Evaluating the Transit Signal Priority Impacts along the U.S. 1 Corridor in Northern Virginia

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Abstract

Heavy traffic volumes in peak hours accompanied by closely located signalized intersections and nearside bus stops on U.S. 1, result in congestion and traffic delays that bus transit may be able to alleviate to some extent. The capital investment and operating costs of other transit solutions such as "Bus Rapid Transit" and "Heavy Rail Transit" projects were found to be cost prohibitive compared to bus transit signal priority (TSP) options. Successful implementation of a limited TSP pilot project led local authorities to conclude that TSP should be extended to the full length of the Fairfax Connector bus routes on U.S. 1.

This research focused on testing the impacts of a ten second green extension priority strategy for all the northbound transit buses in the morning peak period at twenty-six signalized intersections along U.S. 1. A micro simulation model VISSIM 3.7 was used to analyze the impacts of TSP.

The simulation analysis indicates that the Fairfax Connector buses might benefit from the green extension strategy. Overall, improvements of up to 4% for transit travel time savings and 5-13% reduction in control delay for transit vehicles were observed. Considering all side street traffic, the total increase in maximum queue length might be up to 1.23%.

Future research possibilities proposed include the evaluation of different priority strategies such as an early green, red truncation and queue jumps. Impacts of using a dedicated lane for transit buses along with TSP can also be evaluated. Conditional transit signal priority may also include bus occupancy levels and bus latenesses.

Dedication

I would like to dedicate this work to my son, Hiranya Kamdar for his love that gave me eternal encouragement to follow my dream.

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CHAPTER 1: INTRODUCTION

In major urban areas with increasing population and advances in automobile technologies, the traffic congestion problem has spread from the central business district (CBD) to suburban streets. Extending the road network cannot solve transportation problems. Since 1991, when Congress invoked ITS initiatives, very helpful ITS technologies have been used in different traffic control systems. ITS technologies such as TSP are found to be low cost and effective means for enhancing public transit systems. This fact was also observed in other parts of world like, Brazil and Japan (Garcia and Yamamoto, 1998)

If public transit becomes reliable and efficient more commuters and passengers may be encouraged to ride the public transit and there may be less congestion on urban streets. Public transit operations are affected adversely by many factors such as nearside bus stops, closely located intersections, and other factors. Past research shows that the stopped delay at intersections comprises about 20 percent of overall transit delay (Zhang, 2001). TSP is one of the promising technologies that may help reduce intersection delay and in turn total transit travel time. This was evidenced by the implementation of bus priority in SELKENT bus district of South East London and Kent in which 56 traffic signals and 1000 London buses had been equipped for active bus priority (Hounsell, 1988).

U.S. 1, a major 6 lane arterial highway with intersections spaced at an average of 500 ft apart, suffers heavy traffic congestion during morning and evening peak hours. During the morning peak period (6:00-9:00 AM), the major transit traffic destination is northbound towards the intramodal facility, i.e. Huntington Metro Station and during evening peak period (4:00-7:00 PM) the major transit traffic is southbound from Huntington Metro Station to the residential areas. Fairfax Connector bus routes currently serving the section of U.S. 1 south of Huntington Metro are Route: 105, 106 and 107.

1.1 Problem Definition

Heavy traffic volumes in peak hours accompanied by closely located signalized intersections and nearside bus stops on U.S. 1, result in congestion and traffic delays that bus transit may be able to alleviate to some extent. The capital investment and operating costs of other transit solutions such as "Bus Rapid Transit" and "Heavy Rail Transit" projects were found to be cost prohibitive compared to bus transit signal priority (TSP) options. Successful implementation of a limited TSP pilot project (Deshpande, Collura, Teodorovic, and Tignor, 2004) led local authorities to conclude that TSP should be extended to the full length of the Fairfax Connector bus routes on U.S. 1.

This research paper addresses the issue of assessing the impacts of bus priority. Reduction in bus control delay and bus travel time along with the increase in side street queue lengths will be the measures of effectiveness under focus for this research. VISSIM 3.7 the micro simulation software will be used for this research work.

1.2 Existing Conditions

The simulation outcomes as well as the field results of ten second green extension - TSP implementation on U.S. 1 pilot project for the six intersections from North Kings Highway to Popkins Lane, indicate a reduction in transit travel time with negligible impacts to side street traffic (Deshpande, Collura, Teodorovic, and Tignor, 2004). Government officials assume 10% increase in transit ridership as a result of TSP implementation on U.S. 1 corridor as stated on commuter pages website (http://www.commuterpage.com/cnews/column.cfm?ID=4333). The increase in the transit demand may result in revenue generated for Fairfax Connector.

According to the information provided by Virginia Department of Transportation (VDOT), TSP needs to be extended on U.S. 1 corridor from North Kings Highway in the north to Fairfax County Parkway in the south.

1.3 Research Objectives

The main goal of this research is to analyze the results of TSP, i.e. benefits to transit traffic and probable adverse impact on non-transit traffic.

Considering stakeholders' problems and expectations from TSP implementation, certain performance measures were established during the U.S. 1 TSP pilot project. The preliminary objective is to derive what benefits can be achieved in terms of these performance measures, if TSP is extended for the whole U.S. 1 corridor.

The secondary objective is to illustrate the pros and cons of using new technologies in the world of traffic simulation.

1.4 Scope of Research

The first step is to understand and discuss the transportation problems on the major arterial U.S.1. The research then presents in depth literature review for:

a) Need of TSP as a solution to these problems
b) Various TSP strategies
c) Different technologies used to provide TSP
d) Previous experiences with TSP implementation.
e) Pilot project done on U.S.1 with respect to the TSP technology

The research work includes learning efforts required for the simulation software. Next step was to authenticate the results of this effort with the results of the pilot project.

The research focuses on simulation study for TSP on the extended intersections on U.S.1. The SYNCHRO files provided by VDOT were the source of information for U.S.1 road geometry, volumes, traffic signal timing and phasing. VISSIM 3.7 imports traffic data from SYNCHRO files in "Universal Traffic Data Format (UTDF)". In this research, the UTDF feature is used to prepare the VISSIM network. The transit network was prepared using Fairfax Connector schedules and field data. The field data was collected about bus

stops locations and turn out lengths information. TSP of ten second green extension was emulated at the twenty-six signalized intersections of U.S. 1 corridor covering entire Fairfax Connector bus route.

The simulation results were analyzed to reflect TSP effectiveness with respect to total travel time on U.S. 1 corridor, reduction in intersection delays and adverse effect on side street traffic.

1.5 Importance of Thesis

To alleviate the congestion problems and to make the mass transit service more usable, it is being considered to provide preferential treatment to the buses on the U.S. 1 corridor in Northern Virginia. It is very important to know the impacts of vast implementation of this TSP project. This research gains high significance because for the first time, the extensive U.S. 1 corridor with twenty intersections was simulated for TSP in VISSIM 3.7.

The research illustrates how useful Universal Traffic Data Format (UTDF) – the new standard can be in preparing extensive urban network in VISSIM. Finally this thesis gives analysis and probability of various impacts of the TSP implementation.

1.6 Thesis Organization

This thesis consists of seven chapters. The following Chapter 2 is about literature review of the work done in the area of TSP systems. It gives basic idea of various TSP strategies, different detection technologies, the impacts of priority on the transportation system and signal priority experiences in the United States as well as in other parts of the world.

Chapter 3 discusses evaluation plan and research approach for assessing the TSP deployment on U.S.1 in Northern Virginia.

Chapter 4 describes challenges and assumptions made for replicating work done previously. It also describes use of VISSIM 3.7 capabilities such NEMA controller for modeling signal controls and TSP for the U.S.1 Pilot project

Chapter 5 details location of U.S.1 corridor, the traffic and transit data, concept and implementation of TSP used for this research.

Chapter 6 discusses VISSIM model data, calibration method and network modeling. It also introduces use of UTDF for exchanging data across simulation packages. It also discusses TSP logic used in NEMA controller PEEK LMD9200.

Chapter 7 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

An in depth literature review of numerous research papers and articles gave the author a broad perspective and firm foundation for undertaking this research work and writing this thesis. It is important to understand the state-of-art transit signal priority by reviewing all aspects of transit signal priority.

This chapter gives a clear idea about difference between transit priority and emergency vehicle preemption, results of various field studies as well as simulation studies, U.S. 1 traffic congestion problems and U.S. 1 TSP pilot project study.

2.1 Overview of Traffic Signal Priority Systems

2.1.1 Need of TSP

The primary objective of TSP is to reduce the transit travel time by reducing delay at signalized intersections. It is believed that with the amount of congestion along a major arterial, a system like this can greatly increase the operational efficiency of the transit vehicle and maintain a better schedule adherence. Another anticipated benefit of TSP is to increase the overall vehicular flow along the corridor. If the transit vehicles are able to move more smoothly, then their effectiveness will affect the flow of traffic behind them. These facts are proven in the study done for "Superbus", where it is indicated that the ITS enhanced bus priority can substitute the need of segregation of guideway for improving public transport operations (Jones, 1998).

A TSP system would be especially beneficial to the far-side bus stops rather than those on the nearside. The buses that are able to clear an intersection and then make a pick-up/drop-off at a far-side bus stop has to stop only once. However, if the bus has to make a stop, before the intersection to pick-up passengers, there is a good chance the bus will have to stop again at the red light.

Major requirements to meet one or more of these objectives must be defined. One requirement is to be able to detect a bus before it reaches the intersection, and then modify the signal timings in some prescribed manner (e.g. extending the green interval to allow a local bus to clear the intersection.). Another requirement is to grant priority only to those busses that are behind schedule or within a specified time frame. This could prevent bus bunching and also maintain a better schedule adherence.

2.1.2 Difference between Preemption and Transit Signal Priority

At this point it is important to understand difference between the priority treatment given to emergency vehicles and the transit vehicles. Priority and preemption are often used synonymously, when in fact they are different systems (Chang, Collura, Dion, Rakha, Tignor, and Triantis, 2002)

Both systems can use identical technologies that are implemented in the same manner. But the objectives of preemption and priority are quite different (Chang, Collura, Dion, Rakha, Tignor, and Triantis, 2002). TSP is meant for some priority service within the coordinated operation of traffic signals that can reduce delay for the transit vehicles with minimal impact to other traffic.

On the other hand emergency vehicles get preemption because high degree of priority is necessary for safety and performance reasons. For example, at railroad crossings railways get preemption and at signalized intersections emergency vehicles get preemption. Preemption can disrupt the normal traffic operation. Only restrictions in providing the preemption could be the “Pedestrian Phase” or when there is work zone located at intersection.

2.1.3 Transit Signal Priority - Deployment Issues

TSP deployment issues discussed below are well presented in past work done (Gifford, Pelletiere, and Collura, 2002). There can be many factors that affect implementation of traffic signal priority systems (ITS America, 2002).

Factors affecting implementation of traffic signal priority systems can be categorized in two major categories: traffic related factors and transit related factors.

Traffic related factors are:

Roadway Geometry	• Directly dictates the capability of the system and types of possible operations. • Impacted by the surrounding land development, which dictates the number and location of the intersections and the transit stops. • Offers challenges such as plane of vision e.g. for the detection technologies.
Traffic Volumes	• Varies with time for any given intersection or segment. • High traffic volumes during peak hours for general as well as transit vehicles impacts traffic signal priority
Traffic Signal System	• An operating factor, which governs the extent to which the traffic signal priority system can be achieved • Capability of signal hardware and software to deploy intended priority strategies and to store and transfer the data in the required format is important.
Pedestrians	• Time required for a pedestrian to safely cross the street at a signalized intersections limits the time available for the signal priority.
Adjacent Intersection Operations	• Important for understanding the progression for the transit vehicles. • Very crucial in case of closely spaced intersection for maintaining coordination. • Study corridor consists of 26 intersections within 8.8 miles stretch, which make this issue important.

Transit Related Issues are:

Type of transit systems

- Could be heavy rail transit or light rail transit or bus transit
- Easy to implement TSP for rail-based transit than for road-based transit as rail systems are generally on exclusive (or semi exclusive) right of ways and are more reliable for the prediction of vehicle arrival times at the intersections
- Dwell time affects the arrival for bus transit to the intersection and that is why express bus services benefit more from transit priority system than local buses.

Transit stops

- Location of transit stops relative to signalized intersection impacts transit signal priority effectiveness.
- Nearside bus stops make transit detection challenging for providing transit priority and it is challenging to provide detectors for nearside bus stops such that given priority is not wasted in passenger boarding and alighting at bus stop
- Farside stops are more compatible with priority systems.

2.1.3 Transit Priority Strategies

The transit signal priority could be "Passive priority strategy" or "Active priority strategy". All of these strategies are described in depth in previous research done at Virginia Tech (Deshpande, Collura, Teodorovic, and Tignor, 2004). TSP implementation methods are available in UK since the 1970's and different strategies are welknown there but somehow most of the development work has been related to active priority systems (Hounsell, McLeod, and Shrestha, 2004).

Passive Priority strategies can be listed as below:

- Adjustment of Cycle Length
- Area-wide Timing Plans
- Phase Splitting
- Metering Vehicles

Active priority strategies need bus detection in some form and three known different detection categories are "Infrastructure Equipment only", "On-bus and local infrastructure", and "On-bus and central infrastructure" (Hounsell, McLeod, and Shrestha, 2004). The detection systems are discussed in the next chapter.

- Phase Extension (Green Extension)
- Early Green (Red Truncation)
- Actuated Transit Phase (Red Interruption)
- Phase Insertion
- Green Truncation
- Phase Rotation

In U.S. 1 TSP project green extension the active priority strategy is used. In addition to above Adaptive or Real-time Strategies also are in use, which combines some of the above listed strategies. Bus priority integrated with adaptive traffic signal control can optimize the assignment of the traffic flow and reduce the time wasted on the way (Shuyan, Zhiheng, and Deyun, 2003).

Conditional Bus Priority:

Conditional transit priority can be provided using advanced detection technologies such as AVL. A simulation and field study undertaken for London Transport Buses by the Transportation Research Group (TRG) at Southhampton University compared and showed that more benefits occurs in terms of average delay savings for headway based selective bus priority (Hounsell, McLeod, Gardner, Head, and Cook, 2000). The different scenarios for comparison were use of SCOOT for traffic signal coordination and signal timing optimization, use of SCOOT with bus priority, and use of SCOOT with selective i.e. headway based bus priority. AVL was used for the headway information.

Recent study done on bus management with improved passenger situations (Lu and Viegas, 2003) shows the way to provide better environment to the bus passengers on

roadside, takes into account the estimation of their waiting time, and combines the time into the weight coefficient of objective function on the detected and predicted bus message through some kinds of AVL technologies and prediction models. The bus priority signals then can be adjusted on this obtained function.

2.1.4 Detection Technologies

The detection technology is backbone of transit signal priority systems as it is the communication link between approaching transit vehicle and signal controller. Primarily it consists of a message conveyer. Detection technologies should serve the following purposes:

1. The transit vehicle should be detected
2. The signal controller should receive this information in time.

There are different types of media to carry these messages to the signal controller namely light, sound, radio frequencies and others (Deshpande, Collura, Teodorovic, and Tignor, 2004). There has been extensive research performed at Virginia Tech to study different technologies, system requirements and past deployments (Collura, Chang, Willhaus, and Gifford, 2001), which are provided in Appendix B.

Advanced detection technology like global positioning systems (GPS) is widely used for bus priority and it has also made centrally integrated traffic control more sophisticated in European countries (Purdie H, 2002). The bus data gathered for this purpose can also be supplied to the traveling public to encourage the modal shift towards public transport.

2.1.5 Results from TSP implementations within USA and outside USA

The City of Portland performed a detailed operational analysis of the effect of transit preferential strategies on five corridors. They found that on average, only 34% of the total bus travel time was attributable to driving. The remaining 66% was distributed as: 22% at traffic signals, 16% at bus stops, and 28% in traffic congestion (City of Portland-Final report, 1997). Findings from Wilshire and Whittier Boulevards in Los Angeles showed that traffic signal delay was 20% and bus stop delay was 25% (Los Angeles Metro Rapid

Demonstration Program, 2001). These results suggest that the maximum transit travel time reduction attainable by transit priority alone is in the order of 20%.
Table 1 in Appendix A, (Soo, Collura, Hobeika, and Teodorovic, 2004), gives good comparison for results of various transit signal priority strategies implemented in previous field and simulation studies.

Research papers (Deshpande, Collura, Teodorovic, and Tignor, 2004), (Soo, Collura, Hobeika, and Teodorovic, 2004), (Ngan, Sayed, and Abdelfatah, 2004), (Hongchao, Meng, and Skabardonis, 2004) show favorable outcomes of TSP implementation, which are summarized in Table 1.

The simulation study done in VISSIM, for Granville Street in Vancouver British Columbia (Ngan, Sayed, and Abdelfatah, 2004) gave in depth analysis of the effects of various factors of network components on TSP results. The considered factors are bus detector location, near side and far side bus stops, traffic density and others. This study gives pretty good idea of VISSIM capabilities for modeling transit signal priority and related minute field details.

A research paper discusses the behavioral responses of travelers following the implementation of strong bus priority measures (where road capacity is deliberately removed from general traffic and given to buses). The results of the different behavioral responses based on two commercial transport modeling packages (CONTRAM and TRIPS) suggest firstly that the effect of implementing such strong bus priority measures is as dependent on the characteristics of the local travelers as on the scheme itself and secondly that implementing too strong a scheme may not benefit public transport overall (Waterson, Rajbhandari, and Hounsell, 2003).

The research study done using VISSIM for bus priority with highly interruptible traffic signal control - simulation of San Juan's Avenida Ponce de Leon showed the results indicating significant transit travel time savings without slowing general traffic compared with the existing strategy of fixed time control with progression (Janos and Furth, 2002).

Along with all these results, an implementation of conditional bus priority done in Eindhoven, the Netherlands showed that conditional priority given to the buses with lateness only gave better results than the absolute priority given to all buses (Furth and Muller, 2000).

Efforts are made to provide TSP without causing the controller to drop from coordination and disturbing the progression. In a research study (Balke, Dudek, and Urbanik, 2000), implementation of the bus priority strategies was accomplished through normal traffic-signal controller commands such as (Ring Force Offs and Phase Holds). Phase extension, phase insertion, and early return strategies were used to provide priority.

Effective use of dedicated bus lanes along with the bus priority is important in making transit operations more efficient. A study (Viegas and Lu, 2001) gives the concept of Intermittent Bus Lane (IBL). As an enhancement of transit priority, pre-signals are used on bus lanes in U.K., particularly in London and a research paper (Wu and Hounsell, 1998) describes decisive factors, characteristics, analytical approach for using pre-signals, and the benefits of implementing that.

Transport Research Laboratory worked on the signal control method microprocessor optimized vehicle actuation (MOVA), for providing the priority treatment to cater for emergency and/or priority vehicles. Three sites were studied for this research, two in South West London and one just outside Winchester. Research results indicated that in all cases, buses had benefited from the introduction of bus priority with varying degrees depending on site characteristics (Crabtree and Vincent, 1998).

Table 1-A. Recent Results of TSP Projects in U.S.

U.S. Experiences **Field Studies**	**Measure**	**Result**
Fairfax, VA – U.S. 1 VISSIM	Travel time	4 – 10 % decrease

U.S. Experiences **Field Studies**	**Measure**	**Result**
(Projected for entire corridor)	Project Cost: Estimated Payback Period	Decrease from 50.5 to 11 years
El Camino Real, San Francisco Bay area PARAMICS	Travel Time (TT) (sec)	Decrease from 576 to the range of 491 - 509
	Speed (mph)	Increase from 21 to the range of 25 -26 mph
	Dwell Time (% of TT)	Increase from 21.7 to the range of 24.5-25.5 %
	Signal Delay	Decrease fro 131 to the range of 46 to 63 sec
		Decrease form 22.7 to 9.3 – 12.3 %
	Travel Savings	68 to 85 sec decrease
		11.8 to 14.7 % decrease
	Deviation of Bus Headway	Almost 50 % decrease
U.S. Experiences **Simulation Studies**	**Measure**	**Result**
Hypothetical Isolated Intersection	Delay for Bus	28.7 to 44.7 % decrease
	Delay for Passenger Vehicles	0.09 to 1.4 % decrease
	System wide Impacts (delay, vehicle stops, fuel consumption)	1.3 to 4.3 % decrease

Table 1-B. Recent Results of TSP Projects Outside U.S.

Experiences Outside the U.S.	**Measure**		**Result**
Field Studies			
Granville Street, Vancouver British Columbia VISSIM	Green Extension (GE) Success Rate (GESR)	Far side bus-stop	100% for detector location between 50-200m
			Decreases for detector-location >= 250m
		Nearside bus-stop	61% for detector location between 50-150m
			Decreases for detector location >= 200m
		Main-line v/c ratio 0-0.475	100%
		0.475 < v/c < 1.0	Decrease by almost 25 %
	Bus Travel time	Main line v/c ratio 0.6-0.9 beneficial	Decrease from 14 to 13.4 minutes
		Bus headway 2-20 minute	Decrease by1.9 to 5.1 %
	Total Delay	Entire Corridor	Decrease 2 %
		Major Traffic	Decrease 2 %
		Cross Street Traffic	0 %
		Northbound B-Line Buses	Decrease 6 %
		Northbound all Traffic	Decrease 17 %
		Southbound B-Line Buses	0 %
		Southbound all Traffic	Increase 21 %

Table 1-B. Recent Results of TSP Projects Outside U.S.

Experiences Outside the U.S.	**Measure**			**Result**
Field Studies				
Granville Street, Vancouver British Columbia VISSIM	Bus Delay	Main line v/c from 0.2 to 0.95	Far side bus-stop	Increase from 4.4 to 9.2 sec
			Nearside bus-stop	Increase from 8.1 to 13.1 sec
			% Change	Decrease from 85% to 42%
		Detector location 50-300m	Far side bus stop	Marginal increase from 10.5 to almost 11.0 sec
			Nearside bus stop	Decrease from 9.0 to 4.0 sec
		Left Turn volume 0 – 200 veh/h	Opp. Th. v/c 0.37	Increase 0 to 32.3 Permissive LT Phase, shared LT-TH Lane
				Increase 0 to 2.0 Permissive LT Phase, Exclusive LT Lane
				Increase 0 to 0.4 Protected LT Phase, Exclusive LT Lane
			0.55	Increase 0 to 83.9 Permissive LT Phase, shared LT-TH Lane
				Increase 0 to 49.8 Permissive LT Phase, Exclusive LT Lane
				Decrease 0 to -0.1 Protected LT Phase, Exclusive LT Lane
			0.74	Increase 0 to 103.2 Permissive LT Phase, shared LT-TH Lane
				Increase 0 to 58.7 Permissive LT Phase, Exclusive LT Lane
				Increase 0 to 0.5 and at LT volume =200, delay = 0.0 for Protected LT Phase, Exclusive LT Lane

2.2 Review of TSP Pilot Project on U.S. 1

2.2.1 Pilot Project Description

The transit signal priority pilot project has been in operation since 2002. Eight Fairfax County Connector busses have been equipped with emitter devices. Eight bus stops in each direction have been considered, spanning across six intersections all equipped with signal detectors. The intersections start from North King's Highway / Shields Avenue from the north and run down to Popkins Lane to the south, covering a distance of about 1.3 miles as listed in Table 1 in Appendix B. All transit signal priority hardware such as signal emitters and detectors are from 3M Opticom. The system has been programmed to give a 10 second green extension to those buses equipped with emitters.

Analysis of the project was handled using the traffic simulation software VISSIM as shown in Figure 1 in Appendix B. Virginia Department of Transportation's (VDOT) provided SYNCHRO files as shown in Table 2 in Appendix D. The systems uses a Signal Control Junction based approach to model the six intersections. In VISSIM 3.6, the concept of a "time based actuated coordinated signal control system" and transit signal priority were modeled using "Vehicle Actuated Programming" (VAP). The speed of the buses comes out to 13.4 mph. Based on the field observations; the range of 12.4 to 15.5 mph was chosen for buses this analysis. Results of the analysis are used to compare to results collected in the field.

Favorable simulation results

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 (Deshpande, Collura, Teodorovic, and Tignor, 2004).

A report about a public hearing held in February 2004 reports that according to the metro officials, the restructuring of metro buses for Route 1 will increase the transit ridership by 500 passengers per weekday (Commuter news, http://www.commuterpage.com/cnews/column.cfm?ID=4333).

2.2.2 Impacts of Extended Priority for the Pilot Project

The study of 20 and 30 sec green extension strategies through VISSIM 3.6 is described in this paper. For bus service reliability, there is a significant rise in the reduction percentage for the 20 second green extension as compared to the 10 second green extension; the reduction in the standard deviation is almost 26% and 37% respectively for the AM and PM peak period. Whereas for the 30 second green extension the reduction in the standard deviation is 15 % and 9 % respectively for the AM and PM peak period, comparing it with the travel time savings for 20 second green extension. Measure of bus service efficiency i.e. travel time reduction shows the similar results. There is a significant rise in the travel time savings for the 20 second green extension as compared to the 10 second green extension; the rise in the travel time savings is almost 97% and 61% respectively for the AM and PM peak period. Whereas for the 30 second green extension the rise in travel time savings is only 4% and 14% respectively for the AM and PM peak period, comparing it with the travel time savings for 20 second green extension. (Awar, Collura, Teodorovic, and Tignor, 2004)

2.2.3 Transit Operating Costs and Benefits

One studied and analyzed the economic impacts of transit signal priority on U.S. 1, at Virginia Tech (Soo, Collura, Hobeika, and Teodorovic, 2004). Transit travel time reduction of 3.61% (Deshpande, Collura, Teodorovic, and Tignor, 2004) was considered as base and the results for transit operating costs were extrapolated for entire stretch of U.S. 1. The study also gives plan for reduction in transit operating costs for different percentage reduction in transit travel times.

2.3 Objectives of Priority on extended stretch of U.S. 1 corridor

The principal objective of this traffic signal priority system is to improve the operation of the public transit system by reducing the delay it incurs at the signalized intersections. In the peak hours, whole U.S. 1 stretch suffers congestion and low serviceability for buses. With favorable results from the pilot project, TSP will be extended to include nineteen more traffic signals with detectors in 2004 (Virginia Department of Transportation, http://www.mwcog.org/transportation/activities/clrp/descriptions/study-va-18.pdf). In the U.S. 1 pilot project, the stakeholders including the Virginia Department of Transportation (VDOT) and Fairfax County established the following objectives. The objectives remain the same except for transit service reliability because of lack of sufficient data.

1. The system should improve the bus efficiency at which the Fairfax Connector buses operate in the corridor
2. TSP implementation should reduce delay at intersections for the transit vehicles.
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. Provision of a safer interaction between buses and emergency vehicles 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 Stake Holders

In this big project many stakeholders with different, conflicting interests are there. They are listed as below:

1.	Virginia Department of Transportation - (VDOT)	Traffic operational behavior i.e. traffic flows, signal timings, etc., is taken care of by VDOT
2.	Fairfax County	Fairfax County controls Fairfax Connector bus service.
3.	Metropolitan Planning Organization (MPO)	Funding of transportation projects and necessary planning is provided by MPO.
4.	Federal Agencies	Federal agencies such as federal Transit Agency, give guidance with respect to technical assistance, training available and implementation of standards, and also how to manage the limited transit funds.
5.	Traffic Engineers and Traffic Signal Operators	Traffic engineers and traffic signal operators are very important for proper implementation, operations and maintenance of bus transit priority.
6.	Bus Drivers	The implementation affects them with regards to travel time, efficiency and reliability of transit bus service
7.	Public/Riders	All of these efforts are aimed to make the transportation infrastructure more useful such that to serve public in a better way.
8.	Elected Officials	Elected Officials want to satisfy needs of their voters

2.5 Challenges in simulating extensive transportation network

Producing an extensive network like U.S. 1 stretch from North Kings Highway to Fairfax County Parkway manually can be time consuming and the minute details can become very challenging.

Big challenge lies in use of innovative Universal Traffic Data Format (UTDF) feature when majority of the network details were imported and many were missing in preparing the network this way. Completion of such network required thorough traffic engineering knowledge.

2.6 Traffic simulation Software

For beforehand study and planning of large transportation projects, traffic simulation software give in depth, faster idea to the transportation engineers. This software is faster than traditional mathematical, analytical tools. Simulation technologies have replaced traditional mathematical models and graphical user interface and animations in this field; have helped transportation engineers and planners show transportation problems to decision makers for understanding and foreseeing the dynamics of traffic movements and control operations. Many such tools are available in market and transportation professionals need to use good engineering judgment for adopting appropriate, efficient simulation tool for particular type of project.

Here, we discuss the need of traffic simulation software, different available options and widely used software, and the one, which is used in this research in depth.

2.6.1 Need of Traffic Simulation

Prior to simulation techniques, we had to use expensive, time-consuming resources in field experiments for evaluating alternative strategies. For transportation projects, different probabilities are associated with roadway geometries, traffic volumes, intersection locations, and driver behavior. Simulation tools facilitate transportation engineers analyze complex traffic situations, which cannot be provided by other traditional methods. Simulation tools provide the most detailed objective operational analysis technique available for evaluating design and traffic control features (Clark and Daigle, 1997).

A project called MUSIC was done in London, UK, which was aimed to demonstrate that by managing and optimizing the overall performance of the network using new, cost effective, traffic control strategies it will be possible to: reduce congestion; improve the efficiency of public transport; and influence mode choice. The described objectives could be achieved by using the MUSIC software package, which calculates area-wide traffic signal timings (Routledge and Smith, 1996).

2.6.2 Comparison of Some Traffic Simulation Softwares with VISSIM

The differences of various software packages are very well discussed in many of the papers referred and some of these are compared here (Deshpande, Collura, Teodorovic, and Tignor, 2004), (Soo, Collura, Hobeika, and Teodorovic, 2004), (Moen, Fitts, Carter, and Ouyang, 2000), and (Fujimoto and Leonard, 2002).

NETSIM: NETSIM is a powerful microscopic simulation tool but in a study (Chin, Cheu, and Chandrasekar, 2002) it seemed that there are few attempts of its use in studying bus priority. In the study done in Singapore, one of the possible reasons was experienced to be the difficulty in modeling some of the unique characteristics of bus operations.

TRANSYT 7F: Modeling of transit bus turning movements needs to be done by turning bus counts into passenger car equivalents, which is not the case in VISSIM.

CORSIM: Even though in CORSIM, modeling time is lesser than that in VISSIM and CORSIM is less expensive than VISSIM; the studies (Moen, Fitts, Carter, and Ouyang, 2000), have found VISSIM more capable and accurate in modeling complex roadway geometry, transit vehicles, minute field parameters like pedestrians, bus stops, trees etc. In CORSIM to simulate transit signal priority, additional C++ module needs to be developed. This means extensive programming knowledge is needed to simulate TSP in CORSIM.

VISSIM: VISSIM is stochastic microscopic simulation model. Network editing in VISSIM is done completely through graphical user interface, which gives exact idea of how your network will look like in the end. This feature is found very useful for traffic engineers (Moen, Fitts, Carter, and Ouyang, 2000). On comparison of field results to simulation results for U.S. 1 project, it was realized that VISSIM is a reliable tool for TSP simulation. VISSIM

is required in this study because it has good capabilities in providing detailed information regarding measures of effectiveness. Simulation in VISSIM 3.6 also needed use of Vehicle Actuated Programming (VAP) for modeling Transit Signal Priority. Not all transportation engineers know programming.

Why VISSIM 3.7? VISSIM 3.7 has in built feature called NEMA controller, which eliminates need for VAP for simulating TSP for specified time of green extension. For providing advanced traffic simulation VAP coding is needed. VAP comes as separate module with VISSIM 3.7 (PTV America Marketing website).

Summary

- After analyzing other available software in market, VISSIM was chosen for simulating transit signal priority on U.S. 1 pilot project. This is an extension of the previous research, so the same micro simulation software VISSIM but its new version was used here
- As discussed above, it was found that the green extension of twenty second, yields better results for transit traffic but in interest of all stake holders ten second green extension is the implemented TSP strategy for initial six intersections on U.S. 1

CHAPTER 3: RESEARCH APPROACH AND EVALUATION PLAN

In this chapter, the evaluation framework and research approach are discussed.

3.1 Evaluation Plan

The evaluation framework is needed to determine whether a project or a strategy meets the intended purposes. In U.S. 1 pilot project, the evaluation framework prepared at Virginia Tech (Chang, Collura, Dion, Rakha, Tignor, and Triantis, 2002), was used to assess the impacts of transit signal priority deployment. This research study uses the same evaluation plan.

The overall idea of this evaluation framework is explained in Figure 1.

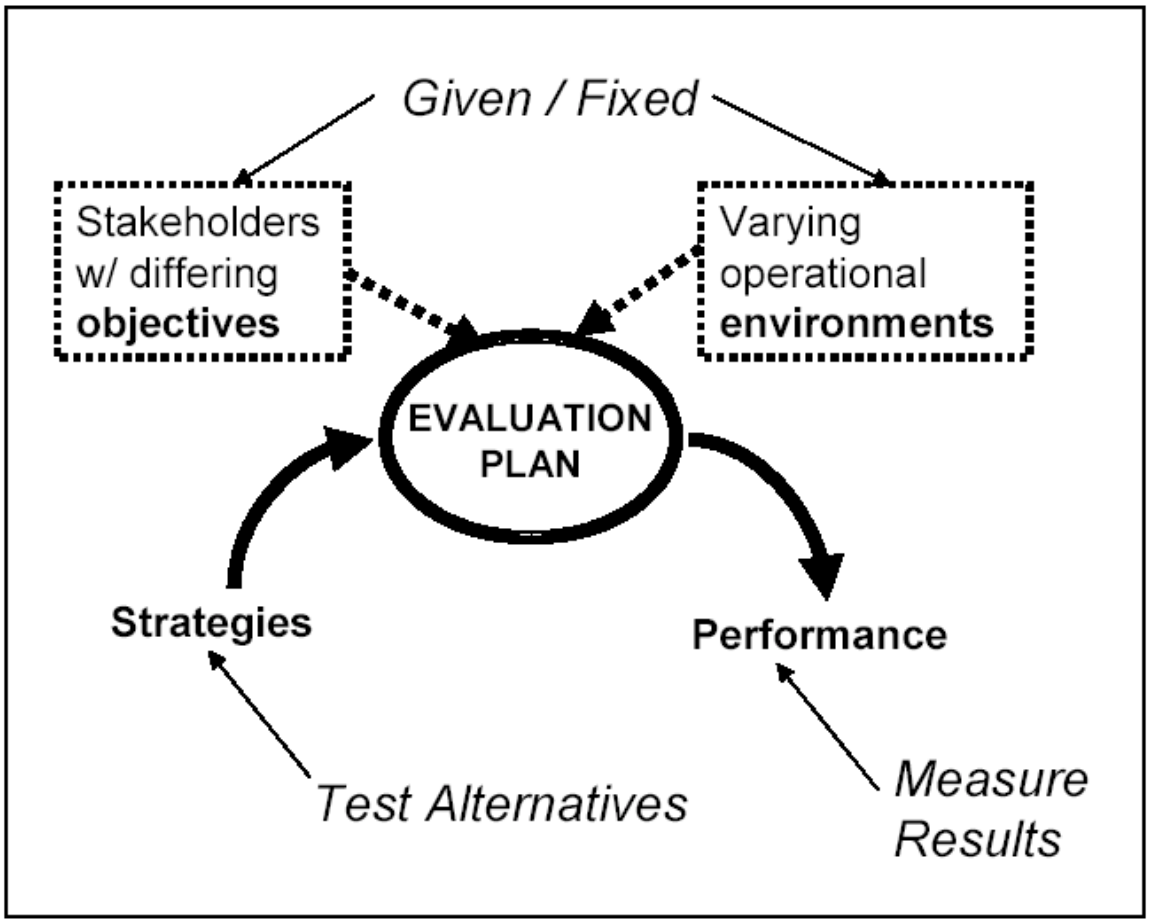


Figure 1. Evaluation Framework Concepts

In U.S. 1 transit signal priority project, there are two major stakeholders: one is Fairfax County which provides the local public transit system i.e. Fairfax Connector buses on U.S. 1; and another stakeholder is Virginia Department of Transportation (VDOT) which decides the operational environment i.e. the traffic flow pattern and traffic signal timing plans. Other stakeholders and their roles in TSP implementation are described in Chapter 2.

All the stakeholders have differing objectives. It is challenging to decide what will be achieved, how much of that will be achieved and what negative outcomes should be expected from this deployment. All possible TSP related objectives and different measures of effectiveness are shown in the Table 1 in Appendix C (Chang, Collura, Dion, Rakha, Tignor, and Triantis, 2002).

In the extensive research carried out at Virginia Tech (Deshpande, Collura, Teodorovic, and Tignor, 2004), focus was on

- The extent to which TSP could improve the schedule reliability of Fairfax Connector buses on U.S. 1 corridor.
- The extent to which TSP could improve main line i.e. U.S. 1 traffic flow
- The extent to which the TSP implementation could adversely affect the side street traffic for the U.S. 1 corridor; from Popkins Lane in the south to North Kings Highway in the north.

Depending upon the objectives and operational environment, the quantitative and qualitative measures of effectiveness were chosen in the evaluation plan. The objectives were addressed in the following categories:

Measures of Effectiveness (MOE): Following is the discussion about MOE.

- Bus Service Reliability can be measured as standard deviation of elapsed time between time points/endpoints.

- Bus Efficiency can be measured as total travel time for a passenger for a single trip measuring the travel time between end points.
- Bus control delay can be measured as average stopped delay for transit vehicles at the intersection.

The performance measures are total travel time, delay at intersection, and side street queue lengths.

Evaluation plan for the entire bus route of Fairfax Connector on U.S. 1 will be implemented through simulation using VISSIM 3.7. Evaluation of the TSP ten second green extension strategy implementation, with emitters on all Fairfax Connector buses and detectors at all the U.S. 1 signalized intersections in northbound direction can be done based on following hypothesis:

Hypothesis #1	Providing priority to the Fairfax Connector buses will increase bus efficiency.
Hypothesis #2	Average control delay for transit vehicle with TSP in northbound direction will be less than the average control delay for transit vehicles without TSP.
Hypothesis #3	There will be very little increase in the side street queue lengths by providing the priority to Fairfax Connector buses on main line.

3.2 Research Approach

To implement the above evaluation plan, following steps were taken:

1. Studied various solutions to U.S. 1 congestion problems, among which improvements to existing mass-transit services were in focus.
2. Understood the importance of various ITS technologies in improving the mass transit operations.
3. Transit Signal Priority - ITS technology and strategy was studied in depth for its positive results in alleviating the congestion and transit operation problems.
4. Studied the importance of micro simulation tools, compared various existing softwares for traffic engineering and selected VISSIM 3.7 for modeling the U.S. 1 traffic flow characteristics.
5. Got acquainted to VISSIM 3.7 by working U.S. 1 pilot project.
6. Used SYNCHRO and TEAPAC/PRESYNCHRO interface for importing and preparing the U.S. 1 network.
7. Configured missing NEMA signal control files, other network elements such as missing links, connectors and routing decisions.
8. Prepared the transit network with TSP elements according to field study and bus-schedules for Fairfax Connector routes 105, 106, 107 on whole U.S. 1 corridor.
9. Model was run for two basic scenarios i.e. without TSP and with TSP and also different random number seed were used to reflect different traffic patterns on the network.
10. The simulation results were compared with previously collected field data.

CHAPTER 4: Modeling U.S. 1 Pilot Project in VISSIM 3.7

Before using new VISSIM 3.7 functionality-NEMA signal controllers for a large number of intersections of U.S. 1, its' operation needed to be checked. Therefore all the traffic data of U.S. 1 pilot project network was kept the same for preparing and testing its' functionality in VISSIM 3.7.The simulation results of VISSIM 3.7 were compared with collected field data and the simulation results from VISSIM 3.6.

4.1 Assumptions for Traffic Network

In the absence of proper information and knowledge transfer, author struggled to find out the basic model parameters. Assumptions made by author are given and discussed as below.

1. **The basic VISSIM network file:** "AMwp20.inp"
    - The six "*.inp" files provided are AMwp20.inp, AMwp20hv.inp, AMwp20lv.inp, pmwp20.inp, pmwp20hv.inp, pmwp20lv.inp. There was no description provided regarding contents of these files.
    - Another confusion was regarding, appending "20" in the file name. Did it mean priority for 20 seconds? VAP files provide priority. There was no significance seen of this "20", so it was ignored.
    - "wp" could mean 'with priority 'or 'without priority ' a confusing situation. In VISSIM 3.6 transit priority is modeled through VAP files only, so the network file name did not affect other traffic characteristics. Therefore it was ignored.
    - The above-mentioned files were checked for the traffic volumes and there were some differences in the traffic volumes for similar turning movement counts that were provided by the SYNCHRO file. Only traffic data from "AMwp20.inp" file matched with the SYNCHRO files data. Therefore "AMwp20.inp" was chosen as basic VISSIM network file.

2. Simulation parameters:

- Simulation parameters were changing for all six VISSIM-network files provided so the default values were used as found from the VISSIM Manual
- The random number seed was taken as 42 and the simulation speed was taken as 10 sim-second/sec

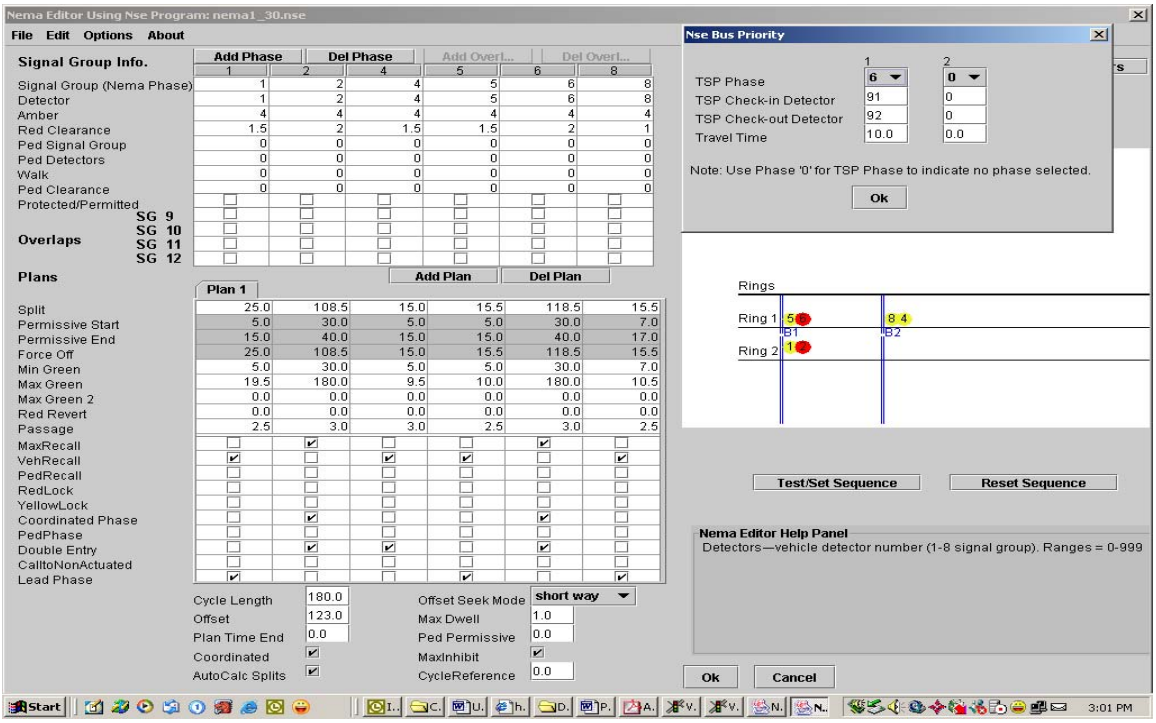
3. Signal Coordination:

- Controller Type: Fully Actuated Coordinated. There was confusion about controller type and it was believed to be semi-actuated coordinated type. As a result of discussions with VDOT representatives it became clear that the controllers were of type fully actuated coordinated.
- For majority of the intersections from Popkins to Shields, the starting phase was number "6". Therefore for the simplicity, the network file was modified to have the phase "6" as the coordinated phase throughout the network.

4. Signal Controllers: The signal controller files were created for the U.S. 1 intersections from Shields to Popkins. For this,

- VISSIM Manual was used, the examples were studied and VISSIM help was used.
- Certain phases and the detectors, which appeared in VISSIM 3.6 work, were not considered in VISSIM 3.7 work, as they did not exist according to the SYNCHRO file.
- The phasing and traffic flow direction of given network files and that of SYNCHRO did not match fully. Initially, this mismatch was kept the same. Finally, when VISSIM nomenclature became available the mismatches were fixed.
- The pedestrian detectors and the details of the pedestrian phases were there in the SYNCHRO files but they were not found in the given network files. Even though this network did not replicate the field situation truly, to keep the data similar; it was ignored at this time. All of the SYNCHRO data was modeled in final VISSIM network.

