AUSCI

Adaptive Urban Signal Control and Integration

Evaluation Final Report

October 2000

Minnesota Department of Transportation

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Adaptive Urban Signal Control and Integration

EVALUATION

FINAL REPORT

October 2000

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1. EXECUTIVE SUMMARY

1.1. AUSCI Project Background

The Minnesota Department of Transportation (Mn/DOT) sponsored the development and evaluation of the Adaptive Urban Signal Control and Integration (AUSCI) Intelligent Transportation System (ITS) Field Operational Test in downtown Minneapolis, Minnesota. AUSCI is a cooperative effort implemented by Mn/DOT, the Federal Highway Administration (FHWA), the City of Minneapolis, and private sector partners Fortran Traffic Systems Limited (Fortran) and Image Sensing Systems, Inc. (ISS).

Traffic demands in the Minneapolis Central Business District (CBD) have changed dramatically over the past few years with the termination of I-394, addition of a 20,000-seat arena, and construction of other structures in the area. These changes have resulted in traffic patterns that vary significantly by time of day, change on a daily basis due to events and incidents, and change on a seasonal basis due to adverse weather conditions and construction activities. After a thorough review of the original system, an adaptive control strategy was selected to address the challenges posed by the significant variations in traffic volumes and patterns.

The AUSCI project encompasses a 56-intersection portion of the Minneapolis CBD. The Split Cycle Offset Optimization Technique (SCOOT) system was selected to provide the adaptive control. AUSCI integrates the SCOOT system with the original Urban Traffic Control (UTC) system, allowing the operator to select which control strategy to implement. The project is unique because 138 video sensors provide the system's detection requirements.

The AUSCI evaluation includes a rigorous examination of several aspects of the project. The evaluation examines the institutional issues, technical issues, and project costs associated with deployment. In addition, transportation system impacts of the SCOOT system are examined through extensive field data collection, featuring travel time runs and intersection delay studies. The evaluation provides valuable information to two audiences. First, the City of Minneapolis will use the results to identify the benefits of expanding the system to place additional intersections under adaptive control. Second, the results will supply agencies in other metropolitan areas with a description of the implementation experience, including the level of effort and cost, as well as the level of benefits resulting from the addition of adaptive control in a downtown network environment.

1.2. DOCUMENT PURPOSE

The AUSCI evaluation is divided into four separate test plans. Each test plan addresses a specific project goal. The *Evaluation Final Report* provides results for each of the following evaluation test plans:

Test Plan One – Assess Performance Characteristics

Test Plan Two – Assess Transportation System Impacts

Test Plan Three – Document Cost Impacts

Test Plan Four – Identify Deployment Issues

1.3. TEST PLAN ONE RESULTS

Test Plan One measures the performance of the adaptive signal control system through eight criteria. Key findings from each of these criteria are presented below:

Integratability – The integration of the SCOOT and T2000C systems was one of the most time-consuming and technically challenging project tasks. The integration of these two systems was accomplished with no loss of functionality. The success of this project attests to the AUSCI project's integratability.

Operability – Based on interviews of system operators, the SCOOT system is considered user-friendly and intuitive to use. In addition, the usability of the original T2000C system was not changed with the introduction of the SCOOT system.

Adaptability – Adaptability is a qualitative assessment of how the SCOOT system adapts to changing traffic conditions, based primarily on operators' experience in observing the system in operation. System operators perceive an improvement in the adaptive performance of the signal system when compared to the previous control strategy. The system has been observed to adapt quickly to changing traffic conditions.

Reliability – System reliability has been excellent. Given the low rate of system failures, there is not enough data to calculate a mean time between failures.

Maintainability – The SCOOT system and supporting systems require an acceptable level of maintenance. Minimal day-to-day interaction is required from system operators and much of the required maintenance can be absorbed into normal maintenance activities performed by the traffic department's field personnel.

Expandability – Since the SCOOT system has been successfully integrated with the T2000C system and the system is performing well, further expansion within the City of Minneapolis may be desired. An assessment of the technical issues related to expansion reveals no major obstacles. Adding additional regions to adaptive control is relatively straightforward, making the system very expandable. The primary obstacle to future expansion is funding.

Transferability – The lessons learned in the AUSCI project are largely transferable to others attempting a similar project. One of the most important lessons is that the project team must have a thorough knowledge of both the existing and proposed systems. This allows the project team to be realistic about the costs involved in integrating an adaptive system with an existing system and the potential benefits that can be derived. Although Minneapolis operates the only T2000C UTC type system in the United States, many of the key findings from this evaluation are transferable to other cities.

Capabilities – The SCOOT system and supporting video detection/surveillance systems provide Minneapolis traffic engineers with a comprehensive set of traffic management, operational and analysis capabilities. In their final configuration, these systems meet or exceed all of the project specifications. By meeting these requirements, the adaptive signal control system is considered very capable.

1.4. TEST PLAN TWO RESULTS

1.4.1. Data Collection and Analysis

The transportation impacts of the SCOOT adaptive signal control system were compared to the transportation system impacts of the original T2000C signal control system. The evaluation featured the ability to switch between SCOOT control and T2000C control. This allowed the network to be operated alternately between the two systems, ensuring similar traffic and environmental conditions for the evaluation of SCOOT's operation.

The evaluation approach included both manual field data collection and automated data collection from SCOOT itself. Manual field data collection activities consisted of floating car studies along travel routes and observations of delay at selected approaches. SCOOT data collection activities consisted of reports of estimated traffic parameters that are produced in the process of developing signal timing plans. A comparison between manual field data and SCOOT data collected during the same time interval was conducted in order to assess the feasibility of using the SCOOT data to supplement the field data collected. Notice that this correlation was not a formal part of the evaluation. Only a preliminary investigation was undertaken; no formal hypotheses were developed or tested. This analysis revealed poor correlation between the two data sets. Therefore, manual data collection results are emphasized.

Field data was collected during a variety of time periods and under various traffic conditions, including morning and afternoon peak periods and off-peak periods. SCOOT system boundary conditions and special events were also evaluated. The transportation impacts at system boundaries are of particular interest, because the adaptive system is independent from the rest of the City's T2000C signal system. This creates numerous boundary approach and departure links, each with the potential to disrupt traffic progression into and out of the SCOOT network. To quantify the boundary impacts, travel time and delay data was collected at both system intersections and the adjacent non-system intersections.

Field data was collected in several different time periods. First, pilot study data was collected in July 1999. The pilot study consisted of a small sample of travel times and delays from each of the travel time routes and delay approaches. Next, extensive travel time and delay data was collected for all test conditions in August 1999. Finally, supplemental data was collected in December 1999.

Most travel time data was collected on an aggregated basis by measuring the time to make one pass along each route. Based on concerns expressed by the evaluation team, link-by-link level of data was collected during the supplemental study in order to provide more detail on the travel times within a route.

Average delay per vehicle was calculated by dividing the number of vehicles stopping by the total approach volume in a sampling period. Unfortunately, a T2000C hard drive failure resulted in the loss of most of the volume data, making average delay per vehicle calculations impossible. Therefore, the evaluation focuses primarily on results from the travel time studies.

1.4.2. Field Data Results

The evaluation of network-wide impacts using adaptive control, such as the AUSCI project, is an inherently difficult task. Since the study area comprises a grid network of 56 intersections, there are no clearly defined corridors or key intersections at which to measure the traffic impacts of the adaptive signal control system. Also, the traffic flow patterns are complicated because drivers travel from multiple origins to multiple destinations. Conducting a “with” and “without” evaluation under these conditions is challenging. No evaluation can fully capture the transportation system impacts associated with such an extensive traffic signal deployment. The complexity of conducting an evaluation in these conditions must be considered when interpreting the results.

At the outset of the AUSCI evaluation, an improvement in travel times and delay of approximately 12 percent was expected from the SCOOT system[1]. This anticipated improvement was based on previous evaluations that compared SCOOT to an up-to-date fixed time-of-day system. The results from the AUSCI project were expected to be even higher, since the original T2000C system’s plans were six years old when the evaluation was conducted.

The evaluation analyzed the traffic impacts after special events at the Target Center on two consecutive days. The SCOOT system was in operation on one day and off the next. Four travel time routes were driven within the AUSCI study area. The results indicate a travel time improvement of approximately 19 percent during special events.

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[1] Expected performance results were discussed during evaluation team meetings in Spring 1998.

Non-special event data was collected during a.m. and p.m. peak periods for two different conditions: travel time routes within the study area, and travel time routes that traverse the study boundary. The impacts from routes within the study area were mixed: travel times improve on some routes, worsen on others. Overall, results from routes within the study area reveal no significant differences in travel times between the SCOOT and T2000C systems. Finally, travel time along routes that traverse the study boundary are approximately 15 percent longer with SCOOT in control.

It should be noted, however, that beyond the findings noted above, SCOOT provides other benefits. For example, during incidents or special events, the SCOOT system is effective at managing unpredictable traffic flows. Also, as times passes, the T2000C timing plans will become more outdated, whereas the SCOOT system will continue to update itself. Thus, while there may be no differences now, the SCOOT system may provide benefits at a later date.

It should also be noted that these results do not fit with the City operators' perception of the SCOOT system's performance. Operators perceive an improvement during all time periods. Unfortunately, it is difficult to reconcile this perception with some of the sample field data collected. Additional field data, collected at a finer level of detail, could provide further insight into this discrepancy.

Finally, research into other evaluations suggests that the network environment in which the AUSCI system was deployed may contribute to the type of results observed here. An extensive SCOOT deployment in Toronto found better performance along arterials than in the CBD.

1.4.3. Key Findings

The following list highlights some of the key findings from the evaluation of traffic system impacts:

- Travel time runs show a significant improvement (19 percent) under SCOOT during special events.
- Peak period travel times within the study area show no significant change under SCOOT. Overall, the results are mixed; some route travel times improve under SCOOT, while some worsen.
- Peak period travel times across the SCOOT and UTC system boundaries show a significant worsening (15 percent) under SCOOT for all routes combined.
- Using traffic counts to volume-weight travel times along one of the routes resulted in an improvement over unweighted travel times, but this change is not significant at the 95 percent confidence interval.
- City of Minneapolis traffic operations personnel perceive an improvement in traffic operations during all time periods, particularly during special events, with the addition of the SCOOT system.

1.5. TEST PLAN THREE RESULTS

1.5.1. Project Costs by Activity

The AUSCI project was comprised of numerous project tasks. Project participants tracked the cost of each of these activities and provided this information to the Mn/DOT Project Manager on a monthly basis. Documenting the cost for each of these activities offers detailed information on the level of effort required to deploy the adaptive signal control system. As an operational test, a significant amount of effort was spent on the proof of concept, testing, and evaluation. In addition, new technology was developed for this project and is reported as a project cost, even though much of this work was provided as an in-kind contribution from private sector project partners. For these reasons, the project costs do not necessarily indicate the cost of a similar deployment in another urban areas. Table 1-1 summarizes the project costs by activity.

TABLE 1-1
PROJECT COST BY ACTIVITY

Activity	Cost
Design and Project Management	$1,247,248
Video Detection and Surveillance	2,381,889
Upgrade Controllers and Cabinets	844,210
SCOOT/T2000C System	1,357,730
Operation Support	108,623
Evaluation	327,147
Travel and Training	183,319
Marketing and Public Education	11,686
Total Cost	**$6,461,852**

1.5.2. Project Training Costs

As with any complex system, the AUSCI project required extensive training during the deployment and operational phases. Training was required for both the SCOOT signal control and the video detection systems. Training was needed to provide City of Minneapolis and Westwood personnel the tools necessary to validate the SCOOT system during the deployment and to establish detection zones with the video detection system. Table 1-2 documents the cost of each major training activity.

TABLE 1-2
TRAINING COSTS

Training Activity	Cost
Initial SCOOT Operation Training	$51,239
T2000C Modification Training	3,500
Initial Video Detection System Installation Training	74,197
Initial Video Detection System Operation Training	33,998
SCOOT Validation Training	5,250
Total	**$168,184**

1.5.3. Project Funding

A unique aspect of the AUSCI project is the public/private partnerships that were created. The partnering process played an important role in project financing. The project was affordable because all partners made significant financial and resource contributions to the project. The FHWA provided the primary source of funds. Funding provided by the project participants is listed in Table 1-3.

TABLE 1-3
SOURCE OF FUNDING

Source of Funding	Amount
FHWA	$2,981,000
Private Partners	1,869,270
City of Minneapolis	1,174,008
Mn/DOT	437,574
Total	**$6,461,852**

1.6. TEST PLAN FOUR RESULTS

1.6.1. Technical Issues

The integration of two different traffic control systems is a unique effort, an undertaking that presented many technical challenges. Meeting these challenges required the concerted effort of individuals familiar with both the original T2000C system and with the SCOOT adaptive control system. Ultimately, integration of the two systems was successfully accomplished. Some of the technical issues encountered in the project are presented below:

Software – Integration of the two systems required extensive software development. Both interface software and a common database had to be developed.

Field Cabinets – Every field cabinet in the SCOOT system had to be modified to accommodate the SCOOT and video detection system components. Modifications required transporting one cabinet at a time to the maintenance shop and adding detection interface panels and harnesses. Fifteen cabinets required upgrades to replace electromechanical controllers.

Timing Standard – Differences between the original system's 1/30th of a second standard for gathering detector status information and SCOOT's 1/4th of a second required a conversion to make them compatible.

System Expansion – A review of the issues related to expanding the SCOOT system revealed that no barriers exist for expanding the SCOOT or video detection systems. Expansion would, however, require a detailed examination of the communication infrastructure and modifications to the T2000C system database.

New Technology – Deployment of ITS systems often involves new technology; this was definitely true for the AUSCI project. Image Sensing Systems developed a new video detection sensor at the same time the AUSCI project was being deployed. A total of 138 sensors were deployed in the study area. Due to the first-of-its-kind nature of the technology, successful integration in the field took longer than anticipated. In the end, the video detection system provided more features than originally required and has been working well as a final, fully deployed system.

In conclusion, the majority of technical issues encountered during the AUSCI project were expected, and were addressed as the project was deployed. The project's implementation has been a remarkable success for the level of sophistication, time required, and number of parties involved.

1.6.2. Institutional Issues

As can be expected in any large ITS team project, there were several institutional issues that surfaced over the course of the AUSCI project. These issues and the approaches for resolving them are summarized as follows:

International – Procurement of SCOOT required dealing with multiple international organizations with their differing laws, practices, and procedures. Challenges were encountered with currency exchange and international legal issues. The partnership nature of the project gave Mn/DOT enough flexibility to successfully deal with these issues.

Contractual – The AUSCI project involved a series of contractual challenges. Most significant was the time required to develop the project's scope of work with the SCOOT system supplier. The scope of work was difficult to develop because the project team members did not have a clear picture of the final SCOOT system configuration. This meant the contract could not be finalized until key design issues were worked out. The project also required a joint powers agreement between the City of Minneapolis and Mn/DOT. Executing this agreement was a lengthy and complex process.

Funding – As with any one-of-its-kind technology development, the funding level required to successfully deploy an ITS project is difficult to assess. The preliminary cost estimates developed for the AUSCI project had to be revised during the detailed design phase. When higher project costs began to emerge, all project partners had to contribute to meet the new project costs.

1.6.3. Partnering Process

Partnering is a non-traditional method of procuring an adaptive traffic signal control system. The partnership concept proved to be very effective in successfully deploying the AUSCI project. The effectiveness of the partnership agreement can be attributed to four factors:

Affordability – The partnering process played a pivotal role in the project's affordability. All AUSCI partners made significant financial and resource contributions to the project.

Latest Technology – Mn/DOT obtained the most suitable state-of-the-art technology for the project. This would have been more difficult if the project was a conventional low-bid process.

Flexibility – Partnership procurement offered Mn/DOT flexibility in overcoming several institutional barriers during contract negotiations with the various team members.

Cooperative Spirit – Traditional institutional barriers were non-existent in the project because the partnership procurement led everyone to own the common goal of project success.

1.6.4. Operators' Perception

City of Minneapolis traffic operations personnel were interviewed to obtain their perception of value and effectiveness of the SCOOT system. The SCOOT system operators indicate that the system responds well to fluctuations in traffic. While the impact is most noticeable when a special event occurs in the study area, operations personnel feel improvement has been achieved during all time periods, including peak and off-peak periods. They also have the perception that the system adjusts well to traffic at critical intersections.

1.6.5. Transferability

Although Minneapolis operates the only T2000C system in the United States, many of the key findings from the AUSCI project evaluation are transferable. Other metropolitan areas considering adding adaptive control to their UTC system will be faced with similar questions and will encounter many of the same project tasks. The AUSCI project can help others be realistic about the amount of effort involved in integrating an adaptive system and the potential benefits that can be achieved.

2. AUSCI PROJECT OVERVIEW

2.1. PROJECT DESCRIPTION

The City of Minneapolis has operated an automated 740-intersection City-wide UTC type system for more than 20 years. The system is timing plan library-based with both time-of-day and traffic-responsive capabilities that requires periodic signal timing updates in order to stay current with constantly changing traffic control requirements. Recognizing the costs inherent in operating this control strategy, in 1992 the City identified adaptive operation as a means to improve traffic flow. A project to conduct a field operational test of an adaptive control strategy within the original signal control system was proposed to Mn/DOT Guidestar Office and FHWA as an initiative under Mn/DOT's Orion Program. Project partners include Fortran Traffic Systems Limited (Fortran), Image Sensing Systems, Inc., Mn/DOT, FHWA, and the City of Minneapolis.

2.2. AUSCI PROJECT TEAM

The AUSCI project team is composed of members representing several public agencies and private organizations. The individuals listed below are representatives of these organizations. Many others were involved, including Minneapolis electricians, Image Sensing System technicians, and systems analysts from Fortran Traffic Systems and Siemens Traffic Control Limited.

Ms. Marilyn Remer, Mn/DOT Project Manager

Mr. Roger Plum, City of Minneapolis

Mr. Steve Mosing, City of Minneapolis

Mr. James McCarthy, Federal Highway Administration

Mr. Dharam Bobra, Hennepin County

Mr. Lowell Benson, University of Minnesota

Dr. Gary Davis, University of Minnesota

Mr. Len Palek, Mn/DOT Traffic Management Center (TMC) Representative

Mr. Allan Klugman, Westwood Professional Services, Inc.

Mr. Dallas Hildebrand, Westwood Professional Services, Inc.

Mr. Mike Belrose, Westwood Professional Services, Inc.

Mr. Peter Ragsdale, Fortran Traffic Systems Limited

Dr. Durga Panda, Image Sensing Systems, Inc.

Mr. Brian Scott, SRF Consulting Group, Inc.

Mr. Erik Minge, SRF Consulting Group, Inc.

Mr. Ben Hao, SRF Consulting Group, Inc.

2.3. PROJECT LIMITS

The AUSCI test area is a 56-intersection integrated network of local streets, freeway ramps, High Occupancy Vehicle (HOV) facilities, and parking garages in the western portion of the Minneapolis CBD. The test area is shown in Figure 2-1. It includes the termini of I-394 and Highway 55 from the western suburbs and connections with I-94 and Highway 52/152 to the northwestern suburbs. These corridors serve large numbers of rush-hour business and commercial center commuters, as well as attendees at major events in the CBD, including those at the Metrodome, Target Center Arena, and the Convention Center.

2.4. PROJECT GOALS

AUSCI project goals were developed to clarify the project's purpose and to guide system deployment. The goals address system integration, traffic control, agency management, and evaluation issues. The goals were formulated based on the National ITS Program goals as presented in the *National ITS Program Plan* (March 1995) and on the Minnesota Guidestar goals as presented in the *Minnesota Guidestar Strategic Plan* (June 1994). The nine project goals are listed below:

1. Add an adaptive control element to the existing computerized traffic signal control system.

2. Operate an adaptive system in a manner that coexists with standard time-of-day and traffic-responsive UTC type system operation.

3. Implement an adaptive control system to produce and maintain optimum traffic settings in the controlled area.

4. Provide an adaptive system operation that minimizes border problems with adjoining non-adaptive control areas.

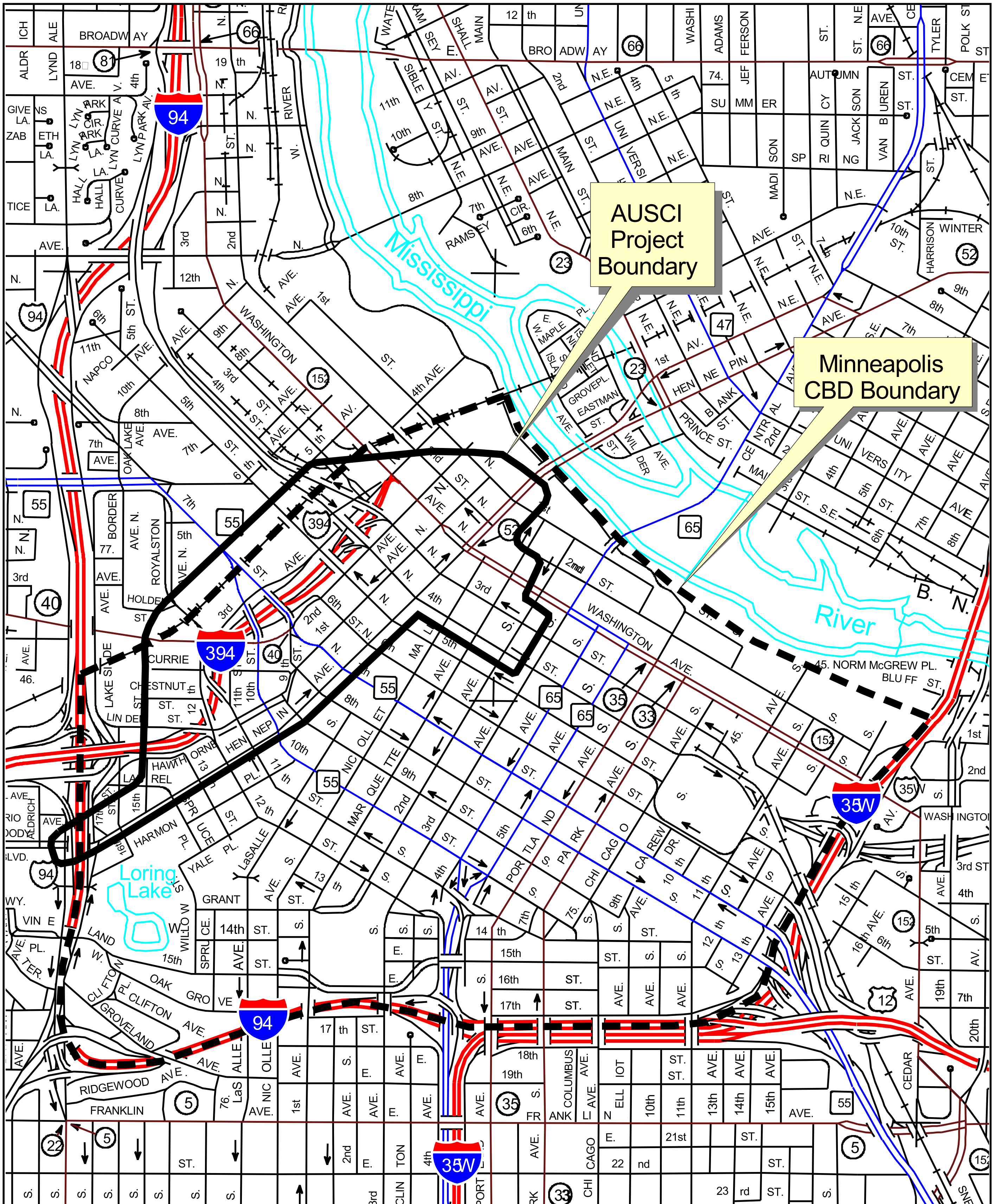
5. Use an adaptive control system to maintain up-to-date traffic signal settings without increased staffing.

