Evaluation of Service Reliability Impacts of Traffic Signal Priority Strategies for Bus Transit

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ABSTRACT

Recent progress in technology has facilitated the design, testing, and deployment of traffic signal priority strategies for transit buses. However, a clear consensus has not emerged regarding the evaluation of these strategies. Each agency implementing these strategies can have differing goals, and there are often conflicting issues, needs, and concerns among the various stakeholders. This research attempts to assist in the evaluation of such strategies by presenting an evaluation framework and plan that provides a systematic method to assess potential impacts. The results of the research include the development of specific measures corresponding to particular objectives, with descriptions to facilitate their use by agencies evaluating traffic signal priority. The use of this framework and plan is illustrated on the Columbia Pike corridor in Arlington, Virginia with the use of the INTEGRATION simulation package. In building upon prior efforts on this corridor, this work presents a method of simulating conditional granting of priority to late buses in an attempt to investigate the

impacts of priority on service reliability. Using the measures developed in this research, statistically significant improvements of 3.2% were found for bus service reliability and 0.9% for bus efficiency, while negative other traffic-related impacts were found in the form of increases in overall delay to the corridor of 1.0% on a vehicle basis or 0.6% on a person basis. Areas identified for future research include extensions to INTEGRATION to permit consideration of real-time conditional priority, further exploration of the relationship between components of bus travel times, and examination of the role of passenger loads on priority operation and impacts.

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1.0 INTRODUCTION

Although traffic signal priority strategies for transit have existed for more than two decades, there has been a great deal of interest in new applications in the past few years, and a shift of some attitudes among professionals towards re-examining the use of priority in their jurisdictions. Given the ongoing growth in travel demand, coupled with the limited resources for traditional capacity expansion, increasing focus has been given to improvements that are thought to be more "sustainable". The enhancement of public transportation systems in a way that provides improved mobility and reliability without needing extensive infrastructure investments may contribute to this trend. Traffic signal priority for transit has the potential to help meet this challenge. In part due to the advances in technologies, local jurisdictions have now been able to examine and deploy traffic signal priority for transit vehicles in a variety of different areas using different detection systems and architectures (*1*).

Problem Statement

In light of the recent interest in testing and deploying signal priority systems, there is a need for an evaluation framework and plan in order to determine the impacts associated with various traffic signal priority strategies as applied to transit. This evaluation framework and plan can provide a systematic basis for local stakeholders to examine the likely impacts of potential deployments and to assess the degree to which the deployments achieve the desired objectives. In particular, the extent to which traffic signal priority strategies can improve the service reliability of bus operations warrants investigation, as this is a commonly cited objective of signal priority.

Research Goal

The goal of this research is two-fold:

1) to formulate an evaluation framework and plan for traffic signal priority strategies for transit; and

2) to illustrate the use of the framework and plan in the assessment of transit service reliability impacts.

Report Structure

This report will document the results of the research. First, a review of the relevant literature will be given, establishing the background in which the research attempts to build upon. The research approach is then discussed, and the evaluation framework and plan is presented. The use of the framework and plan will be illustrated using the Columbia Pike corridor in Arlington, Virginia as an example, and the resulting findings from simulation analyses will be discussed. Finally, the report will offer conclusions from the research and suggest future directions for further research in this area.

2.0 LITERATURE REVIEW

Introduction

The purpose of the literature review is to identify and synthesize appropriate references to demonstrate and illustrate the presence of knowledge gaps to be addressed by this research. These references will include journal articles, conference papers, published reports, and other readily available sources of information, such as World Wide Web pages. The review will provide background on the objectives of signal priority for transit, differentiating between priority and preemption for emergency vehicles; discuss the various detection technologies used; and summarize the prior experiences in the U.S.

Objectives of Transit Signal Priority

Stakeholders in a Washington, DC Metropolitan Area Case Study (*2*) suggested four policy requirements for priority systems. They are presented here in the order in which they were mentioned.

1. The system shall improve schedule adherence.
2. The system shall improve the efficiency with which buses run, reducing operating costs and allowing greater schedule flexibility.
3. A priority system shall be part of a larger ITS system that includes improved rider information and other services.

4. Priority shall increase the overall efficiency with which the road network is used by contributing to an increasing in bus ridership.

In individual past deployments, the objectives varied somewhat, but typically emphasized improving the quality of transit service and/or the efficiency of operations. In terms of measurements, bus travel time and additional delay to general vehicular traffic were the most common metrics used (*3*).

By potentially improving schedule adherence, a priority system can improve the quality of transit service and enhance the mode share of transit. In addition to considering travel time and other factors, travel demand models may include service reliability as a modal attribute representing the need to be punctual (*4*). In addition, service unreliability can have a great impact on ridership, by increasing the uncertainty and anxiety to passengers (*5*). Noland et al (*6*) found that costs associated with uncertainty resulted primarily from costs of early or late arrival. From the perspective of the transit operations planner, the emphasis is often placed on running times between timepoints, as recovery time is built into each trip. However, if a trip falls behind schedule by a significant amount, bunching with the following bus may occur, or subsequent trips may be impacted due to inadequate recovery time at the end of the run. Within a trip, segments that regularly run either ahead of or behind schedule may be identified with the use of ride checks to collect actual running times by segment. The average schedule variance, consisting of the average number of minutes ahead or behind schedule for the trips checked (*7*), may be used to identify scheduled running times that need adjustment, and allowing timetables to be changed accordingly.

Priority vs. Preemption

The Washington, DC Study (*2*) also identified system objectives for emergency vehicle preemption. Again, these objectives are presented here in the order in which they were often mentioned by interviewees.

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

Generally, preemption focuses on safety, while priority attempts to improve transit service quality and efficiency. The granting of preemption typically has minimal restrictions and acts directly on the controller preempt input, owing to the importance afforded to safety of public emergency workers and response to individuals in need, while use of priority is often subject to various conditions and criteria, mostly to limit the severity of impacts on other traffic. Priority also may be considered on a passive basis, using such measures as shortening cycle times, and optimizing signals for bus travel speeds (*8*), though the focus here is on active strategies. The controller strategies used for active priority are often thought of as green extensions which extend the priority phase if it is already green, and early greens or red truncations, which either skip or shorten conflicting phases when the priority phase is red. TCRP Project A-16 includes detailed discussion of signal controller operations for priority, offering a technical explanation of implementation approaches as well as guidance toward more advanced priority strategies (*9*). As can be seen, the objectives and controller strategies for priority and preemption are quite different, though the system architecture in implementation may have similarities. In particular, the detection technologies used for preemption and priority are similar.

Detection Technologies

This section reviews the various detection technologies that have been used in traffic signal preemption and / or priority applications in terms of their functionality, strengths, and limitations (*1*). Since some technologies (e.g. light, sound, etc.) have been utilized by multiple vendors in a different fashion, different vendor implementations will be reviewed individually.

Light – 3M Opticom

Functionality

3M Opticom components consist of infrared strobe emitters, infrared detectors directionally mounted at intersections, and an interface to the signal controller (*10*). The emitters are mounted on the front or top of vehicles that are to be given priority treatment and wired into the vehicle's electrical system. When activated by switch or automatic mechanism, the emitter sends a cone of infrared and visible strobe light in the forward direction. If desired, the visible component of the strobe may be filtered out by mounting an optical filter on the emitter (*11*). Within the strobe's flashing pattern and frequency is a coded message consisting of the vehicle identification number that had been assigned to the emitter. At each intersection approach for which priority is desired, detectors are mounted facing approaching traffic, usually on the mast arm or span wire that supports the signal heads. Opticom supports two or four channels, providing detection capability on two or four approaches respectively. The detectors are connected by wire to the Opticom phase selector card installed in the signal controller cabinet. The phase selector (and card rack for some controllers) provides the interface between the detectors and the preemption inputs of the signal controller. This interface provides authentication and authorization of priority phases using predefined logic and acts through standard controller functions (*9*). In addition, the phase selector supports user classification and operating priorities for vehicle types overriding other vehicle types. Optionally, a confirmation light mounted on the approach can be installed and connected so that priority vehicles may visually confirm that they have obtained the priority right-of-way. Opticom is able to communicate with both centralized and closed loop systems (*12*).

Strengths

One of Opticom's most significant strengths is the popularity it has achieved among fire and rescue departments in the U.S. While it has undergone refinement, the technology has been used for many years and is readily available (*11*). Individual vehicle logging functionality is provided, as long as Opticom equipment is used. Limited compatibility with the Tomar Optronix Strobecom system, which also uses strobe-based technology, is available but logging does not work across vendors (*11*). Since the visible spectrum of the strobe may be filtered, the emitters are usable with both emergency vehicles as well as non-emergency vehicles such as buses and snowplows. The ability for emergency vehicles to override non-emergency vehicles is provided through separate high and low priority levels. Generally, since the emitter can be switched by automated mechanisms, Opticom may be suitable for vehicle-level control authority, as in a “smart bus” application (*13*).

Limitations

As all light based technologies are, Opticom is dependent on a line-of-sight clearance between emitter and detector for detection to be successful. The ability to achieve this clearance may be hindered by curved geometrics, weather-related visibility problems, and obstructing vehicles or objects such as tree foliage (*12*). Due to the wide cone profile of the strobe light, there is the potential for interference with adjacent or neighboring intersections, resulting from light reflection off of surfaces or roadway geometrics. As mentioned earlier, the vehicle logging capability does not function when a non-Opticom emitter is used, and even with matched equipment, the only information transfer capability is a 4-digit vehicle number. This number also acts as security for the system, as individual vehicle numbers can be set to be active or inactive. However, the difficulty in duplicating the correct pattern and frequency for a vehicle number is unclear. Range of the detectors can be adjusted, but the vehicle location can only be determined by presence in the static predefined range. Similarly, the emitter can only be in a binary on or off state.

Light - Optronix / Tomar Strobecom

Functionality

As with Opticom, the Strobecom system consists of strobe emitters on vehicles, detectors at intersections, and an interface device in the controller cabinet. Emitters provide a cone of infrared and optionally filtered visible light, coded with a vehicle identification number. Detectors are placed at the intersection typically near the signal heads, with one detector per desired approach, and are wired to the Optronix interface card in the controller cabinet via serial communications. The interface card provides authentication and authorization for the priority phases, and is preprogrammed to respond to first-come first serve within two bands, with the emergency band overriding the transit band, and up to sixteen priority levels within each band. Upon detection of an emitter, the potential response actions include local preemption, report of detection to central controller and await response, or logging of vehicle passage (*12*). A confirmation light for right-of-way can be installed optionally. Maintenance routines include cleaning detector lenses, inspecting emitters, and testing operation (*12*).

Strengths

Limited compatibility with Opticom is an advantage as long as vehicle logging is not required. Similar to Opticom, the Strobecom system may be used for different vehicle classes including appropriate override logic, and can log vehicle activations by Tomar emitters. Vehicle-level control may be suitable since emitters can be switched only in an on and off fashion.

Limitations

Strobecom is affected by the same light-based issues described under Opticom, including geometrics, weather/visibility, and obstructions. Though limited compatibility with Opticom is useful, mixed vendor systems cannot provide logging functionality. Also, there is low potential for information transfer since the vehicle identification is the only data transmitted by emitters, and the detection capability and emitter activation states are binary in nature.

Light – Novax Bus Plus

Functionality

The Novax Bus Plus system uses infrared light technology in a "sidefire" configuration. Vehicles are equipped with an infrared transceiver ("VTM") directed in the curbside direction, which transmits a coded signal. On the curbside of the intersection approach (check-in) and at a location past the intersection (check-out), corresponding detection modules ("VDMs") are mounted at the appropriate distance from the intersection. These detection modules authenticates and validates the infrared signal from vehicles, and relays the message to a receiver unit ("VIL") installed in the traffic signal controller via low-power radio. The receiver unit applies user-defined conditional statements to activate / deactivate the appropriate priority inputs on the signal controller (*13*).

Strengths

Use of short-range radio communications between detector and controller does not require installation of wiring from detector to controller, only AC power. Infrared technology is resistant to radio frequency (RF) interference and electromagnetic interference (EMI) from the bus (*14*).

Limitations

The receiver in the controller requires an RF antenna in order to receive the relayed message. A suitable mounting location with AC power is also necessary for the sidefire detector at curbside locations.

Sound – Sonic (Unity Wireless) Sonem 2000

Functionality

Sonem 2000 includes a directional microphone array mounted at the intersection, a controller card in the signal controller, and an optional visual confirmation light. The microphone array detects sirens in yelp, wail, or hi-lo with adjustable frequency, period, and range (*15*).

Devices can also be mounted on vehicles to permit detection of non-emergency vehicles (*11*), as well as perform vehicle identification (*12*). Upon detection, the controller card notifies the signal controller of the priority request by direction, and logs the date, start and stop time, type of siren, and direction of travel (*15*).

Strengths

In order to be detected, emergency vehicles do not need to have any additional equipment mounted. This also facilitates interjurisdictional emergency actions since emergency vehicles from other areas may utilize the system. The confirmation light also indicates when another vehicle has preemption control. Use in non-emergency situations may be less likely when an audible siren is necessary for activation. Also, the sound detection capability does not depend on line-of sight or visibility.

Limitations

The system only has a binary sensitivity of vehicle presence on an approach, with no data transfer capability. There does not appear to be the ability to restrict vehicles that are equipped with the appropriate siren type. Anecdotal evidence indicates that sound based systems may be susceptible to false activation by alarms, such as building alarms, and potential drift in siren output from original specifications.

Sound – EPS II

Functionality

The EPS II system consists of a digital sound wave recognition system connected to a phase selector unit that interfaces with the signal controller. Detectors are mounted to distinguish direction and wave profile of sirens, and configured to detect in the desired range. Electronic sirens may be used as the activation device or a special siren emitter can be used to exclude other sirens. Usage is logged by time, date, duration, and direction for each preemption, while individual vehicle use can be tracked with use of on-vehicle equipment (*12*).

Strengths

No modifications are needed for emergency vehicles to use the system, if individual vehicle logging is not required. EPS II has the capability to be activated by both emergency vehicles and non-emergency vehicles equipped with an inaudible sound generator (*11*). Like other sound-based detection systems, EPS II does not depend on line-of sight or visibility for detection.

Limitations

The system only has a binary sensitivity of vehicle presence on an approach, without data transfer capability. There is no ability to restrict vehicles that are equipped with the appropriate siren type without using additional on-vehicle equipment. Individual vehicle logging requires additional equipment on vehicles. Anecdotal evidence indicates that sound based systems may be susceptible to false activation by alarms, such as building alarms, and potential drift in siren output from original specifications.

Loop Detector – IDC LoopComm

Functionality

The IDC LoopComm system consists of low frequency transponders mounted on vehicles, which are detected by standard pavement loops connected to a special amplifier. The transponders are coded with a vehicle identification number that can be read by the amplifier (*13*).

Strengths

LoopComm does not depend on line of sight/visibility. Transponders may be mounted on both emergency and non-emergency vehicles.

Limitations

LoopComm depends on appropriately placed and functional pavement loop detectors. Presence and identification of the vehicle is the only data provided on detection. There is only one state for the transponder when powered on; emergency or other status cannot be transmitted.

Push-button (Hardwired / Firehouse)

Functionality

Typical hardwire systems include a push-button activation device in the firehouse, connected to the adjacent intersection signal controller. When the button is activated, the signal controller begins the programmed preemption sequence.

Strengths

The hardwire mechanism is simple and reliable, works in all weather conditions, and does not require equipment on-board vehicles.

Limitations

Detection is only provided after human activation of the push-button, and is therefore applicable only to vehicles having access, usually emergency vehicles leaving the firehouse. Activation may not be timely due to the need to get from firehouse to intersection. Remote activation of other intersections not connected directly is not possible, though remote activation of a push-button has been accomplished using devices like garage door opener remotes. Activation of the push-button is not controlled, and is not logged by person or vehicle.

Radio – TOTE

Functionality

TOTE consists of RF tag readers installed curbside in advance of intersections, and Amtech AVI185 read/write tags on priority vehicles. Output from the tag reader is provided using RS-232 communication to either the controller or other devices (*13*).

Strengths

Tags may be placed on both emergency and non-emergency vehicles. Tag readers are installed in advance of the intersection, and hence visibility issues are not significant.

Limitations

TOTE only provides detection and does not provide authentication and phase selector functionality; an interface device needs to take TOTE output and interface with signal controller inputs. Tags may not provide dynamic information on status, such as schedule or emergency status, without needing additional equipment on-board. All tag readers installed at curbside require a suitable mounting location, power, and communications capability.

Radio – Econolite EMTRAC

Functionality

EMTRAC includes an intersection-mounted antenna and receiver to receive radio transmissions from a bus-mounted spread spectrum transmitter. Up to three levels of priority can be assigned to the transmitters. Preemption activity is logged by vehicle identification number, priority level, preemption direction, time, date, and duration of preemption (*12*).

Strengths

Transmitters may be mounted on both emergency and non-emergency vehicles. Vehicles are logged on an individual basis along with preemption information.

Limitations

Non-directional nature requires vehicle to provide approach direction; anecdotal reports indicate a potential for system malfunction due to compass failures (*12*).

Radio / GPS-AVL – Priority One

Functionality

Priority One provides preemption at the local controller by using radio (either spread spectrum or narrow band) transmitters placed on vehicles and radio receivers at intersections linked to a preemption module interfacing with the signal controller (*11*). The GPS-AVL component determines vehicle position, direction, speed, and time of day to determine appropriate preemption conditions. Preemption activity is logged including vehicle ID and approach (*12*).

Strengths

Use of the AVL system can permit determination of intersections in advance to be preempted, even around turns (*11*). Preemption can be terminated if the vehicle leaves the intersection approach, or is determined as stopped for too long, or has the door open, etc. (*12*)

Limitations

GPS system is susceptible to accuracy issues especially in urban environments. Due to the polling frequency of the AVL system, accuracy for closely spaced intersections may not be adequate (*11*). Priority activation depends on the AVL system being operational.

Orbtrac 300

Functionality

Since Orbtrac 300 consists of a larger system, comparison with the detection technologies previously discussed is difficult. However, limited information is provided here in order to show how preemption and priority might be managed at a higher level. Orbtrac 300 is a complete bus operations management system that includes GPS tracking and priority capability. Priority requests may be generated by an on-bus processor, or by a transit management center, which relays requests to a traffic management center (*13*).

Strengths

Orbtrac can utilize information on bus occupancy and schedule adherence to selectively request priority. Priority requests are not affected by visibility and weather conditions.

Limitations

For priority, the infrastructure for tracking bus operations needs to be in place. Also, the capability to control local signals from a central management center is necessary. Emergency management may operate separately from transit management, limiting the applicability of Orbtrac for preemption.

U.S. Experiences

This section reviews deployments of emergency vehicle preemption and priority for transit vehicles (*1,16*). This review is not intended to be comprehensive but examined both local applications and deployments in other regions. Information was gathered using a combination of published and unpublished literature as well as conversations with personnel.

Results / Lessons Learned - Emergency Vehicle Preemption

Northern Virginia Field Observations by VDOT (*12*)

Tysons Corner

The Tysons Corner fire station has a push-button activated hardwired preemption system controlling the intersection at Route 7 and Spring Hill Road. When preemption was activated by means of the push-button, coordination was disrupted while the vehicle left the station. Due to the distance from the firehouse to the intersection, additional preempt time was configured to allow sufficient time for the vehicle to reach the intersection. Recovery to time base coordination took 7 minutes; during this period mainline traffic faced significant congestion during peak hours.

McLean

The McLean fire station uses a light-based preemption system for the adjacent signal at Chain Bridge Road. Preemption disrupted the corridor coordination, causing a delay related to the time the strobe stayed in the detection zone. Recovery to time base coordination took 3 minutes, 40 seconds.

Sterling

The Sterling fire station uses a sound-based preemption system (Sonic) at the intersection of Sterling Blvd. This intersection is an isolated signal that operates in fully-actuated (free) control mode 24 hours a day. The duration of delay from preemption was primarily determined by the time the emergency vehicle's siren was present and activated in the detection zone. The minimum delay time observed was 32-37 seconds for the next phase to appear. Since the intersection does not operate in coordination, there is no transition time associated with preemption

Phoenix test of Econolite TS-2 Recovery (*11*)

Phoenix tested the time needed for an Econolite TS-2 controller to recover after preemption activation. The results indicated that the time spent in recovery depended on the point in the cycle where preemption was released. Recovery time was observed to range from 34 seconds to 274 seconds for a 90 second cycle length. The average recovery time for 70% of Phoenix signals was estimated to be 154 seconds, while the remaining 30% of signals would need 200 seconds.

Denver Opticom Study (*11,17*)

Results from a study conducted in Denver using the Opticom system indicated that response times for emergency vehicles were reduced by 14-23% after the deployment of the preemption system. In addition, the reductions were greater on runs that contained more intersections.

Addison, TX (*11*)

Addison, TX has claimed a 50% decrease in response time from preemption.

Houston, TX Opticom (*18*)

A study of Opticom preemption in Houston indicated an average improvement in travel time from station to incident ranged from 16-23%. In addition, drivers reported a reduction in stress levels associated with driving as a result of the preemption functionality.

St. Paul, MN Opticom (*19*)

The City of St. Paul found that accident frequency after deployment of Opticom preemption decreased by 70%. Of the 23 accidents, 19 were found to occur when the emergency vehicle had the right of way (green light).

Washington, DC Opticom (*20*)

In the vicinity of local hospitals, the Georgia Avenue corridor was equipped with the Opticom system as a test of preemption for ambulances. Side street queues were found to be increased at five of six intersections analyzed, but recovery to normal timing was achieved within three cycles. Study of ambulance operating speeds with preemption showed a statistically significant improvement; in nominal terms, improvements of 4 mph during off-peak periods and 1 mph during peak periods were found.

Fairfax, VA Opticom, Strobecom (*21*)

Six intersections were equipped with light-based preemption units for fire and rescue vehicles as a pilot project; three were equipped with Opticom, while the other three utilized Strobecom. Use of preemption was found to be seamless in both cases, with positive opinions from emergency vehicle operators. Traffic personnel noted that since they have a relatively short peak period, the disruption from preemption might be less significant.

Deployments / Results / Lessons Learned – Transit Priority

Charlotte, NC Opticom (*13,22*)

Charlotte equipped express buses along one radial corridor with Opticom; results showed a reduction in average travel time of 4 minutes. Anecdotal evidence indicated less wear and tear on vehicles, lower local emissions, and reduced driver stress. There were no major unacceptable delays found on cross streets.

Portland, OR TOTE & LoopComm Tests (*9,23*)

Portland tested both TOTE and LoopComm detection systems along with 170 Type controllers with Wapiti IKS firmware. The test provided green extensions and early green for priority vehicles up to 10 seconds during off-peak periods and 20 seconds during peak periods. Priority time was created by reallocating phase time from other phases, thus maintaining coordination. Results were inconclusive, but a general reduction in bus passenger travel time was noted.

Bremerton, WA Opticom (*9,24*)

Bremerton, WA uses Opticom for both emergency vehicle preemption as well as transit priority. Transit priority was able to reduce travel time for buses on 4 different routes by an average of 10% with more benefit on routes with more intersections. Stopped delay per vehicle at 8 intersections was measured to be slight and not statistically significant. Coordination transition logic allowed return to coordination within 30 sec by allowing phases to be skipped. This was achieved by making modifications to the Traconex 390 controllers to allow preemptor to return to first open phase that satisfies the signal coordination criteria. The phase was determined by the status of vehicle/pedestrian calls, phase or pedestrian omits. The firmware was also enhanced to allow low priority calls to time pedestrian / vehicle minimums completely, limit priority service time with a maximum timer, and provide for a one-cycle normal return where transit priority would be disabled. As a result of their experiences, the city desires the ability to set the number of cycles between permitting priority requests, the ability to designate non-skippable phases, and the ability to use alternative splits under priority rather than normal minimums.

Chicago Cermak Road (*9*)

Chicago tested a loop detector-based detection system and found it to be simple, reliable, and cost-effective, while performing well. Bus run times in the range of 13-17 minutes was reduced by 2-3 minutes while the impact to traffic was minimal. Improvement in route travel times was significant. Results also indicated that the priority logic in coordinated mode only provided priority to 30% of buses due to the fact that 70% of buses arrived during the normal phase.

Louisiana Ave, MN Opticom Test (*9*)

Opticom was tested at a diamond interchange for through traffic signals; different detectors were used for left turn and through lanes. Econolite ASC-8000 ASC/2 controllers were used in the test. Three levels of priority were tested: low, which gave an extended green while remaining in coordination; medium, which gave a longer extended green and staying in coordination; and high, which provided preemption and left coordination. The high priority reduced bus travel time by 38%, while the medium and low priority did not reduce bus travel time. Medium and low priority did not increase auto-stopped time, but high priority increased it by 4.4 sec (23%). This was judged to be acceptable, while noting that increases were probably due to data variations. The only comments received from the public were regarding phase skipping, which resulted from the return to coordination after preemption.