- The terms in NEMA controller were interpreted, after studying the manual, examples and SYNCHRO files, for example:
    i. Passage = minimum gap (values from SYNCHRO file)
    ii. Maximum Green = Total Split (VAP files' text was studied and as the information sometimes changed from SYNCHRO values, the SYNCHRO file values were used)
- The detailed timing, phasing sequence were modeled using ring and barrier diagram in NEMA signal control files. The ring-barrier diagram is shown in following NEMA file for North Kings Highway. Other NEMA files are depicted in Appendix E.



NEMA File: North Kings Highway / Shields Avenue

5. **Transit Signal Priority Detector Location :** 3M Opticom detectors are used on the field. The normal detection length ranges between 200 feet to 1000 feet (VISSIM Manual)
    - The detector range for the detectors is 200 to 300 feet as per the information provided by VDOT.

- These transit detectors are provided in such a way that checkout detector is on the intersection signal control head and the check-in detector is placed on upstream side so that the travel time between the two will be the same as the desired green extension time.
- For simulating this, the distance between the check-in and checkout detectors was kept as 200 feet uniform throughout the network.

6. Configuration of the files:

Configuration files for vehicle records, travel time, delay, green time distribution, signal controller i.e. information for phasing, and detectors were missing. Therefore using the VISSIM Manual, these files were created.

7. Initial Simulation Run:

1. Simulation ran for 750 seconds out of 3600 seconds of total simulation time.
2. Many errors for accumulation of vehicles in network on some links were found and solved as the project proceeded.

4.2 Assumptions for Transit Network

- For the project corridor, all of the routes are assumed to run for the same length and serving the same bus stops.
- Other important assumption is that only "Inbound buses" will get priority
- Bus details are given as:

Route	Number of Buses per One Hour Simulation Run
105	4
106	2
107	2

As discussed before and following the demo example "TSP_Chicago",

- Vehicle types and vehicle classes for 105, 106 and 107, for inbound buses were created.
- For outbound buses separate vehicle type and vehicle class were created.

- In field not all buses have emitters so to replicate that it was assumed that route 106 and 107 buses had emitters.
- Route 106 and 107 were grouped in one vehicle class named "TSP_Buses" as done in demo example.
- In VISSIM 3.6 network files, the travel time end points were there but the section did not capture the bus data so it was modified according to transit line in VISSIM 3.7 network file.

4.3 Transit Signal Priority Strategy

- The basic 3 M Opticom emitters and detection systems are shown in the Figure 8 and 9.
- Depending upon the travel time between the check-in and checkout detectors, the transit signal priority is given in NEMA controller logic. Travel Time was set as ten seconds.
- To determine the travel time, the average transit speed was assumed as 13.4 mph (Deshpande, Collura, Teodorovic, and Tignor, 2004).

The “NEMA bus priority” input window for TSP parameters is shown the previous NEMA file.

4.4 Comparison of the Simulation Results

Tables 2 to 6, show comparison of field and simulation results for northbound traffic, along U.S. 1 for A.M. Peak Period (6-00 to 9-00am). The traffic data was taken from year 2002 morning peak period SYNCHRO files. The field data represents data collected during the same time period.

Table 2. Results for Northbound Buses Without TSP

Description	Field Results	VISSIM 3.7 Results	VISSIM 3.6 Results:
Range of Northbound Transit Travel Time (sec)	236 to 525	531 to 610	553 to 725
Average Northbound Transit Travel Time (sec)	366	565.9	632

Table 3. Results for Northbound Buses With TSP

Description	Field Results	VISSIM 3.7 Results	VISSIM 3.6 Results		
		10 sec	10 sec	20 sec	30 sec
Range of Northbound Transit Travel Time (sec)	227 to 444	446 to 541	464 to 519	425 to 518	404 to 520
Average Northbound Transit Travel Time (sec)	351	509	492	481	480

Table 4. Results for Non-transit Vehicles

Description	Field Results	VISSIM 3.7 Results
Total Travel Time for Non-Transit Northbound Vehicles (sec)	140 to 257	200.4
Total Travel Time for Non-Transit Southbound Vehicles (sec)	112 to 250	184.33

Table 5. Results for Network Speed considering All Vehicles

Description	Field Results	VISSIM 3.7 Results
Network Speed for All Vehicles (mph)	17.12 to 27.915	27.374

Table 6. % Difference of travel time between field data and simulation results

Field Data and VISSIM 3.6 w/o priority	37 %
Field Data and VISSIM 3.6 with priority	40 %
Field Data and VISSIM 3.7 w/o priority	54 %
Field Data and VISSIM 3.7 with priority	48 %

Comments:

1. If the travel time for the south bound buses is considered, the VISSIM 3.7 simulation results match with the bus travel times from field data as well as VISSIM 3.6 simulation results
2. Considering the travel times for the northbound buses, there is significant difference observed between the field data and the simulation results of VISSIM 3.6 as well as VISSIM 3.7.
3. This difference could be reasoned by considering the dwell time of the buses, which stop at almost all the bus stops in the northbound direction. In fact at some of the bus stops, buses might not be stopping at all in the field.
4. The difference in the results from two simulation models can be reasoned mainly by considering the following facts.
    i. In VISSIM 3.6 simulation models for TSP with 10, 20, and 30 sec green extension, all the northbound buses were given priority.
    ii. In VISSIM 3.7, assumption was made that out of 8 northbound buses 4 buses are with emitters so in the simulation model 4 buses are assumed to get TSP.

Other VISSIM 3.7 Results:

- The average speed of all non-transit vehicles in the network falls in the range of the field results.
- The travel times of all non-transit vehicles in both the directions fall in the range of the field results.

CHAPTER 5: U.S. 1 Traffic and TSP Characteristics

5.1 Location

The study area is located on U.S. 1 from the Fairfax County Parkway in the south, to the North Kings Highway in the north. This 8.8mile stretch covers the longest Fairfax Connector bus route107. Geographic location of U.S. 1 is shown in Figure 2.

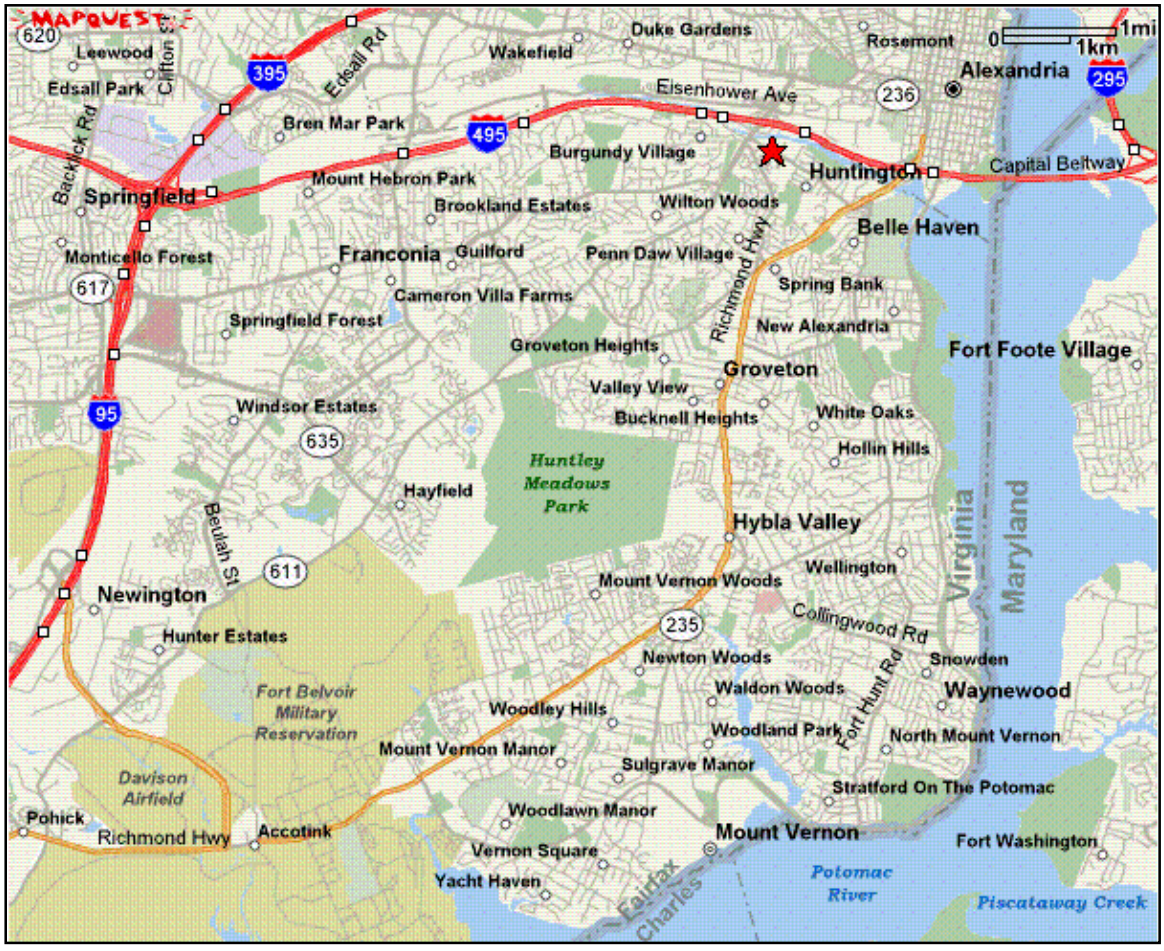


Figure 2. U.S. 1 Study Corridor

The study corridor consists of twenty-six signalized intersections listed in Table 7.

Table 7 U.S. 1 signalized Intersections

Number of Intersection (North to South)	Name Description
1	North King/Shields @ U.S. 1
2	South Kings Hwy @ U.S. 1
3	Southgate Dr @ U.S. 1
4	Beacon Hill Rd @ U.S. 1
5	Memorial St @ U.S. 1
6	Collard @ U.S. 1
7	Popkins @ U.S. 1
8	Lockheed Blvd/Dart Dr. @ U.S. 1
9	Arlington Dr. @ U.S. 1
10	Boswell/Fordson @ U.S. 1
11	Fordson Rd@ U.S. 1
12	Hybla Vally (Belford) @ U.S. 1
13	Sherwood Hall Lane @ U.S. 1
14	Ladson Lane @ U.S. 1
15	Buckman/Mt. Vernon @ U.S. 1
16	Russell/Reddick @ U.S. 1
17	Mohawk Lane @ U.S. 1
18	Buckman (South) @ U.S. 1
19	Frye Rd @ U.S. 1
20	Lukens Lane @ U.S. 1
21	Cooper St @ U.S. 1
22	Sacramento Dr. @ U.S. 1
23	Mt. Vernon Hwy/Old Mill @ U.S. 1
24	Woodlawn Rd @ U.S. 1
25	Belvoir Rd @ U.S. 1
26	Backlick Rd @ U.S. 1
27	Fairfax County Parkway @ U.S. 1

5.1.1 SYNCHRO Model

The overall SYNCHRO traffic network model supplied by VDOT is shown in Figure 3. The transportation network is broken and shown in separate SYNCHRO files for giving clear idea to the U.S. 1 intersections under consideration.

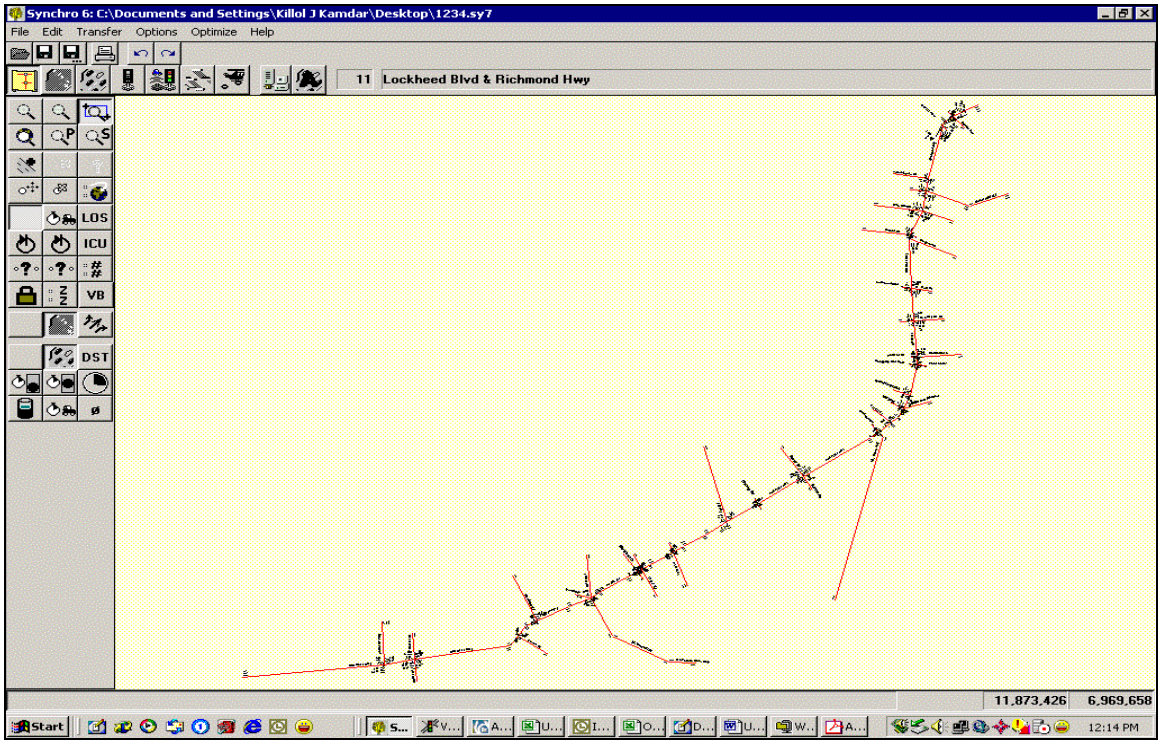
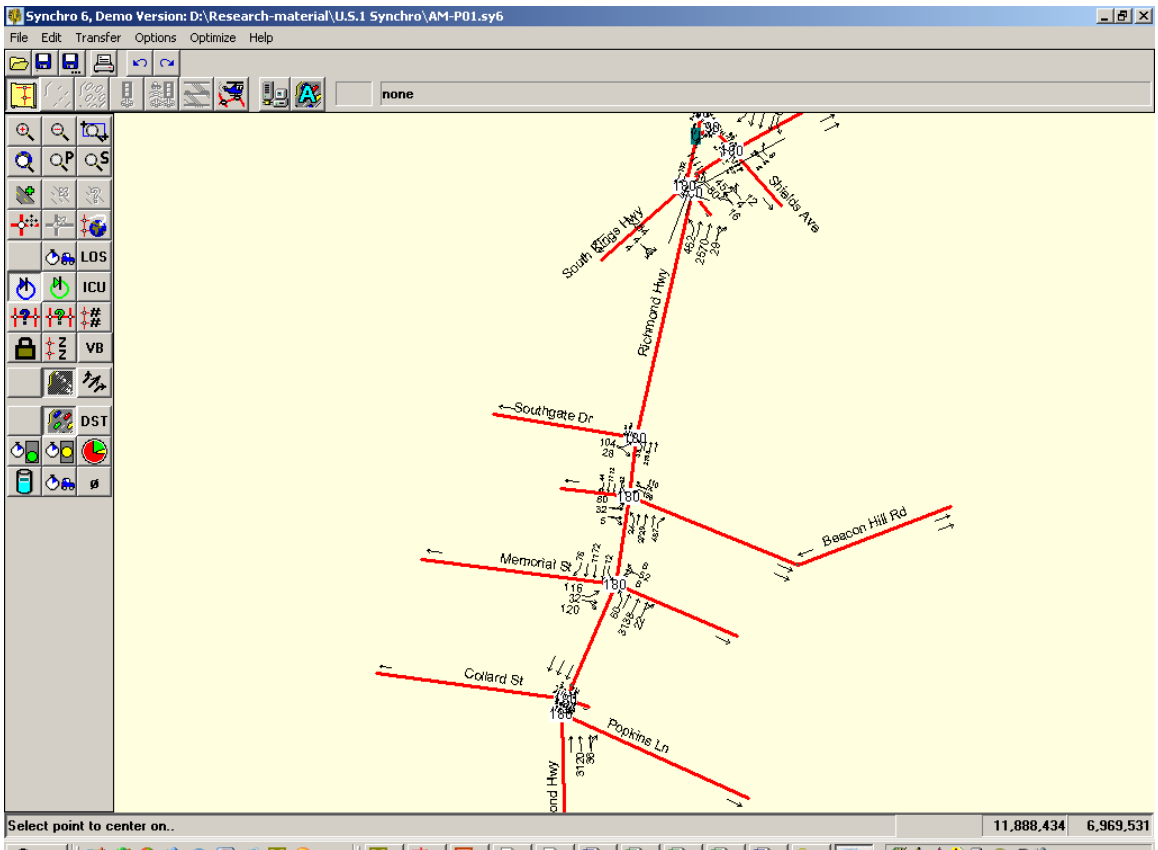


Figure 3. U.S. 1 SYNCHRO model

Timing plans for all of the signals were adjusted to start at the beginning of the green of the coordinated phases as required for the input of VISSIM NEMA control files. The details are discussed in following chapter.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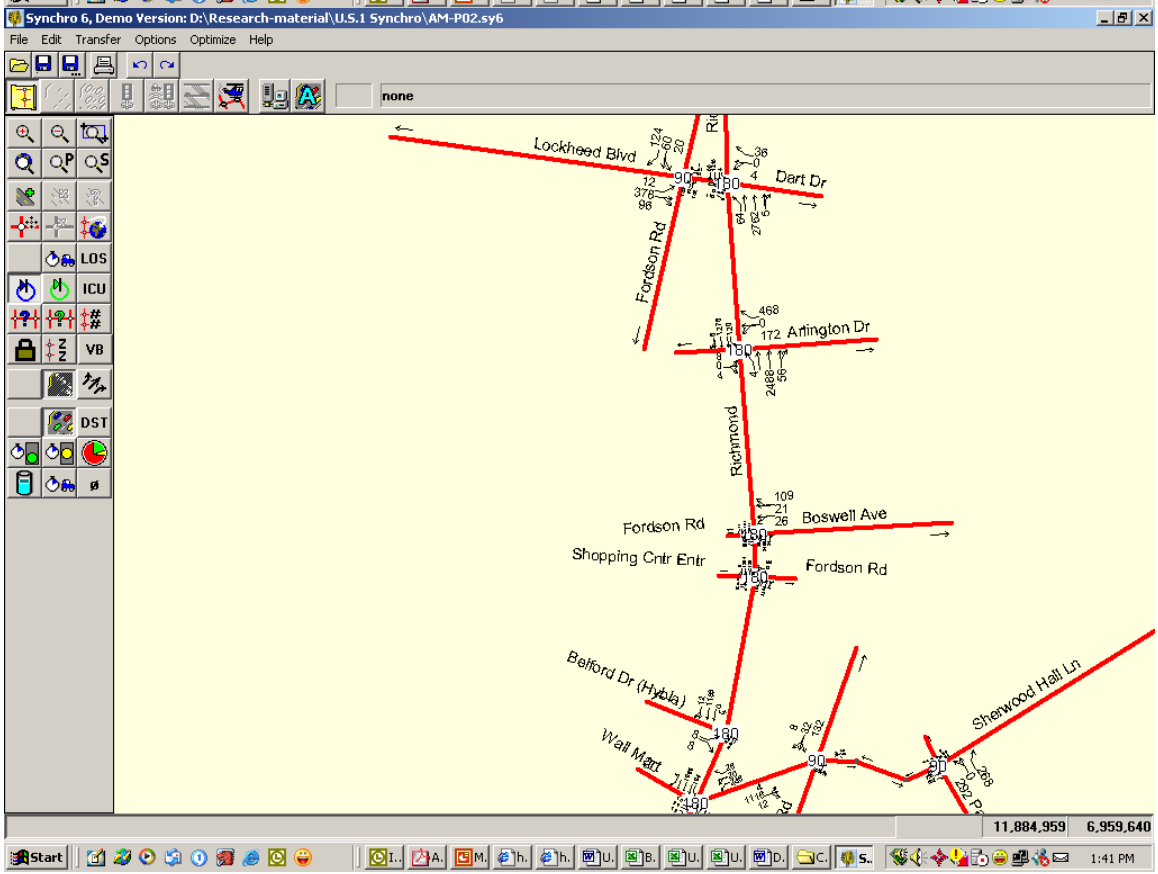
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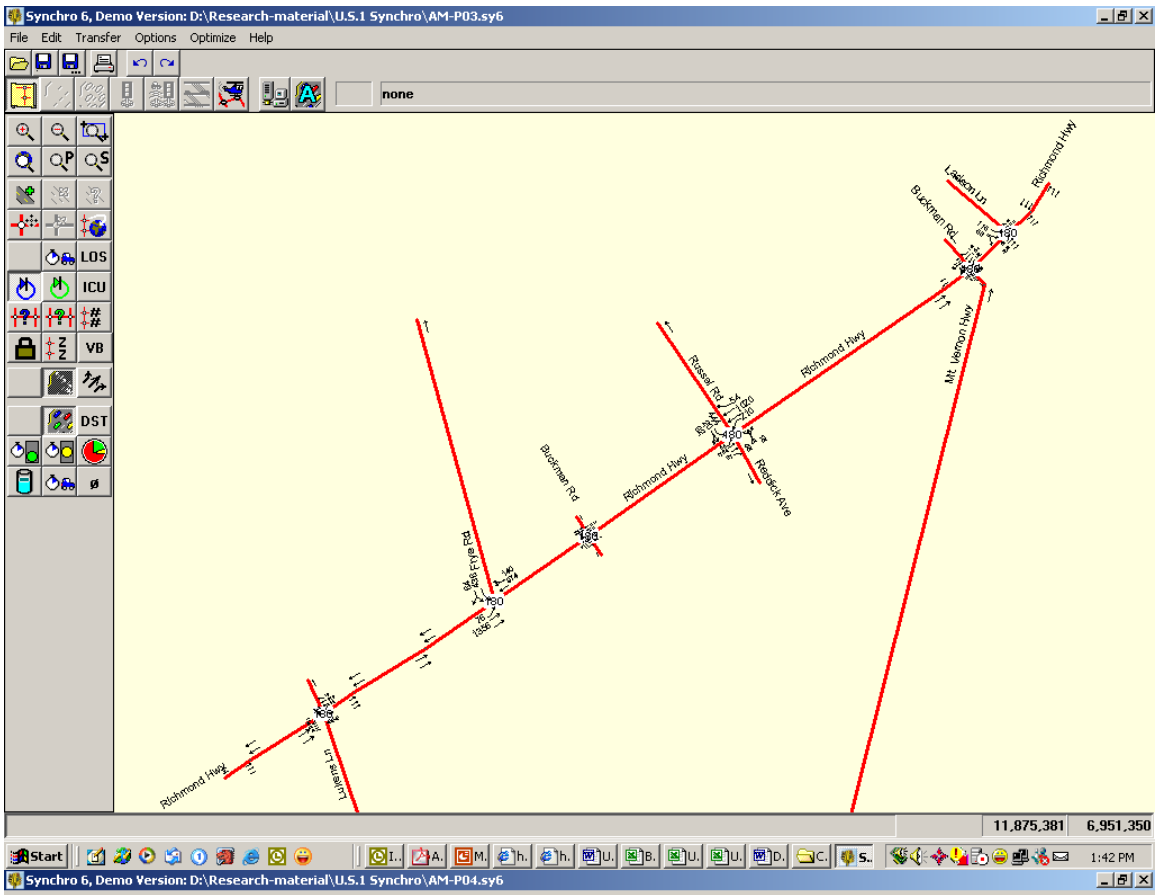
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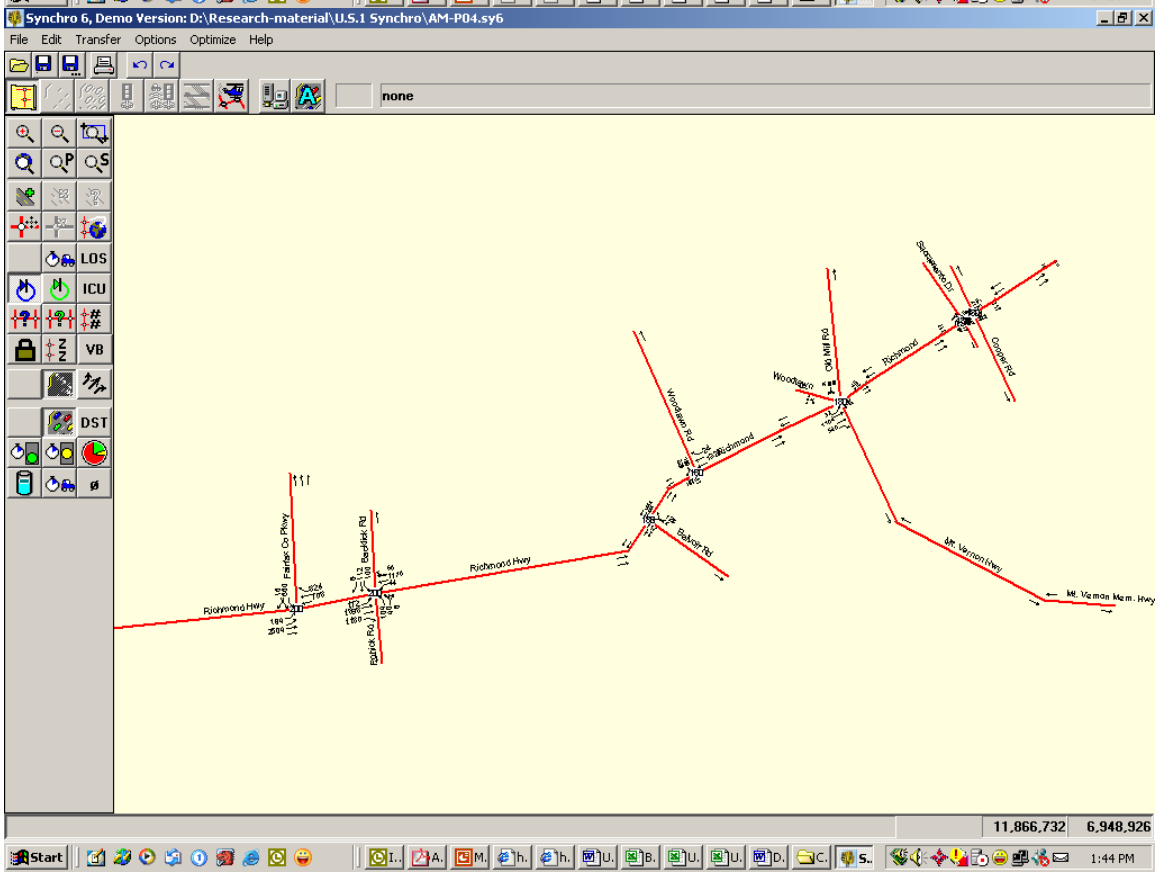
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Old Mill Rd
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Richmond
Winkler Rd
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5.2 Data Collection

This research uses previously collected field data by graduate students at Virginia Tech and is used for basic comparison. Field data collected was for traffic operations during the morning peak period from 6-00a.m. to 9-00a.m. and from Popkins Lane to North Kings Highway/ Shields Avenue only. Table 8 gives some details of that study.

Table 8. 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)	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

5.2.1 Transit Network

The transit network was prepared using Fairfax Connector schedules (Appendix G) and other data shown in Table 9, 10 and 11. Table 9 shows the travel times for different bus route, which is only the assumption and there is no field data to support it.

Table 9. U.S. 1 Bus Route Details

Fairfax Connector route	North End	South End	Route Length (mile)	Estimated Travel Time (Minutes)
105	North Kings / Shields	Buckman / Mt. Vernon	3.0	18
106	North Kings / Shields	Fordson Rd	2.0	14
107	North Kings / Shields	Backlick Rd	8.8	44

Table 10 gives statistics for total number of bus stops, number of farside and nearside bus stops and also the number of bus stops with turnout lanes.

Table 10. Bus Stop Details

Description	Northbound	Southbound
Total Number of stops	31	31
Turnout Lanes	12	7
Far side Bus Stops	9	5
Nearside Bus Stops	7	8

For an hourly simulation period, the frequency of the U.S. 1 routes 105, 106 and 107 was determined according to different route lengths as depicted in Table 11.

Table 11. Bus Start Times for the Hourly Simulation

Bus Routes	Fairfax Connector Schedule	Model Bus Starting Time
Route 105 NB	6:11	660
Route 105 NB	6:26	1560
Route 105 NB	6:41	2460
Route 105 NB	6:56	3360
Route 106 NB	6:14	840
Route 106 NB	6:44	2640
Route 107 NB	6:00	00
Route 107 NB	6:30	1800

The end times are given here, as they are not required in VISSIM transit coding. The total travel times and so the end times depend upon the length of the bus route, number of bus stops served, and other traffic conditions.

U.S. 1 bus stops were created using field data collected by graduate students at Virginia Tech as depicted in Figure 4.

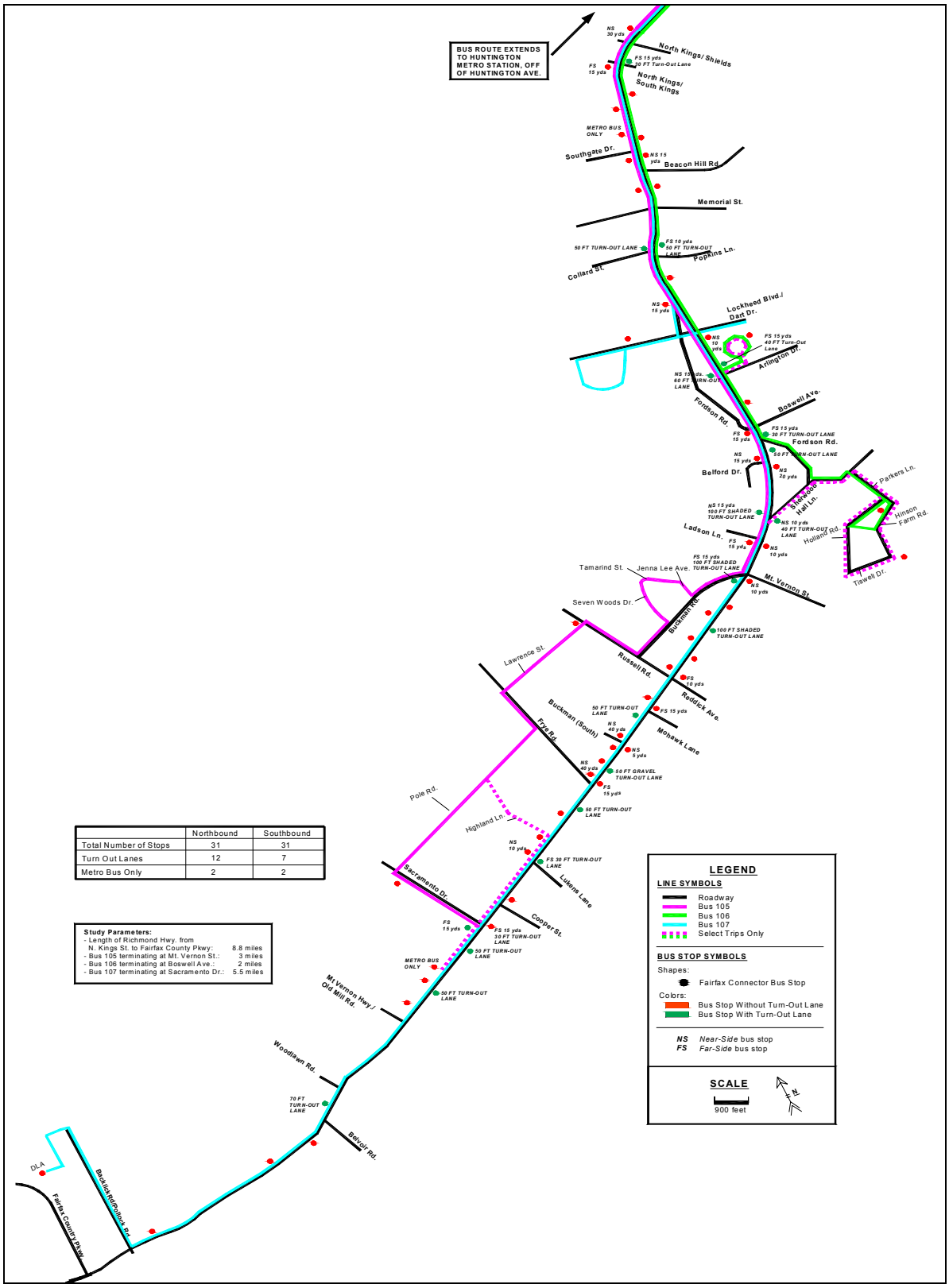


Figure 4. Field Details of U.S. 1 bus stops

5.3 Concept of U.S. 1 TSP

This section provides the perception of transit signal priority provided on U.S. 1 corridor. The concept encompasses logical and physical architecture of TSP as discussed in the following paragraphs.

5.3.1 Logical Architecture

For implementing any ITS technology, it is required to know the logical flow of information transfer at the macro level, the graphical presentation of which is called the logical architecture. Emergency vehicle preemption is often a part of this signal priority process. Therefore, in the logical architecture for TSP in Figure 5 transit signal priority and emergency vehicle preemption are shown.

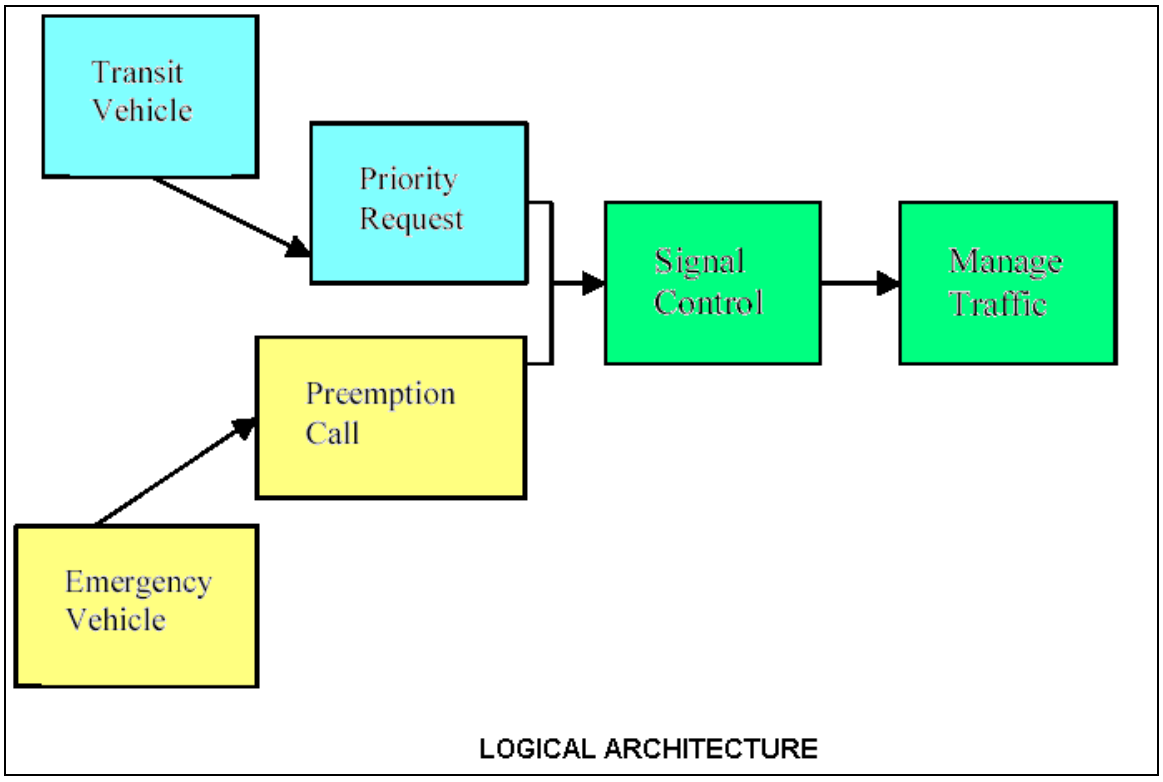


Figure 5. Logical Architecture

5.3.2 Physical Architecture

The physical architecture gives broader sense about the main systems involved in transit signal priority implementation. This can define roles and responsibilities for various stakeholders involved in particular ITS implementation. Standard ITS system architecture is comprised of four systems i.e. traveler, center, vehicle and roadside. These systems consist of a number of one or more components that are connected by a series of wire line and wireless communication systems (Chang, Collura, Dion, Rakha, Tignor, and Triantis, 2002). The primary sub-systems involved in transit signal priority technology are highlighted in Figure 6.

The center sub-systems are traffic management, transit management. They are responsible for deciding the priority strategies, the most appropriate detection technology, particular signal controller software, and finally purchasing and implementing the required equipments.

The vehicle subsystem is transit vehicle, and roadside subsystem is roadway (which contain traffic signals). With probable addition of other ITS technologies such as Automatic Vehicle Location (AVL) and Automatic Passenger Counter (APC) to this project, fleet management sub-system is also involved in this system architecture.

A study was done for three European cities - London, Turin and Gothenburg to link the transit priority at traffic signals within traffic responsive urban traffic control (UTC) systems with AVL and also includes the assessment of the potential for integration of TSP and UTC systems (Burton and Hounsell, 1993). A recent research paper (Hounsell, McLeod, and Shrestha, 2004) discusses several different system architectures for bus priority enhanced with AVL that are used in Europe.

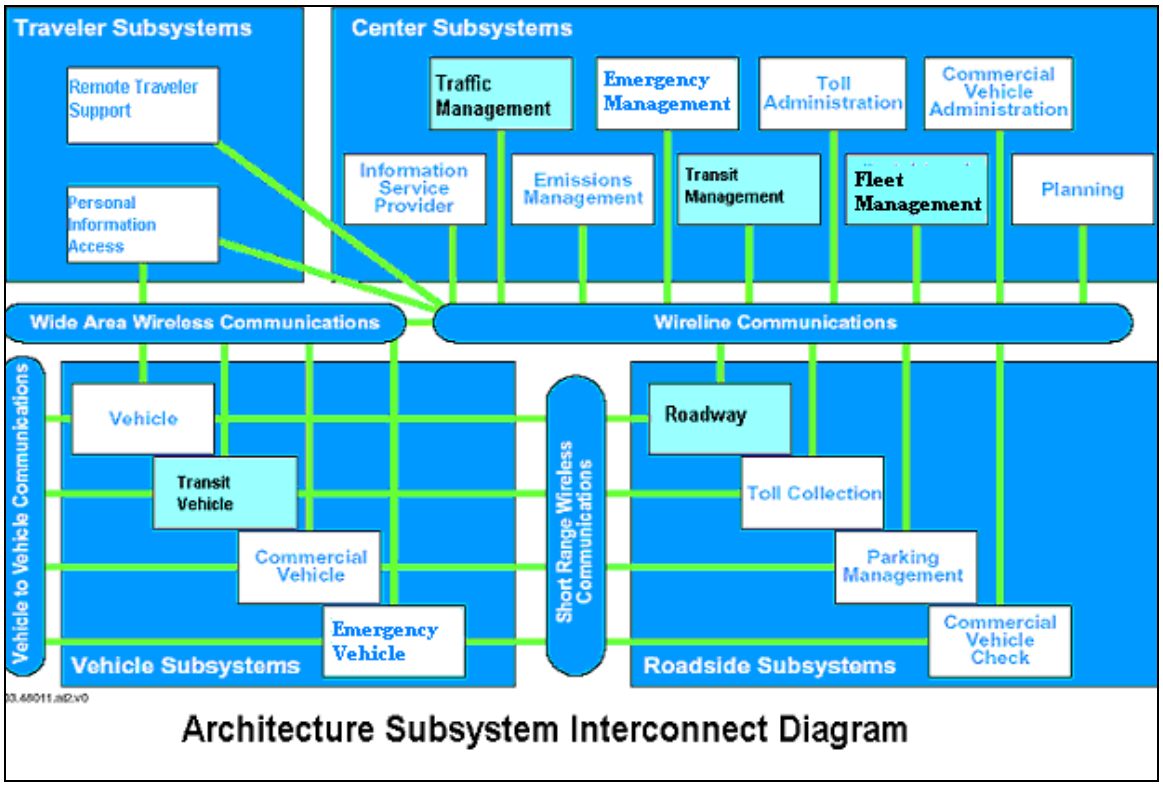


Figure 6. Physical Architecture of Transit Signal Priority Systems

5.3.3 Final System Architecture

Considering all of above factors and existence of emergency vehicle request and transit signal priority call, the system architecture shown in Figure 7 was considered for implementing this project. This shows information flow of the 3M Opticom detection technologies.

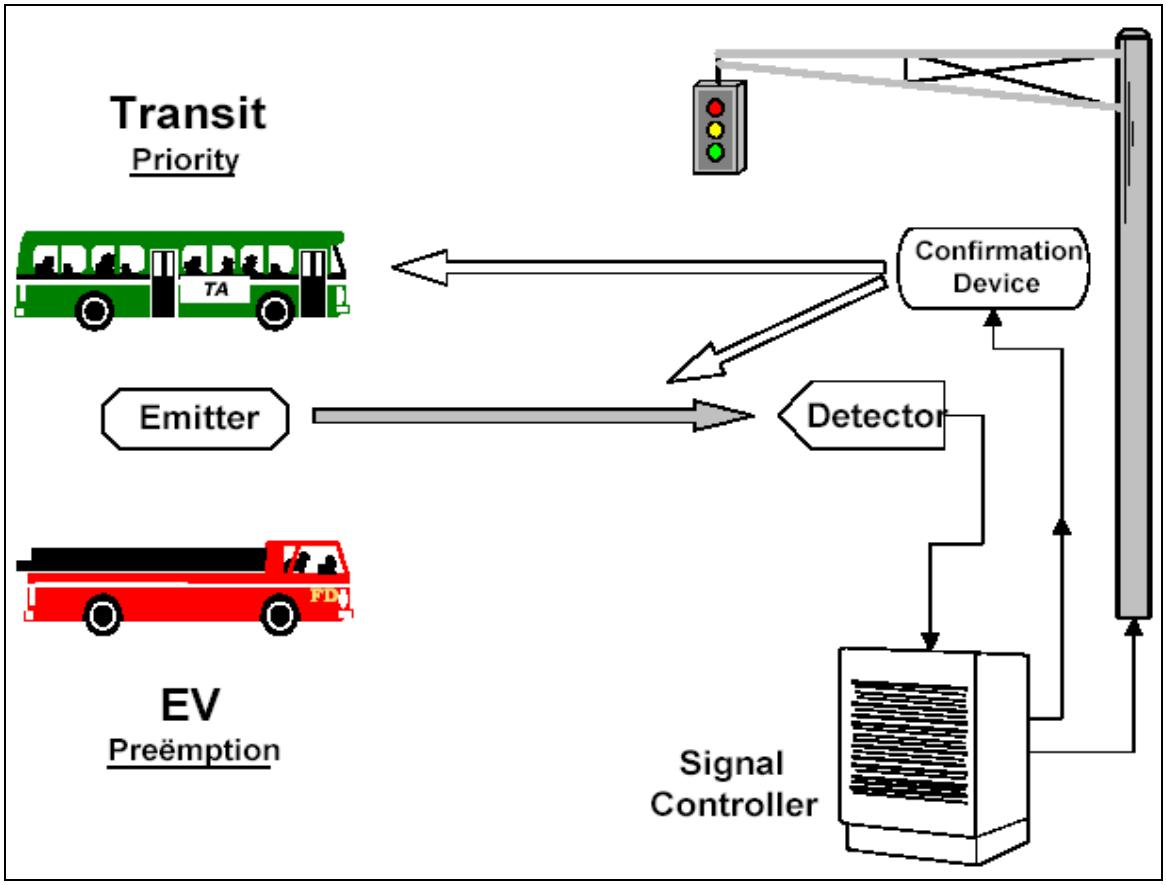


Figure 7. System Architecture for 3M Opticom Emitter Detection Systems

5.4 Implementation of U.S. 1 TSP

U.S. 1 bus priority is based on local detection of transit vehicle at every intersection. The detection is achieved through 3M Opticom emitter systems. The position of emitter on vehicle is as shown in Figure 8 and position of detector on signal head is kept as depicted in Figure 9.

Figure 8. Photographs to show 3M Opticom Emitters

Figure 9. 3M Detectors and Confirmation Light

CHAPTER 6: VISSIM Model For Extended Corridor

Based on previous studies it became clear that VISSIM, a stochastic microscopic simulation model is appropriate to use to model traffic flow characteristics as required in this study. Desired measures of effectiveness are provided as simulation results in VISSIM.

VISSIM was developed in Germany in research originating at the University of Karlsrhue, Karlsrhue, Germany. VISSIM is a German acronym for "traffic in towns – simulation". Two major components of the VISSIM model are the traffic simulator and signal state generator.

The traffic simulator uses car following and lane changing logic, which are based upon 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. 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.