6. Assess the cost, maintenance requirements, and effectiveness of the additional detection required to enable adaptive control operation.

7. Establish effective strategies for managing the adaptive control system.

8. Establish effective working relationships and management mechanisms between agencies involved in major traffic control systems in the area.

9. Evaluate the costs and benefits associated with implementation of an advanced adaptive traffic control system.



AUSCI PROJECT AREA

Figure 2-1

The AUSCI project supports the following National ITS Program Goals:

- Improve safety of the metropolitan system network.
- Improve operational efficiency (Level of Service) and capacity of the surface transportation system.
- Reduce energy and environmental costs associated with traffic congestion.
- Enhance present and future productivity.
- Enhance personal mobility and the convenience and comfort of the surface transportation system.

The AUSCI project also supports one of the goals of the Model Development Initiative. Namely, the project makes a significant contribution toward progressing a signal system from traffic-actuated to fully integrated.

Finally, the AUSCI project supports the following Minnesota Guidestar Goals:

- Five-year goal: Develop a fully adaptive small-area traffic control package.
- Ten-year goal: Deploy real-time adaptive control for the metro-system network.

2.5. SYSTEM DESCRIPTION

This section provides a description of the baseline traffic control system in the Minneapolis CBD and of the SCOOT adaptive signal control system as implemented in the AUSCI project. Next, the video detection and video surveillance systems are presented. Finally, the operation of the SCOOT system is explored.

2.5.1. Baseline Condition

The City of Minneapolis installed the T200 City-wide computerized traffic signal control system in 1975. This system was upgraded in 1993 when the original T200 traffic control software, computer and peripherals, map, and central communication assembly were replaced with the T2000C system. The T2000C system is an enhanced first-generation, multi-user and multi-tasking, real-time control system. The system can operate as a second-by-second, table-lookup, time-scheduled, and traffic-responsive plan selection traffic control system. There are 740 intersections throughout the City of Minneapolis under the T2000C's control. The T2000C system features include scheduling and operation control methods, user-developed selection parameters, detector and controller testing, and on-line database operations. Computer control of each intersection is provided over the City-owned twisted pair communication system through a Communications Modification Unit (CMU) that enables the computer to directly control intersection controllers and other attached equipment.

The T2000C system is a library-style, timing-based system. Timing plans consisting of cycle, split, offset, and control schemes for each intersection are developed off-line in response to historically defined traffic flow patterns. The occurrences of the network traffic flow patterns consistent with the pre-developed timing plans are then assessed to establish the most effective method for timing plan selection.

The T2000C system can make timing plan selections in one of two ways. It can select plans based on time-scheduled operation, or it can select the plans based on traffic-responsive values established by criteria derived from volume- and occupancy-based system detectors and from user-defined parameters. In the years preceding implementation of the AUSCI project, only the time-of-day plan selection had been used for day-to-day traffic management and control.

Several major business/commercial, sports, entertainment, and convention facilities have been constructed in the Minneapolis CBD area in the recent past. Prominent traffic-generating facilities in the CBD include the Target Center Arena, the Metrodome, and the Minneapolis Convention Center. The traffic for these facilities creates different flow conditions, including short-term fluctuations, reverse direction flows, heavy traditional period usage surcharged by special events, off-peak hour event-driven flows, and freeway-destined traffic flows. These conditions have increased the importance of effective traffic control and traffic responsive timing plans selection.

Through review of the original T2000C traffic signal control system capabilities and the changing conditions and flow demands of CBD traffic, it was concluded that a control deficiency had developed in the Minneapolis CBD. Although the original system provided an effective way to control and monitor system equipment, it did not provide adequate timing plan development capabilities. While the original detection scheme provided reasonable inputs for limited traffic-responsive plan selection, it did not provide sufficient data for off-line or automated timing plan development. New timing plans were developed on an as-needed basis, typically several times a year, depending on traffic changes in the downtown area. Developing these new timing plans involves data collection, plan development, implementation, and evaluation, typically costing $4,000 per intersection. This frequent manual development of new timing plans directed specifically at solving timing changes associated with the multiple flow conditions was not practical due to a combination of limited staff, plan development complexity, and expense.

2.5.2. Adaptive/Original System Integration

The adaptive control strategy was selected to address challenges posed by the significant variations in traffic volumes and patterns in the Minneapolis CBD. The fundamental difference in traffic control approaches between the original system and an adaptive traffic signal control system was explored. Instead of utilizing predetermined timing plans, an adaptive control system develops new system timing plans in response to actual traffic flow conditions. This adaptive capability allows the traffic control system to be more responsive to the significant variations in traffic flow experienced in the Minneapolis CBD.

A number of adaptive-type systems exist and even more adaptive algorithms are under development. After reviewing all of the mature adaptive traffic control systems, the SCOOT system was selected to provide adaptive control for the AUSCI project. SCOOT was developed in England by the Transportation Research Laboratory and three British traffic control system suppliers. SCOOT was selected for a variety of reasons. One important selection factor was its availability through the City's T2000C system supplier, Fortran.

Two options were identified for deploying the SCOOT adaptive control system in Minneapolis:

1. Install a stand-alone SCOOT system, independent of the T2000C system.

2. Install a combination of the T2000C and SCOOT systems.

The second option to integrate the two systems was selected. This option was selected for several reasons:

1. This option permits the greatest degree of flexibility, allowing SCOOT to be easily implemented on an as-needed basis and turned completely off if so desired.

2. The City has thousands of person-hours invested in database development, training, and staff time with the original T2000C system and wishes to continue to operate that system.

3. The T2000C system provides effective and reliable operation for standard traffic control applications.

4. The T2000C system had undergone an upgrade in 1993, which cost more than $1 million.

5. The project scope was limited to SCOOT implementation in a specified area.

This integration was accomplished by connecting the SCOOT system to the current T2000C system, allowing the SCOOT system to operate with the in-place T2000C system. The systems are configured such that it is possible to select either the T2000C system or the SCOOT system to control the signal system. The SCOOT system operates on its own computer, where it continuously makes incremental adjustments to signal timing settings that are either globally or locally constrained by the operator. These new timing plan values are passed on to the T2000C system which, in turn, converts the SCOOT timing into control commands and passes them to the traffic signal controllers. This approach required that SCOOT be disconnected from its typical UTC system and that linkage and interfacing software be developed to support a connection to the T2000C UTC system. An integration of two major signal control systems is a unique aspect of the AUSCI project. Extensive fieldwork was required to calibrate the SCOOT system. Each intersection was observed in the field during periods of heavy congestion. The validation parameters were then fine-tuned to achieve optimal performance under SCOOT control. Refer to *Test Plan Four*, *Identify Deployment Issues*, or to the *Concept Definition Report* for more information on the SCOOT installation.

2.5.3. Video Detection

For the SCOOT system, traffic flow is measured in real time through a series of detectors located upstream of each intersection. These upstream detectors are positioned to monitor traffic as it approaches each intersection, providing real-time occupancy data to the SCOOT system. The AUSCI project is unique because it utilizes video technology to provide SCOOT's detection requirements. Video detection was chosen because of its flexibility and its minimal disruption to traffic during installation. A total of 138 Autoscope Solo™ video sensors have been installed for this project, the first deployment of this sensor. These sensors provide over 300 SCOOT detectors.

The SCOOT system performance is closely tied to the quality of the detection inputs. This evaluation assumes that the detection inputs are reliable. Evaluation of the video detection system was not included in this evaluation.

2.5.4. Video Surveillance

The project also includes a system of nine surveillance cameras with pan/tilt/zoom capabilities. Views from the cameras encompass most of the network, allowing an operator to observe network-wide operations.

2.5.5. System Operation

The SCOOT system continuously monitors traffic flow parameters in real time and makes incremental adjustments to traffic signal timing plans to minimize network-wide delays and stops. Traffic signal timing plans are implemented by continuous small changes in order to minimize the disturbance to traffic flow within the system. The minimization of traffic flow stops and delay requires an internal model that can predict short-term traffic movements. Upstream video detection sensors located on each link within the study area provide the SCOOT detection inputs. These detectors output volume and occupancy data four times per second. The data is used to generate cyclic flow profiles. The traffic predicted to be crossing the downstream stop-line in each interval is stored in these profiles. SCOOT uses this data to separately consider the traffic signal split, offset, and cycle time requirements for each intersection. The split optimizer calculates a new split for each phase. The splits can change between one and four seconds for every phase change. The offset optimizer calculates offsets once in each cycle. The offset can change between one and four seconds per cycle. Finally, the cycle optimizer recalculates a new cycle length once every five minutes, unless a rising or falling flow trend is identified, in which case the optimizer can run every 2.5 minutes and change the cycle length. The cycle length can change between four, eight, or 16 seconds, depending on the cycle length that is in effect. Other values are possible since the optimizers are user-definable. By considering all of these parameters in concert, the disturbance to traffic flow is minimized.

2.6. EVALUATION OVERVIEW

2.6.1. Evaluation General Approach

The general approach to this evaluation is to assess the adaptive signal control system's performance, impacts, benefits and costs, and to identify deployment issues. This is accomplished by using a variety of information sources, including traffic data, surveys, logs, interviews, and cost data. The primary objective of the evaluation is to assess the transportation system impacts. Therefore, the evaluation focuses on measuring the impact of the SCOOT adaptive control system on the traffic operations in the study area.

The transportation impacts of the SCOOT adaptive signal control system are being compared to the transportation system impacts of the original signal control system. When the system is under control of each signal control strategy, data for the following four Measures of Effectiveness (MOEs) is collected and evaluated across the 56-intersection network:

- Volume per link
- Average travel time
- Average delay
- Number of stops per link

Assessing the transportation system impacts of the SCOOT system involves examining the MOEs under several operating conditions. The evaluation features the ability to switch between SCOOT control and the original system control. This flexibility of control allows the network to be operated alternately between the two systems, ensuring similar traffic and environmental conditions for evaluating of SCOOT's operation.

The evaluation approach includes both manual field data collection and automated data collection from SCOOT itself. Manual field data consists of floating car studies along travel routes and delay studies at selected approaches. SCOOT data consists of reports of estimated traffic parameters that are produced in the process of developing signal timing plans. This data output was used to analyze the transportation impacts of SCOOT.

Manual field data was collected at selected intersections within the network during a variety of time periods and under various traffic conditions, including morning and afternoon peak periods and off-peak periods. Network boundary conditions and special events were also evaluated. The transportation impacts at system boundaries are of particular interest, because the adaptive system is independent of the rest of the City's signal system. This creates numerous boundary approach and departure links, each with the potential to disrupt traffic progression into and out of the SCOOT network. To quantify the boundary impacts, traffic MOEs were collected from both the non-system intersections and the adjacent system intersections.

SCOOT data outputs (MOEs) were captured to provide network-wide data on volume, delays, and stops. Since the SCOOT system collects data and develops timing plans regardless of its implementation status, SCOOT data was available both when SCOOT was in control and when the original T2000C system was in control. This allowed the evaluation to be conducted both with and without SCOOT in operation. The MOEs collected with each control system were subjected to statistical tests. Finally, a reasonableness check compared the MOEs available from SCOOT with the MOEs obtained by manual field data collection.

In addition to transportation system impacts, the evaluation assessed the adaptive system's operability, integratability, maintainability, reliability, and capabilities. The evaluation also included an analysis of the issues related to system deployment. This information was prepared in a format that is useful to others attempting similar system integration.

The costs associated with implementing the adaptive signal control system within the framework of an original signal control system are examined. Emphasis is placed on both the costs related specifically to the deployment of the adaptive system as configured in Minneapolis, and also to the costs inherent with any adaptive system. These inherent costs would be incurred if a similar system were installed in another metropolitan area. Project benefits include reductions in delay and vehicle operating costs to the motoring public, as well as benefits to the transportation management agency in the form of reductions in costs for maintaining signal timing plans.

The capital, installation, operation, and maintenance costs of the adaptive signal control system are compared to the similar costs associated with the original signal system. Depending on the circumstances, approximately five years is an optimum time interval for updating fixed timing plans, and ten years is more common. Preceding the timing update of 1993, the signal timings in the entire downtown Minneapolis region were last updated approximately 15 years earlier. The evaluation examines the degree to which signal timing updates will be required in the adaptive system study area.

2.6.2. Evaluation Goals and Objectives

The evaluation has been divided into four separate goals, each corresponding to one of the evaluation's test plans. The goals consist of a series of specific objectives, measures of effectiveness, and hypotheses. The hypotheses provide a means of evaluating the objectives. The goals and objectives identified for this project are listed below:

Goal 1: Assess the performance characteristics of the adaptive signal system.

Objective 1-1: Assess the performance of the adaptive signal control system.

Objective 1-2: Assess the capabilities of the adaptive signal control system.

Goal 2: Assess the transportation system impacts of the adaptive signal system.

Objective 2-1: Assess traffic operation impacts during normal peak periods.

Objective 2-2: Assess traffic operation impacts during off-peak periods.

Objective 2-3: Assess traffic operation impacts at the system boundaries during normal peak periods.

Objective 2-4: Assess traffic operation impacts during special events.

Goal 3: Document the cost impacts of the adaptive signal control system.

Objective 3-1: Document the adaptive signal control system costs by system components.

Objective 3-2: Document the adaptive signal control system personnel training costs.

Objective 3-3: Document all partner contributions.

Goal 4: Identify deployment issues associated with the adaptive signal system.

Objective 4-1: Identify technical issues associated with deploying the adaptive system.

Objective 4-2: Identify the methods required for effective maintenance, operations, control, and management of the adaptive signal control system.

Objective 4-3: Identify institutional issues associated with implementing the adaptive signal control system.

Objective 4-4: Identify the effectiveness of procuring a system through a system partnership agreement.

Objective 4-5: Assess operators' perception of the value and effectiveness of the adaptive signal system.

Objective 4-6: Identify transferability issues associated with integrating an adaptive signal control system with an existing urban traffic control system.

2.6.3. Evaluation Project Team

An evaluation team consisting of representatives from FHWA, Mn/DOT, Hennepin County, the University of Minnesota, the University of Utah, Booz-Allen and Hamilton, the City of Minneapolis, Fortran, Image Sensing Systems, and Westwood Professional Services was established to help guide the evaluation process. SRF Consulting Group is the project's independent evaluator. The following people are current or former members of the AUSCI Evaluation Team:

Ms. Marilyn Remer, Mn/DOT Project Manager

Mr. Roger Plum, City of Minneapolis

Mr. Steve Mosing, City of Minneapolis

Mr. James McCarthy, FHWA

Mr. Ali Gord, Booz-Allen & Hamilton, Inc.

Mr. Allan Klugman, Westwood Professional Services, Inc.

Mr. Peter Ragsdale, Fortran Traffic Systems Limited

Dr. Durga Panda, Image Sensing Systems, Inc.

Mr. Len Palek, Mn/DOT

Mr. Jim Kranig, Mn/DOT

Dr. Gary Davis, University of Minnesota

Dr. Peter Martin, University of Utah

Mr. Brian Scott, SRF Consulting Group, Inc.

Mr. Erik Minge, SRF Consulting Group, Inc.

Mr. Ben Hao, SRF Consulting Group, Inc.

The City of Minneapolis traffic operations staff played an important role in the evaluation by keeping detailed logs of system performance observations and providing data outputs from the SCOOT and T2000C systems. The City of Minneapolis, Mn/DOT, Fortran, Westwood, Siemens, and Image Sensing Systems also provided information regarding problems encountered in the installation and operation of the system. Siemens and Fortran provided basic information on the capabilities and format of the output from the SCOOT system. Finally, SRF Consulting Group was responsible for collecting the various field data, including floating car studies and individual intersection observations, in addition to data analysis and report writing activities. All project partners provided cost information related to the installation and operation of the adaptive control system, and related institutional issues encountered.

2.6.4. Previous Evaluation Documents

This document was preceded by the *Preliminary Evaluation Plan*, prepared in December 1995, the final *Evaluation Test Plan*, prepared in August 1998, *Test Plan One Report, Assess Performance Characteristics,* prepared in January 2000, *Test Plan Four Report, Identify Deployment Issues*, prepared in March 2000, *Test Plan Three Report*, *Document Cost Impacts*, prepared in May 2000, and *Draft Test Plan Two Report, Assess Transportation System Impacts*, prepared in July 2000.

2.6.5. Structure of Report

The remainder of this report provides final results for each of the following evaluation test plans. Each test plan addresses a specific project goal.

Test Plan One (Goal One) – Assess Performance Characteristics

Test Plan Two (Goal Two) – Assess Transportation System Impacts

Test Plan Three (Goal Three) – Document Cost Impacts

Test Plan Four (Goal Four) – Identify Deployment Issues

3. TEST PLAN ONE – ASSESS PERFORMANCE CHARACTERISTICS

3.1. PURPOSE

The purpose of *Test Plan One* is to assess performance characteristics associated with the adaptive signal control system. The following objectives are evaluated:

Objective 1-1: Assess the performance of the adaptive signal control system.

Objective 1-2: Assess the capabilities of the adaptive signal control system.

3.2. TEST DESCRIPTION

The assessment of performance characteristics associated with the AUSCI project required interviews or surveys of project participants. Whenever possible, surveys were administered in order to reduce the cost of the data collection. Interviews of some project participants were conducted to provide additional information. Group brainstorming sessions were used to uncover issues that were not already identified, and also to give an indication of the priority of issues. A performance characteristics survey was used to obtain most of the information for this Test Plan. A copy of this survey is provided in Appendix A. The results of these interviews and surveys are presented in this section.

Representatives from the following agencies were contacted for the collection of this information.

- Minnesota Department of Transportation
- City of Minneapolis
- Federal Highway Administration
- Fortran Traffic Systems Limited
- Siemens Traffic Control Limited
- Image Sensing Systems, Inc.
- Westwood Professional Services, Inc.

3.3. FINDINGS

Findings are presented for each of the two test objectives.

3.3.1. Objective 1-1: Assess the performance of the adaptive signal control system

The following criteria were used to assess the performance of the adaptive signal control system:

- Integratability
- Operability
- Adaptability
- Reliability
- Maintainability
- Expandability
- Transferability

3.3.1.1. Integratability

Integratability examines the process of integrating the SCOOT system with the original T2000C system. Any reductions in system features or functions due to the integration process are examined. The integration of two main signal control systems is a unique aspect of the AUSCI project. The T2000C controls hundreds of intersections throughout the City of Minneapolis, while the SCOOT system develops timing plans for a 56-intersection subset in downtown Minneapolis. SCOOT was integrated such that it passes its adaptive timing plans on to the T2000C system for implementation.

The standard SCOOT package has an integrated UTC function. The AUSCI project required the UTC to be disabled so that the T2000C could retain its UTC function and have direct control over signal timing implementation. The UTC function was removed from SCOOT with no loss in adaptive functionality. The SCOOT system's only functional change was a minor impact to SCOOT's adaptive kernel regarding staging for closely spaced intersections. The T2000C was able to approximate this function. Note that this staging function was not inherent to SCOOT itself, but was a feature of the combined SCOOT/UTC system. In addition, no T2000C features or functions were lost. In fact, some T2000C functions were enhanced, such as an increased cycle length capability. The range in permissible cycle lengths went from 40-180 seconds to 32-240 seconds in order to match the SCOOT system's range of cycle lengths.

The T2000C and SCOOT systems were integrated such that each system retained its own user interface. This form of integration allowed each system to retain a degree of functional independence. This simplified the integration process, reducing the amount of work performed while meeting all of the project requirements.

Several tasks were involved in the integration of the T2000C and SCOOT systems. An overview of these tasks is provided below. Detailed technical information is provided in *Objective 4-1: Identify technical issues associated with deploying the adaptive system,* and in the AUSCI project's *Concept Definition Report*.

- **Software Integration –** The development of a software interface and a common database was required to facilitate the software integration.
- **Timing Standard –** Differences between the T2000C's 1/30th of a second standard for gathering status information and SCOOT's 1/4th of a second required a conversion to make them compatible.
- **Synchronization –** The SCOOT system continuously develops new timing plans which the T2000C then implements. A challenge was presented in getting the two systems synchronized with one another.
- **Stage/Phase Conversion –** Differences between the British use of stages and the American use of phases required development of a conversion table.
- **Ethernet Connection –** An Ethernet connection between T2000C and SCOOT had to satisfy each system's timing requirements.
- **Intersection Controller Cabinet Modifications –** Each field cabinet in the SCOOT system was modified to accommodate the SCOOT and video detection system components.
- **Video Detection System –** The video detection system provides the SCOOT detection inputs. Integration required an interface to the City's communication infrastructure. The video detection system's data outputs emulated conventional inductive loop detector outputs and were easily integrated with the SCOOT system.