Miami Orange Streaker (*9,25*)

Miami tested a bus preemption system and other priority measures in 1973 along 16 km of an express bus route, the Orange Streaker. In the effectiveness in reducing bus delay and travel time, the most effective treatment was found to be bus lanes, followed by preemption, and then progression. Preemption was found to not be as effective as progression in maintaining schedule adherence. Traffic impacts were found to be minimal, and influenced more by signal control parameters (fully actuated vs. coordinated actuated and pretimed vs. coordinated-actuated) than the preemption.

Montgomery County, MD ATMS System, TMC staff human intervention

Another type of priority for buses has been implemented, through the use of global positioning system (GPS) tracking from a centralized Advanced Traffic Management System (ATMS). In addition, when transit management center staff encounter problems with a delayed bus due to an incident, they can contact the traffic management staff in the same office to adjust traffic signal timings in an attempt to facilitate the bus getting back on schedule. It should be noted that Montgomery County provides emergency vehicle preemption only for exiting the firehouse driveway, through manual, push-button activation of the local preempt. There are no system or arterial preemption devices.

Maryland State Highway Administration (Anne Arundel County, MD) (*26*)

On Ritchie Highway, express buses are given priority using a combination of Opticom as the detection technology and Econolite ASC/2 controllers with bus priority logic. The types of priority involved include green extension, queue jump (special bus-only signal display for early green from near-side stop), and left turn phase recall (lagging left arrow if bus detected). Bus travel time reductions of 13-18% were observed after implementation of the priority system. Travel time for other vehicles was observed to decrease by 9% in one mainline direction and increase by 4-5% in the other. Similar priority using only the green extension is also provided in the Southern Maryland area.

Eindhoven, Netherlands (*27*)

Though much progress has been made in transit priority outside the U.S., the institutional structure and policies are often quite different, such that direct comparison of projects can sometimes be challenging. However, one example is cited here to illustrate a key attribute of a more sophisticated implementation, conditional priority. In the Eindhoven implementation, buses were given priority only if they were running late, in an attempt to provide operational control for buses to maintain schedule adherence. Measures considered included vehicle delay, bus delay, and bus schedule deviations. As compared with no priority, the conditional priority had little impact on vehicle delay while improving schedule adherence. Bus delay reductions for conditional priority were found to lie between absolute and no priority.

Works In Progress

In addition, several cities are currently in the process of investigating or deploying transit signal priority and have reported preliminary results. These results have been included in Table 1, which summarizes reported results from the transit signal priority deployments previously discussed.

Table 1: Summary of Transit Signal Priority Deployment Results

Deployment	Measure	Result
Charlotte, NC Opticom (Express Buses)	Bus Travel Time	4 minute decrease
	Cross Street Delays	Not unacceptable
Portland, OR TOTE & LoopComm Tests	Bus Travel Time	Reduction noted
Bremerton, WA	Bus Travel Time	10% decrease
	Stopped Delay/vehicle	Insignificant

Chicago, IL Cermak	Bus Travel Time	2-3 minute decrease on 13-17 run
MN Louisana Ave Opticom Hi-Priority	Bus Travel Time	38% decrease
	Auto Stopped Delay	23% increase
MN Louisiana Ave Opticom Med/Lo-Priority	Bus Travel Time	No change
	Auto Stopped Delay	No change
MD SHA Anne Arundel	Bus Travel Time	13-18% reduction
	Auto Travel Time – Same Direction	9% decrease
	Auto Travel Time – Opposing Direction	4-5% increase
Los Angeles, CA Metro Rapid (attributable component) (*28*)*	Bus Travel Time	8-10% decrease
Seattle, WA Rainier (*29*)*	Priority Bus Delay	34% decrease
	Bus Intersection Stops	24% decrease
	Bus Travel Time	8% decrease

Portland, OR Pilot Routes (*30*)*	Bus Travel Time	10% decrease
	On Time Performance	8-10% improvement

* Works currently in progress (initial results)

Transit Priority Evaluation using Simulation

Beyond the evaluations conducted on field deployments and operational tests, several efforts have been made to evaluate transit signal priority using simulation and other analytic approaches. One of the earliest efforts, by Benevelli et al (*31*) in 1983, reflected the technology available at the time. The study attempted to weigh the benefits and costs of signal priority with the use of the UTCS-BPS simulation model; in addition to capital and operating costs for the priority equipment, the user costs considered included travel time delay and fuel consumption. While the results indicated that bus priority was not economically justified for the network tested, the authors noted several important factors influencing the results, such as the simplistic signal priority control algorithms in the simulation, which could not return to coordination.

As the state of technology and simulation tools improved, additional efforts were made to evaluate the potential for transit signal priority using simulation. In 1996, Khasnabis et al (*32*) used the NETSIM simulation model to evaluate a hypothetical bus corridor with priority. However, since NETSIM did not provide the capability for signal priority, the researchers visually tracked the buses using the graphical display tool, and determined whether the bus would be granted priority accordingly. The delay output measures from NETSIM were then adjusted for assumed vehicle occupancy and the resulting person-minutes of delay was used as the evaluation measure. The test corridor evaluated indicated a decrease in delay along the main (priority) direction while the cross streets had an increase in delay. Bus travel time with priority decreased by a range of 0.3 to 13.5 percent as compared to the base.

Garrow and Machemehl (*33*) attempted to use NETSIM simulation to establish what conditions tend to be favorable and unfavorable for transit priority. Unconditional priority was simulated in a similar fashion as Khasnabis et al (*32*), under various scenarios. Delay on a vehicle basis serves as the primary evaluation measure in this analysis, while selected scenarios also examine bus and auto travel times, and delay weighted by vehicle occupancy. The results from this study suggested that degree of saturation plays a key role in the delay impacts when transit vehicles are given priority.

A more comprehensive evaluation process using simulation was designed by the King County Department of Transportation (*34*) in order to satisfy the needs of local stakeholders. This process utilized limited field tests in addition to simulation in order to provide a more solid foundation of evidence before proceeding with transit signal priority. In both the field tests and simulation, the same set of measures of effectiveness were selected so as to facilitate comparison. The measures selected included: intersection control delay, minor movement delay, minor movement cycle failures, bus travel times, bus schedule reliability, intersection bus delay, average person delay, vehicle emissions, and accidents.

Summary

In summary, signal priority for transit attempts to improve the quality of service and/or efficiency of transit operation while considering potential detrimental effects on other vehicular traffic. While schedule adherence is a common element of quality of service, it has not often been measured in prior experience. More frequently, the travel time savings for buses, representing another quality of service element as well as efficiency improvement, have been used as the general metric for benefit to transit riders. In terms of technologies, priority and preemption can often use the same subsystem for interactions between the vehicle and the preemption/priority activation mechanism. However, the detection technologies should be considered within a higher-level view of the overall system design (*1*), keeping in mind that priority for transit and preemption for emergency vehicles have quite different objectives. Past deployment experiences with signal priority for transit have generally been positive, with minimal delay for other traffic, and improvements in travel time for transit buses. However, given the varying situations that exist in the deployments, caution should be exercised in generalizing the results. In particular, variables such as the level of saturation, coordination transition algorithms, and priority criteria, are not the same across the various deployments. These considerations play an important role in the implementation of signal priority and the nature of benefits and impacts.

3.0 RESEARCH APPROACH

This chapter will present an evaluation framework and plan that may be used in the assessment of alternative traffic signal priority strategies for bus transit. First, the formulated evaluation framework will be presented. Subsequently, the framework will be used to develop an evaluation plan for use on the Columbia Pike corridor in Arlington, Virginia. This in turn will lead into the next chapter, which will illustrate the use of this plan in conjunction with simulation analyses.

The evaluation framework establishes the appropriate context in which traffic signal priority strategies for transit will be examined. As in the evaluation of Advanced Public Transportation Systems (APTS), and other Intelligent Transportation Systems (ITS) deployments, the framework will be used to test alternatives in order to assess performance. The evaluation framework provides an important foundation for determining whether a project or an individual strategy meets the intended objectives. Without a framework, there is a risk of attempting to justify the worthwhileness of a project without systematic reasoning. Almost all potential projects have some merits to them. However, when considering whether a project should be developed or deployed, the planning process should consider to what extent the stated objectives would be met and what negative impacts would be realized, relative to other alternatives.

The framework (see Figure 1) centers around the evaluation plan, which considers objectives of stakeholders and the environment surrounding traffic signal priority in order to isolate positive and negative effects of traffic signal priority under various conditions. In order to reduce the susceptibility of choosing a strategy and determining reasons for its use rather than the opposite, the objectives and environment are considered "given" or "fixed" in the framework. Stakeholders' input may be gathered and analyzed to record the issues, needs, and objectives of traffic signal priority for transit before the consideration of the design or performance of various strategies. Similarly, the local operating environment plays an important role in the suitability of any priority strategy in meeting stakeholder objectives. For example, interoperability requirements at a jurisdictional or regional level can greatly affect which strategies could even be considered. However, it should be noted that this is not the only way of relating issues associated with transit signal priority. For example, TCRP Project A-16 (*9*) considers transit priority logic, agency operating policy, and the operational scenario all as mutually interconnected components of a priority strategy.

The various traffic signal priority strategies are an “input” to the evaluation process, while the “output” consists of the performance of each strategy. The central element of the framework, the evaluation plan, specifies how the performance of each strategy in terms of meeting stated objectives in the specific environment would be quantified. After conducting the evaluation, guidelines for application of varying priority strategies can then be established based on performance under varying conditions.

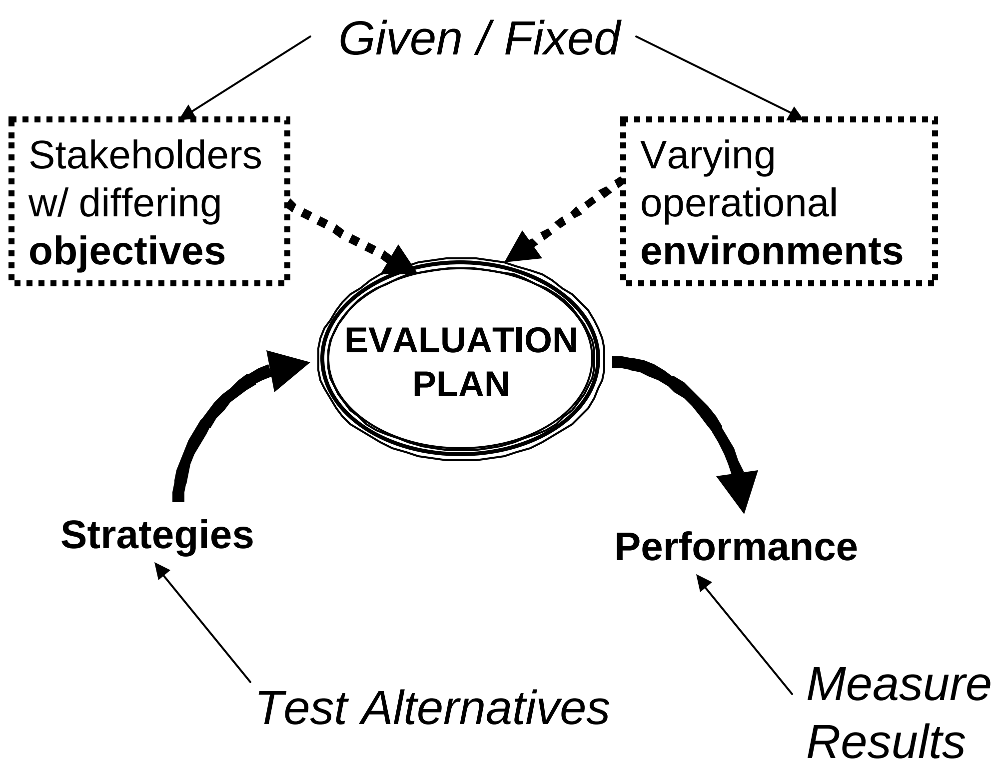

Figure 1: Framework Concept

In the case of the Columbia Pike corridor, a key objective targeted by stakeholders concerns the improvement of bus schedule adherence without substantial negative impacts on other traffic. While the underlying aim deals with provision of a higher quality of service for transit in the subject corridor, schedule adherence can impact riders in varying ways. Adding consideration of the local operating environment can clarify the specific manner in which the objectives would be achieved.

Columbia Pike is a radial arterial that connects inner suburban neighborhoods with the Pentagon, a major employment center, and freeway access to Washington, DC. Within the study area, a 4-mile segment in Arlington, frequent local bus service and peak limited-stop service is provided by the Metrobus division of the Washington Metropolitan Area Transit Authority (WMATA). Primarily, the services connect various neighborhoods with the Columbia Pike corridor and the Pentagon. Significantly, at the Pentagon, a major intermodal transfer center provides connections to buses and Metrorail rapid transit trains traveling into Washington as well as toward destinations in Northern Virginia.

How do these characteristics affect the objective of improved schedule adherence without substantial adverse impacts on other traffic? For example, bus service in the corridor is very frequent during peak periods, with headways in the range of 5 minutes, and less frequent in non-peak periods, typically with 15-minute headways. When headways are below 10 minutes, most riders will choose to arrive randomly at a stop. On the other hand, as headways get longer, riders would tend to attempt to meet a bus at the scheduled time. Hence, the notion of schedule adherence or more generally, service reliability, can have different implications depending on variables such as whether one was considering service in the peak or off-peak period. From this simple distinction, several dimensions of service reliability may be envisioned. The effectiveness of timing of transfers at the Pentagon can reflect the reliability in the arriving service. In the off-peak situation, a traditional attempt may be made to get buses to arrive at the bus stop on schedule, i.e. no earlier than the scheduled time and no later than a certain threshold. During the frequent peak service, schedule adherence may be thought of in the same fashion, or alternatively, a headway-based scheduling approach may be taken. In this case, distinguishing between early and late buses from the passenger perspective may be difficult, making deviations from schedules less relevant. Passengers waiting at a stop might consider the spacing or headway between buses to represent schedule adherence, so that buses arriving at the advertised headway would be considered to adhere to the schedule. Finally, service reliability in the peak may be thought of in terms of consistency in travel time. If a rider's travel time is inconsistent from day to day, the service may be considered to have poor reliability, and vice versa. This particular view of service reliability will be examined further in more detail in the illustration of the evaluation plan.

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

Evaluation Plan

As discussed previously, the evaluation plan embodies the evaluation objective, in this case the measurement of performance impacts resulting from various traffic signal priority strategies. Appropriate measures of effectiveness, both quantitative and qualitative, can be established for each system objective to be assessed in the evaluation. For example, measurement of service reliability may be accomplished through the use of on-time performance (OTP), which gauges the frequency of differences between actual and scheduled arrivals at timepoints beyond certain thresholds. Another measure of service reliability might be the perceived waiting time by riders at bus stops, which may be examined through the riders' subjective opinions of long waits, or perhaps may be related to the actual maximum headway achieved in operation. This research has conceptualized and developed measures of effectiveness corresponding to differing objectives of transit signal priority, as per the methodology defined in the evaluation framework. Table 2 illustrates the measures of effectiveness and the connections to the underlying objectives. Cities desiring to evaluate a transit signal priority deployment can use the framework to establish objectives, the local environmental conditions, and strategies selected. Based on this information, the appropriate evaluation measures can then be selected from Table 2.

Table 2: Evaluation Measures

Objective	Measure	Measurement
1.0 Bus Service Reliability (transit schedule adherence)	*1.1* On Time Performance (OTP)	% of arrivals in on-time window at timepoint(s)
	1.2 Time Reliability	Standard deviation of elapsed time between timepoints or 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 (RT)	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 or intersection], [person or vehicle]

	3.2 # of stops	Stops by [corridor or intersection], [person or vehicle]
	3.3 Mainline Travel Time	%-ile or average operating speed
	3.4 Cross Street Delay	Maximum, 95%-ile, or average delay
	3.5 Fuel Consumption and 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

The plan can also include a design of simulations and field tests to be used in the collection of measures of effectiveness for each alternative strategy to be tested. These simulations and field tests will consider the level of buy-in anticipated, the tradeoffs between precision and level of effort and resources required, and the applicability to dynamic situations, including various operational environments and system objectives.

Some examples of data collection techniques as well as analysis methods appropriate for the system objective will now be briefly described, but additional detail on the measures selected for the case study will be presented in the discussion of the case.

1.0 Bus Service Reliability (transit schedule adherence)

1.1 On Time Performance (% of arrivals in on-time window at timepoint): This measure is often suitable for a general estimation of service reliability. Many transit agencies have an established definition of "on-time", such as from 0 minutes early to 10 minutes late. This measure can therefore provide consistency with established reporting mechanisms. Data for this measurement may be collected by recording arrival times at selected timepoints and comparing with scheduled times for a predefined sample of buses. A simple ratio representing On Time Performance may then be calculated as the number of buses arriving in the "on-time" window divided by the total number of samples.

1.2 Time Reliability (Standard deviation of elapsed time between timepoints or endpoints): This measure is suitable for the assessment of service reliability of a particular route or route segment. This may be used for the purposes of scheduling, to ensure that sufficient recovery time, the out-of-service time planned at the terminal points, is available. If enough recovery time is not planned into the schedule, the ability of a bus to continue service either on a return trip or another route can be negatively impacted. In addition to recovery time considerations, this measure can isolate the routes or segment(s) of routes that have inconsistent running times. These areas may be targeted for alternative improvements ranging from operational control measures such as holding to provision of advanced traveler information systems. This measure may be calculated by gathering the elapsed time between designated timepoints for a sufficient sampling of trips, and calculating the standard deviation of the samples.

1.3 Perceived OTP (Survey measure of rider opinion): This measure provides a tool to assess whether riders feel that reliability is a concern, and to what degree it is viewed to be a problem. Since service reliability is never 100% perfect, it is often desirable to assess whether a given level of reliability, though imperfect, is viewed by riders as adequate or as a key service issue requiring priority attention. Given the limited resources available to a transit agency, prioritizing the efforts to improve service can be important in making the most productive use of resources. Keeping in mind that rider perceptions of "schedule adherence" or "reliable service" can be influenced by other factors such as travel time, survey measures can nonetheless provide valuable direction to planners on specific routes requiring attention. Surveys measuring this opinion may ask questions such as "Do you feel that the buses usually arrive on time?" and ask riders to rate their opinion on a range such as (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). This range may have numeric values assigned and an average may be calculated, or each category may be viewed separately as a proportion of the total.

1.4 Spacing (Maximum headway measured at timepoints): This measure is suitable for measuring service reliability in service with relatively frequent headways. Operational control problems related to bus bunching may cause the apparent headway to be much longer than the scheduled headway. If two buses become bunched, the scheduled headway between them has been lost, and effectively transferred to the bus preceding and following the pair. For a passenger arriving at a stop, the expected waiting time increases accordingly, as the second bus in a pair does not provide any reduction in waiting time over the first bus alone. The maximum headway measured at a timepoint would capture the worst-case waiting time for a passenger arriving at the stop, and may be compared with the passenger's expected waiting time based on the schedule, one-half the scheduled headway. This measurement may be collected by noting the arrival times of buses at a given timepoint, and selecting the two arrival times with the longest period of time in between.

1.5 Arrival Reliability (Standard deviation of delta / actual time vs. scheduled at timepoint): This measure is suitable for assessing service reliability at key locations. While this measure is similar to 1.2 Time Reliability, this measure considers the scheduled time specifically. In the case of a trip or service requiring a connection, the variability in the arrival time at the connection point plays an important role in the overall level of service. For a passenger, high variability in the arrival time translates into an untimed transfer, with the passenger facing the corresponding expected waiting time for the second service. In the case of a timed transfer, the expected waiting time (and travel time) for the passenger is lesser, since the services are designed to meet, and can continue after the later service arrives at the transfer point. From the perspective of the transit operator, the ability to create a successful timed transfer, with a minimum of waiting, depends on consistent arrival times. Since each service will wait until the later one arrives, both services will need to consider a longer expected waiting time in their schedules. This measurement may be calculated by computing the standard deviation of the "delta", defined here as the difference between the actual arrival time and scheduled arrival time, at the timepoint of interest.

2.0 Bus Efficiency (transit travel time savings)

2.1 Run Time (Mean elapsed time between start and end points): This measure is suitable for scheduling purposes, as well as providing information on passenger travel times. The average running time provides the primary information for determining the buses and operating hours required for a given trip and route. If the run time can be reduced, there may be the potential for reducing the operating hours necessary for providing the service. However, since there are other factors, such as maintaining clock-based headways, actual operating savings may or may not occur. Generally, savings of a "bus" are easier to achieve on more frequent, short-headway service. For example, a route with a 10 minute scheduled headway and a 120 minute cycle (complete round trip) time needs 12 buses to operate; if the cycle time could be reduced to 110 minutes, only 11 buses would be required, yielding the cost savings associated with one bus. From the perspective of passengers, run time reductions provide for scheduled and in-vehicle travel time savings which provide benefits depending on the magnitude of savings.

2.2 95%-ile RT (95th percentile elapsed time between start and end points): This measure is similar to 2.1 Run Time, but attempts to integrate some aspects of service reliability. Often, planning decisions are not made based on the average travel time, but on the expected likely maximum travel time. This is based on the need to arrive at a destination on time; if the average travel time were used, one might be late half the time. The use of a percentile (95th in this case) allows some flexibility for extreme cases, and the specific percentile may be selected based on the characteristics of the need and the meaningfulness of the measure. In order to calculate this measurement, a sample of travel times between endpoints would be collected and the value corresponding to the 95th percentile would be selected. It is significant to note that this may require a fair number of samples to provide a more precise estimate.

2.3 Trip Time (Weighted passenger time on board / in-vehicle): This measure is suitable for establishing aggregate benefits from travel time savings, if any. By considering the bus occupancy over time, the net benefit to riders in terms of travel time savings over a base case could be computed for a benefit analysis. This measurement can be difficult to calculate, especially in a field test, since the time and number of passengers boarding and alighting needs to be gathered.

With the use of automatic passenger counters (APCs) or simulation models that include sufficient monitoring of bus operations, this may be possible. In other cases, an approximation may be adequate; for example, the average occupancies may be estimated over certain segments of a route (e.g. between major timepoints) and the segment travel times may be added, weighing each by the corresponding occupancy on the segment.

2.4 Perceived Travel Time (Survey of change in riders' opinions before & after): This measure can provide an assessment of whether signal priority has created a noticeable difference for riders. In cases where the signal priority system is promoted, there should be caution given to potential biases. However, if riders are not aware of the system, a before and after survey measuring perceived travel time can provide useful information. A potential survey question addressing this measurement might be, "My travel time on this route is good," followed by answers such as (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). Since there are many factors that play a role in this perception, the results should be considered carefully.

3.0 Other Traffic-Related Impacts

3.1 Overall Delay (Delay by corridor or intersection, person or vehicle): This measure can provide information on the degree to which other vehicles are being delayed by a signal priority system. On a corridor basis, the delay to vehicles would provide an aggregate basis for potential disbenefits, while an intersection-level analysis would provide information that may suggest certain intersections that should not be included in a priority system or that should be given special consideration. On a person basis, this measurement provides information that can be useful in determining whether the system is benefiting all individuals in the aggregate, considering the higher occupancy of buses. As in the case of Measure 2.3 Trip Time, variable occupancies may be approximated and uses as weighting factors in delay studies or simulation models.

3.2 # of Stops (Stops by corridor or intersection, person or vehicle): This measure is similar to Measure 3.1 Delay, but considers the number of stops made by vehicles rather than delay experienced. The occupancies of vehicles may again be used to weight the vehicle stops accordingly to get an average representing the average number of stops per individual.

3.3 Mainline Travel Time (percentile, or average operating speed): This measure provides an assessment of the overall performance of the main (priority) arterial. Since a priority system is likely to create different impacts on the priority corridor versus the cross streets, it can be useful to examine the impacts separately. This measurement can be calculated over a selected segment of the corridor by averaging a sample of travel times and taking the reciprocal to yield average operating speed. A percentile may also be used to examine how the drivers experiencing the (near) worst-case situations are faring.

3.4 Cross Street Delay (Maximum, 95th percentile, or average delay): This measure considers the impacts of a signal priority system on the drivers on the cross streets. Various signal priority strategies may reduce green times on the side streets or even skip the cross street phases. By examining whether and how much the (near) maximum delay experienced on a cross street has increased with priority, the potential for dissatisfied drivers can be assessed. By using an average measure, the overall impacts of the system can be weighted in comparison with benefits and arterial performance. This measurement may be calculated by taking a sample of delays for a cross street (or streets) and examining the maximum, percentile, and/or average.

3.5 Fuel Consumption / Emissions (Model output for corridor, average per vehicle): This measure is suitable for assessing environmental impacts from the provision of signal priority. Since priority has the ability to increase and decrease speeds, delay, and stops, there are likely to be changes in fuel consumption and emissions. While bus fuel consumption may potentially be measured in a field test, more precise estimates of impacts depend on simulation models that can aggregate environmental impacts over the corridor.