Currently efforts are being made to make simulation software more users friendly; extending the usability of these simulation tools (Clark and Daigle, 1997). VISSIM 3.7 and more recent versions provide such facility i.e. NEMA signal controllers. These

signal controllers are user friendly and eliminate the use of vehicle-actuated programming (VAP) to some extent in designing traffic signal controls and provide TSP. Of course, for emulating some other advance features, VAP is inevitable. This research uses NEMA signal controller capabilities, for simulating TSP at all twenty-six signalized intersections.

"A companion effort is underway to create a standard "Traffic Software Data Dictionary" and a database to combine the disparate roadway definitions and terms into one cohesive structure to allow the exchange of data between the models and also ease the burden of generating the input data sets" (Clark and Daigle, 1997). Today, VISSIM 3.7 imports traffic data from SYNCHRO files in "Universal Traffic Data Format (UTDF)". In this research, the UTDF feature is used to prepare VISSIM network from SYNCHRO files provided by VDOT.

6.1 VISSIM Model Data

Table 12. Data resources

Data Elements	Data Source
Roadway Geometry	SYNCHRO file from VDOT
Traffic Characteristics	SYNCHRO file from VDOT and Previous Field Observations
Traffic Signal Control Information	SYNCHRO file from VDOT
Transit Network	Fairfax Connector Bus Schedules and Field Observations

Data resources for preparing the model are given as in Table 12. The major data requirements of the model are detailed below:

- Roadway Geometry: number of lanes, grades, reduced speed areas, pavement markings, detector locations, yield areas, stop signs, and parking areas.
- Traffic characteristics speed distributions, volumes, turning percentages, percentage of heavy vehicles, vehicle classifications, and acceleration/ deceleration distributions.
- Signal control Information: green times, clearance intervals, maximum and minimum green times, offsets, and permissive periods.

- Transit network includes routes, schedule, ridership levels, transit vehicle characteristics, and bus dwell times.

6.2 Network Modeling

Progression of the traffic on U.S. 1, at the signalized intersections in the morning peak period is from the south to the north. The performance of the network is important as more than 3000 non-transit vehicles and considerable amount of transit buses enter into the network in northbound direction.

U.S. 1 stretch of 8.8 miles from Fairfax County Parkway in south to North Kings Highway / Shields in north, is modeled for morning peak period. U.S. 1 transit network is more detailed for northbound direction for the reasons described above. Overall VISSIM Network is as shown in Figure 10.

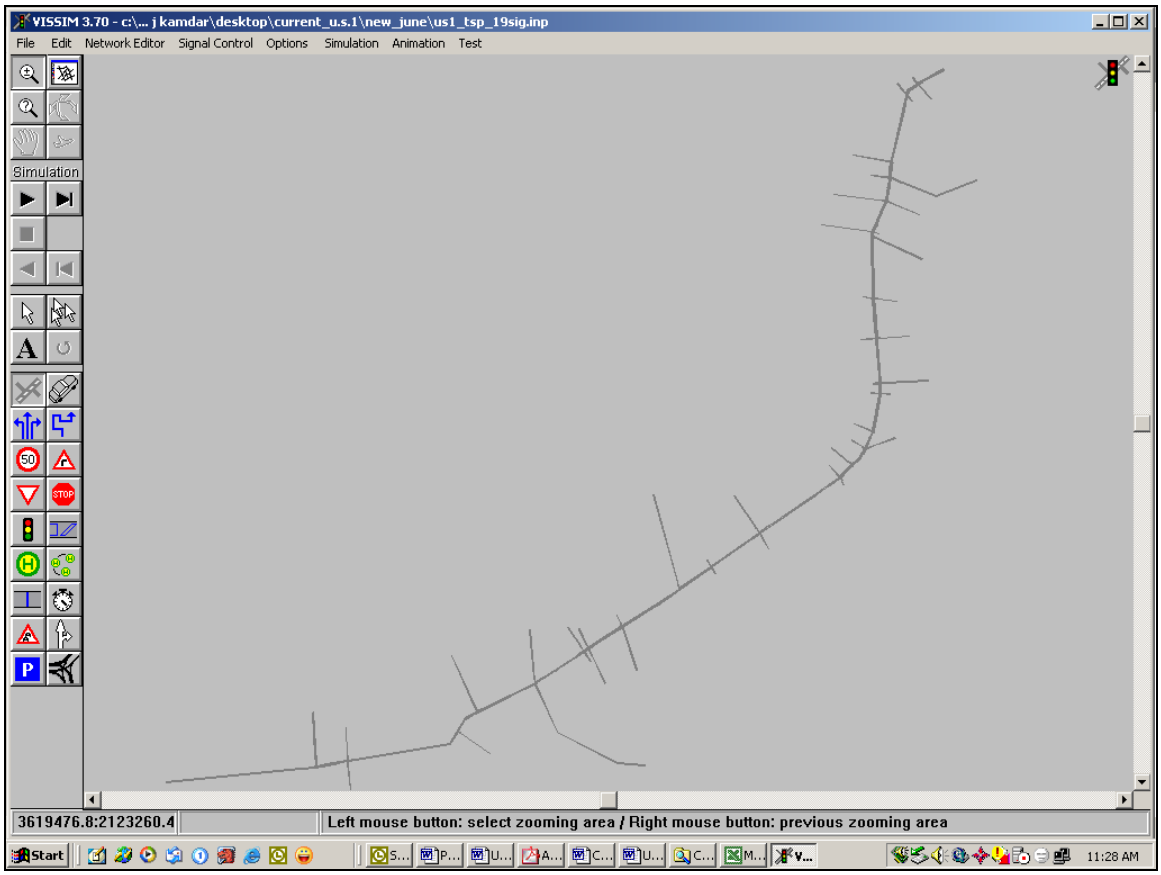


Figure 10. VISSIM Model

6.2.1 Universal Traffic Data Format

For this project Virginia Department of Transportation (VDOT) provided the traffic data through SYNCHRO files. SYNCHRO file contains the basic transportation network such as network geometry, traffic volumes, travel decisions, signal control timing and phasing information.

Usually the basic VISSIM network is prepared by using "*.bmp" or other image files as background. Then it is scaled and links and connectors are placed to create the transportation network, which is time consuming. For this research with limited time and considerably big network, new concept of importing the network through the UTDF was used in hope of saving time and avoiding duplicate work.

6.2.2 Network Import

In SYNCHRO 6.0 we can create 5 types of UTDF "*.dat" files named "layout.dat", "lane.dat", "volume.dat", "timing.dat", "phasing.dat", which are included in Appendix H**.** VISSIM 3.7 requires "movement.dat" file for intersections with diagonal legs and also when the number of legs are more than four. In case of U.S. 1 almost all of the intersections have legs that are diagonally placed and some of the intersections have legs more than four. In import process VISSIM started to give all sort of errors and the network was not getting imported. With the help of SYNCHRO and VISSIM technical help, "movement.dat" file was created and the SYNCHRO file was also modified in a way to overcome difficulties. The network geometries were modified such that the other traffic data would not be affected. But in the resulting network, the original cycle lengths and the phasing times of original SYNCHRO file were dissimilar. The other effects were the links were broken and the related vehicle routing decisions were lost. Some of the examples of these errors can be seen in Figure 11. All of these errors were fixed using the VISSIM manual, technical help, and authors engineering skills.

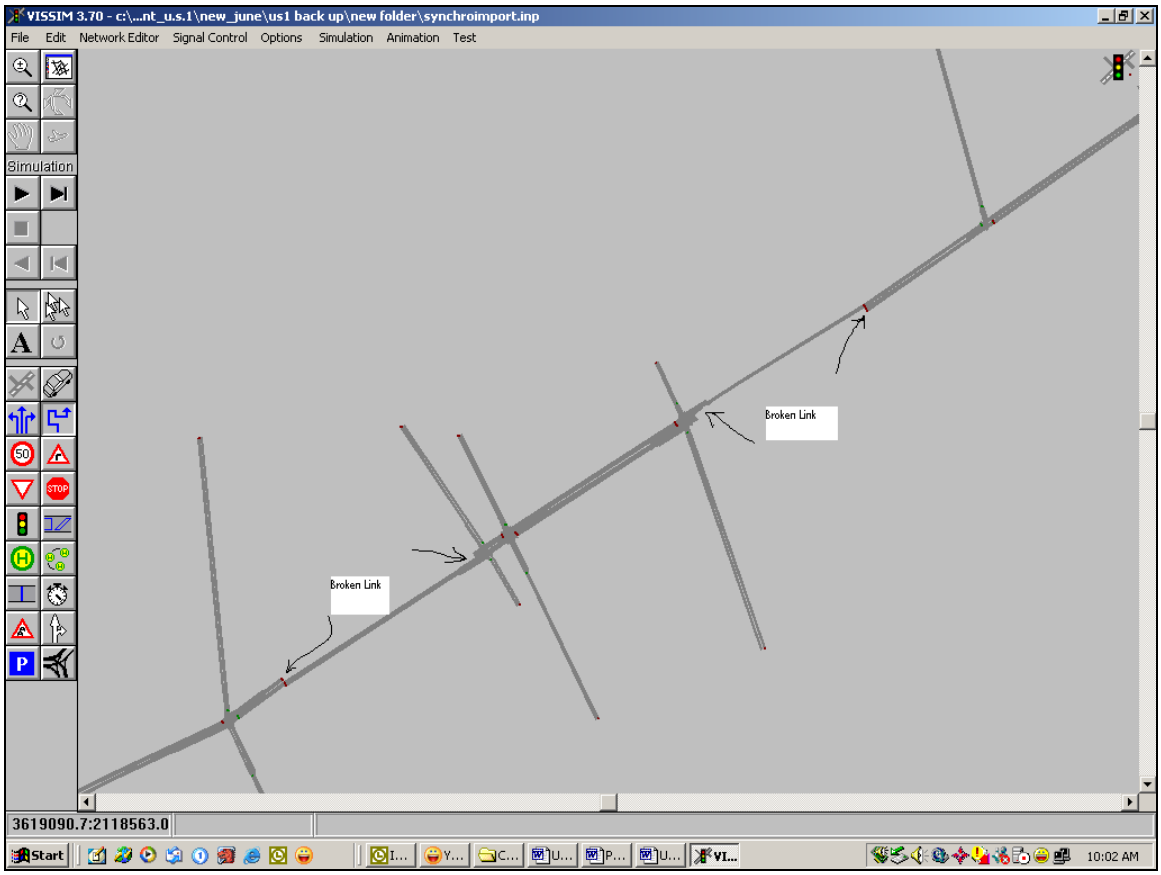


Figure 11. Examples of Errors in the Imported VISSIM Network

6.2.3 NEMA Signal Control Files and Signal Timing Plan

The signal controls, which exist in the field that regulate the signal timing and phasing plan were simulated using NEMA signal controllers.

General Signal Timing Plan Facts and Remedies:

1. The cycle lengths in the imported VISSIM network were different than found in the VDOT SYNCHRO file.
2. The zero point in SYNCHRO and VISSIM are different, so the offset values are different even though the resulting timing remains same. VISSIM default zero point is the start of green of the coordinated phase in the first ring of the ring barrier diagram in signal timing plans. SYNCHRO zero point is at the

start of green phases 1 and 6. As a result of this the imported network showed difficulties in representing these details.

3. As a result of the modification of the road direction or the intersection geometry there occurred change in the signal number, detector number, and signal phase number. This changed the phase sequence, the coordinated phase number and finally the transit signal priority phase.

The required NEMA signal control files were prepared accommodating all these facts and then also reflecting the field conditions. Following modifications were made to do this:

- The cycle lengths, the phase timing and the phase sequence for the VISSIM network were modified manually, as per the original SYNCHRO timing plan
- The SYNCHRO files modified to give the intersection offsets referenced to "Beginning of Green" for the coordinated phase in the first ring. These values were input manually in the NEMA files
- For most of the intersections, phase number two remained coordinated and the phase for transit signal priority in the northbound direction. For some of the signals, where the intersection geometry changed, phase number four became the coordinated and so it was made transit signal priority phase.

Most of the traffic signal controls were imported as NEMA files but some of the signal control files had to be created from scratch.

- In field and SYNCHRO file closely located intersection with different signal control numbers share the timing and phasing plan. But in import process, information for signal control with only the lower number gets imported.
- Two pairs of such intersections are there: (SC #10, SC #229) and (SC #23, SC #561). Signal control plans for SC #10 and SC #23 only, got imported.
- NEMA files for SC #229 and SC #561 were created using SYNCHRO file information and matching phases with imported signal control head, detector information.

Timing plans for all of the signals used in VISSIM NEMA control files, are shown in Appendix I. The related SYNCHRO files are provided in Appendix J.

6.3 Transit Signal Priority Logic

Following the system architecture, ten second green extension priority strategy was emulated by using the concept of Check-In and Check-Out detectors on network and as discussed in section 4.2.1.

Initially basic TSP emulator in NEMA controller was available so it was used for checking pilot project TSP results. But it had less functionality to limit the green extension of ten seconds. Later in this research, license for advance features of transit signal priority became available from PTV America. The signal controller logic was emulated using PEEK LMD9200 firmware running on a NEMA signal controller for each intersection. The PEEK LMD9200 was used to provide ten second green extensions if the transit service call is requested. The transit request was only served after fulfilling the emergency request call and pedestrian phase on signal control cycle.

There are some differences with regard to providing priority, between the field controller and PEEK LMD 9200. However, it was not found to be the critical issue because PEEK LMD 9200 was the controller with the least difference in providing priority compared to other available controllers. Snap shot of NEMA Controller - PEEK LMD9200 is shown in Figure 12.

In TSP implementation, the recovery time of signal control is very important to know. It is the time that the signal controller takes to transition back to its normal timing plan, after serving TSP call or preemption or time-of-day plan changes. PEEK uses the most common and the most efficient transition recovery method - SHORT WAY OFFSET SEEKING.

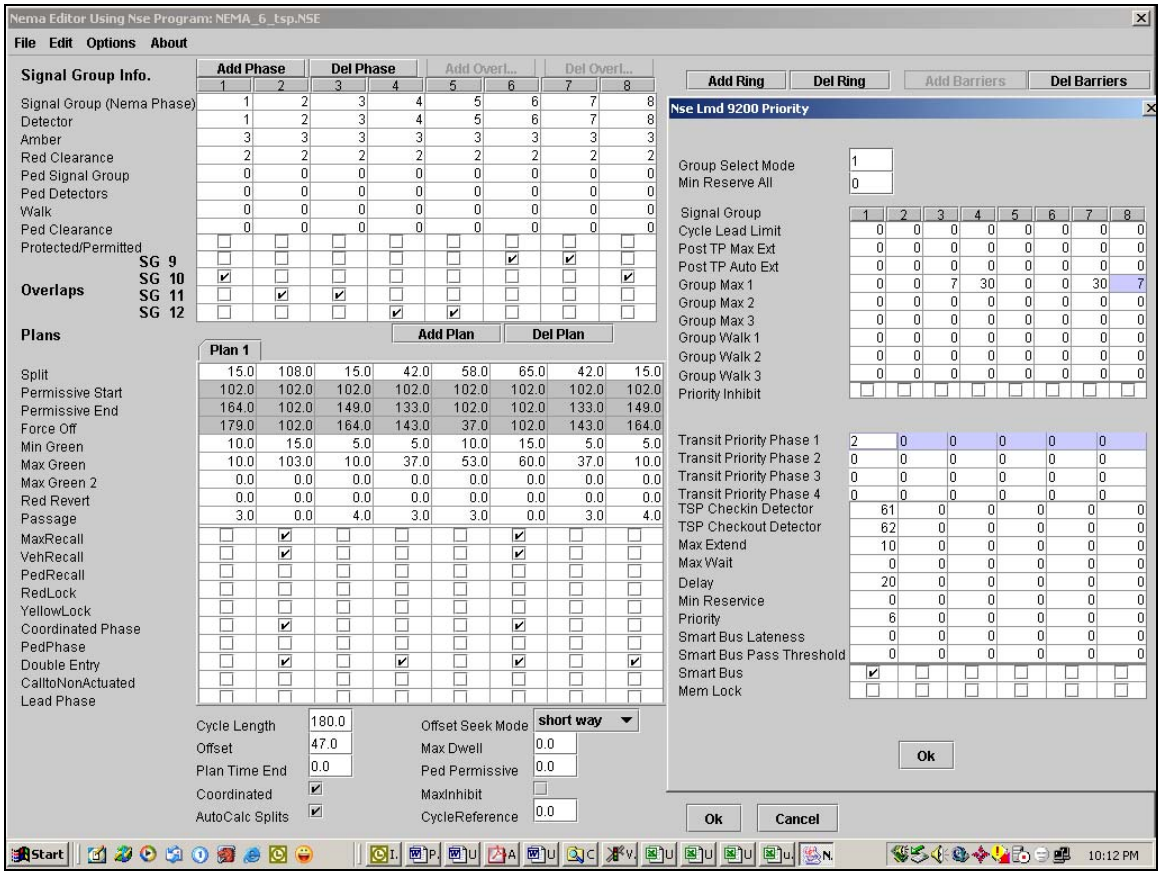


Figure 12. NEMA Controller - PEEK LMD9200

The main components used here are Group Select Mode, Group Max 1, Transit Priority Phase 1, Transit Checkin Detector, Transit Checkout Detector, Max Extend Delay, Priority and Mem Lock. Because of bug in the program (VISSIM 3.7 Technical Help), Smart Bus is checked here.

6.4 Calibration of Model

6.4.1 Traffic Network

The vehicular speeds in the network are resembled to the actual ones in the field, which was given through the SYNCHRO files.

Detection ranges of the 3M Opticom detectors that are employed in the field vary. So the detection points were assumed according to the roadway geometry and the check-in detectors were placed accordingly.

For near side bus stops, the check-in detectors needed to be placed after the bus stop is passed. By doing this the erroneous green extension and also the time wastage in passenger alighting was eliminated.

6.4.2 Transit Network

Network Transit Speed

Network transit speed was kept as 12.4 mph to 15.5 mph, similar to the field speed found from previous work done (Deshpande, Collura, Teodorovic, and Tignor, 2004).

Transit Routes

The transit network is calibrated according to the information given in Table 9, 10 and 11.

Bus stops

Bus stops are coded only for the northbound direction. Figure 13 shows how the on-street bus stops and bus stops on turn out bay are included on transit line in the VISSIM model.

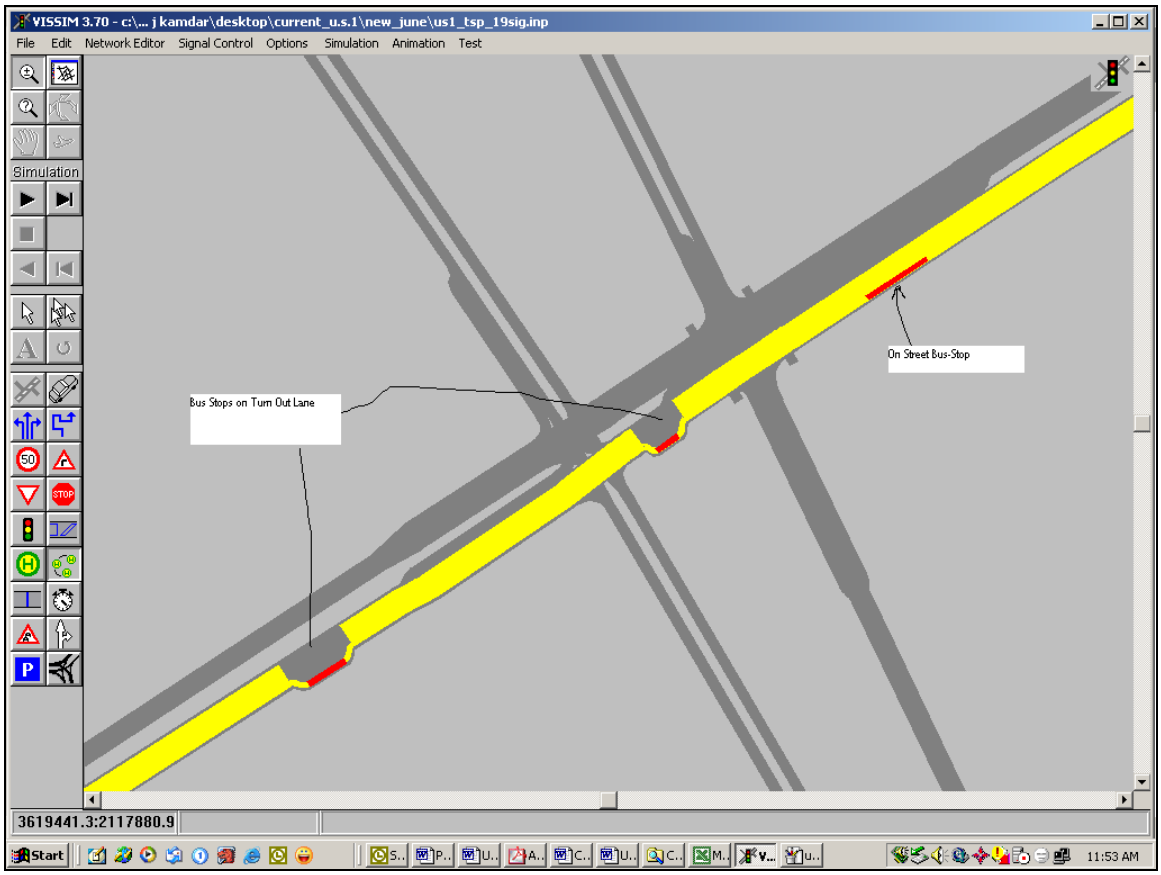


Figure 13. Bus stops on a Transit Line

Average bus occupancy from previous observations is 30 out of 50 total number of seats i.e. 60 percent, which was also used for this model.

6.5 Simulation Scenarios

The simulation was run mainly for two conditions: (1) With transit signal priority and (2) Without transit signal priority.

Different random number seeds were used to generate different traffic patterns for the network.

Table 13 details the Simulation scenarios.

Table 13. Simulation Scenarios

Distinguishing Characteristics of Simulation Runs		
Distinguishing Characteristics	**Possible Values**	**Number of Possible Values**
Priority Capability	Yes or No	2
Random Runs	3 Random Number Seeds -50, 100, 150	3
	Total Runs =	6

CHAPTER 7: RESULTS, CONCLUSIONS AND RECOMMENDATIONS

The simulation results of this research are presented in this chapter. Statistical tests were also run for the observation datasets and results of which are discussed here. Important conclusions will also be presented along with recommendations for future research.

Results

Bus Efficiency / Reduced transit travel Time

Average travel times for the buses along three different bus routes were calculated from three pairs of simulation runs. The travel time comparison between the buses without TSP and with TSP is as shown in Figure 14.

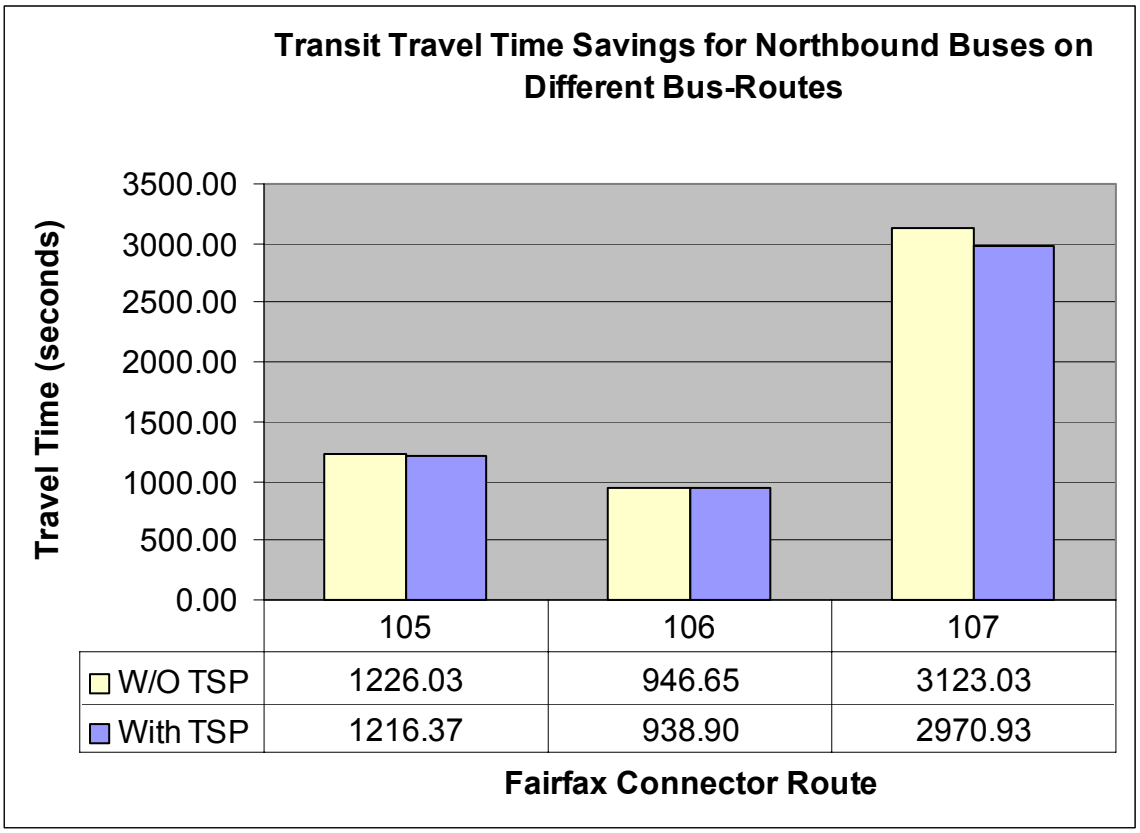


Figure 14. Comparison of Transit Travel Time

Comments:

- Simulation results show that TSP implementation can save transit travel time from 0.8% to 4%.
- The amount of the travel time saved on different bus routes depends upon
    1) Number of bus stops served
    2) Dwell time at bus stops

  Both were kept variable for different bus routes.
- The Kolmogorov-Smirnov (K-S) test showed the maximum difference between the cumulative distributions, absolute observed difference *D*, is 0.34. According to the formula: Dmax = 1.36 * SQRT ((n1 + n2) / (n1*n2)) at the 0.05 significance level, Dmax = 0.56. Here, *D* < Dmax. Therefore the engineer cannot find a statistically significant difference (at the 0.05 significance level) when the TSP is used and is not used.
- The number of data points was 12 in comparing the without TSP results to with TSP results for route 105 travel times. The datasets and the calculations are given in Appendix K.

Reduced Bus Control Delay

VISSIM records the waiting time for transit excluding the dwell time at transit stops. Author correlated the links on which the northbound buses stopped due to red light at the intersection. Average of these waiting times gives average delay in seconds per stop at intersection, for buses on the VISSIM network. The reduced intersection / control delay for buses due to the TSP implementation is shown in Figure 15.

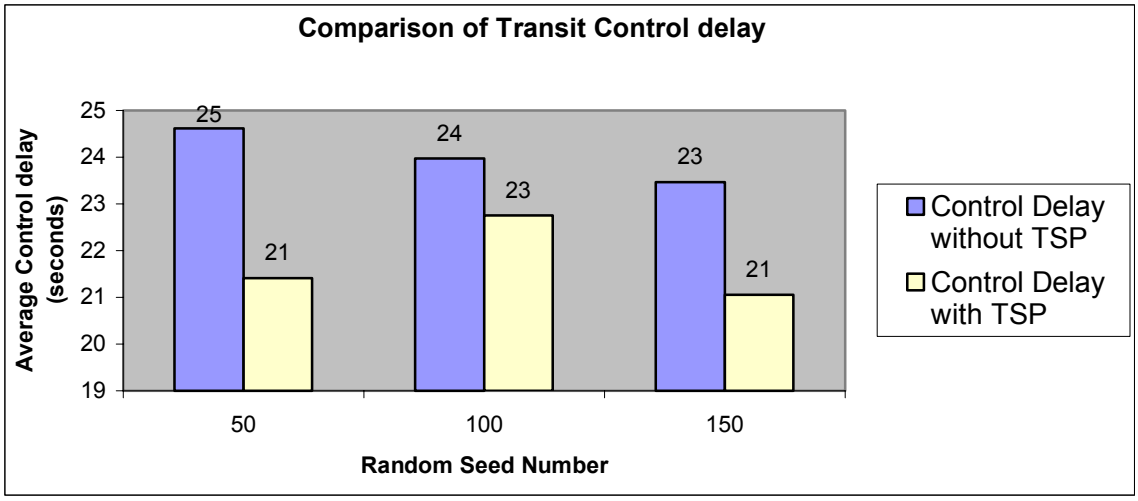


Figure 15. Reduced Bus Control Delay

Comments:

- In all of the simulation runs average control delay for transit buses with priority was found to be less than the average control delay for transit buses without priority.
- Simulation results suggest that the time saved because of reduced control delay varies between 5% to 16%
- The K-S test showed the maximum difference between the cumulative distributions, absolute observed difference *D*, is 0.19. According to the formula: Dmax at the 0.05 significance level, Dmax = 0.35. Here, $D < \text{Dmax}$. Therefore the engineer cannot find a statistically significant difference (at the 0.05 significance level) when the TSP is used and is not used.
- The number of data points was 31 in comparing the simulation run results of random seed 50. The datasets and the calculations are given in Appendix K.

Other Traffic Related Impacts

Impacts on queue length on the side streets are shown in Figure 16 and the data values are shown in Table 14. The number of observations was 44 instead of 26 x 2 = 52 because the U.S. 1 network contains many 3-legged intersections in which case one side street needs to be observed instead of two.

Comments:

- As shown in Figure 16 on majority of the side streets the queue length was found to be more in case TSP condition compared to without TSP condition. However, on some of the links the queue lengths were found to be less in case TSP condition compared to that of without TSP condition.
- Analysis of simulation results for queue length shows that there is no increase in average queue length on the side streets over the entire U.S. 1 corridor.
- Analysis of simulation results for queue length shows that there is increase of one foot in average maximum queue length on the side streets over the entire U.S. 1 corridor.
- Considering entire U.S. 1 corridor the adverse impact i.e. increase in total queue length, for all side street traffic occurred around 1.23% for with TSP implementation.
- The K-S test results are: the maximum difference between the cumulative distributions, absolute observed difference *D*, is 0.09 with a corresponding Dmax = 0.33. Here, $D < \text{Dmax}$. Therefore the engineer cannot find a statistically significant difference (at the 0.05 significance level) when the TSP is used and is not used.
- The number of data points used was 44. Average queue length results without TSP and with TSP conditions was compared. The datasets and the calculations are given in Appendix K.

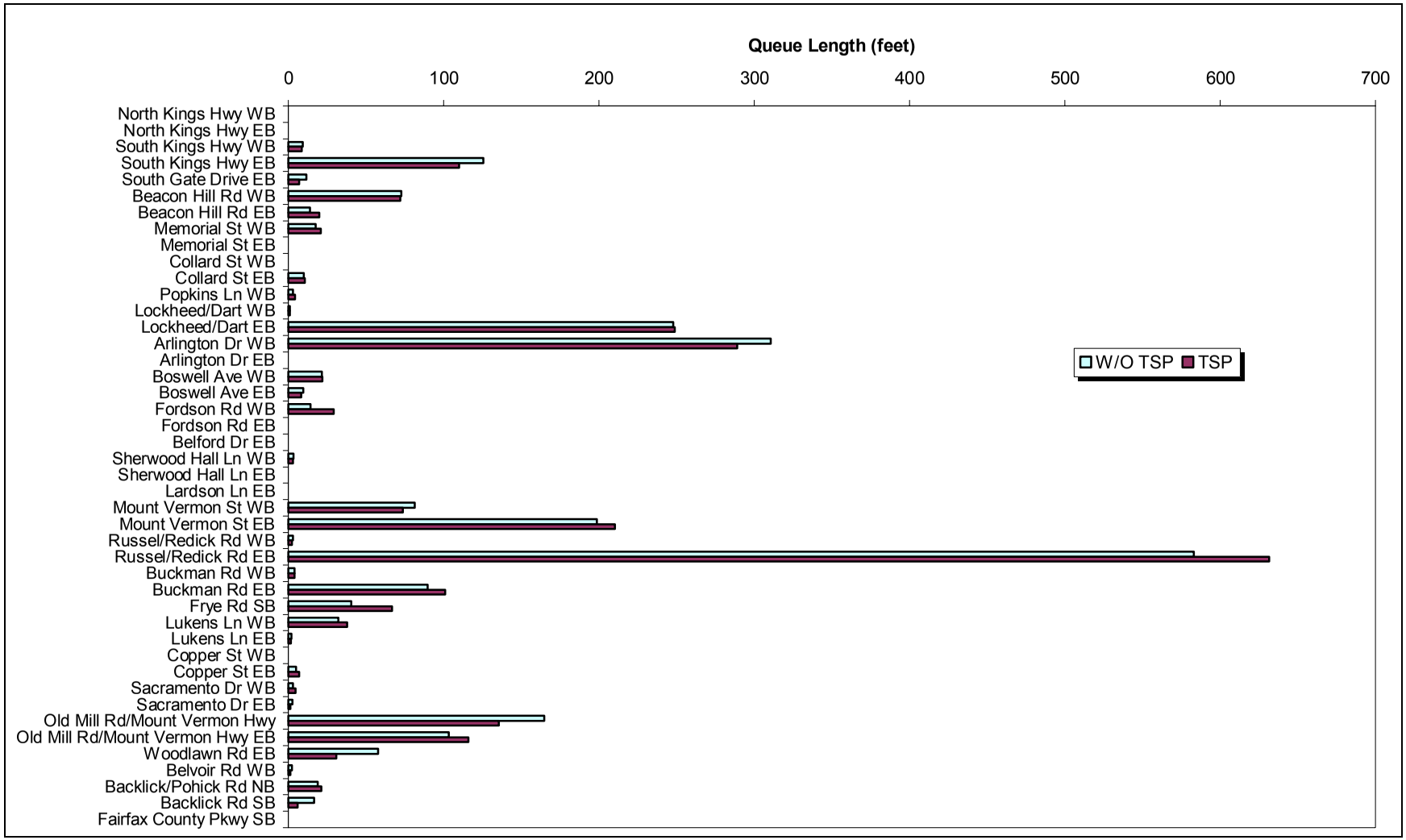


Figure 16. Side Street Queue Length Comparison

Table 14 Comparison of Queue Lengths (feet) On Side Street

Queue Counter	Name	Average Side Street Queue Length		Maximum Side Street Queue Length	
		W/O TSP	TSP	W/O TSP	TSP
1	North Kings Hwy WB	0	0	0.00	0.00
2	North Kings Hwy EB	0	0	40.89	43.19
3	South Kings Hwy WB	9	9	40.56	40.19
4	South Kings Hwy EB	126	110	359.83	343.94
6	South Gate Drive EB	12	7	99.22	66.69
7	Beacon Hill Rd WB	73	72	250.94	253.70
8	Beacon Hill Rd EB	14	20	80.11	95.65
9	Memorial St WB	18	21	77.28	81.09
10	Memorial St EB	0	0	13.33	14.56
11	Collard St WB	0	0	0.00	0.00
12	Collard St EB	10	11	60.17	59.56
13	Popkins Ln WB	3	4	44.78	67.65
15	Lockheed/Dart WB	1	1	7.00	8.22
16	Lockheed/Dart EB	248	249	330.11	333.48
17	Arlington Dr WB	311	289	817.28	805.98
18	Arlington Dr EB	0	0	6.06	3.85
19	Boswell Ave WB	22	22	110.67	119.78
20	Boswell Ave EB	10	8	43.94	45.48
21	Fordson Rd WB	14	29	101.61	152.81
22	Fordson Rd EB	0	0	0.00	0.00
24	Belford Dr EB	0	0	0.00	0.00
25	Sherwood Hall Ln WB	3	3	47.50	44.44
26	Sherwood Hall Ln EB	0	0	0.00	0.00
28	Lardson Ln EB	0	0	0.00	0.00
29	Mount Vermon St WB	81	74	204.56	210.96
30	Mount Vermon St EB	199	210	351.72	352.07
31	Russel/Redick Rd WB	3	2	33.22	27.41
32	Russel/Redick Rd EB	583	632	1056.50	1122.83
33	Buckman Rd WB	4	4	28.11	26.20
34	Buckman Rd EB	90	101	203.67	223.50
36	Frye Rd SB	40	67	301.89	361.30
37	Lukens Ln WB	32	38	134.28	148.59
38	Lukens Ln EB	2	2	28.56	21.52
39	Copper St WB	0	0	0.00	0.00
40	Copper St EB	5	7	68.89	87.19
41	Sacramento Dr WB	3	5	26.11	31.65
42	Sacramento Dr EB	3	1	46.00	26.28
43	Old Mill Rd/Mount Vermon Hwy WB	165	136	571.00	484.61
44	Old Mill Rd/Mount Vermon Hwy EB	103	116	261.50	321.72
46	Woodlawn Rd EB	58	31	319.61	225.37
47	Belvoir Rd WB	2	1	26.61	22.98
49	Backlick/Pohick Rd NB	19	21	132.39	143.91
50	Backlick Rd SB	17	6	72.78	33.93
52	Fairfax County Pkwy SB	0	0	3.94	3.04
	Average	**52**	**52**	**146**	**147**

Conclusions

An evaluation plan for TSP was developed (Chang, Collura, Dion, Rakha, Tignor, and Triantis, 2002) and implemented in a pilot project including six intersections on U.S. 1 (Deshpande, Collura, Teodorovic, and Tignor, 2004). In the research reported in this thesis the impacts of TSP on the entire U.S. 1 corridor including 26 intersections were examined.

Based on the simulation analysis, the following conclusions can be drawn:

- TSP implementation may be able to save transit travel time varying from 0.8% to 4%, which may improve the bus efficiency.
- Reduction in intersection delay for the transit vehicles varies from 5% to 16%; this suggests that with TSP implementation, there may be a reduction in transit control delay that may lead to an overall reduction in transit travel time; this tends to support the first two hypotheses.
- Total increase in maximum queue lengths, considering all side street traffic may be in the order of 1.23% with TSP implementation.
- The above conclusions are consistent with the results and conclusions reported in other TSP deployments studies (Soo, Collura, Hobeika, and Teodorovic, 2004).
- The travel time reduction can reduce the transit operating costs, which in turn can reduce recovery period for transit investments (Soo, Collura, Hobeika, and Teodorovic, 2004).

The above findings suggest that TSP is beneficial. In order to assess them statistical Kolmogorov-Smirnov tests were run for each of the performance measures, transit travel time, intersection delay, and side street queue lengths. For each of the performance measures between TSP and Non TSP results were non-significant at the 0.05 significance level. The author believes the main reason for this finding was the limited sample size of the simulation runs.

It was also concluded that when using VISSIM traffic-engineering software one should utilize a universal traffic data format to its optimum extent. This will make the simulation process faster, more effective and easier for traffic engineers and transportation planners.

Recommendations for Future Research

In this research, impacts of a ten second TSP green extension were evaluated along the entire U.S. 1 corridor for the Fairfax Connector bus routes. Future research possibilities are as:

- The results of the three performance measures was encouraging, however, it is recommended that more simulation runs be performed on the 10 second green extension strategy in the future given the statistical tests found no significant difference between the TSP and Non TSP system.
- Evaluating this network for different priority strategies such as early green, red truncation and queue jumps.
- Analyzing the impacts of using a dedicated lane for transit buses along with TSP.
- Integrating other ITS technologies such as GPS based Automatic Vehicle Location (AVL), Automatic Passenger Counters (APC), and some advanced transportation software for bus scheduling along with TSP.
- Modeling these ITS features, conditional TSP can be provided to the buses with a certain number of passengers or buses running late by some desired time.

References

1. Collura J., Rakha H., Gifford J. Guidelines for the Planning and Deployment of Emergency Vehicle Preemption and Transit Priority Strategies. *Transportation Research Board, National Research Council*, Washington, D.C., 2004.
2. Deshpande V., Collura, J., Teodorovic, D., and Tignor, S. Evaluating the Impacts of Transit Signal Priority Strategies on Traffic Flow Characteristics: Case Study along U.S. 1, Fairfax County, Virginia. *At the Crossroads: Integrating Mobility Safety and Security, ITS America 2004, 14th Annual Meeting and Exposition.* San Antonio, Texas. 26-28 April 2004, p. 23.
3. Awar T., Collura, J., Teodorovic, D., and Tignor, S. Evaluating the Impacts of Green Extension Priority Strategies on U.S. 1, Fairfax County, Virginia, Master's Project, Virginia Polytechnic Institute and State University, 2004. Won Essay Competition, *At the Crossroads: Integrating Mobility Safety and Security, ITS America 2004, 14th Annual Meeting and Exposition.* San Antonio, Texas. 26-28 April 2004.
4. Soo, H., Collura, J., Hobeika, A., and Teodorovic, D. Evaluating the Impacts of Advanced Traffic Signal Control Systems: The Effect of Transit Signal Priority Strategies on Transit Operating Costs. *At the Crossroads: Integrating Mobility Safety and Security, ITS America 2004, 14th Annual Meeting and Exposition.* San Antonio, Texas. 26-28 April 2004, p. 39.
5. Hongchao Liu, Meng Li, Alexander Skabardonis, Optimal Detector Location for Bus Signal Priority. November 2003. *Transportation Research Record*, No. 1867, January 2004, pp. 144-150.
6. Ngan, V., Sayed, T., and Abdelfatah, A. Impacts of Various Traffic Parameters on Transit Signal Priority Effectiveness. *Journal of Public Transportation*, Vol. 7, No. 3, January 2004, pp. 71-93.
7. City of Portland, Oregon, Office of Transportation, *Transit Preferential Streets Program Final Report*, July 1997.

8. Transportation Management & Design, Inc, *Los Angeles Metro Rapid Demonstration Program, July 2001*, http://www.fta.dot.gov/brt/lamrdp. Accessed July 2003.
9. Chang J., Collura, J., Dion, F., Rakha, H., Tignor, S., Triantis, K., Evaluation of Service Reliability Impacts of Traffic Signal Priority Strategies for Bus Transit, Dissertation, Virginia Polytechnic and State University, May 2002.
10. Choa, F., Milam, R., Stanek, D., CORSIM, PARAMICS, and VISSIM: what the Manuals never told you. *ITE Conference*, 2002. http://www.fehrandpeers.com/Papers/corsim_paramics_vissim.pdf
11. PTV America. *VISSIM Users Manual - Version 3.7*, 2004.
12. PTV America: NEMA capability http://www.english.ptv.de/cgi-bin/traffic/traf_vissim.pl
13. 3M Corporation, Opticom informational material http://products3.3m.com/catalog/us/en001/safety/traffic_control/node_GSBNDBN463be/root_GST1T4S9TCgv/vroot_1PGXVVLN9Xge/gvel_C293P3NGDWgl/theme_us_trafficcontrol_3_0/command_AbcPageHandler/output_html
14. Virginia Department of Transportation *US 1 Transit Service Improvements* CONSTRAINED LONG RANGE PLAN (CLRP), March 17, 2003, http://www.mwcog.org/transportation/activities/clrp/descriptions/study-va-18.pdf. Accessed March 2004.
15. Commuter News: Metro bus service along U.S. Route 1 to be restructured Public hearings scheduled for February, February 2, 2004, http://www.commuterpage.com/cnews/column.cfm?ID=4333. Accessed March 2004.
16. Moen B, Fitts J, Carter D., Ouyang Y., A Comparison of the VISSIM model to Other Widely Used Traffic Simulation and Analysis Programs. *ITE 2000 Annual Meeting. Institute of Transportation Engineers*, Nashville, Tennessee, 2000.
17. Intelligent Transportation Society America, *An Overview of Transit Signal Priority Final Draft,* July 11, 2002. http://www.itsa.org/resources.nsf/Files/Transit_Signal_Priority/$file/Transit_Signal_Priority.pdf

18. Gifford, J., Pelletiere D., Collura J., A Study to Examine the Use of Signal Preemption and Other Priority Strategies along Signalized Intersections in the Washington, D.C. Area, *Task 1 Technical Report on Stakeholder Requirements*. October 2002.
19. Gifford, J., Pelletiere, D., and Collura, J., An Analysis of the Issues, Concerns, Needs and Requirements Associated with Traffic Signal Preemption and Priority in the Washington D.C. Region, ITS America. Meeting (11th: 2001: Miami Beach, Fla.). *ITS connecting the Americas: ITS 2001: Proceedings*. 2001, 19p.
20. Fujimoto, R. and Leonard, J., Grand Challenges in Modeling and Simulating Urban Transportation Systems, *First International Conference on Grand Challenges for Modeling and Simulation 2002*, http://www.thesimguy.com/GC/papers/WMC02/G090_FUJIMOTO.pdf, Accessed April 24, 2004.
21. Garber, N. and Hoel, L., *Traffic and Highway Engineering.* Brooks/ Cole publishers, 3rd edition, 2002.
22. Zhang, Y., An Evaluation of Transit Signal Priority and SCOOT Adaptive Signal Control, Master's thesis, Virginia Polytechnic Institute and State University, May 2001
23. Collura, J., Chang, J., Willhaus, E.W., and Gifford, J.L., Traffic Signal Preemption and Priority: Technologies, Past Deployments, and System Requirements, *Conference Proceedings of the ITS America Eleventh Annual Meeting and Exposition*, Miami Beach, Florida, June 2001.
24. Clark, J., Daigle, G., The Importance of Simulation Techniques In Its Research and Analysis, *Proceedings of the 1997 Winter Simulation Conference* ed. S. Andradottir, K.J. Healy, D.H. Withers, and B.L. Nelson, 1997.
25. Waterson, B.J., Rajbhandari, B., Hounsell, N.B., Simulating the impacts of strong bus priority measures*, Journal of Transportation Engineering-ASCE.* Vol. 129, No. 6, November-December 2003, pp. 642-647.
26. Janos, M., Furth, P.G., Bus priority with highly interruptible traffic signal control - Simulation of San Juan's Avenida Ponce de Leon*. Transportation Research Record*, No. 1811, 2002, pp. 157-165.