In summary, integration of the SCOOT and T2000C systems was one of the largest project tasks. The two systems were successfully integrated with no loss of functionality. The integration allowed each system to retain its own user interface. The success of this project confirms the SCOOT system's integratability.

3.3.1.2. Operability

This section examines how the SCOOT system interfaces with its operators. Also referred to as "usability," this is a qualitative measurement. Interviews with City traffic engineers and evaluator experience with the SCOOT system were used to identify the system's operability.

The SCOOT system contains a menu-driven user interface that is used to monitor the system. Some training is required to enable the user to understand the system's features and functions. The City's traffic engineer accesses the system on a daily basis to monitor performance and to investigate any problems that may occur. Traffic operations personnel do not currently interface with the SCOOT system. However, a plan exists to train operations personnel on SCOOT functions in the future.

Based on the information collected during the evaluation, the SCOOT system is considered user-friendly and intuitive to use. In addition, the usability of the T2000C system was not changed with the introduction of the SCOOT system.

3.3.1.3. Adaptability

This section examines how the SCOOT system adapts to changing traffic conditions. The information presented here is of a qualitative nature, based primarily on operators' experience in observing the system in operation. *Test Plan Two* contains a quantitative assessment of the transportation system impacts of the SCOOT system.

City of Minneapolis traffic engineers have observed an improvement in the adaptive functionality of the traffic control system when compared to the previous system. While the previous system used primarily a time-of-day table lookup approach, there were some intersections that were traffic-responsive. System operators perceive an improvement in the adaptive performance of the signal system. The system has been observed to adapt quickly to changing traffic conditions. Note that drastic changes in traffic movements within the study area may require a recalibration of the affected portion of the SCOOT system. For example, if construction activities alter the roadway geometrics, the affected links would need to be reexamined. This is considered an ongoing calibration effort and is discussed in more detail in the maintainability section that follows.

3.3.1.4. Reliability

A system is considered reliable when it can be consistently counted on to do what is expected of it. In the AUSCI project, reliability was quantified through observations of the SCOOT system and supporting systems. Any problems that surfaced with these systems and the level of effort to correct them were documented. Scheduled or unscheduled system maintenance activities are discussed in the maintainability section.

The three-month period from June 1 to August 31, 1999 was selected to collect detailed information on the performance of the SCOOT system and supporting systems. During this period, monthly interviews were conducted with City personnel; results from these interviews are summarized in Table 3-1.

TABLE 3-1
SYSTEM RELIABILITY

Month	Failure
June 1-30, 1999	No system failures.
July 1-31, 1999	No SCOOT system failures, but the T2000C VAX VMS disk drive failed. This failure is considered normal for a system that is approximately six years old. During the failure, the T2000C system was down for the length of time required to diagnose the problem and install a backup drive, roughly six hours.
August 1-31, 1999	No system failures.

Given the excellent reliability of the system during the measurement period, there is not enough data to calculate a mean time between failures. City traffic personnel have stated that both the SCOOT and T2000C systems are very reliable. No change in the T2000C system reliability was observed when the SCOOT system was introduced. (The T2000C system still controls the intersections outside of the SCOOT system boundary.)

3.3.1.5. Maintainability

The maintainability portion of the AUSCI evaluation examines the average amount of time and effort to perform both scheduled and unscheduled maintenance. System maintainability data collected includes the type of maintenance activity, mean time to make repairs, and the level of effort required to perform the maintenance. It includes both regular system maintenance and ongoing validation work required to keep the system correctly calibrated. Finally, the SCOOT system maintenance is compared to the previous system.

As with the reliability analysis, a three-month period from June 1 to August 31, 1999 was selected to examine the maintenance activities of the SCOOT system in detail. During this period, monthly interviews were conducted with City personnel; results from these interviews are presented in Table 3-2.

TABLE 3-2
SYSTEM MAINTAINABILITY

Month	Maintenance Activity
June 1-30, 1999	**SCOOT Revalidation –** Each year, several construction projects take place in the downtown area. When these projects involve changes to roadway geometrics, the SCOOT system needs to be revalidated. In June, three construction projects required modifications to the SCOOT system. For example, construction activity on a new Greyhound Bus Terminal within the study area resulted in geometric changes to one of the SCOOT links. The video detection system detector layout was revised to reflect the changes to the roadway. Two SCOOT links were also revalidated: the link that received the geometric change and the next link upstream. The upstream link required revision because the geometric change resulted in fewer lanes for the link to discharge to, thereby altering the link's operational characteristics. This revalidation took approximately two hours per link. The total effort to revalidate the SCOOT system to reflect this change was approximately six hours. The other two construction projects involved a similar amount of revalidation. The total for June was approximately 18 hours. **Video Sensor Recalibration –** Several sensors were recalibrated to accommodate the construction activities described above. The time required for this is included in the 18-hour total. **Video Detection System Inspection –** The video detection system is manually reviewed for basic functioning on a daily basis. This includes a process called "learning" in which each of the sensors is contacted in order to verify proper operation. Approximately ten minutes per day, or four hours per month, are involved in this task. Throughout the months of June and July, there were problems establishing communications. Although the sensors were providing valid detection outputs, not all sensors could be contacted by the browser. The cause was traced to a weak communication link between several of the sensors and the supervisor computer. Repeaters were placed in several cabinets to boost the communication signal, which corrected the problem. This communication issue is considered a carryover from the installation process and not a maintenance issue. Another video detection system maintenance activity involves review of each video sensor image to verify proper aiming and performance. This is a relatively time-consuming task; the City plans to do it annually when interns are available.

Month	Maintenance Activity
	Video Sensor Cleaning – The sensors are typically mounted at a height of 25 feet and are exposed to hard winter-roadway elements, including salt spray generated by traffic in the winter. In June, two sensors were not functioning properly and had to be cleaned. A bucket truck and two technicians are required to clean the sensors' outer lens covers. Travel time to the site, set-up/removal of traffic control, and lens cover cleaning takes approximately 30 minutes. Currently, the sensors are cleaned as needed; the City plans to develop an annual cleaning schedule. The tentative schedule would involve cleaning roughly half the sensors once per year and cleaning the other half twice per year. **Video Sensor Knockdown –** In June, an errant vehicle struck a luminaire, knocking it and the sensor to the ground. A new sensor had to be installed and calibrated. A sensor knockdown of this nature is anticipated to happen approximately once per year.
July 1-31, 1999	**SCOOT Revalidation –** None (all SCOOT revalidation for the 1999 construction season occurred in June). **Video Detection System Inspection –** As described above, the video detection system was inspected for basic functioning on a daily basis. This process did not reveal any faulty sensors. **Video Sensor Recalibration –** One sensor was recalibrated to accommodate geometric changes resulting from construction. This process took approximately two hours. **Video Sensor Cleaning –** No sensors were cleaned in July.
August 1-31, 1999	**SCOOT Revalidation –** None (all SCOOT revalidation for the 1999 construction season occurred in June). **Video Detection System Inspection –** The video detection system was inspected for basic functioning on a daily basis. This process did not reveal any faulty sensors. **Video Sensor Recalibraiton –** No sensors were recalibrated in August. **Video Sensor Cleaning –** No sensors were cleaned in August.

It is important to note that the T2000C system also requires ongoing system maintenance whenever construction results in geometric or traffic impacts. The calibration required for the T2000C system typically involves more links and takes more time to accomplish than is required to revalidate the same change to the SCOOT system. For example, the recalibration performed to accommodate the new Greyhound Terminal (see description for June) required more time to perform on the original T2000C system. The T2000C change required approximately 12 hours to determine revised splits and offsets, implement the changes, and observe the traffic to verify the operations. This modification took six hours with the SCOOT system.

In summary, the adaptive system is very maintainable. Minimal day-to-day interaction is required from system operators and much of the maintenance that is required can be absorbed into normal maintenance activities performed by the traffic department's field personnel.

3.3.1.6. Expandability

This section contains a brief discussion of the perceived boundaries and opportunities to expand the SCOOT system to include additional intersections and/or functions. A more thorough analysis of the technical issues related to system expansion is included in *Objective 4-1: Identify technical issues associated with deploying the adaptive system.*

The SCOOT system consists of a grid-network of 56 intersections, comprising only a portion of the Minneapolis CBD. Future expansion to incorporate additional intersections may be desired, especially if a high degree of friction is observed at the boundary between the SCOOT system and surrounding T2000C system. Further expansion could include additional regions that generate event traffic. The Metrodome and the area around the University of Minnesota are two possible candidates.

Additional opportunities exist for adding features and functions to the AUSCI system. SCOOT consists of several optional add-on modules that can be implemented depending on future needs and funding availability. Additionally, some SCOOT features are currently not being used. The City may want to utilize INGRID, a SCOOT module that can provide incident detection based on data collected with the ASTRID database. Also, an enhanced graphical user interface can be installed to provide easier control of the surveillance cameras. The video detection system and surveillance system can also be expanded into additional locations.

The following technical issues should be considered before undertaking an expansion of the SCOOT system. These issues are explored in detail in *Test Plan Four: Identify deployment issues associated with the adaptive signal control system,* and include the following.

- SCOOT expansion limitations
- T2000C expansion limitations

- City of Minneapolis control center expansion limitations and required infrastructure improvements
- City of Minneapolis communication system expansion limitations
- Availability of conduit space
- Video detection system expansion limitations
- Limited number of field camera mounting options

With the SCOOT system successfully integrated with the T2000C system, the project's primary technical challenge is accomplished. Adding regions to adaptive control is relatively straightforward, making the system very expandable. The primary obstacle to future expansion is funding.

3.3.1.7. Transferability

Transferability issues are defined as those elements of the project that would apply anywhere a SCOOT adaptive signal control system is integrated with an existing signal control system. The objective is to identify what lessons learned in this project can be transferred to others attempting a similar project. The project's transferability is presented in the following topic areas: base conditions, system integration, project limits, policy and procedures, and system features and functions.

- **Base Conditions**

An important consideration in assessing the AUSCI project's transferability is the conditions that existed when the AUSCI project began. These base conditions provide a frame of reference for others attempting a similar project. In many ways, the Minneapolis CBD is similar to other urban areas. Before AUSCI, the City had an extensive communication network of City-owned and -operated twisted pair communication lines that served the intersection signal controllers in the CBD. This existing communication system was able to support all of the basic SCOOT system communication services. The existing inductive loop detectors were located at only a few locations and did not provide any of the SCOOT system's detection needs. An extensive detection installation was required to deploy SCOOT. Refer to the project's *Concept Definition Report* for additional information.

- **Adaptive/Original System Integration**

This integration was accomplished by adding the SCOOT system to the current T2000C system, allowing the SCOOT system to operate with the in-place T2000C system. The systems are configured to enable selection of either the T2000C system or the SCOOT system to control the signal system. The SCOOT system operates on its own computer, where it continuously develops new timing plans. These new timing plan values are sent to the T2000C system which, in turn, converts the SCOOT timing into control commands and sends them to the traffic signal controllers. This approach required that the SCOOT modeling software be disconnected from its typical UTC system and that linkage and interfacing software be developed to support a connection to the T2000C. An integration of the two major signal control systems is a unique aspect of the AUSCI project.

- **Project Limits**

In many respects, the Minneapolis CBD is similar to other urban centers. The AUSCI test area is a 56-intersection integrated network of local streets, freeway ramps, HOV facilities, and parking garages located in the western portion of the CBD. The test area is bounded by 1st Street North to the north, 5th Avenue North to the west, Lyndale Avenue South to the south and 2nd Avenue South to the east (see Figure 2-1). It includes the termini of Interstate 394 and Highway 55 from the western suburbs and connections with Interstate 94 and Highway 52/152 to the northwestern suburbs. These corridors serve large numbers of rush-hour business and commercial center commuters, as well as attendees at major events in the CBD, including those at the Metrodome, Target Center Arena, and the Convention Center.

- **Policy and Procedures**

Several in-place policies and procedures facilitated a smooth project deployment. The City of Minneapolis made a strong commitment to the AUSCI project. This commitment was essential to ensure that the necessary staff and training were available, so that the system was correctly deployed and operated. The City must maintain support in order to keep the system correctly calibrated and up-to-date. A history of strong support for advanced traffic management strategies is important in other deployments.

- **System Features and Functions**

Many features and functions of the SCOOT adaptive control system proved valuable in the AUSCI project and would be useful in other adaptive system implementations. For example, the ASTRID software module can report a variety of traffic parameters for inspection. The City of Minneapolis staff examines daily summaries of traffic parameters, such as cycle lengths, to monitor the system's performance.

- **Conclusions**

The lessons learned in the AUSCI project are largely transferable to others attempting a similar project. One of the most important lessons is that it is necessary for the project team to have a thorough knowledge of both the existing and proposed systems. This allows the project team to be realistic about the amount of effort involved in integrating an adaptive system and the potential benefits that can be derived. Although Minneapolis operates the only T2000C system in the United States, many of the key findings from this evaluation are transferable to other cities.

3.3.2. Objective 1-2: Assess the capabilities of the adaptive signal control system

The adaptive system's features and functions were reviewed in identifying the system's capabilities. The system was also examined to see that it performed all of the functions stated in the original project scope. Prominent features of the SCOOT Version 3.2 and supporting systems in the AUSCI project are provided below. The system was found to provide all of these capabilities.

- The SCOOT system continuously develops new traffic signal timing plans in response to changing traffic conditions.
- The SCOOT system uses a gating feature to restrict traffic flow into or to increase the outflow from sensitive areas, allowing queues to form in more acceptable locations.
- The SCOOT system uses a congestion management feature to implement a pre-determined offset value during periods of heavy congestion.
- The operator has the ability to change control between the SCOOT system and the original system.
- The SCOOT system can monitor its own performance, providing several measures of effectiveness.
- The SCOOT system can report a variety of system faults.
- The original T2000C system was modified to allow for the additional tasks necessary to provide adaptive control.
- The video detection system met all of its contractual requirements and provided other functions such as the ability to observe real-time video images.

The following system features are available, but were not deployed in the AUSCI project:

- The SCOOT system can provide priority for emergency or transit vehicles.
- The SCOOT system can provide control of variable message signs for driver information.
- The SCOOT system can utilize bicycle logic to accommodate regions that experience high levels of bicycle traffic.

By satisfying all of these requirements, the adaptive signal control system is considered very capable. The system provides a number of other more detailed capabilities as well. Refer to the *Concept Definition Report* for further information.

3.4. CONCLUSIONS

The AUSCI project represents a model deployment of an adaptive signal control system within an existing centrally-controlled system. The lessons learned in this project are transferable to other medium-sized metropolitan areas. The deployment issues, costs, and transportation system impacts are also useful to the City of Minneapolis in determining the future expansion of the adaptive system.

This document presents the performance characteristics of the adaptive signal control system. These characteristics were identified through a combination of surveys, interviews, and observations of project participants. This evaluation has revealed a number of key findings. They are presented below:

- The SCOOT and T2000C systems were successfully integrated.
- The video detection system successfully provides the required detection data for the SCOOT system.
- The SCOOT system has been observed to adapt well to changing traffic conditions.
- The SCOOT system and supporting systems were found to be very reliable.
- With proper training, the SCOOT system is user-friendly.
- The SCOOT system and supporting systems require a minimal amount of maintenance.
- There are no significant obstacles to expanding the SCOOT system.
- Many of the lessons learned from this project are transferable to other metropolitan areas.
- The AUSCI project met or exceeded the original project requirements.

In summary, the performance of the adaptive signal control system has been exemplary. The measures presented here demonstrate the system's integratability, operability, adaptability, reliability, maintainability, expandability, transferability, and capabilities. These findings can provide a valuable tool to decision-makers in the transportation field. By reviewing these key findings and the lessons learned in AUSCI, this evaluation can guide adaptive system deployments in other metropolitan areas. The results are also useful to the City of Minneapolis as they consider future expansions to the system.

4. TEST PLAN TWO – ASSESS TRANSPORTATION SYSTEM IMPACTS

4.1. PURPOSE

The purpose of Test Plan Two is to assess the transportation system impacts of the adaptive signal control system. The following objectives are evaluated:

Objective 2-1: Assess traffic operation impacts during normal peak periods.

Objective 2-2: Assess traffic operation impacts during off-peak periods.

Objective 2-3: Assess traffic operation impacts at the system boundaries during normal peak periods.

Objective 2-4: Assess traffic operation impacts during special events.

4.2. TEST DESCRIPTION

4.2.1. Overview

The AUSCI project's evaluation approach was developed through a series of evaluation team meetings in 1998. During the early stages of this process, consideration was given to two primary strategies for evaluating the SCOOT system's transportation impacts: modeling traffic operations and measuring directly through field data collection. The field data collection approach was ultimately selected and detailed in the *Evaluation Test Plan*, prepared in August 1998. The *Evaluation Test Plan* placed an emphasis on manual field data collection over automated performance measures obtained from SCOOT itself.

A unique aspect of the AUSCI project evaluation is the ability to alternately operate the SCOOT and original T2000C systems. This is possible because the SCOOT system is essentially an add-on to the T2000C system. The evaluation benefited from this feature, which allowed direct comparison of transportation system impacts in similar traffic and environmental conditions.

The City was responsible for documenting the SCOOT implementation status and changing the implementation as necessary during the evaluation activities. In order to eliminate any potential bias in the field data collection process, the evaluator had no prior knowledge of the implementation status.

The evaluation approach included both manual field data collection and automated data collection from the SCOOT and T2000C systems. Field data collection featured floating car studies along travel routes, supplemented with observations of approaches to measure delay. The SCOOT system provides reports of estimated traffic parameters that are produced in the process of developing signal timing plans. This data was captured and analyzed for use as a possible secondary measure of SCOOT's transportation system impacts. Finally, the T2000C system provides volume data for every link within the study area. Table 4-1 summarizes the data collected for the evaluation.

TABLE 4-1
MOE DATA SOURCES

MOE	SCOOT Data	T2000C Data	Manual Observation
Network Volume (vehicles)	Yes (estimated)	Yes	No
Travel Time (seconds)	No	No	Yes (sampling)
Delay (sec/link)	Yes (modeled)	No	Yes (sampling)
Stops (veh/link)	Yes (modeled)	No	Yes (sampling)

The evaluation assessed the transportation system impacts in a variety of different time periods and test conditions. Field and automated data was collected during the following test periods:

- **Pilot Study –** Featured a small sample of data from each travel time route and delay study approach. The data collection experiences from the pilot study were used to make minor modifications to the travel time and delay studies. The data was collected in July 1999, one day "with SCOOT" and one day "without SCOOT."
- **Primary Study –** The majority of the evaluation data was collected during the primary study over a two-week period in August 1999. Ten routes and 14 delay study approaches were observed in the four-hour a.m. period (6:30 to 10:30) and four-hour p.m. period (2:00 to 6:00). "With SCOOT" data was collected from August 10 to 14 and "without SCOOT" data from August 17 to 21, 1999. Automated data was also collected "with SCOOT" from August 24 to 28.
- **Special Event Study –** Included travel time runs after successive events at the Target Center. Four travel time routes were used to collect the data. "With SCOOT" data was collected August 3 and "without SCOOT" data on August 4, 1999.
- **Supplemental Study –** Based on feedback received from the special event and primary study results, supplemental data was collected in December 1999. This data featured link-by-link travel times and volume-weighted intersection delay studies. SCOOT was alternately turned on and off in the middle of each weekday from December 6 to December 17, 1999.

4.2.2. Field Data Collection

Manual field data was collected at several locations within the SCOOT study area. Data was collected during a variety of time periods and under various traffic conditions, including a.m. and p.m. peak periods, off-peak periods, network boundary conditions, and special events. The primary measure of SCOOT system impacts, floating car studies, measured travel times along specific routes. As a secondary measure, delay studies were conducted at specific approaches.

4.2.2.1. Travel Time Data

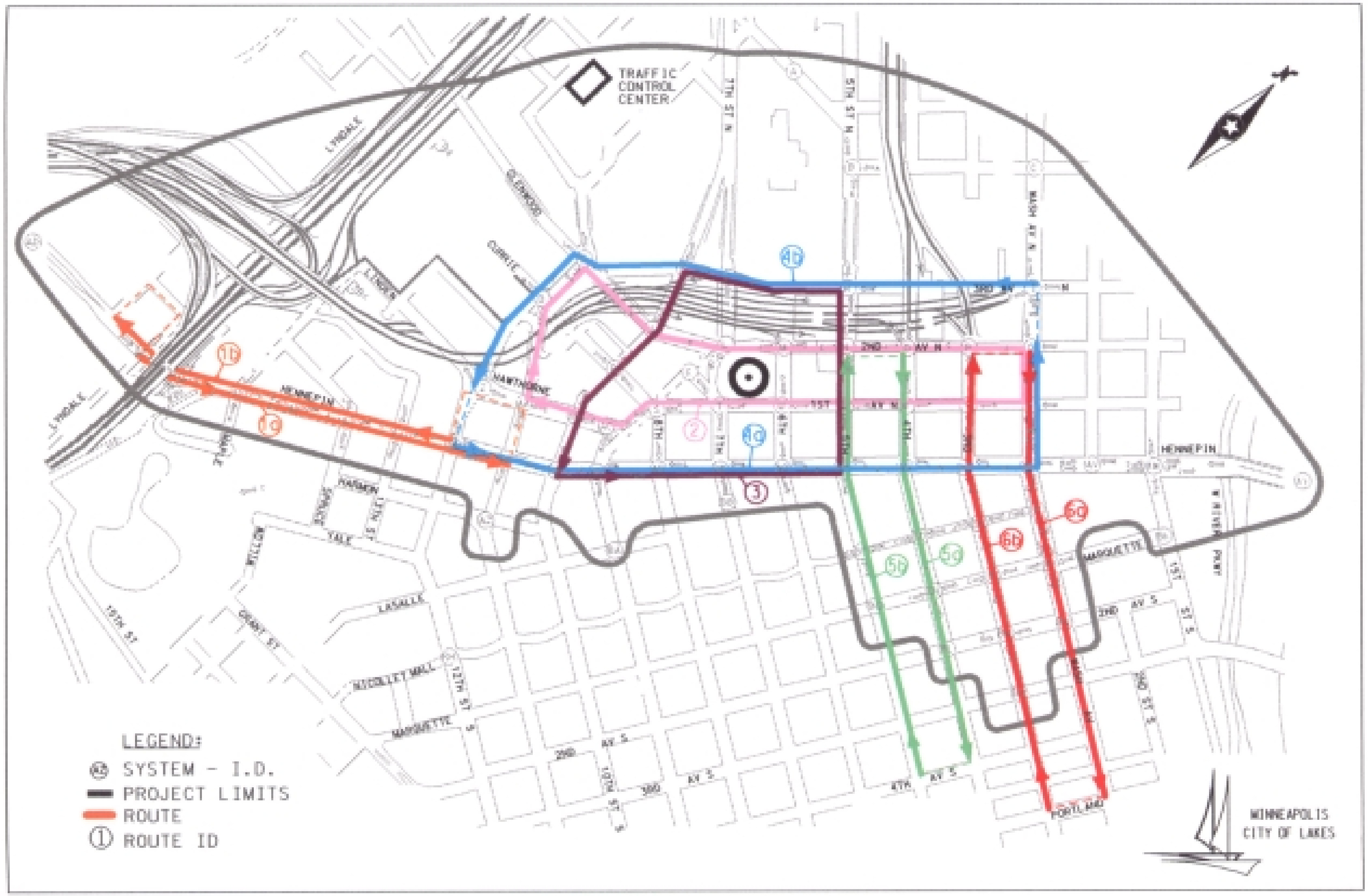
Travel time studies were conducted along a variety of routes within and crossing the SCOOT study area. The routes were developed in consultation with the evaluation team in Spring 1999. Routes were developed for both the primary study and for the special event study (refer to Figures 4-1 and 4-2, respectively). Notice that four of the six travel time runs were split into A and B segments, resulting in a total of ten routes.

