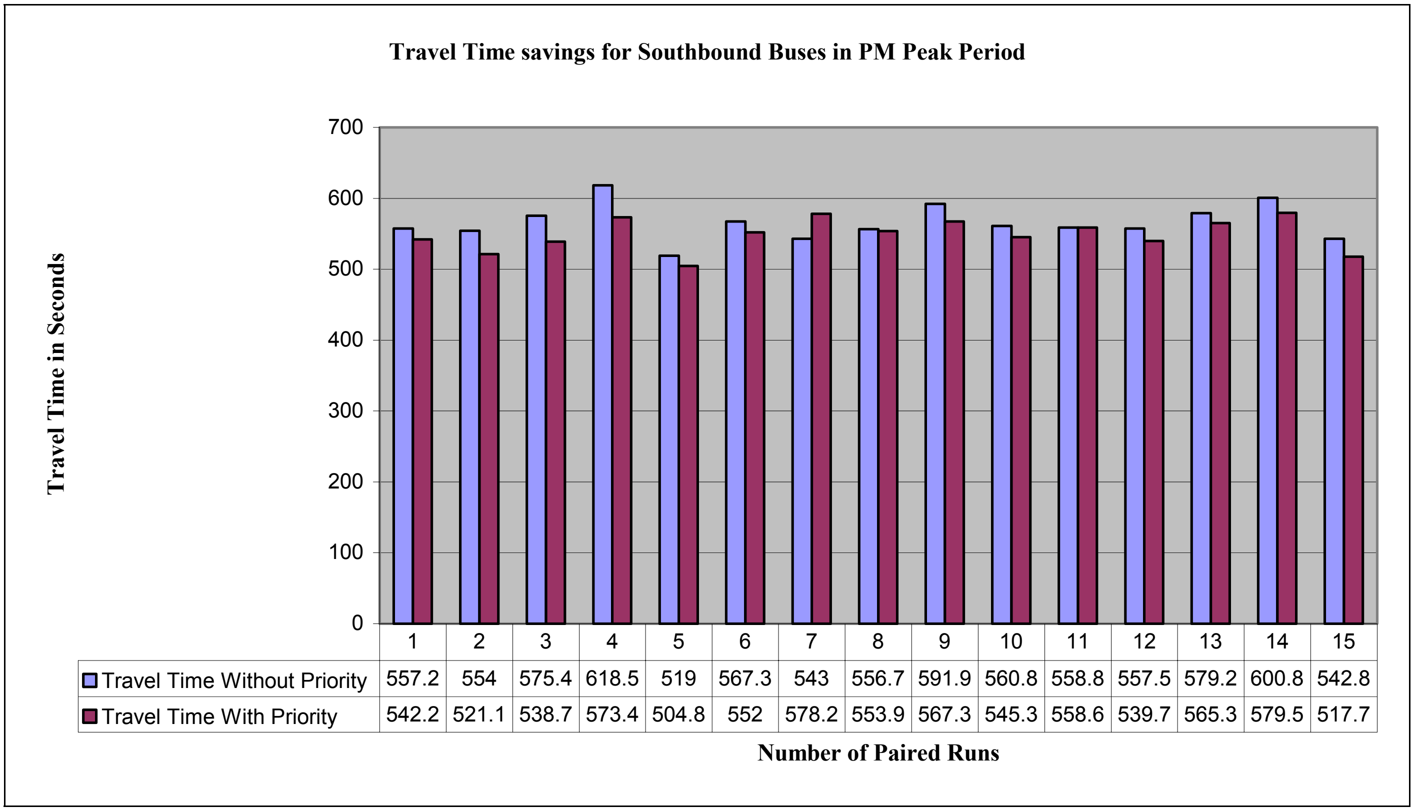


Figure 20: Travel Time Savings for Southbound Buses - PM Peak Period

Comments: -

- In 14 out of 15 in PM Peak period, the provision of priority resulted in a lower average run time, representing greater bus efficiency
- Overall there was an average decrease of 2.89 % in the average run time data between end points

Overall, in 26 of the 30 paired simulation runs, the provision of priority resulted in a lower average run time, representing greater bus efficiency. Overall there was an average decrease of 2.64% in the average run time between end points. This indicates that the bus efficiency is higher with the provision of priority than with no priority, supporting Hypothesis #2, which states that the provision of priority will be associated with higher bus service reliability. While values of travel time decreased when priority was provided one must be cautious to draw conclusions about the statistical significance of the difference in standard deviation values before and after provision of priority. While the paired two-sample t test for means showed the difference to be significant, the Kolmogorov-Smirnov test showed otherwise (K-S test Data Entry Website). Additional observations may assist studying this hypothesis further.

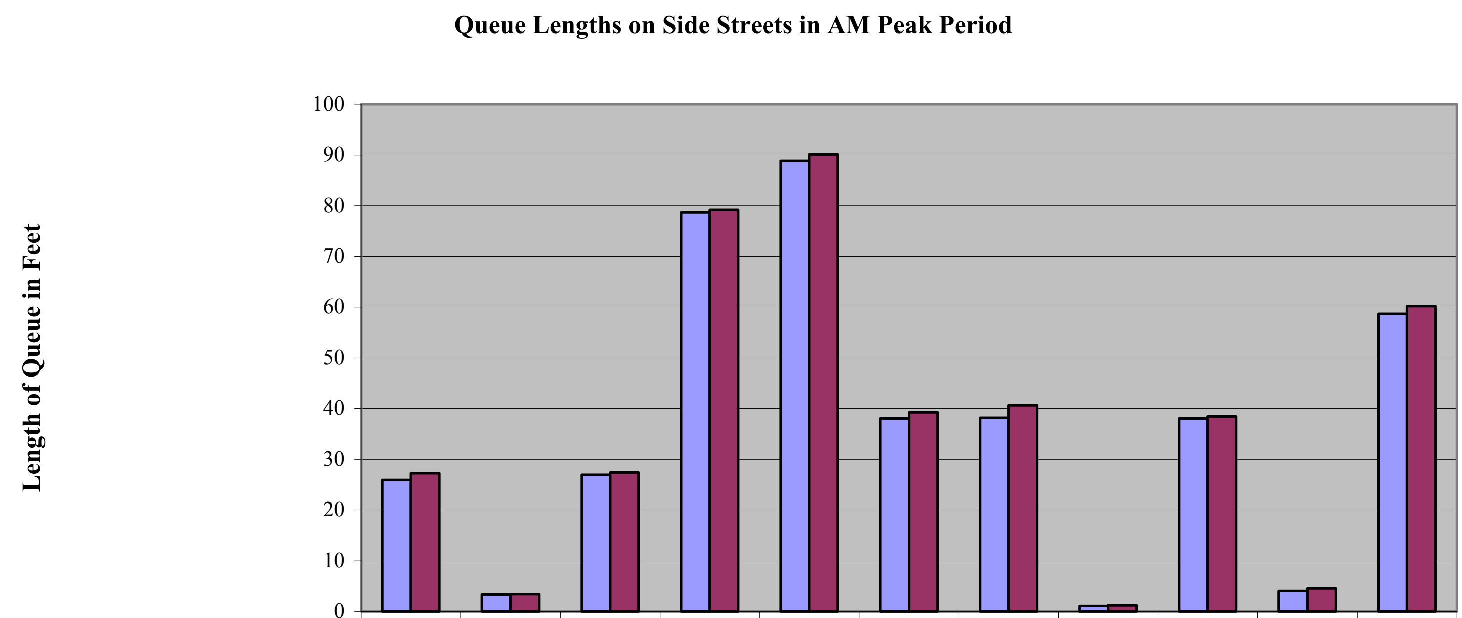
6.3 Other Traffic-Related Impacts – Queue Lengths on Side Streets

Other traffic-related impacts resulting from the use of transit signal priority play a critical role in the evaluation process. Some important stakeholder groups tend to be more cognizant of potential negative impacts on the general motoring public than potential benefits to transit users and operators. In this research, it is very important to study the impacts on other traffic on U.S.1, especially the traffic on side streets.

6.3.1 Other Traffic-Related Impacts – Hypothesis #3

In the case of U.S.1, primary concern was the traffic on the side streets, as they receive minimum share (16%) of green time in the signal timing plan and could be penalized to provide 10 second green extension to the transit buses. As far as U.S.1 traffic is considered, they receive 84%(150 second out of 180 second cycle) of green time and the green extension provided to transit buses will tend to further increase this percentage. Therefore, provision of priority to transit buses will have little to no negative impact on through traffic on U.S.1.

In order to test hypothesis #3, the measure used is queue lengths on side streets. VISSIM provides an inbuilt data collection tool called ‘queue-counter’ which measures the queue length after a given time interval and compiles them in an output file. . As VISSIM uses three dimensionality of the vehicles to take this into account, the queue length is measured in feet. In order to get the queue length after every cycle, the time interval for the queue counter was chosen as the same as the cycle length for all the signals in the study corridor i.e.180 second. Figure 21 shows average queue lengths on all the side streets in AM as well as PM peak period. Values are averages of queue lengths at the end of each cycle further averaged over 15 paired simulation runs in each period.

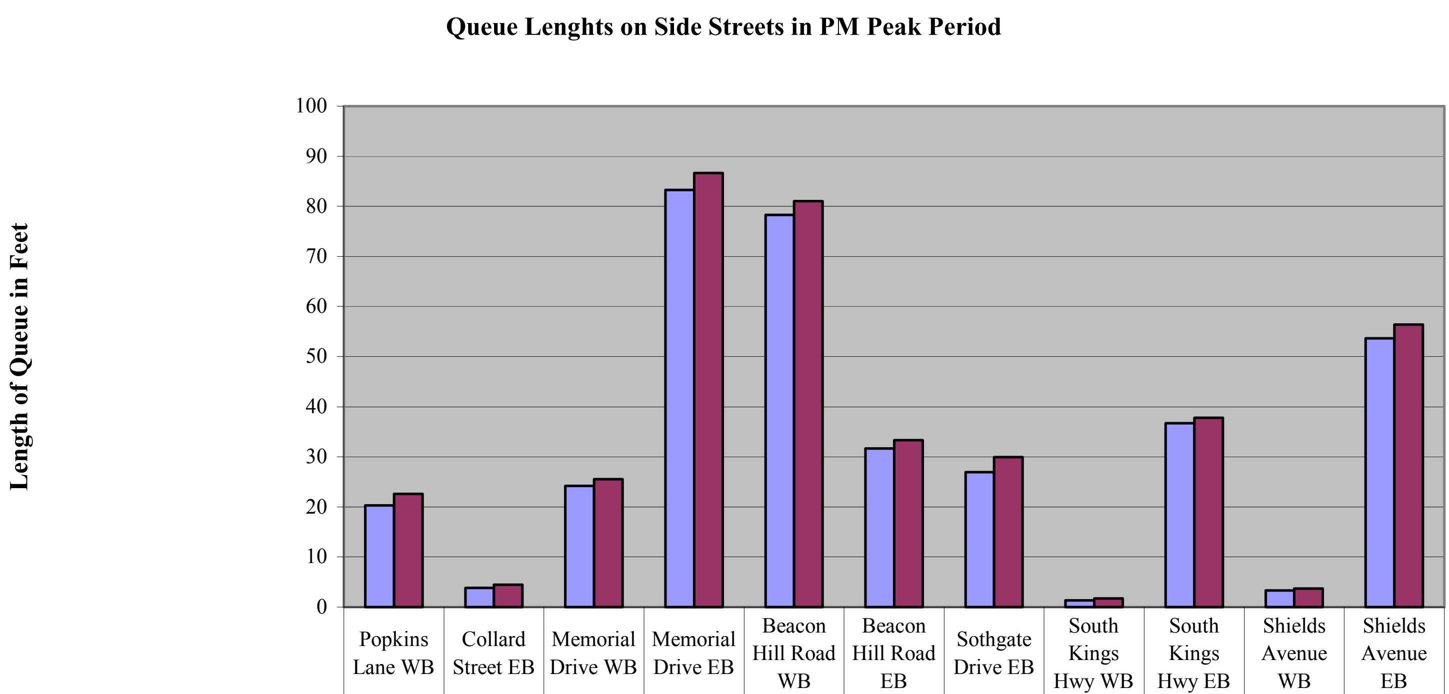


	Popkins Lane WB	Collard Street EB	Memorial Drive WB	Memorial Drive EB	Beacon Hill Road WB	Beacon Hill Road EB	Sothgate Drive EB	South Kings Hwy WB	South Kings Hwy EB	Shields Avenue WB	Shields Avenue EB
Queue Lengths in 'Before' Case	25.91	3.37	26.96	78.66	88.85	38.03	38.15	1.1	38.06	4.04	58.65
Queue Lengths in 'After' case	27.23	3.4	27.4	79.17	90.07	39.25	40.61	1.21	38.41	4.57	60.18

Figure 21 : Average Queue Lengths on Side Streets - AM Peak Period

Comments: -

- In the AM peak period, the provision of priority resulted in an increase in average queue length on all the 11 side streets
- Overall there was an average increase of 0.88 feet with a maximum increase of 2.46 feet in the queue length data on side streets
- Increase in queue length is relatively insignificant and represents less than one car length



	Popkins Lane WB	Collard Street EB	Memorial Drive WB	Memorial Drive EB	Beacon Hill Road WB	Beacon Hill Road EB	Sothgate Drive EB	South Kings Hwy WB	South Kings Hwy EB	Shields Avenue WB	Shields Avenue EB
Queue Lengths in 'Before' case	20.32	3.84	24.21	83.25	78.27	31.67	26.97	1.33	36.74	3.29	53.63
Queue Lengths in 'After' Case	22.63	4.48	25.53	86.68	81.01	33.35	29.95	1.7	37.82	3.68	56.39

Figure 22: Average Queue Lengths on Side Streets - AM Peak Period

Comments: -

- In PM the peak period, provision of priority resulted in an increase in average queue length on all 11 side streets
- Overall there was an average increase of 1.69 feet with a maximum increase of 3.43 feet in the queue length data on side streets
- Increase in queue length is relatively insignificant and represents less than one car length.