3.6 Overall System Efficiency (Throughput achieved vehicles per hour, persons per hour): This measure attempts to consider the overall impacts on traffic and person flow. On a network basis, this may be assessed with the use of simulation models, weighting occupancies accordingly if desired. However, one needs to consider the potential for route diversion to impact this measure if delay changes are significant.

3.7 Intersection Safety (Red light running, accident frequency): This measure attempts to gauge some of the safety impacts of implementing priority. With potential increases in cross street delay, there may be an increase in frustration of drivers forced to wait longer at red lights. This may translate into an increase in the number of drivers who run red lights. Since accident frequencies are generally low, it may be difficult to assess the safety impacts using accidents, but red light running and other driver behaviors may be related to the potential for accidents. Simulation models would provide only limited assistance in this measure (e.g. vehicles do not run red lights in simulations); before-and-after field studies would likely provide a better basis for measurements.

As an example, if local stakeholders desire to implement traffic signal priority for transit for the purpose of decreasing bus "bunching" on a service with short headways, Measure 1.4, Spacing, would be an appropriate measure since bunching tends to enlarge the gap between bus "bunches" arriving at a given location. The corresponding measurement in this case would be the maximum headway between buses, measured at key points. In a simulation or field test, the bus arrival times at the key timepoints would be noted and the maximum headway in the analysis period would be computed. After gathering sufficient samples with the priority strategy active and inactive for the desired statistical confidence intervals, a comparison may then be made to determine whether the priority strategy was associated with any improvement.

Application to Service Reliability (Theory & Hypotheses)

Building upon the previous discussions of service reliability, the framework and plan are applied in this research to the evaluation of bus service reliability impacts resulting from various traffic signal priority strategies. A theory is posited which establishes bus transit reliability as a function of four major factors; this theory attempts to apply the insights of Markowitz (*35*) in Modern Portfolio Theory to analysis and optimization of transit reliability. Furthermore, the composition of running times are in part developed from analyses on running times and reliability, while attempting to incorporate claims and results from traffic signal priority studies and deployments. The first factor concerns dwell time associated with the bus' need to service passengers stops, and includes passenger demand and stop locations, vehicle characteristics, and the boarding / alighting process. The second factor pertains to signal delay, which is affected by signal locations, signal operations and signal timing plans. Congestion and traffic-related delay make up the third factor, and is dependent on traffic volumes, road capacity / characteristics, weather, and bus dynamics. Finally, the fourth factor considers the “controllable” measures, such as the bus schedule / assigned slack time, timepoints / driver actions, and the priority criteria / strategy. By adjusting the fourth factor, a specific priority strategy attempts to impact the other factors in a way such that the overall running time is favorably affected. Signal priority for transit targets most directly the reduction of the second factor, though due to the interrelationships between factors, the other factors can also be influenced.

Columbia Pike Model

The evaluation plan will be applied using field and simulation data from the Columbia Pike corridor (See Appendix B for map). This research builds upon prior work by Dion et al (*36*) and Zhang (*37*), including the substantial effort that had been expended in the construction of the base simulation network. While a summary is provided here, additional detail may be found in those references. This base network was constructed in the INTEGRATION simulation package, which provides strength in modeling of individual vehicles on a second by second basis, as well as a signal priority feature that is selectable by vehicle class and intersection. Since the operation of priority depends on the location and travel of the buses, precise location and tracking is necessary for analysis. INTEGRATION was used in conjunction with the QueensOD model, which provided the means to calibrate the INTEGRATION model. INTEGRATION uses a zonal origin-destination matrix; QueensOD utilized the observed data from field traffic counts at intersections and traffic detectors to provide INTEGRATION with the required zonal flows. The geometric data, fixed signal timings, and bus stop locations were provided by the Arlington County Department of Public Works, while speed data was collected using a GPS-equipped vehicle. While the corridor currently uses the SCOOT signal system, the fixed timings provided were recently optimized plans intended for backup operations. Given the particular conditional priority strategy developed and tested in this research, it was necessary to use the simple fixed timing plans as they provided repeatability over multiple runs, whereas SCOOT may alter the timings in successive runs. Transit data was based on a combination of published schedules and field data collection of occupancy, travel time, and dwell times. It is important to note that INTEGRATION provides limited modeling capabilities for transit operations, and therefore, simplifying assumptions, such as buses servicing each stop with a uniform dwell time, were necessary.

The corridor itself includes numerous cross streets, of which 21 are signalized. As mentioned previously, bus service is frequent with one mainline trunk route and a few crossing or overlapping routes; this research will focus on the performance of the mainline trunk route, Route 16, at a corridor level. There was an ongoing effort to gather base data so that it could be used for both the simulation and field data portion of the evaluation data. Such base data included traffic related information such as speed, delay, and stops, as well as transit information such as travel time composition (composed of the four factor variables: dwell, signal delay, traffic delay, and control measures) and occupancy. After signal priority is deployed in the corridor, it is anticipated that "after" data collection will occur in a similar fashion. Statistical analyses, in the form of paired two-sample t-tests for means, will attempt to determine whether priority control measures are related to reliability. Since 30 sample runs will be conducted, the central limit theorem suggests that the averages will approximate a normal distribution. The priority strategy to be examined will be limited to extended green and early green phases, with the thresholds and conditions for activation that exist in INTEGRATION (see Appendix D).

In the illustration of the evaluation plan, a specific situation will be examined, namely the AM peak period for buses traveling eastbound on Columbia Pike. The measures of effectiveness to be used were selected from Table 2, and were chosen to represent passengers who board eastbound buses destined for the Pentagon as either a final destination or transfer point. Given that many of the trips are work trips, the bus service reliability measure was selected to be arrival reliability, since workers are generally trying to arrive to work on time, usually the same time each day. With the large number of people transferring at the Pentagon bus/rail station, the significance of arrival time is magnified, since missing a transfer often translates into the addition of a relatively long wait time for the next bus, or to a lesser extent, the next train. In general, these passengers would be able to adjust to somewhat longer or shorter travel times, as long as they are consistent. However, to the extent to which travel times vary greatly, passengers are likely to add additional planned travel time by leaving early enough to arrive on-time most of the time. In terms of bus efficiency, the measure to be used is the averaged Run Time, noting that while the 95^{th} percentile Run Time would yield an enhanced estimate of planned travel time, one measure of reliability is already being considered and also, a good estimate of the 95^{th} percentile may require many samples. Finally, the impact on other traffic will be evaluated based on impacts on overall delay in the corridor, both on a person and vehicle basis. Since stakeholders are cautious so as not to create substantial adverse impacts on other traffic, measurements of change in average delay are important to examine.

The selection of these measures under the given conditions on the Columbia Pike corridor give rise to the following hypotheses which were examined, using INTEGRATION:

Hypothesis # 1. The provision of priority to eastbound buses that are late will be associated with higher *bus service reliability*.

Hypothesis # 2. The provision of priority to eastbound buses that are late will be associated with higher *bus efficiency*.

Hypothesis # 3. The provision of priority to eastbound buses that are late will be associated with *other traffic-related impacts* such as increased overall delay.

4.0 RESULTS

As previously stated, the application of the evaluation framework and plan will be illustrated through its use in evaluating potential transit signal priority applications on Columbia Pike. This chapter describes the results achieved in the assessment of a scenario of a “catch up” priority strategy for eastbound buses in the AM peak period, using the INTEGRATION simulation tool. In the “catch up” priority strategy, a single checkpoint is used to establish whether a particular bus is behind schedule by more than a certain threshold. If so, the bus is given priority for the remaining portion of the corridor, in order to “catch up” to its schedule. Since INTEGRATION does not currently have direct support for real-time conditional priority, this “catch up” strategy was selected as a compromise that provides conditional priority yet entails a reasonable level of complexity in implementation. At the same time, the strategy has a practical basis in operations by attempting to address the problem of late-running buses through the use of conditional priority.

The checkpoint selected for this analysis is the intersection of Columbia Pike and George Mason Drive. This location was chosen primarily to balance the data requirements for the simulation. The longer the length of the test segment, the more distinguishable the priority results should be. However, as the checkpoint is placed farther upstream, fewer buses will traverse the segment, due to the branching of interlined routes off of Columbia Pike. This leads to a reduction in the number of data samples. From a practical standpoint, some limitation on the extent of priority deployment is likely given cost considerations; as such, the segments that are more frequently traversed by buses would probably be deployed prior to other segments. The endpoint of the segment was selected based on the availability of a scheduled timepoint near the end of the corridor. The timepoint at Columbia Pike at the Navy Annex was chosen. Overall, this segment covers 2.3 miles of the 4-mile test corridor.

The threshold for determining whether a bus is sufficiently behind schedule to warrant the "catch up" priority was estimated based on the priority logic in the INTEGRATION simulation model and the characteristics of the priority segment. However, such as strategy should not make the bus get ahead of schedule as a result of receiving priority treatment. Therefore, the threshold is set to a value approximating the total maximum additional green time for a bus receiving priority. In this way, a bus would need to be sufficiently behind schedule at the threshold so as not to arrive at the destination early even if receiving the maximum benefit from priority. The priority logic provides for a green extension or early green recall up to a maximum green time constrained by amber time (3 seconds/phase) and a 5 second minimum green time per phase. Based on the phase splits on the 10 signals on the segment, a total maximum additional green time of 221 seconds could theoretically be achieved by a bus arriving at precise times (see Table 3). However, the probability of this occurring is extremely small; a more balanced estimated maximum benefit was assigned two-thirds of this value, rounded to a value of 150 seconds. This value was used as the threshold for priority, so buses which arrive more than 150 seconds later than the scheduled time at Columbia Pike and George Mason Drive are given priority for the remainder of the corridor.

Table 3: Maximum Additional Green Times by Intersection

Cross Street	Cross Street Green Split (s)	Max extension / truncation (s)
George Mason	39	31
Quincy	25	17
Monroe	25	17
Glebe	45	37
Highland	23	15
Walter Reed	32	24
Barton	27	19
Wayne	25	17
Courthouse	35	27
Quinn	25	17
Sum of Maximum Additional Green Time		221

Simulation Process

The simulation process used in this research builds upon prior work by Dion, Rakha and Zhang (*36*). Their INTEGRATION model network of the Columbia Pike corridor was used as a base network upon which testing was conducted. Since INTEGRATION currently does not provide real-time priority, a method was developed for using the existing class-based priority mechanism. Due to limitations in the vehicle classes available, cross street buses were recoded as local buses so that an additional vehicle class would be available for priority buses. This “priority class” was configured as eligible for priority on signals from George Mason Dr. to the Navy Annex. In order to activate priority for a particular bus, the bus would be reclassified into the “priority class” vehicle type prior to the run. However, in order to determine which buses were eligible for priority based on the lateness threshold, it was necessary to first run the simulation without priority and analyze the bus operations. The arrival times of buses at George Mason Dr. were compared with the scheduled times, yielding the lateness to be compared with the threshold. Hence, each simulation run needed to be run at least twice for each random number seed.

Postprocessing of the output from the simulation was conducted external to INTEGRATION, using the Microsoft Excel spreadsheet package. INTEGRATION can provide time and other information when designated vehicles complete an individual network link. This data was imported into Excel and filtered to find the eastbound buses of interest. Then, the simulation times for each bus were extracted for George Mason Dr. and Navy Annex. These times were compared with the scheduled timepoints at these locations, and by subtraction, the arrival time “delta” (representing lateness) was calculated. In the non-priority (first) run, the lateness at the threshold location (George Mason Dr.) was used to determine which buses would receive priority. In addition, the endpoint lateness was also captured in order to provide a basis for comparison with the priority case. After recoding the input files to reflect the priority buses, by reclassifying the vehicle class to the priority class, the simulation process was repeated. In this priority (second) case, the calculation of arrival time delta was made at the endpoint (Navy Annex). By computing the standard deviation of these lateness values, the selected measure of bus service reliability was generated. In order to capture run time for use in measuring bus efficiency, the same simulation times at George Mason Dr. and Navy Annex were used, with the difference representing the run time between the endpoints. Finally, the simulation summary file with aggregate traffic measures including delay was saved and postprocessed to extract overall delay by vehicle class.

Relationship with hypotheses

The application of the “catch up” priority strategy attempts to illustrate the presence of a relationship between the priority condition, being behind schedule by at least a certain amount, and bus service reliability. In particular, this analysis attempts to establish a relationship between the priority strategy and the signal delay experienced by buses. By selecting buses for priority treatment using the lateness criteria, overall bus service reliability may be increased, as the first hypothesis states. In addition, by reducing the signal delay, the bus efficiency would also be increased, as stated in the second hypothesis. Finally, the third hypothesis suggests that the priority given will have other traffic-related impacts due to the changes in signal timing resulting from priority.

Bus Service Reliability – Arrival Reliability

Based upon the capabilities of INTEGRATION and the priority strategy being tested, the measure selected for bus service reliability is arrival reliability (Measure 1.5 from Table 2). In the test scenario, buses begin at varying origin points since there are several interlined routes. Arrival reliability may be quantified by the standard deviation of the arrival time delta or lateness (the difference between actual and scheduled arrival time) at the endpoint, Columbia Pike at the Navy Annex. If buses arrive very close to the scheduled arrival time, the standard deviation would be low, and arrival reliability would be high. Conversely, if buses arrive much earlier and later than the scheduled time, arrival reliability would be low. However, further clarification of an exception to this statement is warranted. If buses arrive consistently late or early by a certain amount, the arrival reliability could be high, even if the degree of earliness or lateness is significant. The reasoning in this case is that the service may be reliable, but the schedule may not reflect arrival times accurately.

Individual Trip Level Analysis

By applying the measure of arrival reliability at the trip level, individual scheduled runs may be analyzed to examine the impact of priority on a specific trip, and hence, the riders who regularly ride that trip. The run time from George Mason Dr. to the Navy Annex was examined for a particular scheduled trip, scheduled to depart at 1350 seconds into the simulation (see Appendix F). Based on 30 runs, the arrival reliability of this trip, measured by the standard deviation of the "delta" at the Navy Annex, was 340.8 seconds in the base case, and 325.7 seconds with priority active, representing a 4% decrease. This increase in arrival reliability was found to be statistically significant using the paired two-sample t test for means with a p value of 0.039 (see Appendix G).

Analysis of Reliability over a Period of Time

Schedule reliability may be examined across the peak period, rather than looking at individual scheduled runs. By using the measure of arrival reliability, quantified by the standard deviation of the difference between arrival time and scheduled time, one can get a picture of the bus service reliability over a time period. As the standard deviation decreases, the arrival time becomes more consistent. Though there may be an offset versus a printed schedule, this may be remedied in a consistent service by adjusting the timetable, or otherwise regular riders would become accustomed to the offset. Ideally, the offset, represented by the mean deviation from schedule, would approach zero as the standard deviation narrows, but may be a tradeoff in preventing buses from getting ahead of schedule.

Bus Service Reliability – Hypothesis #1

In the case of the test segment on Columbia Pike from George Mason Drive to Navy Annex, the arrival reliability (Measure 1.5 from Table 2) represented by the standard deviation of arrival time “delta”, or difference between actual and scheduled time, was calculated at Navy

Annex for eastbound buses. The resulting values for the 30 pairs of simulation runs without and with priority are shown in Figure 2. In 23 of the 30 cases, the provision of priority resulted in a lower standard deviation, representing greater bus service reliability. Overall there was an average decrease of 3.2% in the standard deviation of arrival time delta, from 209 to 202.4 seconds. Using the paired two-sample t test for means, this difference was found to be statistically significant with a p value of 0.003. This indicates that the arrival reliability is higher with conditional priority than with no priority, affirming Hypothesis #1, which states that the provision of priority will be associated with higher bus service reliability.

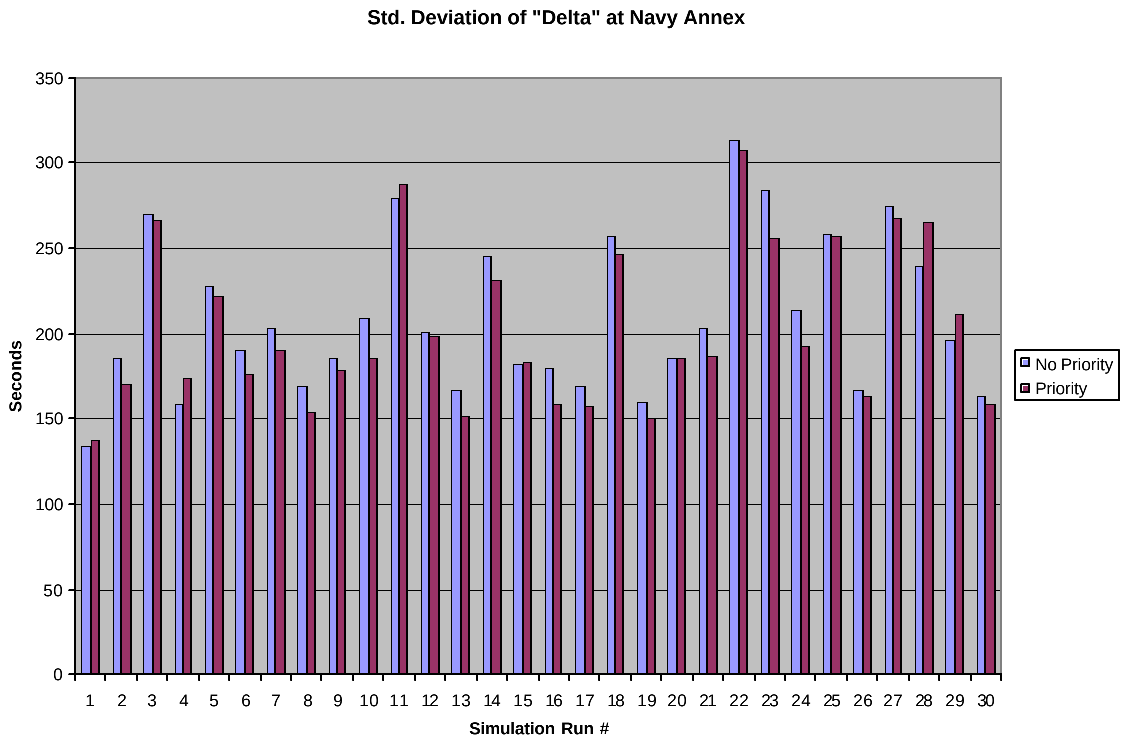

Figure 2: Standard Deviation of "Delta" Time at Navy Annex

Aggregating the data from the 30 runs depicted in Figure 2, the effect of priority on arrival reliability (Measure 1.5 from Table 2) can also be visualized in a smoothed frequency chart of arrival time delta, as shown in Figure 3. The arrival reliability relates graphically to the "narrowness" and height of the curve, which corresponds to the same measure used previously, the standard deviation of arrival time delta. Ideally, the curve would be represented by an impulse function, located at the exact scheduled time, i.e. 0 minutes behind schedule. In reality, the most desirable distributions have a steep cutoff at 0 minutes, meaning few early buses, a tall peak immediately after, representing arrivals on time and immediately after, and again a steep cutoff downward near as possible to the 0 point, representing few buses that are significantly behind schedule. Improved arrival reliability would result in a lower standard deviation of arrival time delta, and a narrower and taller, and hence more desirable, frequency distribution chart. The “catch up” priority treatment for late buses appears to narrow the distribution of arrival time delta by a small amount, consistent with the prior results in terms of standard deviation.

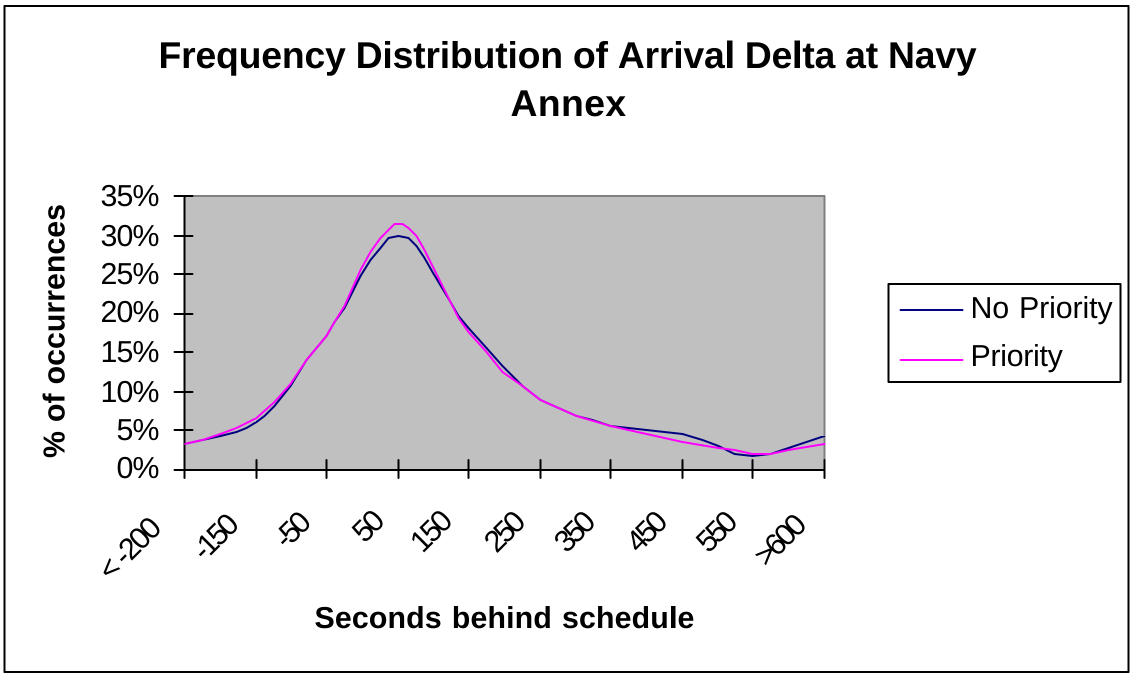

Figure 3: Alternative Visualization of Arrival Reliability

A Comparison with Autos (Time Reliability)

As a reference for comparison of variability in travel times, a sampling of probe vehicles, consisting of normal autos, was specified for the 30 base simulation runs in INTEGRATION. The arrival times for these vehicles were captured at the two timepoints at George Mason Dr. and the Navy Annex, just as bus arrival times were captured. However, since autos do not have a schedule, Time Reliability (Measure 1.2 from Table 2) was used for analysis. Travel times were calculated based on these arrival times, and the standard deviations of these travel times for each run were computed. Averaging the data for 30 runs (see Appendix F), the average standard deviation for a run was found to be 41.9 seconds. Comparing to the corresponding value for buses in the base case (see Appendix F), 157.7 seconds, the results indicate substantially less variability in travel time for autos as compared to buses. This is consistent with the prior discussion of the four factors impacting bus reliability. Autos and buses would generally have similar exposure to the factors of signal delay (in the base case) and traffic-related delay. However, buses are exposed to the significant factor of dwell time, which is likely to be highly variable due to passenger demand and loading variations. For example, a limited sample of field data from Columbia Pike indicated a coefficient of variation for dwell times of 0.7 (*36*).

Bus Efficiency – Average Run Time

In terms of bus efficiency from an operational perspective, the 95th percentile running time (Measure 2.2 from Table 2) can provide a good indication of potential performance in terms of bus schedules. If a particular run may be completed in a shorter time on a consistent basis, there exists the potential for operational savings. However, one reliability measure is already being considered; also, in order to get a good estimate of the 95th percentile running time, it is desirable to complete a large number of simulation runs since each run only provides one observation for any particular bus trip, and the potential for a fewer number of samples to skew the result is substantial.

Bus Efficiency – Hypothesis #2

Meanwhile, the average running time (Measure 2.1 from Table 2), can be used for scheduling by considering it along with applicable recovery/layover time. For passengers, changes in mean running time without priority and with priority, should provide evidence of potential direct travel time benefits. Figure 4 shows the average bus run times for the test segment for the 30 simulation run pairs. In 20 of the 30 cases, the average run time was lower in the case with priority.

Overall, a 0.9% decrease in travel times was observed on average over the segment when “catch up” priority was granted, from 552.6 to 547.8 seconds. Using the paired two-sample t test for means, this difference was found to be statistically significant with a p value of 0.015. This indicates that the average bus run time is lower with conditional priority than with no priority, affirming Hypothesis #2, which states that the provision of priority will be associated with higher bus efficiency.