The floating car studies were conducted with probe vehicles driven along specific routes. The probe vehicle was driven such that the vehicle traveled with the average flow of traffic, passing other vehicles as often as it was passed. Drivers recorded the travel time information on a data collection sheet developed for the evaluation. The sheet requested time of day each run was started, the elapsed time for each route, and any relevant comments regarding the weather or traffic conditions encountered. Other than rain during a portion of the pilot study, no weather factors were encountered during any of the data collection periods. The travel time data collection sheet is provided in Appendix D. The drivers started their stopwatches when entering the intersection at the beginning of each route, and stopped them at the end point, or midway point, depending on the route. Note that only aggregated travel time data was collected, not block-by-block travel times.

Each of the ten routes was driven once during the pilot study and minor adjustments were made as necessary. A total of 480 hours of travel time data was then collected by six drivers during the primary data collection effort, in August 1999. “With SCOOT” data was collected from August 10 to 14 and “without SCOOT” data from August 17 to 21. The travel times for each route were collected during the following periods:

- Morning period (6:30 to 10:30 a.m.)
- Afternoon period (2:00 to 6:00 p.m.)

Four travel time routes and a total of 12 hours of travel time data were collected after special events at the Target Center. “With SCOOT” data was collected after a *Tom Petty* concert with 14,000 in attendance on August 3. “Without SCOOT” data was collected after a *Cher* concert with 13,600 in attendance on August 4. The maximum seating capacity of the Target Center is 20,000. Data was collected from 10:00 to 11:30 p.m. as the concerts ended.



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LASALLE
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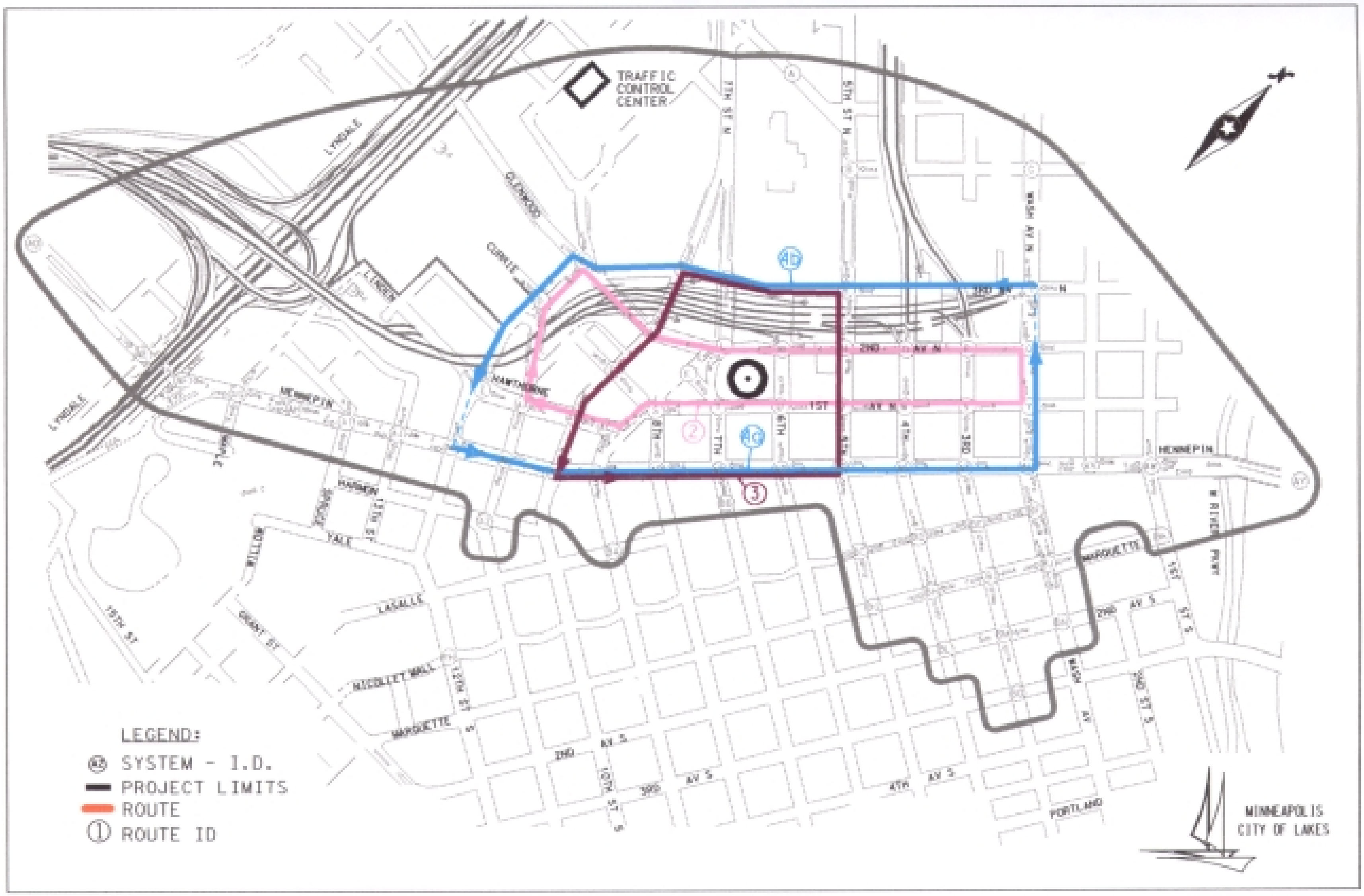
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10TH ST S
5TH ST N
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4.2.2.2. Concerns Regarding Travel Time Data Collection

After reviewing the travel time results, some members of the evaluation team were surprised that aggregated travel time data had been collected for each route, not block-by-block or link-by-link data, as they had expected. The consensus of the evaluation team is that aggregated travel time data does not allow the data to be analyzed in the desired level of detail. The following items highlight the concern with link-by-link versus aggregated data:

1. Link-by-link data allows routes to be broken down and examined to see how individual links perform. For example, the travel time along links that are heavily traveled is of interest. Also, if delays occur on only a few links within the route, detailed link data would uncover this.

2. Link-by-link data allows travel times across the SCOOT/T2000C system boundaries to be examined in detail; aggregated data does not allow one to determine how much delay is due to the boundary as opposed to the different timing plans in effect along the route.

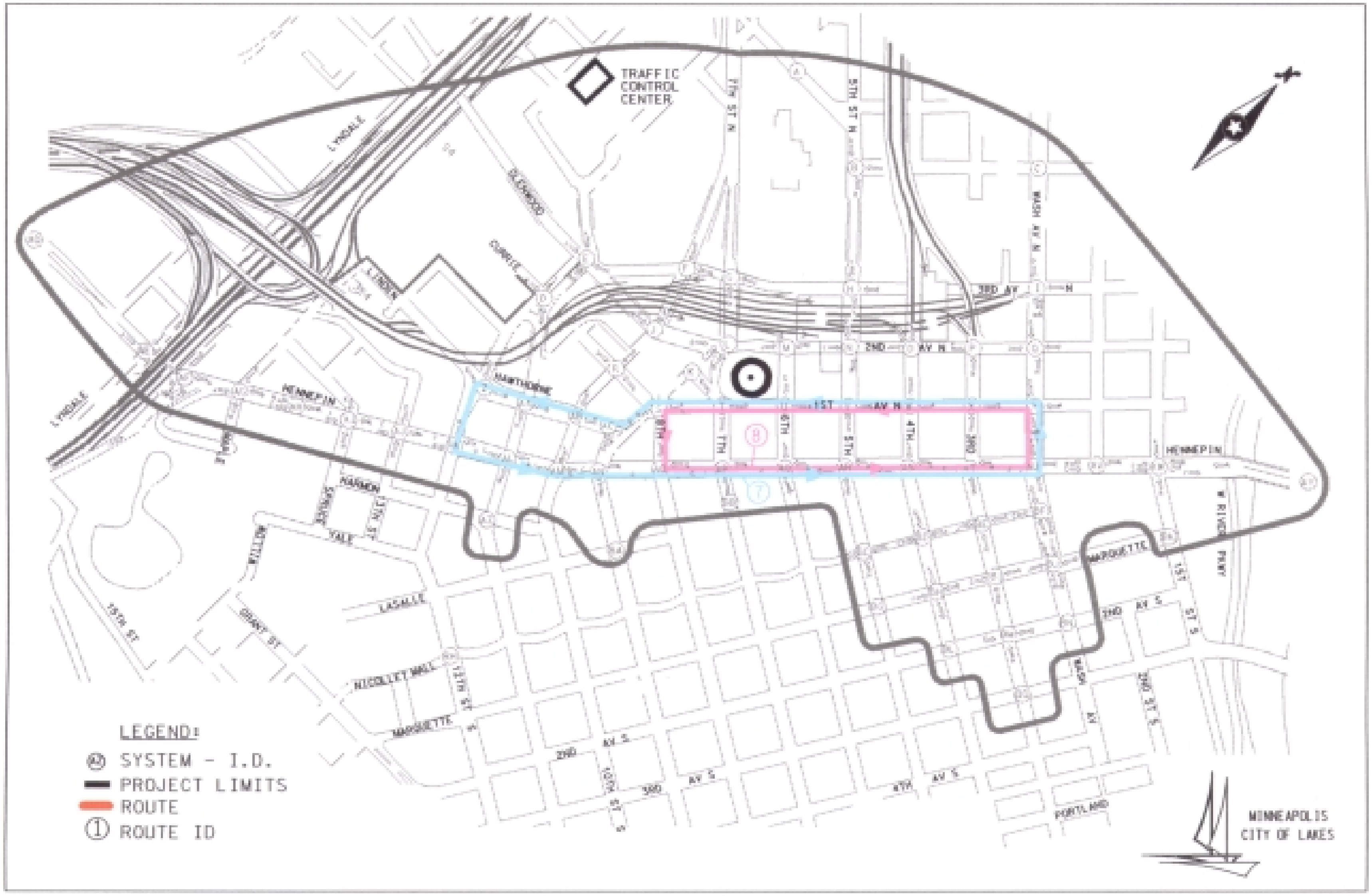
3. Link-by-link data makes it possible to identify “problem links.” This would have allowed the City to direct their efforts at ways to improve the SCOOT operation.

4. Link-by-link data makes it possible to verify that the data was collected correctly. Especially for pretimed timing plans, stops are expected at certain links, and link-by-link travel times would have verified these locations.

5. Finally, link-by-link data makes it possible to volume-weight the link travel times so travel time data is more reflective of the overall SCOOT system performance.

In response to these concerns, link-by-link travel time data was collected during a supplementary data collection effort in December 1999. A new route was identified in consultation with the evaluation team. This route is slightly different in the a.m. and p.m. periods. The a.m. period route (Route 7) follows Hennepin Avenue north to Washington Avenue, west to 1st Avenue, south to 12th Street and east back to Hennepin. The p.m. period (Route 8) only extends to 8th Street in order to avoid traffic queues from the 12th Street on-ramp to I-394 (refer to Figure 4-3).

In order to manage data collection costs, a two-hour a.m. period and a two-hour p.m. period were selected for data collection. The a.m. period is 7:30 to 9:30 a.m., which includes the peak hour and the hour following. The p.m. period is 3:45 to 5:45 p.m., the peak hour and the hour preceding. Data was collected beginning with the p.m. period on December 13 and ending with the a.m. period on December 17. A total of 16 hours of travel time data was collected. The weather was clear during all data collection periods. Refer to Table 4-2 for the SCOOT implementation status for each data collection period.



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MINNEAPOLIS
CITY OF LAKES

TABLE 4-2
SUPPLEMENTARY STUDY – SCOOT STATUS

Time Period	Dec 13	Dec 14	Dec 15	Dec 16	Dec 17
A.M. Period	Off	On	Off	On	Off
P.M. Period	On	Off	On	Off	On

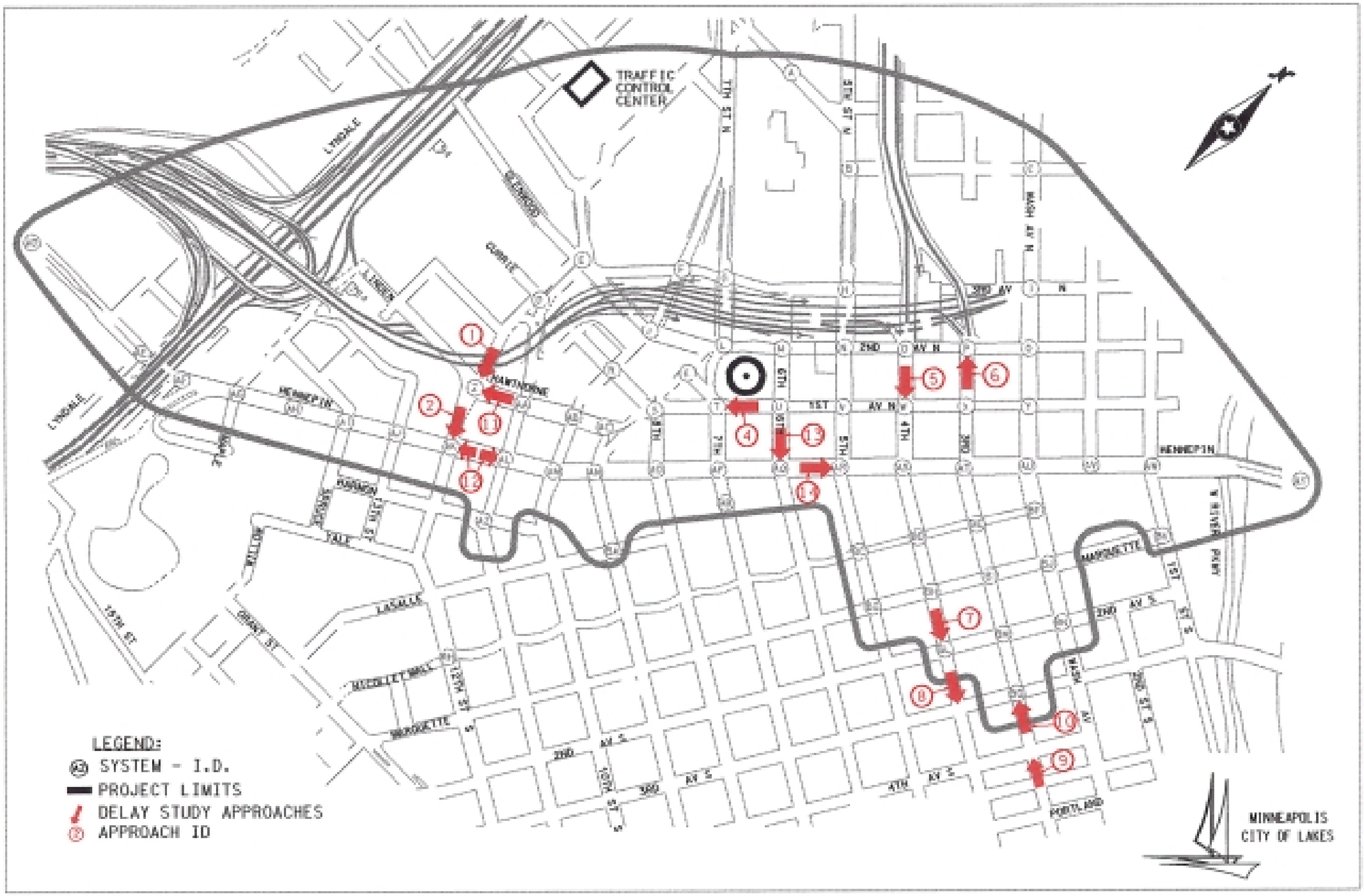
SRF personnel conducted the travel time runs using a stopwatch to obtain the travel time for each link along the route. When the driver crossed the stop bar at each intersection, the cumulative travel time was recorded by a handheld cassette recorder. This information was later entered into a spreadsheet for analysis.

4.2.2.3. Delay Data

Approach delay was collected through manual observations of traffic at selected links. The approaches were selected in consultation with the evaluation team and were both within and outside of the SCOOT study area (refer to Figure 4-4). Some approaches were observed by personnel in the field, while other approaches were later observed with videotapes obtained from surveillance cameras in the study area. The observers recorded the number of vehicles stopped at the approach at the beginning of each 20-second sampling interval. With this method, the same vehicle is counted more than once if it is stopped at the approach for more than one interval. This data was entered on data collection sheets developed for the evaluation. Space was also available for any relevant comments regarding the weather or traffic conditions encountered. This data collection sheet is contained in Appendix D.

Each of the approaches was observed once during the pilot study in order to assess the feasibility of conducting more extensive studies. Concerns regarding excessive traffic levels or difficulty in viewing the entire approach were discussed and minor revisions to the approaches were made as necessary. During the primary study, a total of nine approaches was observed in the field and five by videotape. Two relievers rotated through the study area to provide breaks to the data collection personnel. Delay data was collected for the same time periods as the travel time data; “with SCOOT” data was collected from August 10 to 14 and “without SCOOT” data from August 17 to 21, 1999. As mentioned earlier, the weather was clear during all data collection periods.

The *Evaluation Test Plan* specified the collection of delay study data after the special events at the Target Center. However, when the exact events and times of data collection were identified (10:00 p.m. to 11:30 p.m. after two concerts), the evaluation team decided that the data collection personnel would be exposed to an unacceptable level of risk to personal safety if data was collected during that time. Therefore, only travel times were used to assess the SCOOT impacts during special events.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PROJECT LIMITS
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APPROACH ID
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4.2.2.4. Concerns Regarding Delay Data Collection

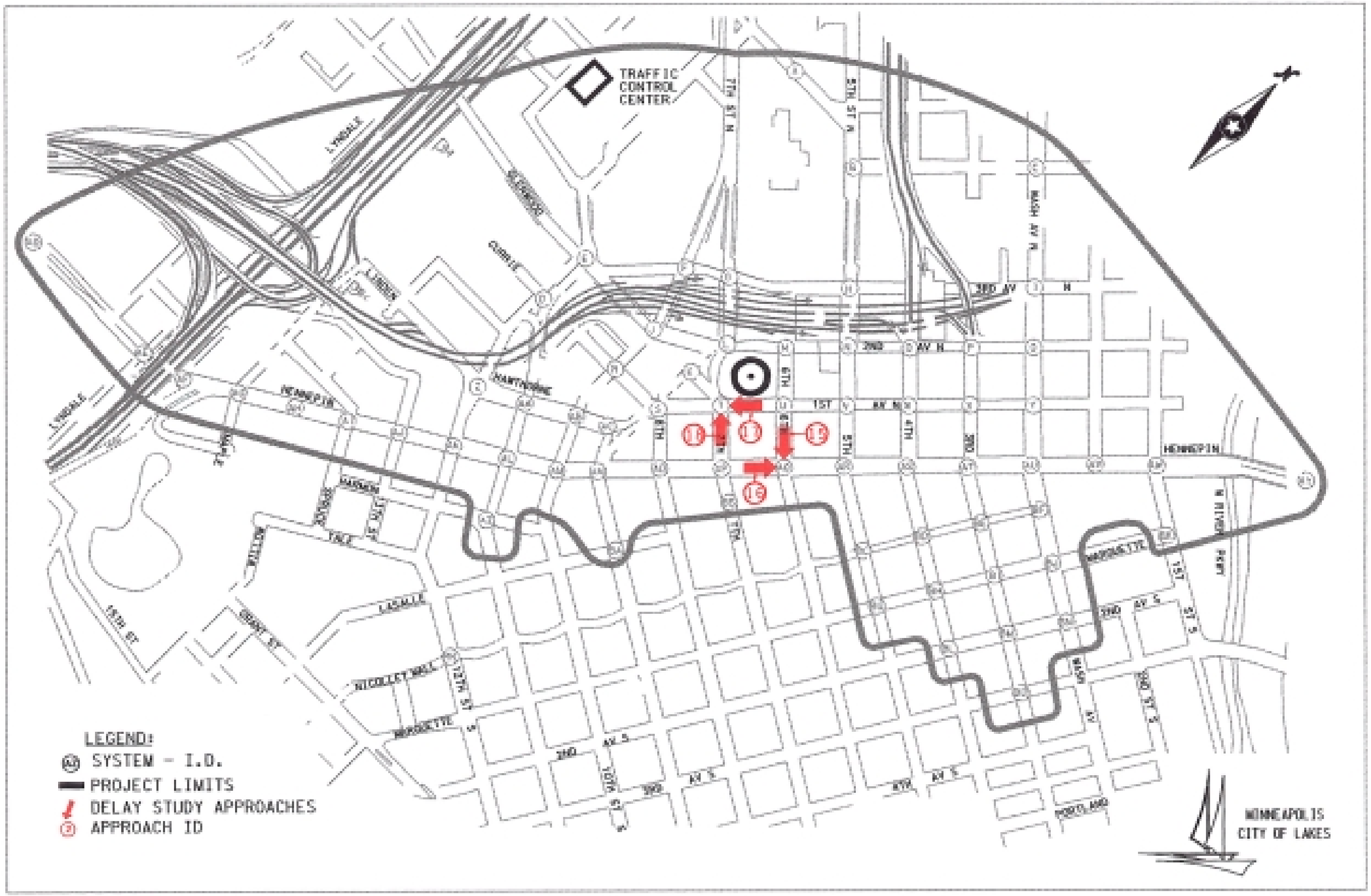
After reviewing results from the primary study, the evaluation team realized that the delay studies had not been conducted as expected. Specifically, the 14 approaches selected for analysis were distributed throughout the study area, making it impossible to analyze the performance at a full intersection. The concern is that only a full intersection is a relevant measure of performance in a complex network found in the study area.