27. Chin, H.C., Cheu, R.L., and Chandrasekar, P. Application of NETSIM in modeling B-signals, *Journal Of Advanced Transportation,* Vol. 36, No. 2, Spring-Summer 2002, pp. 211-224.
28. Furth, P.G. and Muller, T.H.J. Conditional bus priority at signalized intersections - Better service with less traffic disruption. *Transportation Research Record*, No. 1731, 2000, pp. 23-30.
29. Balke, K.N., Dudek, C.L., and Urbanik T. Development and evaluation of intelligent bus priority concept. *Transportation Research Record,* No. 1727, 2000, pp. 12-19.
30. Viegas, J., and Lu, B.C., Widening the scope for bus priority with intermittent bus lanes. *Transportation Planning And Technology,* Vol. 24, No. 2, 2001, pp. 87-110.
31. Wu, J.P., and Hounsell, N., Bus priority using pre-signals. *Transportation Research Part A-Policy and Practice*, Vol. 32, No. 8, NOV 1998, pp. 563-583.
32. Crabtree, M.R. and Vincent, R.A. Bus priority in MOVA. *Road Transport Information and Control, 1998. 9th International Conference* on (Conf. Publ. No. 454), 21-23 April 1998, pp. 85 – 89.
33. Garcia, M. and Yamamoto, K. Busways and bus lanes in Brazil and Japan. *Vehicle Navigation and Information Systems Conference*, 1994. Proceedings. 1994, 31 August-2 September 1994, pp.689 – 694.
34. Gillam, W.J. and Wright, D.A. An innovative approach to real-time bus information and signal priority. *Road Transport Information and Control, 2000. Tenth International Conference* (Conf. Publ. No. 472), 4-6 April 2000, pp.205 – 208.
35. Hounsell, N.B. Active bus priority at traffic signals. *UK Developments in Road Traffic Signaling, IEE Colloquium*. 5 May 1988, pp.4/1 - 4/5.
36. Shuyan H., Zhiheng L., and Deyun X. A research on strategy of bus priority. *Intelligent Transportation Systems, 2003. Proceedings. 2003 IEEE*, Volume. 2, 12-15 October 2003, pp.1324 – 1328.

37. Burton, R., and Hounsell, N. Bus priority and UTC systems: the PROMPT project. *Vehicle Navigation and Information Systems Conference, 1993, Proceedings of the IEEE-IEE*, 12-15 October 1993, pp.602 – 605.
38. Hounsell, N.B., McLeod, F.N., Gardner, K., Head, J.R. and Cook, D. Headway-based bus priority in London using AVL: first results. *Road Transport Information and Control, 2000. Tenth International Conference* (Conf. Publ. No. 472), 4-6 April 2000, pp.218 – 222.
39. Lu, B. and Viegas, J. Bus management with improved passenger situations. *Intelligent Transportation Systems, 2003. Proceedings. 2003 IEEE*, Vol. 1, October 2003, pp.797 – 801.
40. Hounsell, N.B., McLeod, F.N., and Shrestha, B.P. Bus priority at traffic signals: investigating the options. *Road Transport Information and Control, 2004. RTIC 2004. 12th IEE International Conference*, 2004, pp.287 – 294.
41. Purdie, H.M.G. A "biased" view from Glasgow [urban traffic control]. *Road Transport Information and Control, 2002. Eleventh International Conference* (Conf. Publ. No. 486), 19-21 March 2002, pp.108 – 113.
42. Jones, S. Creating the Superbus with ITS-experiences in Leeds. Using ITS in Public Transport and in Emergency Services (Ref. No. 1998/524), *IEE Seminar,* 4 December 1998, pp.3/1 - 3/3.
43. Routledge, I.W. and Smith, M.J. Management of traffic using controls and other measures: MUSIC. *Transport Telematics in the Fourth Framework (Digest No: 1996/070), IEE Colloquium*, 26 March 1996, pp.2/1 - 2/5.

Appendix A: Transit Signal Priority Results

Table #1 Previous Transit Signal Priority Impacts

Strategy	Deployment	Simulation
Signal Optimization	2% - 5% [1][2][3]	None
Green Extension Only	0% - 9.7% [2][3][4]	0% - 6% [4][15][16][17][18]
Red Truncation Only	None	1% - 10.6% [18]
GE + RT	1.4% - 20% [1][2][3][4][5][6][7][8][9]	1.6% - 14.2% [4][18]
GE + RT + Queue Jump	0% - 18% [10][11][12]	None
Combinations	1.8% - 28% [3][7][11][13][14]	2.7% - 17.6% [18][19]

Appendix B: Detection Technologies

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 interjurisdict ional deployment.	Does need some audible signal form the vehicle. Susceptible to false alarms.	Conformati on 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 modification s 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.	Predetermination 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.	

Appendix C: Evaluation Measures

Table 1 Evaluation 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

Appendix D: U.S. 1 Pilot Project Features

Table #1 List of Intersections for Pilot Project

1	Popkins Lane @ U.S. 1 and Collard Streets @ U.S. 1
2	Memorial Drive @ U.S. 1
3	Beacon Hill Road @ U.S. 1
4	Southgate Drive @ U.S. 1
5	South Kings Highway @ U.S. 1
6	North Kings Highway/ Shields Avenue @ U.S. 1.

Note: Popkins Lane @ U.S. 1 and Collard Streets @ U.S. 1 are very close and same signal control works for both, so we'll consider them as one intersection

Table #2 the data requirements for the model and its sources are provided below:

Data Requirements	Data Sources
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 Buses & Field Observations

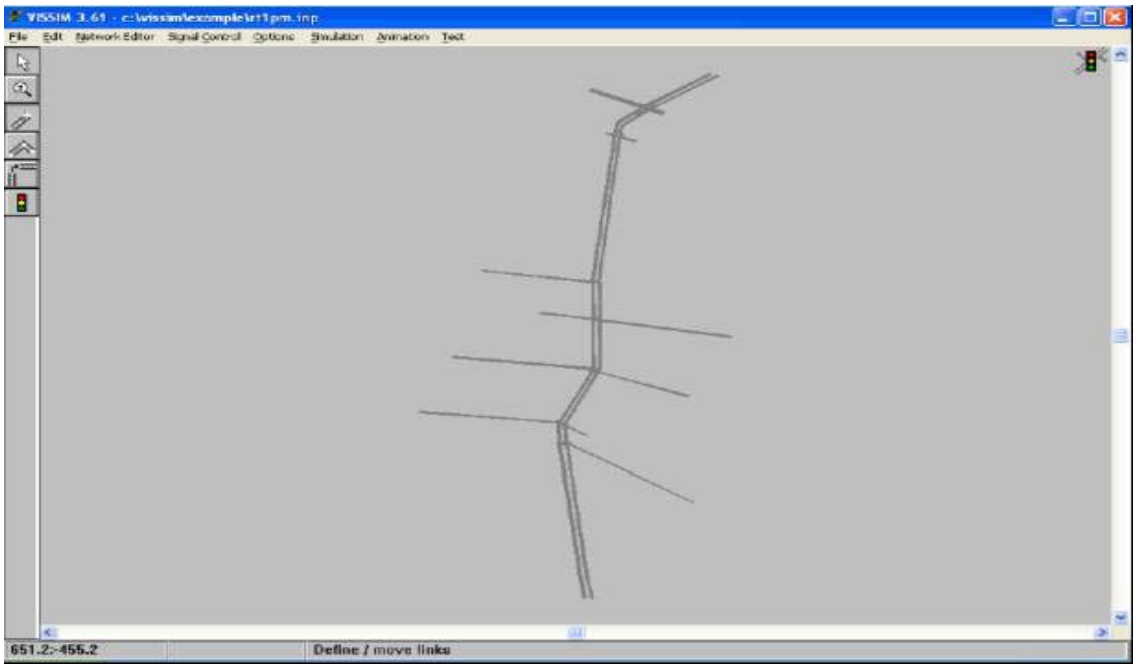
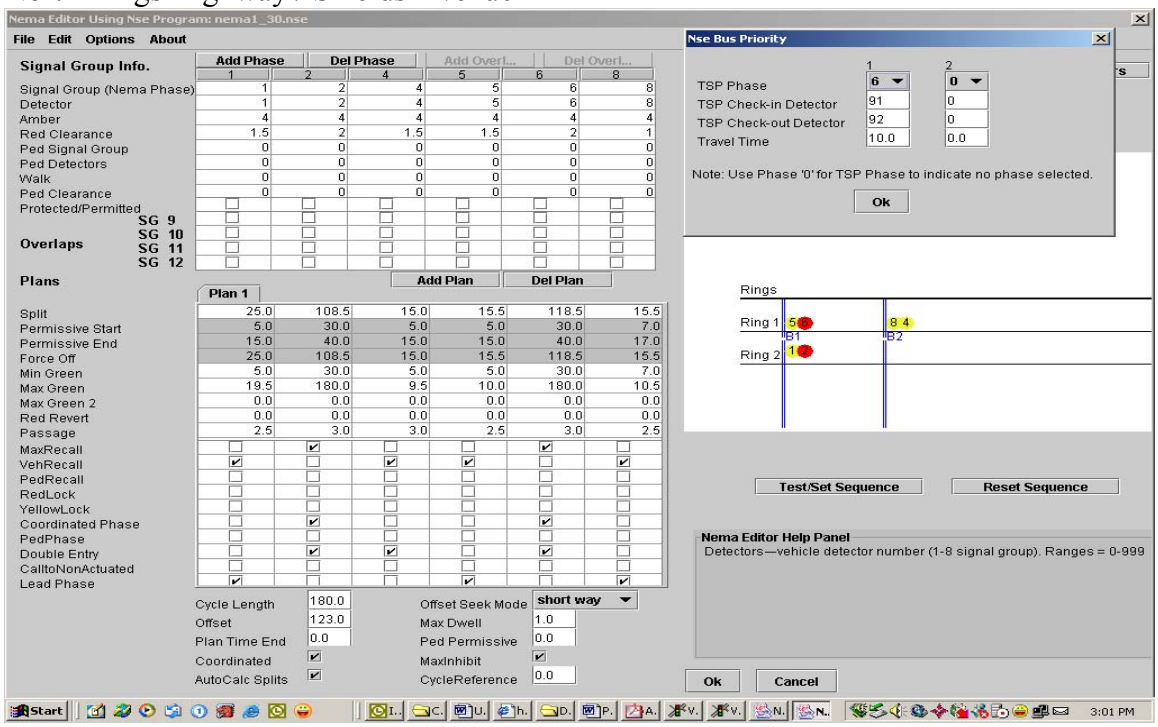


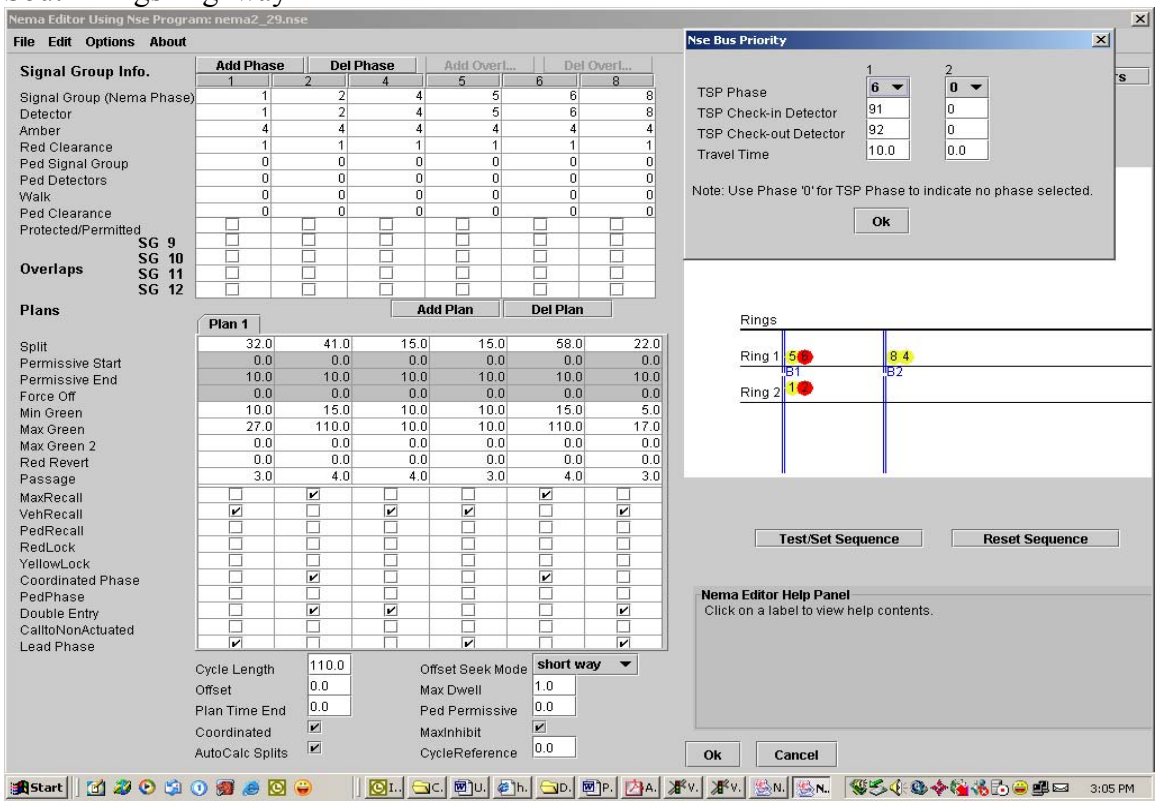
Figure 1. VISSIM Model for U.S. 1 pilot Project

Appendix E: NEMA Control Files for the Pilot Project

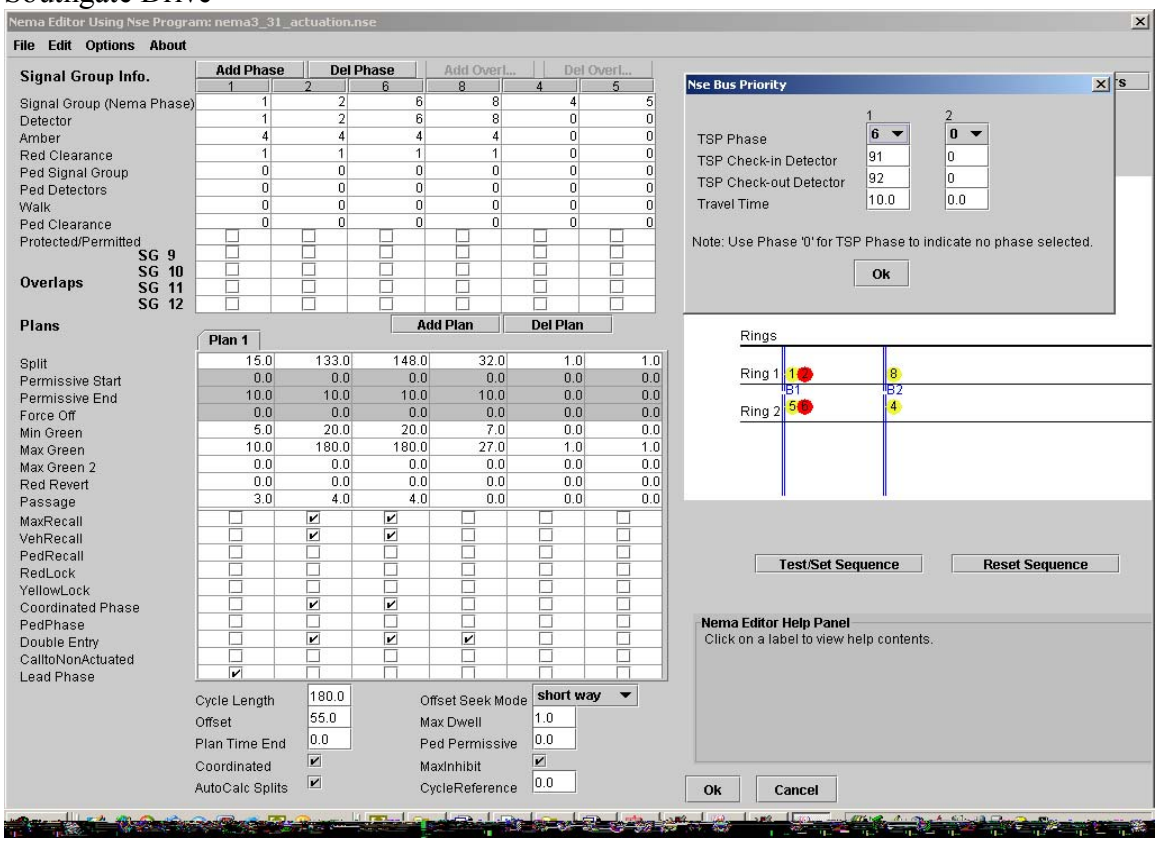
North Kings Highway / Shields Avenue



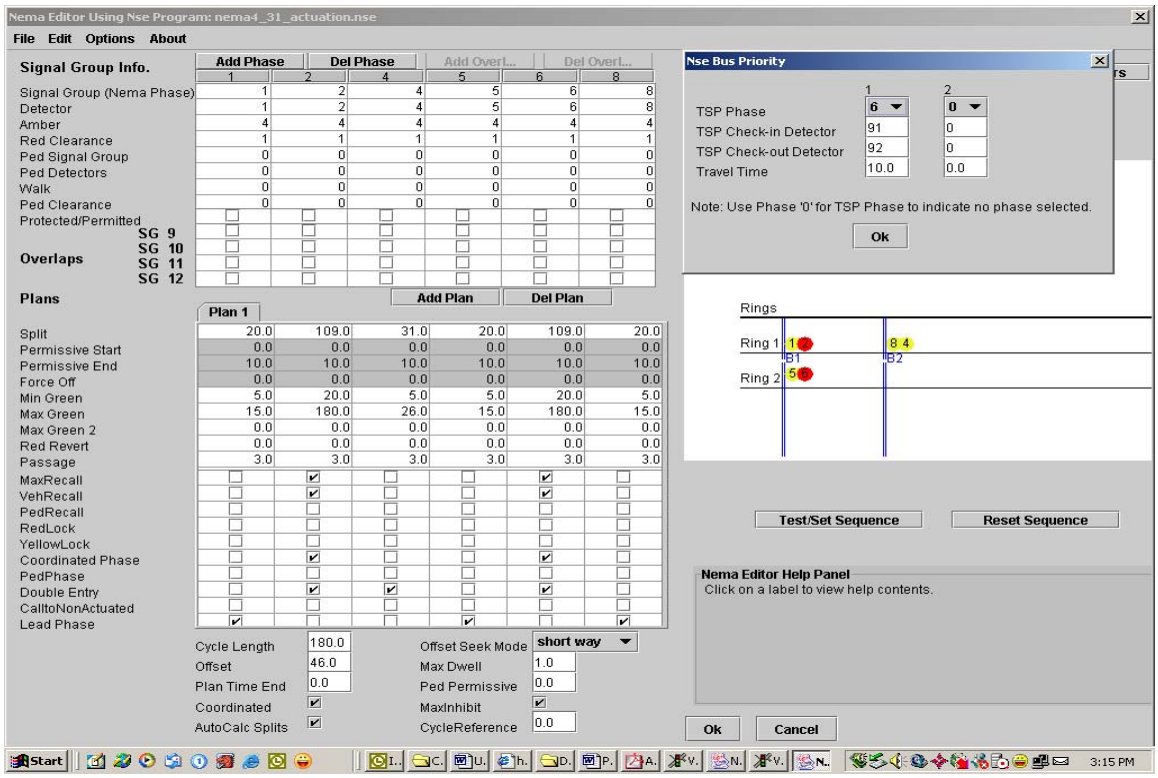
South Kings Highway



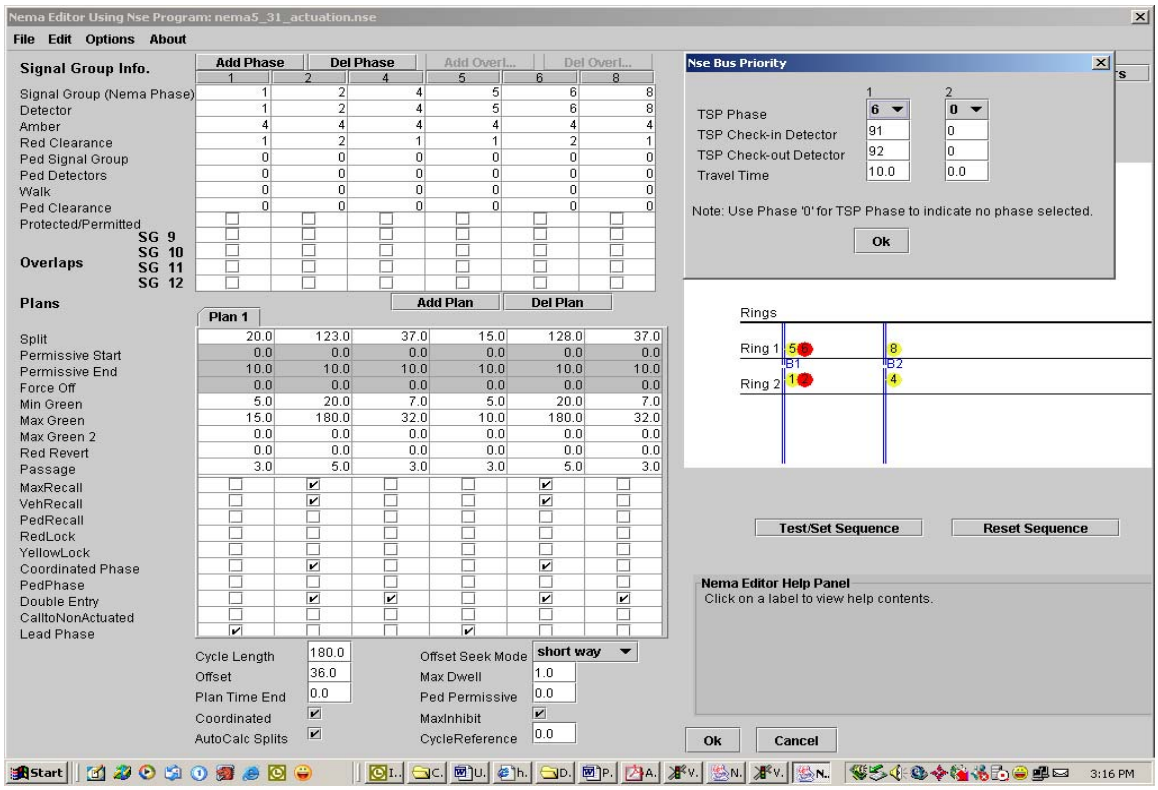
Southgate Drive



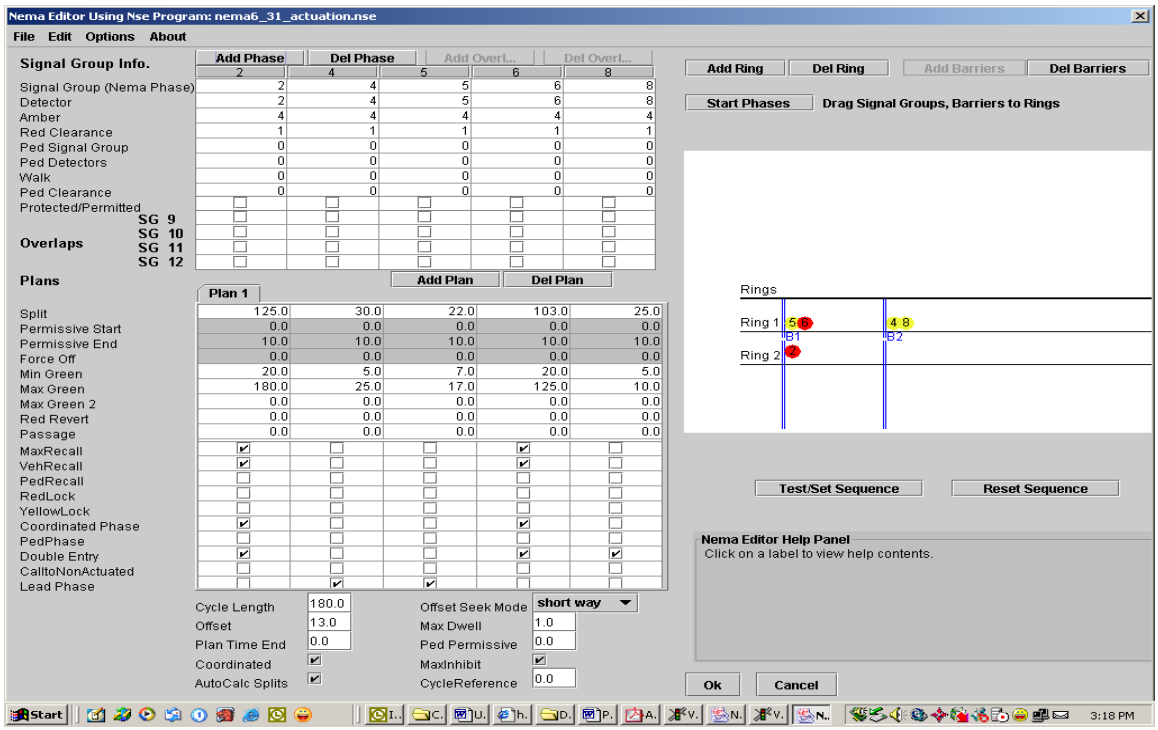
Beacon Hill Road



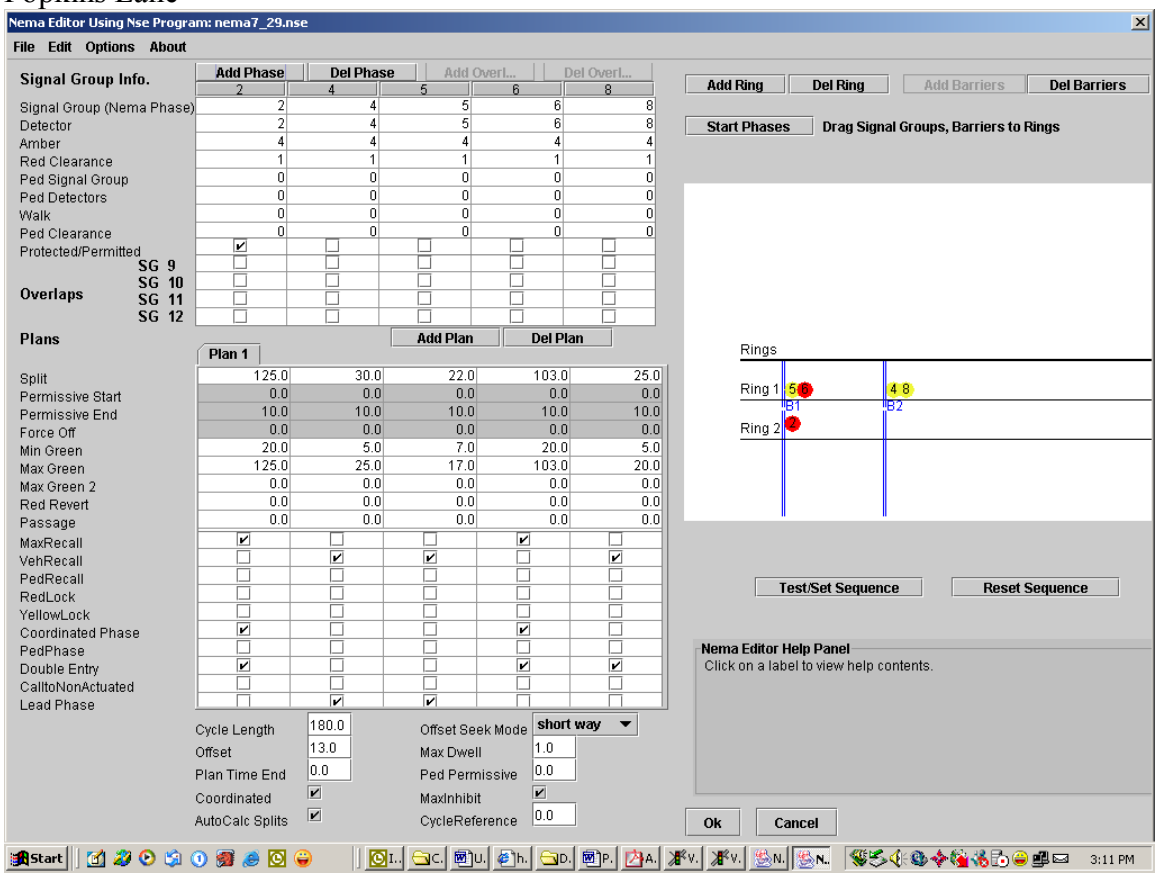
Memorial Street



Collard



Popkins Lane



Appendix F: Signal Timing Plans for U.S. 1 Pilot Project

Phasings

5: Richmond Hwy & Shields Ave 1/29/2003

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)	25.0	118.5	15.0	108.5	31.0	31.0	31.0	15.5	15.5
Total Split (%)	14%	66%	8%	60%	17%	17%	17%	9%	9%
Maximum Green (s)	19.5	112.5	9.5	102.5	26.0	26.0	26.0	10.0	10.0
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)	.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)	11.0	115.6	7.5	108.1	29.0	29.0	29.0	7.9	7.9
90th %ile Term Code	Gap	Coord	Gap	Coord	Max	Max	Max	Gap	Gap
70th %ile Green (s)	11.0	134.0	8.5	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)	11.5	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)	11.1	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)	3.9	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

Phasings

6: Richmond Hwy & S Kings Hwy 1/29/2003

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)	.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	5.8	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

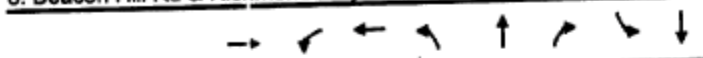
Actuated Cycle Length: 180

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)	11.5	24.7	24.7	8.9	108.8	24.7	15.0	114.6
70th %ile Term Code	Gap	Gap	Gap	Gap	Coord	Gap	Max	Coord
50th %ile Green (s)	10.3	21.0	21.0	7.8	114.5	21.0	14.2	120.6
50th %ile Term Code	Gap	Gap	Gap	Gap	Coord	Gap	Gap	Coord
30th %ile Green (s)	8.1	17.6	17.6	0.0	120.6	17.6	12.5	138.3
30th %ile Term Code	Gap	Gap	Gap	Skip	Coord	Gap	Gap	Coord
10th %ile Green (s)	7.4	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

229: Collard St & Richmond Hwy 1/29/2003

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

Phasings

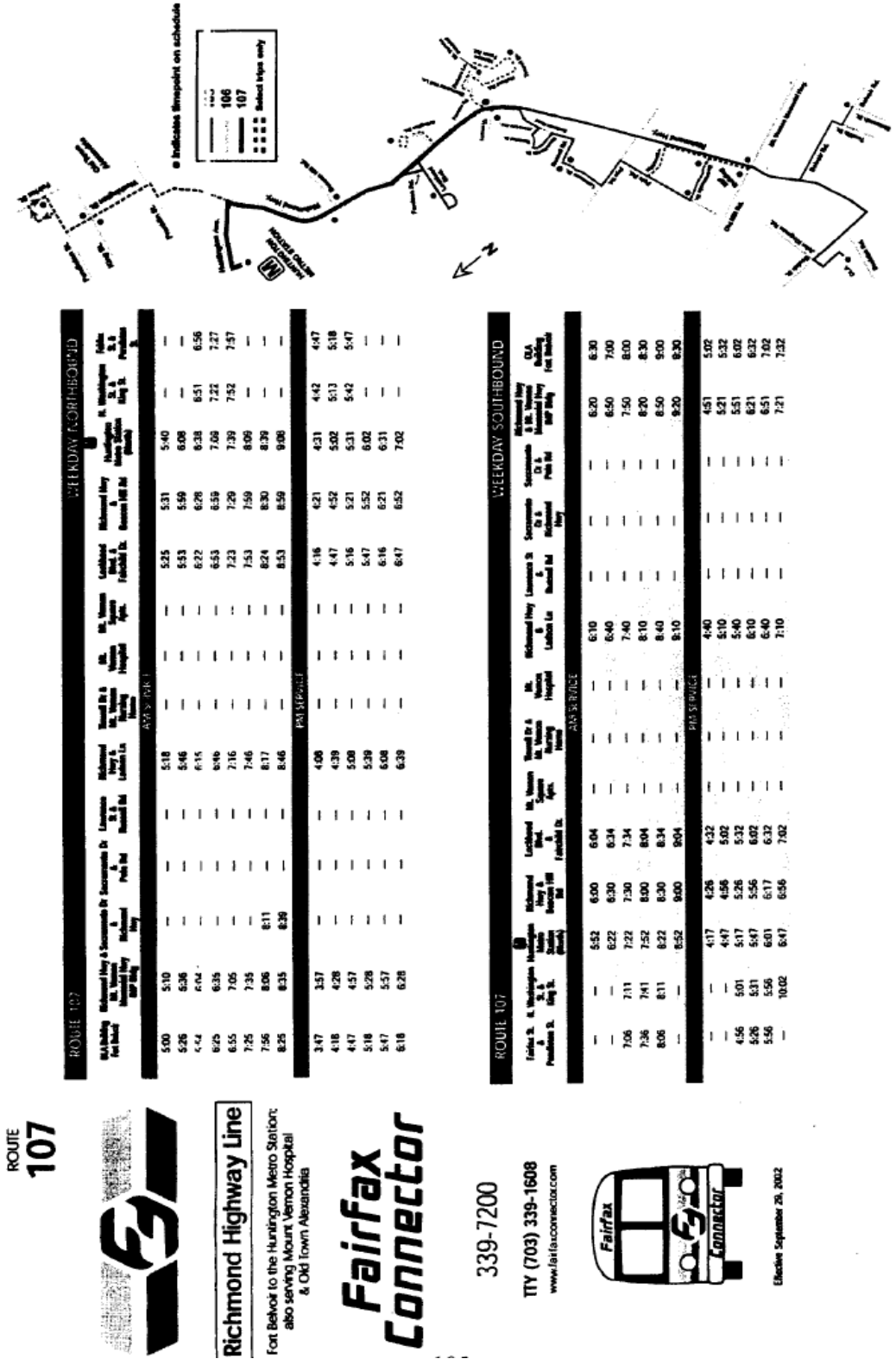
10: Popkins Ln & Richmond Hwy 1/29/2003

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)	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)	16.7		126.1			7.0	9.2	140.1	
30th %ile Term Code	Gap		Coord			Min	Gap	Coord	
10th %ile Green (s)	5.0		149.8			0.0	6.4	149.6	
10th %ile Term Code	Gap		Coord			Skip	Gap	Coord	

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

Appendix G: Fairfax Connector Bus Schedule

(All bus schedules are not included here)



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

Appendix H: Universal Transportation Data Format Files

Layout Data: "LAYOUT.DAT"

INTID	TYPE	X	Y	NID	SID	EID	WID	NEID	NWID	SEID	SWID
1	1	11885435	6955219				18				
2	1	11858184	6943030			28					
4	1	11889542	6971761			5					
5	0	11888492	6971181	54	855	4	107				
6	0	11888050	6970727	107	7	355	533				
7	0	11887438	6968058	6	8	704					
8	0	11887364	6967427	7	9	131	168				
9	0	11887224	6966466	8	151	84	133				
10	0	11886638	6965059	229	11	91					
11	0	11886700	6962550	10	12	233	46				
12	0	11886816	6960931	11	13	217	567				
13	0	11886961	6959122	12	14	93	224				
14	0	11886977	6958704	13	15	537	536				
15	0	11886685	6957174	14	16	89					
16	0	11886387	6956494	15	100	47	566				
17	0	11885842	6955825	80	100	18					
18	0	11885347	6955325	83	1	17	163				
19	0	11882107	6953088	87	88	163	20				
20	0	11880150	6951721	85	160	19	21				
21	0	11878872	6950829	90	20	164					
22	0	11876554	6949314	565	92	171	185				
23	0	11875207	6948445	563	94	179	561				
24	0	11873046	6947012	96	159	73	166				
25	0	11870719	6945858	317	166	152					
26	0	11869929	6945089	152	153	539					
27	0	11865489	6943908	221	508	153	28				
28	0	11864221	6943645	414	27	2					
44	1	11877492	6943716		98						
45	1	11890868	6967308		131						
46	1	11886271	6962609	11							
47	1	11887573	6956910		16						
54	1	11888271	6971448				5				
73	2	11873474	6947323	180				24			
80	1	11885025	6956527				17				
83	1	11884994	6955733				18				
84	1	11888539	6965907		9						
85	1	11879988	6951983	20							
86	1	11884608	6965505	229							
87	1	11881091	6954594	19							
88	1	11882477	6952440	19							
89	1	11885906	6957486	15							
90	1	11877825	6954641	21							

91	1	11888667	6964135	10					
92	1	11877156	6947573	22					
93	1	11888896	6959229	13					
94	1	11875884	6947035	23					
96	1	11872836	6949190	24					
98	2	11876344	6943800	44	159				
99	1	11886930	6965129	229					
100	2	11886151	6956091	16	17				
107	2	11888107	6970930	6	5				
131	2	11889210	6966678	45	8				
133	1	11885105	6966738	9					
151	2	11886743	6965370	9	229				
152	2	11870250	6945608	26	25				
153	2	11869606	6944595	26	27				
159	2	11873956	6945061	24	98				
160	1	11880316	6951453	20					
163	2	11884970	6955061	18	19				
164	2	11877942	6950188	171	21				
166	2	11872078	6946552	24	25				
168	1	11886623	6967509	8					
171	2	11876970	6949592	164	22				
179	2	11875564	6948679	185	23				
180	2	11874694	6948109	561	73				
185	2	11876344	6949177	22	179				
217	1	11888160	6961030	12					
221	1	11865416	6945259	27					
224	1	11886693	6959105	13					
229	0	11886679	6965224	151	10	99	86		
233	1	11887624	6962424	11					
317	1	11869689	6948156	25					
355	1	11888253	6970486	6					
414	1	11864096	6945854	28					
508	1	11865606	6942768	27					
533	1	11887671	6971196	6					
536	1	11886609	6958721	14					
537	1	11887371	6958685	14					
539	1	11871217	6944188	26					
561	0	11875032	6948328	564	568	23	180		
563	1	11874829	6949213	23					
564	1	11874387	6949281	561					
565	1	11876341	6949765	22					
566	1	11885814	6956823	16					
567	1	11886187	6960892	12					
568	1	11875278	6947909	561					
704	1	11885887	6968314	7					
855	1	11889026	6970590	5					

Turning Movement Count: "VOLUME.DAT"

60 Minute Counts

DATE	TIME	INTID	NBL	NBT	NBR	SBU	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
5/19/2004	1700	5	4	4	8		54	5	497	147	2728	10	8	764	36
5/19/2004	1700	6	452	2570	29		60	1152	80	264	4	4	16	4	12
5/19/2004	1700	7	36	2768			1208	28	104		28				
5/19/2004	1700	8	24	2729	487		92	1112	44	60	32	5	156	74	110
5/19/2004	1700	9	60	3138	22		12	1172	76	116	32	120	8	52	8
5/19/2004	1700	10		3120	36		44	1255			60		48		
5/19/2004	1700	11	64	2762	5		4	1216	60	454	6	116	4		36
5/19/2004	1700	12	4	2488	56		120	1276	5	8		4	172		468
5/19/2004	1700	13	36	2490	24		76	1266	16	40	48	60	26	21	109
5/19/2004	1700	14	104	2500	8		136	1204	5	8	8	16	4	12	100
5/19/2004	1700	15	24	2521			1188	12	8		8				
5/19/2004	1700	16	36	2423	1016		104	1096	5	16	20	12	248	20	28
5/19/2004	1700	17			116		68	56	3296		1350	44			
5/19/2004	1700	18	56	32	396		612	32	10	8	2282	52	192	1154	148
5/19/2004	1700	19	48	6	18		444	20	92	68	1794	27	210	1020	54
5/19/2004	1700	20	4	4	4		60	16	60	44	1768	10	12	1084	
5/19/2004	1700	21			436		64	76	1356		974	140			
5/19/2004	1700	22	52	16	52		40	8	40	100	1300	100	32	970	10
5/19/2004	1700	23	36	20	56		84	8	16	4	1278	24	72	972	32
5/19/2004	1700	24	440	28	52		60	88	24	32	1164	540	204	836	32
5/19/2004	1700	25			160		228	188	1500		1328	24			
5/19/2004	1700	26		1560	208		360	1236			44		128		
5/19/2004	1700	27	104	40	5		100	112	8	172	1696	1160	44	1170	60
5/19/2004	1700	28			560		16	184	2504		706	624			
5/19/2004	1700	229	20	3148			1299	5	48			5			
5/19/2004	1700	561	24	12	4		124	16	60	48	1178	60		944	80

Timing Plans: “TIMING.DAT”

PLANID	INTID	S1	S2	S3	S4	S5	S6	S7	S8	CL	OFF	LD	REF	CLR
DEFAULT	5	13.5	116.5	30	35.5	23.5	106.5			195.5	0	135	26	
DEFAULT	6	15	107	41	21	57	64			184	0	135	26	
DEFAULT	7	14	132		32		147			179	0	1	26	
DEFAULT	8	19	108	35	30	19	108			192	0	135	26	
DEFAULT	9	14	126		37	19	121		36	177	0	15	26	
DEFAULT	10	21	102	29	24		124			177	0	13	26	
DEFAULT	11	23	95	33	44	12	106			195	0	135	26	
DEFAULT	12	14	123		40	34	103			177	0	15	26	
DEFAULT	13	20	108	19	30	20	108			177	0	135	26	
DEFAULT	14	19	114	14	30	25	108			177	0	135	26	
DEFAULT	15	27	121		30		149			179	0	1	26	
DEFAULT	16	14	117	14	42	23	108			187	0	135	26	
DEFAULT	17	19	126		33		146			179	0	1	26	
DEFAULT	18	22	88	17.5	47	14	96			174.5	0	135	26	
DEFAULT	19	24	93		59	14	103		59	176	0	15	26	
DEFAULT	20	18	104	15	35	18	104			172	0	235	26	
DEFAULT	21	24	97		55		122			177	0	1	26	
DEFAULT	22	24	118		34	24	118		34	176	0	15	26	
DEFAULT	23	23	96	26	31	23	96			176	0	135	26	
DEFAULT	24	29	52	54		18	63	24		159	0	167	26	
DEFAULT	25		135		43	29	105			178	0	5	26	
DEFAULT	26	49.5	100.5		22.5		152.5			175	0	1	26	
DEFAULT	27	19	118	31	28	24	113			196	0	135	26	
DEFAULT	28	29	121		46		151			197	0	1	26	

Phasing Data: "PHASING.DAT"

(This is a very long file so only the first few points are shown here.)

```
RECORDNAME      INTID   D1   D2   D3   D4   D5   D6   D7   D8   D9 D10 D11 D12
D13  D14  D15  D16
BRP              5  111  112  211  212  121  122  213  214  311  312  411  412  321  322
421  422
MinGreen           5    5   30    7    5    5   30
MaxGreen           5    8110.5   25   30   18100.5
VehExt             5  2.5    3  2.5    3  2.5    3
TimeBeforeReduce     5    0    0    0    0    0    0
TimeToReduce         5    0    0    0    0    0    0
MinGap             5  2.5    3  2.5    3  2.5    3
Yellow             5    4    4    4    4    4    4
AllRed             5  1.5    2    1  1.5  1.5    2
Recall             5    0    3    0    0    0    0
Walk               5                7
DontWalk           5                23
PedCalls           5                0
MinSplit           5 10.5   36   12 35.5 10.5   36
BRP              6  111  112  211  212  121  122  213  214  311  312  411  412  321  322
421  422
MinGreen           6   10   15    5   10   10   15
MaxGreen           6   10  102   36   16   52   59
VehExt             6    3    4    3    4    3    4
TimeBeforeReduce     6    0    0    0    0    0    0
TimeToReduce         6    0    0    0    0    0    0
MinGap             6    3    4    3    4    3    4
Yellow             6    4    4    4    4    4    4
AllRed             6    1    1    1    1    1    1
Recall             6    0    3    0    0    0    3
Walk               6
DontWalk           6
PedCalls           6
MinSplit           6   15   20   10   15   15   20
BRP              7  111  112  211  212  121  122  221  222  311  312  411  412  321  322
421  422
MinGreen           7    5   20        7       20
MaxGreen           7    9  127       27      142
VehExt             7    3    4        4        4
TimeBeforeReduce     7    0    0        0        0
TimeToReduce         7    0    0        0        0
MinGap             7    3    4        4        4
Yellow             7    4    4        4        4
AllRed             7    1    1        1        1
```

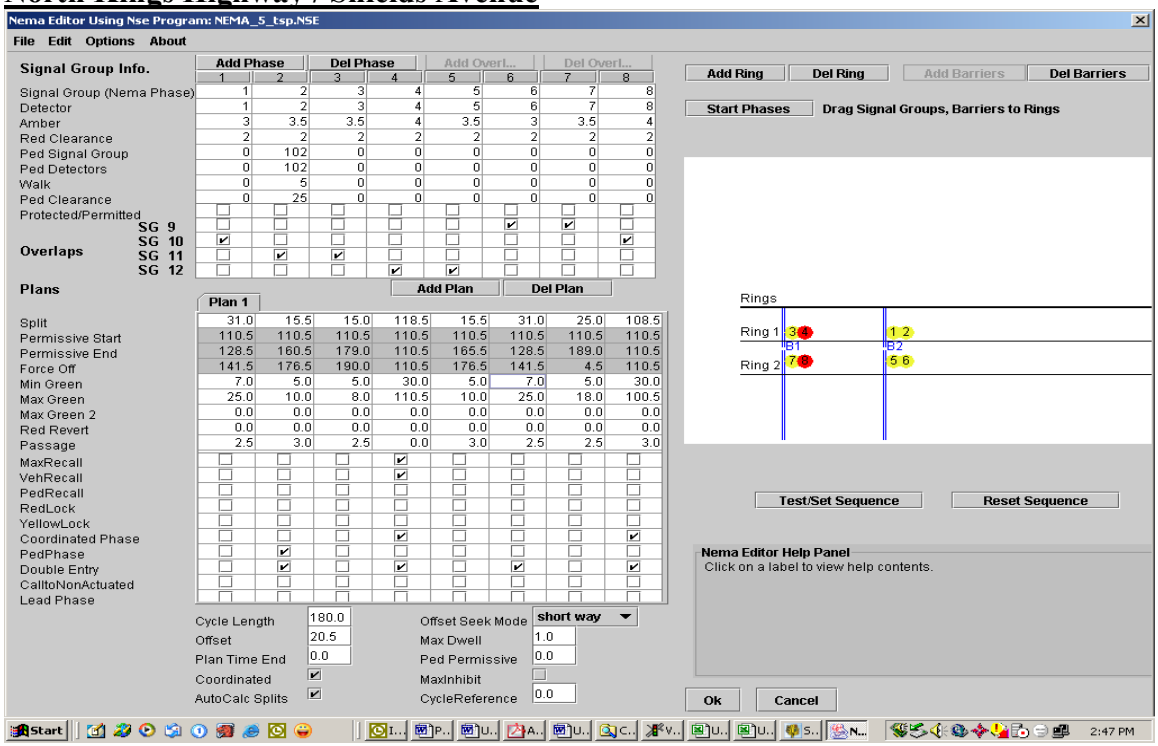
Lane Group Data: "LANES.DAT"

(This is a very long file so only the first few points are shown here.)