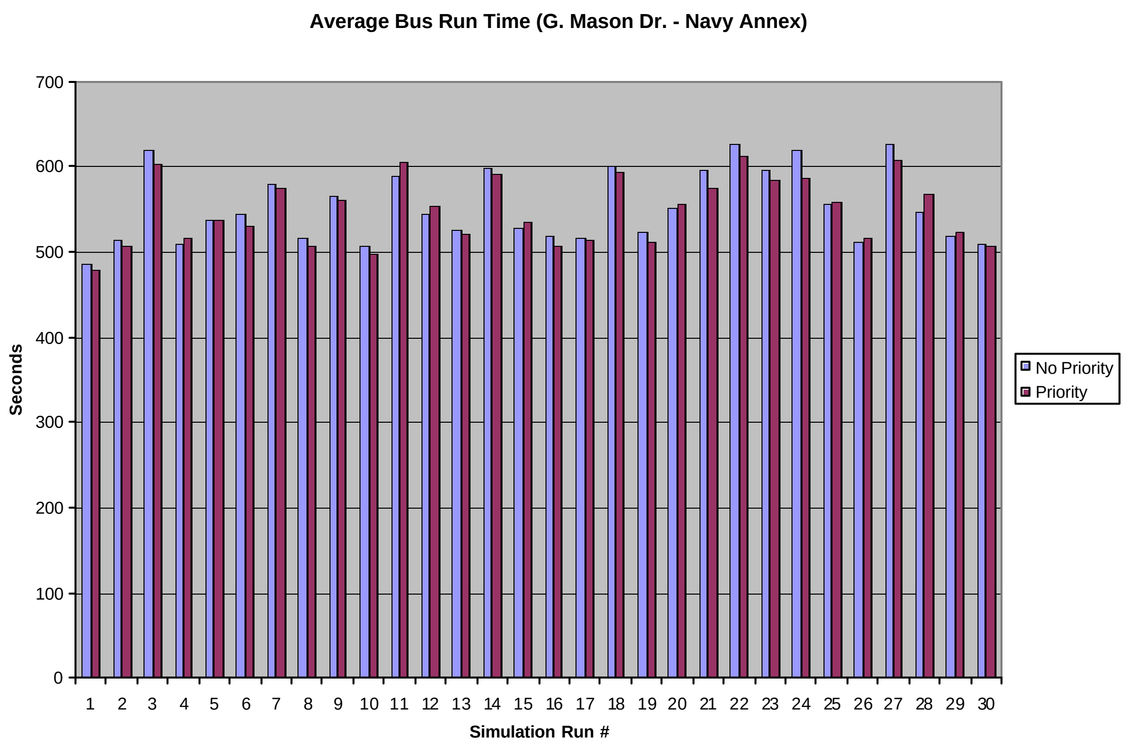

Figure 4: Average Bus Run Times

Other Traffic-Related Impacts – Overall Delay (person, vehicle)

Other traffic-related impacts resulting from the use of transit signal priority play a critical role in the evaluation process. Some important stakeholder groups tend to be more cognizant of potential negative impacts on the general motoring public than potential benefits to transit users and operators. The ability to quantify these potential impacts using simulation is a key part of the evaluation plan.

Other Traffic-Related Impacts – Hypothesis #3

The INTEGRATION simulation model contains built-in measurement tools to assess changes in delay, emissions, and other similar impacts. In this case of evaluating transit signal priority, two measures relating to Overall Delay (Measure 3.1 from Table 2) were selected to reflect the other traffic-related impacts. Overall vehicle delay on the corridor captures the aggregate delays experienced by all vehicles. Given the same underlying conditions, the simulation runs without and with priority may be compared to estimate average changes in delay per vehicle. Figure 5 shows the results from the 30 simulation run pairs. In 21 of the 30 cases, the average delay per vehicle was higher when priority was given. Overall, there is an average increase in vehicle delay of 1.0% with priority, from 86.5 seconds to 87.4 seconds per vehicle. Using the paired two-sample t test for means, this difference was found to be statistically significant with a p value of 0.003. This indicates that the overall delay on a vehicle basis is higher with conditional priority than with no priority, affirming Hypothesis #3, which states that the provision of priority will be associated with other traffic-related impacts such as increased overall delay.

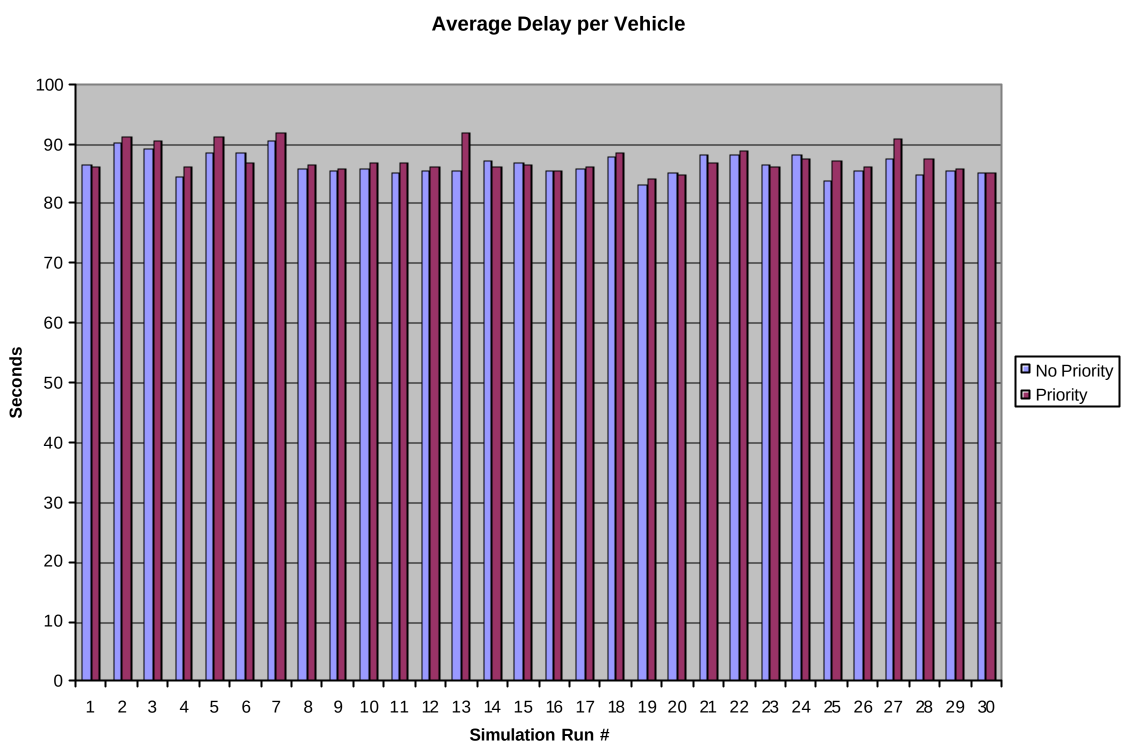

Figure 5: Average Vehicle Delays

Another way to analyze the impacts that transit signal priority has on other traffic is to examine the average change in delay experienced by each individual person traveling in the corridor. Since buses typically carry a much higher passenger load than other vehicles, the delay impact on buses is magnified relative to other vehicles. Based on field data, the average occupancy for buses was assigned a value of 23 passengers, while other traffic was given an average occupancy of 1.1. Figure 6 shows the results after weighting the delay amounts by number of passengers. Overall, the net average increase in person delay over the corridor is 0.6% when priority is granted, from 104.4 to 105.1 seconds per person. Using the paired two-sample t test for means, this difference was found to be statistically significant with a p value of 0.021. This indicates that the overall delay on a person basis is higher with conditional priority than with no priority, affirming Hypothesis #3, which states that the provision of priority will be associated with other traffic-related impacts such as increased overall delay.

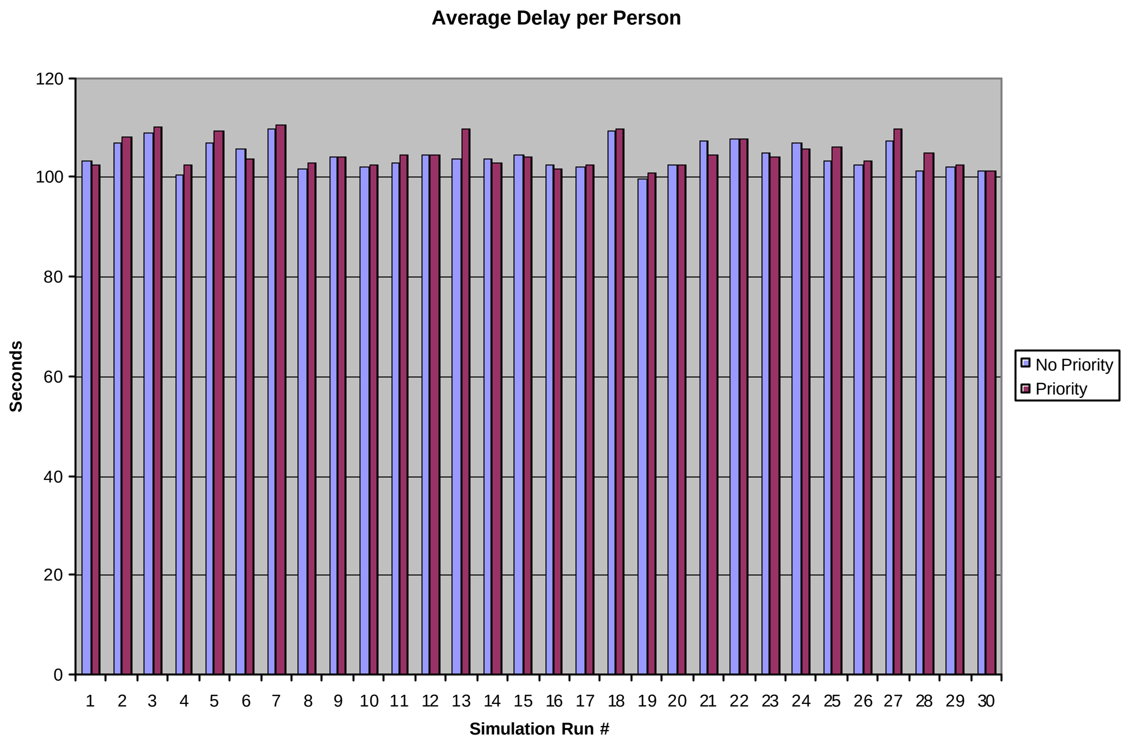

Figure 6: Average Person Delay

5.0 SUMMARY / CONCLUSIONS / RECOMMENDATIONS

Summary

This research resulted in the development of an evaluation framework and plan that assesses the impacts of signal priority strategies for transit buses. Three major categories of impacts were considered:

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

Within these categories, a variety of indicators were proposed, each measuring a different aspect of impact. Depending on the particular environment and objectives, the most appropriate measures of effectiveness could be chosen from the proposed measures.

The application of the framework and plan was illustrated through its application on the Columbia Pike corridor in Arlington, Virginia, using the INTEGRATION simulation package. A specific strategy was considered in this analysis, namely a "catch up" provision for eastbound buses in the AM peak period. This provision had the intended goal of lessening the lateness of buses at the destination by offering conditional priority to buses that were late at a certain checkpoint. The priority status was continued for late buses until the end of the corridor. The priority given to buses consisted of extending the green indication on the main street (Columbia Pike) up to a certain limit, or providing an early green indication, again up to a limit.

The INTEGRATION simulation software was used to model the movement of vehicles and provide priority through an external computer-assisted conditional priority method developed in this research. The method involves using the simulation to determine which buses would be late at the checkpoint, and assigning the late buses to a different vehicle class which would be then be given priority in a new simulation run. Results were tabulated and analyzed with the use of the Microsoft Excel spreadsheet package.

Conclusions

Under the given conditions, the results indicated a statistically significant change in each of the selected impact measures when conditional priority was granted to the eastbound AM peak buses:

- A 3.2% improvement the bus service reliability, as measured by arrival reliability in the form of standard deviation of arrival time delta was found.
- In terms of bus efficiency, a 0.9% decrease in run time, also statistically significant, was observed when transit buses were given conditional priority.

- An average 1.0% increase in vehicle delay, or a 0.6% increase in terms of person delay, was found for all vehicles and persons traveling on the corridor.

These impacts are consistent with prior expectations as well as results from transit signal priority field deployments (see Table 1), keeping in mind that only buses late by more than 150 seconds were given priority. In this situation, transit signal priority granted on a conditional basis is associated with improvements in bus service reliability and bus efficiency. Since the late buses should have a reduced travel time as a result of priority, they should arrive at the endpoint closer to the scheduled time. The provision of extended green and early green to priority buses also tends to reduce travel time for those buses and therefore the average for all buses. While the absolute magnitude of the travel time savings (0.9%) is small, it is important to note that the primary objective of the "catch-up" strategy is not to make transit travel time faster, but more reliable. At the same time, when conditional priority is granted, an increase in delay to other travelers is found, though the average magnitude is small. Since the signal timing plan attempts to optimize the efficiency of overall vehicular traffic, changes to the signal timings resulting from priority would tend to move the timings away from the optimal state, thereby increasing vehicle delay. Given the higher occupancy of the buses that benefit from priority, the observed lesser impact on person delay is expected.

Significance of Research

This research has contributed to the body of knowledge relating to transit signal priority evaluation. There are often conflicting goals and objectives from multiple stakeholders when transit signal priority strategies are being considered. The framework presented here provides a basis for stakeholders to use objective measures and data to evaluate various proposed signal priority strategies. Depending on the local issues, concerns, and needs, the appropriate level of importance can be assigned to the selected evaluation criteria. Agencies evaluating deployments or planning evaluations of traffic signal priority for transit can utilize the evaluation framework and plan, selecting measures that are suitable for the particular situation.

This research has also built upon the analysis of Dion, Rakha, and Zhang (*36*), which examined the use of unconditional priority on the Columbia Pike corridor. Buses in selected classifications (e.g. local buses, express buses, cross street buses, and combinations) were given priority at all intersections without regard to lateness, occupancy, or other bus dependent factors; however, the priority functionality in INTEGRATION contains internal conditions such as minimum green times and a limit of one activation per cycle. On the same corridor during the same time period, but with unconditional priority for regular buses along Columbia Pike, the prior study found a 6% decrease in travel time for buses, an 8% increase in overall person-delay. A comparison with the results of this research must be considered carefully given the substantially different degree of priority; however, the results indicate that a “lesser” (i.e., conditional) priority strategy yielded a smaller decrease in bus travel time, and a smaller increase in overall person-delay.

The technique developed in this research to institute conditional priority using a computer-assisted technique external to INTEGRATION may be extended to examine other cases along the “spectrum” between no priority and full unconditional priority in order to gain a better understanding of the relationship. The small nominal impacts found in this research suggest that the priority strategy selected, "catch-up", under the given conditions, falls close to the no priority part of the spectrum. Nevertheless, using the INTEGRATION simulation package, research demonstrated the ability to show measurable and statistically significant impacts, lending support to the evaluation framework and plan. These impacts were found to be comparable and consistent with prior results from other research. In addition, the impact on service reliability was shown to be greatest of the impacts measured, results in line with the primary objective of the strategy.

Recommendations for Future Research

While this research has developed a foundation for the evaluation of transit signal priority strategies, future efforts can build upon this research. The capabilities of INTEGRATION may be extended to allow conditional priority to be granted internally in real-time rather than on an external basis. This would also permit priority to be granted based on lateness at each intersection, rather than priority for a corridor segment as was performed in this research. If the lateness of buses at each intersection were evaluated, the threshold for priority could be lowered from the 150 seconds late in this research to a lower value corresponding to intersection-level benefits. Such priority could illustrate the similarities and differences with a "keep on schedule" approach rather than the "catch up" approach. Research could also examine the relationship between various lateness threshold values and the impacts of priority. In this research, the lateness threshold was set high so as not to cause buses to get ahead of schedule. With only a small number of buses per run receiving priority, the impacts were relatively minor. It is likely that as more buses are given priority (as in a "keep on schedule" approach), the impacts would be greater.

While this research has illustrated the application of several of the evaluation measures developed, further work may examine the measures not directly tested here using this corridor or other networks. Such research may test other alternative priority strategies, unconditional or conditional on various other criteria, such as the degree of saturation at the intersections (*33*), that may alter the nature and magnitude of impacts. For example, in order to minimize adverse impacts on traffic delays while still providing benefits to buses, cross streets that are near saturation may potentially be excluded from priority, while intersections below saturation may have priority activated. In addition, future studies may examine the application of the measures as part of a field study rather than using a simulation model. Lessons learned from such additional studies may be used to refine the evaluation measures.

Also, further exploration of the relationship between the factors affecting bus service reliability would provide a better understanding of the role transit signal priority plays relative to other measures. Using INTEGRATION for this exploration would also require extending the capabilities of INTEGRATION since the components of bus travel time are in some cases unrelated. For example, dwell time is related to passenger loads and demand as well as achieved headways. Since priority can affect the time at which a bus arrives at a stop, the dwell time can in turn be affected. As was illustrated in the comparison of Time Reliability between autos and buses, the dwell time factor plays a significant role in variability, and capturing such interactions in INTEGRATION would be a significant area of further research.

In addition, the role of passenger loads and demand may also be examined in the context of overall impacts on person delay. As mentioned previously, the overall delay increases are lesser on a person delay basis as compared to a vehicle delay basis. Future work can investigate the contribution of higher passenger loads to potential reductions in negative person delay impacts and even potential improvements on a person delay basis.

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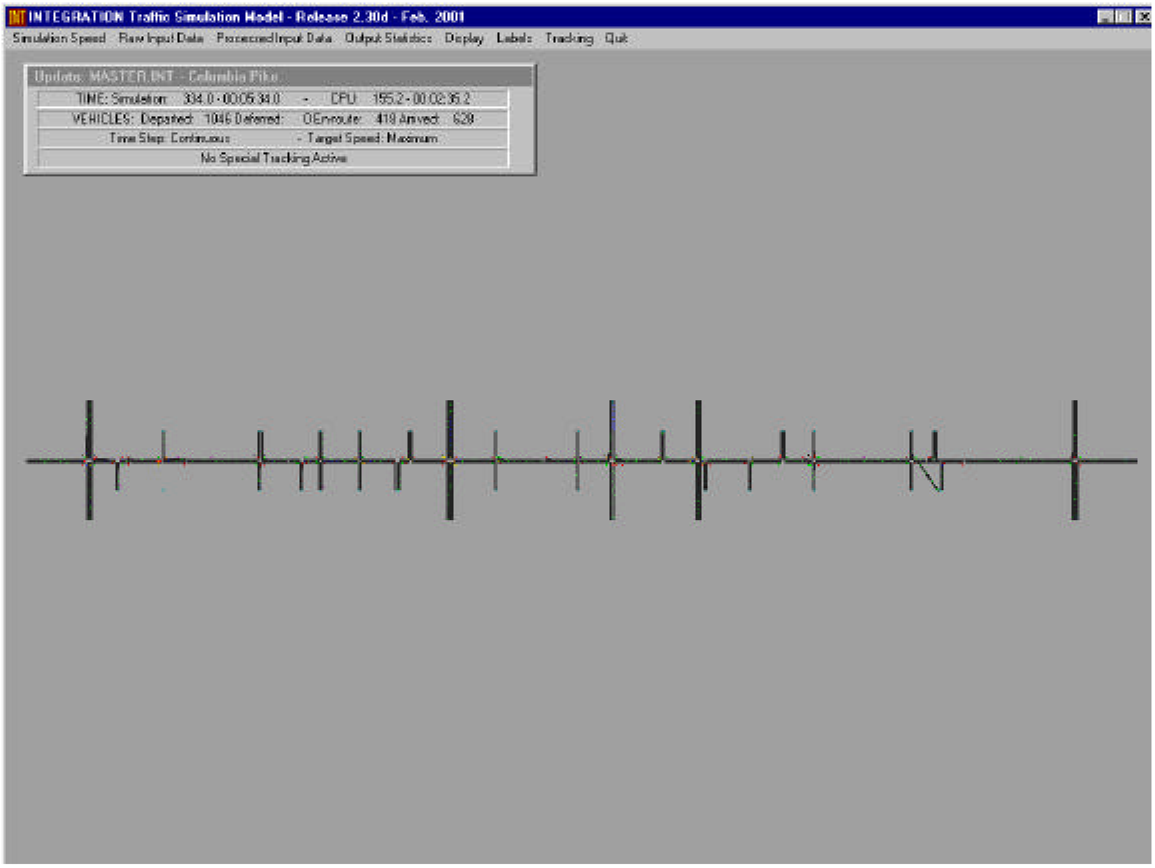
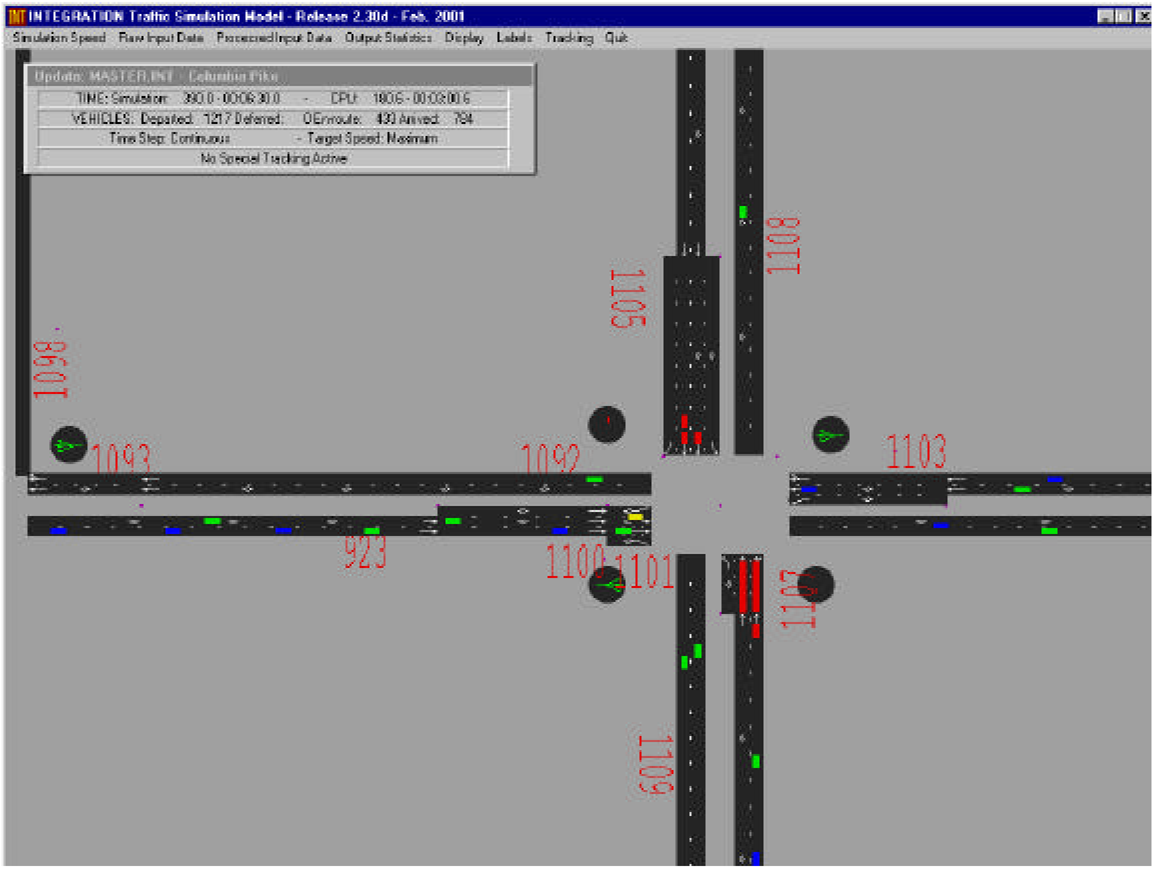
Appendix B: Map of Columbia Pike Corridor in Arlington, Virginia

Source: 1983 USGS Topographic Map, from www.terraserver.microsoft.com

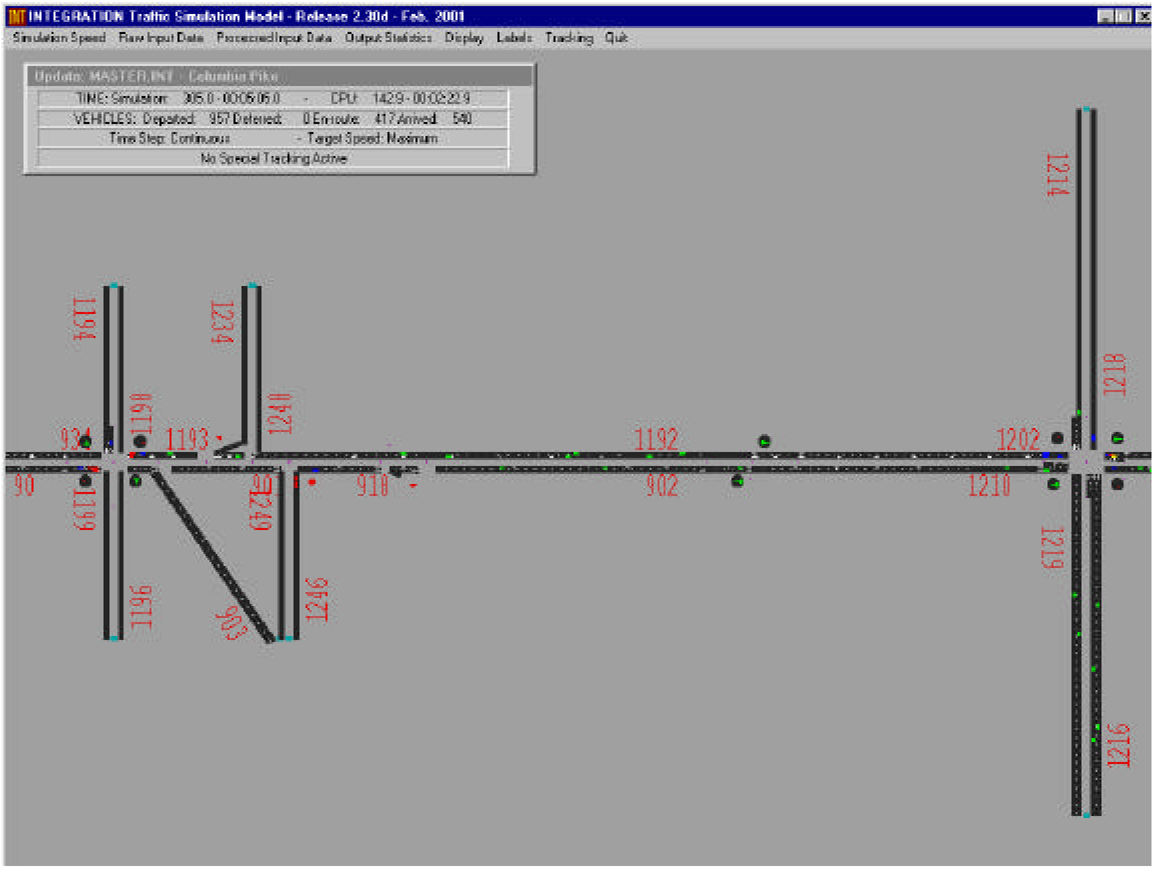
Appendix C: Screen Views of Columbia Pike Network in INTEGRATION



View of Entire Columbia Pike Network (Carlin Springs Dr. to Joyce St.)