Overall, the provision of priority to the transit buses resulted in an average increase of 1.285 feet (less that one car length) with a maximum value of 3.43 feet. This indicates that provision of priority tends to have very little impact on the side streets, affirming hypothesis#3 which states that provision of priority will be associated with little to no impact on the other traffic. While it is acknowledged that the Side Streets impacts can be evaluated in terms of 'time' (e.g. vehicle delay, person delay), this research evaluates them in terms of queue lengths to address specific concerns of stakeholders. As part of the field test, traffic engineers were interested in how many more vehicles would be delayed on the side streets and whether the queue could be dissipated in a same cycle.

6.4 Conclusions

This research focused on analyzing the impacts of transit signal priority on Fairfax Connector buses on U.S.1 and on overall traffic characteristics in the corridor. Three major categories of impacts were considered: -

-Effects on Bus Service Reliability
-Effects on Bus Efficiency
-Other Traffic Related Impacts

Within these categories, a variety of indicators was considered according to the framework proposed by Chang (Chang, 2002). Depending on the particular environment and objectives, the most appropriate measures of effectiveness were chosen from the proposed measures to evaluate the potential impacts of provision of signal priority to Fairfax Connector buses and impacts on other non-transit traffic. These measures were then used in the simulation analysis. Based on the simulation analysis the following conclusions are drawn:

- Priority may contribute to bus service reliability. When priority was provided, a 3.61% improvement occurred in the standard deviation of elapsed time between end points.
- Priority may also assist improving bus efficiency; a 2.64% decrease in run time was estimated when transit buses were given priority.

- Priority had little to no impact on side street traffic; an average increase of 1.825 feet was observed in average queue lengths on side streets with a maximum value of 3.46 feet.
- Priority may lead to reductions in transit travel time and thus contribute to improvement in on time schedule performance.
- These above impacts are consistent with the results reported in other priority deployment studies.
- Provision of priority resulted in improved bus service reliability and bus efficiency with little to no negative impacts on other non-transit traffic affirming all three tested hypotheses

6.5 Recommendations for Future Research

While this research has provided a foundation for the evaluation of transit signal priority in Northern Virginia area for VDOT and Fairfax County, future efforts can build upon this research. There are several potential areas which remain to be examined and can have a significant influence on the way ITS preferential treatment projects are planned in the region. Some of the potential areas are mentioned here:

- Provision of priority for a longer segment of U.S.1 needs to be examined to see the impacts on schedule adherence, headway preservation and negative impacts on other traffic.
- Considering impacts of relative occupancy levels of transit vehicles will be important.
- Advanced priority strategies like early-green and queue jumpers should be examined over a stretch of U.S.1 in future
- Fuzzy Logic might be considered to formulate a methodology to find the 'best' priority strategy for a given operational environment

- In addition to local detection strategies, a system wide priority should be considered as Fairfax County plans for future ITS investments.
- Impacts of transit priority need to be examined under varying volume to capacity ratios.
- The capabilities of VISSIM should be further explored to program preemption for emergency vehicles.
- This research focuses on intersection based programming for redistribution of green time and does not address alternate ‘transition’ or ‘recovery’ strategy for traffic signal controllers to revert back to the original timing plan. The capabilities of VISSIM and VAP should be explored to program such recovery strategies to identify an optimum strategy.
- Further investigations should be conducted to convert benefits and other impacts of transit priority into monetary terms

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Appendix A

- **Examples of Data Collection Sheets Used for Field Data Collection**
- **Fairfax Connector Bus Schedules**

North Bound Traffic					**AM Peak Period**			
Morning 7.00-7.30am								
		Run1		Run 2		Run3		Run 4
Intersection 1	Stop			0'4"				
Popkins LA Road	Go			0'11"				
	Pass	0'5"		0'17"		0'4"		0'4'"
Intersection 2	Stop							
Collorad St	Go							
	Pass	0'8"		0'19"		0'8"		0'6"
Intersection 3	Stop					0'30"		
Memorial St	Go					0'34"		
	Pass	0'30"		0'45"		0'53"		0'27"
Intersection 4	Stop			1'0'"				
Becon St	Go			1'26"				
	Pass	0'47"		1'36"		1'25"		0'48"
Intersection 5	Stop							
Southbound St	Go							
	Pass	0'57"		1'48"		1'40"		1'02"
Intersection 6	Stop	1'45"				2'45"		1'40"
S. Kings Street	Go	1'48"				3'58"		2'03"
	Pass	2'05"		2'45"		4'02"		2'25"
Intersection 7	Stop							
N. King Street	Go							
	Pass	2'15"		2'55"		4'12"		2'37"
	Final	2'20"		2'59"		4'17"		2'41"

North Bound Traffic					AM Peak Period			
Morning 7.45-8.15am								
		Run1		Run 2		Run3		Run 4
Intersection 1	Stop					0'4"		
Popkins LA Road	Go					0'33"		
	Pass	0'04"		0'3"		0'36"		0'05"
Notes:								
Intersection 2	Stop							
Collorad St	Go							
	Pass	0'8"		0'7"		0'42"		0'10"
Intersection 3	Stop							
Memorial St	Go							
	Pass	0'29"		0'32"		1'05"		0'30"
Intersection 4	Stop	0'45"		0'50"		1'20"		
Becon St	Go	0'56"		0'53"		1'31"		
	Pass	1'06"		1'0"		1'40"		0'47"
Intersection 5	Stop							
Southbound St	Go							
	Pass	1'23"		1'14"		1'54"		0'57"
Intersection 6	Stop	2'10"		2'0"		2'37"		1'40"
S. Kings Street	Go	2'14"		2'05"		2'46"		1'50"
	Pass	2'25"		2'10"		2'56"		2'05"
Intersection 7	Stop							
N. King Street	Go							
	Pass	2'38"		2'24"		3'10"		2'15"
	Final	2'44"		2'29"		3'16"		2'20"

Name : Beacon Hill Road
Approach: west bound
Time : 4:47:5:17

Cycle	Red Time		Queue Length	Green/		Passing		Total
		Left	Throu+right	Amber Time	Left	Throu+right	Left	Throu+right
1	2:15:00	2	4	0:20:00	1	0	3	4
2	2:30:00	4	6	0:20:00	0	0	4	6
3	2:40:00	4	9	0:38:00	3	0	7	9
4	2:20:00	7	8	0:38:00	3	0	10	8
5	2:20:00	2	8	0:35:00	1	4	3	12
6	2:25:00	3	3	0:40:00	2	4	5	7
7	2:20:00	9	5	0:30:00	0	0	9	5
8	2:30:00	2	8	0:35:00	0	2	2	10
9	2:25:00	7	7	0:35:00	1	2	8	9
10	2:25:00	4	8	0:25:00	1	1	5	9
11	2:35:00	5	3	0:30:00	1	0	6	3

Intersection Queue

Name : Beacon Hill Street

Approach: Eastbound

Time : 4:45-5:15

Cycle	Red Time	Queue Length	Green/ Amber Time	Passing	Total Passing	Note
1	2:20:00	7	0:00:20	0	7	
2	2:40:00	10	0:00:30	1	11	
3	2:25:00	7	0:00:35	4	11	
4	2:30:00	12	0:00:40	0	12	
5	2:20:00	9	0:00:30	0	9	
6	2:30:00	8	0:00:30	2	10	
7	2:25:00	6	0:00:25	1	19	
8	2:35:00	8	0:00:35	5	19	
9	2:25:00	8	0:00:35	3	11	
10	2:30:00	7	0:00:30	2	9	

Name : Beacon Hill Road
Approach: west bound
Time : 4:47:5:17

Cycle	Red Time		Queue Length	Green/		Passing		Total
		Left	Throu+right	Amber Time	Left	Throu+right	Left	Throu+right
1	2:15:00	2	4	0:20:00	1	0	3	4
2	2:30:00	4	6	0:20:00	0	0	4	6
3	2:40:00	4	9	0:38:00	3	0	7	9
4	2:20:00	7	8	0:38:00	3	0	10	8
5	2:20:00	2	8	0:35:00	1	4	3	12
6	2:25:00	3	3	0:40:00	2	4	5	7
7	2:20:00	9	5	0:30:00	0	0	9	5
8	2:30:00	2	8	0:35:00	0	2	2	10
9	2:25:00	7	7	0:35:00	1	2	8	9
10	2:25:00	4	8	0:25:00	1	1	5	9
11	2:35:00	5	3	0:30:00	1	0	6	3

ROUTE
105

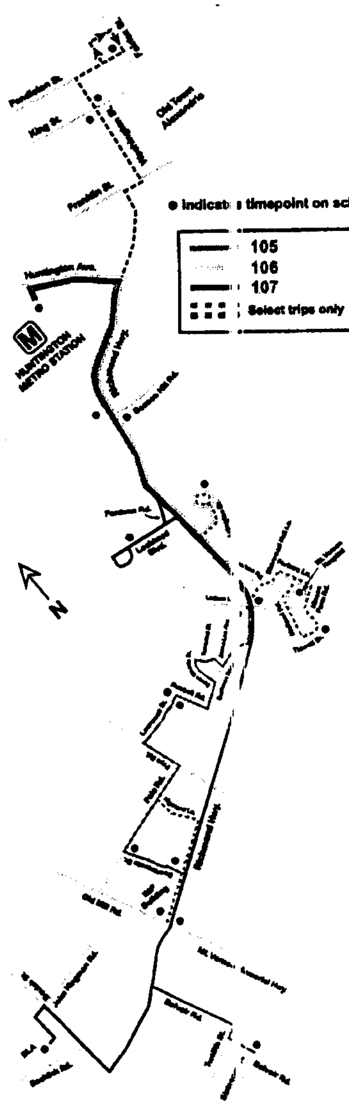
Richmond Highway Line

Fort Belvoir to the Huntington Metro Station; also serving Mount Vernon Hospital & Old Town Alexandria

Fairfax Connector

339-7200
TTY (703) 339-1608
www.fairfaxconnector.com

Effective September 2002



Route 105 — Sunday Northbound

Sacramento Dr & Richmond Hwy	Richmond Hwy & Ladson Ln	Tiswell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Mt. Vernon Square Apts.	Richmond Hwy & Beacon Hill Rd	Huntington Metro Station (North)
AM SERVICE						
7:25	7:33	7:38	7:39	7:48	7:54	8:00
8:25	8:33	8:38	8:39	8:48	8:54	9:00
9:25	9:33	9:38	9:39	9:48	9:54	10:00
10:25	10:33	10:38	10:39	10:48	10:54	11:00
11:25	11:33	11:38	11:39	11:48	11:54	12:00
PM SERVICE						
12:25	12:33	12:38	12:39	12:48	12:54	1:00
1:25	1:33	1:38	1:39	1:48	1:54	2:00
2:25	2:33	2:38	2:39	2:48	2:54	3:00
3:25	3:33	3:38	3:39	3:48	3:54	4:00
4:25	4:33	4:38	4:39	4:48	4:54	5:00
5:25	5:33	5:38	5:39	5:48	5:54	6:00
6:25	6:33	6:38	6:39	6:48	6:54	7:00
7:25	7:33	7:38	7:39	7:48	7:54	8:00
8:25	8:33	8:38	8:39	8:48	8:54	9:00

Route 105 — Sunday Southbound

Huntington Metro Station (North)	Richmond Hwy & Beacon Hill Rd	Mt. Vernon Square Apts.	Tiswell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Richmond Hwy & Ladson Ln	Sacramento Dr & Richmond Hwy
AM SERVICE						
8:10	8:18	8:24	8:32	8:33	8:36	8:47
9:10	9:18	9:24	9:32	9:33	9:36	9:47
10:10	10:18	10:24	10:32	10:33	10:36	10:47
11:10	11:18	11:24	11:32	11:33	11:36	11:47
PM SERVICE						
12:10	12:18	12:24	12:32	12:33	12:36	12:47
1:10	1:18	1:24	1:32	1:33	1:36	1:47
2:10	2:18	2:24	2:32	2:33	2:36	2:47
3:10	3:18	3:24	3:32	3:33	3:36	3:47
4:10	4:18	4:24	4:32	4:33	4:36	4:47
5:10	5:18	5:24	5:32	5:33	5:36	5:47
6:10	6:18	6:24	6:32	6:33	6:36	6:47
7:10	7:18	7:24	7:32	7:33	7:36	7:47
8:10	8:18	8:24	8:32	8:33	8:36	8:47
9:10	9:18	9:24	9:32	9:33	9:36	9:47