Another concern was raised regarding the calculation of delay. The field observations consisted of recording the number of vehicles stopped at the approach at the beginning of each 20-second period. The total stop-delay was then calculated by multiplying the number of stops by 20 seconds. The intention was to then divide this number by the volume in order to arrive at the average stop-delay per vehicle. Unfortunately, a T2000C hard drive crash during the second week of the primary study resulted in the loss of most of the volume data. The concern is that the total number of stops or the total stop-delay is not as good a measure of performance as the average stop-delay per vehicle. Average stop-delay per vehicle provides a measure of performance that is not affected by day-to-day variations in traffic volumes.

In response to these concerns, additional delay data was collected during the supplementary data collection effort in December 1999. Delay studies were conducted at two key intersections within the study area. The key intersection in the a.m. period was Hennepin Avenue and 6th Street; the key intersection in the p.m. period was 1st Avenue and 7th Street. Figure 4-5 shows the approaches for supplemental delay study. Each intersection is comprised of two one-way streets – a delay study was conducted on each approach. The delay studies were performed from videotaped images obtained from the City’s surveillance cameras. Since only two cameras were located in the immediate area, only one intersection could be videotaped at a time.

Videotapes were made for the same four-hour a.m. and four-hour p.m. periods selected for the data collection conducted in August 1999. These periods are 6:30 to 10:30 a.m. and 2:00 to 6:00 p.m. Videotapes were made from December 6 through 17, coinciding with the travel time data collection periods. During this time, no unusual weather conditions were observed.

Of this videotaped data, a two-hour period from 3:45 to 5:45 p.m. was selected for delay studies on two days, December 13 and December 14. The p.m. period includes the two approaches to the intersection of 1st Avenue and 7th Street. Since two approaches were observed, a *total* of eight hours of videotape was analyzed. These time periods were selected to coincide with the travel time studies being collected at the same time.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Delay studies were conducted with the Jamar Technology TDC-8 Traffic Data Collector™. The TDC-8 uses the same method of conducting intersection delay studies as outlined in the *Manual for Traffic Engineering Studies* published by the Institute of Transportation Engineers. This method involves two separate but related procedures for observing traffic at the intersection. The first procedure classifies every vehicle on a particular approach as either stopping at the intersection, or going through the intersection without stopping. Each vehicle is counted only once. The second procedure is to enter the number of cars that are stopped on the approach at each sampling interval. With this procedure, a car may be counted more than once if it is stopped at the approach for more than one sampling interval. For this study, a 16-second sampling rate was used. Taken together, these two procedures generated several measures of stops and delays at the approach.

4.2.3. SCOOT Data Collection

In addition to field data collection, the transportation system impacts were examined with MOEs available from the SCOOT and T2000C systems. SCOOT outputs were captured to provide network-wide data on volume, delay, and stops. The T2000C system provided link volumes for each of the video detectors.

“Without” studies were conducted by disabling the SCOOT optimizers and implementing the T2000C control regime. However, the SCOOT model continued to function, providing performance data even though the optimizers were disabled. “With” status was conducted under full SCOOT optimization, again supplying the same MOEs.

The SCOOT data was downloaded directly from the SCOOT computer via a dial-in modem connection. The SCOOT data was provided in five-minute intervals, 24 hours per day for the duration of the study period. The study periods coincided with the primary, special event, and supplemental field data collection activities. Table 4-3 lists the SCOOT messages that were requested for the evaluation.

TABLE 4-3
SCOOT MESSAGES

SCOOT Message (by link, node, and region)
1. Flow
2. Delay
3. Stops
4. Implementation Status (SCOOT on or off)
5. Detector Faults

4.2.4. Operator Perception

SCOOT system operators were interviewed in order to assess their perception of the SCOOT system's transportation system impacts. The interviews covered impacts during peak periods, off-peak periods, special events, boundary conditions, and incidents. Results from these interviews are presented in the findings section of this document.

4.2.5. Data Analysis

4.2.5.1. Travel Time Data Analysis

The first step in analyzing the travel time data was to copy all of the travel time data and driver comments from the field data collection sheets into a spreadsheet for manipulation. Separate columns were created for "with SCOOT" and "without SCOOT" data sets. The data was then further aggregated into an average travel time for each route and for each time period.

Next, the travel time data was inspected in order to identify any outlying data points. Outlying data points were compared to the original data collection sheets and corrected as necessary. Where the outlying data points could not be accounted for in this fashion, the driver comment log was examined to see if something in the field was creating an unusual condition. Ultimately, very few outlying data points were identified. Considering the amount of data collected, very few driver comments were logged. A summary of all relevant driver comments is provided in Table 4-4. Notice that the number of comments logged were the same during the week SCOOT was implemented and the week SCOOT was not implemented. Given the low number of comments and their even distribution across studies, the data sets were not revised based on these comments.

The next step in the travel time data analysis was to calculate the percent difference between the "with" and "without" SCOOT-in-control data sets. The percent difference was calculated as follows. Notice that, with this convention, a negative percent change indicates a decrease in travel time and, therefore, an improvement with SCOOT.

$$\text{Percent change with SCOOT} = \frac{(\text{Travel time with SCOOT} - \text{Travel time without SCOOT})}{\text{Average link travel time without SCOOT}}$$

Next, statistical tests were applied to the data in order to determine if the difference in the means was statistically significant. The statistical test used depended on the sample size and the nature of the sample data. After verifying that the data collected was normally distributed, either a t-test or a z-test was available for analysis, depending on the sample size. A t-test is generally used when the sample size is 30 or less. For larger sample sizes, a z-test is used. Having an adequate sample size is critical to conducting this evaluation. All sample sizes were over 30, so a z-test was used.

TABLE 4-4
TYPICAL TRAVEL TIME DRIVERS' COMMENTS

With SCOOT			Without SCOOT		
Date	Route	Comment	Date	Route	Comment
8/10 p.m.	2	Lane closed on 1st at 11th.	8/17 p.m.	2	Heavy traffic
	3	Heavy traffic on 5th from 4:30 to 5:00.	8/18 a.m.	3	Traffic signals out at 7th & Hennepin. Stop sign in place until 9:30.
	5	Truck or police car blocking lane.		4	Traffic signals out at 7th & Hennepin. Stop sign in place until 9:30; rain.
8/11 a.m.	6	People crossing street against light at 10:00.	8/18 p.m.	1	Construction left lane at 17th closed from 2:00 to 2:40.
8/11 p.m.	3	Heavy traffic from 5:00 to 5:30.		2	Heavy traffic after 5:00.
	5	Police car blocking right lane.		5	Left lane closed all day - 2nd Ave & 4th St crossing some delay.
	6	Heavy traffic after 2:30.		6	Heavy traffic after 3:45.
8/12 a.m.	3	One lane closed.	8/19 a.m.	1	Car accident from 8:30 to 9:00.
	5	Left lane blocked at Marquette and 4th from 7:45 to 9:00.		5	Left lane on 4th closed at Marquette from 8:00 to 9:00.
8/12 p.m.	3	Police and ambulance blocking lane 5:30 to 6:00.	8/19 p.m.	3	Truck causing significant delay at 4:13.
				5	Left lane on 4th blocked from Marquette to 3rd.

The z-tests reveal the likelihood that two data sets, in this case travel time "with" and travel time "without," are close enough to have been drawn from the same population, rather than simply occurring through chance. Some portion of the differences observed between the data sets was undoubtedly due to differences in volumes, some to systematic differences that cannot be fully anticipated, some to SCOOT, and some to noise.

A z-test was conducted for each of the ten routes and for each of the time periods that comprise the primary study. For the special event study, all of the travel time data was combined into one data set in order to achieve a large enough sample size. Disaggregate data was used for all z-tests. The tests were performed in a spreadsheet assuming a two-sample test with unequal variance.

The resulting z values were compared to the critical z value identified from the degrees of freedom and confidence interval. As stated in the *Evaluation Test* Plan, a confidence interval of 95 percent was used for all tests. The *Traffic and Transportation Engineering Handbook* defines the confidence interval as the "degree of confidence that the sampling error of a produced estimate will fall within a desired fixed range." For the sample size and confidence intervals used in this evaluation, the critical z value is 1.96.

For the supplemental study, the travel time data was analyzed on a link-by-link level. Based on input from the evaluation team, two analyses were undertaken to more closely examine the network-wide impact of the SCOOT system:

- Volume-weight the travel times by block and by direction. The rationale is that if SCOOT is giving preference to the peak-direction traffic, and if there is a substantial directional traffic split, then the weighted travel time under SCOOT will improve because it is benefiting a greater number of vehicles.
- Eliminate the two end segments from the loop travel time runs (left turns). The rationale for this correction being that the ends (left turns) are not elements of typical through movements in the Minneapolis CBD. A similar correction could be applied to other segments that are not typical movements, such as the delays associated with entering a corridor and arriving out-of-sync with the progression.

4.2.5.2. Delay Data Analysis

As with the travel time data, field observations of vehicle stops collected during the primary study were entered into a spreadsheet for analysis. Total stopped delay was calculated by summing the number of vehicles stopped at each approach at the beginning of each 20-second sampling period and multiplying by 20 seconds. The intent was to then calculate the stop-delay per vehicle by dividing by the volume on the approach. As described earlier, however, a system failure resulted in the loss of the volume data. Ultimately, the average number of vehicles stopped per sampling period was selected for presentation. The delay data was subjected to the same statistical analysis procedures used for the travel time data.

For the supplemental study, a more detailed analysis of approach delay was conducted. The field data was first imported from the Jamar™ data collection equipment into a spreadsheet for manipulation. The data was then aggregated from the 16-second sampling rate into the five-minute intervals in order to allow comparison to the SCOOT data from the same time periods. Several measures are available from the delay studies (see the following list).

1. Total number of vehicles stopped during each sampling interval (stops/hour)
2. Total delay (vehicle-seconds) (also referred to as stopped-time delay, is the time during which the traffic is actually standing still, which equals the total number of vehicles stopped during each sampling interval multiplied by the sampling interval)
3. Approach volume (vehicles/hour)
4. **Average delay per approach vehicle** (seconds/vehicle) (equals the total delay divided by the approach volume)
5. Total number of vehicles in the traffic stream that came to a stop (stops/hour)

6. Average delay per stopped vehicle (seconds/vehicle) (equals the total delay divided by the number of vehicles that are stopped on the intersection approach using the period of delay measurement)
7. Percent of vehicles stopped (equals the ratio of the number of stopped vehicles to the total approach volume)

The average delay per approach vehicle was selected for presentation (see bold item in above list).

4.2.5.3. SCOOT Data Analysis

The flow, stops, and delay SCOOT MOEs were downloaded directly from the SCOOT computer and entered into a spreadsheet for analysis. The SCOOT data was analyzed in two ways. For the primary study, the data was aggregated on a network-wide basis for all data collection time periods.

For the supplemental study, the delay and stop data corresponding to the same approaches as the field data collection was analyzed to assess the correlation between the two data sets. This data was aggregated into five-minute intervals during the a.m. and p.m. peak periods and peak hours. This analysis was conducted in order to assess the feasibility of using the SCOOT data to supplement the field data collected. Notice that this correlation was not a formal part of the evaluation. Only a preliminary investigation was undertaken; no formal hypotheses were developed or tested.

The T2000C volume data was also entered into a spreadsheet for analysis. The data was supplied in five-minute increments and analyzed on both a network-wide and corresponding link basis.

4.3. FINDINGS

Findings are presented for the field data, SCOOT data, and for each of the four test objectives.

4.3.1. Travel Time Study Findings

4.3.1.1. Overview

Given the data collected for the evaluation, the consensus of the evaluation team is that travel time studies provide the best measure of the SCOOT system's transportation impacts. Travel time studies can sample traffic operations at a wide variety of intersections within the study area. As described earlier, the AUSCI evaluation featured travel time data collection from twelve different routes, including routes within the study area and routes that traverse the system boundary.

Results from all of the travel time data collected are summarized in Table 4-5. Notice that these results include a wide variety of locations and test conditions. Pilot study data is not included because the sample size is inadequate. These results are interpreted in further detail in the sections that follow.

TABLE 4-5
SUMMARY OF TRAVEL TIME RESULTS

Description	No. of Routes	Result (1)	Comments
1. Special Event	4	-19.1%	Improvement (2)
2. Primary Data Collection (within study area)	6	2.2%	3 Improve 5 Worse 16 No difference
3. Primary Data Collection (crossing study boundary)	4	14.6%	0 Improve 10 Worse 6 No difference
4. Supplemental Data Collection (within study area)	2	-2.3%	0 Improve 0 Worse 2 No Difference

Notes:
(1) Negative result indicates improvements with SCOOT. Results shown represent the average from a.m. and p.m. periods for all routes.
(2) All routes combined to obtain adequate sample size.

4.3.1.2. Pilot Study

The primary purpose of the pilot study was to assess the field data collection approach. The travel time results obtained from this study do not represent a statistically significant sample size and should not be compared directly to the results obtained from the other study periods. In addition, rain occurred during part of the data collection period. The following findings are identified:

- Ten routes (six within study area, four crossing study boundary)
- Morning and afternoon periods combined
- Within study area: -13.3 percent (improved)
- Crossing study area: 18.4 percent (worse)

4.3.1.3. Primary Study

This section presents detailed results from the travel time data collected during the primary study, in August 1999. Travel times were analyzed for each travel time route and for the a.m. and p.m. periods and peak hours. The data was then subjected to statistical tests as described in the data analysis section of this document.

The results listed in Table 4-6 include a.m. and p.m. periods and peak hours for travel time routes within the study area. Table 4-7 provides results for routes that cross the study boundary. The table lists the control strategy that performed best for each test period. A blank in the table indicates that the travel time difference between the T2000C and SCOOT systems was not statistically significant. The overall average percent difference is also provided for each time period. Notice that a negative percent difference indicates an improvement with SCOOT.

Notice that SCOOT performs better when the routes are within the study area. Routes that cross the SCOOT system boundary experience friction with the nearby intersections under T2000C control and this was expected at the outset of the project. Vehicles transitioning from one system to another are essentially random arrivals and were expected to experience increased delay. The results tend to vary significantly from one route to the next. Refer to the detailed results in the Appendix for more information.

TABLE 4-6
PRIMARY STUDY TRAVEL TIME RESULTS – WITHIN STUDY AREA

Route ID	Better Control				a.m. & p.m. Period Average
	a.m. Period	a.m. Peak Hour	p.m. Period	p.m. Peak Hour	
1a					-0.4%
1b	SCOOT	SCOOT		T2000C	-15.5%
2					2.1%
3	T2000C		T2000C	T2000C	18.3%
4a		SCOOT	T2000C		5.3%
4b					0.9%
Average	-0.8%	-10.6%	7.6%	5.0%	3.4%

TABLE 4-7
PRIMARY STUDY TRAVEL TIME RESULTS – CROSSING STUDY BOUNDARY

Route ID	Better Control				a.m. & p.m. Period Average
	a.m. Period	a.m. Peak Hour	p.m. Period	p.m. Peak Hour	
5a			T2000C	T2000C	21.0%
5b	T2000C	T2000C	T2000C	T2000C	23.6%
6a	T2000C		T2000C		11.4%
6b	T2000C	T2000C			15.7%
Average	19.4%	16.4%	14.1%	8.8%	16.8%

4.3.1.4. Special Event Study

The travel time data collected following special events at the Target Center was analyzed for each of the travel time routes. The average travel time and percent difference for each of the four routes are provided in Table 4-8. Notice that all of the travel time data was combined in order to achieve a statistically significant sample size.

The special event travel time data demonstrates a clear improvement in traffic operations with the SCOOT system in control. The combined impact from all four routes is a 19.1 percent reduction in travel time. This improvement was expected because SCOOT can respond to the unpredictable heavy traffic flows associated with special events, outperforming a fixed time-of-day system. With a seating capacity of 20,000, the Target Center generates a significant amount of unpredictable traffic.

TABLE 4-8
SPECIAL EVENT TRAVEL TIME RESULTS

Route ID	Travel Time With SCOOT (min:sec)	Travel Time Without SCOOT (min:sec)	Percent Difference	Statistically Significant
2	7:01	9:22	-25.1%	
3	5:19	6:27	-17.6%	
4a	4:35	5:44	-20.0%	
4b	3:40	3:54	-5.9%	
Average	5:09	6:22	-19.1%	Yes-SCOOT

4.3.1.5. Supplemental Study

This section presents detailed results from the travel time data collected during the supplemental study in December 1999. As discussed earlier, the travel time data was collected on a link-by-link basis in order to provide additional detailed analysis.

The supplemental study data was first aggregated for each of the two travel time routes. The aggregated data indicates a 0.7 percent increase in travel times with SCOOT in the a.m. period and a -5.1 percent decrease in the p.m. period. An initial inspection of this data suggests that it is inconsistent with the primary study, which found better travel times during the a.m. period. Keep in mind, however, that this represents a relatively small data point and should not be interpreted as a contradiction to the aggregated results obtained from the primary study.

Next, the supplemental study data was analyzed on a link-by-link basis by volume-weighting the overall travel time. Table 4-9 presents results from both the aggregated data and the volume-weighted data. Notice that an improvement is observed when the data is volume-weighted. In the a.m. period (Route 7), volume-weighting changes SCOOT's impact from 0.7 percent to -4.1 percent. In the p.m. (Route 8), this change is -5.1 percent to -11.6 percent. In each case, this change is not statistically significant at the 95 percent confidence interval selected for this test. In the interest of more closely examining the results, the confidence interval at which the difference becomes significant was calculated. During most of the tests, a confidence interval of 75 percent or less was calculated. During the p.m. period, however, the volume-weighted data was found to satisfy a 93 percent confidence interval. This information is included to indicate that an improvement is observed with the volume-weighting. The change at the 90 percent confidence interval is significant for the p.m. route, but not for the a.m. route.

TABLE 4-9
SUPPLEMENTAL STUDY TRAVEL TIME RESULTS – VOLUME WEIGHTED

Time Period	Non Volume-Weighted	Statistically Significant at 90% CI (1)	Volume-Weighted	Statistically Significant at 90% CI (1)
a.m.	0.7%	No	-4.1%	No
p.m.	-5.1%	No	-11.6%	Yes

(1) The Confidence Interval (CI) indicates the likelihood that the difference is statistically significant.

Figures 4-6 and 4-7 present the volume-weighted travel times for a.m. and p.m. routes, respectively. Visual inspection of these figures reveals that in the a.m., seven of the 22 links had roughly the same weighted travel time with and without SCOOT, seven links had lower travel times under SCOOT, and eight had higher travel times under SCOOT. Results for the p.m. period are as follows: eight of the 14 links have about the same travel time, four have lower travel times under SCOOT, and two have higher travel times under SCOOT. These results demonstrate the high degree of variability within the data, making statistically significant differences difficult to obtain.

Next, the supplemental study data was analyzed by removing specific links within each of the routes. Links were removed to eliminate travel times along links that were not felt to represent a major movement. Table 4-10 presents travel time results with specific links removed. Again, the confidence interval at which the difference is statistically significant was explored. During the a.m. period, a confidence interval of less than 75 percent was calculated. During the p.m. period, however, the link removed data satisfied a 94 percent confidence interval. The combination of link removal and volume weighting resulted in a significant change at the 96 percent confidence interval.

TABLE 4-10
SUPPLEMENTAL STUDY TRAVEL TIME RESULTS – LINK REMOVAL

Time Period	Link Removed	Statistically Significant at 90% CI (1)	Vol-Weight & Link Removed	Statistically Significant at 90% CI (1)
a.m.	-2.4%	No	-5.7%	No
p.m.	-12.3%	Yes	-13.6%	Yes

(1) The Confidence Interval (CI) indicates the likelihood that the difference is statistically significant.