View of Starting Timepoint (end of Link 1101) at George Mason Dr.



View of Ending Timepoint (end of Link 902) at Navy Annex

Appendix D: Description of INTEGRATION Modeling Approach

(from *INTEGRATION User's Guide Release 2.30 for Windows- Volume I*, Section 2.3-Microscopic Modeling Approach) (*38*)

INTEGRATION is a fully microscopic simulation model, as it tracks both the lateral and longitudinal movements of individual vehicles at a resolution of up to one deci-second.

This microscopic approach permits the analysis of many dynamic traffic phenomena, such as shock waves, gap acceptance, and weaving. These attributes are usually very difficult, or infeasible, to capture under non-steady state conditions using a macroscopic rate-based model, but become emergent behavior with the INTEGRATION model. For example, in a dynamic network, average gap acceptance curves typically cannot be utilized at permissive left turns if the opposing flow rate varies from cycle to cycle and/or within a particular cycle. These curves also cannot be used if the size of the acceptable gap varies as a function of the length of time for which a vehicle has been waiting to find an acceptable gap. Similarly, most microscopic models cannot model platoon progression between adjacent traffic signals that have cycle lengths that are not multiples of each other.

The INTEGRATION model can consider virtually continuous time varying traffic demands, routings, link capacities and traffic controls without the need to pre-define explicit time-slice duration between these processes. This implies that the model is not restricted to hold departure rates, signal timings, incident severity, or even traffic routings, at a constant setting for any particular common period of time. Consequently, instead of treating each of the above model attributes as a sequence of steady-state conditions, as needs to be done in most rate-based models, all of these attributes can be changed on virtually a continuous basis over time.

The microscopic approach also permits considerable flexibility in terms of representing spatial variations in traffic conditions. For example, while most rate-based models consider traffic conditions to be uniform along a given link, INTEGRATION permits the density of traffic to vary continuously along the link. In particular, such dynamic density variation permits, along an arterial link, the representation of platoons departing from traffic signals and the associated propagation of shock waves in an upstream or downstream direction, or both.

Finally, it is important to note that the model is primarily microscopic. However, these microscopic rules have been carefully calibrated in order to capture concurrently most of the target macroscopic traffic features that traffic engineers are most familiar with. Examples of these features are link speed-flow relationships, multi-path equilibrium traffic assignment, and uniform, random or over-saturation delay, as well as weaving and ramp capacities. The main challenge in the design of INTEGRATION has been to ensure that these important macroscopic features automatically remain emergent behavior arising from the more fundamental microscopic model rules that are needed to represent the system dynamics using a single integrated approach.

INTEGRATION Signal Priority Summary (Summarized from (*36*) – see reference for complete details)

- Buses detected 100 m upstream from intersection
- If priority already provided in current cycle, no change to timing made
- If bus arrives early in green and should reach intersection, no change made
- If bus arrives near end of green, extend green in 5 s intervals until bus served or max green is reached (cycle length – amber times – 5 s min green for each phase)
- If bus arrives on red, truncate red phase after minimum green has been served, and provide required amber interval
- If conflicting priority vehicles detected, no change made

Appendix E: Selected Excerpts from INTEGRATION Input/Output Files

FILE03AM.DAT (Signal Timings – Note Priority given to class 3 vehicles indicated by <NODE>.00100)

```
FILE  3     -     Columbia    Pike  -     Signal      Timings     (AM)

21    1     9000

1

101.00000   130   40    180   0     5     48    3     17    3     28
      3     15    3     7     3     0
102.00000   100   40    180   39    2     63    3     31    3     0

103.00000   100   40    180   56    3     61    3     23    3     7
      3     0
104.00000   100   40    180   84    2     63    3     31    3     0

105.00000   100   40    180   2     2     74    3     20    3     0

106.00000   100   40    180   11    2     73    3     21    3     0

107.00000   100   40    180   22    2     72    3     22    3     0

108.00000   100   40    180   36    2     70    3     24    3     0

109.00000   100   40    180   32    2     73    3     21    3     0

110.00100   100   40    180   53    3     37    3     36    3     21
      0     0
111.00100   100   40    180   70    2     72    3     22    3     0

112.00100   100   40    180   4     2     72    3     22    3     0

113.00100   100   40    180   15    2     52    3     42    3     0

114.00100   100   40    180   15    2     74    3     20    3     0

115.00100   100   40    180   27    3     53    3     29    3     12
      0     0
116.00100   100   40    180   53    2     70    3     24    3     0

117.00100   100   40    180   65    2     72    3     22    3     0

118.00100   100   40    180   75    2     62    3     32    3     0

119.00100   100   40    180   8     2     72    3     22    3     0

120.00000   100   40    180   75    2     69    3     25    3     0
```

121.00000 0	100 0	40	180	0	3	54	3	30	3	10

FILE04AM.DAT – EXCERPT (OD Flows, showing scheduled bus departures; BASE CASE (No Priority) does not have Class 3 vehicles)

```
11098 25    26    60    0     1005.075    1065.075    0     -1    0
      0     0     1     2
11099 25    26    60    0     2805.075    2865.075    0     -1    0
      0     0     1     2
11100 25    26    60    0     4605.075    4665.075    0     -1    0
      0     0     1     2
11101 25    26    60    0     6405.075    6465.075    0     -1    0
      0     0     1     2
11102 1     36    60    0     1607.207    1667.207    0     -1    0
      0     0     1     2
11103 1     36    60    0     5387.207    5447.207    0     -1    0
      0     0     1     2
11104 5     36    60    0     7860  7920  0     -1    0     0     0
      1     2
11105 1     36    60    0     3407.207    3467.207    0     -1    0
      0     0     1     2
11106 1     36    60    0     7187.207    7247.207    0     -1    0
      0     0     1     2
11107 1     36    60    0     107.2068    167.2068    0     0     0
      -1    0     1     2
11108 1     36    60    0     707.2068    767.2068    0     0     0
      -1    0     1     2
11109 1     36    60    0     1307.207    1367.207    0     0     0
      -1    0     1     2
11110 1     36    60    0     1907.207    1967.207    0     0     0
      -1    0     1     2
11111 1     36    60    0     2507.207    2567.207    0     0     0
      -1    0     1     2
11112 1     36    60    0     3287.207    3347.207    0     0     0
      -1    0     1     2
11113 1     36    60    0     3707.207    3767.207    0     0     0
      -1    0     1     2
11114 1     36    60    0     4427.207    4487.207    0     0     0
      -1    0     1     2
11115 1     36    60    0     5207.207    5267.207    0     0     0
      -1    0     1     2
11116 1     36    60    0     5807.207    5867.207    0     0     0
      -1    0     1     2
11117 7     36    60    0     766.6695    826.6695    0     -1    0
      0     0     1     2
11118 7     36    60    0     2446.67     2506.67     0     -1    0
      0     0     1     2
11119 7     36    60    0     4486.67     4546.67     0     -1    0
      0     0     1     2
11120 7     36    60    0     6346.67     6406.67     0     -1    0
      0     0     1     2
11121 4     36    60    0     1320  1380  0     -1    0     0     0
      1     2
11122 4     36    60    0     3000  3060  0     -1    0     0     0
      1     2
```

11123	4 1	36 2	60	0	4920	4980	0	-1	0	0	0
11124	4 1	36 2	60	0	6720	6780	0	-1	0	0	0
11125	27 0	36 0	60 1	0 2	1365.075		1425.075		0	-1	0
11126	27 0	36 0	60 1	0 2	3165.075		3225.075		0	-1	0
11127	27 0	36 0	60 1	0 2	4965.075		5025.075		0	-1	0
11128	27 0	36 0	60 1	0 2	6885.075		6945.075		0	-1	0
11129	11 0	36 0	60 1	0 2	1065.075		1125.075		0	-1	0
11130	11 0	36 0	60 1	0 2	2265.075		2325.075		0	-1	0
11131	11 0	36 0	60 1	0 2	2505.075		2565.075		0	-1	0
11132	11 0	36 0	60 1	0 2	3525.075		3585.075		0	-1	0
11133	11 0	36 0	60 1	0 2	4845.075		4905.075		0	-1	0
11134	11 0	36 0	60 1	0 2	6045.075		6105.075		0	-1	0
11135	11 0	36 0	60 1	0 2	7305.075		7365.075		0	-1	0
11136	13 0	12 0	60 1	0 2	136.7537		196.7537		0	-1	0
11137	13 0	12 0	60 1	0 2	1336.754		1396.754		0	-1	0
11138	13 0	12 0	60 1	0 2	2716.754		2776.754		0	-1	0
11139	13 0	12 0	60 1	0 2	3436.754		3496.754		0	-1	0
11140	13 0	12 0	60 1	0 2	5056.754		5116.754		0	-1	0
11141	13 0	12 0	60 1	0 2	6316.754		6376.754		0	-1	0
11142	10 0	36 0	60 1	0 2	465.0746		525.0746		0	-1	0
11143	10 0	36 0	60 1	0 2	1665.075		1725.075		0	-1	0
11144	10 0	36 0	60 1	0 2	3045.075		3105.075		0	-1	0
11145	10 0	36 0	60 1	0 2	3765.075		3825.075		0	-1	0
11146	10 0	36 0	60 1	0 2	5385.075		5445.075		0	-1	0
11147	10 0	36 0	60 1	0 2	6645.075		6705.075		0	-1	0
11148	16 1	11 2	60	0	780	840	0	-1	0	0	0
11149	16 1	11 2	60	0	1980	2040	0	-1	0	0	0
11150	16 1	11 2	60	0	3180	3240	0	-1	0	0	0

11151	16 1	11 2	60	0	4380	4440	0	-1	0	0	0
11152	16 1	11 2	60	0	6000	6060	0	-1	0	0	0
11153	30 1	35 2	60	0	450	510	0	-1	0	0	0
11154	30 1	35 2	60	0	1950	2010	0	-1	0	0	0
11155	30 1	35 2	60	0	3630	3690	0	-1	0	0	0
11156	30 1	35 2	60	0	5130	5190	0	-1	0	0	0
11157	30 1	35 2	60	0	6630	6690	0	-1	0	0	0
11158	2 1	3 2	60	0	420	480	0	-1	0	0	0
11159	2 1	3 2	60	0	2820	2880	0	-1	0	0	0
11160	2 1	3 2	60	0	4620	4680	0	-1	0	0	0
11161	2 1	3 2	60	0	7680	7740	0	-1	0	0	0
11162	1 0	3 0	60 1	0 2	1127.207		1187.207		0	-1	0
11163	1 0	3 0	60 1	0 2	3047.207		3107.207		0	-1	0
11164	1 0	3 0	60 1	0 2	4967.207		5027.207		0	-1	0
11165	1 0	3 0	60 1	0 2	6647.207		6707.207		0	-1	0
11166	26 0	25 0	60 1	0 2	1485.075		1545.075		0	-1	0
11167	26 0	25 0	60 1	0 2	3525.075		3585.075		0	-1	0
11168	26 0	25 0	60 1	0 2	4905.075		4965.075		0	-1	0
11169	26 0	25 0	60 1	0 2	6345.075		6405.075		0	-1	0
11170	36 0	1 0	60 1	0 2	1089.851		1149.851		0	-1	0
11171	36 0	1 0	60 1	0 2	4689.851		4749.851		0	-1	0
11172	36 0	1 0	60 1	0 2	789.8507		849.8507		0	-1	0
11173	36 0	1 0	60 1	0 2	1389.851		1449.851		0	-1	0
11174	36 0	1 0	60 1	0 2	1989.851		2049.851		0	-1	0
11175	36 0	1 0	60 1	0 2	2589.851		2649.851		0	-1	0
11176	36 0	1 0	60 1	0 2	3189.851		3249.851		0	-1	0
11177	36 0	1 0	60 1	0 2	3789.851		3849.851		0	-1	0
11178	36 0	5 0	60 1	0 2	489.8507		549.8507		0	-1	0

11179	36	5	60	0	2289.851		2349.851		0	-1	0
	0	0	1	2							
11180	36	5	60	0	4089.851		4149.851		0	-1	0
	0	0	1	2							
11181	36	5	60	0	7389.851		7449.851		0	-1	0
	0	0	1	2							
11182	36	1	60	0	2889.851		2949.851		0	-1	0
	0	0	1	2							
11183	36	1	60	0	6489.851		6549.851		0	-1	0
	0	0	1	2							
11184	36	4	60	0	1689.851		1749.851		0	-1	0
	0	0	1	2							
11185	36	4	60	0	3489.851		3549.851		0	-1	0
	0	0	1	2							
11186	36	4	60	0	5589.851		5649.851		0	-1	0
	0	0	1	2							
11187	11	16	60	0	945.0746		1005.075		0	-1	0
	0	0	1	2							
11188	11	16	60	0	2145.075		2205.075		0	-1	0
	0	0	1	2							
11189	11	16	60	0	3345.075		3405.075		0	-1	0
	0	0	1	2							
11190	11	16	60	0	4605.075		4665.075		0	-1	0
	0	0	1	2							
11191	11	16	60	0	5805.075		5865.075		0	-1	0
	0	0	1	2							
11192	11	16	60	0	7005.075		7065.075		0	-1	0
	0	0	1	2							
11193	35	30	60	0	369.8507		429.8507		0	-1	0
	0	0	1	2							
11194	35	30	60	0	1869.851		1929.851		0	-1	0
	0	0	1	2							
11195	35	30	60	0	3369.851		3429.851		0	-1	0
	0	0	1	2							
11196	35	30	60	0	4869.851		4929.851		0	-1	0
	0	0	1	2							
11197	35	30	60	0	6369.851		6429.851		0	-1	0
	0	0	1	2							
11198	35	30	60	0	7869.851		7929.851		0	-1	0
	0	0	1	2							
11199	3	2	60	0	1230	1290	0	-1	0	0	0
	1	2									
11200	3	2	60	0	2160	2220	0	-1	0	0	0
	1	2									
11201	3	2	60	0	4860	4920	0	-1	0	0	0
	1	2									
11202	3	2	60	0	6060	6120	0	-1	0	0	0
	1	2									
11203	3	1	60	0	1005.075		1065.075		0	-1	0
	0	0	1	2							
11204	3	1	60	0	2805.075		2865.075		0	-1	0
	0	0	1	2							
11205	3	1	60	0	4905.075		4965.075		0	-1	0
	0	0	1	2							
11206	3	1	60	0	6705.075		6765.075		0	-1	0
	0	0	1	2							

FILE04-30.DAT – EXCERPT FOR PRIORITY RUN #30 (OD Flows, showing selected scheduled bus departures; has late buses coded as Class 3 vehicles - 11121, 11122, 11143 are late in BASE RUN #30)

11120	7 0	36 0	60 1	0 2	6346.67		6406.67		0	-1	0
11121	4 1	36 2	60	0	1320	1380	0	0	-1	0	0
11122	4 1	36 2	60	0	3000	3060	0	0	-1	0	0
11123	4 1	36 2	60	0	4920	4980	0	-1	0	0	0
11124	4 1	36 2	60	0	6720	6780	0	-1	0	0	0
11125	27 0	36 0	60 1	0 2	1365.075		1425.075		0	-1	0
11126	27 0	36 0	60 1	0 2	3165.075		3225.075		0	-1	0
11127	27 0	36 0	60 1	0 2	4965.075		5025.075		0	-1	0
11128	27 0	36 0	60 1	0 2	6885.075		6945.075		0	-1	0
11129	11 0	36 0	60 1	0 2	1065.075		1125.075		0	-1	0
11130	11 0	36 0	60 1	0 2	2265.075		2325.075		0	-1	0
11131	11 0	36 0	60 1	0 2	2505.075		2565.075		0	-1	0
11132	11 0	36 0	60 1	0 2	3525.075		3585.075		0	-1	0
11133	11 0	36 0	60 1	0 2	4845.075		4905.075		0	-1	0
11134	11 0	36 0	60 1	0 2	6045.075		6105.075		0	-1	0
11135	11 0	36 0	60 1	0 2	7305.075		7365.075		0	-1	0
11136	13 0	12 0	60 1	0 2	136.7537		196.7537		0	-1	0
11137	13 0	12 0	60 1	0 2	1336.754		1396.754		0	-1	0
11138	13 0	12 0	60 1	0 2	2716.754		2776.754		0	-1	0
11139	13 0	12 0	60 1	0 2	3436.754		3496.754		0	-1	0
11140	13 0	12 0	60 1	0 2	5056.754		5116.754		0	-1	0
11141	13 0	12 0	60 1	0 2	6316.754		6376.754		0	-1	0
11142	10 0	36 0	60 1	0 2	465.0746		525.0746		0	-1	0
11143	10 0	36 0	60 1	0 2	1665.075		1725.075		0	0	-1
11144	10 0	36 0	60 1	0 2	3045.075		3105.075		0	-1	0

SUMMARY.OUT (Summary Output Measures for each vehicle class, including Delay for one run e.g. #30 Priority)

```
MASTER.INT - Columbia Pike
 Total Statistics:
  1       28225          96           3          10           0
28334     - vehicle trips
  2       28225          96           3          10           0
28334     - person trips
  3       38516         328          18          71           0
38935     - vehicle-km
  4       38516         328          18          71           0
38935     - person-km
  5       52369         885          59         152           0
53466     - vehicle-stops
  6     4578568       48943        3226        9701           0
4640440     - vehicle-secs
  7     4578568       48943        3226        9701           0
4640440     - person-secs
  8     2345453       30684        2196        5889           0
2384224     - total delay
  9     1018689       17616        1387        2734           0
1040427     - stopped delay
 10     1326767       13068         808        3155           0
1343800     - accel/decel delay
 11  1443501568    16405954     1126355     3685915           0
1464719872     - accel-noise
 12        5376          63           4          12           0
5456     - fuel (l)
 13       10483         167          10          29           0
10690     - HC (g)
 14      262626        4806         292         816           0
268541     - CO (g)
 15       11517         165          10          30           0
11724     - NOx (g)
 16      187262        1855         103         342           0
189562     - crashes*10e-6
 17       83530         798          43         150           0
84524     - injury crashes
 18         268           1           0           0           0
271     - fatal crashes
 19        5749          38           1           9           0
5799     - no damage
 20      111315        1325          76         212           0
112930     - minor damage
 21       40969         287          14          70           0
41341     - moderate damage
 22           0           0           0           0           0
0     - dollars of toll

 Average Statistics:
  1       1.000       1.000       1.000       1.000       0.000
1.000     - vehicle trips
  2       1.000       1.000       1.000       1.000       0.000
1.000     - person trips
```

3	1.365	3.425	6.304	7.120	0.000	1.374	- vehicle-km
4	1.365	3.425	6.304	7.120	0.000	1.374	- person-km
5	1.855	9.224	19.846	15.260	0.000	1.887	- vehicle-stops
6	162.217	509.825	1075.633	970.190	0.000	163.776	- vehicle-secs
7	162.217	509.825	1075.633	970.190	0.000	163.776	- person-secs
8	83.098	319.633	732.276	588.970	0.000	84.147	- total delay
9	36.092	183.500	462.663	273.437	0.000	36.720	- stopped delay
10	47.007	136.133	269.613	315.533	0.000	47.427	- accel/decel delay
11	51142.660	170895.359	375451.875	368591.563	0.000	51694.777	- accel-noise
12	0.190	0.659	1.347	1.236	0.000	0.193	- fuel (l)
13	0.371	1.744	3.389	2.951	0.000	0.377	- HC (g)
14	9.305	50.067	97.401	81.642	0.000	9.478	- CO (g)
15	0.408	1.728	3.620	3.046	0.000	0.414	- NOx (g)
16	6.635	19.331	34.365	34.201	0.000	6.690	- crashes*10e-6
17	2.959	8.320	14.660	15.095	0.000	2.983	- injury crashes
18	0.010	0.019	0.028	0.037	0.000	0.010	- fatal crashes
19	0.204	0.404	0.636	0.910	0.000	0.205	- no damage
20	3.944	13.810	25.460	21.253	0.000	3.986	- minor damage
21	1.452	2.991	4.836	7.023	0.000	1.459	- moderate damage
22	0.000	0.000	0.000	0.000	0.000	0.000	- dollars of toll

FILE16AM.DAT – EXCERPT PRIORITY RUN #30 (Shows time of individual bus link traversals)

```
11   3464.5    9772 3  1101    4   36 3030.0 3030.0    5.0      3.0
0.0      0.1  0.040  28.8    0.013147    0.032111    0.974078
0.052493    0.147316    0.061837    0.000000    0.000774    0.109083
0.022428   0.00     3960.47
 11   3464.6   10977 2  1091   11   16 3375.0 3375.0   10.7      6.3
0.8      0.6  0.081  27.3    0.024547    0.105539    4.026154
0.085320    0.392253    0.168255    0.000374    0.007997    0.299969
0.048871   0.00     4363.49
 11   3464.9    7954 4   360    1   36 2537.0 2537.0   41.9     22.6
11.1      0.6  0.350  30.1    0.055127    0.107678    3.085329
0.137091    1.059081    0.487266    0.000997    0.039601    0.499715
0.301363   0.00     5938.53
 11   3467.5   10758 4   910    1   36 3317.0 3317.0    9.7      4.0
0.0      0.2  0.110  40.8    0.031754    0.138940    5.140512
0.123205    0.147316    0.059835    0.000000    0.000000    0.128743
0.011111   0.00     4676.79
 11   3467.9    8275 2   942   36    1 2619.0 2619.0   20.5     13.5
7.0      0.8  0.128  22.5    0.016367    0.016196    0.182451
0.023743    0.235352    0.113563    0.000806    0.014276    0.088317
0.077205   0.00     2373.25
 11   3468.8    7954 4   361    1   36 2537.0 2537.0    3.9      1.2
0.0      0.1  0.050  46.2    0.007255    0.017335    0.444922
0.029367    0.274577    0.132563    0.000949    0.016731    0.102730
0.090211   0.00    25817.79
 11   3471.0    9404 2   939   36    1 2919.0 2919.0   16.5     15.2
12.3      0.6  0.025   5.5    0.014961    0.015658    0.215123
0.038425    0.589266    0.233397    0.000000    0.000000    0.574734
0.009128   0.00     1786.05
 11   3473.0    9404 2   940   36    1 2919.0 2919.0    2.0      0.7
0.0      0.0  0.025  45.0    0.010312    0.037685    1.308222
0.054109    0.073658    0.033061    0.000051    0.001939    0.038716
0.019188   0.00     2332.49
 11   3475.2   10977 2   923   11   16 3375.0 3375.0   10.6      2.7
0.0      0.1  0.155  52.6    0.022875    0.111580    3.649433
0.067351    0.368291    0.179221    0.001439    0.023884    0.133852
0.122837   0.00     1164.29
 11   3477.2    8275 2  1032   36    1 2619.0 2619.0    9.3      0.9
0.0      0.0  0.153  59.2    0.050123    0.331948   10.269860
0.174582    0.156901    0.067964    0.000037    0.002588    0.094528
0.034974   0.00     3403.02
 11   3478.6   10326 2  1181   27   36 3195.0 3195.0   29.6     27.3
21.0      0.6  0.040   4.9    0.018332    0.016519    0.111184
0.020927    1.169763    0.479543    0.000000    0.003924    0.970147
0.116047   0.00     1726.24
 11   3478.8   11330 2  1076   13   12 3466.0 3466.0   12.8      2.1
0.0      0.3  0.150  42.2    0.011379    0.011057    0.145574
0.009653    0.236951    0.113987    0.000772    0.014016    0.089958
0.077248   0.00     2033.01
 11   3479.3   10758 4   911    1   36 3317.0 3317.0   11.8     10.8
8.6      0.5  0.020   6.1    0.005776    0.006075    0.034415
0.004252    0.441949    0.177634    0.000000    0.001012    0.405200
0.021072   0.00     1392.56
```