Route 105 — Saturday Northbound

Sacramento Dr & Richmond Hwy	Richmond Hwy & Ladson Ln	Tiswell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Mt. Vernon Square Apts.	Richmond Hwy & Beacon Hill Rd	Huntington Metro Station (North)
AM SERVICE						
6:20	6:30	6:35	6:36	6:46	6:53	7:03
7:20	7:30	7:35	7:36	7:46	7:53	8:03
8:20	8:30	8:35	8:36	8:46	8:53	9:03
9:20	9:30	9:35	9:36	9:46	9:53	10:03
10:20	10:30	10:35	10:36	10:46	10:53	11:03
11:20	11:30	11:35	11:36	11:46	11:53	12:03
PM SERVICE						
12:20	12:30	12:35	12:36	12:46	12:53	1:03
1:20	1:30	1:35	1:36	1:46	1:53	2:03
2:20	2:30	2:35	2:36	2:46	2:53	3:03
3:20	3:30	3:35	3:36	3:46	3:53	4:03
4:20	4:30	4:35	4:36	4:46	4:53	5:03
5:20	5:30	5:35	5:36	5:46	5:53	6:03
6:20	6:30	6:35	6:36	6:46	6:53	7:03
7:20	7:30	7:35	7:36	7:46	7:53	8:03
8:20	8:30	8:35	8:36	8:46	8:53	9:03
9:20	9:30	9:35	9:36	9:46	9:53	10:03

Route 105 — Saturday Southbound

Huntington Metro Station (North)	Richmond Hwy & Beacon Hill Rd	Mt. Vernon Square Apts.	Tiswell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Richmond Hwy & Ladson Ln	Sacramento Dr & Richmond Hwy
AM SERVICE						
6:10	6:18	6:25	6:33	6:34	6:38	8:56
7:10	7:18	7:25	7:33	7:34	7:38	7:56
8:10	8:18	8:25	8:33	8:34	8:38	8:56
9:10	9:18	9:25	9:33	9:34	9:38	9:56
10:20	10:28	10:35	10:43	10:44	10:48	11:06
11:20	11:28	11:35	11:43	11:44	11:48	12:06
PM SERVICE						
12:20	12:28	12:35	12:43	12:44	12:48	1:06
1:20	1:28	1:35	1:43	1:44	1:48	2:06
2:20	2:28	2:35	2:43	2:44	2:48	3:06
3:20	3:28	3:35	3:43	3:44	3:48	4:06
4:20	4:28	4:35	4:43	4:44	4:48	5:06
5:20	5:28	5:35	5:43	5:44	5:48	6:06
6:20	6:28	6:35	6:43	6:44	6:48	7:06
7:20	7:28	7:35	7:43	7:44	7:48	8:06
8:20	8:28	8:35	8:43	8:44	8:48	9:06
9:20	9:28	9:35	9:43	9:44	9:48	10:06
10:20	10:28	10:35	10:43	10:44	10:48	11:06

ROUTE 105													WEEKDAY NORTHBOUND
DLA Building Fort Belvoir	Richmond Hwy & Mt. Vernon Memorial Hwy IMP Bldg	Sacramento Dr & Richmond Hwy	Sacramento Dr & Pole Rd	Lawrence St & Russell Rd	Richmond Hwy & Ladson Ln	Tewell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Mt. Vernon Square Apts.	Lockheed Blvd. & Fairchild Dr.	Richmond Hwy & Beacon Hill Rd	Huntington Metro Station (North)	N. Washington St. & King St.	Fairfax St. & Pendleton St.
AM SERVICE													
—	—	[illegible]	5:15	5:22	5:29	—	—	—	—	5:37	5:45	—	—
—	—	[illegible]	5:29	5:35	5:42	—	—	—	—	5:50	6:00	—	—
—	—	[illegible]	5:43	5:50	5:57	—	—	—	—	6:05	6:15	—	—
—	—	[illegible]	5:59	6:05	6:12	—	—	—	—	6:20	6:30	—	—
—	—	[illegible]	6:13	6:20	6:27	—	—	—	—	6:35	6:45	—	—
—	—	[illegible]	6:29	6:35	6:42	—	—	—	—	6:50	7:00	—	—
—	—	[illegible]	6:42	6:49	6:56	—	—	—	—	7:04	7:14	—	—
—	—	[illegible]	6:59	7:05	7:12	—	—	—	—	7:20	7:30	—	—
—	—	[illegible]	7:13	7:20	7:27	—	—	—	—	7:35	7:45	—	—
—	—	[illegible]	7:42	7:50	7:57	—	—	—	—	8:05	8:15	—	—
—	—	[illegible]	8:13	8:21	8:28	—	—	—	—	8:38	8:46	—	—
—	—	[illegible]	8:41	8:50	8:57	—	—	—	—	9:06	9:16	—	—
—	—	[illegible]	9:08	9:15	9:22	9:26	9:28	9:38	—	9:45	9:55	—	—
—	—	[illegible]	9:39	9:46	9:53	9:57	9:59	10:09	—	10:15	10:25	—	—
—	10:02	[illegible]	10:09	10:16	10:23	10:27	10:29	10:39	—	10:45	10:55	—	—
—	—	[illegible]	10:41	10:48	10:55	10:59	11:01	11:11	—	11:17	11:27	—	—
—	11:06	[illegible]	11:13	11:20	11:27	11:31	11:33	11:43	—	11:49	11:59	—	—
—	—	[illegible]	11:45	11:52	11:59	12:03	12:05	12:15	—	12:21	12:31	—	—
PM SERVICE													
—	12:10	[illegible]	12:17	12:24	12:31	12:35	12:37	12:47	—	12:53	1:03	—	—
—	—	[illegible]	12:49	12:56	1:03	1:07	1:09	1:19	—	1:25	1:35	—	—
—	1:14	[illegible]	1:21	1:28	1:35	1:39	1:41	1:51	—	1:57	2:07	—	—
—	—	[illegible]	1:53	2:00	2:07	2:11	2:13	2:23	—	2:29	2:39	—	—
—	2:13	[illegible]	2:20	2:27	2:34	2:38	2:40	2:50	—	2:56	3:06	—	—
—	—	[illegible]	2:56	3:03	3:10	3:14	3:16	3:26	—	3:32	3:42	—	—
—	3:26	[illegible]	3:33	3:40	3:47	—	—	—	—	3:57	4:07	—	—
—	—	[illegible]	4:07	4:14	4:21	—	—	—	—	4:31	4:41	—	—
—	—	[illegible]	4:38	4:45	4:53	—	—	—	—	5:03	5:13	—	—
—	—	[illegible]	5:10	5:17	5:25	—	—	—	—	5:35	5:45	—	—
—	—	[illegible]	—	—	—	—	5:56	6:03	—	6:10	6:19	—	—
—	—	[illegible]	6:10	6:17	6:25	—	—	—	—	6:35	6:45	—	—
—	—	[illegible]	6:43	6:50	6:57	—	7:03	7:12	—	7:19	7:29	—	—
—	—	[illegible]	7:25	7:32	7:39	—	7:45	7:54	—	8:00	8:10	—	—
—	—	[illegible]	7:55	8:02	8:09	—	8:15	8:24	—	8:30	8:40	—	—
—	—	[illegible]	8:25	8:32	8:39	—	8:45	8:54	—	9:00	9:10	—	—
—	—	[illegible]	8:57	9:04	9:11	—	9:17	9:26	—	9:32	9:42	—	—
—	—	[illegible]	9:25	9:32	9:39	—	9:45	9:54	—	10:00	10:10	—	—
—	—	[illegible]	10:11	10:18	10:25	—	10:31	10:40	—	10:46	10:56	—	—

ROUTE 105													WEEKDAY SOUTHBOUND
Fairfax St. & Pendleton St.	N. Washington St. & King St.	Huntington Metro Station (North)	Richmond Hwy & Beacon Hill Rd	Lockheed Blvd. & Fairchild Dr.	Mt. Vernon Square Apts.	Tewell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Richmond Hwy & Ladson Ln	Lawrence St & Russell Rd	Sacramento Dr & Richmond Hwy	Sacramento Dr & Pole Rd	Richmond Hwy & Mt. Vernon Memorial Hwy IMP Bldg	DLA Building Fort Belvoir
AM SERVICE													
—	—	[illegible]	6:08	—	—	—	—	6:14	6:20	6:28	—	—	—
—	—	[illegible]	6:38	—	—	—	—	6:44	6:50	6:58	—	—	—
—	—	[illegible]	7:09	—	—	—	—	7:15	7:21	7:29	—	—	—
—	—	[illegible]	7:39	—	—	—	—	7:45	7:51	7:59	—	—	—
—	—	[illegible]	8:09	—	—	—	—	8:15	8:21	8:29	—	—	—
—	—	[illegible]	8:39	—	—	—	—	8:45	8:51	8:59	—	—	—
—	—	[illegible]	9:09	—	—	9:20	9:22	9:26	9:32	9:40	—	9:41	—
—	—	[illegible]	9:35	—	9:40	9:48	9:50	9:54	10:02	10:12	—	—	—
—	—	[illegible]	10:09	—	10:14	10:21	10:23	10:28	10:35	10:43	—	10:44	—
—	—	[illegible]	10:41	—	10:46	10:53	10:55	11:00	11:07	11:17	—	—	—
—	—	[illegible]	11:11	—	11:16	11:23	11:25	11:30	11:37	11:45	—	11:46	—
—	—	[illegible]	11:43	—	11:48	11:55	11:57	12:02	12:07	12:22	—	—	—
PM SERVICE													
—	—	[illegible]	12:15	—	12:20	12:28	12:30	12:35	12:42	12:50	—	12:51	—
—	—	[illegible]	12:47	—	12:52	1:00	1:02	1:07	1:14	1:24	—	—	—
—	—	[illegible]	1:19	—	1:24	1:32	1:34	1:39	1:46	1:54	—	1:55	—
—	—	[illegible]	1:51	—	1:56	2:04	2:06	2:11	2:18	2:28	—	—	—
—	—	[illegible]	2:23	—	2:28	2:36	2:38	2:43	2:50	2:58	—	2:59	—
—	—	[illegible]	2:55	—	3:01	3:09	3:11	3:16	3:23	3:33	—	—	—
—	—	[illegible]	3:21	—	3:27	3:35	3:38	3:43	3:50	3:58	—	3:59	—
—	—	[illegible]	3:49	—	3:54	—	—	3:59	4:06	4:16	—	—	—
—	—	[illegible]	4:34	—	—	—	—	4:43	4:51	5:02	5:03	—	—
—	—	[illegible]	4:52	—	—	—	—	5:01	5:09	5:18	—	—	—
—	—	[illegible]	5:04	—	—	—	—	5:13	5:21	5:32	5:33	—	—
—	—	[illegible]	5:22	—	—	—	—	5:31	5:39	5:48	—	—	—
—	—	[illegible]	5:34	—	—	—	—	5:43	5:51	6:02	6:03	—	—
—	—	[illegible]	5:52	—	—	—	—	6:01	6:09	6:18	—	—	—
—	—	[illegible]	6:04	—	—	—	—	6:13	6:21	6:32	6:33	—	—
—	—	[illegible]	6:22	—	—	—	—	6:31	6:39	6:48	—	—	—
—	—	[illegible]	6:34	—	—	—	—	6:43	6:51	7:02	—	—	—
—	—	[illegible]	6:52	—	—	—	—	7:01	7:09	7:18	—	—	—
—	—	[illegible]	7:05	—	7:11	—	7:19	7:23	7:29	7:39	—	—	—
—	11:06	[illegible]	7:28	—	7:34	—	7:42	7:46	7:52	8:01	—	—	—
—	—	[illegible]	7:58	—	8:03	—	8:11	8:15	8:21	8:30	—	—	—
—	—	[illegible]	8:28	—	8:33	—	8:41	8:45	8:51	9:00	—	—	—
—	—	[illegible]	8:58	—	9:03	—	9:11	9:15	9:21	9:30	—	—	—
—	—	[illegible]	9:28	—	9:34	—	9:42	9:46	9:52	10:01	—	—	—
—	—	[illegible]	10:25	—	10:30	—	10:38	10:42	10:48	10:57	—	—	—
—	—	[illegible]	11:19	—	11:24	—	11:32	11:36	11:42	11:51	—	—	—

ROUTE 106

Richmond Highway Line

Fort Belvoir to the Huntington Metro Station; also serving Mount Vernon Hospital & Old Town Alexandria

FairFax Connector

339-7200

TTY (703) 339-1608

www.fairfaxconnector.com

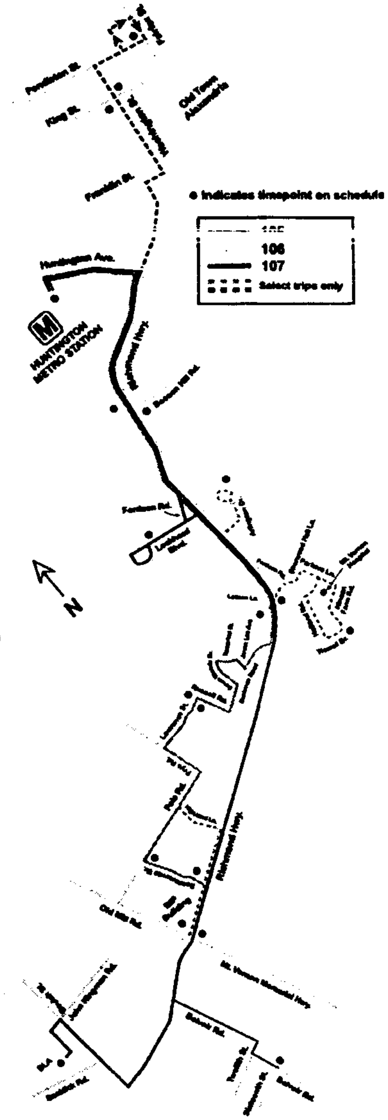
Effective September 29, 2002

ROUTE 106 — WEEKDAY NORTHBOUND

DLA Building Fort Belvoir	Richmond Hwy & Mt. Vernon Memorial Hwy BMP Bldg	Sacramento Dr & Richmond Hwy	Sacramento Dr & Pole Rd	Lawrence St & Russell Rd	Richmond Hwy & Ladson Ln	Towell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Mt. Vernon Square Apts.	Lockheed Blvd. & Fairchild Dr.	Richmond Hwy & Beacon Hill Rd	Huntington Metro Station (North)	N. Washington St. & King St.	Fairfax St. & Pendleton St.
AM Service													
—	—	—	—	—	—	—	5:34	5:41	—	5:47	5:57	—	—
—	—	—	—	—	—	—	6:04	6:11	—	6:17	6:27	—	—
—	—	—	—	—	—	—	6:34	6:41	—	6:47	6:57	—	—
—	—	—	—	—	—	—	7:04	7:11	—	7:18	7:27	—	—
—	—	—	—	—	—	—	7:34	7:41	—	7:48	7:57	—	—
—	—	—	—	—	—	—	8:05	8:12	—	8:19	8:29	—	—
—	—	—	—	—	—	—	8:36	8:43	—	8:50	9:00	—	—
PM Service													
—	—	—	—	—	—	—	3:55	4:02	—	4:08	4:17	—	—
—	—	—	—	—	—	—	4:26	4:33	—	4:39	4:48	—	—
—	—	—	—	—	—	—	4:56	5:03	—	5:10	5:19	—	—
—	—	—	—	—	—	—	5:12	5:19	—	5:26	5:35	—	—
—	—	—	—	—	—	—	5:56	6:03	—	6:10	6:19	—	—
—	—	—	—		—	—	6:25	6:32	—	6:39	6:48	—	—