FIGURE 4-6
A.M. Volume-Weighted Travel Time Results

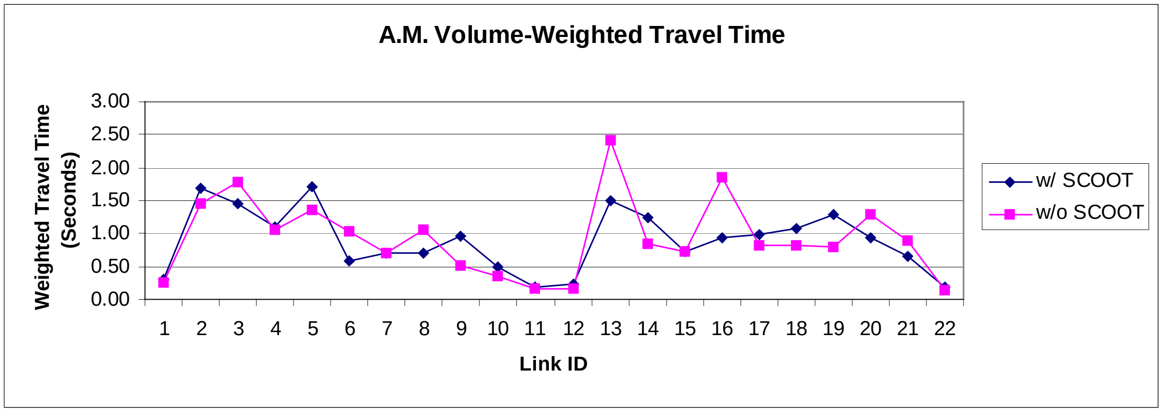
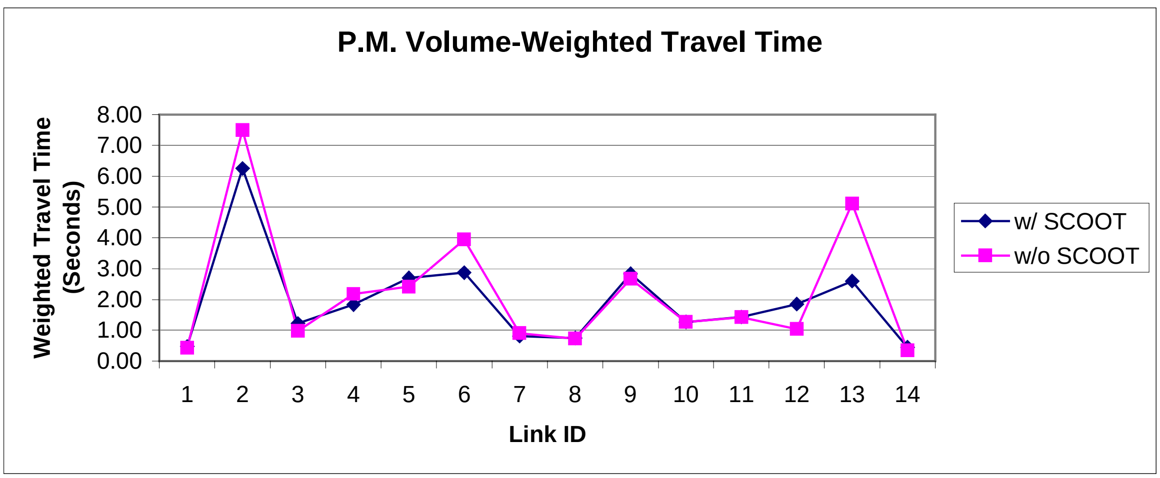


FIGURE 4-7
P.M. Volume-Weighted Travel Time Results



A positive impact from volume-weighting and link removal suggests that the SCOOT system is more effective at improving traffic operations than the T2000C system. A positive impact implies that the SCOOT system is effectively identifying high-volume links and giving them priority over low-volume links. The results found here, however, indicate that these effects are difficult to identify. While the a.m. and p.m. periods indicate an improvement in performance, the change is only significant in the p.m. period. While the sample size for these routes is adequate, the samples represent just two routes within a much larger study area. Further investigation is required to more precisely state the effect of volume-weighting and link removal.

4.3.2. Delay Study Findings

4.3.2.1. Overview

This section presents the results from the delay studies conducted at specific approaches within the study area. As mentioned earlier, the majority of these results provides the total number of stops or total stopped delay at a given approach, not the average stopped delay per vehicle. Additionally, the approaches do not represent full intersections. For these reasons, the evaluation team does not feel comfortable with the validity of the data collected during the primary study. The supplemental study, however, did analyze the average stopped delay per vehicle at a complete intersection. Given these concerns, the evaluation emphasis is placed on the results obtained from the travel time studies.

4.3.2.2. Pilot Study

The pilot study was used to assess the method and locations for conducting delay studies. Therefore, the results are not based on a statistically significant sample size. The following findings are identified:

- Ten approaches (six within study area, four near study boundary)
- Morning and afternoon periods combined
- Within study area: -11.9 percent (improved)
- Near study area boundary: -50.6 percent (improved)

4.3.2.3. Primary Study

This section presents summarized results from the delay data collected during the primary study in August 1999. The results listed in Table 4-11 include a.m. and p.m. periods and peak hours for approaches within the study area. Table 4-12 provides the results for approaches near the study boundary. The table lists the control strategy that performed best for each test period. A blank in the table indicates that the difference between the T2000C and SCOOT systems was not statistically significant. The overall average percent difference is also provided for each time period. Notice that a negative percent difference indicates an improvement with SCOOT. The primary study delay results are presented in the interest of releasing all of the evaluation data, but please note that the evaluation team has expressed concern over the method in which this data was collected.

TABLE 4-11
PRIMARY STUDY DELAY RESULTS – WITHIN STUDY AREA

Approach ID	Better Control			
	a.m. Period	a.m. Peak Hour	p.m. Period	p.m. Peak Hour
2			SCOOT	SCOOT
4	T2000C	T2000C	SCOOT	SCOOT
5		SCOOT	SCOOT	SCOOT
6	T2000C	T2000C	T2000C	T2000C
11	T2000C	T2000C	T2000C	T2000C
12	T2000C	T2000C	SCOOT	SCOOT
13		SCOOT	T2000C	T2000C
14	T2000C	T2000C	T2000C	T2000C
Average	16%	0.0%	5.7%	13.5%

TABLE 4-12
PRIMARY STUDY DELAY RESULTS – CROSSING STUDY BOUNDARY

Approach ID	Better Control			
	a.m. Period	a.m. Peak Hour	p.m. Period	p.m. Peak Hour
1	T2000C	T2000C		
7	SCOOT	SCOOT	SCOOT	SCOOT
8	T2000C	T2000C	T2000C	T2000C
9	T2000C		SCOOT	SCOOT
10	T2000C		T2000C	
Average	-8%	-17%	8.9%	-3.0%

In general, the total stopped delay within the study area is higher with SCOOT in control. At the boundary, however, the delays are shorter. Closer inspection of the boundary data reveals a very high percentage difference on some links when the T2000C is in control. This is not intuitive, because the T2000C system should not encounter a boundary condition problem. While the T2000C system is split into sub areas and traffic flow friction can be encountered at these boundaries, this friction should not be present during peak periods when all of the sub areas operate on the same cycle length. Further investigation is needed to understand this result.

4.3.2.4. Special Event Study

The original intent of the evaluation was to collect delay data at several key approaches following events at the Target Center. However, when the events and times of data collection were identified (10:00 p.m. to 11:30 p.m. after two concerts), the evaluation team decided that the data collection personnel would be exposed to an unacceptable level of risk to personal safety if data was collected during that time. Therefore, delay data was not collected during special events.

4.3.2.5. Supplemental Study

This section presents detailed results from the delay data collected during the supplemental study in December 1999. This delay study was conducted by classifying vehicles as either stopping or not stopping, and by observing the number of stopped vehicles every 16 seconds. This data collection method provides several measures of delay, including total stop-delay and average stop-delay per vehicle.

Table 4-13 presents delay results for both the total stop-delay and average stop-delay per approach vehicle. Notice the drastically different performance between approach 17 and approach 18. This difference provides an example of the complexities of evaluating the SCOOT system. SCOOT minimizes delay on approach 17 (7.9 seconds of delay per vehicle), while the T2000C does not (13.9 seconds per vehicle). Approach 18, however, has the opposite condition with the T2000C minimizing delay (6.4 seconds per vehicle), compared to SCOOT (11.7 seconds per vehicle). The combination of both approaches provides the average delay at the intersection, 10.9 seconds per vehicle with SCOOT and 9.1 seconds per vehicle without SCOOT, resulting in a 20.2 percent increase in the average stop-delay per vehicle under SCOOT. While the differences in delay is statistically significant for approaches 17 and 18, the combined data set for the intersection is not statistically different due to the variability in the data. Note that conclusions drawn from this table cannot be extrapolated to other intersections. These intersections were selected knowing that they are critical intersections. Results at non-critical intersections could easily have been different, since there is much more flexibility in the allocation of green time. Finally, notice the relatively minor change between the total delay and average delay per vehicle. The impact of calculating delay on a per-vehicle basis is very minor. This is most likely because the volumes between the "with" and "without" tests are relatively similar.

TABLE 4-13
SUPPLEMENTAL STUDY DELAY RESULTS

Approach	Total Stop-delay	Statistical Significance	Average Stop-delay per Vehicle	Statistically Significant
17	-35.9%	Yes – SCOOT	-32.9%	Yes – SCOOT
18	134.4%	Yes – T2000C	117.2%	Yes – T2000C
Average	15.6%	No	20.2%	No

4.3.3. SCOOT Data Findings

4.3.3.1. Overview

While the *Evaluation Test Plan* emphasized the collection of field data in assessing SCOOT's transportation system impacts, the MOEs available from SCOOT were captured during all field data collection periods and are reported as evaluation findings.

4.3.3.2. Primary Study

Table 4-14 provides the SCOOT system's assessment of its network-wide performance during the primary study. Notice that only delay, stop, and volume data was available from SCOOT; the system was not calibrated to provide travel time or queue length data. Notice that some data is not available because a T2000C hardware failure resulted in the loss of most of the data during the second week of the evaluation, including all of the data from the p.m. period and roughly half of the a.m. period. Notice that the volume data varies by roughly only one percent between the weeks with and without SCOOT. Finally, notice that a negative percent difference indicates an improvement with SCOOT.

TABLE 4-14
PRIMARY STUDY NETWORK-WIDE SCOOT DELAY RESULTS – WEEK 1 TO 2

MOE	a.m. Period	a.m. Peak Hour	p.m. Period	p.m. Peak Hour
Stops	-8.8%	-11.4%	N/A	N/A
Volume	1.1%	0.7%	N/A	N/A
Delay		-15.8%	N/A	N/A

In order to acquire additional data, SCOOT data was collected after the T2000C system was fixed, during the week after the primary study. Table 4-15 presents results from the data collected during "weeks two and three."

TABLE 4-15
PRIMARY STUDY NETWORK-WIDE SCOOT DELAY RESULTS – WEEK 2 TO 3

MOE	a.m. Period	a.m. Peak Hour	p.m. Period	p.m. Peak Hour
Stops	-14.1%	14.3%	-0.8%	2.1%
Volume	-3.5%	-2.2%	5.0%	8.9%
Delay		-19.3%		11.5%

4.3.3.3. Supplemental Study

Correlation between the SCOOT MOEs and the manual field observation results was briefly examined during the supplemental study. If a strong correlation could be identified, the SCOOT MOEs could be utilized to evaluate the system's transportation impacts. Unfortunately, a thorough analysis of the correlation between SCOOT MOEs and field data collection data was outside of the scope of the evaluation. The correlation addressed here represents a relatively brief attempt to compare to the two data sets. This data could be further analyzed under a separate initiative.

The correlation between the two SCOOT MOEs and the field data sets were very poor. Correlation coefficient values of less than 0.5 were recorded (a value of 1.0 indicates a perfect correlation between data sets). This correlation is lower than those found in other evaluations. In the Anaheim SCOOT installation, for example, the correlation coefficient for flow data was 0.86. In England, correlation coefficient values as high as 0.96 have been obtained. Anaheim's correlation coefficient for delay was 0.65.

Tables 4-16 and 4-17 present side-by-side comparisons of SCOOT's measure of stops and delay to the manual observations. Figures 4-8 and 4-9 present this same data in a graphical format. Notice that the SCOOT data has much less variability than the manual data. All of the data was aggregated into five-minute intervals for analysis.

TABLE 4-16
SCOOT/MANUAL COMPARISON – STOPS

Control	SCOOT Data			Manual Data		
	(1st/7th)	(7th/1st)	(Total)	(1st/7th)	(7th/1st)	(Total)
With SCOOT	415	349	763	384	408	792
Without SCOOT	700	363	1,063	360	252	612
Percent Difference	-40.7%	-4.1%	-28.2%	6.7%	61.9%	29.4%
Significance	Yes	No	Yes	No	Yes	Yes

TABLE 4-17
SCOOT/MANUAL COMPARISON – DELAY

Control	SCOOT Data			Manual Data		
	(1st/7th)	(7th/1st)	(Total)	(1st/7th)	(7th/1st)	(Total)
With SCOOT	2.3	3.4	5.6	7.9	13.9	10.9
Without SCOOT	4.6	2.1	6.7	11.7	6.4	9
Percent Difference	-50.8%	57.7	-16.5%	-32.9%	117.2%	20.2%
Significance	Yes	Yes	No	n/a	n/a	n/a

FIGURE 4-8
SCOOT/MANUAL DATA COMPARISON - STOP

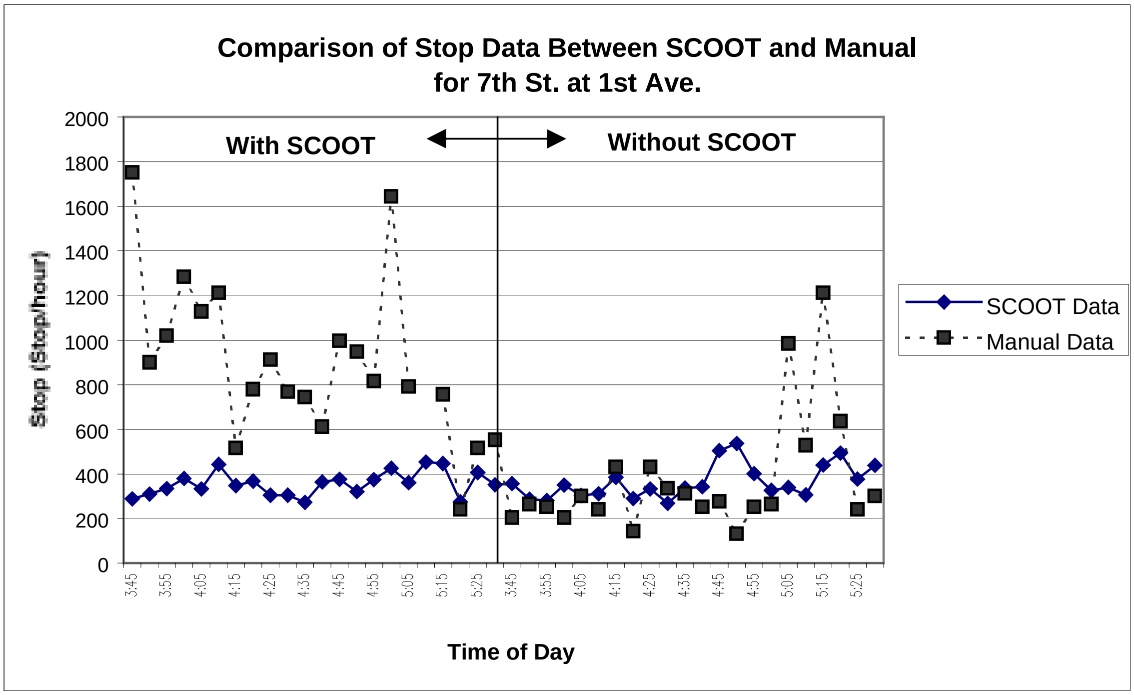
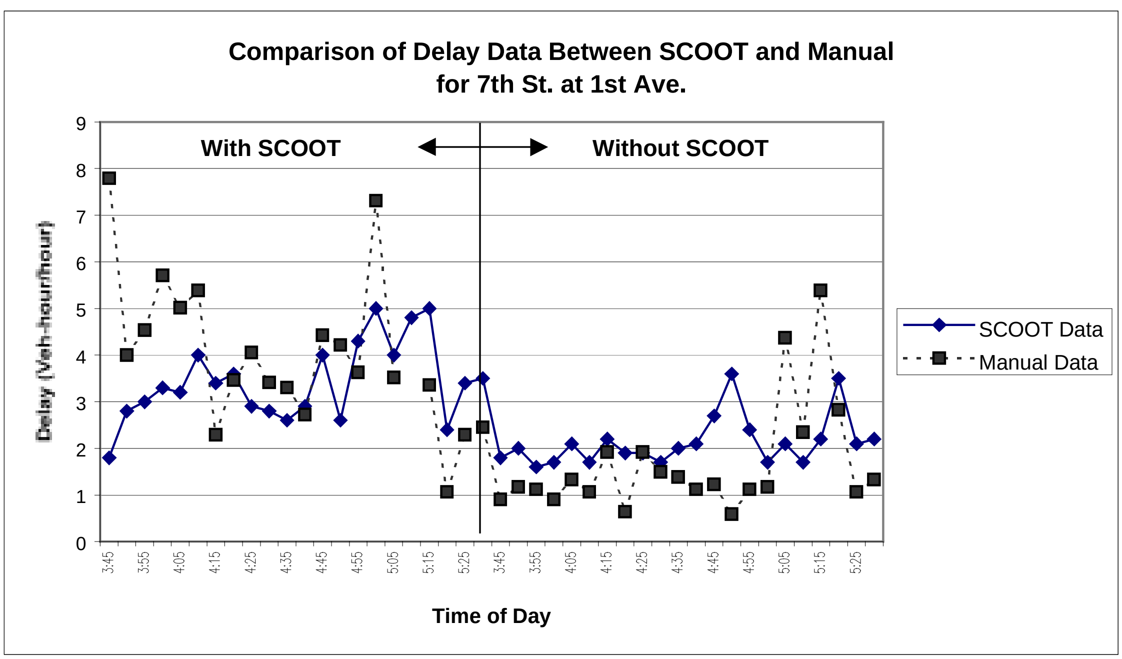


FIGURE 4-9
SCOOT/MANUAL DATA COMPARISON - DELAY



Owner Perception Findings

Minneapolis traffic system operators indicate that the SCOOT system responds well to fluctuations in traffic. The impact is most noticeable when unpredictable changes to traffic flow occur. Special events, incidents, or construction activities may cause these changes. The original T2000C system had minimal capability to respond to variations in traffic; the SCOOT system's primary advantage comes in its ability to immediately detect and respond to these changes. While the changes may be most pronounced during these events, operations personnel perceive an improvement during non-event time periods as well, including both peak and off-peak periods.

As with any multiple-intersection traffic system in a CBD area, the AUSCI project contains several key intersections. The traffic movement at these critical intersections is often the limiting factor in the performance of a traffic control strategy. For example, during the a.m. peak period, Hennepin Avenue at 6th Street is a critical intersection, and during the p.m. period the intersection of 1st Avenue and 7th Street is critical. The SCOOT system operators have the perception that the system adjusts well to varying traffic conditions at these and other critical intersections within the study area.

Minneapolis traffic operations personnel frequently receive unsolicited comments and recommendations regarding the performance of the traffic signals located within the City limits. Since the SCOOT system was installed, the City staff has received some positive and no negative comments from the motoring public. A typical comment came from one motorist who stated "whatever you've done to the signals is good."

4.4. CONCLUSIONS

Many issues must be considered in evaluating the network-wide effects of a traffic signal system, especially in a downtown setting. No evaluation can fully capture all of the transportation system impacts associated with a 56-intersection traffic signal deployment. The following factors contributed to the complexity in assessing the SCOOT system's transportation system impacts:

- Downtown Minneapolis, with about 140,000 employees and a substantial number of housing and hotel units, generates a very large number of trip origins and destinations.
- The study area is predominantly a one-way grid pattern without well-defined corridors. The corridors that do exist are generally no more than three or four blocks in length.
- The lack of corridors creates a nearly infinite number of routes, making system-wide delay and travel times more applicable than travel time along specific corridors.
- SCOOT minimizes delay on a network-wide level. Delay measured along a single corridor does not accurately capture SCOOT's performance.

- There are numerous surface parking lots and several 500- to 2,000-space parking garages in the downtown area. These facilities create mid-block sources and sinks, making the traffic flow highly variable between the upstream SCOOT detectors and the downstream intersection.

The evaluation of network-wide impacts using adaptive control, such as the AUSCI project, is an inherently difficult task. Since the study area comprises a grid network of 56 intersections, there are no clearly defined corridors or key intersections at which to measure the traffic impacts of the adaptive signal control system. Also, the traffic flow patterns are complicated because drivers travel from multiple origins to multiple destinations. Conducting a “with” and “without” evaluation under these conditions is challenging. No evaluation can fully capture the transportation system impacts associated with such an extensive traffic signal deployment. The complexity of conducting an evaluation in these conditions must be considered when interpreting the results.

At the outset of the AUSCI evaluation, an improvement in travel times and delay of approximately 12 percent was expected from the SCOOT system[2]. This anticipated improvement was based on previous evaluations that compared SCOOT to an up-to-date fixed time-of-day system. The results from the AUSCI project were expected to be even higher, since the original T2000C system’s plans were six years old when the evaluation was conducted.

The evaluation analyzed the traffic impacts after special events at the Target Center on two consecutive days. The SCOOT system was in operation on one day and off the next. Four travel time routes were driven within the AUSCI study area. The results indicate a travel time improvement of approximately 19 percent during special events.

Non-special event data was collected during a.m. and p.m. peak periods for two different conditions: travel time routes within the study area, and travel time routes that traverse the study boundary. The impacts from routes within the study area were mixed: travel times improve on some routes, worsen on others. Overall, results from routes within the study area reveal no significant differences in travel times between the SCOOT and T2000C systems. Finally, travel time along routes that traverse the study boundary are approximately 15 percent longer with SCOOT in control.

It should be noted, however, that beyond the findings noted above, SCOOT provides other benefits. For example, during incidents or special events, which have become more frequent with the addition of the Target Center and the Convention Center, the SCOOT system is effective at managing unpredictable traffic flows. Also, as times passes, the T2000C timing plans will become more outdated, due to the expected growth of 5 million square feet of office space in Minneapolis over the next five years, whereas the SCOOT system will continue to update itself. Thus, while there may be no differences now, the SCOOT system may provide benefits at a later date.

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[2] Expected performance results were discussed during evaluation team meetings in Spring 1998.

It should also be noted that these results do not fit with the City operators' perception of the SCOOT system's performance. Operators perceive an improvement during all time periods. Unfortunately, it is difficult to reconcile this perception with some of the sample field data collected. Additional field data, collected at a finer level of detail, could provide further insight into this discrepancy.

Finally, research into other evaluations suggests that the network environment in which the AUSCI system was deployed may contribute to the type of results observed here. An extensive SCOOT deployment in Toronto found better performance along arterials than in the CBD.

4.4.1. Other SCOOT Experiences

The City of Toronto has an extensive SCOOT system deployment along two major corridors and within the CBD. Toronto completed a thorough evaluation of its system's performance in 1995 and found that SCOOT performed well along their arterials, but improvement in the CBD was not as pronounced. As a result, they have selected the arterials for subsequent system expansion.

Of the 20 travel time studies conducted in the Toronto CBD, ten were not statistically significant, seven improved under SCOOT, and three worsened under SCOOT. Overall, the SCOOT system resulted in a 5.7 percent reduction in travel times. The project's *Technical Appendix 2 – The Evaluation,* summarized their CBD performance as follows:

> "The CBD routes displayed more mixed results. SCOOT was certainly better overall, but there were a few cases where the predetermined timing (PDT) control was better, and numerous examples where there was not significant difference."