Appendix F: Data Summaries from INTEGRATION Runs

Main Summary Comparing No Priority (NP) with Priority for 30 runs

	Avg. Delta Navy Annex			St. Dev. Delta Navy Annex			Avg. Run Time GM-Navy Ann.			St Dev Run Time GM-Navy Ann.			Average Delay per vehicle			Average Delay per person		
Run #	NP	P		NP	P		NP	P		NP	P		NP	P		NP	P	
1	32.91	20.38		133.9	137.7		485.2	479.1		78.122	81.404		86.58	86.24		103.5	102.8	
2	66.18	64.82		185.9	170.8		515.1	505.7		148.33	129.23		90.23	91.22		107	108	
3	235.6	210.3		269.9	266.2		619.9	602.5		221.11	224.72		89.08	90.59		109.2	110.2	
5	62.84	63.79		158.9	173.1		508.1	515.5		104.24	124.37		84.38	86.06		100.7	102.7	
9	98.44	95.84		227.3	221.6		536.6	537.6		163.05	163.8		88.57	91.12		106.8	109.3	
10	111.5	97.75		190.8	176.2		544.1	530.4		140.29	127.69		88.33	86.92		105.8	103.7	
11	154.2	139.9		203	190.6		580.1	574.9		156.33	157.91		90.41	91.82		109.9	110.7	
13	75.32	65.51		169.3	153.3		515.9	506		126.57	114.57		85.66	86.61		101.9	102.9	
14	128.2	130.9		185.9	178.7		564.5	561.9		150.75	159.69		85.57	85.73		104.1	104.3	
17	76.17	58.58		209.1	185.2		505.9	496.9		131.19	106.06		85.85	86.68		102.2	102.4	
19	150.6	167.1		278.7	287.7		588.7	604.5		209.51	231.8		85.32	86.84		102.9	104.8	
20	113.2	116.3		200.8	198.4		543.2	554.7		145.88	142.74		85.53	86.32		104.5	104.8	
21	102.3	92.44		166.9	152.1		526.2	520.3		117.01	106.66		85.43	91.81		103.7	109.7	
24	164.4	152.1		245.8	231.6		598.8	590.9		185.44	195.97		87.33	86.26		103.9	102.8	
25	88.74	88.01		182.1	183.7		528.5	534.4		137.71	143.98		86.87	86.47		104.7	104.3	
26	87.14	61.79		179.6	158.1		518.2	506.9		119.1	95.22		85.55	85.51		102.6	101.9	
27	77.54	72.89		169.3	157.8		516.5	513.1		114.13	104.22		85.77	86.03		102.2	102.5	
28	164.9	156.9		257.6	246.4		600.7	593.9		196.42	182.62		87.74	88.58		109.4	109.6	
30	75.23	68.94		160.1	150.5		524.2	512.7		123.19	112.85		83.09	84.15		99.93	101	
4	114.9	123		185.2	185.8		550.9	555.8		162.76	157.42		85.04	84.92		102.6	102.6	
6	167.6	142.7		203.2	186.8		596.4	574.8		189.27	165.15		88.3	86.85		107.3	104.8	
7	208	193.4		312.9	307.3		625.3	613		229.15	223.47		88.22	88.75		107.6	107.9	
8	172	158.1		283.5	255.6		596.8	584		201.77	182.31		86.46	86.17		104.9	104.4	
12	187.2	152.2		214	192.6		619.6	586.8		182.62	165.87		88.13	87.38		107	105.9	
15	136.9	125.4		258.2	257.4		557	557.5		207.94	212.49		83.89	87.06		103.3	106	
16	61.93	67.44		166.6	163.4		510.5	516.4		132.63	136.95		85.61	86.19		102.6	103.5	
18	199.9	184.6		274.7	267.3		626.8	608		232.01	236.2		87.47	90.69		107.2	109.9	
22	96.39	118.2		239.2	265.7		546	567.2		187.01	219.48		84.66	87.53		101.4	104.9	
23	69.24	68.14		195.9	210.9		519.1	522.6		131.47	150.5		85.41	85.79		102.2	102.8	
29	61.51	61.79		163.4	158.1		509.2	506.9		105.37	95.22		85.11	85.27		101.5	101.4	
AVG	118	110.6	-6.3%	209	202.4	-3.2%	552.6	547.8	-0.9%	157.68	155.02	-1.7%	86.52	87.39	1.0%	104.4	105.1	0.6%
STDEV	51.76	47.72		45.42	46.78		42.18	38.85		40.992	45.211		1.809	2.159		2.715	2.946	

Sample of More Detailed Table: Base Run #30 Showing Timepoints

	GMASON	NA			nopriority time	SCHDEP	SCH GM	SCH NA		DEV GM	DEV NA	
439.2	459	819.8	459	0	380.6	137	540	900		-100.8	-80.2	np
676.7	1517	1029.9	1517	0	353.2	495	600	1200		76.7	-170.1	np
1083.2	2427	1784.4	2427	0	701.2	796	960	1500		123.2	284.4	np
1178.5	2245	1824	2245	0	645.5	737	1140	1500		38.5	324	np
1235.4	3357	1841.2	3357	0	605.8	1095	1200	1800		35.4	41.2	np
1735.5	4106	2218.9	4106	0	483.4	1350	1560	2100	1320	175.5	118.9	PR
1888.9	4066	2314.5	4066	0	425.6	1337	1740	2100		148.9	214.5	np
1989.6	5144	2807.5	5144	0	817.9	1695	1800	2400	1665	189.6	407.5	PR
2069.5	4957	2828.1	4957	0	758.6	1637	2040	2580		29.5	248.1	np
2435.7	5981	2854.7	5981	0	419	1937	2340	2700		95.7	154.7	np
2535.6	7152	3242.3	7152	0	706.7	2295	2400	3000		135.6	242.3	np
2733.8	7943	3266.1	7943	0	532.3	2535	2640	3240		93.8	26.1	np
2738.9	7741	3295.5	7741	0	556.6	2476	2640	3360		98.9	-64.5	np
2967.2	7954	3381.3	7954	0	414.1	2537	2940	3360		27.2	21.3	np
3235.6	9940	3695.5	9940	0	459.9	3075	3180	3780		55.6	-84.5	np
3435.6	9772	3918.5	9772	0	482.9	3030	3240	3960	3000	195.6	-41.5	PR
3735.1	11682	4346.8	11682	0	611.7	3555	3660	4260		75.1	86.8	np
3739.6	10758	4131.8	10758	0	392.2	3317	3720	4140		19.6	-8.2	np
3833.8	11210	4374	11210	0	540.2	3437	3840	4560		-6.2	-186	np
3987.6	12634	4467	12634	0	479.4	3795	4200	4800		-212.4	-333	np
4235.7	12422	4639.7	12422	0	404	3737	4140	4560		95.7	79.7	np
4735.6	15381	5185.1	15381	0	449.5	4516	4680	5160		55.6	25.1	np
4848.6	15152	5237.5	15152	0	388.9	4457	4860	5220		-11.4	17.5	np
5035.6	16763	5527	16763	0	491.4	4875	4980	5460		55.6	67	np
5289.2	17029	5786.9	17029	0	497.7	4950	5220	5760		69.2	26.9	np
5637.8	18784	6113	18784	0	475.2	5415	5520	6000		117.8	113	np
5735.6	18064	6146.2	18064	0	410.6	5237	5640	6000		95.6	146.2	np
5939.6	18794	6505.2	18794	0	565.6	5417	5820	6360		119.6	145.2	np
6185.8	20354	6583.7	20354	0	397.9	5837	6240	6600		-54.2	-16.3	np
6271.5	21232	6909.1	21232	0	637.6	6075	6180	6660		91.5	249.1	np
6633.7	22385	7085.5	22385	0	451.8	6376	6540	7020		93.7	65.5	np
6786.2	23489	7583.5	23489	0	797.3	6675	6780	7260		6.2	323.5	np
7087.7	23761	7599.1	23761	0	511.4	6750	7020	7560		67.7	39.1	np
7535.5	25832	8080	25832	0	544.5	7335	7440	7920		95.5	160	np
7742.4	25436	8413.1	25436	0	670.7	7217	7620	8160		122.4	253.1	np
8159.8	27654	8571.8	27654	0	412	7890	8220	8760		-60.2	-188.2	np
					524.2472						75.22778	
											160.0719	
					123.1917							

Delay Table for Base Cases

t-total, p-per vehicle										occup =	23			
01-t	8	2409771	33208	0	6053	0	2449034 -	total	delay	#veh	28176.88	98.99715	9.998398	28285.87
01-p	8	85.523	335.444	0	605.397	0	86.581 -	total	delay					103.455
02-t	8	2491256	32868	0	5846	0	2529971 -	total	delay	#veh	27932.95	94.99806	9.998717	28037.95
02-p	8	89.187	345.986	0	584.675	0	90.234 -	total	delay					107.0268
03-t	8	2484401	38080	0	7900	0	2530381 -	total	delay	#veh	28298.07	97.99935	9.999266	28406.07
03-p	8	87.794	388.574	0	790.058	0	89.079 -	total	delay					109.1955
04-t	8	2368743	34061	0	6158	0	2408963 -	total	delay	#veh	28218.13	98.99928	9.999286	28327.13
04-p	8	83.944	344.053	0	615.844	0	85.041 -	total	delay					102.6194
05-t	8	2349802	32274	0	6488	0	2388564 -	total	delay	#veh	28197.06	98.99818	9.999476	28306.06
05-p	8	83.335	326.006	0	648.834	0	84.384 -	total	delay					100.7355
06-t	8	2462043	36475	0	6699	0	2505218 -	total	delay	#veh	28262.96	99.00009	9.99894	28371.96
06-p	8	87.112	368.434	0	669.971	0	88.299 -	total	delay					107.3082
07-t	8	2455019	37006	0	6610	0	2498635 -	total	delay	#veh	28215.04	98.99946	9.99941	28324.04
07-p	8	87.011	373.8	0	661.039	0	88.216 -	total	delay					107.6442
08-t	8	2404713	35481	0	7035	0	2447230 -	total	delay	#veh	28194.88	98.99888	9.99882	28303.88
08-p	8	85.289	358.398	0	703.583	0	86.462 -	total	delay					104.9354
09-t	8	2435960	34702	0	5553	0	2476216 -	total	delay	#veh	27852.91	95.99951	9.9991	27958.91
09-p	8	87.458	361.481	0	555.35	0	88.566 -	total	delay					106.7942
10-t	8	2462347	34332	0	6123	0	2502802 -	total	delay	#veh	28224.98	98.99882	9.99982	28333.98
10-p	8	87.24	346.792	0	612.311	0	88.332 -	total	delay					105.8451
11-t	8	2482623	36647	0	6806	0	2526077 -	total	delay	#veh	27834.9	95.99964	9.998928	27940.9
11-p	8	89.191	381.741	0	680.673	0	90.408 -	total	delay					109.881
12-t	8	2452448	36224	0	7245	0	2495918 -	total	delay	#veh	28212.08	99	9.999558	28321.08
12-p	8	86.929	365.899	0	724.532	0	88.13 -	total	delay					106.9874
13-t	8	2392083	32214	0	5794	0	2430092 -	total	delay	#veh	28258.85	98.99968	9.998585	28367.84
13-p	8	84.649	325.395	0	579.482	0	85.663 -	total	delay					101.8603
14-t	8	2383071	35404	0	6499	0	2424975 -	total	delay	#veh	28230.09	97.99954	9.998954	28338.09
14-p	8	84.416	361.267	0	649.968	0	85.573 -	total	delay					104.1296
15-t	8	2329433	36237	0	6430	0	2372101 -	total	delay	#veh	28171.01	96.99853	9.999191	28278.01
15-p	8	82.689	373.583	0	643.052	0	83.885 -	total	delay					103.2829
16-t	8	2386638	33343	0	5681	0	2425663 -	total	delay	#veh	28223.86	98.99794	9.99919	28332.86
16-p	8	84.561	336.805	0	568.146	0	85.613 -	total	delay					102.6438
17-t	8	2395654	32406	0	6211	0	2434271 -	total	delay	#veh	28244.97	98.9998	9.999404	28353.97
17-p	8	84.817	327.334	0	621.137	0	85.853 -	total	delay					102.1673
18-t	8	2434119	37214	0	6697	0	2478030 -	total	delay	#veh	28223.96	96.99911	9.999433	28330.96
18-p	8	86.243	383.653	0	669.738	0	87.467 -	total	delay					107.2494
19-t	8	2381673	34104	0	6507	0	2422286 -	total	delay	#veh	28280.86	98.99823	9.998848	28389.86
19-p	8	84.215	344.491	0	650.775	0	85.322 -	total	delay					102.8637
20-t	8	2382809	36042	0	5736	0	2424589 -	total	delay	#veh	28238.02	98.99799	9.998797	28347.02
20-p	8	84.383	364.068	0	573.669	0	85.532 -	total	delay					104.4913
21-t	8	2372667	35056	0	6569	0	2414293 -	total	delay	#veh	28149.86	98.99833	9.999589	28258.85
21-p	8	84.287	354.107	0	656.927	0	85.434 -	total	delay					103.7238
22-t	8	2361300	32858	0	6238	0	2400398 -	total	delay	#veh	28244.88	98.99731	9.999263	28353.87
22-p	8	83.601	331.908	0	623.846	0	84.658 -	total	delay					101.3888
23-t	8	2374794	33006	0	6294	0	2414094 -	total	delay	#veh	28156.05	98.9982	9.999523	28265.05
23-p	8	84.344	333.4	0	629.43	0	85.409 -	total	delay					102.2337
24-t	8	2438126	32609	0	6583	0	2477319 -	total	delay	#veh	28262.88	95.99946	9.999165	28368.88
24-p	8	86.266	339.679	0	658.355	0	87.325 -	total	delay					103.874
25-t	8	2420531	34587	0	5617	0	2460736 -	total	delay	#veh	28217.89	98.99933	9.999057	28326.89
25-p	8	85.78	349.366	0	561.753	0	86.869 -	total	delay					104.6978
26-t	8	2381781	33427	0	6285	0	2421494 -	total	delay	#veh	28196.1	98.99779	9.998855	28305.1
26-p	8	84.472	337.654	0	628.572	0	85.55 -	total	delay					102.6433
27-t	8	2390115	32561	0	6007	0	2428684 -	total	delay	#veh	28205.94	98.99849	9.999467	28314.94
27-p	8	84.738	328.904	0	600.732	0	85.774 -	total	delay					102.2323
28-t	8	2435568	40070	0	6530	0	2482168 -	total	delay	#veh	28179.99	98.99938	9.999357	28288.98
28-p	8	86.429	404.75	0	653.042	0	87.743 -	total	delay					109.4296
29-t	8	2381480	32421	0	5953	0	2419856 -	total	delay	#veh	28323.98	98.99723	9.998673	28432.97
29-p	8	84.08	327.494	0	595.379	0	85.107 -	total	delay					101.4563
30-t	8	2315337	32824	0	5978	0	2354139 -	total	delay	#veh	28225.15	98.99837	9.999582	28334.14
30-p	8	82.031	331.561	0	597.825	0	83.085 -	total	delay					99.93189

Delay Table for Priority Cases

t-total, p-per vehicle										occup =	23				
01-t	8	2400848	32161	526	5928	0	2439464 -	total	delay	#veh	28176.98	97.99984	0.998654	9.999342	28285.98
01-p	8	85.206	328.174	526.709	592.839	0	86.243 -	total	delay						102.7727
02-t	8	2518770	29792	3224	5980	0	2557767 -	total	delay	#veh	27933.88	90.9985	3.999385	9.999431	28038.88
02-p	8	90.169	327.39	806.124	598.034	0	91.222 -	total	delay						108.0426
03-t	8	2528086	30246	7214	7638	0	2573185 -	total	delay	#veh	28297.99	89.99857	7.999973	9.999385	28405.99
03-p	8	89.338	336.072	901.753	763.847	0	90.586 -	total	delay						110.1509
04-t	8	2364802	29686	4567	6552	0	2405609 -	total	delay	#veh	28217.91	93.99688	4.998949	9.999786	28326.91
04-p	8	83.805	315.819	913.592	655.214	0	84.923 -	total	delay						102.6371
05-t	8	2396696	30147	2649	6426	0	2435920 -	total	delay	#veh	28197.09	95.99763	2.999789	9.999004	28306.08
05-p	8	84.998	314.039	883.062	642.664	0	86.057 -	total	delay						102.6536
06-t	8	2422658	28750	6070	6701	0	2464181 -	total	delay	#veh	28263.12	92.99873	5.999328	9.998553	28372.12
06-p	8	85.718	309.144	1011.78	670.197	0	86.853 -	total	delay						104.7908
07-t	8	2470481	29614	7007	6518	0	2513621 -	total	delay	#veh	28215.04	92.99916	5.999884	9.999386	28324.04
07-p	8	87.559	318.433	1167.856	651.84	0	88.745 -	total	delay						107.859
08-t	8	2396950	29571	5534	6899	0	2438956 -	total	delay	#veh	28195.1	93.99854	4.999679	9.998696	28304.1
08-p	8	85.013	314.59	1106.871	689.99	0	86.17 -	total	delay						104.3998
09-t	8	2507381	28047	6888	5308	0	2547625 -	total	delay	#veh	27852.98	87.9997	7.999703	9.999642	27958.98
09-p	8	90.022	318.717	861.032	530.819	0	91.12 -	total	delay						109.3279
10-t	8	2423474	28699	4518	6125	0	2462817 -	total	delay	#veh	28224.89	93.99985	4.999331	9.99938	28333.89
10-p	8	85.863	305.309	903.721	612.538	0	86.921 -	total	delay						103.746
11-t	8	2522927	31100	4910	6584	0	2565521 -	total	delay	#veh	27834.89	90.99953	4.999908	9.999529	27940.89
11-p	8	90.639	341.76	982.018	658.431	0	91.819 -	total	delay						110.7277
12-t	8	2432334	30325	5351	6547	0	2474558 -	total	delay	#veh	28212.1	92.99922	5.999451	9.998809	28321.09
12-p	8	86.216	326.078	891.915	654.778	0	87.375 -	total	delay						105.9202
13-t	8	2418812	28791	3675	5779	0	2457058 -	total	delay	#veh	28259.13	94.99723	3.999983	9.999775	28368.13
13-p	8	85.594	303.072	918.754	577.913	0	86.614 -	total	delay						102.9166
14-t	8	2387730	33103	2363	6104	0	2429302 -	total	delay	#veh	28230.1	95.9997	1.999596	9.998428	28338.1
14-p	8	84.581	344.824	1181.739	610.496	0	85.726 -	total	delay						104.3265
15-t	8	2419741	30793	5165	6308	0	2462008 -	total	delay	#veh	28170.92	90.99855	5.999034	9.999287	28277.91
15-p	8	85.895	338.39	860.972	630.845	0	87.064 -	total	delay						106.0216
16-t	8	2402520	29820	3987	5785	0	2442114 -	total	delay	#veh	28224.1	93.99912	4.998853	9.998462	28333.1
16-p	8	85.123	317.237	797.583	578.589	0	86.193 -	total	delay						103.5075
17-t	8	2419751	29007	2684	6341	0	2457785 -	total	delay	#veh	28245.02	94.99777	3.998981	9.998896	28354.02
17-p	8	85.67	305.344	671.171	634.17	0	86.682 -	total	delay						102.4166
18-t	8	2525852	28474	8238	6721	0	2569286 -	total	delay	#veh	28224.02	88.99849	7.999169	9.99994	28331.02
18-p	8	89.493	319.938	1029.857	672.104	0	90.688 -	total	delay						109.8626
19-t	8	2423827	29383	5485	6630	0	2465326 -	total	delay	#veh	28281.05	93.99823	4.999508	9.999849	28390.04
19-p	8	85.705	312.591	1097.108	663.01	0	86.838 -	total	delay						104.8033
20-t	8	2405024	28858	6576	6366	0	2446825 -	total	delay	#veh	28237.92	90.99939	7.999416	9.99945	28346.92
20-p	8	85.17	317.123	822.06	636.635	0	86.317 -	total	delay						104.7613
21-t	8	2522306	30068	4540	6415	0	2563331 -	total	delay	#veh	27813.01	88.99755	6.998947	9.999766	27919
21-p	8	90.688	337.852	648.669	641.515	0	91.813 -	total	delay						109.721
22-t	8	2441654	31095	2966	6229	0	2481946 -	total	delay	#veh	28244.85	96.00007	2.999137	9.99886	28353.84
22-p	8	86.446	323.906	988.951	622.971	0	87.534 -	total	delay						104.9015
23-t	8	2384912	30452	2816	6763	0	2424944 -	total	delay	#veh	28155.84	95.99889	2.999187	9.999985	28264.83
23-p	8	84.704	317.212	938.921	676.301	0	85.793 -	total	delay						102.7624
24-t	8	2408459	29882	2635	6193	0	2447171 -	total	delay	#veh	28262.99	92.9985	2.999134	9.998951	28368.99
24-p	8	85.216	321.317	878.587	619.365	0	86.262 -	total	delay						102.8373
25-t	8	2409324	30299	4259	5490	0	2449374 -	total	delay	#veh	28217.84	93.99702	4.999859	9.99827	28326.84
25-p	8	85.383	322.34	851.824	549.095	0	86.468 -	total	delay						104.3113
26-t	8	2382076	28387	4101	5915	0	2420481 -	total	delay	#veh	28195.92	93.99762	4.999098	9.998969	28304.92
26-p	8	84.483	301.997	820.348	591.561	0	85.514 -	total	delay						101.949
27-t	8	2397505	27894	4688	5754	0	2435842 -	total	delay	#veh	28205.94	92.99829	5.99955	9.999496	28314.94
27-p	8	85	299.941	781.392	575.429	0	86.027 -	total	delay						102.4878
28-t	8	2459737	33607	5703	6769	0	2505816 -	total	delay	#veh	28179.88	92.99912	5.999855	9.999882	28288.88
28-p	8	87.287	361.369	950.523	676.908	0	88.579 -	total	delay						109.6487
29-t	8	2386090	31264	871	6354	0	2424580 -	total	delay	#veh	28323.9	97.9989	0.999228	9.999072	28432.89
29-p	8	84.243	319.024	871.673	635.459	0	85.273 -	total	delay						101.394
30-t	8	2345453	30684	2196	5889	0	2384224 -	total	delay	#veh	28225.14	95.9976	2.998869	9.998811	28334.14
30-p	8	83.098	319.633	732.276	588.97	0	84.147 -	total	delay						100.9537

Results of Analysis of Arrival Reliability at Individual Trip Level

Trip scheduled to depart at 1350 sec. Arriving at GM at 1560 s, NA at 2100 s

	NP		P		
Run	GM	Dev NA	GM	Dev NA	
1	1735.6	122.7	1694.2	42.4	
2	1738.9	196	1705.4	125.7	
3	1635.5	-78.4	1637.6	-77.8	
4	1688.3	6.8	1733.4	101.1	
5	1735	118.6	1705.6	70.4	
6	1846	408.2	1807.2	285.4	
7	2235.7	1336.2	2214.2	1336.2	
8	2235.3	1251.6	2143.2	1132.8	
9	1740.1	133.1	1729.8	147.2	
10	1766.8	121.9	1736	123.5	
11	1835.7	390.8	1807.3	309.1	
12	1767.1	176.2	1770.2	147	
13	1935.6	634.5	1936.3	593.3	
14	1635.5	-68.3	1635.6	-33.7	
15	1688.5	510.5	1677.8	509.6	
16	1735.6	94.9	1709.2	37.3	
17	1678.8	-12.5	1680.9	23.2	
18	1735.6	121.4	1705.5	111.8	
19	1690.3	92	1690.4	94.5	
20	1935.2	552.6	1845.8	457.9	
21	1735.6	115	1705.6	80.1	
22	1935.2	552.6	1768.8	186.9	
23	1687.3	109.7	1680.1	18.6	
24	1659.3	44.2	1669.2	49.8	
25	1741.4	141	1743.1	181.2	
26	1635.6	-77.7	1633.8	-80.5	
27	1768	182.4	1768.1	179.5	
28	1841	422.2	1733.8	602.9	
29	1841	422.2	1844.6	385.3	
30	1735.5	118.9	1724.1	107.1	
		271.31		241.5933	-11%
		340.8089		325.7345	-4%