ROUTE 106 — WEEKDAY SOUTHBOUND

Fairfax St. & Pendleton St.	N. Washington St. & King St.	Huntington Metro Station (North)	Richmond Hwy & Beacon Hill Rd	Lockheed Blvd. & Fairchild Dr.	Mt. Vernon Square Apts.	Towell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Richmond Hwy & Ladson Ln	Lawrence St & Russell Rd	Sacramento Dr & Richmond Hwy	Sacramento Dr & Pole Rd	Richmond Hwy & Mt. Vernon Memorial Hwy BMP Bldg	DLA Building Fort Belvoir
AM SERVICE													
—	—	6:04	6:11	—	6:18	—	6:28	—	—	—	—	—	—
—	—	6:45	6:52	—	6:59	—	7:09	—	—	—	—	—	—
—	—	7:15	7:23	—	7:31	—	7:41	—	—	—	—	—	—
—	—	7:45	7:53	—	8:01	—	8:11	—	—	—	—	—	—
—	—	8:15	8:24	—	8:32	—	8:42	—	—	—	—	—	—
—	—	8:45	8:54	—	9:02	—	9:12	—	—	—	—	—	—
PM SERVICE													
—	—	4:08	4:17	—	4:25	—	4:35	—	—	—	—	—	—
—	—	4:40	4:49	—	4:57	—	5:07	—	—	—	—	—	—
—	—	5:10	5:19	—	5:27	—	5:37	—	—	—	—	—	—
—	—	5:40	5:49	—	5:57	—	6:07	—	—	—	—	—	—
—	—	6:10	6:19	—	6:26	—	6:36	—	—	—	—	—	—
—	—	6:40	6:49	—	6:56	—	7:06	—	—	—	—	—	—



ROUTE
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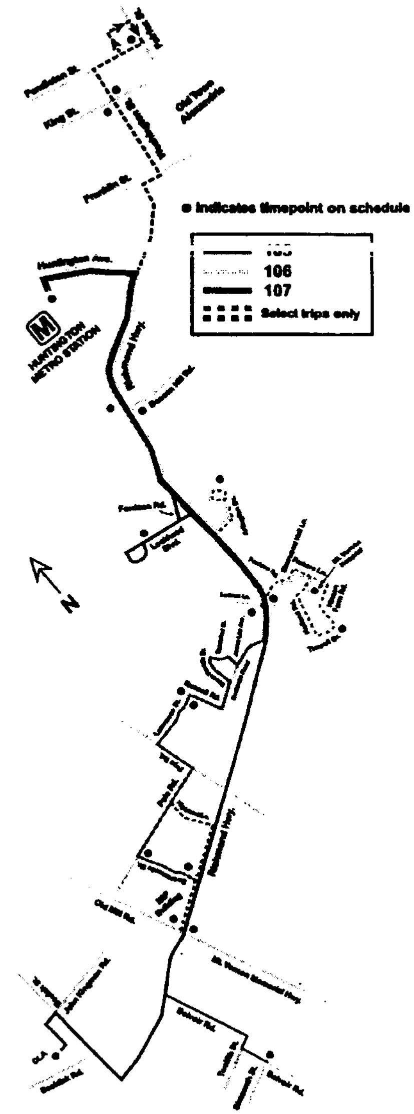
ROUTE 107 — WEEKDAY NORTHBOUND

ULA Building Fort Belvoir	Richmond Hwy & Mt. Vernon Memorial Hwy IMP Bldg	Sacramento Dr & Richmond Hwy	Sacramento Dr & Pole Rd	Lawrence St & Russell Rd	Richmond Hwy & Ladson Ln	Towell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Mt. Vernon Square Apts.	Lockheed Blvd. & Fairchild Dr.	Richmond Hwy & Beacon Hill Rd	Huntington Metro Station (North)	N. Washington St. & King St.	Fairfax St. & Pendleton St.
AM SERVICE													
5:00	5:10	—	—	—	5:18	—	—	—	5:25	5:31	5:40	—	—
5:26	5:36	—	—	—	5:46	—	—	—	5:53	5:59	6:08	—	—
5:54	6:04	—	—	—	6:15	—	—	—	6:22	6:28	6:38	6:51	6:56
6:25	6:35	—	—	—	6:46	—	—	—	6:53	6:59	7:09	7:22	7:27
6:55	7:05	—	—	—	7:16	—	—	—	7:23	7:29	7:39	7:52	7:57
7:25	7:35	—	—	—	7:46	—	—	—	7:53	7:59	8:09	—	—
7:56	8:06	8:11	—	—	8:17	—	—	—	8:24	8:30	8:39	—	—
8:25	8:35	8:39	—	—	8:46	—	—	—	8:53	8:59	9:08	—	—
PM SERVICE													
3:47	3:57	—	—	—	4:08	—	—	—	4:16	4:21	4:31	4:42	4:47
4:18	4:28	—	—	—	4:39	—	—	—	4:47	4:52	5:02	5:13	5:18
4:47	4:57	—	—	—	5:08	—	—	—	5:16	5:21	5:31	5:42	5:47
5:18	5:28	—	—	—	5:39	—	—	—	5:47	5:52	6:02	—	—
5:47	5:57	—	—	—	6:08	—	—	—	6:16	6:21	6:31	—	—
6:18	6:28	—	—	—	6:39	—	—	—	6:47	6:52	7:02	—	—

ROUTE 107 — WEEKDAY SOUTHBOUND

Fairfax St. & Pendleton St.	N. Washington St. & King St.	Huntington Metro Station (North)	Richmond Hwy & Beacon Hill Rd	Lockheed Blvd. & Fairchild Dr.	Mt. Vernon Square Apts.	Towell Dr & Mt. Vernon Nursing Home	Mt. Vernon Hospital	Richmond Hwy & Ladson Ln	Lawrence St & Russell Rd	Sacramento Dr & Richmond Hwy	Sacramento Dr & Pole Rd	Richmond Hwy & Mt. Vernon Memorial Hwy IMP Bldg	OLA Building Fort Belvoir
AM SERVICE													
—	—	5:52	6:00	6:04	—	—	—	6:10	—	—	—	6:20	6:30
—	—	6:22	6:30	6:34	—	—	—	6:40	—	—	—	6:50	7:00
7:06	7:11	7:22	7:30	7:34	—	—	—	7:40	—	—	—	7:50	8:00
7:36	7:41	7:52	8:00	8:04	—	—	—	8:10	—	—	—	8:20	8:30
8:06	8:11	8:22	8:30	8:34	—	—	—	8:40	—	—	—	8:50	9:00
—	—	8:52	9:00	9:04	—	—	—	9:10	—	—	—	9:20	9:30
PM SERVICE													
—	—	4:17	4:26	4:32	—	—	—	4:40	—	—	—	4:51	5:02
—	—	4:47	4:56	5:02	—	—	—	5:10	—	—	—	5:21	5:32
4:56	5:01	5:17	5:26	5:32	—	—	—	5:40	—	—	—	5:51	6:02
5:26	5:31	5:47	5:56	6:02	—	—	—	6:10	—	—	—	6:21	6:32
5:56	5:56	6:01	6:17	6:32	—	—	—	6:40	—	—	—	6:51	7:02
—	10:02	6:47	6:56	7:02	—	—	—	7:10	—	—	—	7:21	7:32



Appendix B

- **VAP Programs**
- **Examples of VISSIM Output Files**

VAP Program for No Priority

```
PROGRAM TSP;

CONST

/**********************************/
/***********CONSTANTS*************/
/**********************************/

FALSE = 0,
TRUE = 1,
BusDetector1 = 91,
BusDetector2 = 92,
Factor1 = 1,
Factor2 = 1;


ARRAY

/******************************/
/***********ARRAYS*************/
/******************************/

tClearance[8] = [4,4,0,4,4,4,0,4],
Recall[8] =     [0,1,0,0,0,1,0,0],
Passage[8] =    [2,2,2,2,2,2,2,2],
MaxGreen[8] =   [32,41,0,15,15,58,0,10],
TempMaxGreen[8]=[0,0,0,0,0,0,0,0];


/**********************************/
/**** TRANSIT SIGNAL PRIORITY ****/
/**********************************/

SUBROUTINE TransitPriority1;

IF BusDetector1 THEN
    IF presence(BusDetector1) THEN
            CheckIn:=TRUE;
    END;
END;


IF BusDetector2 THEN
    IF presence(BusDetector2) THEN
            CheckIn:=FALSE;
    END;
END;

/**** TEMPORARILY MODIFY MAXGREEN VALUES ****/

IF CheckIn THEN
        TempMaxGreen[1]:=Factor1*MaxGreen[1];
        TempMaxGreen[2]:=Factor2*MaxGreen[2];
        TempMaxGreen[4]:=Factor1*MaxGreen[4];
        TempMaxGreen[5]:=Factor1*MaxGreen[5];
        TempMaxGreen[6]:=Factor2*MaxGreen[6];
        TempMaxGreen[8]:=Factor1*MaxGreen[8];
ELSE
        TempMaxGreen[1]:=MaxGreen[1];
        TempMaxGreen[2]:=MaxGreen[2];
        TempMaxGreen[4]:=MaxGreen[4];
```

```
        TempMaxGreen[5]:=MaxGreen[5];
        TempMaxGreen[6]:=MaxGreen[6];
        TempMaxGreen[8]:=MaxGreen[8];
END.

/**** PREVENT PHASES 2 AND 6 FROM GAPPING OUT ****/

SUBROUTINE TransitPriority2;
IF CheckIn THEN
        GapOut2:=FALSE;
        GapOut6:=FALSE;
        GapOut26:=FALSE;
END.


SUBROUTINE Compute_Conditionals;

/*****************************************/
/**** DEFINE CONDITIONALS ****/
/*****************************************/

Call1 := presence(1) or occupancy(1) OR RECALL[1];
Call2 := presence(2) or occupancy(2) OR RECALL[2];
Call4 := presence(4) or occupancy(4) OR RECALL[4];
Call5 := presence(5) or occupancy(5) OR RECALL[5];
Call6 := presence(6) or occupancy(6) OR RECALL[6];
Call8 := presence(8) or occupancy(8) OR RECALL[8];

GapOut1 := headway(1) > Passage[1];
GapOut2 := headway(2) > Passage[2];
GapOut4 := headway(4) > Passage[4];
GapOut5 := headway(5) > Passage[5];
GapOut6 := headway(6) > Passage[6];
GapOut8 := headway(8) > Passage[8];

MinOver1 := t_green(1) >= t_green_min(1);
MinOver2 := t_green(2) >= t_green_min(2);
MinOver4 := t_green(4) >= t_green_min(4);
MinOver5 := t_green(5) >= t_green_min(5);
MinOver6 := t_green(6) >= t_green_min(6);
MinOver8 := t_green(8) >= t_green_min(8);

MaxOut1 := t_green(1) >= TempMaxGreen[1];
MaxOut2 := t_green(2) >= TempMaxGreen[2];
MaxOut4 := t_green(4) >= TempMaxGreen[4];
MaxOut5 := t_green(5) >= TempMaxGreen[5];
MaxOut6 := (t_green(6) >= TempMaxGreen[6]);
MaxOut8 := (t_green(8) >= TempMaxGreen[8]);


/*****************************************/
/**** CONDITIONS TO CAUSE PHASES ****/
/**** TO CROSS BARRIER TOGETHER ******/
/*****************************************/

GapOut26 := GapOut2 AND GapOut6;
MinOver26 := MinOver2 AND MinOver6;
MaxOut26 := MaxOut2 AND MaxOut6;
GapOut48 := (GapOut4 OR MaxOut4) AND (GapOut8 OR MaxOut8);
MinOver48 := MinOver4 AND MinOver8;
Call48 := Call4 OR Call8.
```

```
SUBROUTINE Ring1;

/************************************/
/**** RING #1 ACTUATED LOGIC ****/
/************************************/
IF t_green(1) THEN
        IF (Call2 AND MinOver1 AND (GapOut1 or MaxOut1)) THEN
                sg_red(1);
                start(Phase1ClearTimer);
                NextRing1Phase := 2;
        END;
END;

IF t_green(2) THEN
        IF (Call48 AND MinOver26 AND (GapOut26 or MaxOut26)) THEN
                sg_red(2);
                start(Phase2ClearTimer);
                NextRing1Phase := 4;
        END;
END;

IF t_green(4) THEN
        IF (Call1 AND MinOver48 AND (GapOut48)) THEN
                sg_red(4);
                start(Phase4ClearTimer);
                NextRing1Phase := 1;
        ELSE
                IF (Call2 AND MinOver48 AND (GapOut48)) THEN
                        sg_red(4);
                        start(Phase4ClearTimer);
                        NextRing1Phase := 2;
                END;
        END;
END;


/************************************/
/**** RING #1 Clearance TIMERS ****/
/************************************/

IF (Phase1ClearTimer = tClearance[1]) THEN
        IF NextRing1Phase = 2 THEN
                Cycle:=0;
                sg_green(2);
        END;
        stop(Phase1ClearTimer);
        reset(Phase1ClearTimer);

END;

IF (Phase2ClearTimer = tClearance[2]) THEN
        IF NextRing1Phase = 4 THEN
                sg_green(4);
        END;
        stop(Phase2ClearTimer);
        reset(Phase2ClearTimer);

END;

IF (Phase4ClearTimer = tClearance[4]) THEN
        IF NextRing1Phase = 1 THEN
                sg_green(1);
        ELSE
```

```
            IF NextRing1Phase = 2 THEN
            cycle:=0;
                    sg_green(2);
            END;
        END;
        stop(Phase4ClearTimer);
        reset(Phase4ClearTimer);

END;


/*******************/
/**** SET CLOCK ****/
/*******************/

Set_Cycle_Second(Cycle);
Cycle:=Cycle+1.


SUBROUTINE Ring2;

/*******************************/
/**** RING #2 ACTUATED LOGIC ****/
/*******************************/

IF t_green(5) THEN
        IF (Call6 AND MinOver5 AND (GapOut5 or MaxOut5)) THEN
                sg_red(5);
                start(Phase5ClearTimer);
                NextRing2Phase := 6;
        END;
END;

IF t_green(6) THEN
        IF (Call48 AND MinOver26 AND (GapOut26 or MaxOut26)) THEN
                sg_red(6);
                start(Phase6ClearTimer);
                NextRing2Phase := 8;
        END;
END;

IF t_green(8) THEN
        IF (Call5 AND MinOver48 AND (GapOut48)) THEN
                sg_red(8);
                start(Phase8ClearTimer);
                NextRing2Phase := 5;
        ELSE
                IF (Call6 AND MinOver48 AND (GapOut48)) THEN
                        sg_red(8);
                        start(Phase8ClearTimer);
                        NextRing2Phase := 6;
                END;
        END;
END;


/*******************************/
/**** RING2 Clearance TIMERS ****/
/*******************************/

IF (Phase5ClearTimer = tClearance[5]) THEN
        IF NextRing2Phase = 6 THEN
                sg_green(6);
```

```
        END;
        stop(Phase5ClearTimer);
        reset(Phase5ClearTimer);
END;

IF (Phase6ClearTimer = tClearance[6]) THEN
        IF NextRing2Phase = 8 THEN
                sg_green(8);
        END;
        stop(Phase6ClearTimer);
        reset(Phase6ClearTimer);
END;

IF (Phase8ClearTimer = tClearance[8]) THEN
        IF NextRing2Phase = 5 THEN
                sg_green(5);
        ELSE
                IF NextRing2Phase = 6 THEN
                        sg_green(6);
                END;
        END;
        stop(Phase8ClearTimer);
        reset(Phase8ClearTimer);
END.

/*****************************/
/**** BEGIN MAIN SECTION ****/
/*****************************/

GOSUB TransitPriority1;
GOSUB Compute_Conditionals;
GOSUB TransitPriority2;
GOSUB Ring1;
GOSUB Ring2.
```