> "SCOOT control is substantially better than PDT control in terms of travel time along arterial routes that are not in a SCOOT network… In the CBD, SCOOT also provided reduced travel times in many situations including the Bay Clearway, but there were also many situations where there was no statistically significant difference."

The evaluation results identified in the AUSCI project may be representative of SCOOT performance in a complex network environment associated with CBDs. If the performance in Toronto is any indication, SCOOT appears to have its greatest impact along arterials where traffic flow is optimized along a linear corridor. SCOOT is best in sub-congested conditions, adapting to changing traffic conditions. Transyt, the model upon which SCOOT is based, works best when dealing with progression. SCOOT may have a harder time smoothing offsets in a CBD where there are four directions of movement, not just the predominant two found along corridors. The introduction of a complex network with two-dimensional traffic flow may correlate to the type of results found in the CBDs of Minneapolis and Toronto.

4.4.2. Key Findings

The following list highlights some of the key findings from the evaluation of traffic system impacts:

- Travel time runs show a significant improvement (19 percent) under SCOOT during special events.
- Peak period travel times within the study area show no significant change under SCOOT. Overall, the results are mixed; some route travel times improve under SCOOT, while some worsen.
- Peak period travel times across the SCOOT and UTC system boundaries show a significant worsening (15 percent) under SCOOT for all routes combined.
- Using traffic counts to volume-weight travel times along one of the routes resulted in an improvement over unweighted travel times, but this change is not significant at the 95 percent confidence interval.
- City of Minneapolis traffic operations personnel perceive an improvement in traffic operations during all time periods, particularly during special events, with the addition of the SCOOT system.

4.4.3. Lessons Learned

As with any evaluation, there are, fortunately, lessons to be learned, and the AUSCI project evaluation was no exception. Following are some of the lessons learned during the process of assessing SCOOT's transportation system impacts:

- As discussed earlier, the collection of aggregate travel time data, as opposed to link-by-link data, was a significant issue in this project. Several factors could have prevented the misunderstanding that led to this situation. First and foremost, the project's *Evaluation Test Plan* should have prevented the issue from occurring in the first place. The plan was prepared well in advance of the data collection activities and included numerous details related to the collection of the data. Some members of the evaluation team feel that the data was not collected in a manner consistent with the methods outlined in the plan. However, there is some ambiguity in the interpretation of these methods. One clear lesson learned is that a higher level of detail regarding data collection would have avoided this data collection controversy.
- In addition, the pilot study conducted for this evaluation was intended to avoid just such an incident. But, delays in deploying the SCOOT system pushed back the date of the pilot study data. By the time the pilot study data was collected, analyzed, and distributed to key members of the evaluation team, there were only a couple of weeks before the start of the primary data collection. No comments were received on the pilot study results and the primary data collection proceeded as scheduled. Also, the pilot study data results, while not statistically significant, revealed an improvement in performance with SCOOT. Had the pilot study results been closer to the primary study results, the data collection methodology may have received more attention. In retrospect, a meeting should have been held to fully explore the pilot study data

collection methods and results, even at the expense of the evaluation schedule. In the AUSCI project, this could have avoided the concerns raised after the full data set was collected and analyzed.

- Finally, the T2000C and SCOOT system failures resulted in a substantial loss of automated data collection during the primary study. If the primary study were conducted as a series of smaller studies, the risk and consequences of losing valuable data due to system failures, or other factors outside the control of the evaluator, such as inclement weather, could have been reduced or better managed.

4.4.4. Future Evaluation Opportunities

Substantial opportunities exist for conducting further evaluation of the SCOOT system's transportation system impacts. Perhaps the easiest and most economical approach is to collect additional automated data directly from the SCOOT system. The data available from SCOOT's ASTRID software, while not available during the evaluation, can provide numerous evaluation MOEs. Ideally, SCOOT data could be used to monitor ongoing system performance, and manipulated to assess traffic patterns at specific locations within the study area. However, before this analysis is undertaken, the poor correlation between SCOOT and the manually collected field data needs to be more carefully explored, as described below.

The poor correlation encountered between the SCOOT outputs and field data in this evaluation greatly affected the utility of the SCOOT MOEs. Further examination of the SCOOT and field data collected during this evaluation could shed some light on the cause for this poor correlation, and possibly the cause for the unexpected data collection findings.

Additionally, the volume weighting and link removal performed with the supplementary data reveals an improvement over the unadjusted data. Further field data collection could provide further insight into the SCOOT system's ability to minimize delay on a network basis.

Finally, opportunities exist for conducting additional travel time and delay studies. Several videotapes were recorded but not observed during the primary and supplemental study periods. Analysis of these tapes can provide the data for further delay studies. Alternatively, additional delay data can be collected via field observations or from observations of new videotapes. The City's surveillance cameras provide an efficient method of obtaining this information. Another data collection option that was discussed, but never pursued, was the collection of further travel time data. Additional data could be collected along the same travel time routes that were used in the primary study, only this time with link-by-link level of detail. This new data could be used to calibrate the original data set.

4. TEST PLAN THREE – DOCUMENT COST IMPACTS

5.1. PURPOSE

The purpose of Test Plan Three is to document the cost impacts associated with implementing the adaptive signal control system. The following objectives are evaluated:

Objective 3-1: Document the adaptive signal control system costs by system components.

Objective 3-2: Document the adaptive signal control system personnel training costs.

Objective 3-3: Document all partner contributions.

5.2. TEST DESCRIPTION

A wide variety of costs are associated with deploying the AUSCI project. In order to document these costs, information was collected from all project participants on a monthly basis. Interviews of some project team members were conducted to provide additional information as necessary. The following agencies supplied the Mn/DOT Project Manager with detailed cost information:

- Mn/DOT
- City of Minneapolis
- Fortran Traffic Systems Limited
- Image Sensing Systems, Inc.
- Westwood Professional Services, Inc.
- SRF Consulting Group, Inc.

Several public and private sources provided funds for the AUSCI project. This information was also provided to the Mn/DOT Project Manager on a monthly basis. The following agencies contributed funds or made in-kind contributions to the project:

- FHWA
- Mn/DOT
- City of Minneapolis
- Fortran Traffic Systems Limited
- Image Sensing Systems, Inc.

5.3. FINDINGS

Findings are presented for each of the three test objectives.

5.3.1. Objective 3-1: Document the adaptive signal control system costs by system component

The adaptive signal control system costs are documented for each system and system component. A detailed cost breakdown is important for a national audience. This level of detail allows for an independent assessment of the AUSCI project's cost on a system and component basis. When available, these costs are divided into capital, installation, operation, and maintenance classifications. In addition to the costs directly related to the system deployment, other costs, such as the video surveillance system and the evaluation costs, while supplemental in nature, are also included.

5.3.1.1 Cost by Activity

Project participants tracked the cost of each system component throughout the design and procurement phase of the project. This information was provided to the Mn/DOT Project Manager on a monthly basis. Costs are provided for both Phase One and Phase Two of the project. Completed in 1996, Phase One involved primarily preliminary engineering and some project management and evaluation activities. Table 5-1 summarizes the project costs by activity, including in-kind contributions from private sector partners. Additional detail is available for each of the activities listed in Table 5-1; that detail is contained in Appendix K.

TABLE 5-1
PROJECT COST BY ACTIVITY

Activity	Phase I	Phase II	Total
Design and Project Management	$156,102	$1,091,146	$1,247,248
Video Detection and Surveillance		2,381,889	2,381,889
Upgrade Controllers and Cabinets		844,210	844,210
SCOOT/T2000C System		1,357,730	1,357,730
Operation Support		108,623	108,623
Evaluation	25,000	302,147	327,147
Travel and Training		183,319	183,319
Marketing and Public Education		11,686	11,686
Total Cost	**$181,102**	**$6,280,750**	**$6,461,852**

5.3.1.2 Ongoing Project Costs

In addition to the costs incurred for project development and deployment, the ongoing operations and maintenance costs are also explored. Since the AUSCI system has been fully operational for approximately one year, these costs are estimated. For the purposes of this evaluation, any activity that involved City of Minneapolis traffic engineering and operations personnel is classified as an operational expense. Any activity that was conducted by field technicians is considered a maintenance cost. This approach tends to classify most activities as operations.

AUSCI was deployed alongside the existing T2000C system, which is a City-wide automated signal control system. The original T2000C system is still fully operational, controlling the 684 intersections outside of the AUSCI project area. For the purposes of this evaluation, the ongoing costs of the AUSCI project are defined only as those costs that are incurred above and beyond the ongoing costs of the original system.

Another traffic signal operational cost is associated with periodic system-wide timing plan updates. An adaptive control system has a distinct advantage over fixed time-of-day systems because the signal timing is continuously updated in response to changing traffic conditions. In most adaptive applications, the background fixed timing plans would never have to be updated. The AUSCI system, however, is only a subset of the Minneapolis CBD. According to City traffic engineering personnel, when the timing plans in the CBD are next updated, the SCOOT study area will likely be included in this effort. Therefore, the AUSCI project will not result in any cost savings associated with timing plan updates. However, if enough additional intersections in the CBD are placed under adaptive control, it will not be necessary to update this region.

Several activities contribute to the cost of operating and maintaining the AUSCI system. The following *operations* activities have been identified:

1. As necessary, revalidate the SCOOT system due to roadway geometric changes within study area. Construction activities and other roadway changes are estimated to result in approximately three geometric changes per year. Each change requires revalidation of two to four links, with each link validation requiring approximately two hours of effort.

2. Recalibrate the video detection system due to roadway geometric changes; level of effort is similar to above.

3. Examine SCOOT parameters, such as cycle length, to identify any problems with the network. Level of effort required is approximately two hours per week.

4. Use the video detection system's "learn" process to verify communications with each video sensor. Requires approximately one hour per week.

5. Repair SCOOT or video detection system failures (no costs were used for this activity because no failures have been reported in the first year of system operation).

6. No recurring communication costs are assumed, since the City-owned communication infrastructure is being used.

7. Annual electrical costs for field equipment.

The following *maintenance* activities have been identified:

1. Clean lens covers on all 138 video sensors and nine surveillance cameras annually. Clean additional cameras more often as necessary. Assumes 30 minutes per camera for two personnel and a bucket truck.

2. Replace approximately one camera per year due to failure or damage.

Operations and maintenance costs are estimated from the activities listed above, refer to Table 5-2. Further detail on the AUSCI system's maintenance and operations is provided in *Test Plan One, Assess Performance Characteristics.*

TABLE 5-2
ONGOING PROJECT COSTS

Activity	Annual Cost
Operations	$27,000
Maintenance	$30,000
Total	**$57,000**

5.3.1.3 Expandability Costs

In addition to the costs involved in deploying, operating, and maintaining the AUSCI project, the evaluation also examines the costs involved in expanding the AUSCI system by placing additional intersections under adaptive control. Expansion is assumed to occur adjacent to the current system's boundary. Developing an accurate cost estimate for expansion in another part of the City is difficult because the cost can vary significantly depending on the specific location.

AUSCI system expansion is cost-effective because many of the costs incurred during the original system implementation can be considered "sunken costs" that would not be encountered again. Simply dividing the total project cost by the number of intersections in the study area overestimates the expansion cost per intersection.

Expansion costs are examined for two traffic detection scenarios. The first scenario utilizes the video detection system implemented in the current system. The second scenario utilizes inductive loop detectors for the system's detection requirements. There are also costs associated with system expansion that are common to both inductive loop and video detectors. The estimated expansion costs for each detection option and the common or "Basic Cost" is presented in Table 5-3. The following assumptions are made:

1. Installation prices reflect construction in an urban environment consistent with the Minneapolis CBD.

2. The intersection of a four lane two-way street and a three lane one-way street (i.e., Washington and 2nd Avenue South) was used as a typical intersection.

3. Cost reflects an average of one surveillance camera per six intersections.

4. Assumes the existing communication infrastructure can be utilized with minimal additional cost.

5. Assumes the SCOOT and video detection databases can accommodate additional intersections with minimal development effort. At some point, a limit will be reached and more substantial database modifications will be required.

6. Assumes that one cabinet per intersection will need to be modified.

TABLE 5-3
EXPANSION COST

Detection Method	Basic Cost	Detection Cost	Total Cost (per intersection)
Video	$9,000-14,000	$20,000-24,000	$29,000-38,000
Inductive Loop	$9,000-14,000	$17,000-21,000	$26,000-35,000

5.3.2. Objective 3-2: Document the adaptive signal control system personnel training costs

As with any complex system, the AUSCI project required extensive training during the deployment and operational phases of the project. Training was required for both the SCOOT signal control and the video detection systems. SCOOT training provided the City of Minneapolis and Westwood personnel the tools necessary to validate the SCOOT system during deployment. Training was also provided for the SCOOT system's operations. Similarly, training on the video detection system was necessary to enable project personnel to establish detection zones and operate the system. Table 5-4 documents the cost of each major training activity. Note that the video detection system's training costs are high because the deployment involved a "first-of-a-kind" sensor that was developed for this project. The training cost for a video application already in full production and released to the market is typically $1,500.

TABLE 5-4
TRAINING COSTS

Training Activity	Cost
Initial SCOOT Operation Training	$51,239
T2000C Modification Training	3,500
Initial Video Detection System Installation Training	74,197
Initial Video Detection System Operation Training	33,998
SCOOT Validation Training	5,250
Total	**$168,184**

5.3.3. Objective 3-3: Document all partner contributions

A unique aspect of the AUSCI project is the public/private partnerships that were created. The partnering process played an important role in project financing. The project was affordable because all partners made significant financial and resource contributions to the project. The FHWA provided the primary source of funds. Funding was provided by the project participants listed in Table 5-5.

TABLE 5-5
SOURCE OF FUNDING

Source of Funding	Phase I	Phase II	Total
FHWA	$111,000	$2,870,000	$2,981,000
Private Partners	37,220	1,832,050	1,869,270
City of Minneapolis	5,308	1,168,700	1,174,008
Mn/DOT	27,574	410,000	437,574
Total	**$181,102**	**$6,280,750**	**$6,461,852**

5.4. CONCLUSIONS

The AUSCI project evaluation provides a comprehensive assessment of the many aspects of the project. The deployment issues, costs, and transportation system impacts will be useful to the City of Minneapolis in determining the future expansion of the adaptive system. Also, the lessons learned in this project are transferable to other metropolitan areas considering a similar installation.

This document identifies the cost impacts of the adaptive signal control system. These costs were documented through information provided to the Mn/DOT Project Manager by the project participants. The following conclusions have been identified:

- The total project cost was approximately $6,500,000.
- FHWA contributed the majority of the project funds – nearly $3,000,000.
- In-kind contributions from private sector partners totaled over $1,800,000, representing nearly 30 percent of the total project cost.
- Training played an important role in the success of the project deployment; the training cost was $168,184.
- Operations and Maintenance costs are estimated at $57,000 per year.
- Expansion cost estimates range between $26,000 and $38,000 per intersection, depending on the type of detection and other assumptions.

As an operational test, the AUSCI project included a significant amount of development, testing, and evaluation activities. Much of the project costs were incurred as an in-kind contribution from private sector project partners. A similar deployment in another metropolitan area would likely encounter a different project cost.

6. TEST PLAN FOUR – IDENTIFY DEPLOYMENT ISSUES

6.1. PURPOSE

The purpose of Test Plan Four is to identify the deployment issues associated with implementing the adaptive signal control system. The following objectives are evaluated:

Objective 4-1: Identify technical issues associated with deploying the adaptive system.

Objective 4-2: Identify the methods required for effective maintenance, operations, control, and management of the adaptive signal control system.

Objective 4-3: Identify institutional issues associated with implementing the adaptive signal control system.

Objective 4-4: Identify the effectiveness of procuring a system through a system partnership agreement.

Objective 4-5: Assess operators' perception of the value and effectiveness of the adaptive signal system.

Objective 4-6: Identify transferability issues associated with integrating an adaptive signal control system with an existing urban traffic control system.

6.2. TEST DESCRIPTION

A wide variety of deployment issues was encountered over the course of the AUSCI project. In order to document these issues, information was collected from a variety of project participants using a combination of surveys, interviews, and group discussions with relevant project personnel. The use of diverse data sources was important in minimizing bias in the interpretation of data.

The primary source of data was the information collected from surveys of a variety of project participants. Surveys were developed in conjunction with the Evaluation Oversight Team (EOT) and administered in the fall of 1998 and again in the fall of 1999. Two surveys were used to obtain most of the information for this Test Plan, a technical issues survey and an institutional issues survey. Refer to Appendices A and B for these surveys. Deployment issues were also obtained from follow-up interviews on an as-needed basis with participants. Finally, data was obtained by evaluator observations during project team meetings and evaluation team meetings. Some evaluation meetings featured brainstorming sessions to flush out issues that were not already identified, and also to give an indication of the priority of issues. The following individuals responded to the surveys or participated in interviews or discussions:

Ms. Marilyn Remer, Mn/DOT Project Manager

Mr. Dallas Hildebrand, City of Minneapolis

Mr. Roger Plum, City of Minneapolis

Mr. Steve Mosing, City of Minneapolis

Mr. James McCarthy, FHWA

Mr. Allan Klugman, Westwood Professional Services, Inc.

Mr. Mike Belrose, Westwood Professional Services, Inc.

Mr. Gerry Blair, Westwood Professional Services, Inc.

Mr. Peter Ragsdale, Fortran Traffic Systems Limited

Dr. Durga Panda, Image Sensing Systems, Inc.

6.3. FINDINGS

Findings are presented for each of the six test objectives.

6.3.1. Objective 4-1 Identify Technical Issues

Many technical issues are associated with deploying an adaptive signal system within a legacy signal system. In this evaluation, emphasis was placed on identifying practical issues that would be faced by any agency attempting an integration of this magnitude. Notice that in this document the term *issues* is used to describe both negative and positive aspects of the project, not just *problems*. Issues include challenges, opportunities, and successes. Evaluation results are presented for the seven technical issues categories listed below:

- Hardware integration
- Software integration
- Adaptive system installation
- Adaptive system calibration/validation
- Video detection system
- Adaptive system expandability
- Miscellaneous/remaining technical issues

6.3.1.1. Hardware Integration

A key component of the AUSCI project is the integration of the SCOOT system with the original T2000C system. While most of this integration effort involved modifications to the system's software, there was also a considerable amount of work that went into integrating hardware components.

Ethernet Connection – The SCOOT system operates on its own computer, which is linked to the T2000C system computer. An Ethernet connection is used to pass real-time information between the two systems. A critical goal of the hardware integration was ensuring that the Ethernet connection satisfy the timing accuracy required by the T2000C control algorithms. It was a challenge establishing the communication on the receiving end at a high enough interrupt level so the computers would not have to wait for one another. Along with this timing issue was the need to incorporate SCOOT's communication protocols into the T2000C system. Each system uses its own set of protocols and the two had to be successfully integrated.

Significant attention to detail was required to integrate the hardware systems. For example, during system acceptance testing, a hardware problem was discovered that caused the Ethernet communication link to hang up the system whenever the connection between the SCOOT system and the T2000C system was broken between 45 seconds and 2.5 minutes of system turn-on. Although difficult to isolate, this hardware issue was identified as an incorrect switch setting on the back of the computer and corrected.

Dial Supervision Control/Direct Control – The implementation of adaptive control required significant modifications to the intersection controller cabinets. Due to the amount of work involved and the age of the cabinets, every intersection controller cabinet needed to be shop-modified to accommodate the necessary hardware additions. The primary change was to the method by which the T2000C controlled the intersections. The original T200 system provided electromechanical dial supervision control. This allowed supervision of the controller coordination through pauses at certain times of the dial. Advancements in the traffic control industry replaced the electromechanical hardware timers with software-based timing control. The introduction of software with the T2000C upgrade in 1993 still allowed the use of dial control, but the upgrade to SCOOT required direct control. New intersection controllers were required where electromechanical controllers still existed (15 locations). Direct control allows for the issuance of phase holds and phase force-offs from the central computer system. Additional modifications required that each phase be monitored at the Traffic Control Center. Upgrading to direct control required replacing the Input/Output (I/O) circuit boards and related wire harnesses in the Communication Modification Unit (CMU).

Cabinet Modifications – The City uses a Type M cabinet to house the intersection control equipment. The cabinets have dimensions of 17″ by 33″ by 63″ and an interior volume of approximately 20 cubic feet. Refer to Figure 6-1, AUSCI System Components, for images of the intersection controller cabinets and other hardware. With the addition of the AUSCI system components, space within the cabinet was tight. The video detection system required an interface panel in each of the cabinets. In some instances, terminal blocks had to be relocated in order to accommodate the panels (approximate panel dimensions 18″ by 12″ by 3″).

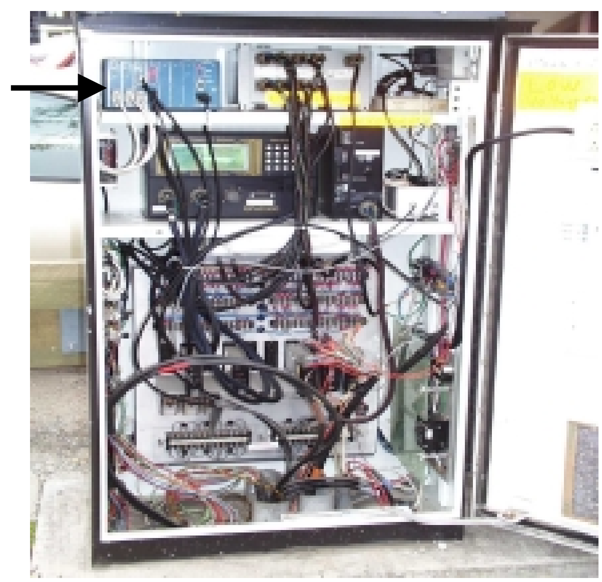
Other cabinet additions were SCOOT detector interface boards and harnesses installed in vacant slots in each of the CMUs. These boards were needed to transmit the detector inputs from the video detection system to the Traffic Control Center for use by the SCOOT system. These field changes were occasionally a challenge when attempting to fit everything into one cabinet.