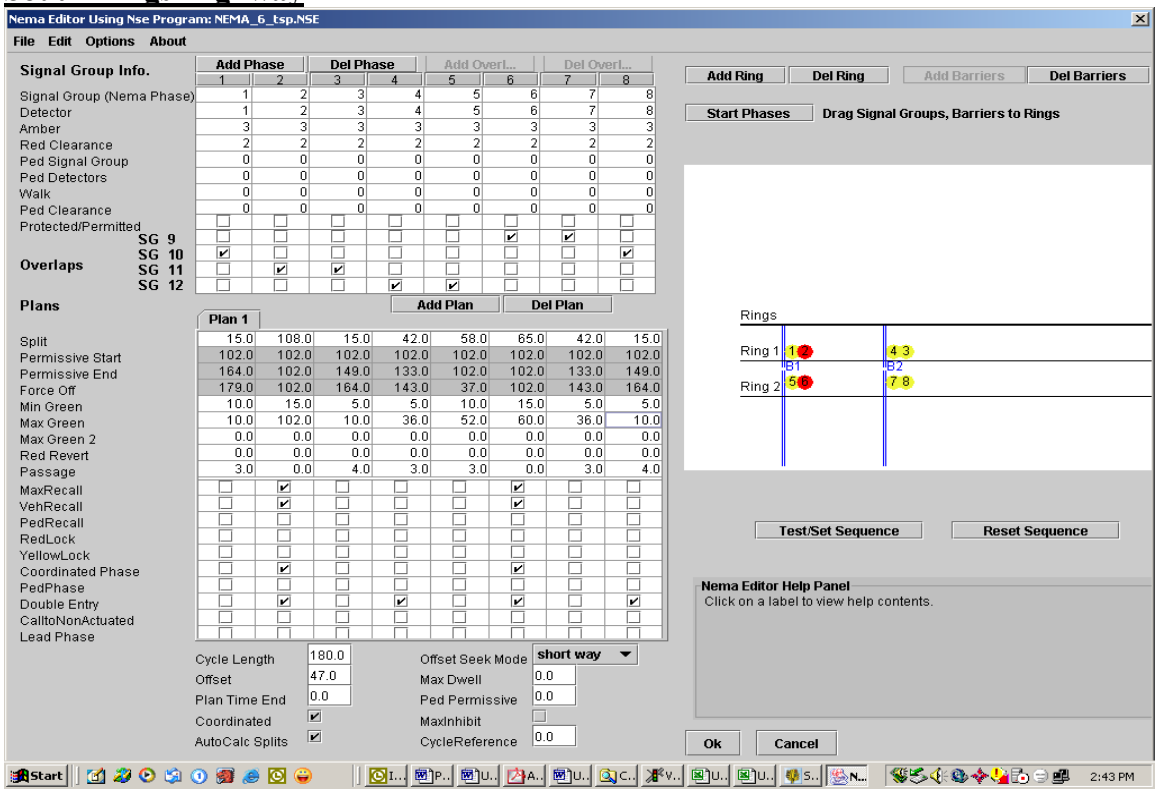
```
RECORDNAME      INTID NBL NBT NBR SBU SBL SBT SBR EBL EBT EBR
WBL WBT WBR
Lanes            5   0   1   1   0   1   1   1   2   3   0   1   4   0
Shared           5   0   1       0   2       0   2       0   2
Width            5  12  12  12  12  12  12  12  12  12  12  12  12  12
Storage          5             175         400         140     310
StLanes          5               1           2           1       1
Grade            5       0           0           0           0
Speed            5      25           35          45          45
FirstDetect      5  50  35  35      35  35  35  35   0      35   0
LastDetect       5   0  -5  -5      -5  -5  -5  -5   0      -5   0
Phase1           5   4   4          3   3       5   2       1   6
PermPhase1       5           4               3
DetectPhase1     5   4   4   4      3   3   3   5   2       1   6
IdealFlow        5 1900 1900 1900 1900 1900 1900 1900 1900 1900 1900 1900
1900
LostTime         5   3   3   3   4   3   3   3   3   3   3   3   3   3
SatFlow          5   0 1818 1583   0 1770 1513 1504 3433 5080   0 1770 6363   0
SatFlowPerm      5   0 1818 1583   0 1770 1513 1504 3433 5080   0 1770 6363   0
SatFlowRTOR      5   0   0   8   0   0 158 339   0   0   0   0   7   0
HeadwayFact      5 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Volume           5   4   4   8   0  54   5 497 147 2728  10   8 764  36
Peds             5   0   0   0   0   0   0   0   0   0   0   0   0   0
Bicycles         5   0   0   0   0   0   0   0   0   0   0   0   0   0
PHF              5 1.00 1.00 1.00 0.92 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
Growth           5 100 100 100 100 100 100 100 100 100 100 100 100 100
HeavyVehicles    5   2   2   2   2   2   2   2   2   2   2   2   2   2
BusStops         5   0   0   0   0   0   0   0   0   0   0   0   0   0
Midblock         5       0               0           0           0
Distance         5     797             *300        *443        1200
TravelTime       5    21.7              5.8         6.7        18.2
Lanes            6   1   3   0   0   1   3   1   0   1   0   0   2   0
Shared           6   0   2           0   0       0   3       0   3
Width            6  12  12  12  12  12  12  12  12  12  12  12  12  12
Storage          6 480             140
StLanes          6   1               1
Grade            6       0               0           0           0
Speed            6      45               45          25          15
FirstDetect      6  35   0           35   0  35  50  50      50  73
LastDetect       6  -5   0           -5   0  -5   0   0       0   0
Phase1           6   5   2           1   6   3   3   3       4   4
PermPhase1       6                               3
```