VAP Program with Priority

```
PROGRAM TSP;

CONST

/********************************/
/***********CONSTANTS************/
/********************************/

FALSE = 0,
TRUE = 1,
BusDetector1 = 91,
BusDetector2 = 92,
Factor1 = 0.83,
Factor2 = 1.17;


ARRAY

/******************************/
/***********ARRAYS************/
/******************************/

tClearance[8] = [4,4,0,4,4,4,0,4],
Recall[8] =     [0,1,0,0,0,1,0,0],
Passage[8] =    [2,2,2,2,2,2,2,2],
MaxGreen[8] =   [32,11,0,15,15,58,0,10],
TempMaxGreen[8]=[0,0,0,0,0,0,0,0];


/*********************************/
/**** TRANSIT SIGNAL PRIORITY ****/
/*********************************/

SUBROUTINE TransitPriority1;

IF BusDetector1 THEN
    IF presence(BusDetector1) THEN
            CheckIn:=TRUE;
    END;
END;


IF BusDetector2 THEN
    IF presence(BusDetector2) THEN
            CheckIn:=FALSE;
    END;
END;

/**** TEMPORARILY MODIFY MAXGREEN VALUES ****/

IF CheckIn THEN
        TempMaxGreen[1]:=Factor1*MaxGreen[1];
        TempMaxGreen[2]:=Factor2*MaxGreen[2];
        TempMaxGreen[4]:=Factor1*MaxGreen[4];
        TempMaxGreen[5]:=Factor1*MaxGreen[5];
        TempMaxGreen[6]:=Factor2*MaxGreen[6];
        TempMaxGreen[8]:=Factor1*MaxGreen[8];
ELSE
        TempMaxGreen[1]:=MaxGreen[1];
        TempMaxGreen[2]:=MaxGreen[2];
        TempMaxGreen[4]:=MaxGreen[4];
```

```
        TempMaxGreen[5]:=MaxGreen[5];
        TempMaxGreen[6]:=MaxGreen[6];
        TempMaxGreen[8]:=MaxGreen[8];
END.

/**** PREVENT PHASES 2 AND 6 FROM GAPPING OUT ****/

SUBROUTINE TransitPriority2;
IF CheckIn THEN
        GapOut2:=FALSE;
        GapOut6:=FALSE;
        GapOut26:=FALSE;
END.


SUBROUTINE Compute_Conditionals;

/******************************/
/**** DEFINE CONDITIONALS ****/
/******************************/

Call1 := presence(1) or occupancy(1) OR RECALL[1];
Call2 := presence(2) or occupancy(2) OR RECALL[2];
Call4 := presence(4) or occupancy(4) OR RECALL[4];
Call5 := presence(5) or occupancy(5) OR RECALL[5];
Call6 := presence(6) or occupancy(6) OR RECALL[6];
Call8 := presence(8) or occupancy(8) OR RECALL[8];

GapOut1 := headway(1) > Passage[1];
GapOut2 := headway(2) > Passage[2];
GapOut4 := headway(4) > Passage[4];
GapOut5 := headway(5) > Passage[5];
GapOut6 := headway(6) > Passage[6];
GapOut8 := headway(8) > Passage[8];

MinOver1 := t_green(1) >= t_green_min(1);
MinOver2 := t_green(2) >= t_green_min(2);
MinOver4 := t_green(4) >= t_green_min(4);
MinOver5 := t_green(5) >= t_green_min(5);
MinOver6 := t_green(6) >= t_green_min(6);
MinOver8 := t_green(8) >= t_green_min(8);

MaxOut1 := t_green(1) >= TempMaxGreen[1];
MaxOut2 := t_green(2) >= TempMaxGreen[2];
MaxOut4 := t_green(4) >= TempMaxGreen[4];
MaxOut5 := t_green(5) >= TempMaxGreen[5];
MaxOut6 := (t_green(6) >= TempMaxGreen[6]);
MaxOut8 := (t_green(8) >= TempMaxGreen[8]);


/************************************/
/**** CONDITIONS TO CAUSE PHASES ****/
/**** TO CROSS BARRIER TOGETHER ******/
/************************************/

GapOut26 := GapOut2 AND GapOut6;
MinOver26 := MinOver2 AND MinOver6;
MaxOut26 := MaxOut2 AND MaxOut6;
GapOut48 := (GapOut4 OR MaxOut4) AND (GapOut8 OR MaxOut8);
MinOver48 := MinOver4 AND MinOver8;
Call48 := Call4 OR Call8.
```

```
SUBROUTINE Ring1;

/**********************************/
/**** RING #1 ACTUATED LOGIC ****/
/**********************************/
IF t_green(1) THEN
        IF (Call2 AND MinOver1 AND (GapOut1 or MaxOut1)) THEN
                sg_red(1);
                start(Phase1ClearTimer);
                NextRing1Phase := 2;
        END;
END;

IF t_green(2) THEN
        IF (Call48 AND MinOver26 AND (GapOut26 or MaxOut26)) THEN
                sg_red(2);
                start(Phase2ClearTimer);
                NextRing1Phase := 4;
        END;
END;

IF t_green(4) THEN
        IF (Call1 AND MinOver48 AND (GapOut48)) THEN
                sg_red(4);
                start(Phase4ClearTimer);
                NextRing1Phase := 1;
        ELSE
                IF (Call2 AND MinOver48 AND (GapOut48)) THEN
                        sg_red(4);
                        start(Phase4ClearTimer);
                        NextRing1Phase := 2;
                END;
        END;
END;


/**********************************/
/**** RING #1 Clearance TIMERS ****/
/**********************************/

IF (Phase1ClearTimer = tClearance[1]) THEN
        IF NextRing1Phase = 2 THEN
                Cycle:=0;
                sg_green(2);
        END;
        stop(Phase1ClearTimer);
        reset(Phase1ClearTimer);

END;

IF (Phase2ClearTimer = tClearance[2]) THEN
        IF NextRing1Phase = 4 THEN
                sg_green(4);
        END;
        stop(Phase2ClearTimer);
        reset(Phase2ClearTimer);

END;

IF (Phase4ClearTimer = tClearance[4]) THEN
        IF NextRing1Phase = 1 THEN
                sg_green(1);
        ELSE
```

```
            IF NextRing1Phase = 2 THEN
            cycle:=0;
                  sg_green(2);
            END;
      END;
      stop(Phase4ClearTimer);
      reset(Phase4ClearTimer);

END;

/*******************/
/**** SET CLOCK ****/
/*******************/

Set_Cycle_Second(Cycle);
Cycle:=Cycle+1.


SUBROUTINE Ring2;

/********************************/
/**** RING #2 ACTUATED LOGIC ****/
/********************************/

IF t_green(5) THEN
      IF (Call6 AND MinOver5 AND (GapOut5 or MaxOut5)) THEN
            sg_red(5);
            start(Phase5ClearTimer);
            NextRing2Phase := 6;
      END;
END;

IF t_green(6) THEN
      IF (Call48 AND MinOver26 AND (GapOut26 or MaxOut26)) THEN
            sg_red(6);
            start(Phase6ClearTimer);
            NextRing2Phase := 8;
      END;
END;

IF t_green(8) THEN
      IF (Call5 AND MinOver48 AND (GapOut48)) THEN
            sg_red(8);
            start(Phase8ClearTimer);
            NextRing2Phase := 5;
      ELSE
            IF (Call6 AND MinOver48 AND (GapOut48)) THEN
                  sg_red(8);
                  start(Phase8ClearTimer);
                  NextRing2Phase := 6;
            END;
      END;
END;

/********************************/
/**** RING2 Clearance TIMERS ****/
/********************************/

IF (Phase5ClearTimer = tClearance[5]) THEN
      IF NextRing2Phase = 6 THEN
            sg_green(6);
```

```
        END;
        stop(Phase5ClearTimer);
        reset(Phase5ClearTimer);
END;

IF (Phase6ClearTimer = tClearance[6]) THEN
        IF NextRing2Phase = 8 THEN
                sg_green(8);
        END;
        stop(Phase6ClearTimer);
        reset(Phase6ClearTimer);
END;

IF (Phase8ClearTimer = tClearance[8]) THEN
        IF NextRing2Phase = 5 THEN
                sg_green(5);
        ELSE
                IF NextRing2Phase = 6 THEN
                        sg_green(6);
                END;
        END;
        stop(Phase8ClearTimer);
        reset(Phase8ClearTimer);
END.

/*****************************/
/**** BEGIN MAIN SECTION ****/
/*****************************/

GOSUB TransitPriority1;
GOSUB Compute_Conditionals;
GOSUB TransitPriority2;
GOSUB Ring1;
GOSUB Ring2.
```

VISSIM Travel Time Results Table

Table of Travel Times

U.S.1 Traffic Signal Priority Project w/o tsp

Time;	Trav;	#Veh;	Trav;	#Veh;
VehC;	Bus;;		Bus;;	
No.:;	1;	1;	2;	2;
180;	0.0;	0;	0.0;	0;
360;	0.0;	0;	0.0;	0;
540;	0.0;	0;	0.0;	0;
720;	0.0;	0;	0.0;	0;
900;	704.2;	1;	725.0;	1;
1080;	0.0;	0;	607.9;	1;
1260;	725.8;	1;	0.0;	0;
1440;	0.0;	0;	0.0;	0;
1620;	0.0;	0;	0.0;	0;
1800;	0.0;	0;	643.5;	2;
1980;	625.9;	2;	0.0;	0;
2160;	0.0;	0;	0.0;	0;
2340;	0.0;	0;	0.0;	0;
2520;	586.0;	1;	602.3;	1;
2700;	0.0;	0;	591.5;	1;
2880;	599.0;	1;	0.0;	0;
3060;	0.0;	0;	0.0;	0;
3240;	0.0;	0;	0.0;	0;
3420;	0.0;	0;	0.0;	0;
3600;	553.8;	1;	550.9;	2;