Variability of Auto Travel Time in Base (No Priority) Runs

n=866
Avg. Travel Time=369 s
Avg. Standard Deviation of Travel Time within a Run= 41.9 s

Run #	t @ G Mason	veh id	t @ NA	veh id	Trav. Time.	Stdev TT (for run)
1	381.6	469	708.6	469	327	
1	541.6	819	898.1	819	356.5	
1	1244.1	3001	1586.5	3001	342.4	
1	1281.6	3225	1607.9	3225	326.3	
1	1341.6	3140	1700.6	3140	359	
1	2554.2	7128	2897.7	7128	343.5	
1	2637.7	7170	2999.2	7170	361.5	
1	3344.1	9956	3711.5	9956	367.4	
1	3433.8	9963	3808.7	9963	374.9	
1	3641	10669	4004.7	10669	363.7	
1	4046.8	12553	4418.8	12553	372	
1	4135.9	12808	4556.1	12808	420.2	
1	4453	13766	4811.8	13766	358.8	
1	4938.1	15696	5307.8	15696	369.7	
1	5033.7	15955	5452.2	15955	418.5	
1	5581.2	18198	5891.7	18198	310.5	
1	5676.4	18295	6020.4	18295	344	
1	5835.5	18919	6210.5	18919	375	
1	5933.7	19539	6356.1	19539	422.4	
1	6082.2	20155	6465.4	20155	383.2	
1	6356.9	21068	6702.8	21068	345.9	
1	6433.7	21262	6812.6	21262	378.9	
1	6659.6	22450	7012	22450	352.4	
1	7055.7	23484	7405.3	23484	349.6	
1	7333.8	24184	7772.3	24184	438.5	
1	7369	24739	7785.4	24739	416.4	
1	7646	25363	7995.9	25363	349.9	
1	7767	26253	8105	26253	338	31.73
2	240.4	7	587.4	7	347	
2	388.3	400	704.1	400	315.8	
2	787.5	1494	1101.8	1494	314.3	
2	1242.4	2990	1604.4	2990	362	
2	1540.4	3897	1887.4	3897	347	
2	1841.4	4786	2214	4786	372.6	
2	2235.6	5921	2606.3	5921	370.7	
2	3040	8834	3408.8	8834	368.8	
2	3238.3	9369	3587.3	9369	349	
2	3251.9	9599	3616.4	9599	364.5	
2	3433.8	10111	3801.6	10111	367.8	
2	3739.7	10918	4105.9	10918	366.2	
2	3969.2	11869	4304.1	11869	334.9	
2	4050.1	12489	4398	12489	347.9	
2	4052.1	12425	4461.2	12425	409.1	
2	4474.2	14130	4823.6	14130	349.4	
2	5040.4	16015	5401.1	16015	360.7	
2	5145	16534	5553.9	16534	408.9	
2	5182.1	16798	5580.2	16798	398.1	
2	6042.5	19882	6455.3	19882	412.8	

2	6033.5	19752	6467.4	19752	433.9	
2	6535.1	21849	6877.3	21849	342.2	
2	6944.1	23452	7365.8	23452	421.7	
2	7338.5	24687	7685.3	24687	346.8	
2	7435.3	24859	7752.7	24859	317.4	
2	7733.8	26203	8078.7	26203	344.9	
2	8236.3	27917	8492.8	27917	256.5	
2	8285.8	28056	8562.7	28056	276.9	40.43
3	233.8	72	555.5	72	321.7	
3	742	1290	1098	1290	356	
3	1553.3	4000	1905.1	4000	351.8	
3	1637.6	4228	1932.1	4228	294.5	
3	2264	6351	2606.6	6351	342.6	
3	2383.7	6419	2699.1	6419	315.4	
3	2541.8	6926	2916.9	6926	375.1	
3	3135.4	8841	3628.3	8841	492.9	
3	3186.3	9234	3683.7	9234	497.4	
3	3289.7	9639	3717.4	9639	427.7	
3	3842.3	11442	4191.6	11442	349.3	
3	4035.6	12461	4401.3	12461	365.7	
3	4257.4	13105	4618	13105	360.6	
3	4635.5	14706	4998.4	14706	362.9	
3	4888.7	15797	5216.2	15797	327.5	
3	5037.7	16383	5445.9	16383	408.2	
3	5556.9	18019	5906	18019	349.1	
3	5562.2	18278	5917.1	18278	354.9	
3	5838.1	19371	6215	19371	376.9	
3	6137.4	20221	6512.3	20221	374.9	
3	6357.7	20985	6774.5	20985	416.8	
3	6565.2	22077	6960.2	22077	395	
3	7033.8	23743	7369.5	23743	335.7	
3	7570.2	25295	7995.4	25295	425.2	
3	7554.3	25369	8078.6	25369	524.3	
3	7789.3	26504	8211.2	26504	421.9	
3	8075.1	27293	8379.9	27293	304.8	
3	8186.6	27756	8498.9	27756	312.3	58.22
4	638	990	987.5	990	349.5	
4	1339.3	3247	1681.4	3247	342.1	
4	1835.5	4703	2199.1	4703	363.6	
4	2087.8	5439	2454.5	5439	366.7	
4	2451.3	6853	2799.1	6853	347.8	
4	2537.8	7135	2889.7	7135	351.9	
4	2646.7	7304	3001.2	7304	354.5	
4	2760.4	7741	3109.7	7741	349.3	
4	3636	10821	4011.2	10821	375.2	
4	3845.1	11449	4208.1	11449	363	
4	4145.1	12752	4522.1	12752	377	
4	4345	13716	4802.8	13716	457.8	
4	4541.8	14139	4963.8	14139	422	
4	5041.2	16167	5470.6	16167	429.4	
4	5148.4	16617	5583.5	16617	435.1	
4	5384.3	17552	5712.1	17552	327.8	
4	5477.9	17963	5906	17963	428.1	
4	5548.6	18065	5987	18065	438.4	
4	5668	18837	6015.1	18837	347.1	
4	5741.5	18824	6114.5	18824	373	
4	5954.7	19856	6318	19856	363.3	
4	7239.2	24578	7702.6	24578	463.4	

4	7336.5	24539	7779.2	24539	442.7	
4	8039.6	27192	8356.5	27192	316.9	
4	8136.6	27269	8464.5	27269	327.9	
4	8237.7	28017	8489.6	28017	251.9	50.28
5	389.4	429	695.5	429	306.1	
5	1074.7	2224	1403.5	2224	328.8	
5	1762.1	4459	2090.3	4459	328.2	
5	2080.4	5625	2459.1	5625	378.7	
5	2752.6	7804	3091.9	7804	339.3	
5	2738.4	7690	3097	7690	358.6	
5	2839.8	7977	3211.4	7977	371.6	
5	3041.9	8803	3399.7	8803	357.8	
5	3335.3	9637	3731.2	9637	395.9	
5	3333.8	9768	3755.6	9768	421.8	
5	3637.3	11021	3984.9	11021	347.6	
5	4171.5	12817	4567.6	12817	396.1	
5	4535.9	14079	4919.8	14079	383.9	
5	4637.4	14564	5014.5	14564	377.1	
5	4933.7	15626	5300.6	15626	366.9	
5	4954.6	15943	5310.2	15943	355.6	
5	5433.5	17774	5799.7	17774	366.2	
5	5766.6	18996	6154.9	18996	388.3	
5	6038.9	20289	6400.9	20289	362	
5	6044.6	20143	6417.6	20143	373	
5	6835.5	22923	7207	22923	371.5	
5	7133.8	23445	7567	23445	433.2	
5	7150.6	24051	7589.2	24051	438.6	
5	8033.7	27242	8369.6	27242	335.9	
5	8233.5	27709	8495.7	27709	262.2	
5	8185.9	27794	8503.4	27794	317.5	38.75
6	435.6	685	796.6	685	361	
6	633.8	1206	970.4	1206	336.6	
6	876.8	1945	1250.3	1945	373.5	
6	1633.7	4132	1910.2	4132	276.5	
6	1836.7	4674	2207	4674	370.3	
6	1848.8	4722	2214.1	4722	365.3	
6	2240.3	6008	2595.8	6008	355.5	
6	2368.2	6313	2705.9	6313	337.7	
6	3148	8763	3517.9	8763	369.9	
6	3333.8	9640	3727.3	9640	393.5	
6	3335.3	9851	3771.1	9851	435.8	
6	3444.3	10247	3833.1	10247	388.8	
6	3733.8	11104	4145.2	11104	411.4	
6	3945.3	11960	4358.9	11960	413.6	
6	4733.8	14945	5082.5	14945	348.7	
6	4754.2	14737	5089.7	14737	335.5	
6	4847.1	15461	5205.1	15461	358	
6	4939.5	15657	5308.5	15657	369	
6	5236.4	17028	5653.9	17028	417.5	
6	5641.9	18177	6009.3	18177	367.4	
6	5743	18945	6147.3	18945	404.3	
6	6551.8	21956	6910.8	21956	359	
6	6568.5	21999	6952.2	21999	383.7	
6	6752.6	22755	7096.3	22755	343.7	
6	7039.3	23911	7409.8	23911	370.5	
6	7360.5	24884	7690.2	24884	329.7	
6	7935.3	26995	8276.3	26995	341	
6	8251.2	28003	8570.9	28003	319.7	33.75

7	536.4	734	802	734	265.6	
7	586.3	913	887.6	913	301.3	
7	643.8	1059	1009.4	1059	365.6	
7	840.4	1813	1200.3	1813	359.9	
7	1436.4	3459	1795	3459	358.6	
7	1540.2	3802	1907	3802	366.8	
7	1839	4666	2184.3	4666	345.3	
7	2545.8	7103	2975.9	7103	430.1	
7	2554.4	6889	2987.2	6889	432.8	
7	2847.1	8117	3284.8	8117	437.7	
7	3174.2	9197	3607.1	9197	432.9	
7	3241.8	9545	3652.5	9545	410.7	
7	3451.3	10492	3811.8	10492	360.5	
7	3774.3	11228	4117.7	11228	343.4	
7	3844.3	11351	4188	11351	343.7	
7	4236.4	13010	4620.7	13010	384.3	
7	4556.6	14427	4912.5	14427	355.9	
7	4753	14769	5107.8	14769	354.8	
7	5039.1	16028	5415.3	16028	376.2	
7	5259.7	17174	5685.9	17174	426.2	
7	5437.3	17515	5892.7	17515	455.4	
7	5538.7	17696	5917.4	17696	378.7	
7	6135.3	20351	6526	20351	390.7	
7	6253.8	20697	6616.5	20697	362.7	
7	6339.2	20680	6781.1	20680	441.9	
7	6837.1	23112	7203.9	23112	366.8	
7	7041.1	23447	7490.3	23447	449.2	
7	7337.2	24552	7772.1	24552	434.9	
7	7437.2	25224	7806.2	25224	369	
7	7939.9	26875	8284	26875	344.1	
7	8033.7	27216	8366.9	27216	333.2	45.47
8	435.4	558	713	558	277.6	
8	641.2	1144	997.7	1144	356.5	
8	936.3	1911	1284.8	1911	348.5	
8	1064	2213	1388.5	2213	324.5	
8	1237.7	2886	1661.6	2886	423.9	
8	1386.1	3518	1700	3518	313.9	
8	1440.2	3442	1786.5	3442	346.3	
8	1582.7	3899	1969.8	3899	387.1	
8	2633.7	7259	3092.6	7259	458.9	
8	2845.1	7912	3350.3	7912	505.2	
8	3260.7	9286	3621	9286	360.3	
8	3540.2	10471	3989	10471	448.8	
8	3740.2	10899	4165.9	10899	425.7	
8	3842.3	11560	4216.2	11560	373.9	
8	3939.4	11851	4317.5	11851	378.1	
8	4154.1	12728	4493.5	12728	339.4	
8	4339.1	13698	4719.5	13698	380.4	
8	4654	14586	5009	14586	355	
8	5154.4	16916	5519.5	16916	365.1	
8	5548.7	18042	5906.8	18042	358.1	
8	5663.5	18361	6054.6	18361	391.1	
8	5939.5	19274	6335	19274	395.5	
8	5945.6	19678	6368.1	19678	422.5	
8	6137.4	20435	6508.2	20435	370.8	
8	6235.4	20640	6588.7	20640	353.3	
8	6262.3	20989	6682.1	20989	419.8	
8	6954.5	23460	7323.1	23460	368.6	

8	7533.8	25273	7826.1	25273	292.3	
8	7742	26228	8104.3	26228	362.3	
8	8087.9	27425	8389.8	27425	301.9	49.91
9	477.9	739	791.7	739	313.8	
9	1142	2582	1491.4	2582	349.4	
9	1166.5	2837	1501	2837	334.5	
9	1249	3097	1588.3	3097	339.3	
9	1969.1	5125	2298.6	5125	329.5	
9	2169.5	5729	2496.7	5729	327.2	
9	2238.3	5572	2578.9	5572	340.6	
9	2389.1	6372	2751.1	6372	362	
9	3157.3	9000	3570.3	9000	413	
9	3254.4	9702	3608	9702	353.6	
9	3358.6	9917	3704.1	9917	345.5	
9	3456.1	10312	3879.8	10312	423.7	
9	3552.5	10405	3966.4	10405	413.9	
9	3946.4	11886	4315.3	11886	368.9	
9	4033.7	12171	4353	12171	319.3	
9	4435.4	14049	4811.4	14049	376	
9	4745.8	14897	5085.5	14897	339.7	
9	4874.9	15331	5214.8	15331	339.9	
9	5035.3	15994	5496.1	15994	460.8	
9	5437.3	17576	5813.4	17576	376.1	
9	5489.8	18094	5915.9	18094	426.1	
9	5557.7	18123	5955.5	18123	397.8	
9	5753.5	18744	6148.6	18744	395.1	
9	5840.9	19185	6283.3	19185	442.4	
9	6071.4	20318	6473.8	20318	402.4	
9	6144	20251	6521.9	20251	377.9	
9	6744	22343	7127.3	22343	383.3	
9	7135.2	23877	7507.7	23877	372.5	
9	7283.2	24676	7628.8	24676	345.6	
9	7739.9	26092	8096.6	26092	356.7	
9	8041.1	27246	8372.5	27246	331.4	
9	8333.8	28172	8581.9	28172	248.1	43.28
10	645.3	1268	984.7	1268	339.4	
10	1655.2	4183	1998	4183	342.8	
10	1738.4	4363	2015.8	4363	277.4	
10	2239.3	6081	2586.7	6081	347.4	
10	2553.4	7013	2900.9	7013	347.5	
10	2785.5	7822	3190	7822	404.5	
10	3048.8	8709	3406.4	8709	357.6	
10	3440.9	10306	3882.5	10306	441.6	
10	3540	10760	3917.2	10760	377.2	
10	3781.8	11229	4156.1	11229	374.3	
10	3886.5	11990	4289.9	11990	403.4	
10	4139.5	12813	4493.9	12813	354.4	
10	4744.8	14986	5101	14986	356.2	
10	4747	14916	5110.1	14916	363.1	
10	4884.3	15598	5214.6	15598	330.3	
10	4941.3	15801	5366.6	15801	425.3	
10	5685.3	18653	6066.9	18653	381.6	
10	5742.8	19118	6097.3	19118	354.5	
10	6138.1	20377	6558.8	20377	420.7	
10	6143.8	20545	6567	20545	423.2	
10	6335.4	20972	6716.7	20972	381.3	
10	6635.6	22209	7003.1	22209	367.5	
10	6844.4	23066	7212.1	23066	367.7	

10	7249.8	24375	7600.6	24375	350.8	
10	8087.7	27425	8392.7	27425	305	
10	8239.6	27797	8565.5	27797	325.9	38.01
11	541	822	892.1	822	351.1	
11	890.2	1872	1217.2	1872	327	
11	942	1932	1282.2	1932	340.2	
11	1581.4	3993	1954.6	3993	373.2	
11	1845.4	4680	2206.6	4680	361.2	
11	1869	4905	2223.1	4905	354.1	
11	2238.5	6082	2607.4	6082	368.9	
11	2379.3	6392	2713.8	6392	334.5	
11	2847	8021	3260.3	8021	413.3	
11	2935.2	8526	3317.9	8526	382.7	
11	3239.5	9149	3562.4	9149	322.9	
11	3483.5	10408	3825	10408	341.5	
11	3543.4	10418	3990.7	10418	447.3	
11	3744.3	11008	4194.1	11008	449.8	
11	4247.1	13079	4687	13079	439.9	
11	4451.5	13994	4810.7	13994	359.2	
11	4655.2	14343	5047.7	14343	392.5	
11	4739.6	14870	5121.2	14870	381.6	
11	4887.6	15567	5218	15567	330.4	
11	5050.4	16134	5506.3	16134	455.9	
11	5080	16303	5570.5	16303	490.5	
11	5883.9	19465	6218.3	19465	334.4	
11	6146.5	20339	6511.6	20339	365.1	
11	6556.2	22024	6915.8	22024	359.6	
11	6689.3	22393	7073.5	22393	384.2	
11	6739.2	22785	7105.9	22785	366.7	
11	6867.7	22736	7247.5	22736	379.8	
11	7240.8	24335	7617.5	24335	376.7	
11	7335.3	24506	7701.1	24506	365.8	
11	7540.1	25563	7879.6	25563	339.5	
11	7933.8	26857	8281	26857	347.2	
11	7975.7	26843	8296.9	26843	321.2	42.65
12	238.1	147	512.2	147	274.1	
12	639.3	1165	988.6	1165	349.3	
12	939.2	2118	1246.5	2118	307.3	
12	1274.1	3180	1614.2	3180	340.1	
12	1835.5	4759	2205.7	4759	370.2	
12	2155.9	5919	2515.9	5919	360	
12	2484	6778	2812.1	6778	328.1	
12	2768.7	7476	3095.7	7476	327	
12	3069.1	8878	3481.7	8878	412.6	
12	3443.6	10240	3824	10240	380.4	
12	3579	10612	3973.9	10612	394.9	
12	3778.3	11166	4266.4	11166	488.1	
12	4243.7	13171	4697.4	13171	453.7	
12	4240.3	12994	4705.6	12994	465.3	
12	4772.2	15187	5114	15187	341.8	
12	5035.5	15997	5487.1	15997	451.6	
12	5058	16019	5502.6	16019	444.6	
12	5082.4	16220	5532.2	16220	449.8	
12	5360.1	17513	5780.3	17513	420.2	
12	5546.9	18258	5915.6	18258	368.7	
12	5840.7	18794	6209	18794	368.3	
12	6058.2	20096	6427	20096	368.8	
12	6080.2	20179	6446.1	20179	365.9	

12	6245.2	20652	6618.6	20652	373.4	
12	6939.4	23312	7332	23312	392.6	
12	7264.4	24388	7608.5	24388	344.1	
12	7341.1	24746	7707.1	24746	366	
12	7584	25811	7899.1	25811	315.1	
12	7633.8	25781	7979.8	25781	346	
12	8246.9	27874	8576.9	27874	330	51.78
13	739.2	1311	1092.7	1311	353.5	
13	1042.9	2256	1391.4	2256	348.5	
13	1138.6	2521	1489.6	2521	351	
13	1733.8	4422	2005.8	4422	272	
13	1943.9	5013	2314.4	5013	370.5	
13	2241.2	6034	2615.4	6034	374.2	
13	2243.9	5967	2625.6	5967	381.7	
13	2833.7	7600	3196.2	7600	362.5	
13	2841.3	8066	3204.6	8066	363.3	
13	3236.4	9446	3604.7	9446	368.3	
13	3333.8	9696	3620.1	9696	286.3	
13	3473.1	10248	3826.6	10248	353.5	
13	3567.8	10451	3904.6	10451	336.8	
13	4154.3	12817	4565	12817	410.7	
13	4451.2	13765	4814.4	13765	363.2	
13	5338.7	17332	5705.5	17332	366.8	
13	5537.1	17900	5901.6	17900	364.5	
13	5538.3	17889	5916.3	17889	378	
13	5637.8	18539	6018.5	18539	380.7	
13	5652.1	18559	6026.5	18559	374.4	
13	5833.8	18827	6196.1	18827	362.3	
13	6140.8	20613	6504.8	20613	364	
13	6443.3	21414	6850.5	21414	407.2	
13	6481.9	21645	6899.2	21645	417.3	
13	6835.5	22683	7196	22683	360.5	
13	6837.3	22873	7203	22873	365.7	
13	7339.4	24627	7701.1	24627	361.7	
13	7444.3	24964	7809.9	24964	365.6	
13	7588.4	25898	7957.5	25898	369.1	
13	8282	28049	8568.6	28049	286.6	
13	8335.6	28299	8658.3	28299	322.7	32.11
14	845.6	1740	1118.9	1740	273.3	
14	1250.7	3049	1556.5	3049	305.8	
14	1344.9	3396	1695.8	3396	350.9	
14	1850.6	4539	2216.6	4539	366	
14	1951.5	5010	2295.2	5010	343.7	
14	2233.5	5910	2602.5	5910	369	
14	2936	8054	3334	8054	398	
14	3075.2	8822	3411.8	8822	336.6	
14	3082.2	8736	3456.3	8736	374.1	
14	3339.3	9668	3711.8	9668	372.5	
14	3687.8	10936	4008.6	10936	320.8	
14	4187.5	12904	4596.3	12904	408.8	
14	4235.6	13107	4611.8	13107	376.2	
14	4454.1	14182	4870	14182	415.9	
14	4544.4	14401	4947.6	14401	403.2	
14	4842.2	15563	5206.6	15563	364.4	
14	5036.2	16265	5388.6	16265	352.4	
14	5339	17147	5704.2	17147	365.2	
14	5565.4	18246	5977.2	18246	411.8	
14	6033.8	19816	6422.7	19816	388.9	

14	6141.4	20367	6567.5	20367	426.1	
14	6137.1	20538	6574	20538	436.9	
14	6487.8	21901	6848.8	21901	361	
14	6957.6	23382	7307.3	23382	349.7	
14	7276.1	24452	7645.6	24452	369.5	
14	8236.5	27904	8485.9	27904	249.4	43.87
15	446.5	536	794.5	536	348	
15	957.1	2204	1284.7	2204	327.6	
15	943.2	2035	1290	2035	346.8	
15	1545.5	3838	1920.7	3838	375.2	
15	1936.4	5010	2416.6	5010	480.2	
15	2037.7	5245	2471.7	5245	434	
15	2146.1	5700	2522.1	5700	376	
15	2236.6	5985	2604.8	5985	368.2	
15	2237.3	5948	2614.8	5948	377.5	
15	2365.6	6469	2682	6469	316.4	
15	3061.3	8562	3416.5	8562	355.2	
15	3189.4	9072	3572.3	9072	382.9	
15	3485.6	10459	3960.6	10459	475	
15	3849.1	11513	4268.9	11513	419.8	
15	4088.5	12540	4476.6	12540	388.1	
15	4436.8	13756	4800.1	13756	363.3	
15	4635.6	14601	5000.4	14601	364.8	
15	4942.3	15656	5311.3	15656	369	
15	5175.1	16864	5575.3	16864	400.2	
15	5467.7	17513	5910	17513	442.3	
15	5649.4	18659	6005.6	18659	356.2	
15	5736.4	18821	6108.1	18821	371.7	
15	5887.7	19589	6268.5	19589	380.8	
15	5988.9	19731	6325.6	19731	336.7	
15	6144.4	20396	6524.6	20396	380.2	
15	6142.9	20283	6527	20283	384.1	
15	6651.4	22188	7011.4	22188	360	
15	6741.7	22447	7108.2	22447	366.5	
15	6982.1	23290	7315.2	23290	333.1	
15	7439	24938	7795.2	24938	356.2	
15	7768.7	26339	8092	26339	323.3	
15	8137.4	27305	8459.6	27305	322.2	40.05
16	440.4	440	783.1	440	342.7	
16	733.8	1281	1084.9	1281	351.1	
16	1135.5	2594	1489.4	2594	353.9	
16	1538.1	3878	1914.2	3878	376.1	
16	2333.8	6204	2689.9	6204	356.1	
16	2436.7	6534	2813.5	6534	376.8	
16	2954.4	8549	3358.1	8549	403.7	
16	3133.8	8826	3503.1	8826	369.3	
16	3444	10299	3882.9	10299	438.9	
16	3740.4	11253	4105.8	11253	365.4	
16	4057.1	12570	4445.4	12570	388.3	
16	4238.9	13300	4599.5	13300	360.6	
16	4236.5	13115	4605.5	13115	369	
16	4738.6	15018	5091.3	15018	352.7	
16	4943	15677	5294.1	15677	351.1	
16	5189.1	16941	5551.8	16941	362.7	
16	5239.1	16912	5704.8	16912	465.7	
16	5440.6	17651	5847.9	17651	407.3	
16	5875.3	19371	6286.3	19371	411	
16	6035.1	20196	6415.8	20196	380.7	