Appendix I: NEMA Signal Control Files for U.S. 1 Extended Corridor

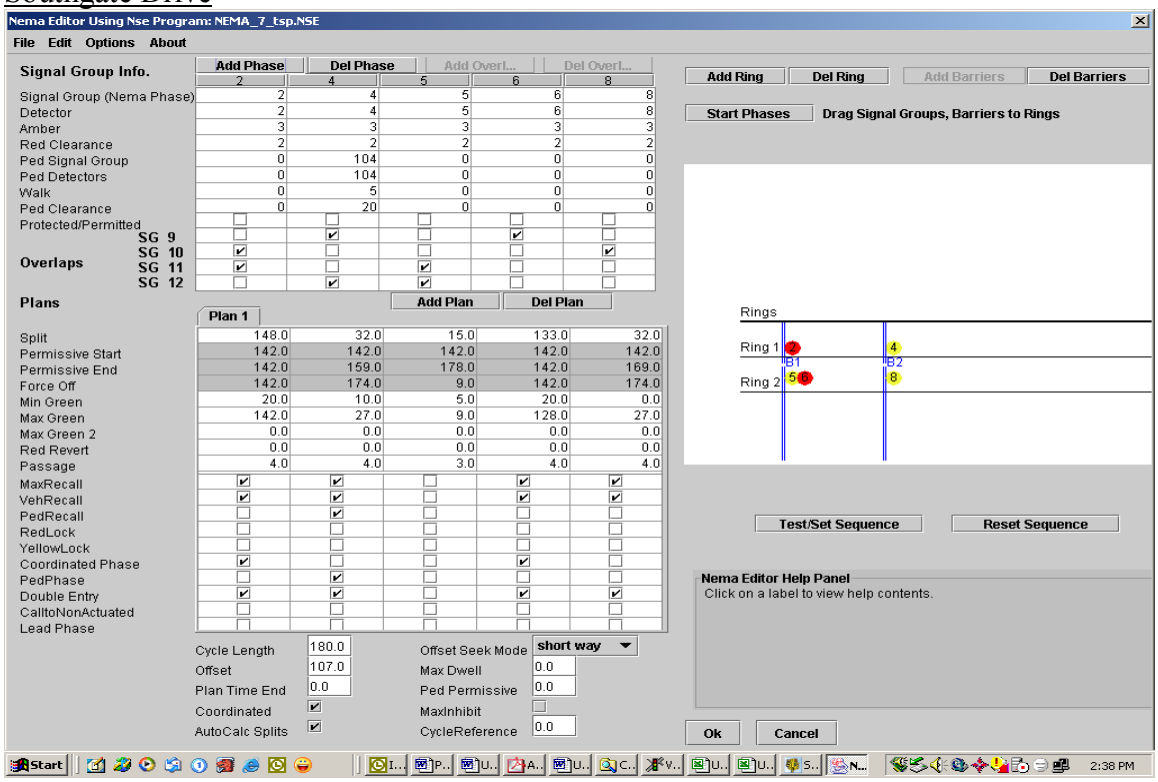
North Kings Highway / Shields Avenue



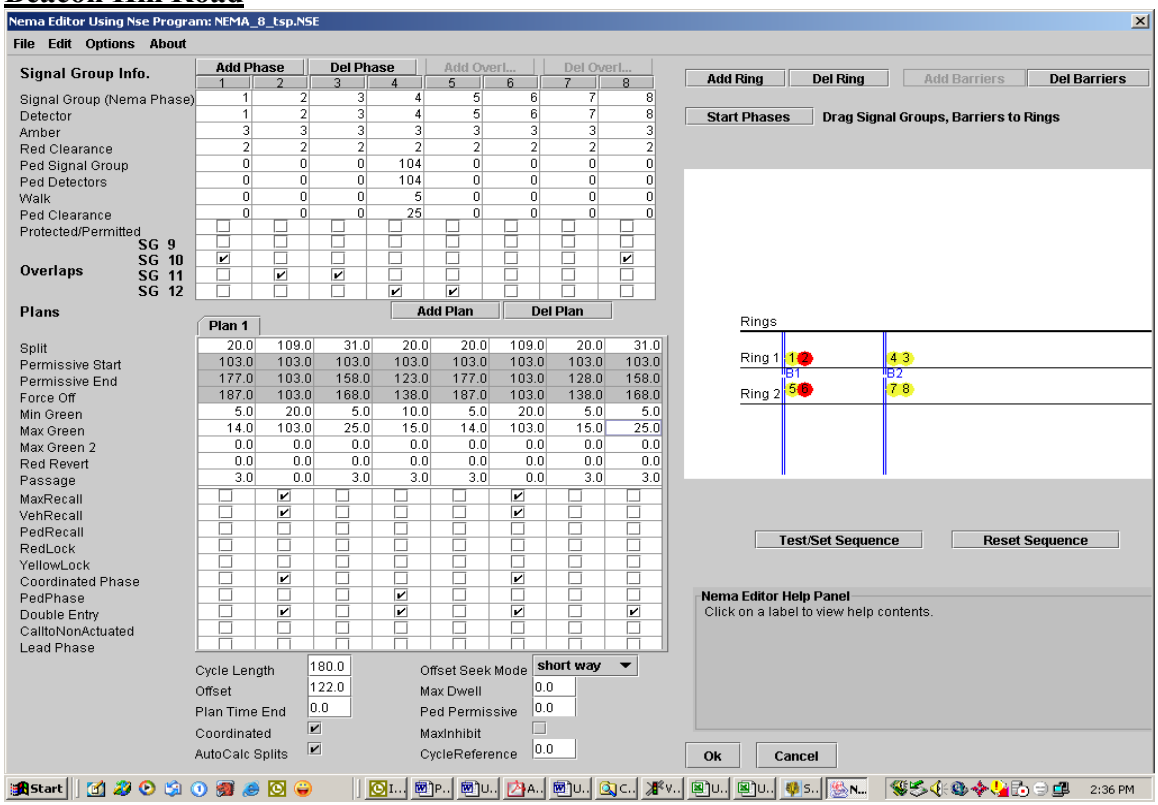
South Kings Highway



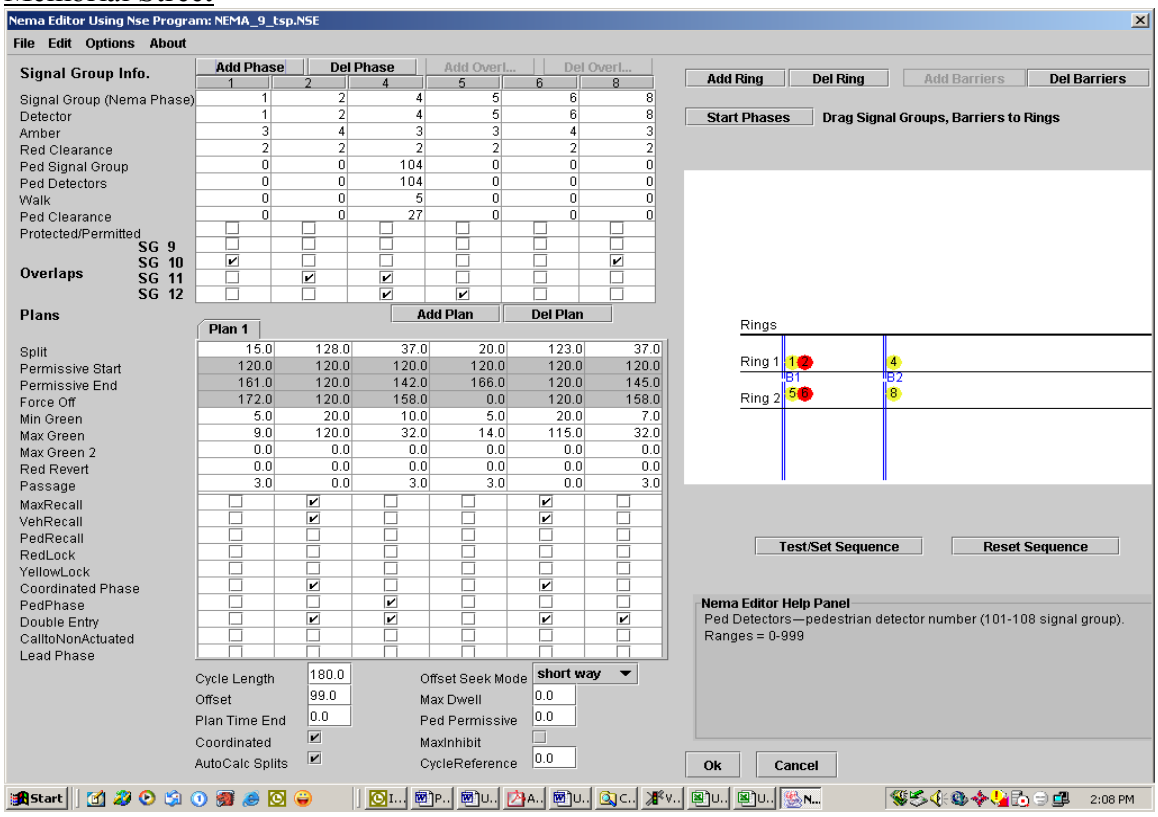
Southgate Drive



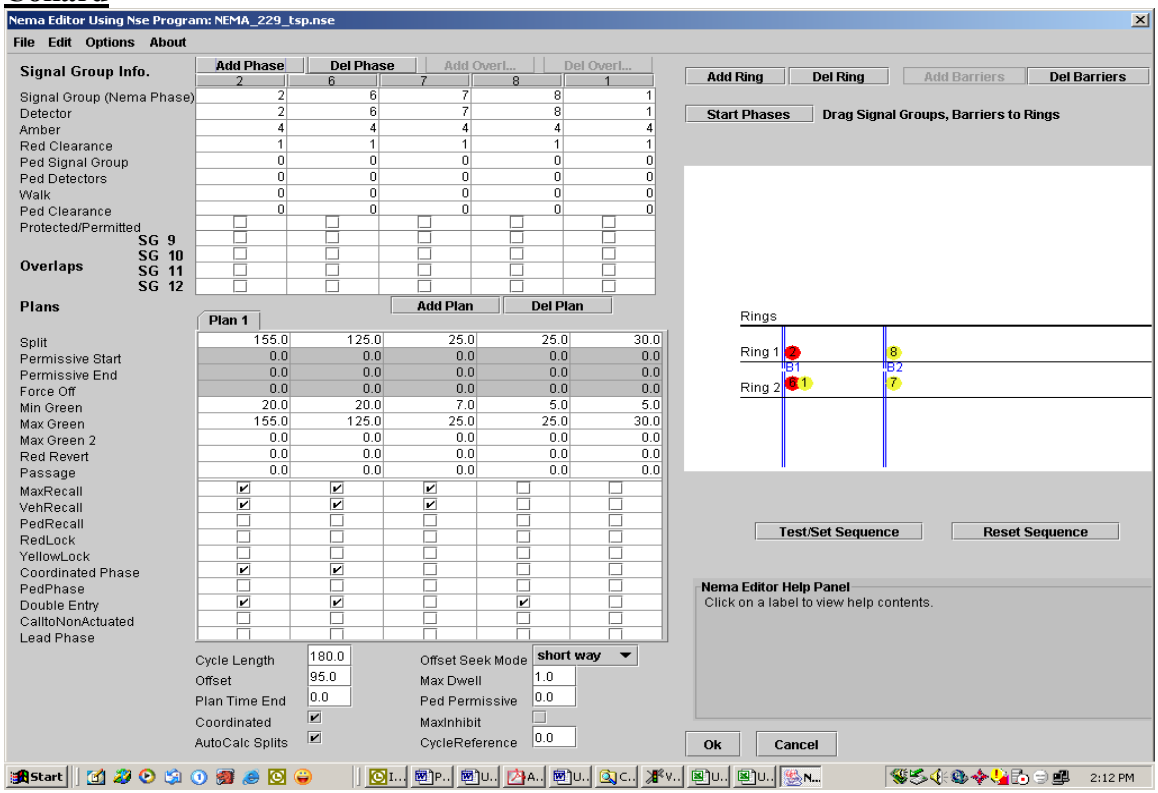
Beacon Hill Road



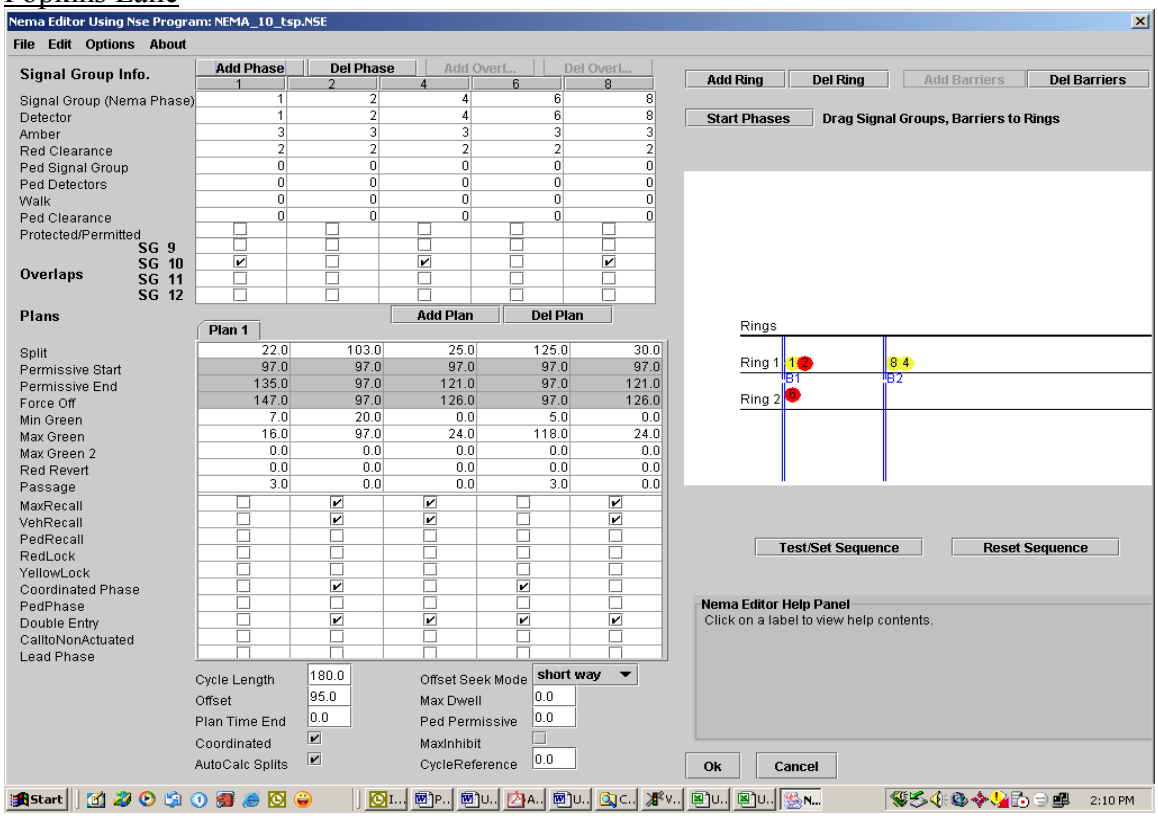
Memorial Street



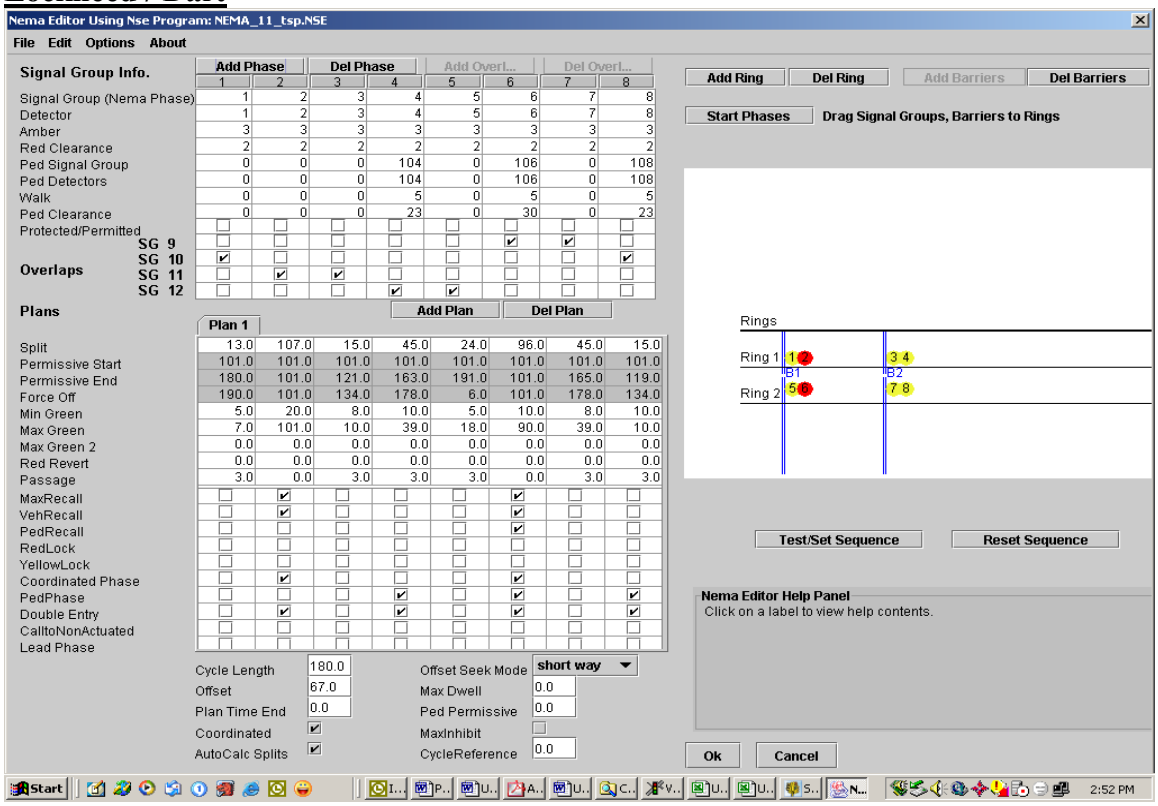
Collard



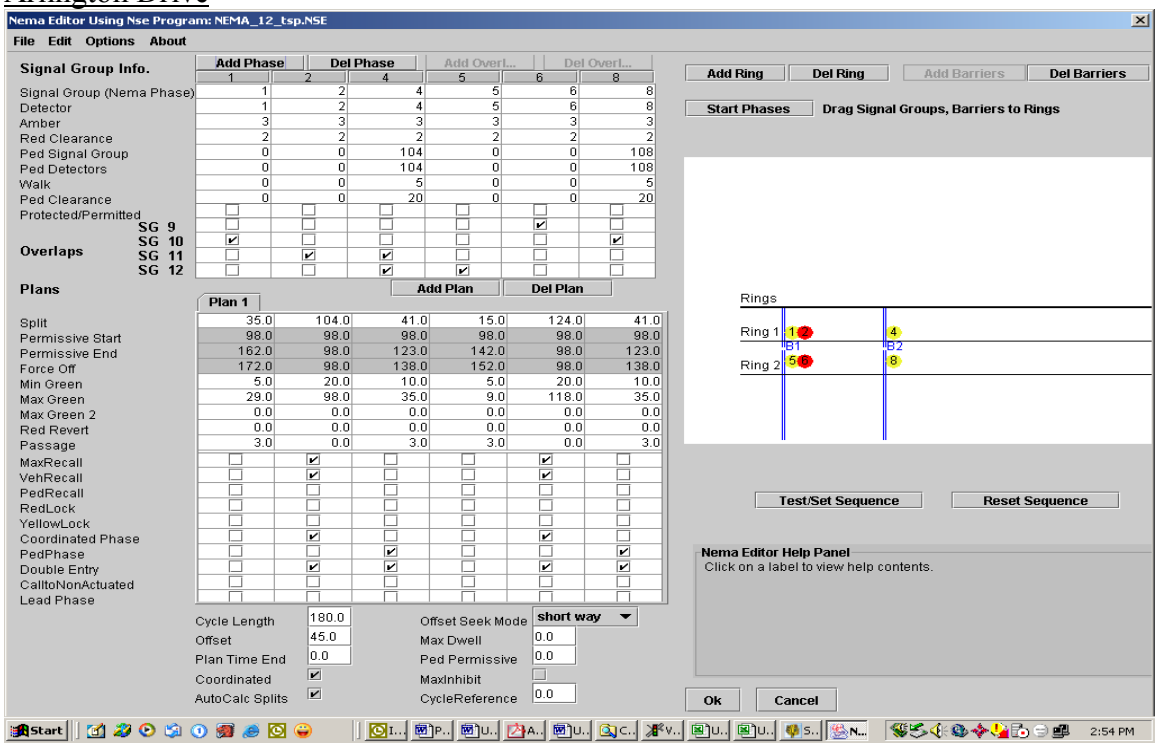
Popkins Lane



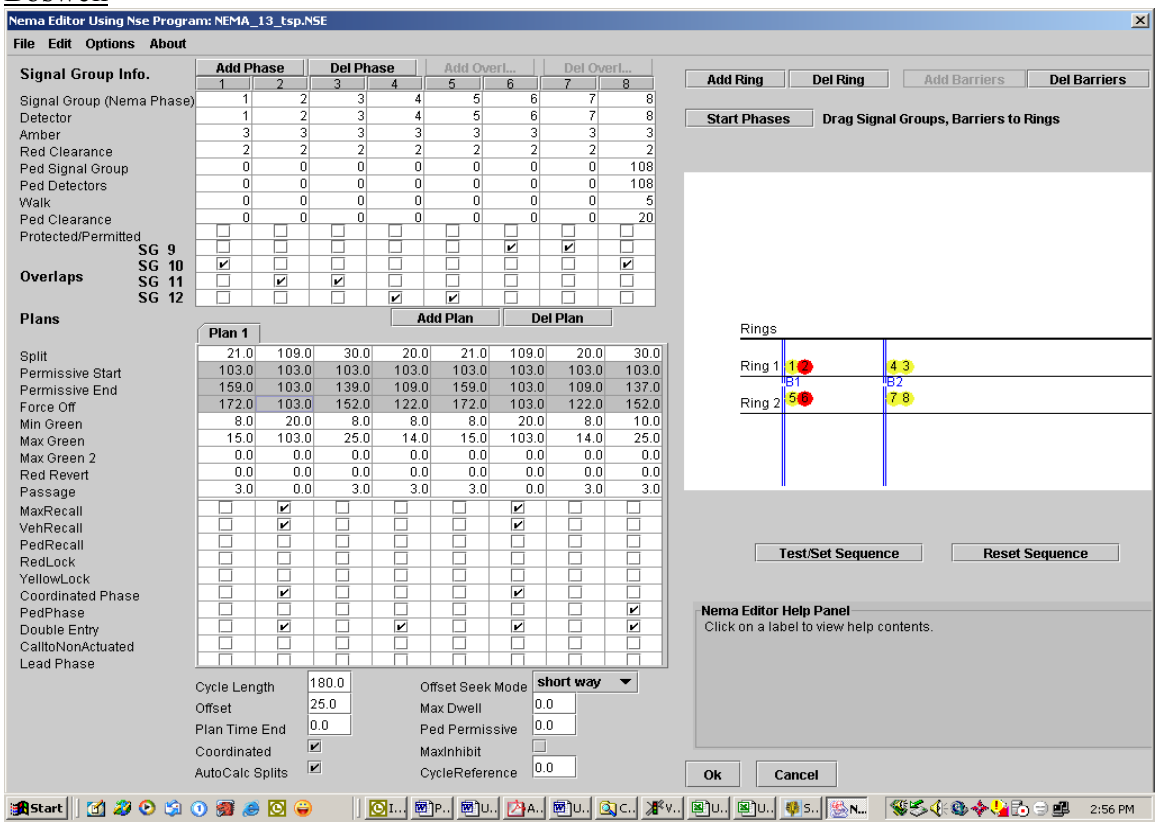
Lockheed / Dart



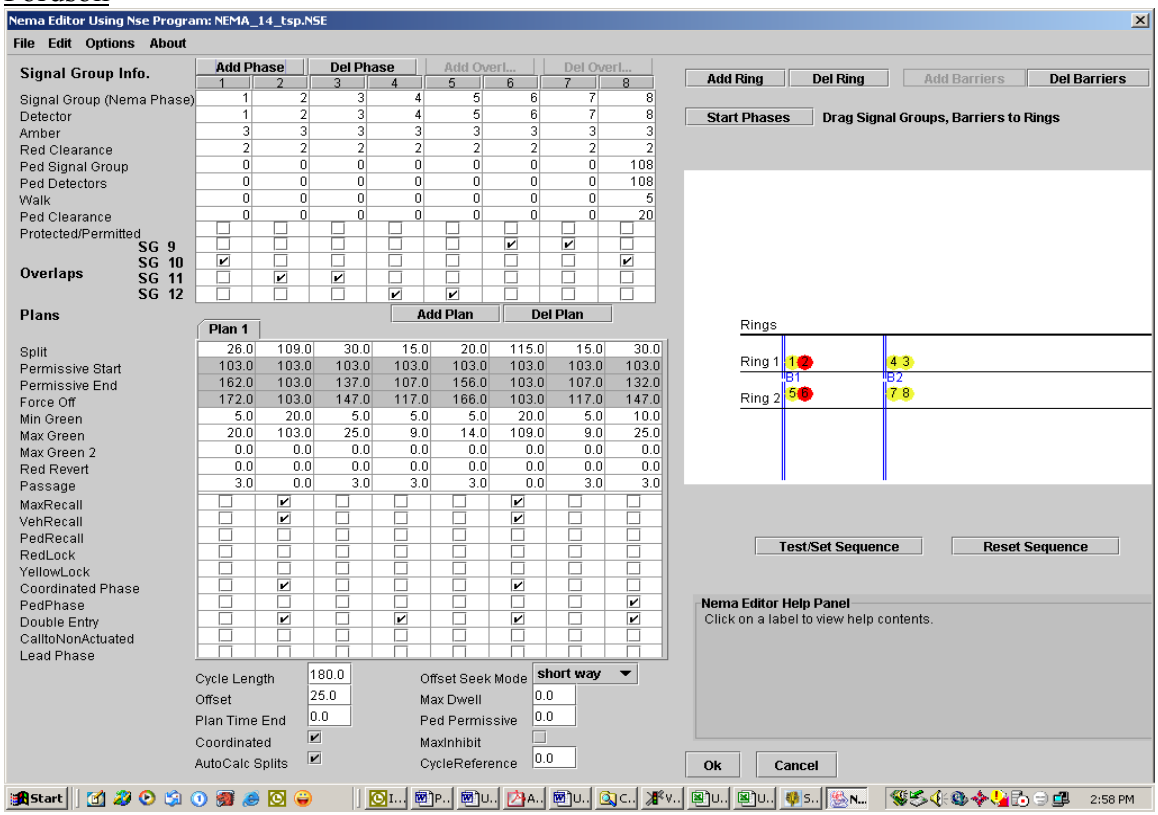
Arlington Drive



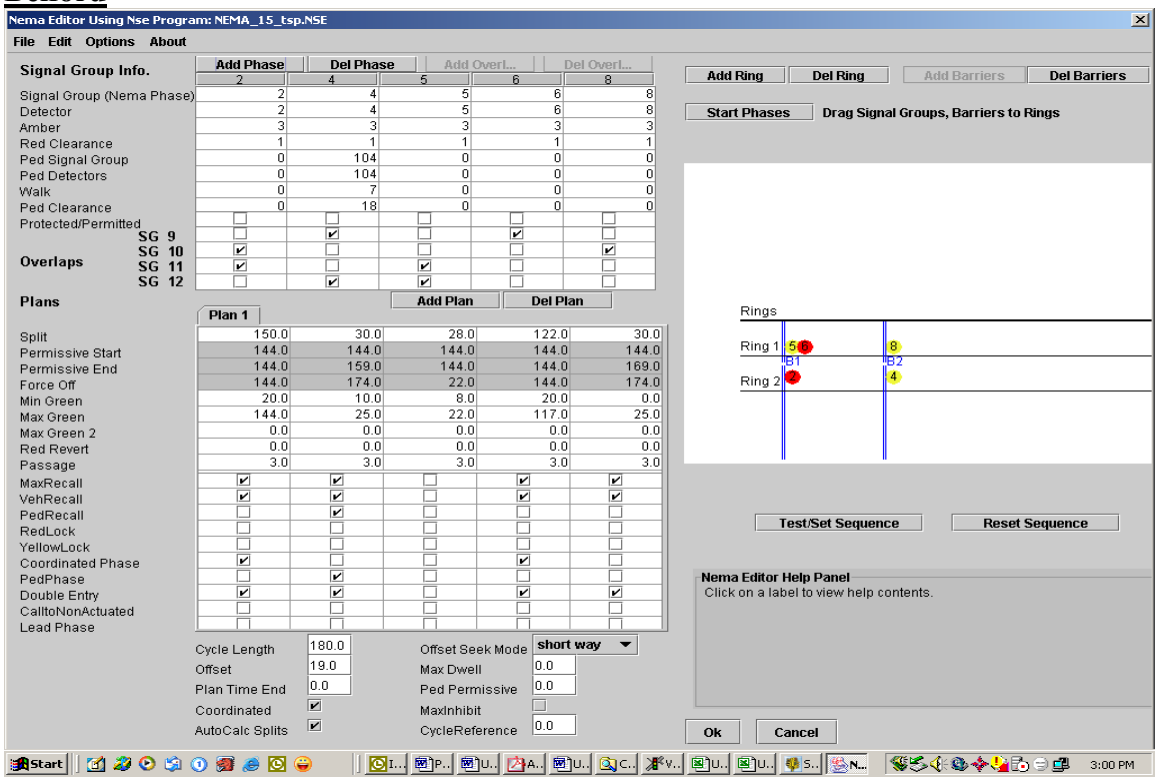
Boswell



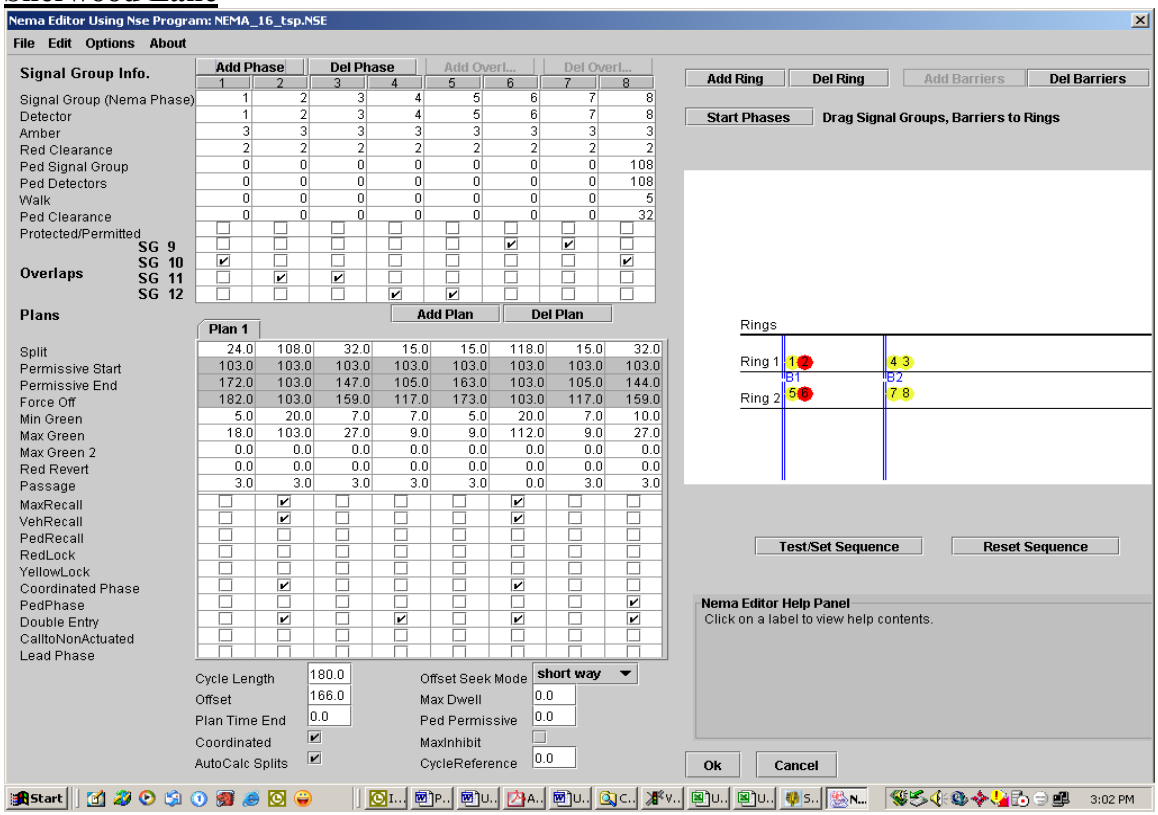
Fordson



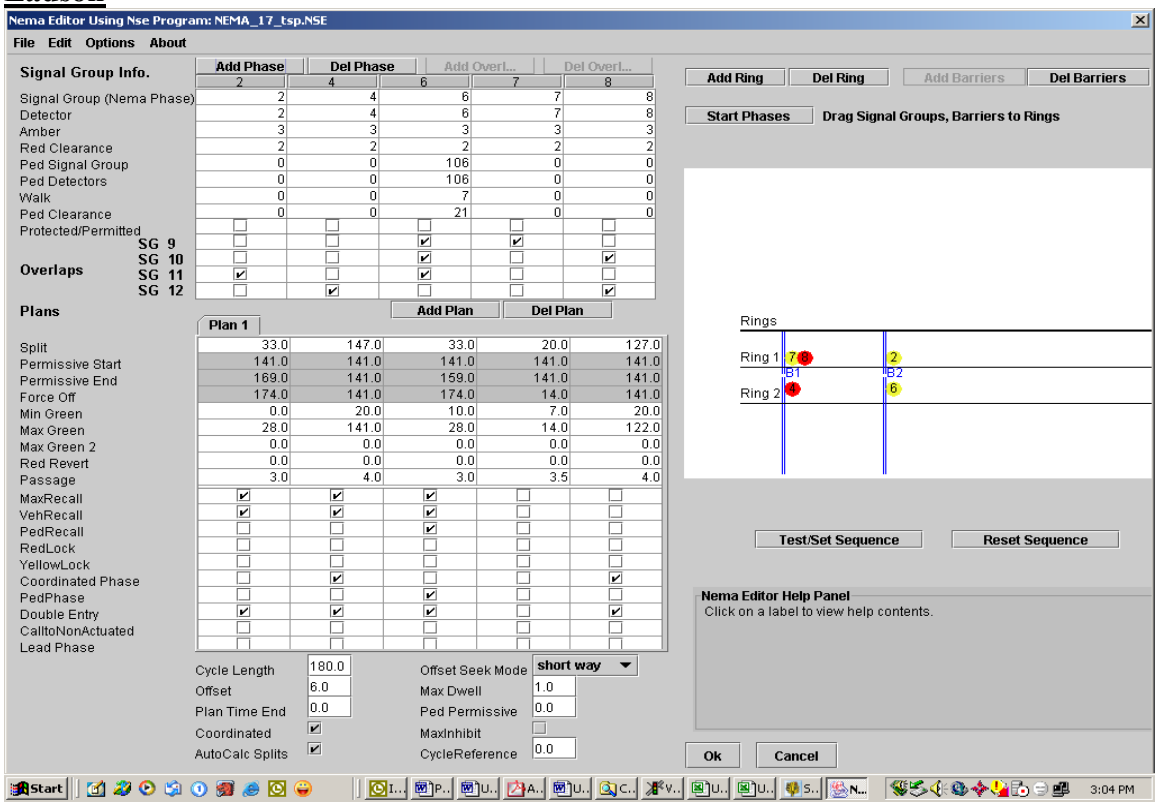
Belford



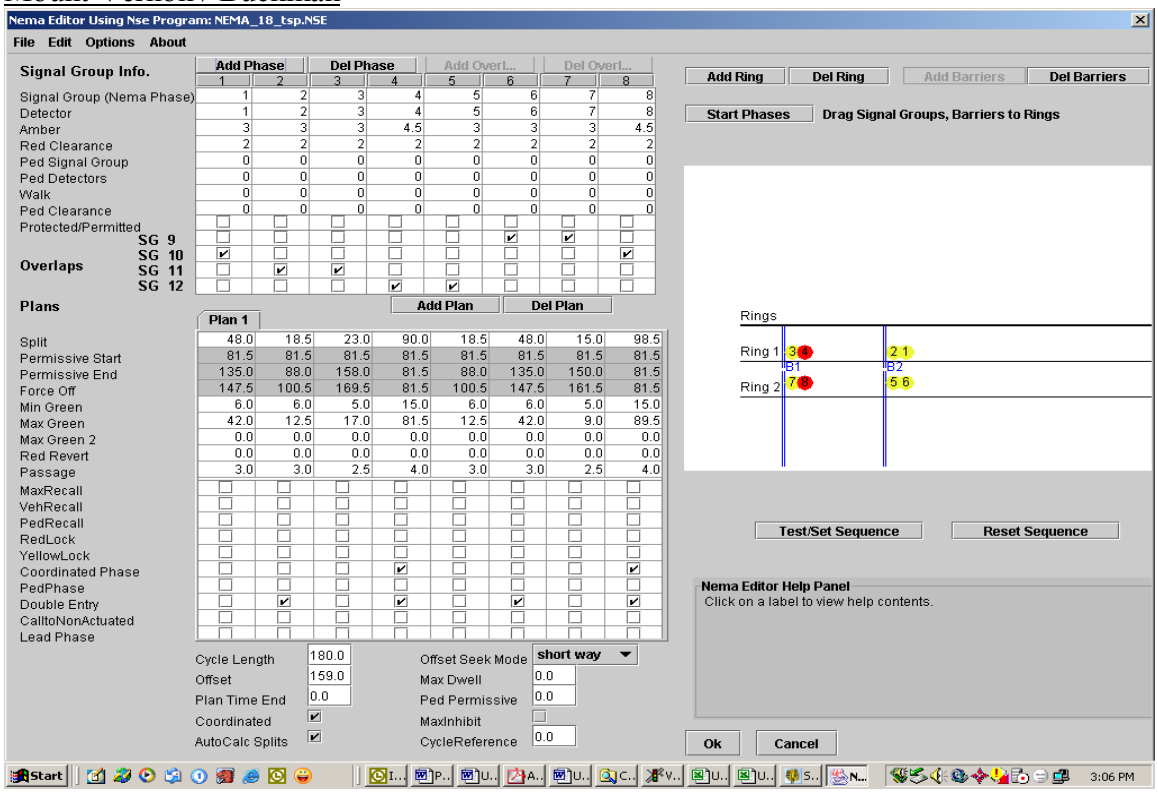
Sherwood Lane



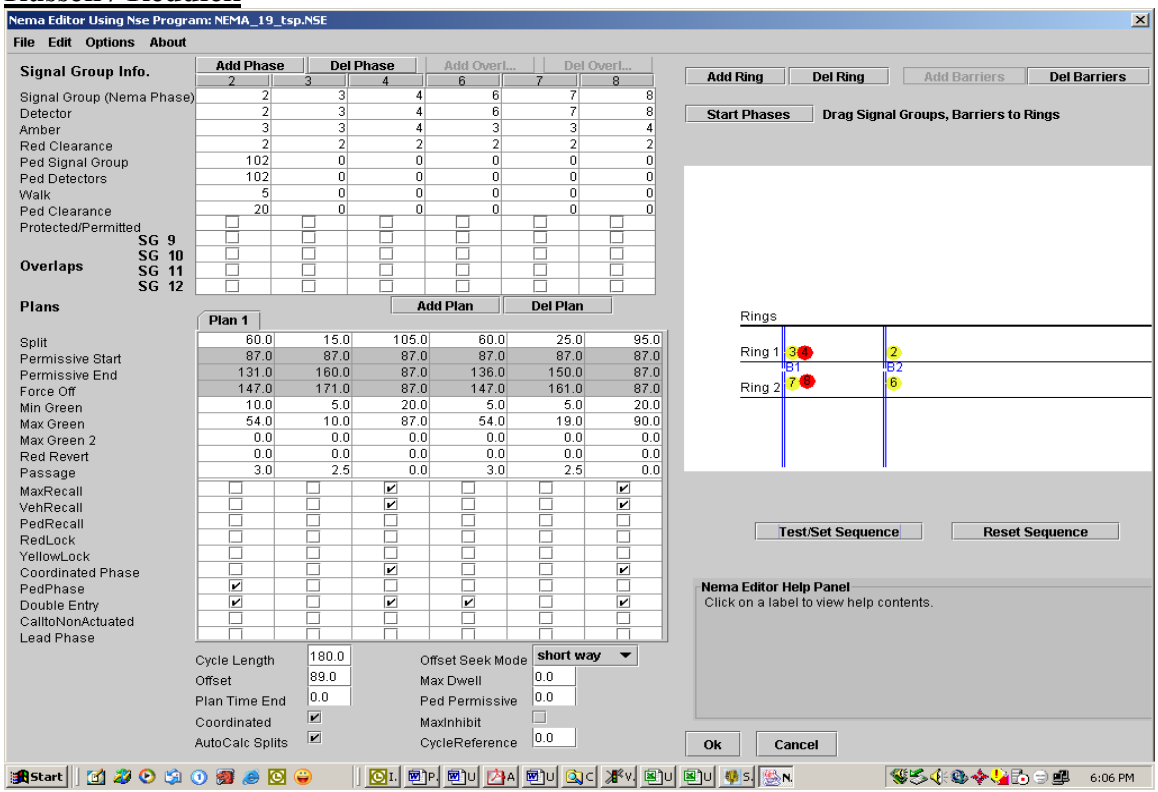
Ladson



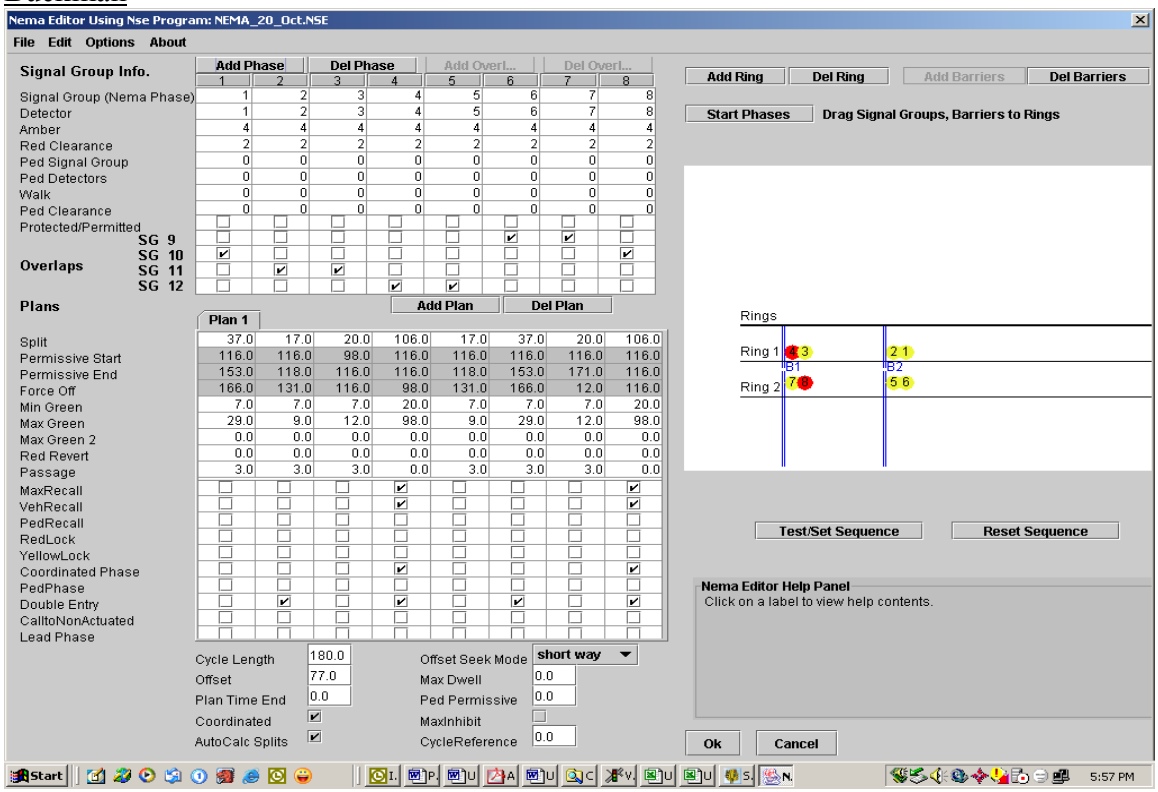
Mount Vernon / Buckman



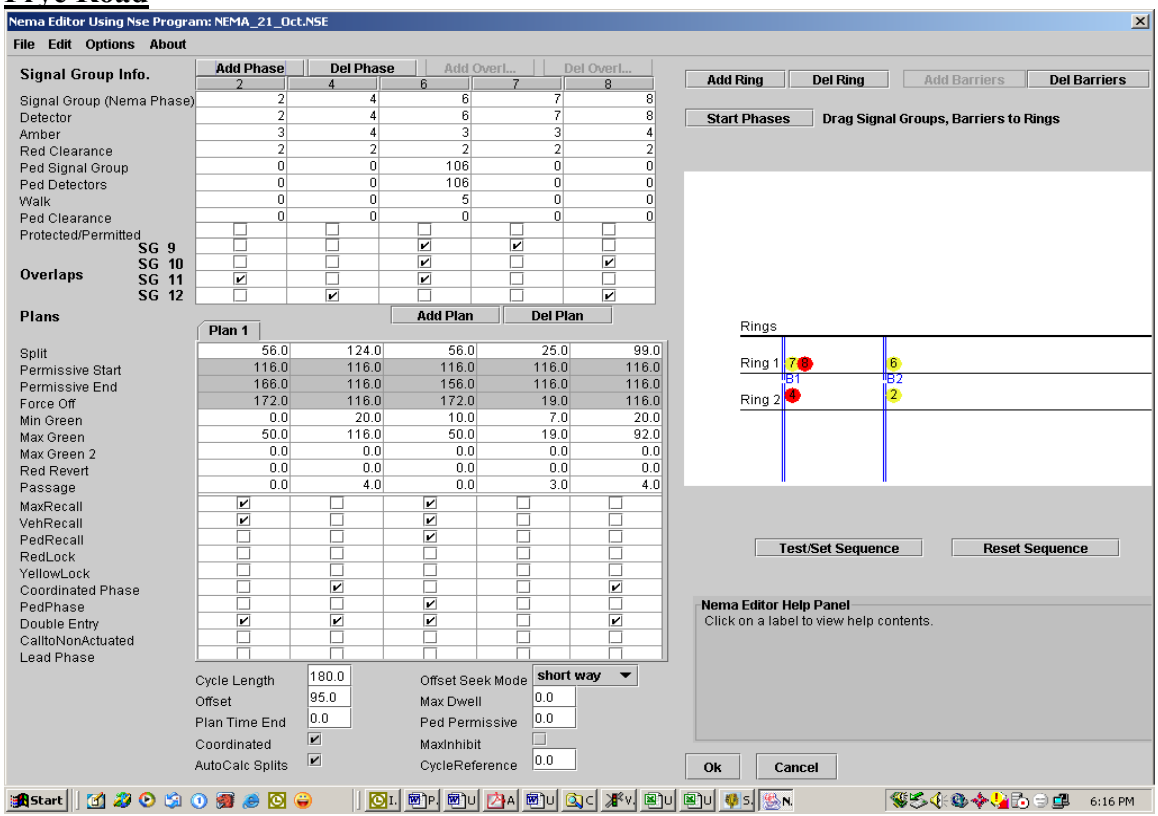
Russell / Reddick



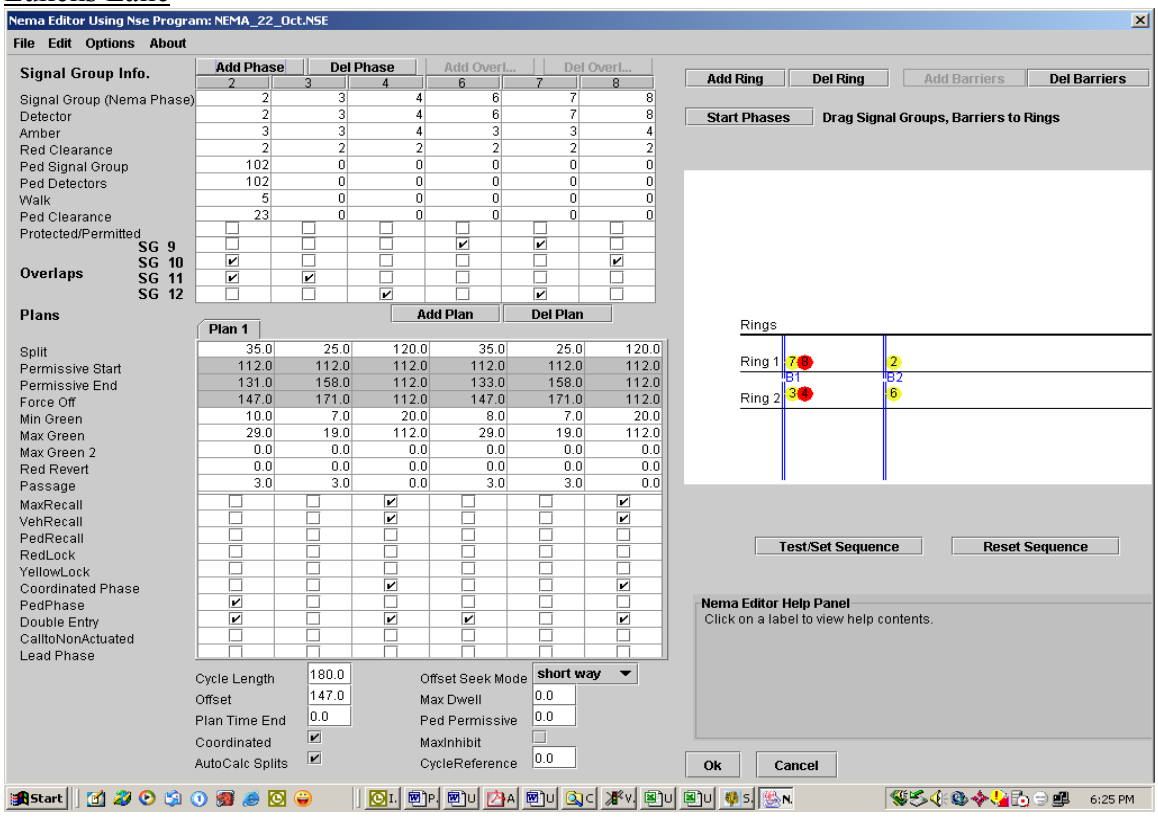
Buckman



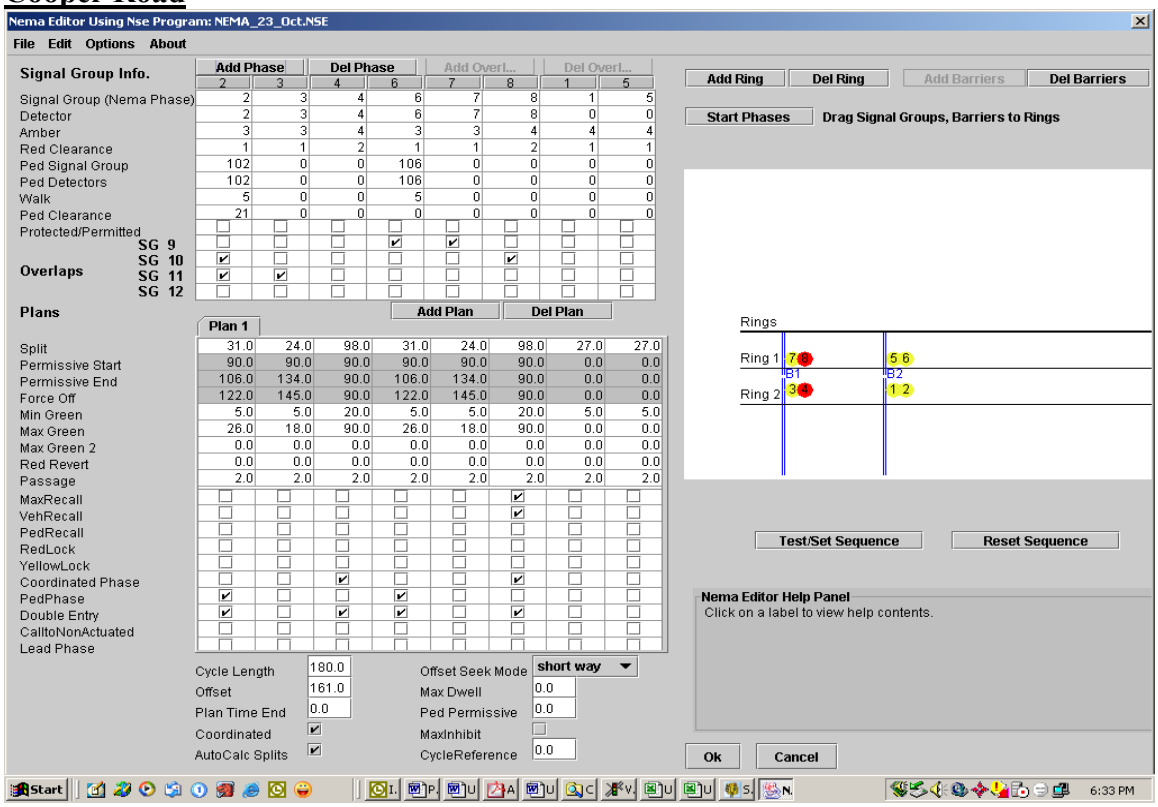
Frye Road



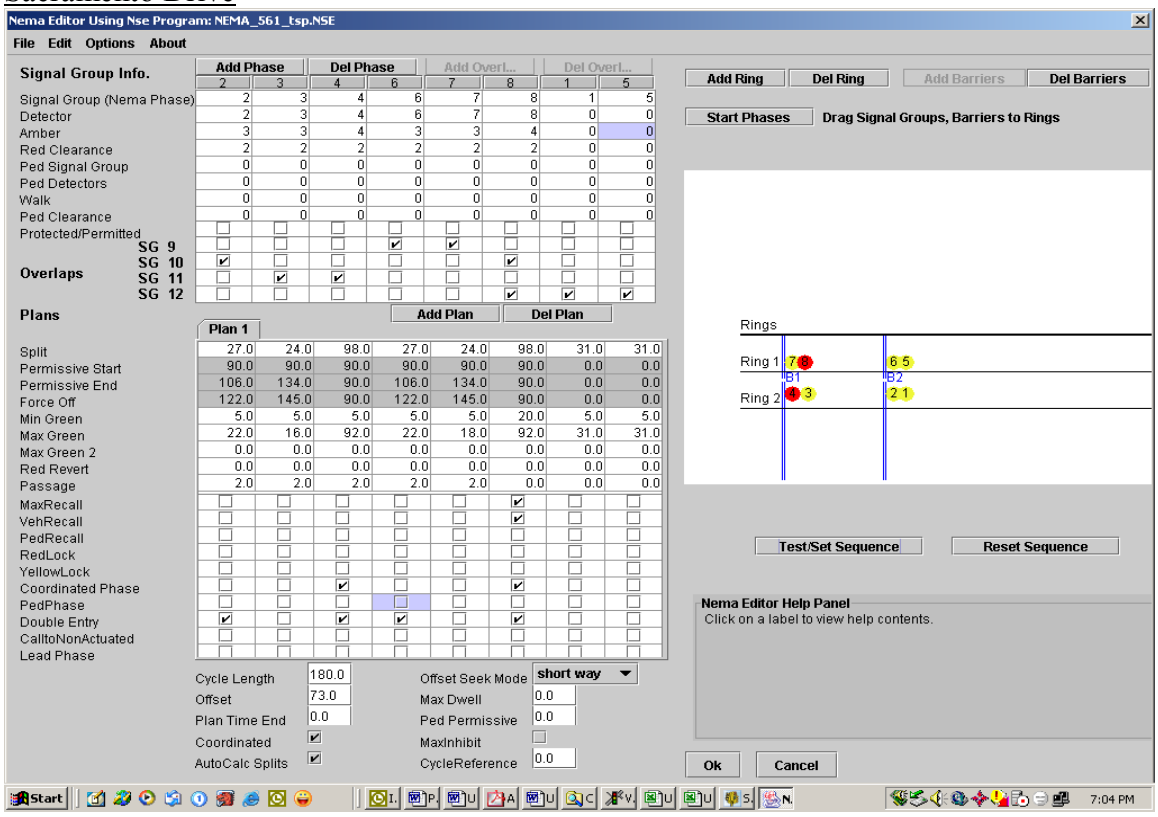
Lukens Lane



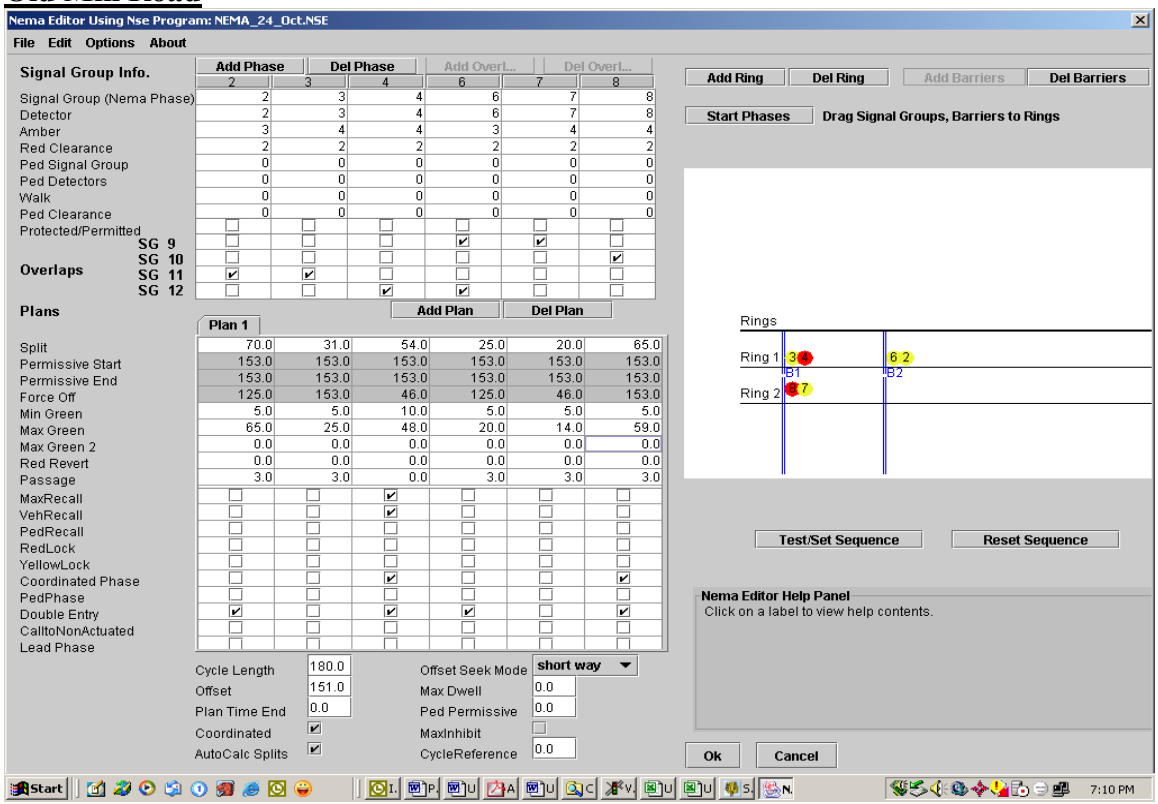
Cooper Road



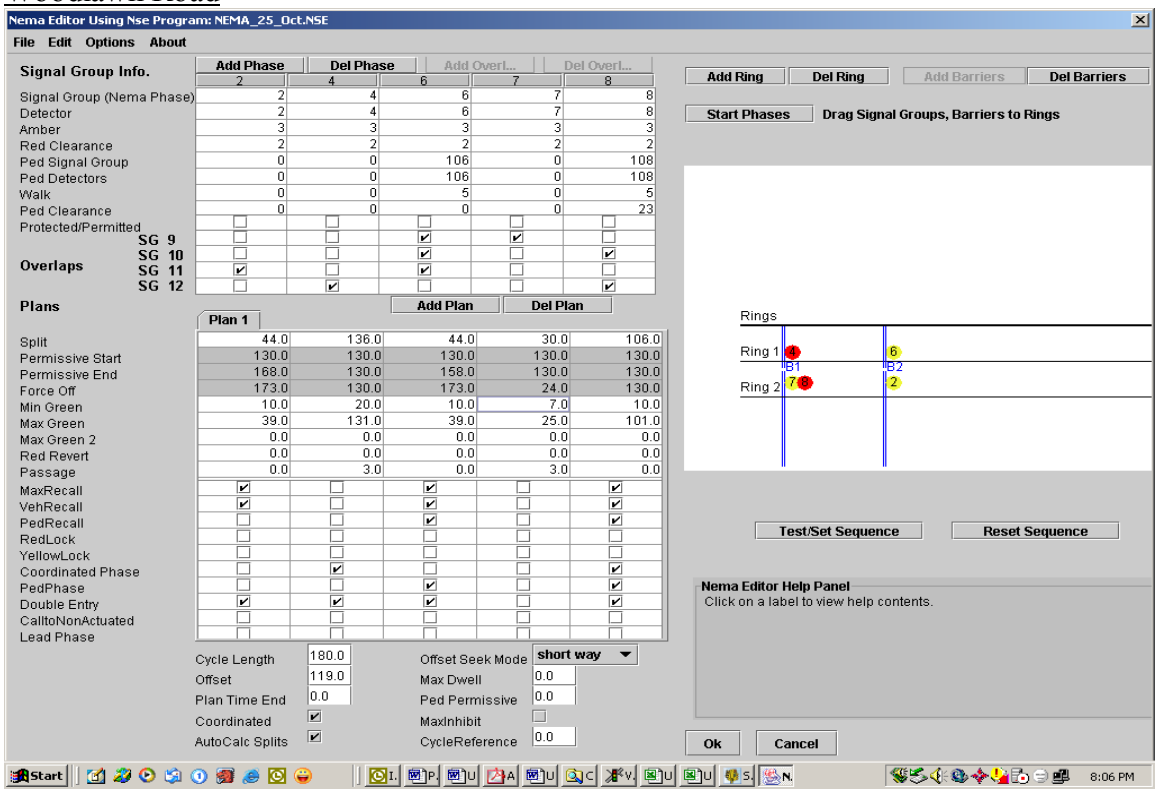
Sacramento Drive



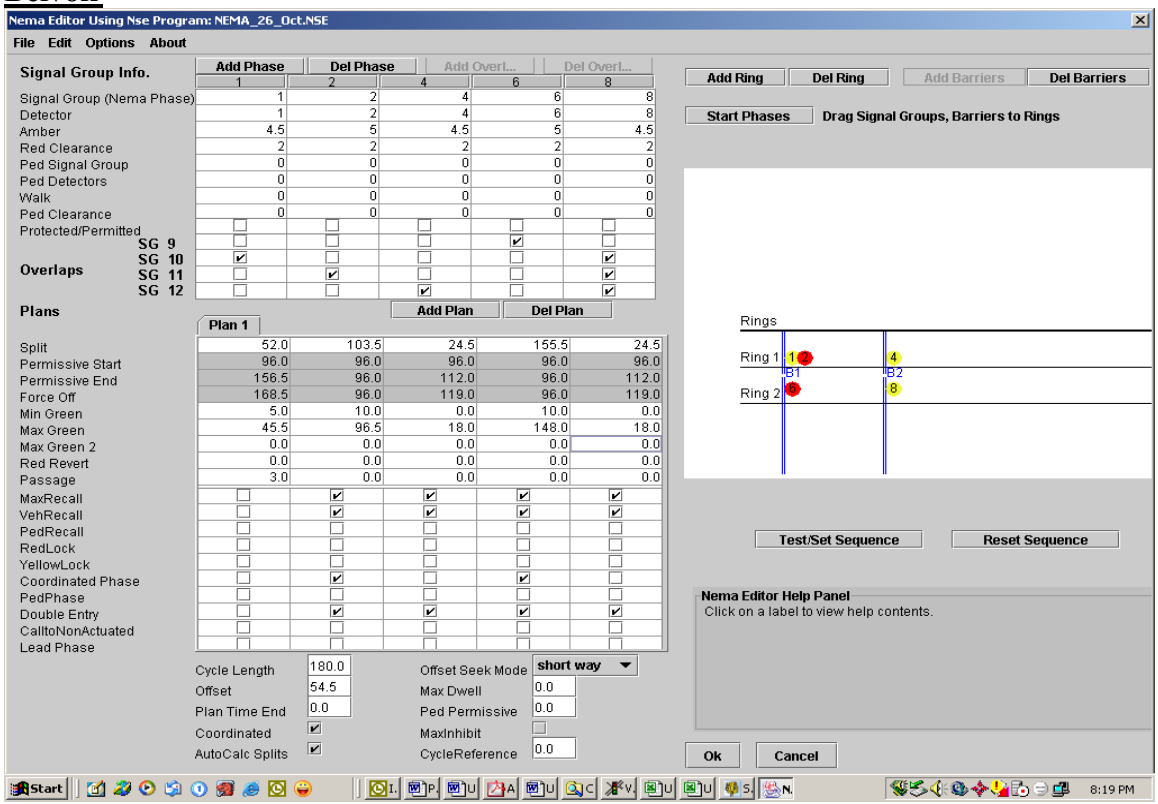
Old Mill Road



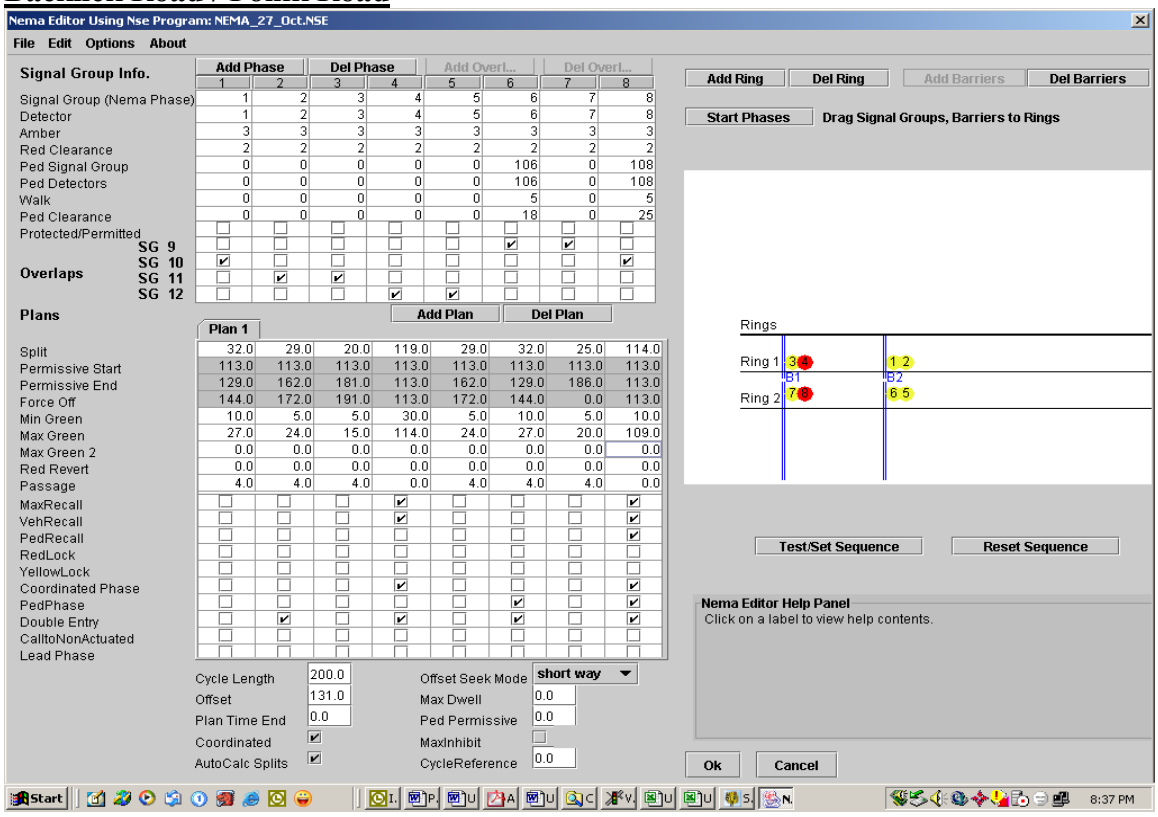
Woodlawn Road



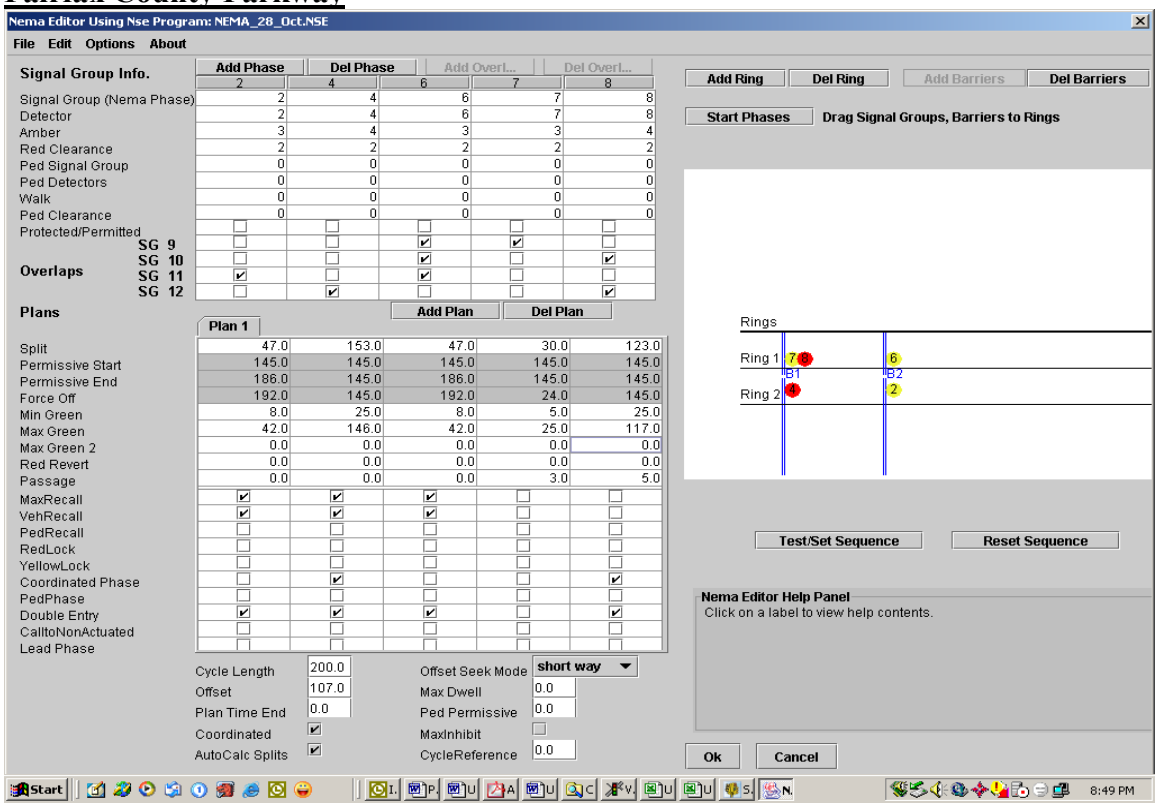
Belvoir



Backlick Road / Pohik Road

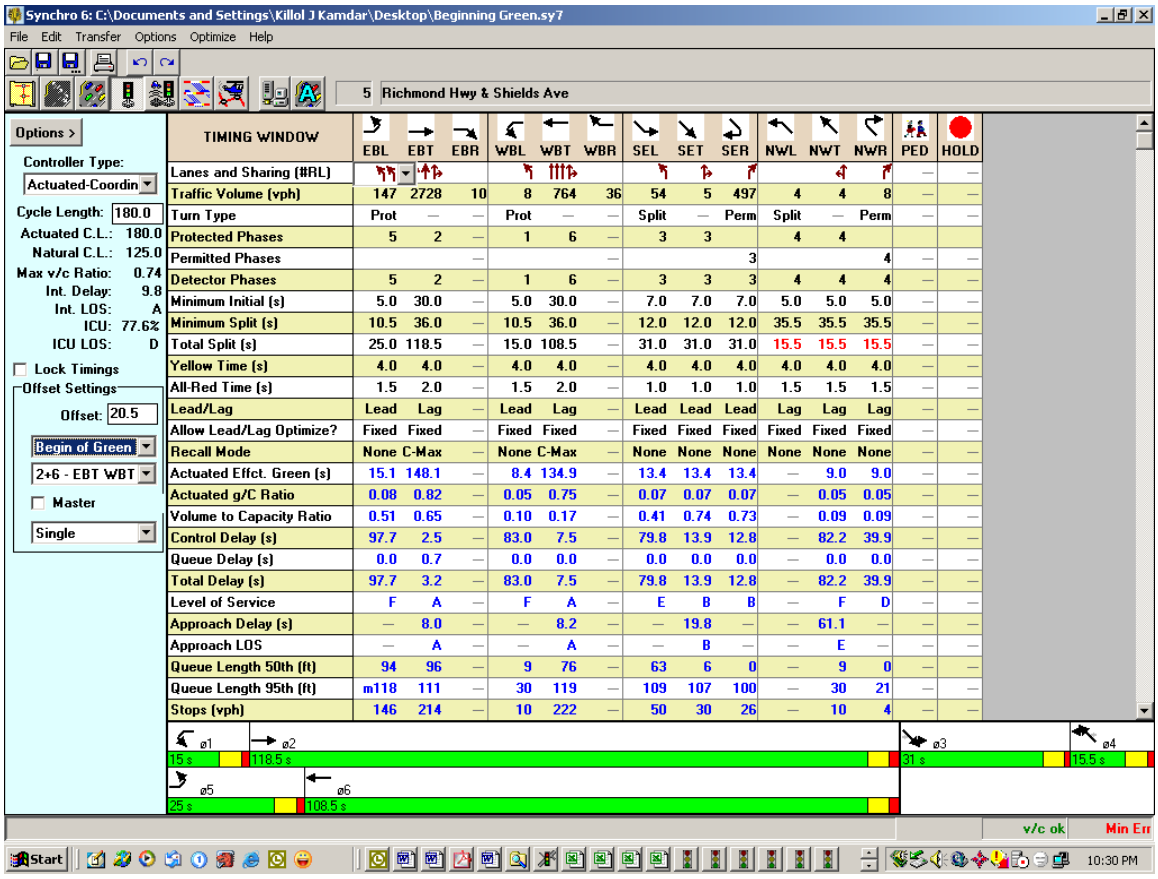


Fairfax County Parkway

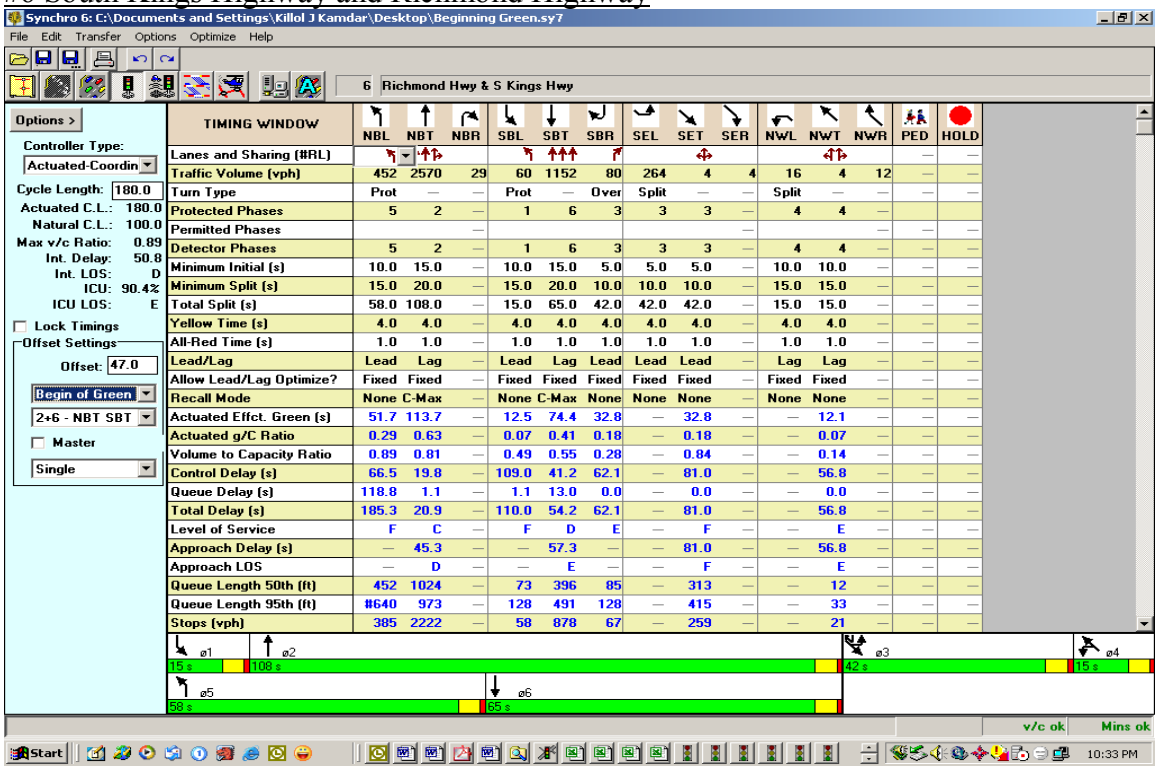


Appendix J: Synchro Files for U.S 1 Corridor

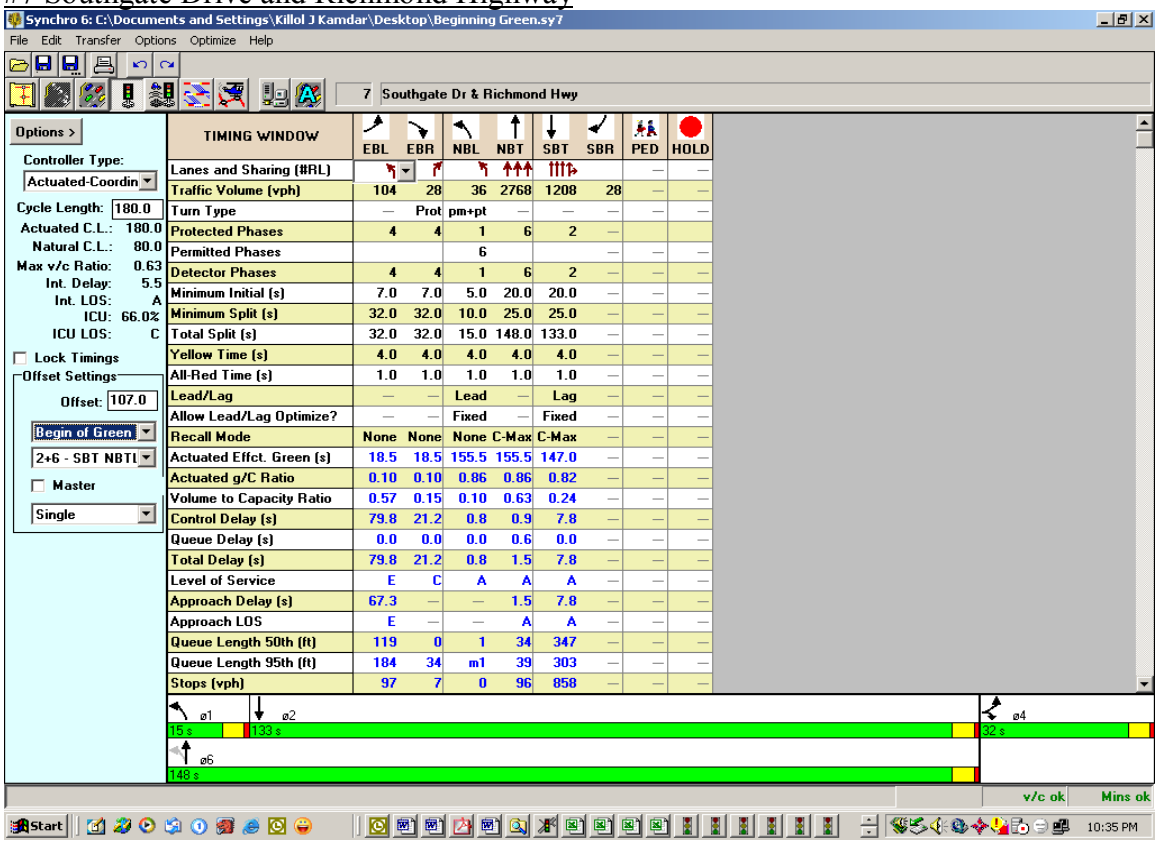
#5 North Kings Highway and Richmond Highway