VISSIM Queue Couters Output

Queue Length Record

U.S.1 Traffic Signal Priority Project w/o tsp

```
Queue Counter      11: Link   35 At   2114.173 ft
Queue Counter      21: Link   33 At    306.759 ft
Queue Counter      22: Link   31 At   2018.373 ft
Queue Counter      31: Link   25 At   1389.764 ft
Queue Counter      32: Link   23 At   2080.709 ft
Queue Counter      41: Link   18 At   1956.693 ft
Queue Counter      42: Link   16 At    752.625 ft
Queue Counter      51: Link   13 At   1600.722 ft
Queue Counter      61: Link    7 At    192.677 ft
Queue Counter      62: Link    6 At     82.021 ft
Queue Counter      71: Link   12 At    148.622 ft
Queue Counter      72: Link   11 At    776.575 ft

Avg.: average queue length [ft] within time interval
Max.: maximum queue length [ft] within time interval
Stop: number of stops within queue

  Time; Avg.;Max.;Stop; Avg.;Max.;Stop; Avg.;Max.;Stop; Avg.;Max.;Stop;
Avg.;Max.;Stop; Avg.;Max.;Stop; Avg.;Max.;Stop; Avg.;Max.;Stop; Avg.;Max.;Stop;
Avg.;Max.;Stop; Avg.;Max.;Stop; Avg.;Max.;Stop;
  No.:;   11;  11;  11;   21;  21;  21;  22;  22;  22;  31;  31;  31;  32;  32;
32;  41;  41;  41;   42;  42;  42;  51;  51;  51;  61;  61;  61;  62;  62;  62;
 71;  71;  71;   72;  72;  72;
   180;   10;  54;   2;    0;   0;   0;   0;   0;   0;  36;  97;   4;  23;  49;
1;   33; 168;  12;   28;  71;   3;  13;  54;   2;   0;   0;   0;  60;  96;  10;
 0;   0;   0;   8;   77;  11;
   360;   46; 173;   6;    0;   0;   0;   0;   0;   0;  51;  99;   4; 130; 292;
12; 115; 239;  22;   32;  72;   3;  67;  99;   4;   0;   0;   0;  29;  80;   5;
 0;   0;   0;  33;  100;  19;
   540;   43; 104;   8;    0;   0;   0;   0;   0;   0;  67; 191;   8; 128; 274;
11;  78; 188;  16;   32;  92;   4;   9;  52;   2;   1;  33;   1;  14;  83;   5;
 1;  21;   1;  29;  111;  20;
   720;  171; 227;  34;    0;   0;   0;   9;  23;   2;  26;  56;   2; 112; 208;
8;   46; 117;   8;    0;   0;   0;  18;  30;   1;   2;  34;   1;  52;  85;   9;
11;  21;   0;  70;  125;  15;
   900;  240; 331;  22;    0;   0;   0;   8;  23;   0;   7;  57;   2; 101; 208;
7;   85; 159;  14;   54; 101;   4;  10;  31;   1;   0;   0;   0;  55;  96;   9;
 0;   0;   0;  45;  154;  20;
  1080;  178; 228;   3;    0;   0;   0;   6;  31;   2;  19;  83;   4; 125; 230;
12;  36; 118;   8;  102; 160;   7;  28;  99;   4;   0;   0;   0;  40;  83;   8;
 27;  47;   2;  88;  195;  23;
  1260;   84; 194;   8;    0;   0;   0;   2;  25;   0;  29;  54;   2;  95; 266;
11;  98; 209;  20;   26;  74;   3;  47; 123;   2;   2;  34;   1;  26;  82;   4;
 0;   0;   0;  29;   92;  17;
  1440;   33;  78;   3;    0;   0;   0;   0;   0;   0;   9;  35;   1;  77; 266;
6;  103; 184;  14;   29;  77;   3;  57; 128;   4;   0;   0;   0;  45;  98;  10;
 0;   0;   0;  41;  198;  31;
  1620;   22;  77;   4;    0;   0;   0;   0;   0;   0;  45;  82;   3; 120; 223;
9;  118; 190;  19;   60; 180;   8;   8;  57;   2;   0;   0;   0;  41;  99;   8;
 0;   0;   0;  51;  134;  19;
  1800;   36; 123;   2;    0;   0;   0;  10;  26;   1;  13;  79;   0;  79; 311;
7;  130; 248;  19;   62; 156;   6;   0;   0;   0;   0;   0;   0;  36; 100;   9;
 0;   0;   0;  47;  131;  23;
  1980;    0;   0;   0;    0;   0;   0;   0;   0;   0;  30;  56;   3;  51; 239;
7;   68; 112;   8;   36; 152;   7;  20;  73;   3;   0;   0;   0;  46;  85;   9;
 6;  19;   1;  54;  169;  19;
  2160;    2;  36;   2;    0;   0;   0;   0;  26;   1;  18;  54;   0;  27; 125;
```

```
4; 112; 278; 25; 60; 114;
2; 18; 0; 53; 161; 27;
2340; 5; 34; 0; 0;
10; 51; 125; 11; 66; 111;
0; 0; 0; 50 196; 28;
2520; 22; 50; 2; 0;
9; 79; 192; 14; 51; 149;
18; 43; 2; 96; 260; 32;
2700; 0; 0; 0; 0;
4; 79; 158; 13; 55; 98;
0; 0; 0; 43; 139; 21;
2880; 0; 0; 0; 0;
7; 140; 235; 27; 48; 113;
0; 0; 0; 57; 176; 23;
3060; 2; 27; 1; 0;
2; 92; 235; 20; 25; 59;
18; 42; 2; 104; 199; 26;
3240; 4; 43; 1; 0;
1; 98; 226; 23; 53; 146;
0; 0; 0; 45; 153; 15;
3420; 12; 39; 0; 0;
3; 102; 224; 15; 28; 55;
0; 0; 0; 47; 113; 23;
3600; 17; 35; 2; 0;
4; 90; 200; 30; 52; 114;
9; 19; 1; 142; 260; 36;
```

```
4; 48; 67; 3; 0; 0; 0; 51; 85; 6;

0; 0; 0; 0; 0; 21; 53; 2; 104; 237;
6; 23; 113; 2; 0; 0; 0; 56; 86; 7;

0; 0; 0; 26; 1; 31; 53; 2; 91; 304;
6; 1; 28; 1; 0; 0; 0; 50; 93; 7;

15; 1; 0; 0; 0; 34; 77; 3; 66; 177;
4; 18; 107; 4; 0; 0; 0; 24; 86; 7;

0; 0; 14; 90; 4; 69; 150; 6; 62; 148;
5; 2; 28; 1; 0; 0; 0; 35; 76; 7;

0; 0; 10; 90; 0; 57; 148; 1; 59; 145;
2; 31; 72; 3; 0; 0; 0; 29; 80; 8;

0; 0; 12; 55; 2; 52; 89; 6; 31; 92;
6; 0; 0; 0; 0; 0; 0; 37; 86; 8;

0; 0; 0; 0; 0; 55; 128; 2; 15; 68;
2; 16; 45; 2; 0; 0; 0; 37; 78; 9;

0; 0; 16; 75; 3; 45; 97; 4; 58; 130;
4; 30; 90; 2; 0; 0; 0; 38; 102; 7;
```

Appendix C

- **Synchro files maintained by VDOT**
- **VISSIM Green Time Distribution File**

Protected Phases	5	2	1	6	3	3		4	
Permitted Phases							3		4
Minimum Initial (s)	5.0	30.0	5.0	30.0	7.0	7.0	7.0	5.0	5.0
Minimum Split (s)	10.5	36.0	10.5	36.0	12.0	12.0	12.0	35.5	35.5
Total Split (s)	20.0	84.5	15.0	79.5	60.0	60.0	60.0	20.5	20.5
Total Split (%)	11%	47%	8%	44%	33%	33%	33%	11%	11%
Maximum Green (s)	14.5	78.5	9.5	73.5	55.0	55.0	55.0	15.0	15.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.5	2.0	1.5	2.0	1.0	1.0	1.0	1.5	1.5
Lead/Lag	Lead	Lag	Lead	Lag	Lead	Lead	Lead	Lag	Lag
Lead-Lag Optimize?									
Vehicle Extension (s)	2.5	3.0	2.5	3.0	2.5	2.5	2.5	3.0	3.0
Minimum Gap (s)	2.5	3.0	2.5	3.0	2.5	2.5	2.5	3.0	3.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	Coord	None	Coord	None	None	None	None	None
Walk Time (s)								7.0	7.0
Flash Dont Walk (s)								23.0	23.0
Pedestrian Calls (#/hr)								0	0
90th %ile Green (s)	14.5	97.8	9.0	92.3	39.8	39.8	39.8	11.4	11.4
90th %ile Term Code	Max	Coord	Gap	Coord	Gap	Gap	Gap	Gap	Gap
70th %ile Green (s)	11.2	104.8	7.6	99.2	38.0	38.0	38.0	9.6	9.6
70th %ile Term Code	Gap	Coord	Gap	Coord	Gap	Gap	Gap	Gap	Gap
50th %ile Green (s)	1[illegible].8	111.0	6.6	105.8	32.0	32.0	32.0	8.4	8.4
50th %ile Term Code	Gap	Coord	Gap	Coord	Gap	Gap	Gap	Gap	Gap
30th %ile Green (s)	10.3	133.0	0.0	117.2	23.4	23.4	23.4	7.1	7.1
30th %ile Term Code	Gap	Coord	Skip	Coord	Gap	Gap	Gap	Gap	Gap
10th %ile Green (s)	[illegible].3	162.0	0.0	148.2	7.0	7.0	7.0	0.0	0.0
10th %ile Term Code	Gap	Coord	Skip	Coord	Min	Min	Min	Skip	Skip

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 27 (15%), Referenced to phase 2:EBT and 6:WBT, Start of Yellow
Control Type: Actuated-Coordinated

Lane Group	↰	↑	↳	↓	↵	↘	↖
Protected Phases	5	2	1	6	3	3	4
Permitted Phases							
Minimum Initial (s)	10.0	15.0	10.0	15.0	5.0	5.0	10.0
Minimum Split (s)	15.0	20.0	15.0	20.0	10.0	10.0	15.0
Total Split (s)	3[illegible].0	116.0	15.0	100.0	34.0	34.0	15.0
Total Split (%)	1[illegible]%	64%	8%	56%	19%	19%	8%
Maximum Green (s)	2[illegible].0	111.0	10.0	95.0	29.0	29.0	10.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	[illegible].0	1.0	1.0	1.0	1.0	1.0	1.0
Lead/Lag	Lead	Lag	Lead	Lag	Lead	Lead	Lag
Lead-Lag Optimize?							
Vehicle Extension (s)	3.0	4.0	3.0	4.0	3.0	3.0	4.0
Minimum Gap (s)	3.0	4.0	3.0	4.0	3.0	3.0	4.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	Coord	None	Coord	None	None	None
Walk Time (s)							
Flash Dont Walk (s)							
Pedestrian Calls (#/hr)							
90th %ile Green (s)	2[illegible].0	111.0	10.0	95.0	29.0	29.0	10.0
90th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
70th %ile Green (s)	2[illegible].0	111.0	10.0	95.0	29.0	29.0	10.0
70th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
50th %ile Green (s)	2[illegible].0	111.0	10.0	95.0	29.0	29.0	10.0
50th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
30th %ile Green (s)	2[illegible].0	111.2	10.0	95.2	28.8	28.8	10.0
30th %ile Term Code	Max	Coord	Max	Coord	Gap	Gap	Max
10th %ile Green (s)	2[illegible].2	131.6	0.0	102.4	23.4	23.4	10.0
10th %ile Term Code	Gap	Coord	Skip	Coord	Gap	Gap	Max

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 39 (22%), Referenced to phase 2:NBT and 6:SBT, Start of Yellow
Control Type: Actuated-Coordinated

	↲	↘	↖	↑	↓
Protected Phases	4	4	1	6	2
Permitted Phases			6		
Minimum Initial (s)	7.0	7.0	5.0	20.0	20.0
Minimum Split (s)	32.0	32.0	10.0	25.0	25.0
Total Split (s)	32.0	32.0	25.0	148.0	123.0
Total Split (%)	18%	18%	14%	82%	68%
Maximum Green (s)	27.0	27.0	20.0	143.0	118.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0
Lead/Lag			Lead		Lag
Lead-Lag Optimize?					
Vehicle Extension (s)	4.0	4.0	3.0	4.0	4.0
Minimum Gap (s)	4.0	4.0	3.0	4.0	4.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	None	None	Coord	Coord
Walk Time (s)	7.0	7.0			
Flash Dont Walk (s)	20.0	20.0			
Pedestrian Calls (#/hr)	0	0			
90th %ile Green (s)	21.3	21.3	20.0	148.7	123.7
90th %ile Term Code	Gap	Gap	Max	Coord	Coord
70th %ile Green (s)	18.0	18.0	17.3	152.0	129.7
70th %ile Term Code	Gap	Gap	Gap	Coord	Coord
50th %ile Green (s)	15.7	15.7	14.4	154.3	134.9
50th %ile Term Code	Gap	Gap	Gap	Coord	Coord
30th %ile Green (s)	13.4	13.4	11.5	156.6	140.1
30th %ile Term Code	Gap	Gap	Gap	Coord	Coord
10th %ile Green (s)	10.2	10.2	7.4	159.8	147.4
10th %ile Term Code	Gap	Gap	Gap	Coord	Coord

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 104 (58%), Referenced to phase 2:SBT and 6:NBTL, Start of Yellow
Control Type: Actuated-Coordinated