16	6059.5	20155	6419.7	20155	360.2	
16	6139.1	20429	6506.6	20429	367.5	
16	6953.1	23428	7321.3	23428	368.2	
16	7267.2	24630	7621.5	24630	354.3	
16	7283.2	24508	7657.3	24508	374.1	
16	7338.1	24659	7696.3	24659	358.2	
16	7839.4	26594	8202.9	26594	363.5	
16	8160	27498	8474.3	27498	314.3	30.08
17	739.3	1242	1079.8	1242	340.5	
17	847	1814	1195.2	1814	348.2	
17	1544.9	3935	1887.5	3935	342.6	
17	2544.5	6657	2882.2	6657	337.7	
17	2933.7	8083	3285.6	8083	351.9	
17	3363.7	9621	3707.8	9621	344.1	
17	3737.6	10986	4111.9	10986	374.3	
17	3755.7	11211	4115.4	11211	359.7	
17	4343.4	13726	4700.6	13726	357.2	
17	4345.4	13406	4702.6	13406	357.2	
17	4557.5	14485	4904.7	14485	347.2	
17	4490.3	14164	4906.3	14164	416	
17	4937	15582	5307.6	15582	370.6	
17	5139.5	16535	5522.6	16535	383.1	
17	5544.6	18086	5957.6	18086	413	
17	5741.7	18565	6087.1	18565	345.4	
17	5956.1	19797	6350.3	19797	394.2	
17	6441.8	21362	6785.4	21362	343.6	
17	6548.2	22143	6916.7	22143	368.5	
17	6733.8	22654	7096.8	22654	363	
17	6746.5	22245	7116.8	22245	370.3	
17	7138.4	24093	7490.1	24093	351.7	
17	7340.4	25112	7690.6	25112	350.2	
17	7739.6	26128	8023.6	26128	284	
17	7941.2	26818	8288.7	26818	347.5	26.21
18	546.4	807	887.6	807	341.2	
18	557.5	900	897.3	900	339.8	
18	740.6	1318	1092.3	1318	351.7	
18	739.2	1557	1094.1	1557	354.9	
18	1250.8	3080	1616	3080	365.2	
18	2835.3	7535	3195.9	7535	360.6	
18	2842.6	7761	3199.7	7761	357.1	
18	2861.1	8009	3289.6	8009	428.5	
18	3269.6	9634	3700	9634	430.4	
18	3736.7	10994	4102	10994	365.3	
18	3746.3	11255	4114.8	11255	368.5	
18	3963.2	12065	4364.7	12065	401.5	
18	4061.8	12518	4414.9	12518	353.1	
18	4535.3	14112	4905	14112	369.7	
18	4635.5	14392	5016	14392	380.5	
18	4774.9	15184	5103.8	15184	328.9	
18	4939.9	15632	5374	15632	434.1	
18	5584.7	18287	5981.4	18287	396.7	
18	5644	18247	6060	18247	416	
18	5862.1	19213	6220.9	19213	358.8	
18	6235.5	20477	6661.5	20477	426	
18	6446.7	21485	6852	21485	405.3	
18	6535.5	22020	6951.4	22020	415.9	
18	6668.5	22586	6999.7	22586	331.2	
18	6658.5	22323	7010.1	22323	351.6	

18	7538.8	25472	7903.6	25472	364.8	
18	7739.5	26179	8120	26179	380.5	
18	7933.8	26957	8218.9	26957	285.1	36.06
19	1040.5	2436	1375	2436	334.5	
19	1084.6	2605	1405.6	2605	321	
19	1954.5	5111	2302.8	5111	348.3	
19	2033.7	5339	2380.9	5339	347.2	
19	2642.5	7390	3070.4	7390	427.9	
19	2955.4	8254	3383	8254	427.6	
19	3336.3	9752	3701	9752	364.7	
19	3287.7	9847	3704.4	9847	416.7	
19	3545.1	10505	3902.3	10505	357.2	
19	3844.1	11506	4253.4	11506	409.3	
19	4061.3	12669	4454.6	12669	393.3	
19	4243.1	13102	4606.1	13102	363	
19	4433.7	13717	4811	13717	377.3	
19	4582.4	14607	4986.7	14607	404.3	
19	4739.7	14857	5086.5	14857	346.8	
19	4857.3	15688	5183.9	15688	326.6	
19	4851.3	15617	5210.9	15617	359.6	
19	5157.6	16715	5500	16715	342.4	
19	5235.4	16747	5617.8	16747	382.4	
19	5237.5	16904	5622.8	16904	385.3	
19	5953.3	19406	6298.3	19406	345	
19	5944.2	19690	6306.1	19690	361.9	
19	6240.1	20767	6604.1	20767	364	
19	6370.2	21091	6723.3	21091	353.1	
19	6643.4	22314	6997.4	22314	354	
19	6666	22414	7013.5	22414	347.5	
19	7154.3	24144	7493.5	24144	339.2	
19	7140.8	23925	7586.6	23925	445.8	
19	7744.1	26310	8088.1	26310	344	
19	7839	26681	8194.8	26681	355.8	
19	8054.1	27073	8373.6	27073	319.5	32.80
20	384.6	400	692.4	400	307.8	
20	1037.3	2249	1392	2249	354.7	
20	1063.5	2385	1401.3	2385	337.8	
20	1269.9	3046	1755.8	3046	485.9	
20	1937.6	4980	2280.2	4980	342.6	
20	2069.4	5535	2459.9	5535	390.5	
20	2935.6	8246	3288.8	8246	353.2	
20	3356	10011	3790.2	10011	434.2	
20	3641.7	10906	3991.2	10906	349.5	
20	3736	10888	4098.4	10888	362.4	
20	3848.2	11595	4218.4	11595	370.2	
20	3954.5	11998	4298.2	11998	343.7	
20	3951.7	12085	4306.4	12085	354.7	
20	3981.7	12318	4319.1	12318	337.4	
20	4556.9	14520	4894	14520	337.1	
20	4753.5	14795	5108	14795	354.5	
20	4936.7	15669	5309	15669	372.3	
20	5186.5	16891	5597.4	16891	410.9	
20	5471.6	17827	5814	17827	342.4	
20	5549.2	17925	5924.3	17925	375.1	
20	5533.7	17743	5929	17743	395.3	
20	5874.4	19219	6219.4	19219	345	
20	5940.3	19311	6314.4	19311	374.1	
20	5980.5	19774	6362.4	19774	381.9	

20	6638.9	22291	7021.7	22291	382.8	
20	6733.8	22531	7072.9	22531	339.1	
20	7142.6	24162	7596	24162	453.4	
20	7250.7	24529	7623.6	24529	372.9	
20	7635.6	25500	7967.8	25500	332.2	
20	7741.7	26403	8101.6	26403	359.9	
20	8035.4	27138	8375.4	27138	340	37.48
21	871.6	1847	1196.7	1847	325.1	
21	847.8	1669	1206.5	1669	358.7	
21	940.8	2143	1290.4	2143	349.6	
21	1339.5	3036	1685.5	3036	346	
21	1976.8	5105	2363.7	5105	386.9	
21	2344.1	6314	2721.2	6314	377.1	
21	2433.7	6478	2863.1	6478	429.4	
21	2646.1	7403	3059.2	7403	413.1	
21	3054	8764	3393.2	8764	339.2	
21	3247.8	9597	3596.3	9597	348.5	
21	3249.2	9454	3605.7	9454	356.5	
21	3737.9	11112	4167.4	11112	429.5	
21	4135.3	12397	4521.2	12397	385.9	
21	4633.8	14549	5012.4	14549	378.6	
21	4638.2	14232	5058	14232	419.8	
21	4976.7	15754	5393.6	15754	416.9	
21	5044	16062	5473.7	16062	429.7	
21	5240.7	16796	5657.9	16796	417.2	
21	5385.7	17640	5763.2	17640	377.5	
21	5442.7	17595	5819.8	17595	377.1	
21	6086.9	20291	6511.1	20291	424.2	
21	6139.6	20135	6517.1	20135	377.5	
21	6561.2	21935	6924.3	21935	363.1	
21	6785.8	22751	7162.9	22751	377.1	
21	7037.1	23665	7449	23665	411.9	
21	7341.1	24731	7699.3	24731	358.2	
21	7368.1	24541	7717.7	24541	349.6	
21	7573.7	25475	7900.3	25475	326.6	
21	7739.5	26142	8013.4	26142	273.9	
21	8135.5	27406	8469.3	27406	333.8	38.01
22	1072.5	2330	1393.3	2330	320.8	
22	1140.7	2439	1494.5	2439	353.8	
22	1635.5	4108	1982.2	4108	346.7	
22	1837.3	4765	2198.2	4765	360.9	
22	2480.4	6699	2849	6699	368.6	
22	2657.2	7568	3079.7	7568	422.5	
22	2748.6	7536	3294.1	7536	545.5	
22	3377.2	10120	3702.5	10120	325.3	
22	3451.5	9971	3799.5	9971	348	
22	3578.3	10678	4003.3	10678	425	
22	3873.2	11919	4244.8	11919	371.6	
22	4452.8	13857	4808.4	13857	355.6	
22	4676.1	14805	5012.9	14805	336.8	
22	4842.7	15410	5255.7	15410	413	
22	5042	16278	5416.1	16278	374.1	
22	5450.7	17904	5818.4	17904	367.7	
22	5537.2	18166	5884.6	18166	347.4	
22	5935.4	19471	6303.3	19471	367.9	
22	5933.7	19229	6310	19229	376.3	
22	6340.4	20995	6700.2	20995	359.8	
22	6339	21158	6708.9	21158	369.9	

22	6744.9	22509	7175.1	22509	430.2	
22	6936.4	23374	7311.5	23374	375.1	
22	7145.7	23744	7508.4	23744	362.7	
22	7776.2	26093	8110.2	26093	334	
22	8035.5	27093	8321.5	27093	286	
22	8335.6	28158	8585.9	28158	250.3	52.72
23	1061.7	2254	1384.6	2254	322.9	
23	1236.8	3021	1603.8	3021	367	
23	1437.8	3516	1753.7	3516	315.9	
23	1538.2	3957	1864.7	3957	326.5	
23	2638.6	7139	2987.7	7139	349.1	
23	2937.3	8382	3289.6	8382	352.3	
23	3151.2	9122	3511.8	9122	360.6	
23	3287.9	9444	3607.6	9444	319.7	
23	3665.3	10925	4023.7	10925	358.4	
23	3641.7	10821	4029.1	10821	387.4	
23	4173.9	12671	4561.5	12671	387.6	
23	4340.2	13589	4760.9	13589	420.7	
23	4572.7	14361	4919.1	14361	346.4	
23	4776.2	15136	5165.9	15136	389.7	
23	4874.7	15453	5223.9	15453	349.2	
23	5039	16018	5392.5	16018	353.5	
23	5133.8	16301	5607.3	16301	473.5	
23	5863.2	18970	6216.9	18970	353.7	
23	5948.3	19217	6312.3	19217	364	
23	6038.8	19911	6499.8	19911	461	
23	6364.6	20969	6692.1	20969	327.5	
23	6446.1	21398	6817	21398	370.9	
23	6676.4	22239	6998.6	22239	322.2	
23	7141.1	24056	7490.9	24056	349.8	
23	7235.9	24306	7578.7	24306	342.8	
23	7355.9	24765	7694.3	24765	338.4	
23	7786.2	26471	8116.1	26471	329.9	
23	7984.5	26722	8299.9	26722	315.4	
23	8137.8	27352	8410	27352	272.2	42.05
24	965.1	2089	1280.1	2089	315	
24	1244.3	2686	1609.3	2686	365	
24	1841.6	4731	2205.1	4731	363.5	
24	2033.8	5445	2393.7	5445	359.9	
24	2241.8	6061	2587	6061	345.2	
24	2633.8	7381	2998.5	7381	364.7	
24	2933.8	8096	3301.3	8096	367.5	
24	2943	8403	3411.3	8403	468.3	
24	3233.7	9490	3657.5	9490	423.8	
24	3337.1	9789	3771.7	9789	434.6	
24	3441.4	10157	3873.2	10157	431.8	
24	3543.4	10422	4008	10422	464.6	
24	3737.8	11168	4110.3	11168	372.5	
24	3875.9	11976	4275.8	11976	399.9	
24	4337.4	13362	4694.2	13362	356.8	
24	4458.9	14237	4870.1	14237	411.2	
24	5150.2	16759	5600.3	16759	450.1	
24	5247.3	17062	5668.5	17062	421.2	
24	5635.4	18083	6016.9	18083	381.5	
24	5769.2	19086	6156	19086	386.8	
24	5790.1	18872	6174.6	18872	384.5	
24	6433.8	21399	6784.2	21399	350.4	
24	6481	21793	6804.2	21793	323.2	

24	6539.4	21604	6900.2	21604	360.8	
24	6833.5	22806	7220.8	22806	387.3	
24	7075.1	23795	7508	23795	432.9	
24	7139.1	24141	7518.1	24141	379	
24	7439	25351	7792.1	25351	353.1	
24	7743	26293	8099.2	26293	356.2	
24	7933.7	26738	8272.7	26738	339	
24	8163.8	27659	8468.6	27659	304.8	42.30
25	233.8	77	508.3	77	274.5	
25	1169.6	2541	1484	2541	314.4	
25	1236.7	3144	1601.8	3144	365.1	
25	2539.2	6866	2915	6866	375.8	
25	2535.5	7051	2925.1	7051	389.6	
25	2664.3	7364	2996.1	7364	331.8	
25	2844.7	7819	3210.9	7819	366.2	
25	3039.1	8864	3507.1	8864	468	
25	3037	8712	3517.9	8712	480.9	
25	3435.4	10006	3803.4	10006	368	
25	3959	12137	4302	12137	343	
25	4441.7	13870	4796.7	13870	355	
25	4465.5	14177	4803.4	14177	337.9	
25	4542.7	14291	4895.6	14291	352.9	
25	5035.5	15922	5413.7	15922	378.2	
25	5149.8	16555	5504.2	16555	354.4	
25	5151.7	16503	5514	16503	362.3	
25	5146.5	16367	5677.8	16367	531.3	
25	5450.3	17661	5868.5	17661	418.2	
25	5942	19312	6365.5	19312	423.5	
25	6251.8	20673	6650.7	20673	398.9	
25	6335.5	20926	6712.5	20926	377	
25	6358.1	21009	6716.9	21009	358.8	
25	6679.4	22378	7010.8	22378	331.4	
25	6681.5	22642	7017.7	22642	336.2	
25	6684	22605	7065.2	22605	381.2	
25	6841.9	22961	7199.4	22961	357.5	
25	7252	24344	7607.1	24344	355.1	
25	7538.5	25458	7899.2	25458	360.7	
25	7544.1	25357	7907.8	25357	363.7	
25	8256.9	27727	8504.5	27727	247.6	54.51
26	753.4	1592	1099	1592	345.6	
26	780.3	1587	1108.4	1587	328.1	
26	1768.5	4576	2114.3	4576	345.8	
26	2233.7	5722	2588.1	5722	354.4	
26	2947.7	8467	3315.5	8467	367.8	
26	3055.1	8896	3412.8	8896	357.7	
26	3354.4	9953	3704.5	9953	350.1	
26	3742.7	10830	4117.1	10830	374.4	
26	4049.7	12384	4397.4	12384	347.7	
26	4638.4	14322	5015.5	14322	377.1	
26	4944.1	15762	5308.6	15762	364.5	
26	4940.5	15802	5318.6	15802	378.1	
26	5546.8	18179	5951.3	18179	404.5	
26	5749.4	18693	6108.4	18693	359	
26	6037.2	19953	6404.2	19953	367	
26	6040.7	19888	6412.9	19888	372.2	
26	6044.5	19821	6459.1	19821	414.6	
26	6641.5	22627	7050.6	22627	409.1	
26	6862.3	22971	7188.9	22971	326.6	

26	6952.3	23527	7362.7	23527	410.4	
26	7339.1	24427	7691.4	24427	352.3	
26	7681.1	25805	8087.9	25805	406.8	
26	7850.8	26705	8203.5	26705	352.7	
26	8240	27886	8501.4	27886	261.4	33.33
27	433.8	374	719.9	374	286.1	
27	1088.9	2445	1396.4	2445	307.5	
27	1736.5	4499	2008.4	4499	271.9	
27	1863.5	4920	2210.5	4920	347	
27	2074.6	5399	2403.5	5399	328.9	
27	2146	5854	2522.1	5854	376.1	
27	2262.5	6187	2611.9	6187	349.4	
27	2769.2	7519	3150.2	7519	381	
27	3045.9	8763	3400.9	8763	355	
27	3345.5	9565	3714.5	9565	369	
27	3453.7	10131	3852.3	10131	398.6	
27	3485.1	10228	3912	10228	426.9	
27	3467.8	10452	3916.6	10452	448.8	
27	3936.6	12040	4291.1	12040	354.5	
27	4235.6	13116	4605.1	13116	369.5	
27	4639.6	14637	5003.8	14637	364.2	
27	4643.8	14695	5015.7	14695	371.9	
27	4988.8	16146	5360.6	16146	371.8	
27	5033.4	16222	5418.6	16222	385.2	
27	5134.9	16622	5521.5	16622	386.6	
27	5162.5	16705	5570.4	16705	407.9	
27	5585.7	18195	5994.8	18195	409.1	
27	6086.5	20330	6488.4	20330	401.9	
27	6141.1	20443	6523.6	20443	382.5	
27	6339.4	21237	6721.3	21237	381.9	
27	6388.5	21144	6755	21144	366.5	
27	6648.1	22346	7002.5	22346	354.4	
27	6837.5	22899	7190.1	22899	352.6	
27	7158.2	24221	7519.3	24221	361.1	
27	7176	24287	7567.7	24287	391.7	
27	7346.3	24765	7696.3	24765	350	
27	7589.3	25686	7894.3	25686	305	
27	7664	25798	7984.9	25798	320.9	
27	8290.2	28049	8571.3	28049	281.1	40.05
28	233.5	25	515.4	25	281.9	
28	1133.8	2529	1475.5	2529	341.7	
28	1154.3	2464	1502	2464	347.7	
28	1687	4371	2049.1	4371	362.1	
28	2147.1	5746	2616.4	5746	469.3	
28	2437.4	6531	2798.1	6531	360.7	
28	2481.8	6555	2812.3	6555	330.5	
28	2761.4	7722	3113.6	7722	352.2	
28	3137.7	9127	3503.4	9127	365.7	
28	3178.2	9373	3559.6	9373	381.4	
28	3182.4	9481	3578.6	9481	396.2	
28	3643.4	10973	4108.4	10973	465	
28	3737.4	11032	4160.5	11032	423.1	
28	4366.3	13724	4756.5	13724	390.2	
28	4368.4	13625	4773.4	13625	405	
28	4733.8	14816	5079.3	14816	345.5	
28	5033.7	16090	5418.4	16090	384.7	
28	4942.5	15894	5473.3	15894	530.8	
28	5471.1	17860	5878.2	17860	407.1	

28	5533.7	17916	5928.5	17916	394.8	
28	5542.5	17824	5981.8	17824	439.3	
28	5778.3	18876	6091.9	18876	313.6	
28	6037.3	19881	6416.7	19881	379.4	
28	6435.3	21368	6806.3	21368	371	
28	6456.3	21382	6864.8	21382	408.5	
28	6537.7	21764	6985.3	21764	447.6	
28	6836.3	22907	7194.4	22907	358.1	
28	7140.8	24102	7619.5	24102	478.7	
28	7436.5	25209	7797.5	25209	361	
28	8073.4	27128	8373.9	27128	300.5	
28	8241.2	28034	8565.6	28034	324.4	
28	8363.6	28188	8599.8	28188	236.2	60.45
29	552.8	821	896.7	821	343.9	
29	738.8	1518	1016.5	1518	277.7	
29	1346.9	3177	1707.2	3177	360.3	
29	1460.8	3633	1878.2	3633	417.4	
29	1942.5	4995	2282.7	4995	340.2	
29	2545.7	7169	2890.8	7169	345.1	
29	2843.1	7959	3283	7959	439.9	
29	3452.7	10380	3814.5	10380	361.8	
29	3574.3	10578	3986.7	10578	412.4	
29	3644.5	11061	4026.7	11061	382.2	
29	4247.9	13151	4674.7	13151	426.8	
29	4438.1	13881	4790.7	13881	352.6	
29	4541.7	14305	4906.8	14305	365.1	
29	4637.1	14621	5015.4	14621	378.3	
29	4733.8	14957	5106.9	14957	373.1	
29	4960.6	15837	5401.7	15837	441.1	
29	4986.7	16059	5468.5	16059	481.8	
29	5237.1	17040	5611.5	17040	374.4	
29	6433.5	21157	6797.9	21157	364.4	
29	6488.7	21464	6819.4	21464	330.7	
29	6558.8	21515	6949.7	21515	390.9	
29	6687.8	22367	7058.9	22367	371.1	
29	7256.2	24484	7613.5	24484	357.3	
29	7344.8	25029	7695.5	25029	350.7	
29	7681	26280	8048.2	26280	367.2	
29	7781.8	26515	8114.6	26515	332.8	
29	8287.1	28237	8568.1	28237	281	45.14
30	733.8	1285	1059.6	1285	325.8	
30	1688.5	4389	2011.9	4389	323.4	
30	2839.7	7835	3259.1	7835	419.4	
30	2838.7	7730	3268.4	7730	429.7	
30	2936.4	8364	3317	8364	380.6	
30	3290.3	9582	3613.5	9582	323.2	
30	3333.8	9731	3696.8	9731	363	
30	3454.5	10091	3800.6	10091	346.1	
30	4245	12767	4613.1	12767	368.1	
30	4552.5	14349	4915.5	14349	363	
30	4545.8	14213	4921.9	14213	376.1	
30	4643.5	14723	5009.7	14723	366.2	
30	5278.4	17088	5607.6	17088	329.2	
30	5457	17635	5866.5	17635	409.5	
30	5439.1	17481	5872.1	17481	433	
30	5558.9	18045	5909.1	18045	350.2	
30	5949.7	19657	6312.1	19657	362.4	
30	6045.8	19993	6489.1	19993	443.3	

30	6537.4	21710	6933.4	21710	396	
30	7181.5	24059	7602.1	24059	420.6	
30	7435.4	25014	7763.8	25014	328.4	
30	7842.8	26658	8217.3	26658	374.5	
30	8033.8	27222	8377.3	27222	343.5	
30	8335.3	28050	8592.2	28050	256.9	44.02

Appendix G: Statistical Tests

Standard Deviation of Deviation at Navy Annex

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	209.0459	202.3611
Variance	2062.751	2187.926
Observations	30	30
Pearson Correlation	0.965839	
Hypothesized Mean Difference	0	
df	29	
t Stat	3.019989	
P(T<=t) one-tail	0.002616	
t Critical one-tail	1.699127	
P(T<=t) two-tail	0.005231	
t Critical two-tail	2.045231	

Average Bus Run Time

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	552.6018	547.8307
Variance	1779.006	1509.181
Observations	30	30
Pearson Correlation	0.963753	
Hypothesized Mean Difference	0	
df	29	
t Stat	2.293052	
P(T<=t) one-tail	0.014643	
t Critical one-tail	1.699127	
P(T<=t) two-tail	0.029285	
t Critical two-tail	2.045231	

Average Vehicle Delay

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	86.5198	87.38553
Variance	3.272702	4.663067
Observations	30	30
Pearson Correlation	0.685193	
Hypothesized Mean Difference	0	
df	29	
t Stat	-2.95079	
P(T<=t) one-tail	0.003108	
t Critical one-tail	1.699127	
P(T<=t) two-tail	0.006215	
t Critical two-tail	2.045231	

Average Person Delay

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	104.4243	105.087
Variance	7.373114	8.678925
Observations	30	30
Pearson Correlation	0.822618	
Hypothesized Mean Difference	0	
df	29	
t Stat	-2.135	
P(T<=t) one-tail	0.020668	
t Critical one-tail	1.699127	
P(T<=t) two-tail	0.041337	
t Critical two-tail	2.045231	

Individual Trip Level Arrival Reliability

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	271.31	241.5933
Variance	116150.7	106103
Observations	30	30
Pearson Correlation	0.96551	
Hypothesized Mean Difference	0	
df	29	
t Stat	1.833005	
P(T<=t) one-tail	0.038543	
t Critical one-tail	1.699127	
P(T<=t) two-tail	0.077087	
t Critical two-tail	2.045231	