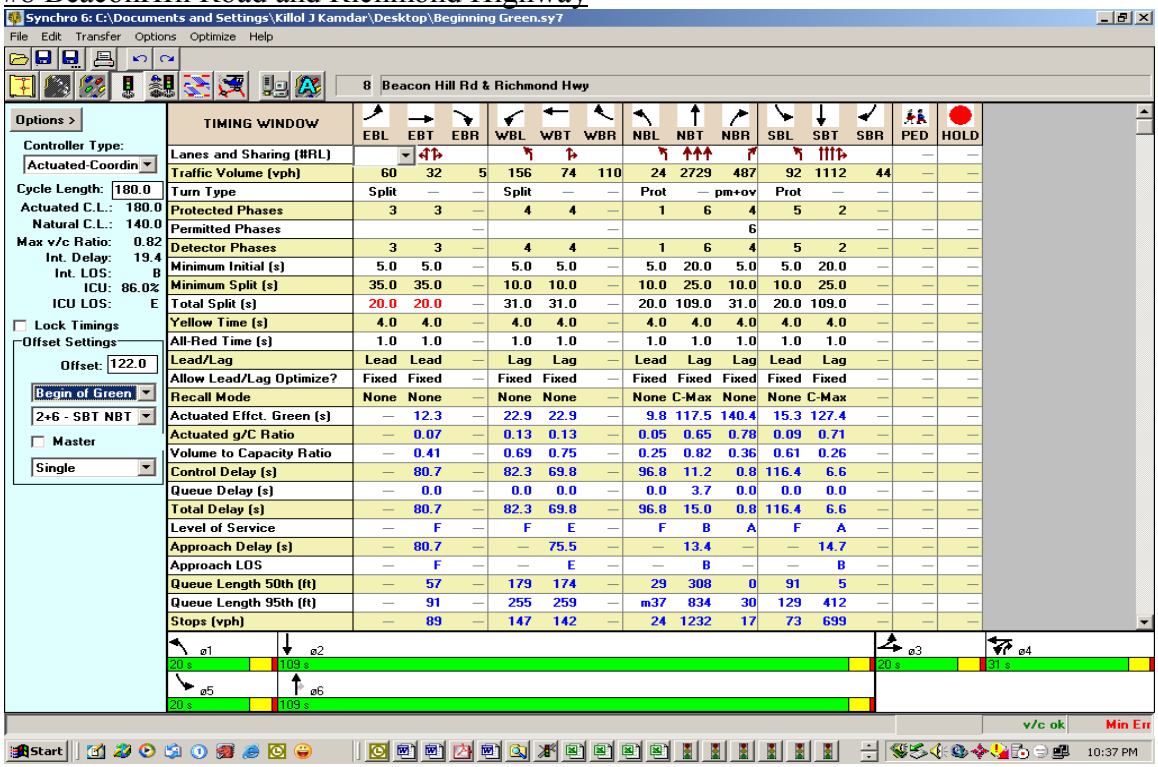
#6 South Kings Highway and Richmond Highway



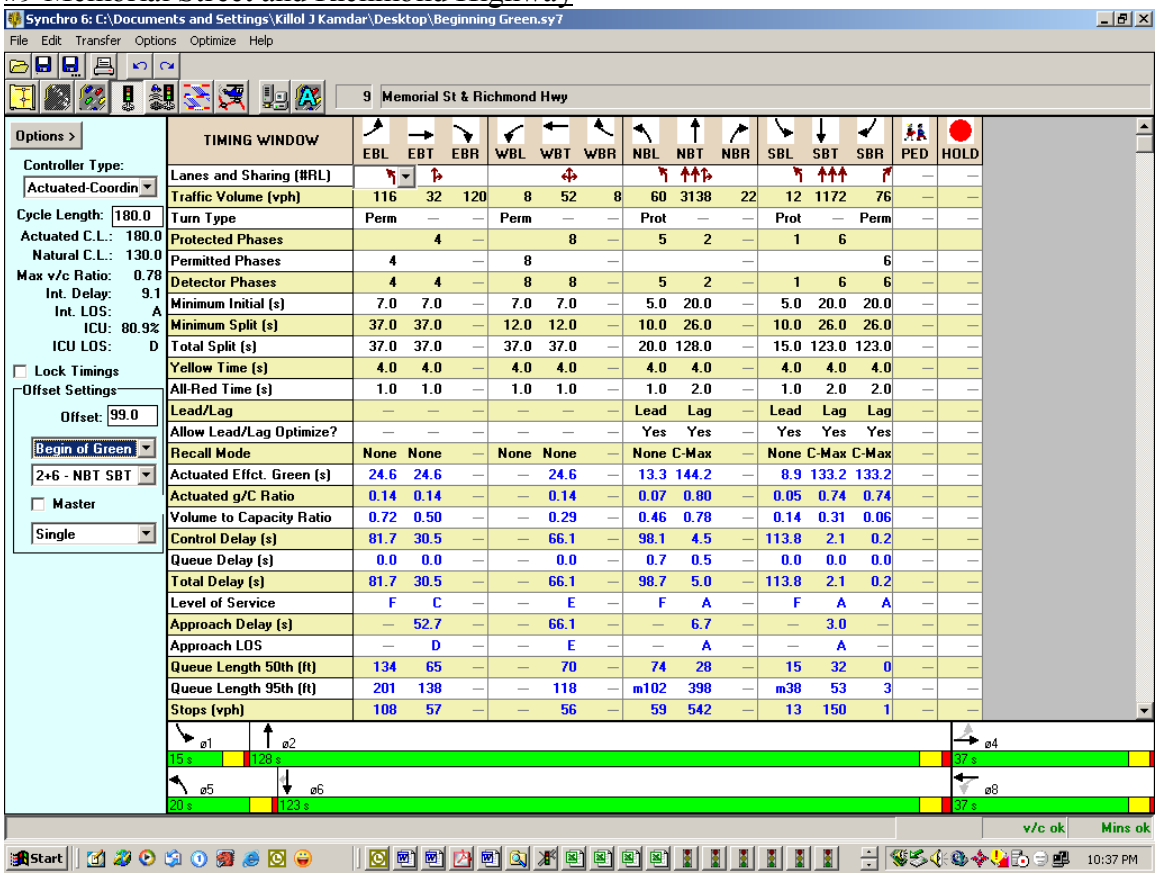
#7 Southgate Drive and Richmond Highway



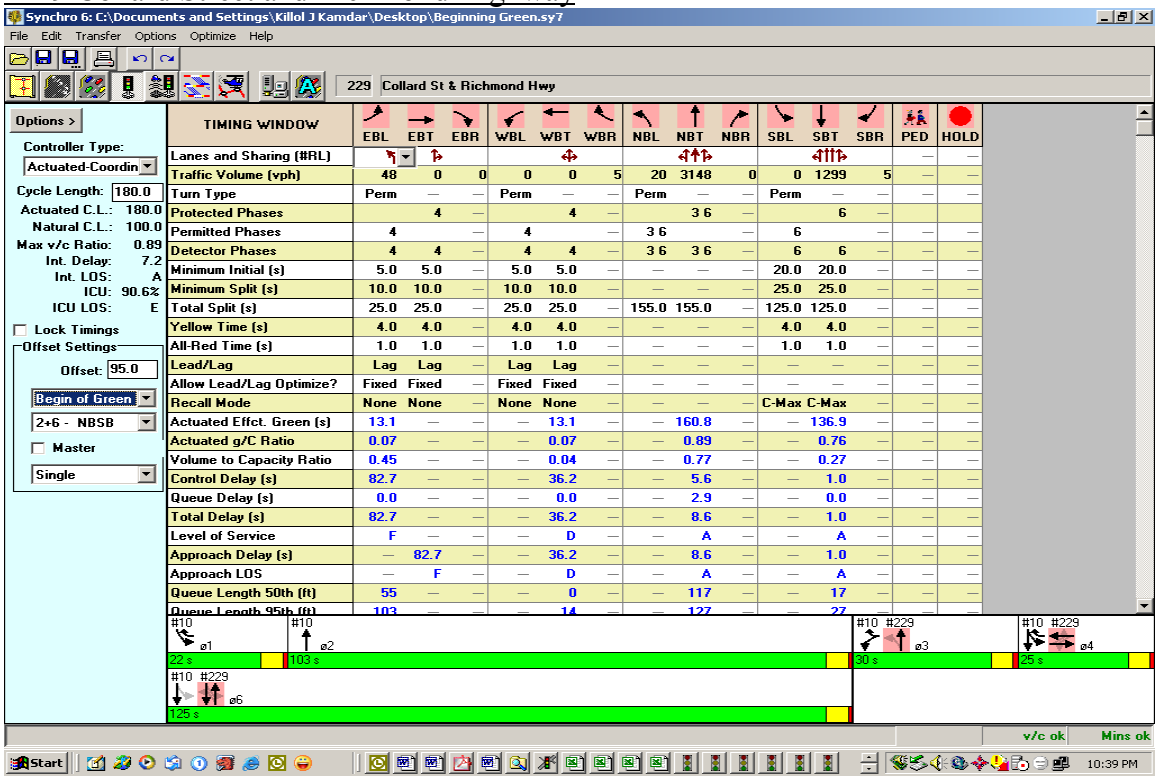
#8 BeaconHIll Road and Richmond Highway



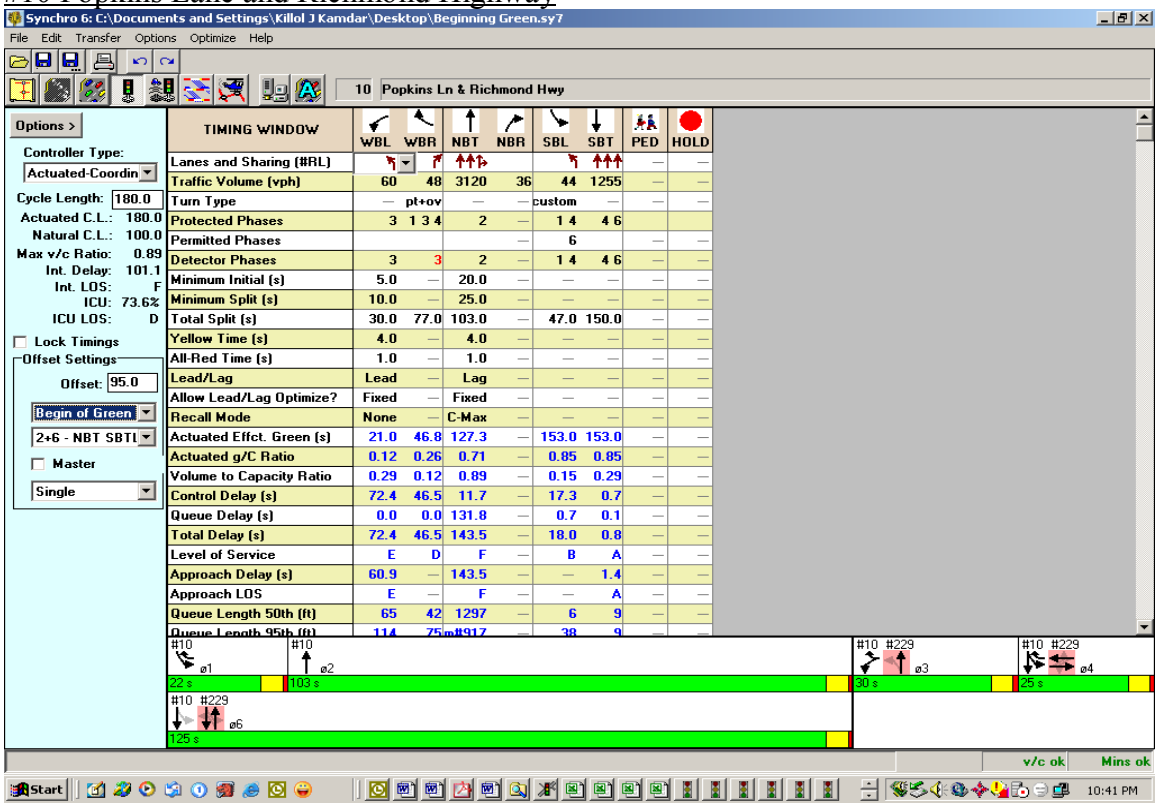
#9 Memorial Street and Richmond Highway



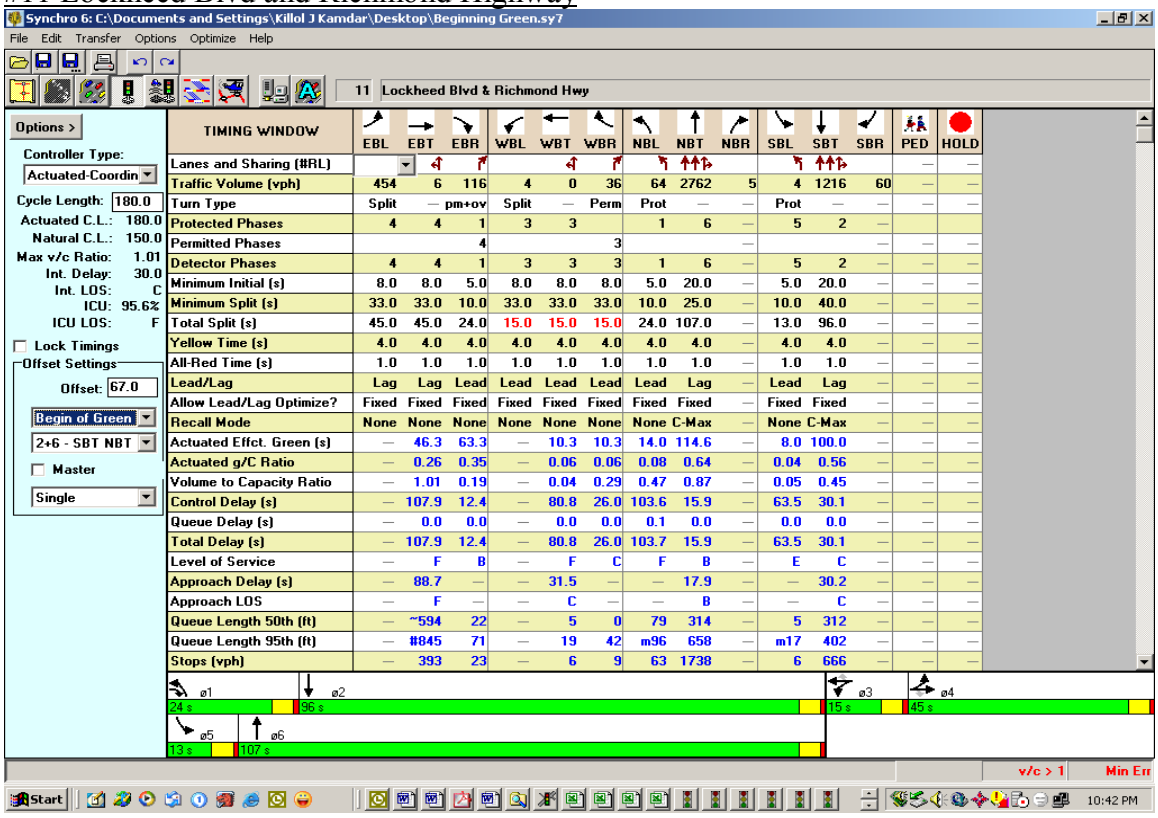
#229 Collard Street and Richmond Highway



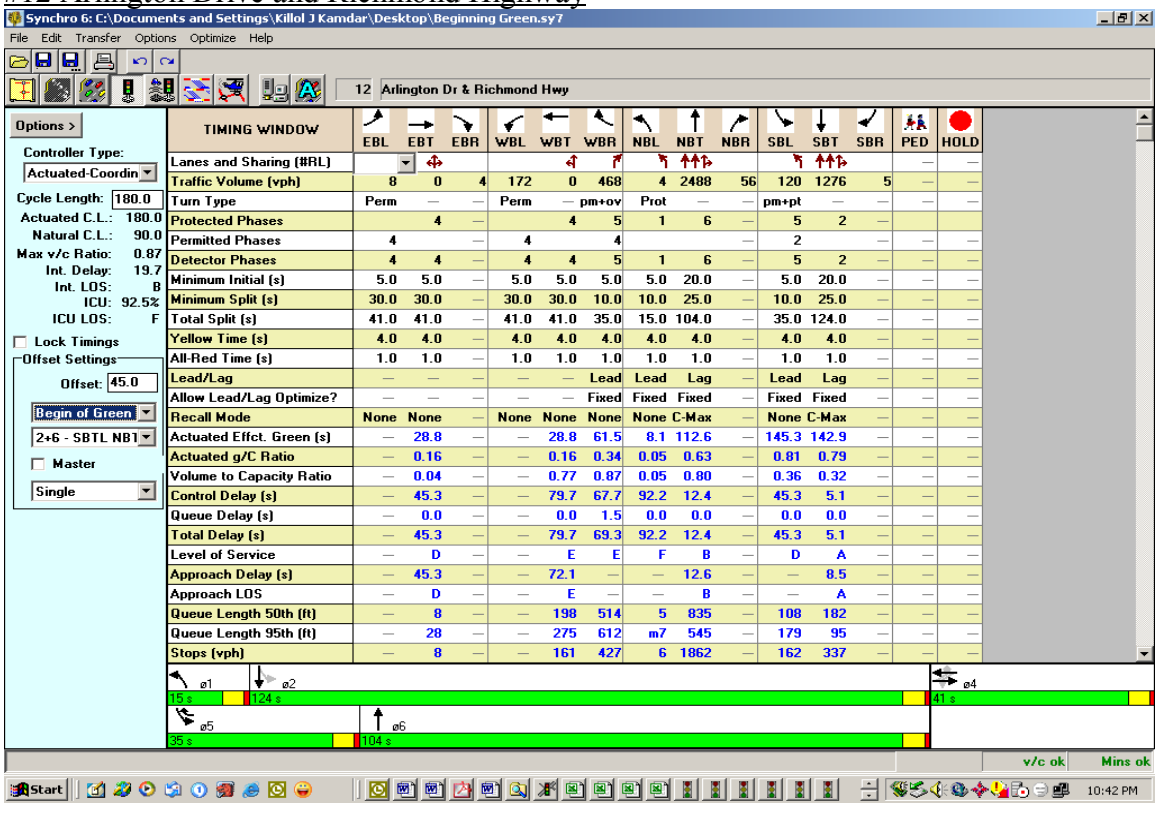
#10 Popkins Lane and Richmond Highway



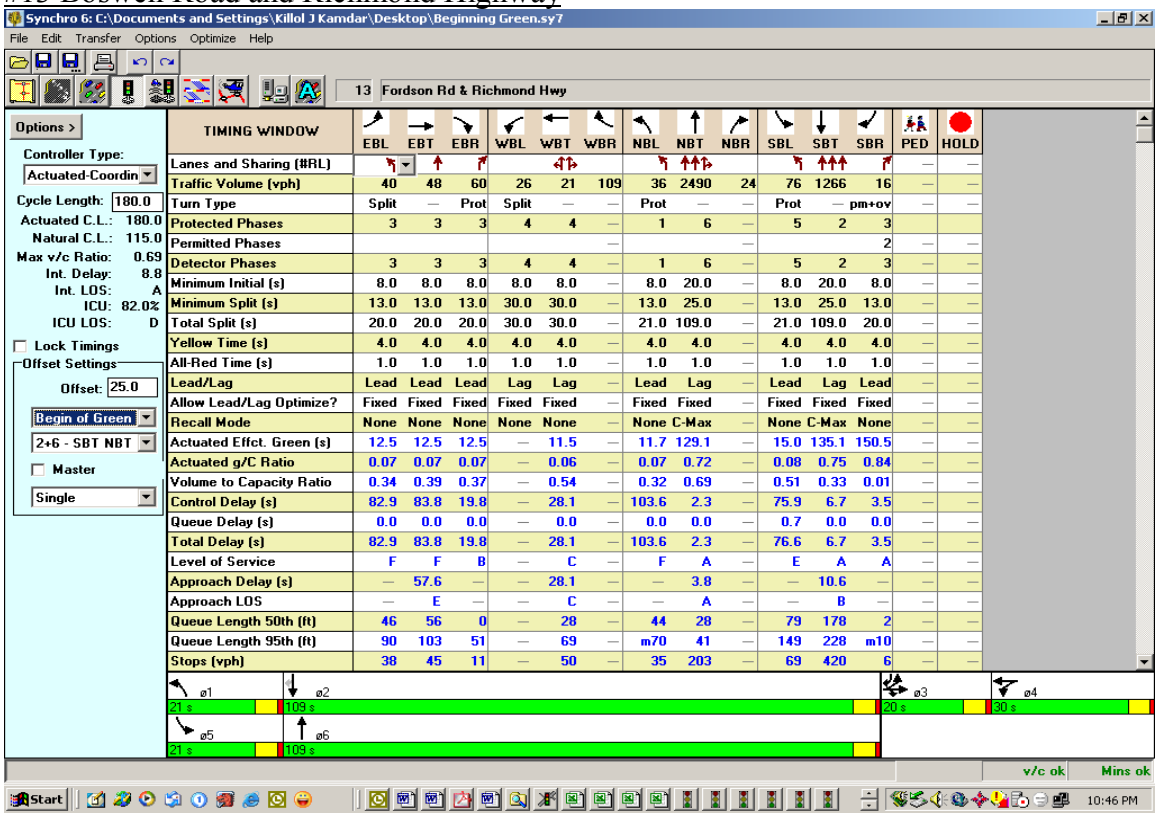
#11 Lockheed Blvd and Richmond Highway



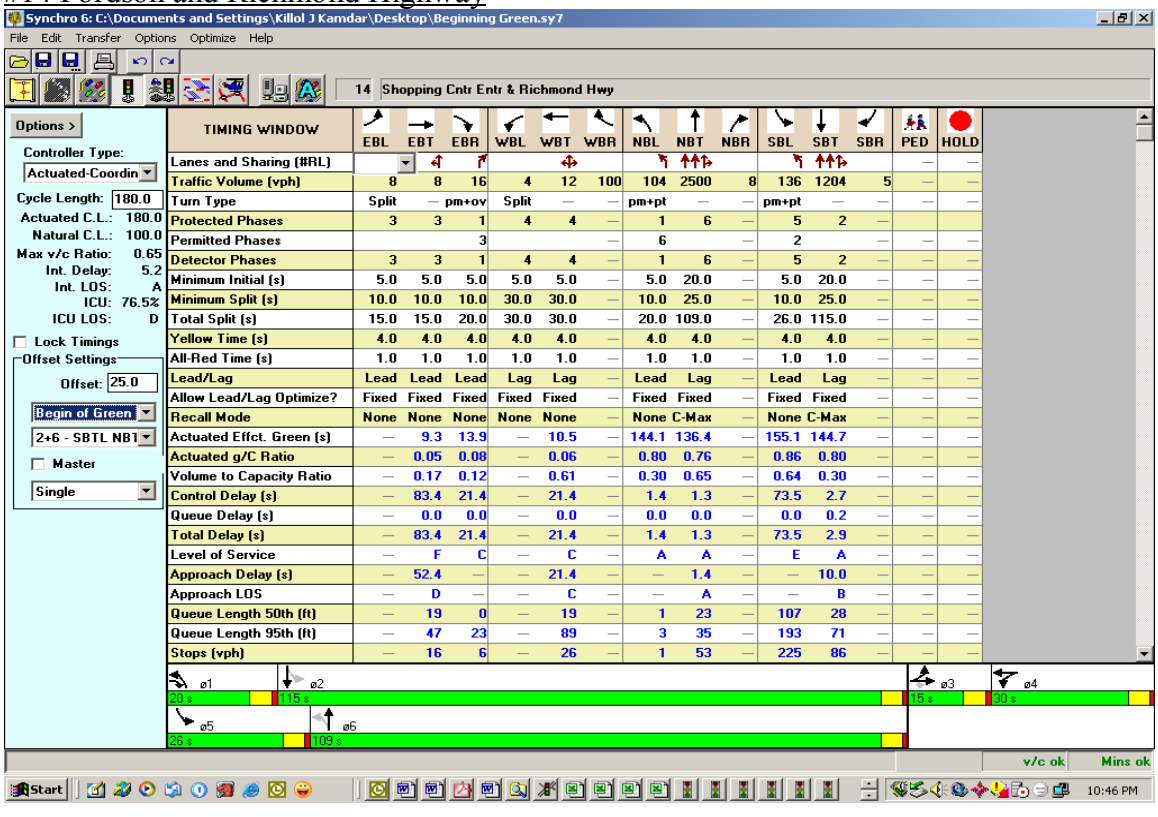
#12 Arlington Drive and Richmond Highway



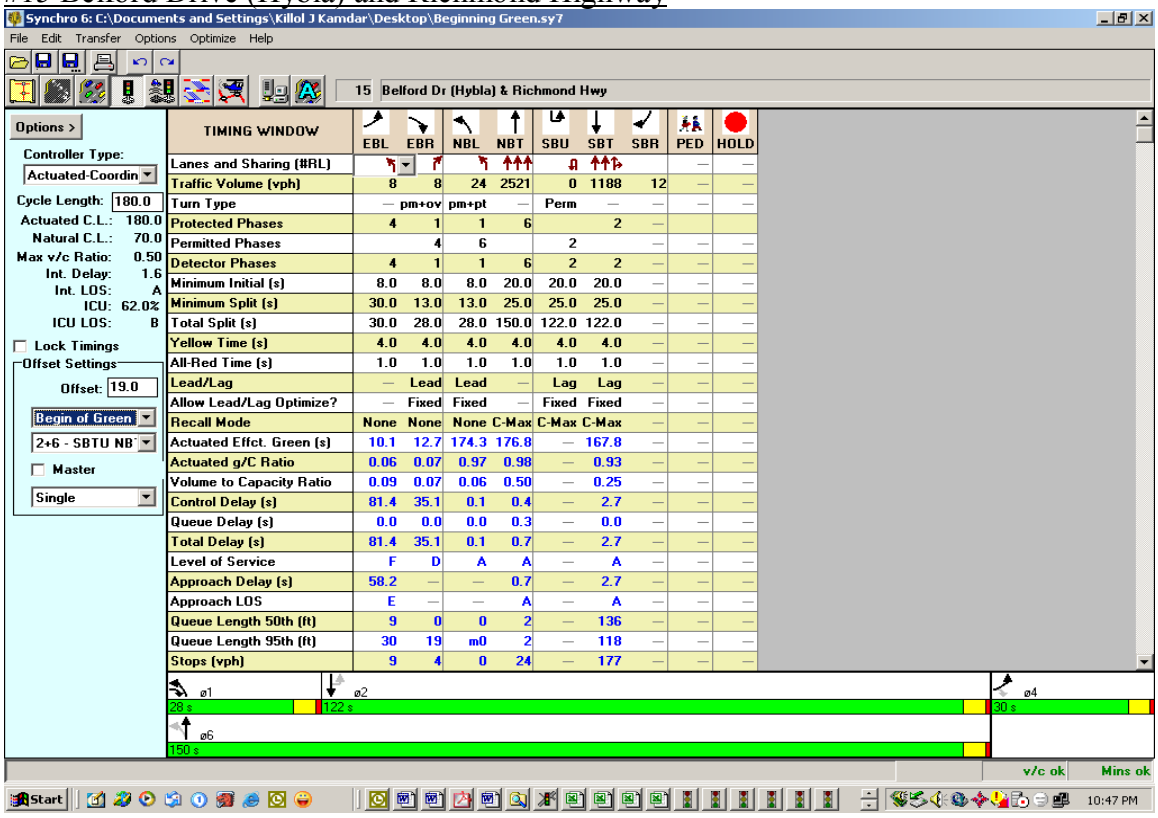
#13 Boswell Road and Richmond Highway



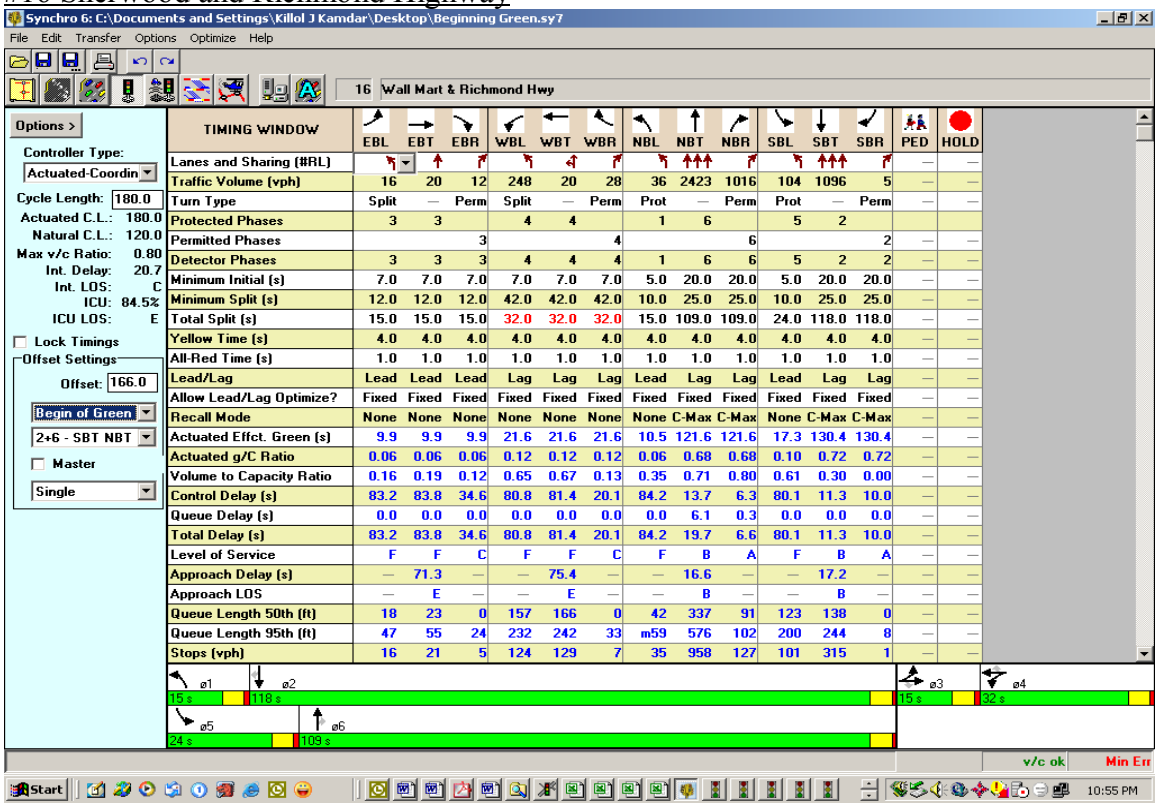
#14 Fordson and Richmond Highway



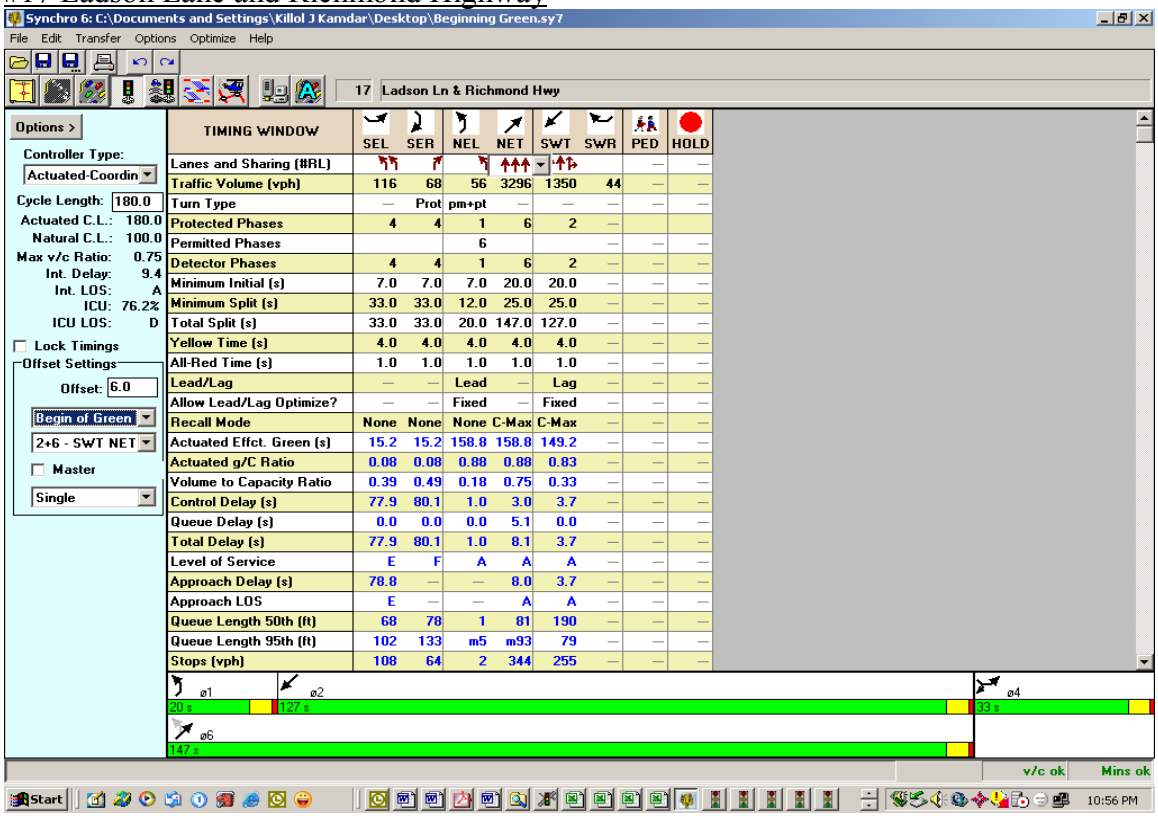
#15 Belford Drive (Hybla) and Richmond Highway



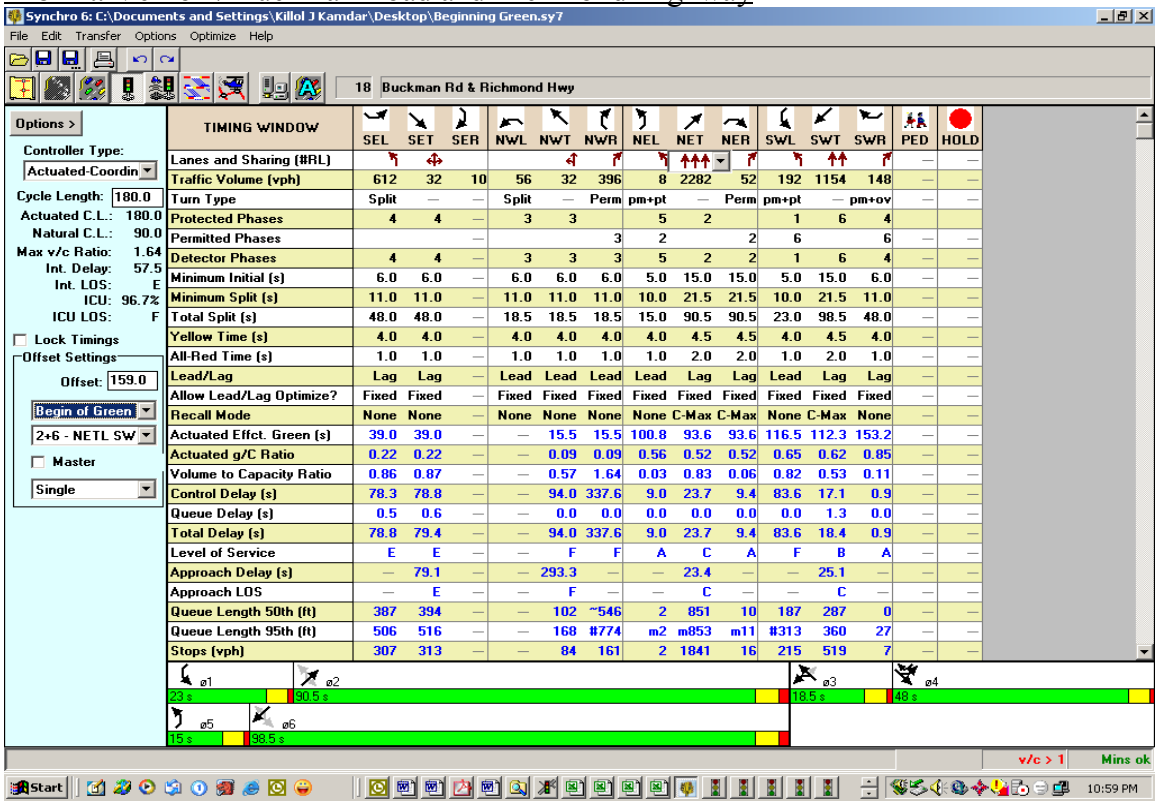
#16 Sherwood and Richmond Highway



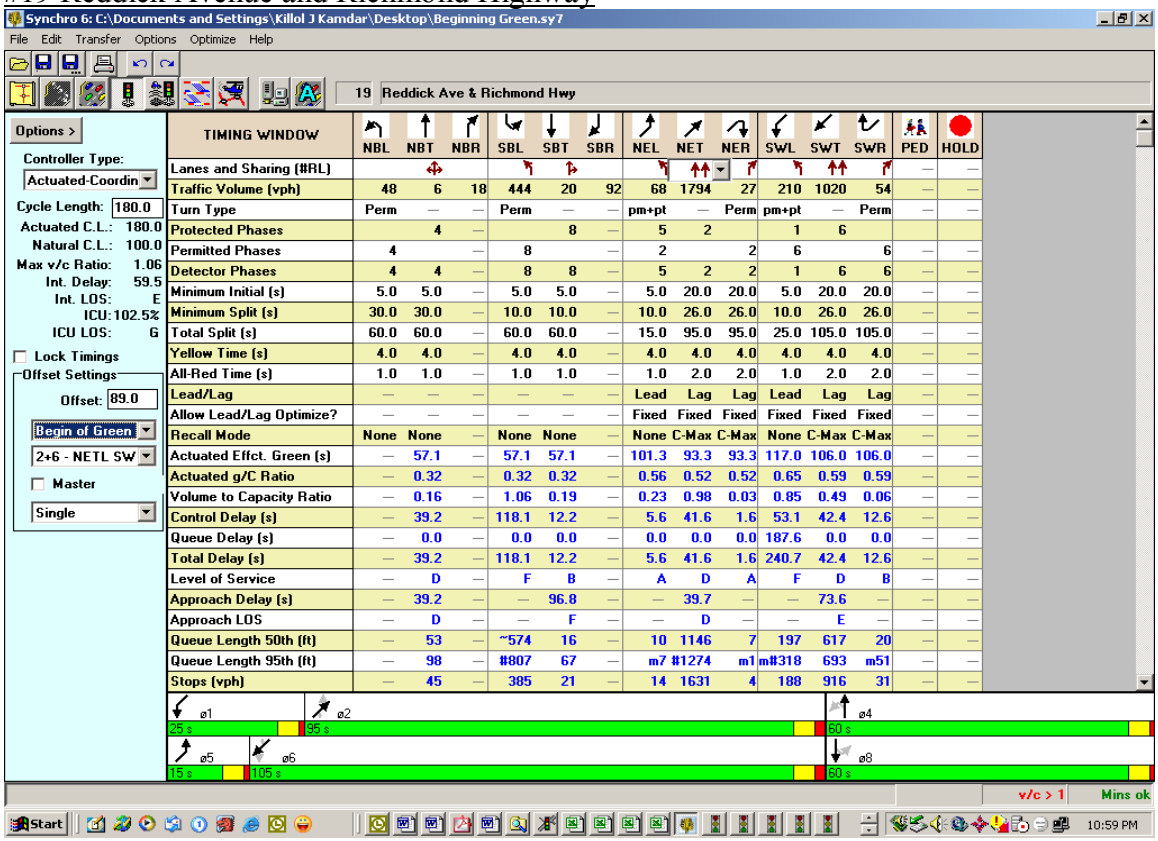
#17 Ladson Lane and Richmond Highway



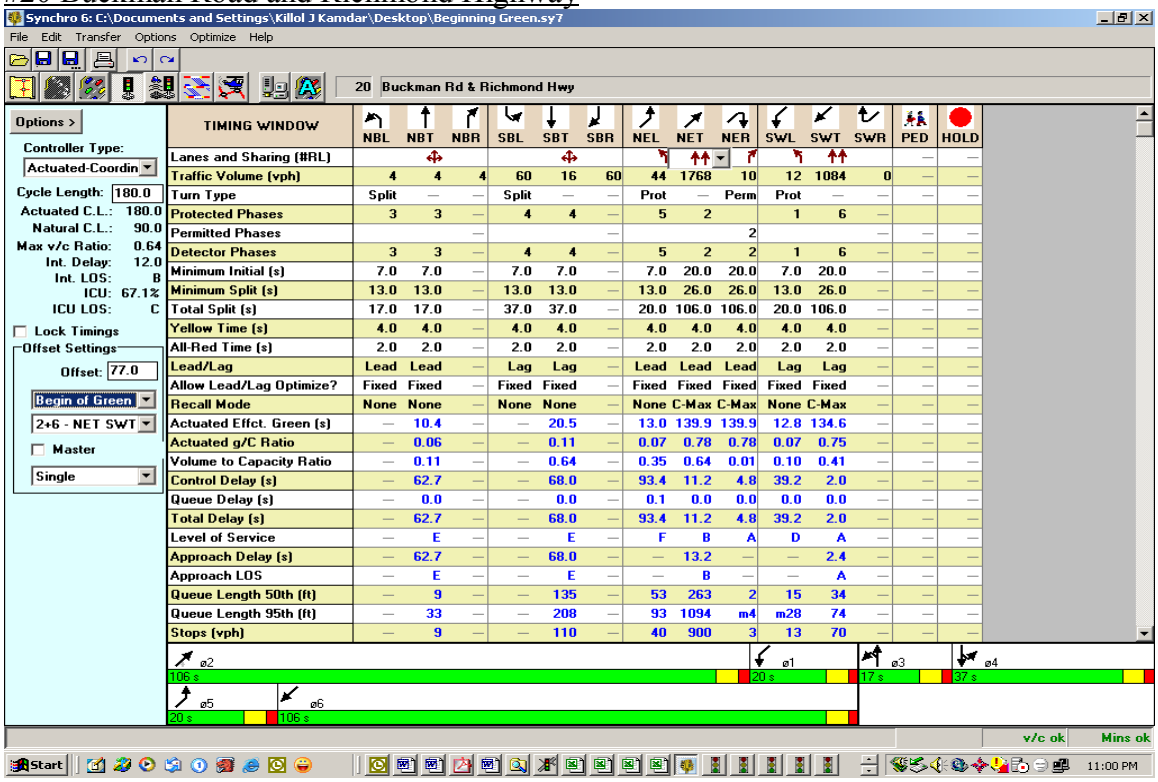
#18 Mt. Vernon / Buckman Road and Richmond Highway