	→	↙	←	↖	↑	↗	↘	↓
Protected Phases	3	4	4	1	6	4	5	2
Permitted Phases						6		
Minimum Initial (s)	5.0	5.0	5.0	5.0	20.0	5.0	5.0	20.0
Minimum Split (s)	35.0	10.0	10.0	10.0	25.0	10.0	10.0	25.0
Total Split (s)	35.0	36.0	36.0	20.0	79.0	36.0	30.0	89.0
Total Split (%)	19%	20%	20%	11%	44%	20%	17%	49%
Maximum Green (s)	30.0	31.0	31.0	15.0	74.0	31.0	25.0	84.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lead/Lag	Lead	Lag	Lag	Lead	Lag	Lag	Lead	Lag
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Minimum Gap (s)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	None	None	None	Coord	None	None	Coord
Walk Time (s)	7.0							
Flash Dont Walk (s)	21.0							
Pedestrian Calls (#/hr)	0							
90th %ile Green (s)	21.0	31.0	31.0	15.0	82.0	31.0	25.0	92.0
90th %ile Term Code	Gap	Max	Max	Max	Coord	Max	Max	Coord
70th %ile Green (s)	19.1	31.0	31.0	15.0	87.8	31.0	22.1	94.9
70th %ile Term Code	Gap	Max	Max	Max	Coord	Max	Gap	Coord
50th %ile Green (s)	17.1	31.0	31.0	15.0	92.5	31.0	19.4	96.9
50th %ile Term Code	Gap	Max	Max	Max	Coord	Max	Gap	Coord
30th %ile Green (s)	15.2	31.0	31.0	13.2	97.2	31.0	16.6	100.6
30th %ile Term Code	Gap	Max	Max	Gap	Coord	Max	Gap	Coord
10th %ile Green (s)	12.4	31.0	31.0	9.3	104.6	31.0	12.0	107.3
10th %ile Term Code	Gap	Max	Max	Gap	Coord	Max	Gap	Coord

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 88 (49%), Referenced to phase 2:SBT and 6:NBT, Start of Yellow
Control Type: Actuated-Coordinated

	⤴	→	↙	←	↖	↑	↘	↓	↙
Protected Phases		4		8	5	2	1	6	
Permitted Phases	4		8						6
Minimum Initial (s)	'.0	7.0	7.0	7.0	5.0	20.0	5.0	20.0	20.0
Minimum Split (s)	3'.0	37.0	12.0	12.0	10.0	26.0	10.0	28.0	28.0
Total Split (s)	5:.0	52.0	52.0	52.0	30.0	103.0	25.0	98.0	98.0
Total Split (%)	2i%	29%	29%	29%	17%	57%	14%	54%	54%
Maximum Green (s)	4'.0	47.0	47.0	47.0	25.0	97.0	20.0	92.0	92.0
Yellow Time (s)	.l.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	I.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0
Lead/Lag					Lead	Lag	Lead	Lag	Lag
Lead-Lag Optimize?									
Vehicle Extension (s)	).0	3.0	3.0	3.0	3.0	5.0	3.0	5.0	5.0
Minimum Gap (s)	).0	3.0	3.0	3.0	3.0	5.0	3.0	5.0	5.0
Time Before Reduce (s)	).0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	).0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	Nc ne	None	None	None	None	Coord	None	Coord	Coord
Walk Time (s)	'.0	7.0							
Flash Dont Walk (s)	2 ;.0	25.0							
Pedestrian Calls (#/hr)	0	0							
90th %ile Green (s)	4 '.0	47.0	47.0	47.0	25.0	105.0	12.0	92.0	92.0
90th %ile Term Code	N ax	Max	Hold	Hold	Max	Coord	Gap	Coord	Coord
70th %ile Green (s)	4 !.3	42.3	42.3	42.3	23.0	111.7	10.0	98.7	98.7
70th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Gap	Coord	Coord
50th %ile Green (s)	3 ;.7	35.7	35.7	35.7	19.8	119.6	8.7	108.5	108.5
50th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Gap	Coord	Coord
30th %ile Green (s)	3).1	30.1	30.1	30.1	16.7	126.5	7.4	117.2	117.2
30th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Gap	Coord	Coord
10th %ile Green (s)	2 !.6	22.6	22.6	22.6	12.5	146.4	0.0	128.9	128.9
10th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Skip	Coord	Coord

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 102 (57%), Referenced to phase 2:NBT and 6:SBT, Start of Yellow
Control Type: Actuated-Coordinated

Phasings
229: Collard St & Richmond Hwy

1/29/2003

Protected Phases		4		4		3 6		6	1	2	3
Permitted Phases	4		4		3 6		6				
Minimum Initial (s)	5.0	5.0	5.0	5.0			20.0	20.0	7.0	20.0	5.0
Minimum Split (s)	10.0	10.0	10.0	10.0			25.0	25.0	12.0	25.0	10.0
Total Split (s)	25.0	25.0	25.0	25.0	155.0	155.0	130.0	130.0	18.0	112.0	25.0
Total Split (%)	14%	14%	14%	14%	86%	86%	72%	72%	10%	62%	14%
Maximum Green (s)	20.0	20.0	20.0	20.0			125.0	125.0	13.0	107.0	20.0
Yellow Time (s)	4.0	4.0	4.0	4.0			4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0			1.0	1.0	1.0	1.0	1.0
Lead/Lag	Lag	Lag	Lag	Lag					Lead	Lag	Lead
Lead-Lag Optimize?											
Vehicle Extension (s)	3.0	3.0	3.0	3.0			3.0	3.0	3.0	3.0	3.0
Minimum Gap (s)	3.0	3.0	3.0	3.0			3.0	3.0	3.0	3.0	3.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0
Recall Mode	None	None	None	None			Coord	Coord	None	Coord	None
Walk Time (s)											
Flash Dont Walk (s)											
Pedestrian Calls (#/hr)											
90th %ile Green (s)	10.0	10.0	10.0	10.0			135.0	135.0	7.0	123.0	20.0
90th %ile Term Code	Gap	Gap	Gap	Gap			Coord	Coord	Min	Coord	Max
70th %ile Green (s)	8.4	8.4	8.4	8.4			137.6	137.6	7.0	125.6	19.0
70th %ile Term Code	Gap	Gap	Gap	Gap			Coord	Coord	Min	Coord	Gap
50th %ile Green (s)	7.4	7.4	7.4	7.4			141.2	141.2	7.0	129.2	16.4
50th %ile Term Code	Gap	Gap	Gap	Gap			Coord	Coord	Min	Coord	Gap
30th %ile Green (s)	6.6	6.6	6.6	6.6			144.6	144.6	7.0	132.6	13.8
30th %ile Term Code	Gap	Gap	Gap	Gap			Coord	Coord	Min	Coord	Gap
10th %ile Green (s)	5.9	5.9	5.9	5.9			147.8	147.8	0.0	147.8	11.3
10th %ile Term Code	Gap	Gap	Gap	Gap			Coord	Coord	Skip	Coord	Gap

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 140 (78%), Referenced to phase 2:NBT and 6:SBTL, Start of Yellow
Control Type: Actuated-Coordinated

Phasings

10: Popkins Ln & Richmond Hwy

1/29/2003

Protected Phases	3	1 3 4	2	1 4	4 6	1	4	6
Permitted Phases				6				
Minimum Initial (s)	5.0		20.0			7.0	5.0	20.0
Minimum Split (s)	10.0		25.0			12.0	10.0	25.0
Total Split (s)	25.0	68.0	112.0	43.0	155.0	18.0	25.0	130.0
Total Split (%)	14%	38%	62%	24%	86%	10%	14%	72%
Maximum Green (s)	20.0		107.0			13.0	20.0	125.0
Yellow Time (s)	4.0		4.0			4.0	4.0	4.0
All-Red Time (s)	1.0		1.0			1.0	1.0	1.0
Lead/Lag	Lead		Lag			Lead	Lag	
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0		3.0			3.0	3.0	3.0
Minimum Gap (s)	3.0		3.0			3.0	3.0	3.0
Time Before Reduce (s)	0.0		0.0			0.0	0.0	0.0
Time To Reduce (s)	0.0		0.0			0.0	0.0	0.0
Recall Mode	None		Coord			None	None	Coord
Walk Time (s)								
Flash Dont Walk (s)								
Pedestrian Calls (#/hr)								
90th %ile Green (s)	20.0		123.0			7.0	10.0	135.0
90th %ile Term Code	Max		Coord			Min	Gap	Coord
70th %ile Green (s)	1[illegible].0		125.6			7.0	8.4	137.6
70th %ile Term Code	Gap		Coord			Min	Gap	Coord
50th %ile Green (s)	1[illegible].4		129.2			7.0	7.4	141.2
50th %ile Term Code	Gap		Coord			Min	Gap	Coord
30th %ile Green (s)	1[illegible].8		132.6			7.0	6.6	144.6
30th %ile Term Code	Gap		Coord			Min	Gap	Coord
10th %ile Green (s)	1[illegible].3		147.8			0.0	5.9	147.8
10th %ile Term Code	Gap		Coord			Skip	Gap	Coord

Cycle Length: 180

Actuated Cycle Length: 180

Offset: 140 (78%), Referenced to phase 2:NBT and 6:SBTL, Start of Yellow

Control Type: Actuated-Coordinated

Distribution of Signal Times

U.S.1 Traffic Signal Priority Project w/o tsp

Duration of Simulation: 3600

SCJ 7, Average Green Times:Shields Avenue

Signal group;	t;	
1;	16.7;	
2;	110.9;	Main Line Phase(Actual 102.5)
4;	7.3;	
5;	10.9;	
6;	114.7;	Main Line Phase(Actual 112.5)
8;	7.3;	

SCJ 6, Average Green Times:South Kings Highway

Signal group;	t;	
1;	32.0;	
2;	29.5;	Main Line Phase(Actual 36)
4;	14.9;	
5;	11.1;	
6;	48.5;	Main Line Phase(Actual 53)
8;	14.9;	

SCJ 5, Average Green Times:Southgate Drive

Signal group;	t;	
1;	15.6;	
2;	98.5;	Main Line Phase(Actual 122)
4;	15.0;	
5;	0.0;	
6;	110.7;	Main Line Phase(Actual 117)
8;	15.0;	

SCJ 4, Average Green Times:Beacon Hill Road

Signal group;	t;	
1;	20.0;	
2;	111.3;	Main Line Phase(Actual 104)
4;	35.0;	
5;	0.0;	
6;	119.9;	Main Line Phase(Actual 114)
8;	35.0;	

SCJ 3, Average Green Times:Memorial Drive

Signal group;	t;	
1;	8.9;	
2;	105.1;	Main Line Phase(Actual 117)
4;	21.8;	
5;	0.0;	
6;	109.5;	Main Line Phase(Actual 122)
8;	21.8;	

SCJ 2, Average Green Times:Collard Strret

Signal group;	t;	
1;	19.5;	
2;	109.1;	Main Line Phase(Actual 103)
4;	37.0;	
5;	0.0;	
6;	113.1;	Main Line Phase(Actual 125)

```
       8;      37.0;

SCJ 1, Average Green Times:Popkins Lane
   Signal group;        t;
       1;      16.4;
       2;     110.2;Main Line Phase(Actual 117)
       4;      35.0;
       5;       3.3;
       6;     115.8;Main Line Phase(Actual 117)
       8;      35.0;
```

Protected Phases	5	2	1	6	3	3		4	
Permitted Phases							3		4
Minimum Initial (s)	[illegible].0	30.0	5.0	30.0	7.0	7.0	7.0	5.0	5.0
Minimum Split (s)	1[illegible].5	36.0	10.5	36.0	12.0	12.0	12.0	35.5	35.5
Total Split (s)	2[illegible].0	118.5	15.0	108.5	31.0	31.0	31.0	15.5	15.5
Total Split (%)	1[illegible]%	66%	8%	60%	17%	17%	17%	9%	9%
Maximum Green (s)	1[illegible].5	112.5	9.5	102.5	26.0	26.0	26.0	10.0	10.0
Yellow Time (s)	[illegible].0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	.5	2.0	1.5	2.0	1.0	1.0	1.0	1.5	1.5
Lead/Lag	Lead	Lag	Lead	Lag	Lead	Lead	Lead	Lag	Lag
Lead-Lag Optimize?									
Vehicle Extension (s)	[illegible].5	3.0	2.5	3.0	2.5	2.5	2.5	3.0	3.0
Minimum Gap (s)	[illegible].5	3.0	2.5	3.0	2.5	2.5	2.5	3.0	3.0
Time Before Reduce (s)	[illegible].0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	[illegible].0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	Coord	None	Coord	None	None	None	None	None
Walk Time (s)								7.0	7.0
Flash Dont Walk (s)								23.0	23.0
Pedestrian Calls (#/hr)								0	0
90th %ile Green (s)	1[illegible].0	116.6	7.5	108.1	26.0	26.0	26.0	7.9	7.9
90th %ile Term Code	Gap	Coord	Gap	Coord	Max	Max	Max	Gap	Gap
70th %ile Green (s)	1[illegible].0	134.0	6.6	126.5	10.5	10.5	10.5	7.0	7.0
70th %ile Term Code	Gap	Coord	Gap	Coord	Gap	Gap	Gap	Gap	Gap
50th %ile Green (s)	1[illegible].5	148.0	0.0	130.0	9.2	9.2	9.2	6.3	6.3
50th %ile Term Code	Gap	Coord	Skip	Coord	Gap	Gap	Gap	Gap	Gap
30th %ile Green (s)	1[illegible].1	161.3	0.0	144.7	7.7	7.7	7.7	0.0	0.0
30th %ile Term Code	Gap	Coord	Skip	Coord	Gap	Gap	Gap	Skip	Skip
10th %ile Green (s)	[illegible].9	162.0	0.0	147.6	7.0	7.0	7.0	0.0	0.0
10th %ile Term Code	Gap	Coord	Skip	Coord	Min	Min	Min	Skip	Skip

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 123 (68%), Referenced to phase 2:EBT and 6:WBT, Start of Yellow
Control Type: Actuated-Coordinated

6: Richmond Hwy & S Kings Hwy

Protected Phases	5	2	1	6	3	3	4
Permitted Phases							
Minimum Initial (s)	10.0	15.0	10.0	15.0	5.0	5.0	10.0
Minimum Split (s)	15.0	20.0	15.0	20.0	10.0	10.0	15.0
Total Split (s)	32.0	58.0	15.0	41.0	22.0	22.0	15.0
Total Split (%)	29%	53%	14%	37%	20%	20%	14%
Maximum Green (s)	27.0	53.0	10.0	36.0	17.0	17.0	10.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lead/Lag	Lead	Lag	Lead	Lag	Lead	Lead	Lag
Lead-Lag Optimize?							
Vehicle Extension (s)	3.0	4.0	3.0	4.0	3.0	3.0	4.0
Minimum Gap (s)	3.0	4.0	3.0	4.0	3.0	3.0	4.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	Coord	None	Coord	None	None	None
Walk Time (s)							
Flash Dont Walk (s)							
Pedestrian Calls (#/hr)							
90th %ile Green (s)	27.0	53.0	10.0	36.0	17.0	17.0	10.0
90th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
70th %ile Green (s)	27.0	53.0	10.0	36.0	17.0	17.0	10.0
70th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
50th %ile Green (s)	27.0	53.0	10.0	36.0	17.0	17.0	10.0
50th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
30th %ile Green (s)	27.0	53.0	10.0	36.0	17.0	17.0	10.0
30th %ile Term Code	Max	Coord	Max	Coord	Max	Max	Max
10th %ile Green (s)	27.0	68.0	0.0	36.0	17.0	17.0	10.0
10th %ile Term Code	Max	Coord	Skip	Coord	Max	Max	Max

Cycle Length: 110
Actuated Cycle Length: 110
Offset: 0 (0%), Referenced to phase 2:NBT and 6:SBT, Start of Yellow
Control Type: Actuated-Coordinated

Phasings

7: Southgate Dr & Richmond Hwy

1/29/2003

Protected Phases	4	4	1	6	2
Permitted Phases			6		
Minimum Initial (s)	7.0	7.0	5.0	20.0	20.0
Minimum Split (s)	32.0	32.0	10.0	25.0	25.0
Total Split (s)	32.0	32.0	15.0	148.0	133.0
Total Split (%)	18%	18%	8%	82%	74%
Maximum Green (s)	27.0	27.0	10.0	143.0	128.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0
Lead/Lag			Lead		Lag
Lead-Lag Optimize?					
Vehicle Extension (s)	4.0	4.0	3.0	4.0	4.0
Minimum Gap (s)	4.0	4.0	3.0	4.0	4.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	None	None	Coord	Coord
Walk Time (s)	7.0	7.0			
Flash Dont Walk (s)	20.0	20.0			
Pedestrian Calls (#/hr)	0	0			
90th %ile Green (s)	22.4	22.4	5.8	147.6	136.8
90th %ile Term Code	Gap	Gap	Gap	Coord	Coord
70th %ile Green (s)	18.9	18.9	5.7	151.1	140.4
70th %ile Term Code	Gap	Gap	Gap	Coord	Coord
50th %ile Green (s)	16.5	16.5	5.7	153.5	142.8
50th %ile Term Code	Gap	Gap	Gap	Coord	Coord
30th %ile Green (s)	14.1	14.1	5.6	155.9	145.3
30th %ile Term Code	Gap	Gap	Gap	Coord	Coord
10th %ile Green (s)	10.8	10.8	0.0	159.2	159.2
10th %ile Term Code	Gap	Gap	Skip	Coord	Coord

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 55 (31%), Referenced to phase 2:SBT and 6:NBTL, Start of Yellow
Control Type: Actuated-Coordinated

Phasings
8: Beacon Hill Rd & Richmond Hwy

1/29/2003

	→	↙	←	↖	↑	↗	↘	↓
Protected Phases	3	4	4	1	6	4	5	2
Permitted Phases						6		
Minimum Initial (s)	5.0	5.0	5.0	5.0	20.0	5.0	5.0	20.0
Minimum Split (s)	35.0	10.0	10.0	10.0	25.0	10.0	10.0	25.0
Total Split (s)	20.0	31.0	31.0	20.0	109.0	31.0	20.0	109.0
Total Split (%)	11%	17%	17%	11%	61%	17%	11%	61%
Maximum Green (s)	15.0	26.0	26.0	15.0	104.0	26.0	15.0	104.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lead/Lag	Lead	Lag	Lag	Lead	Lag	Lag	Lead	Lag
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Minimum Gap (s)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	None	None	None	Coord	None	None	Coord
Walk Time (s)	7.0							
Flash Dont Walk (s)	23.0							
Pedestrian Calls (#/hr)	0							
90th %ile Green (s)	13.2	26.0	26.0	10.6	105.8	26.0	15.0	110.2
90th %ile Term Code	Gap	Max	Max	Gap	Coord	Max	Max	Coord
70th %ile Green (s)	1[illegible].5	24.7	24.7	8.9	108.8	24.7	15.0	114.9
70th %ile Term Code	Gap	Gap	Gap	Gap	Coord	Gap	Max	Coord
50th %ile Green (s)	10.3	21.0	21.0	7.8	114.8	21.0	14.2	120.9
50th %ile Term Code	Gap	Gap	Gap	Gap	Coord	Gap	Gap	Coord
30th %ile Green (s)	[illegible].1	17.6	17.6	0.0	120.8	17.6	12.5	138.3
30th %ile Term Code	Gap	Gap	Gap	Skip	Coord	Gap	Gap	Coord
10th %ile Green (s)	[illegible].4	13.3	13.3	0.0	130.6	13.3	8.7	144.3
10th %ile Term Code	Gap	Gap	Gap	Skip	Coord	Gap	Gap	Coord

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 46 (26%), Referenced to phase 2:SBT and 6:NBT, Start of Yellow
Control Type: Actuated-Coordinated

Phasings
9: Memorial St & Richmond Hwy

1/29/2003

	↰	→	↙	←	↖	↑	↘	↓	↙
Protected Phases		4		8	5	2	1	6	
Permitted Phases	4		8						6
Minimum Initial (s)	7.0	7.0	7.0	7.0	5.0	20.0	5.0	20.0	20.0
Minimum Split (s)	37.0	37.0	12.0	12.0	10.0	26.0	10.0	26.0	26.0
Total Split (s)	37.0	37.0	37.0	37.0	20.0	128.0	15.0	123.0	123.0
Total Split (%)	21%	21%	21%	21%	11%	71%	8%	68%	68%
Maximum Green (s)	32.0	32.0	32.0	32.0	15.0	122.0	10.0	117.0	117.0
Yellow Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0
Lead/Lag					Lead	Lag	Lead	Lag	Lag
Lead-Lag Optimize?					Yes	Yes	Yes	Yes	Yes
Vehicle Extension (s)	3.0	3.0	3.0	3.0	3.0	5.0	3.0	5.0	5.0
Minimum Gap (s)	3.0	3.0	3.0	3.0	3.0	5.0	3.0	5.0	5.0
Time Before Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recall Mode	None	None	None	None	None	Coord	None	Coord	Coord
Walk Time (s)	7.0	7.0							
Flash Dont Walk (s)	25.0	25.0							
Pedestrian Calls (#/hr)	0	0							
90th %ile Green (s)	32.0	32.0	32.0	32.0	15.0	123.2	8.8	117.0	117.0
90th %ile Term Code	Max	Max	Hold	Hold	Max	Coord	Gap	Coord	Coord
70th %ile Green (s)	26.4	26.4	26.4	26.4	13.4	130.1	7.5	124.2	124.2
70th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Gap	Coord	Coord
50th %ile Green (s)	22.5	22.5	22.5	22.5	11.6	146.5	0.0	129.9	129.9
50th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Skip	Coord	Coord
30th %ile Green (s)	18.7	18.7	18.7	18.7	9.8	150.3	0.0	135.5	135.5
30th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Skip	Coord	Coord
10th %ile Green (s)	13.2	13.2	13.2	13.2	7.1	155.8	0.0	143.7	143.7
10th %ile Term Code	Gap	Gap	Hold	Hold	Gap	Coord	Skip	Coord	Coord

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 36 (20%), Referenced to phase 2:NBT and 6:SBT, Start of Yellow
Control Type: Actuated-Coordinated

Protected Phases		4		3 6	6	1	2	3
Permitted Phases	4		3 6					
Minimum Initial (s)	5.0	5.0			20.0	7.0	20.0	5.0
Minimum Split (s)	10.0	10.0			25.0	12.0	25.0	10.0
Total Split (s)	25.0	25.0	155.0	155.0	125.0	22.0	103.0	30.0
Total Split (%)	14%	14%	86%	86%	69%	12%	57%	17%
Maximum Green (s)	20.0	20.0			120.0	17.0	98.0	25.0
Yellow Time (s)	4.0	4.0			4.0	4.0	4.0	4.0
All-Red Time (s)	1.0	1.0			1.0	1.0	1.0	1.0
Lead/Lag	Lag	Lag				Lead	Lag	Lead
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0	3.0			3.0	3.0	3.0	3.0
Minimum Gap (s)	3.0	3.0			3.0	3.0	3.0	3.0
Time Before Reduce (s)	0.0	0.0			0.0	0.0	0.0	0.0
Time To Reduce (s)	0.0	0.0			0.0	0.0	0.0	0.0
Recall Mode	None	None			Coord	None	Coord	None
Walk Time (s)								
Flash Dont Walk (s)								
Pedestrian Calls (#/hr)								
90th %ile Green (s)	16.0	16.0			124.0	7.0	112.0	25.0
90th %ile Term Code	Gap	Gap			Coord	Min	Coord	Max
70th %ile Green (s)	13.0	13.0			127.0	7.0	115.0	25.0
70th %ile Term Code	Gap	Gap			Coord	Min	Coord	Max
50th %ile Green (s)	11.1	11.1			132.2	7.0	120.2	21.7
50th %ile Term Code	Gap	Gap			Coord	Min	Coord	Gap
30th %ile Green (s)	9.2	9.2			140.1	7.0	128.1	15.7
30th %ile Term Code	Gap	Gap			Coord	Min	Coord	Gap
10th %ile Green (s)	6.4	6.4			149.6	0.0	149.6	9.0
10th %ile Term Code	Gap	Gap			Coord	Skip	Coord	Gap

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 13 (7%), Referenced to phase 2:NBT and 6:SBTL, Start of Yellow
Control Type: Actuated-Coordinated

[redacted]

Protected Phases	3	1 3 4	2	1 4	4 6	1	4	6
Permitted Phases				6				
Minimum Initial (s)	5.0		20.0			7.0	5.0	20.0
Minimum Split (s)	10.0		25.0			12.0	10.0	25.0
Total Split (s)	30.0	77.0	103.0	47.0	150.0	22.0	25.0	125.0
Total Split (%)	17%	43%	57%	26%	83%	12%	14%	69%
Maximum Green (s)	25.0		98.0			17.0	20.0	120.0
Yellow Time (s)	4.0		4.0			4.0	4.0	4.0
All-Red Time (s)	1.0		1.0			1.0	1.0	1.0
Lead/Lag	Lead		Lag			Lead	Lag	
Lead-Lag Optimize?								
Vehicle Extension (s)	3.0		3.0			3.0	3.0	3.0
Minimum Gap (s)	3.0		3.0			3.0	3.0	3.0
Time Before Reduce (s)	0.0		0.0			0.0	0.0	0.0
Time To Reduce (s)	0.0		0.0			0.0	0.0	0.0
Recall Mode	None		Coord			None	None	Coord
Walk Time (s)								
Flash Dont Walk (s)								
Pedestrian Calls (#/hr)								
90th %ile Green (s)	25.0		112.0			7.0	16.0	124.0
90th %ile Term Code	Max		Coord			Min	Gap	Coord
70th %ile Green (s)	25.0		115.0			7.0	13.0	127.0
70th %ile Term Code	Max		Coord			Min	Gap	Coord
50th %ile Green (s)	21.7		120.2			7.0	11.1	132.2
50th %ile Term Code	Gap		Coord			Min	Gap	Coord
30th %ile Green (s)	15.7		128.1			7.0	9.2	140.1
30th %ile Term Code	Gap		Coord			Min	Gap	Coord
10th %ile Green (s)	9.0		149.6			0.0	6.4	149.6
10th %ile Term Code	Gap		Coord			Skip	Gap	Coord

[redacted]

Cycle Length: 180
Actuated Cycle Length: 180
Offset: 13 (7%), Referenced to phase 2:NBT and 6:SBTL, Start of Yellow
Control Type: Actuated-Coordinated

VITA

Vinit Deshpande was born on September 12, 1979 in Pune, India. In 1995, he graduated from M.E.S. Boy's High school in Pune. He completed his junior college from A. Garware College in 1997. In 1998 he went to Maharashtra Institute of Technology to pursue a Bachelor of Science in Civil Engineering. He started his work towards his Masters Degree in Civil Engineering at Virginia Polytechnic Institute and State University in the Spring 2002.

Mr. Deshpande recently accepted a job with DMJM+HARRIS, Inc. in Fairfax County, Virginia.