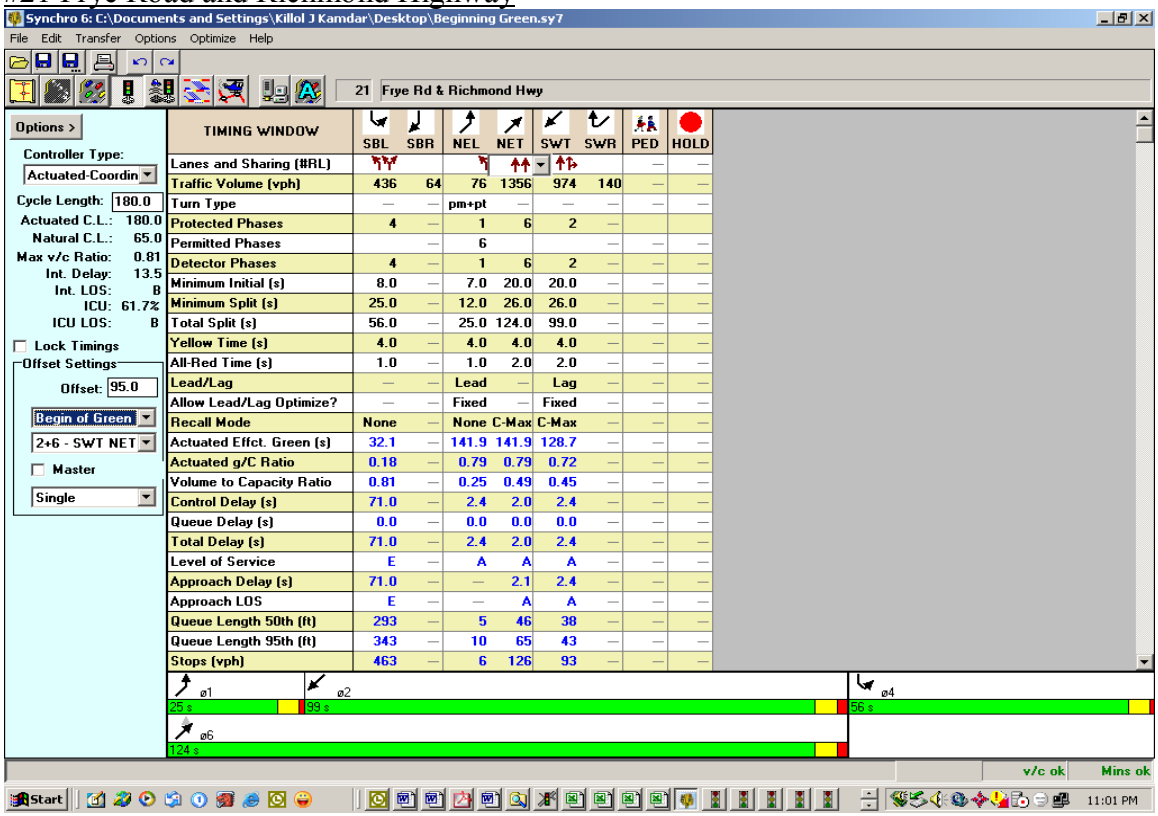
#19 Reddick Avenue and Richmond Highway



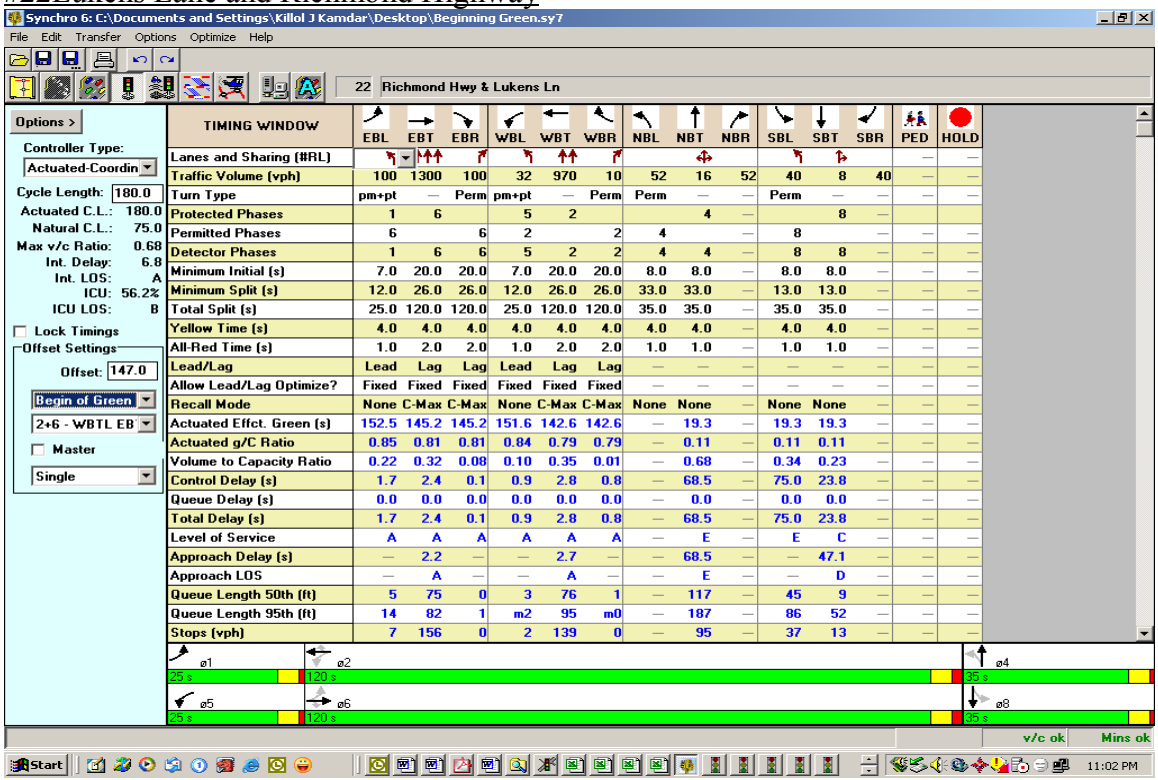
#20 Buckman Road and Richmond Highway



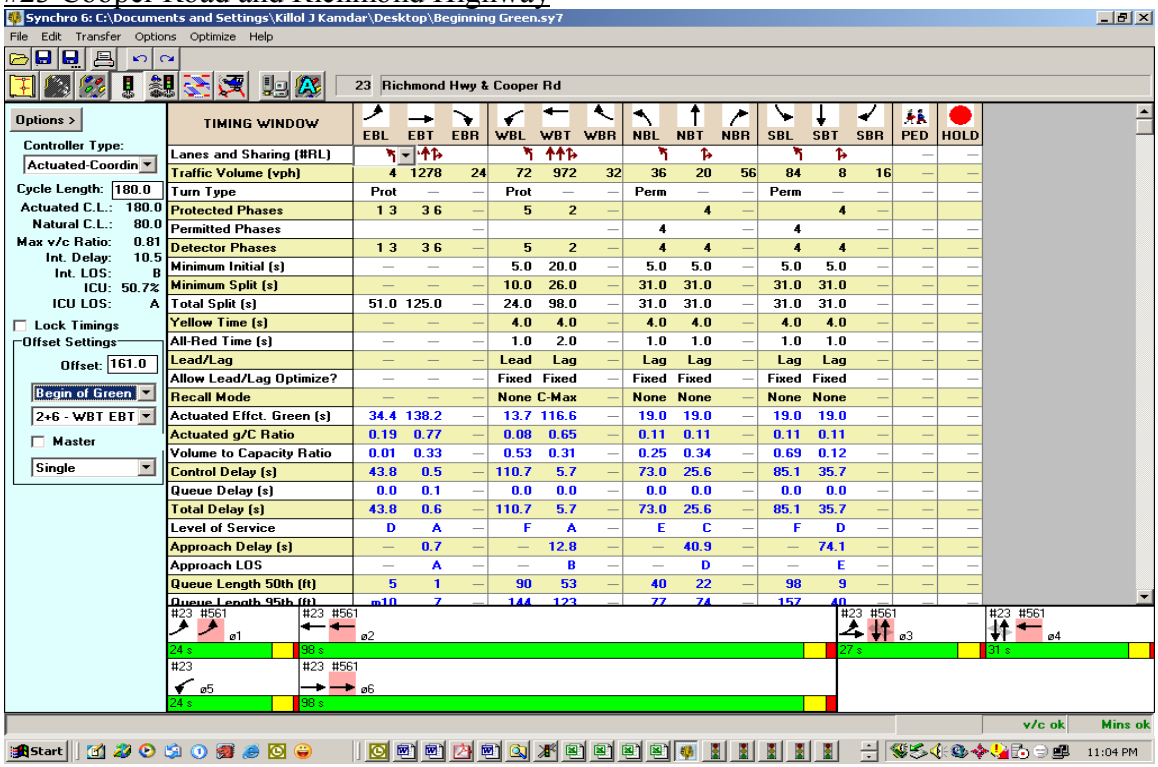
#21 Frye Road and Richmond Highway



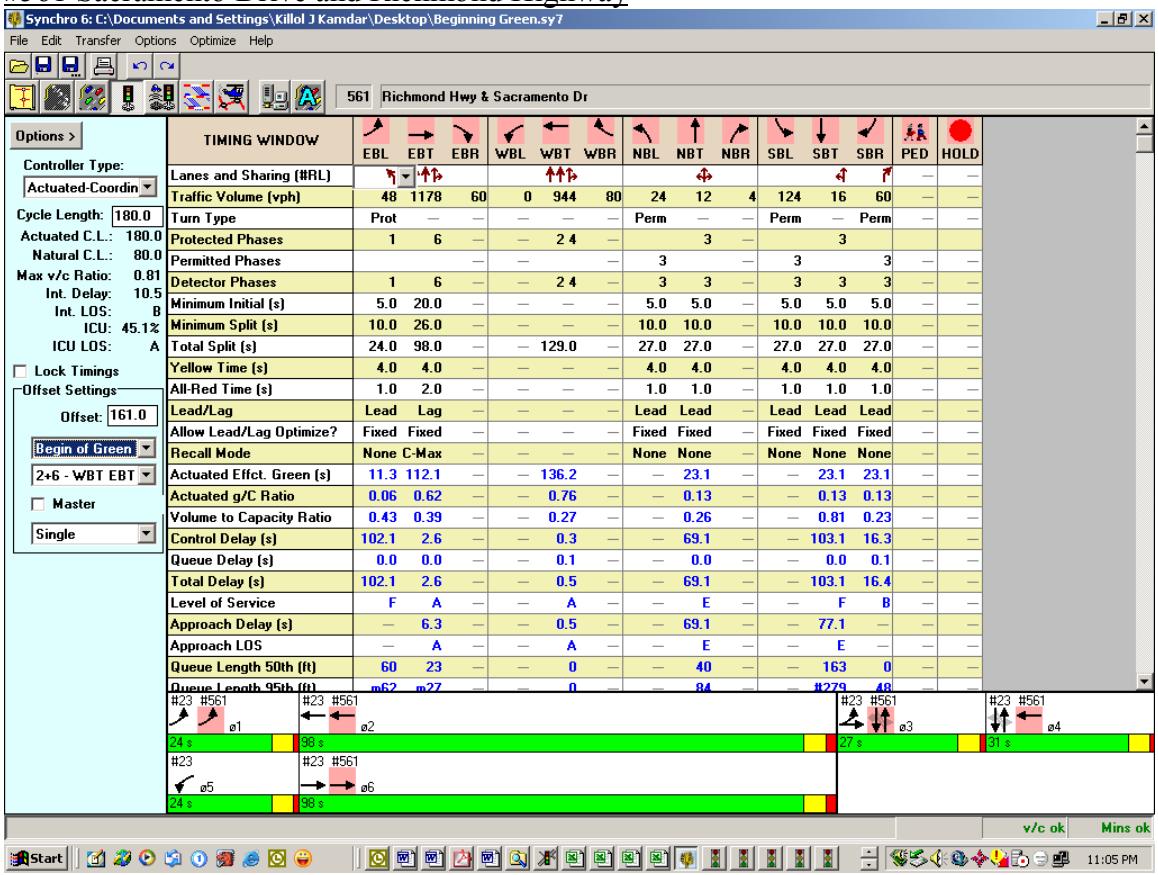
#22Lukens Lane and Richmond Highway



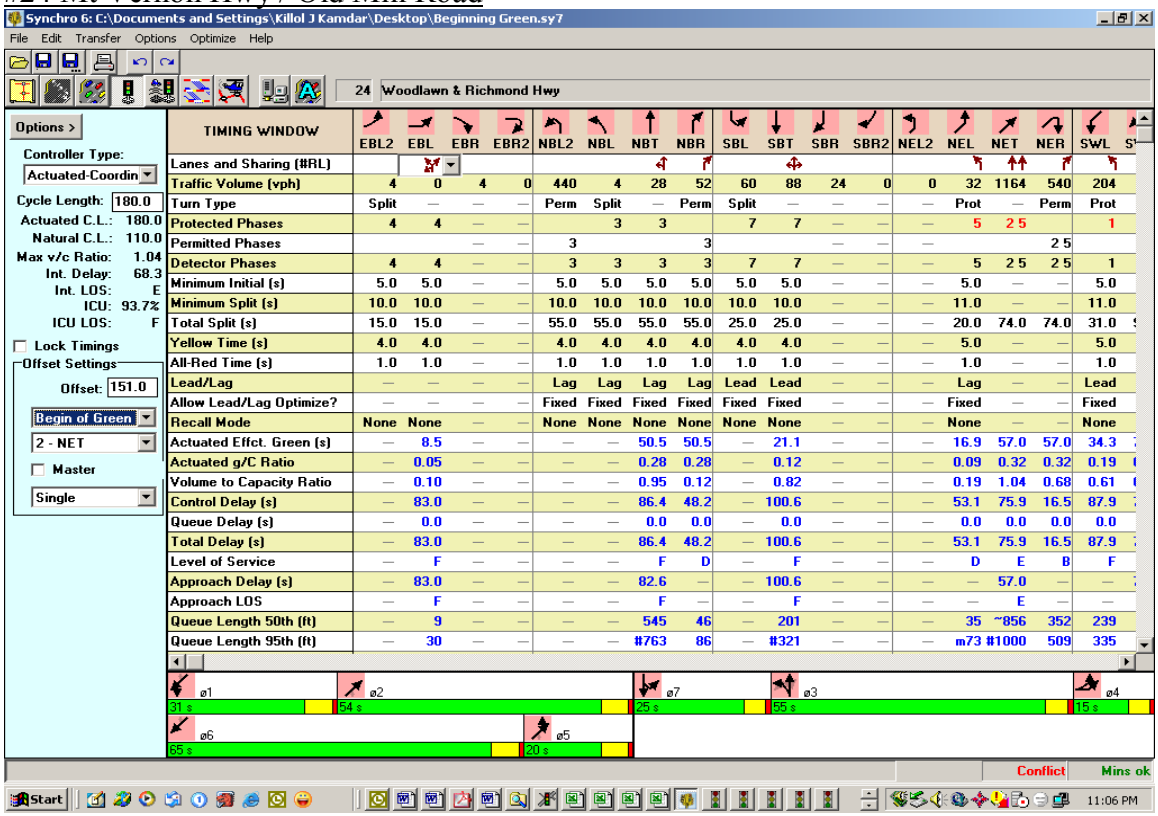
#23 Cooper Road and Richmond Highway



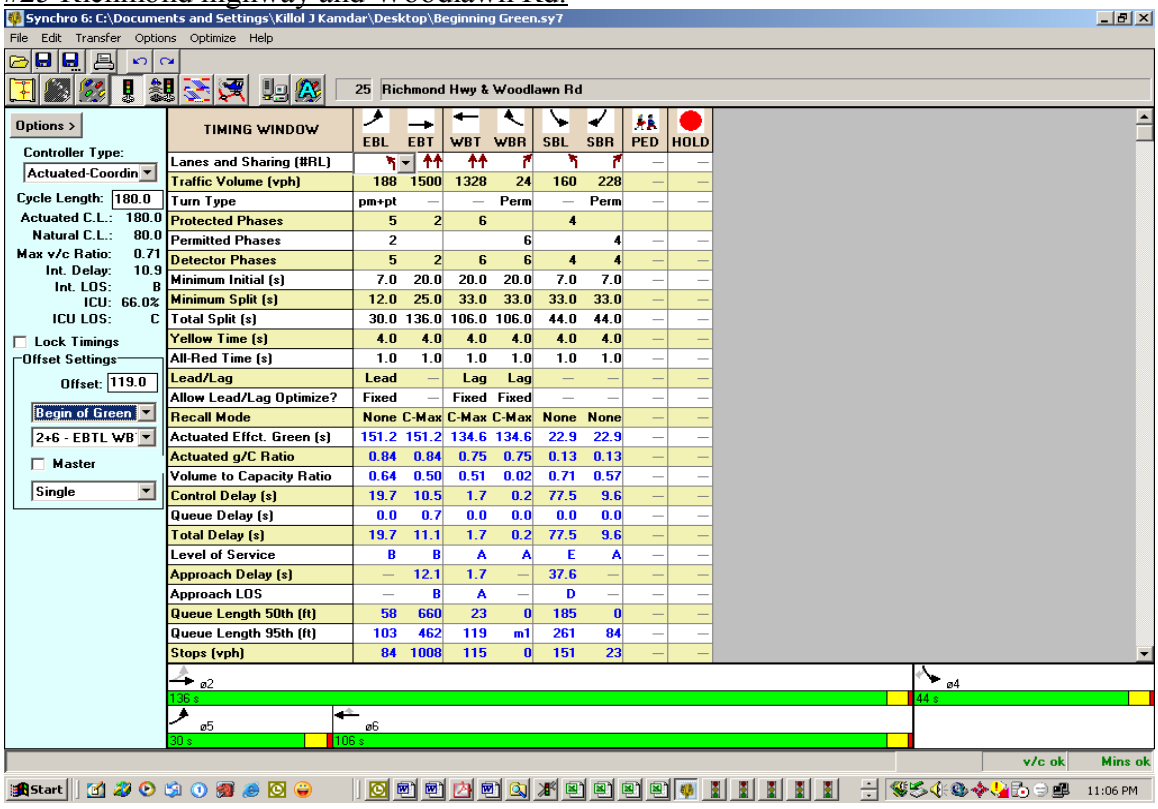
#561 Sacramento Drive and Richmond Highway



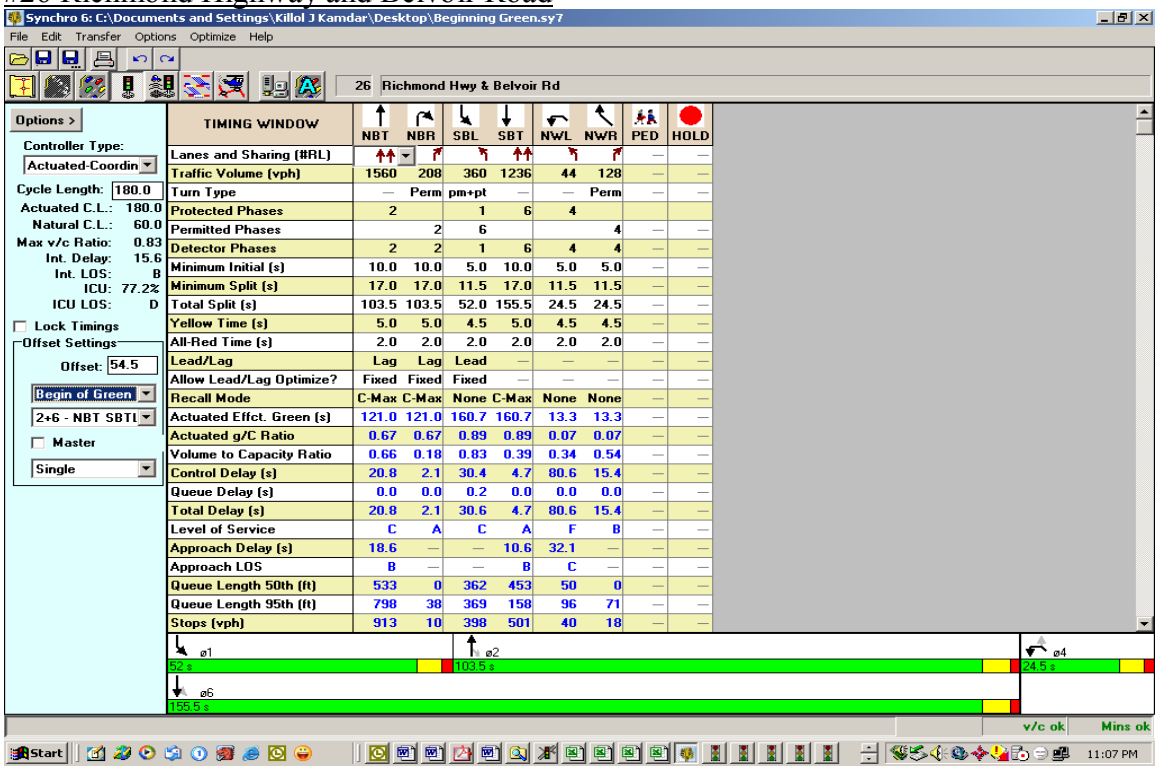
#24 Mt Vernon Hwy / Old Mill Road



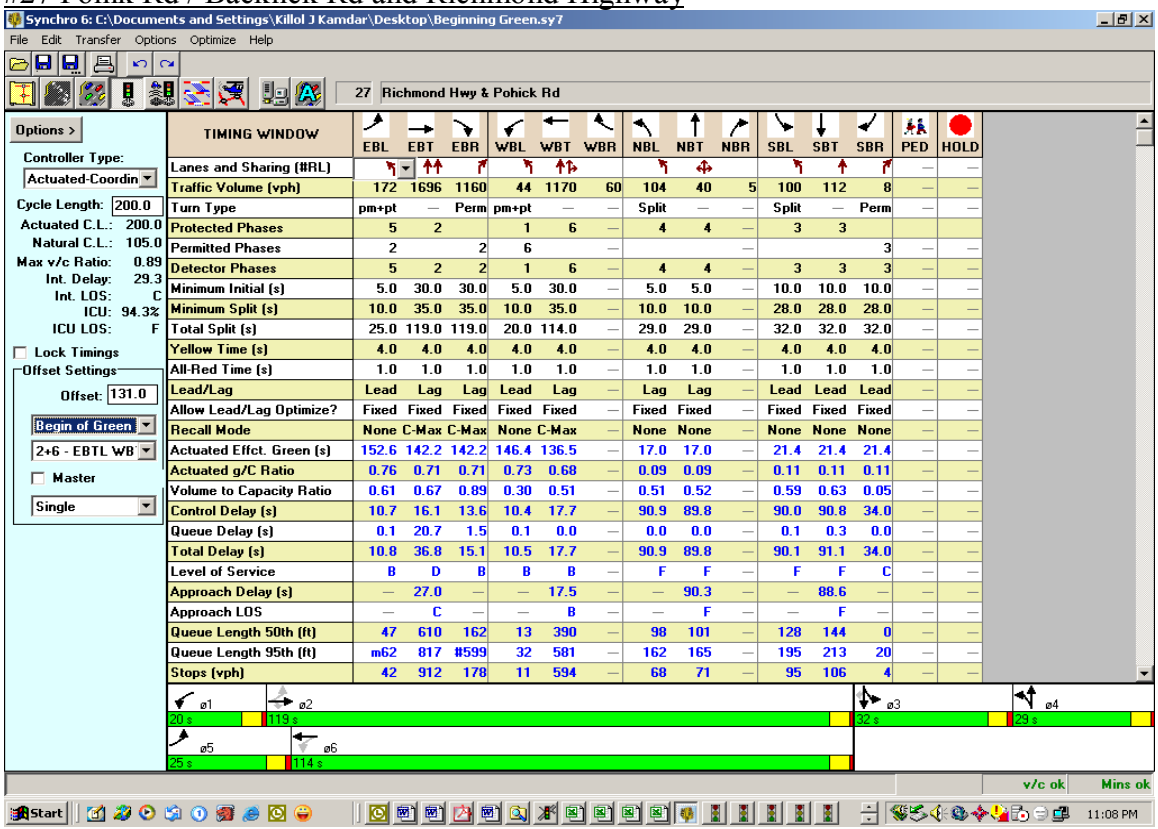
#25 Richmond highway and Woodlawn Rd.



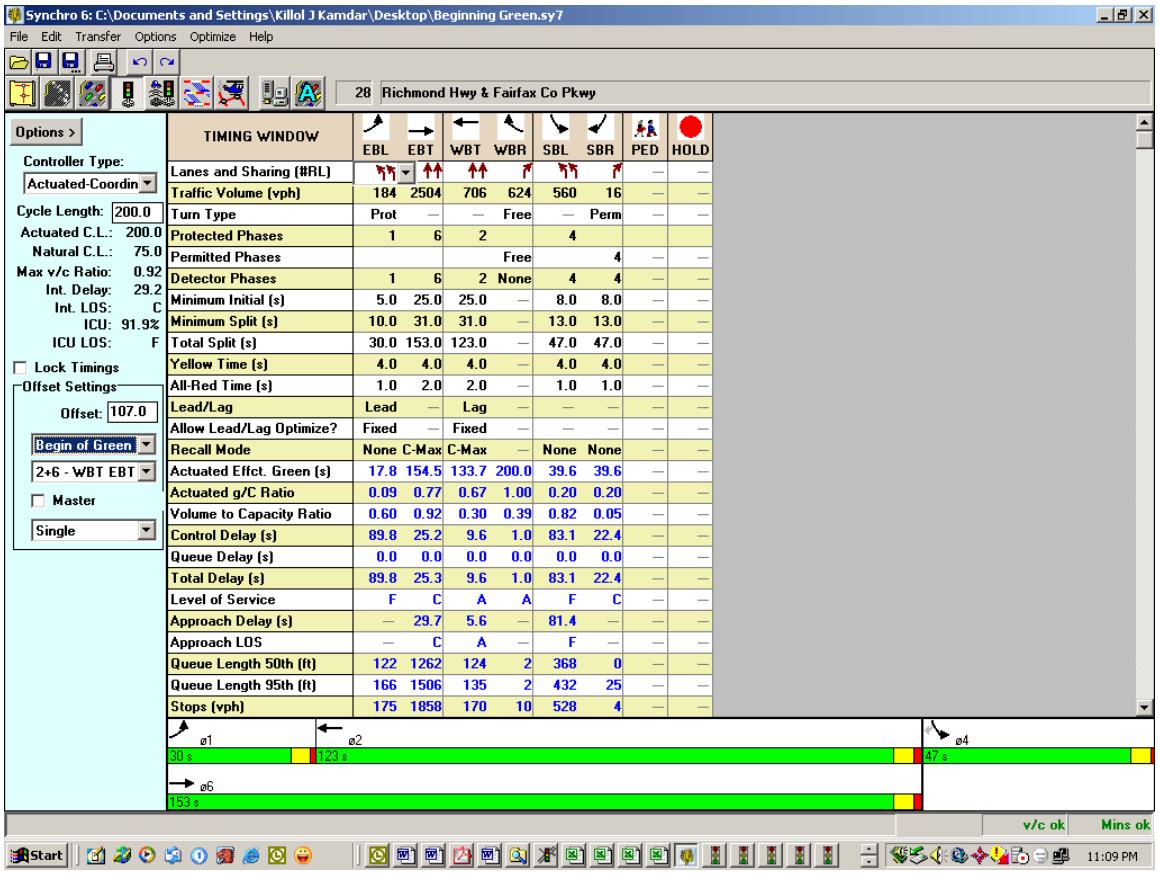
#26 Richmond Highway and Belvoir Road



#27 Pohik Rd / Backlick Rd and Richmond Highway



#28 Richmond Highway and Fairfax County Parkway



Appendix K: Statistical Analysis and Examples of VISSIM Output

Transit Travel Time Data:

Data set 1

1220 1215 1236 1215 1247 1222 1242 1225 1220 1265 1230 1221

Dataset 2

1225 1238 1219 1217 1211 1210 1218 1245 1306 1206 1215 1064

Kolmogorov – Smirnov Test:

	Range of Transit travel Time (seconds)						
	< 1200	**1200 - 1220**	**1220 - 1240**	**1240 - 1260**	**1260 - 1280**	**1280 - 1300**	**> 1300**
With TSP Number of Observation	0	4	5	2	1	0	0
Cumulative Number	0	4	9	11	12	12	12
Cumulative Percentage	0	0.33	0.75	0.92	1	1	1
Without TSP Number of Observation	1	7	2	1	0	0	1
Cumulative Number	1	8	10	11	11	11	12
Cumulative Percentage	0.08	0.67	0.83	0.92	0.92	0.92	1
Absolute observed difference	0.08	**0.34**	0.08	0	0.08	0.08	0

Significance Level: 0.05

Dmax = 1.36 * SQRT ((n1 + n2) / (n1*n2))

Dmax = 0.56

Significance Level: 0.10

Dmax = 1.22 * SQRT ((n1 + n2) / (n1*n2))

Dmax= 0.50

Here, absolute observed difference D < Dmax. Therefore the engineer cannot find a statistically significant difference (at the 0.05 significance level) when the TSP is used and is not used.

Bus Control Delay Data:

Data set 1

14 17 26 63 36 30 2 34 4 3 42 30 45 8 22 39 5 16 32 14 37 31 3 7 29 23 16 7 20 9 3

Dataset 2

18 1 15 53 3 32 8 38 46 6 2 55 47 27 64 44 52 4 24 4 7 34 28 13 11 2 24 49 1 44 7

Kolmogorov – Smirnov Test:

	Range of Bus Control Delay (seconds)							
	0 - 10	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	
With TSP Number of Observation	10	6	6	6	2	0	1	
Cumulative Number	10	16	22	28	30	30	31	= n1
Cumulative Percentage	0.32	0.52	0.71	0.90	0.97	0.97	1	
Without TSP Number of Observation	11	4	4	3	5	3	1	
Cumulative Number	11	15	19	22	27	30	31	= n2
Cumulative Percentage	0.35	0.48	0.61	0.71	0.87	0.97	1	
Absolute observed difference	0.03	0.03	0.10	**0.19**	0.10	0	0	

Significance Level: 0.05

Dmax = 1.36 * SQRT ((n1 + n2) / (n1*n2))

Dmax = 0.35

Significance Level: 0.10

Dmax = 1.22 * SQRT ((n1 + n2) / (n1*n2))

Dmax = 0.31

Here, absolute observed difference D < Dmax. Therefore the engineer cannot find a statistically significant difference (at the 0.05 significance level) when the TSP is used and is not used.

Side Street Queue Length Data:

Dataset 1

	9	126	12	73	14	18	0	0	10	3	1
	248	311	0	22	10	14	0	0	3	0	0
	81	199	3	583	4	90	40	32	2	0	5
	3	3	165	103	58	2	19	17			

Dataset 2

	9	110	7	72	20	21	0	0	11	4	1
	249	289	0	22	8	29	0	0	3	0	0
	74	210	2	632	4	101	67	38	2	0	7
	5	1	136	116	31	1	21	6			

Kolmogorov – Smirnov Test:

	Range of Bus Side Street Queue Lengths (feet)						
	< 20	**21 - 80**	**81 - 140**	**141 - 200**	**201 - 260**	**> 261**	
With TSP Number of Observation	19	5	4	2	1	2	
Cumulative Number	19	24	28	30	31	33	= n1
Cumulative Percentage	0.58	0.73	0.85	0.91	0.94	1	
Without TSP Number of Observation	16	9	4	0	2	2	
Cumulative Number	16	25	29	29	31	33	= n2
Cumulative Percentage	0.49	0.76	0.88	0.88	0.94	1	
Absolute observed difference	**0.09**	0.03	0.03	0.03	0	0	

Significance Level: 0.05

Dmax = 1.36 * SQRT ((n1 + n2) / (n1*n2))

Dmax = 0.33

Significance Level: 0.10

Dmax = 1.22 * SQRT ((n1 + n2) / (n1*n2))

Dmax = 0.30

Here, absolute observed difference D < Dmax. Therefore the engineer cannot find a statistically significant difference (at the 0.05 significance level) when the TSP is used and is not used.

Examples of VISSIM Output for U.S. 1 No-TSP Condition

1) TABLE OF TRAVEL TIMES

U.S. 1 Model for Entire Fairfax Connector us Route

No. 2 (Southbound): from link 149 at 285.1 ft to link 112 at 5000.8 ft, Distance 47963.4 ft
No. 105 (105_NB): from link 1000144 at 12.2 ft to link 150 at 687.1 ft, Distance 17260.9 ft
No. 106 (106_NB): from link 134 at 75.9 ft to link 150 at 687.1 ft, Distance 13673.8 ft
No. 107 (107_NB): from link 111 at 4.3 ft to link 150 at 686.9 ft, Distance 48419.2 ft

Time; Trav;#Veh; Trav;#Veh; Trav;#Veh; Trav;#Veh; Trav;#Veh; Trav;#Veh; Trav;#Veh;
VehC; All;; 105_NB;; Car;; 106_NB;; Car;; 107_NB;; Car;;
No.:; 2; 2; 105; 105; 105; 105; 106; 106; 106; 106; 107; 107; 107; 107;
Name;Southbound;Southbound;105_NB;105_NB;105_NB;105_NB;106_NB;106_NB;106_NB;106_NB;107_NB;107_NB;107_NB;107_NB;
600; 0.0; 0; 0.0; 0; 363.5; 11; 0.0; 0; 282.0; 21; 0.0; 0; 0.0; 0;
1200; 972.5; 1; 0.0; 0; 359.3; 90; 0.0; 0; 269.4; 110; 0.0; 0;1006.7; 1;
1800; 958.2; 2; 0.0; 0; 372.7; 145; 914.2; 1; 279.6; 180; 0.0; 0;1088.4; 10;
2400;1121.7; 2;1220.2; 1; 374.9; 113; 0.0; 0; 282.9; 133; 0.0; 0;1027.5; 12;
3000;1127.2; 2;1215.3; 1; 373.3; 150; 0.0; 0; 281.5; 172;2948.4; 1;1028.0; 8;
3600;1114.2; 2; 0.0; 0; 370.0; 117; 907.2; 1; 277.8; 147; 0.0; 0;1032.5; 5;

2) TABLE OF TRANSIT CONTROL DELAY

U.S. 1 Model for Entire Fairfax Connector us Route

No. 1: Travel time section(s) 2
No. 2: Travel time section(s) 105
No. 3: Travel time section(s) 106
No. 4: Travel time section(s) 107
No. 5: Travel time section(s) 107

Time; Delay; Stopd; Stops; #Veh; Pers.; #Pers; Delay; Stopd; Stops; #Veh; Pers.; #Pers; Delay; Stopd; Stops; #Veh; Pers.; #Pers; Delay; Stopd; Stops; #Veh; Pers.; #Pers; Delay; Stopd; Stops; #Veh; Pers.; #Pers;
VehC; All;;;;;; 105_NB;;;;;; 106_NB;;;;;; 107_NB;;;;;; Car;;;;;;
No.:; 1; 1; 1; 1; 1; 1; 2; 2; 2; 2; 2; 2; 3; 3; 3; 3; 3; 3; 4; 4; 4; 4; 4; 4; 5; 5; 5; 5; 5; 5;
600; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0;
1200; 180.1; 111.8; 7.00; 1; 180.1; 1; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0; 233.1; 84.2; 11.00; 1; 233.1; 1;
1800; 202.9; 69.9; 10.00; 2; 202.9; 2; 0.0; 0.0; 0.00; 0; 0.0; 0; 125.8; 79.1; 2.00; 1; 125.8; 33; 0.0; 0.0; 0.00; 0; 0.0; 0; 321.7; 137.6; 14.20; 10; 321.7; 10;
2400; 361.9; 231.2; 14.00; 2; 361.9; 2; 196.3; 113.5; 8.00; 1; 196.3; 30; 0.0; 0.0; 0.00; 0; 0.0; 0; 0.0; 0.0; 0.00; 0; 0.0; 0; 245.2; 125.1; 7.67; 12; 245.2; 12;
3000; 350.7; 251.3; 7.00; 2; 350.7; 2; 201.1; 126.9; 6.00; 1; 201.1; 35; 0.0; 0.0; 0.00; 0; 0.0; 0; 338.6; 201.5; 8.00; 1; 338.6; 35; 249.5; 124.6; 7.25; 8; 249.5; 8;
3600; 353.9; 168.6; 9.50; 2; 353.9; 2; 0.0; 0.0; 0.00; 0; 0.0; 0; 129.0; 81.2; 3.00; 1; 129.0; 33; 0.0; 0.0; 0.00; 0; 0.0; 0; 271.0; 137.4; 9.40; 5; 271.0; 5;
Total; 302.1; 172.6; 9.78; 9; 302.1; 9; 198.7; 120.2; 7.00; 2; 198.9; 65; 127.4; 80.1; 2.50; 2; 127.4; 66; 338.6; 201.5; 8.00; 1; 338.6; 35; 270.7; 129.1; 9.72; 36; 270.7; 36;

3) QUEUE LENGTH RECORD

U.S. 1 Model for Entire Fairfax Connector us Route

Queue Counter 1: Link 2 At 635.400 ft
Queue Counter 2: Link 1000010 At 85.000 ft
Queue Counter 3: Link 1000015 At 13.900 ft
Queue Counter 4: Link 28 At 503.000 ft
Queue Counter 6: Link 4 At 1426.904 ft
Queue Counter 7: Link 1000035 At 455.600 ft
Queue Counter 8: Link 1000040 At 132.300 ft
Queue Counter 9: Link 1000046 At 151.200 ft
Queue Counter 10: Link 66 At 1763.800 ft
Queue Counter 11: Link 1000272 At 16.000 ft
Queue Counter 12: Link 45 At 1996.400 ft
Queue Counter 13: Link 80 At 2069.800 ft
Queue Counter 18: Link 1000087 At 161.800 ft
Queue Counter 19: Link 1000092 At 155.500 ft
Queue Counter 20: Link 48 At 18.800 ft
Queue Counter 21: Link 24 At 303.400 ft
Queue Counter 22: Link 26 At 213.641 ft
Queue Counter 24: Link 84 At 696.100 ft
Queue Counter 26: Link 10 At 491.800 ft
Queue Counter 28: Link 96 At 841.760 ft
Queue Counter 29: Link 127 At 204.500 ft
Queue Counter 30: Link 1000153 At 40.619 ft
Queue Counter 31: Link 1000160 At 154.000 ft
Queue Counter 32: Link 88 At 1524.400 ft
Queue Counter 33: Link 1000173 At 75.800 ft
Queue Counter 34: Link 1000178 At 85.000 ft
Queue Counter 36: Link 1000186 At 17.500 ft
Queue Counter 37: Link 78 At 1735.200 ft
Queue Counter 38: Link 12 At 343.400 ft
Queue Counter 39: Link 74 At 1240.000 ft
Queue Counter 40: Link 16 At 697.600 ft
Queue Counter 41: Link 6 At 386.400 ft
Queue Counter 42: Link 14 At 882.700 ft
Queue Counter 43: Link 108 At 5531.200 ft
Queue Counter 44: Link 1000224 At 122.700 ft
Queue Counter 46: Link 36 At 2350.400 ft
Queue Counter 47: Link 22 At 1431.900 ft
Queue Counter 49: Link 30 At 977.800 ft
Queue Counter 50: Link 50 At 1100.600 ft
Queue Counter 52: Link 32 At 1732.100 ft
Queue Counter 151: Link 1000070 At 60.100 ft
Queue Counter 152: Link 1000069 At 87.100 ft
Queue Counter 161: Link 1000076 At 50.800 ft
Queue Counter 162: Link 1000075 At 102.700 ft
Queue Counter 171: Link 1000082 At 47.300 ft
Queue Counter 172: Link 1000081 At 74.300 ft
Queue Counter 201: Link 1000100 At 76.900 ft
Queue Counter 202: Link 1000099 At 123.800 ft
Queue Counter 203: Link 1000098 At 98.600 ft
Queue Counter 251: Link 1000123 At 297.800 ft
Queue Counter 252: Link 1000121 At 291.000 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; 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; 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; 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; Avg.;Max.;Stop;
Avg.;Max.;Stop; Avg.;Max.;Stop;
No.:; 1; 1; 1; 2; 2; 2; 3; 3; 3; 4; 4; 4; 6; 6; 6; 7; 7; 7; 8; 8; 8; 9; 9; 9; 10; 10; 10; 11; 11; 11; 12; 12; 12; 13; 13; 13; 18; 18; 18; 19;
19; 19; 20; 20; 20; 21; 21; 21; 22; 22; 22; 24; 24; 24; 26; 26; 26; 28; 28; 28; 29; 29; 29; 30; 30; 30; 31; 31; 31; 32; 32; 32; 33; 33; 33; 34; 34; 34;
36; 36; 36; 37; 37; 37; 38; 38; 38; 39; 39; 39; 40; 40; 40; 41; 41; 41; 42; 42; 42; 43; 43; 43; 44; 44; 44; 46; 46; 46; 47; 47; 47; 49; 49; 49; 50; 50; 50;
52; 52; 52; 151; 151; 151; 152; 152; 152; 161; 161; 161; 162; 162; 162; 171; 171; 171; 172; 172; 172; 201; 201; 201; 202; 202; 202; 203; 203; 203; 251; 251; 251; 252;
252; 252;
600; 0; 0; 0; 0; 64; 3; 10; 41; 4; 88; 422; 37; 0; 0; 0; 66; 236; 26; 22; 73; 7; 16; 95; 6; 2; 58; 3; 0; 0; 0; 5; 43; 3; 2; 31; 1; 0; 14; 1;
20; 52; 9; 0; 0; 0; 1; 43; 6; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 7; 133; 57; 65; 341; 51; 4; 104; 6; 210; 869; 90; 7; 37; 2; 58; 212; 18; 27; 295;
26; 54; 180; 17; 6; 74; 5; 0; 0; 0; 0; 0; 0; 4; 57; 2; 1; 39; 4; 5; 97; 4; 36; 132; 15; 59; 368; 43; 0; 0; 0; 7; 134; 7; 2; 55; 3; 0; 0; 0; 8;
60; 3; 0; 0; 0; 70; 330; 18; 205; 325; 88; 17; 178; 131; 25; 182; 32; 0; 0; 0; 17; 128; 8; 0; 0; 0; 0; 0; 0; 0; 0; 0;
1200; 0; 0; 0; 0; 0; 0; 17; 64; 3; 141; 336; 50; 1; 51; 3; 57; 249; 22; 14; 73; 5; 21; 116; 8; 0; 0; 0; 0; 0; 0; 9; 71; 6; 0; 0; 0; 0; 0; 0;
44; 140; 19; 0; 0; 0; 17; 102; 9; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 5; 144; 61; 183; 351; 76; 6; 60; 4; 744;1354; 680; 0; 15; 1; 119; 253; 43; 15;
181; 19; 34; 119; 19; 0; 0; 0; 0; 0; 0; 3; 66; 3; 0; 0; 0; 0; 0; 0; 205; 705; 184; 32; 112; 15; 114; 428; 65; 0; 0; 0; 47; 188; 35; 0; 0; 0; 0; 0;
0; 5; 42; 3; 0; 0; 0; 0; 0; 0; 266; 340; 85; 109; 517; 270; 95; 518; 121; 0; 18; 1; 3; 46; 3; 1; 31; 2; 0; 0; 0; 0; 27; 1;
1800; 0; 0; 0; 0; 38; 1; 10; 64; 8; 103; 307; 29; 10; 114; 8; 67; 217; 38; 8; 79; 6; 19; 73; 6; 0; 0; 0; 0; 0; 0; 16; 90; 8; 0; 0; 0; 0; 0; 0;
12; 139; 10; 0; 0; 0; 46; 233; 28; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 91; 216; 209; 218; 351; 137; 3; 37; 3; 988;1541;1348; 0; 0; 0; 71; 214; 35;
40; 377; 51; 23; 126; 15; 0; 0; 0; 0; 0; 0; 3; 88; 4; 0; 16; 1; 0; 0; 0; 130; 622; 112; 91; 263; 34; 28; 325; 25; 0; 0; 0; 4; 56; 10; 3; 50; 2; 0;
0; 0; 9; 41; 1; 0; 0; 0; 68; 320; 24; 253; 331; 77; 286;1022; 737; 239;1023; 298; 0; 0; 0; 13; 95; 5; 5; 34; 1; 0; 0; 0; 0; 0; 0;
2400; 0; 0; 0; 0; 62; 2; 6; 40; 3; 93; 311; 39; 1; 29; 1; 47; 230; 20; 25; 116; 8; 29; 92; 10; 0; 0; 0; 0; 0; 0; 11; 66; 5; 8; 119; 6; 0; 0; 0;
20; 134; 15; 0; 0; 0; 62; 269; 17; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 56; 211; 326; 225; 350; 116; 1; 16; 1; 968;1537; 896; 4; 32; 1; 67; 233; 22;
120; 473; 117; 50; 171; 19; 0; 0; 0; 0; 0; 0; 10; 105; 4; 6; 33; 2; 0; 0; 0; 7; 214; 10; 71; 357; 44; 10; 131; 13; 0; 0; 0; 21; 129; 10; 0; 0; 0; 0;
0; 0; 6; 45; 4; 0; 0; 0; 0; 0; 0; 254; 343; 103; 106; 640; 229; 208; 766; 149; 0; 19; 1; 4; 33; 1; 6; 65; 5; 0; 0; 0; 0; 26; 1;
3000; 0; 0; 0; 0; 80; 3; 8; 37; 6; 132; 349; 48; 39; 203; 15; 107; 352; 55; 0; 31; 1; 0; 0; 0; 0; 0; 0; 0; 0; 0; 3; 42; 2; 10; 121; 11; 0; 0; 0;
19; 134; 9; 0; 0; 0; 11; 139; 23; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 132; 224; 247; 226; 350; 89; 1; 20; 2; 805;1539; 765; 0; 36; 1; 72; 173; 25; 15;
182; 30; 9; 104; 6; 0; 0; 0; 0; 0; 0; 4; 44; 3; 0; 0; 0; 4; 88; 4; 149; 669; 129; 110; 258; 31; 98; 393; 53; 0; 0; 0; 10; 124; 7; 1; 31; 1; 0; 0;
0; 4; 20; 2; 0; 0; 0; 32; 331; 30; 264; 340; 93; 54; 511; 80; 147; 573; 106; 0; 0; 0; 10; 50; 3; 8; 71; 1; 0; 0; 0; 4; 48; 7;

3600; 0; 0; 0; 0; 39; 1; 14; 61; 7; 117; 329; 38; 17; 76; 6; 37; 210; 13; 3; 75; 4; 21; 123; 11; 0; 0; 0; 0; 0; 0; 9; 43; 4; 5; 55; 4; 0; 16; 1; 6; 35; 4; 0; 0; 0; 6; 133; 7; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 134; 231; 564; 204; 349; 144; 10; 67; 5; 1192;1536;1604; 5; 36; 0; 73; 243; 18; 33; 316; 43; 22; 77; 13; 2; 54; 2; 0; 0; 0; 1; 27; 1; 0; 17; 1; 12; 164; 4; 169; 464; 129; 37; 129; 14; 72; 374; 44; 26; 159; 13; 25; 98; 17; 232; 428; 104; 0; 0; 0; 8; 41; 3; 0; 0; 0; 38; 331; 0; 246; 328; 94; 247; 815; 484; 293; 816; 357; 0; 0; 0; 12; 58; 4; 14; 54; 5; 0; 0; 0; 4; 74; 14;