FIGURE 6-1: AUSCI SYSTEM COMPONENTS

Minneapolis Traffic Control Center Computer

SCOOT

Intersection Controller Cabinet Equipment



Video Detection System

The procedure for modifying the cabinets involved removing an entire cabinet and transporting it to the City of Minneapolis Traffic engineering maintenance shop. In the shop, new interface panels and CMU harnesses were installed. All pluggable equipment (i.e., controller, conflict monitor, etc.) stayed with the cabinet so the entire cabinet could be tested as a unit in the shop. Revised cabinets were then swapped for another cabinet, which was, in turn, taken back to the maintenance shop for modification. Four-way stop control was utilized during the time cabinets were being swapped and the intersection was out of service. All cabinets were modified in this leapfrog fashion.

6.3.1.2. Software Integration

Fortran/Siemens Cooperation – Many technical issues were associated with integrating the original signal control system software with the adaptive system's software. The software development and integration process was one of the largest project tasks. The original T2000C system was developed by Fortran in North America. The SCOOT system, however, was developed in part by Siemens Traffic Control Limited in the United Kingdom. These two parties had to work closely together to develop the integrated system required for the AUSCI project.

UTC Component – The standard SCOOT package has an integrated UTC function, which typically provides control of the individual intersection controllers. The AUSCI project required the UTC to be functionally removed so that the T2000C system could retain its UTC function and have direct control over signal timing implementation. The UTC functionality was removed from SCOOT in a manner that minimized the loss of adaptive control capability. An impact to the SCOOT's adaptive kernel was realized in the multi-node function, which handles phasing control for closely spaced intersections. The T2000C system cannot handle the multi-node function that SCOOT has, making it impossible to use this adaptive feature from SCOOT. However, the T2000C system was able to approximate this functionality. The T2000C and SCOOT systems each have an automatic report command function. The goal was to not lose any features when integrating the two systems. When choices could be made regarding what was used, the two systems were not integrated, but were kept separate so no functionality was lost. Two user interfaces were created to avoid loss of functionality and to reduce cost. Thus, the two systems were not *fully* integrated. Notice that no features or functions of the SCOOT system were lost, but features of the combined SCOOT/UTC system may have been lost if SCOOT had not been separated from the UTC. Similarly, no T2000C system features or functions were lost. In fact, some T2000C functions were enhanced, such as an increased cycle length capability. The range in permissible cycle lengths went from 40-180 seconds to 32-240 seconds in order to match SCOOT.

Phase to Stage Conversion - Part of the software integration process was to gather the message information (splits, offsets, etc.) provided by one system and convert it to something recognizable by the other system. This task was complicated by the differences between North American and European traffic control standards, such as the definition for intersection movements. A translation between the North American phases was required to match the SCOOT system's European stages.

SCOOT/T2000C Interface – The SCOOT and T2000C systems must communicate with each other in real time. The software is configured such that the SCOOT system receives detector information from the T2000C and uses it to develop timing plans. These timing plans are then sent to the T2000C system for implementation. The SCOOT system consists of core programs together with shell interfacing programs, which allow SCOOT to connect to and interact with the T2000C system. In order to efficiently develop and deploy the software, Fortran installed a duplicate system at their headquarters in Toronto. When the software was first installed in Minneapolis, there were some software inconsistencies that had to be resolved, but the development and testing work done in Toronto greatly reduced these occurrences.

Database Development – Another element of the software development was the design of the systems databases. For example, one database is required to define the SCOOT network. Detailed information on each link needs to be entered, including maximum allowed queue, queue clear time, link type, and many other parameters. City of Minneapolis personnel developed this database based on training they received during their visit to England. When the project first began, the development of a complete database package that would accommodate both the SCOOT and T2000C systems was analyzed. The cost for this common database package was prohibitively high, so the decision was made to have separate databases. Since the T2000C and SCOOT systems are so inherently different, the database had to define the cycle, splits, and offsets in order for the two systems to interact. The database includes management plans that allow for easy on and off control of the SCOOT system from within the T2000C system. Also included in the T2000C system database was detector information that was added as a part of this project.

A third database is required for the video detection system. This database is comprised of the detector files for each of the sensors. Creating the detector files involved identifying the type of detector and its orientation and inputting the detector layouts on a snapshot of the sensor's image. Image Sensing Systems did the initial database development for the acceptance testing done on the detectors. The project consultant then created the detector files for each sensor. Finally, the configuration data was downloaded to the sensors in the field.

Detector Limit – The original T2000C system software could accommodate a finite number of detectors. This limit was reached when controllers were upgraded and detectors were added to the system. The software was then modified to accommodate the additional detectors.

Timing Standard – The original T2000C system is based on a 1/30th of a second standard for gathering status information on each detector in the field. This information is sent back to the control center every second, providing detailed information on the detector occupancy over the previous second. A technical challenge arose in integrating this with SCOOT's standard of gathering information every 1/4th of a second. A conversion was necessary to make the two standards compatible. Beyond simply converting between the two standards, there was a concern about whether 1/30th of a second detector information would give a similar representation of traffic as occurs with a 1/4th of a second interval. In order to validate this conversion, Fortran tested this change on the SCOOT system in Toronto. The testing involved developing a special Remote Control and Communication Unit (RCCU) to collect volume and occupancy data. This data was used to develop algorithms that could simulate the detector data collection method used by the T2000C system. Based on the successful test in Toronto, Fortran felt confident using it in Minneapolis.

Synchronization – Another significant integration effort was involved in synchronizing the timing plans between the SCOOT and T2000C systems. SCOOT has up to four minutes to synchronize an intersection. If it cannot synchronize within this time frame, the UTC implements a force hold. Since it is disruptive to implement a force hold immediately, it is preferable to have the T2000C system get the controller phases into step with the SCOOT requests. Synchronization is particularly difficult because the SCOOT system is continuously developing new cycle lengths, making synchronization a "moving target."

6.3.1.3. Adaptive System Installation

This section addresses technical issues related to the adaptive system's installation. As addressed earlier, the system installation in Minneapolis went fairly smoothly because Fortran first set up and tested the full system in Toronto. Installation activities included installing the SCOOT computer, establishing communication with the T2000C system, and updating the software. Being able to do development and testing work in Toronto greatly reduced the amount of debugging required when installing the adaptive system in Minneapolis.

In July 1998, the T2000C system crashed during SCOOT installation. When the system was brought back up, some of the original timing plans were lost and had to be recreated. The crash was caused by a hard disk failure and was unrelated to the SCOOT system. Approximately eight hours of effort was required to recreate the lost timing information. The hard disk failure is not unusual for a system that is approximately six years old.

6.3.1.4. Adaptive System Calibration/Validation

After the AUSCI system was installed, the system had to be calibrated or validated according to the traffic patterns in the study area. This section addresses technical issues related to the initial system calibration/validation and ongoing work required to keep the system optimized.

Validation Procedure – Each link within the SCOOT system must be visually observed by crews in the field in order to optimize SCOOT parameters. The procedure for validation involves first verifying that the intersection can operate under SCOOT control and that all detectors on the link are working properly. The crews go into the field to observe traffic operations and provide real-time information back to the control center for validation. A single link is usually validated in each peak period. The SCOOT system validation was a significant effort, requiring several months to validate the entire system.

Communication Problems – Communications are required for passing data between the SCOOT computer and crews performing validation activities in the field. Two types of communications were attempted. The first utilized the existing twisted pair infrastructure, and the second utilized a cellular data communication link. The twisted pair medium was often not robust enough to support the data communication requirements due to interference. A problem occurred when the communication server crashed during the second week of validation. Two days of validation time was lost while waiting for a new server to be delivered from Canada. Also, digital cellular communication was unavailable at the time the validation activities began, so analog cellular service had to be used. Digital data transfer is more reliable than analog; the analog cellular connection experienced delays of up to 30 seconds because data packets were not received properly.

Abnormal Traffic Conditions – In addition to the technical issues described above, there were some problems that were beyond the control of the project. Several Garth Brooks concerts were held at the Target Center Arena during the third and fourth weeks of validation. Since the Target Center is located entirely within the AUSCI study area, the abnormal traffic congestion levels created by these events impacted the validation activities. In particular, traffic was disrupted by buses that double-parked on the street near the arena, restricting the number of lanes available for regular traffic. Validation work during the afternoon peak periods on these days could not be done.

Ongoing Validation – In addition to initial system calibration, ongoing system validation is required to keep the system in tune with changes in the operating environment. Validation is required whenever a significant and permanent change to roadway geometry, on-street parking regulations, or similar impacts are introduced to the system. This typically occurs when major construction occurs in the downtown area. Detailed ongoing system validation information was collected from June through August of 1999. During this time, approximately one ongoing validation effort was required every month (little to no ongoing validation is expected outside of the summer construction season). The ongoing validation will be further examined in the cost/benefit analysis and in the maintainability portions of the evaluation.

6.3.1.5. Video Detection System

This section identifies technical issues related to installing the video detection system in the field and within the existing control center environment. Due to the variety of challenges encountered with the video detection system, the technical issues have been separated into seven categories: product development, acceptance testing, detection area siting study, field installation activities, communication issues, system calibration activities, and summary.

6.3.1.5.1. Video Detection System Product Development

Many of the technical challenges encountered during the video detection system's deployment were related to the fact that the system was a newly developed product. The agreement with Image Sensing Systems called for the development of a brand-new video sensor, the Autoscope Solo, specifically for the AUSCI project. Mn/DOT and the City of Minneapolis benefited from this agreement by being able to influence the development to meet their specific needs. Of course, this being a first-of-a-kind sensor, not yet available in the market, field testing and subsequent modifications were required. The project partners knew that development activities would be involved in the use of the video sensor and worked closely with Image Sensing Systems to deploy the system. Thus, many of the technical challenges presented here involved ongoing system test and modifications.

6.3.1.5.2. Video Detection System Acceptance Testing

Before the video detection system was deployed, it underwent extensive acceptance testing at a test intersection in the study area. A test intersection was selected that had two six-foot by six-foot inductive loop detectors that were situated in a way that allowed the video detection zones to be overlaid in exactly the same location. The acceptance test criterion was that the video detection system would perform as well as the in-place loop detectors. Occupancy and volume were the two measures of effectiveness analyzed. The video detection system was expected to perform within 95 percent of the loop detectors in volume and occupancy data. A video surveillance camera was also installed at this location and used to provide a baseline record of traffic operations at the test location. Videotaped images proved invaluable in identifying the cause of differences between the inductive loop and video detection. The acceptance testing was expanded to include installations at a total of four sites within the study area. The combination of these four sites accounted for most of the mounting conditions that would be encountered during the full deployment. Only a high sensor mount (deployment at 50 feet), a vertical sensor alignment, and snow conditions could not be evaluated during the acceptance testing.

Differences between loop and video data were examined in detail. The video detection system was required to provide accurate volume and occupancy values in varying light conditions, which do not affect inductive loop detectors. Initially, there were problems with double-counting vehicles when a vehicle's headlights and taillights were detected as two separate vehicles. A series of iterative software changes was required to ensure that occupancy values measured in night and day conditions were similar. A method to transition from twilight to dawn conditions was developed by downloading a solstice calendar into every video sensor. Video detection operation faced other challenges, such as detection in the varying shadow conditions found in a central business district. This issue was also successfully addressed.

The acceptance testing played an important role in demonstrating the feasibility of using video technology to meet the detector requirements. Successful completion of the testing gave the other project team members confidence in the use of the system. A side benefit of the acceptance testing was the experience gained with the equipment, which proved useful during the full installation of the video detection system.

6.3.1.5.3. Video Detection System Detection Area Siting Study

The next step in the video detection system deployment was to conduct the detection area siting study. The existing roadway geometrics and potential video sensor mounting locations were documented for the entire 56-intersection study area. The video sensor mounting locations were then selected; in all cases, they were mounted on existing street light luminaire poles.

6.3.1.5.4. Video Detection System Field Installation

Communication Components – The video detection system also required installation of hardware components in the control center. A dedicated computer with a serial connection to the City's intersection communication twisted pair wire network was provided for the video detection system. Other hardware included communication electronics to allow communication between the Autoscope Supervisor in the control center and the video sensors in the field over twisted pair. Display of video images required video switching hardware. Using the communication capabilities of the Autoscope, it is possible to incorporate video images from the nine surveillance cameras into the switching hardware. The switching made it possible to view the nine surveillance cameras and 138 video sensor images over only ten communication lines. Autoscope hubs located in the field cabinets do the actual switching. Each hub can receive four sources and provide one output. By daisy-chaining all of the hubs together, it is possible to select any image. Currently, the operator must know the video linkage tree, but a graphical user interface is under consideration that would allow an operator to select a camera from a digital map of the study area.

Communication Issues – A problem with the video detection surfaced after the system had been installed and the SCOOT system was fully operational. As part of normal maintenance activities, communication is established with all of the sensors on a daily basis – a process called "learning," in which all of the sensors are contacted, in order to verify proper operation. Each time the sensors were contacted, a different number would respond. Out of the 200 sensors and hubs, typically only 170 to 180 were contacted. These sensors were still providing valid detection outputs, but could not be contacted by the browser. Tracking down the sensors which were not responding was a time-consuming process that went on for several months. The cause was found to be a weak communication link between the sensor and supervisor computer. Repeaters were placed in several cabinets to boost the communication signal, which corrected the problem.

Sensor Installation – The video detection system installation involved mounting video sensors and making connections back to the field controller cabinet. The detector siting study was necessary to provide the sensor locations. The SCOOT system requires detection of traffic a minimum of seven seconds upstream of the actual intersection. This requirement governed the desired placement of the sensors. Unlike inductive loop detectors that can be installed anywhere, the sensors were mounted on existing luminaires whenever possible (refer to Figure 6-2, AUSCI Surveillance and Video Detection Systems). Given the location of some of the existing luminaires, some less-than-optimal views of the general detection areas were obtained. In one case, a short block made it critical to place the sensor as close to the upstream intersection as possible. The nearest luminaire was located at this upstream intersection and the sensor was installed on it. The sensor had to be carefully aimed so that pedestrians did not interfere with the detection zone.

The off-the-shelf brackets initially provided for the video sensor did not fit on the City's existing light poles along Hennepin Avenue. The poles along Hennepin Avenue have a decorative feature that includes a very short luminaire mast arm – a gap that the camera's "mast arm" style mounting bracket could not accommodate. In some cases, the bracket could be side-mounted and in other cases, new brackets with a modified design were ordered and installed.

Conduit Installation – Several logistical challenges surfaced when running the "homerun" cable from the sensor to the cabinet. Some as-built information was inaccurate and impacted the desired conduit and cable alignment. There are several "areaways" in downtown Minneapolis in which the basements of buildings extend underneath the sidewalk and toward the curb line. The sidewalk then forms the structural ceiling for this part of the building. Since many of these areaways were installed in the early 1900s, they were sometimes not included in the City's as-built information. Where areaways were encountered, alternative conduit routes had to be selected. This type of problem would likely be encountered in other urban areas.

Field Testing – During installation, the sensors were field-tested as they were installed. Originally, the sensors were tested at the base of the pole where the camera pigtail and cabinet homerun cable were spliced. This location proved difficult and the plan was modified so that all aspects of the testing were done at the cabinet instead. The field test was used to confirm that all equipment components (except cabling) worked properly.

Underscan Monitor – During installation, an underscan monitor was used to obtain proper video camera aiming. Originally, it was thought that a simple, battery-operated hand-held monitor could be used to view the video image in the field. However, most common televisions do not display the entire video image (they overscan the image). An underscan monitor that displayed the entire image was used to obtain proper aiming. The difference between an underscan and overscan monitor is important for avoiding mistakes, such as inadvertently including the skyline in the field of view. If the sky were in the field of view, extreme brightness from the sky could make the pavement appear too dark for accurate vehicle detection. During installation, the operator in the bucket truck used a standard monitor and the inspector on the ground used an underscan monitor.

FIGURE 6-2: AUSCI SURVEILLANCE AND VIDEO DETECTION SYSTEMS

Surveillance Camera
up)

Surveillance Camera (Close-

Video Detection System Sensor
(Close-up)

Video Detection System Sensor

Defective Components – After the initial installation, communications tests were performed on all of the sensors. This test revealed that some of the sensors were not operational. They were removed and shop testing revealed that one of the integrated circuit chips supplied with these sensors was heat-sensitive. The sensors were shipped back to the manufacturer for replacement. Another delay occurred at several locations when lenses of different focal lengths were required to overcome unanticipated field conditions. The lenses had to be reordered and changed out.

6.3.1.5.5. Video Detection System Communication Issues

Video Image – Through the course of the project, it was determined that it would be technically feasible to get full-motion video from the detectors back to the City's control center. Although not a part of the original system requirement, the decision was made to utilize this feature. Extensive work was required to identify the communication network path that would minimize losses in video quality. Discussions at the bi-weekly meetings between the project partners helped determine the best solution to the communication issue.

At several locations, the distance between some of the hubs was too great to make this feature feasible. One solution involved boosting the communication signal by adding an additional hub in order to make some of the connections. Also, the available quantity of twisted pair was not sufficient in one segment to provide the necessary connection. A microwave link was implemented for this segment.

6.3.1.5.6. Video Detection System Calibration Activities

Detection Zone Configuration – This section addresses technical issues related to the initial video detection system calibration, as well as to ongoing system calibration. The first step in the video detection system calibration phase was to examine the video image and program appropriate detection zones into each sensor's software. The initial assumption was that the video detection areas would be configured when the sensors were first mounted. However, the need to remove, revise, and modify controller cabinets, which generally occurred after the detectors were installed, required that the sensors be installed and aimed. Then, a follow-up effort was required to actually install the detection areas in each sensor.

Detection Zone Modifications – After the detection configurations were initially configured in each sensor, they were modified several times in order to arrive at an optimal detection approach. The final detection configuration addressed a variety of field conditions, including day-to-night transition and shadows. The configuration involved placing multiple detection zones operating in concert with one another. One of the initial unsuccessful configurations for a typical three-lane application utilized 12 different detection zones. This many zones on one sensor made it impossible for the original processor to keep up. The sampling rate was reduced to an unacceptable level, resulting in a degradation of performance. Ultimately, the detectors were reconfigured to utilize Boolean logic built into the software, thus improving the performance without increasing the processor load.

Detection area field marks faded because of the length of time between the sensor installations and the actual video detection system calibration. The detector area markings were repainted so that the detection zones were visible when calibration activities were performed.

Other Issues – Other minor issues surfaced during the video detection system development. Among other things, this included problems with the camera's auto-iris, hub lockups, and inconsistent occupancy values. These problems were typically identified in the field, and then addressed through a combination of modifications to the software and revised detector configurations. In some cases, videotapes were viewed to identify the cause of certain detection problems. Changes to the software were made frequently during installation of the video sensors. Because the software was being modified, there was sometimes confusion as to which sensors had the most recent software. The video detection system was not performing adequately enough to begin validation when the SCOOT system became operational. Therefore, the project was delayed for approximately two months while additional testing was done and modifications to the video detection system were made. These issues were largely related to the fact that the video detection system was under development and required a series of revisions and updates before it could be successfully deployed.

6.3.1.5.7. Video Detection System Summary

The video technology used for vehicle detection provided several features that conventional detection technology cannot supply. For example, the video detection system allows for viewing a video image of the detection area. This assists in trouble-shooting a video detection fault. The system also has the flexibility to redraw detection zones. This is especially valuable in construction areas because, rather than cut new loops or doing without detection altogether, the detection zones can be adjusted remotely. Video technology can also perform self-diagnostics in order to help manage the system's maintenance and operations requirements.

Since a new video detection product was developed for the AUSCI project, more effort was required to deploy this system than a standard off-the-shelf detection system. In addition, the development effort took longer than anticipated. Much testing and development of the detector occurred as a project activity. From the beginning, the City and other project participants knew the video product was a prototype and were willing to work with Image Sensing Systems to test and refine it. The positive aspect of this development work is that the City received a system that was designed to meet their needs. The time spent resolving the video problems has resulted in an accurate detection system that is operating reliably. In addition, the video detection system has provided more features than had originally been intended. For example, full-motion video from all of the sensors is available for viewing at the control center.

6.3.1.6. Adaptive System Expandability

The adaptive system consists of a network of 56 intersections. These intersections comprise only a portion of downtown Minneapolis. Future expansion to incorporate additional intersections may be desirable, especially if a high degree of congestion is observed at the boundaries between the adaptive and original signal systems. Technical issues related to expandability include limits on the number of detector inputs, software limitations, etc. This section examines several different areas that could limit system expansion.

- As a part of the AUSCI project, the T2000C system database code had to be expanded in order to accommodate the number of detectors required by the SCOOT system. Substantial further expansion of the area under adaptive control would require further modification of the T2000C system database.

- The City of Minneapolis has an extensive twisted pair communication system that interconnects all of the signalized intersections under SCOOT control. The AUSCI project required the addition of a 25-pair communication cable in order to meet all of the project's video communication requirements. The existing communication system will need to be closely examined to determine if further expansion could be accommodated. Also, if additional cabling is required, the availability of conduit space will need to be studied.

- The City of Minneapolis Traffic Control Center was examined for expansion limitations. Due to the nature of the adaptive control system, no expansion problems were identified.

- The video detection system was also examined for expansion limitations. The system is flexible, allowing it to be configured for virtually any size. Some items to consider regarding expansion are the availability of sensor mounting locations, availability of conduit space, and the number of hubs supported by a port. The number of hubs is not likely to pose a problem. The video detection system can accommodate over 200 nodes on a single communication port. The AUSCI system uses 60 nodes on its busiest port. The Autoscope Supervisor uses five ports to communicate with the hubs in the field cabinets. Currently, most of the communication is accomplished on four of these five ports, with the fifth port being used by one surveillance camera and one of the sensors. The Supervisor has the capability to accommodate eight ports with the present hardware configuration. Should expansion be desired, additional twisted pairs could be installed in order to utilize additional communication ports.

- Finally, the SCOOT system itself was examined for expansion limitations. A preliminary review indicates that the SCOOT system can be configured to a network of any size.

6.3.1.7. Miscellaneous/Remaining Technical Issues

Boundary Concerns – The SCOOT system abuts the original time-of-day system in all directions. Because no coordination between the SCOOT and original systems occurs, there is a concern that the SCOOT system boundaries could have a negative effect on traffic operations. The SCOOT signal timing parameters (cycle length, split, offset and configuration), can be adjusted by the adaptive control system, but the original system operates on a time-of-day schedule and remains relatively fixed throughout the peak periods. Traffic platoons may encounter the system boundary as random arrivals and experience extensive delays. An attempt to mitigate this effect was made when selecting the system boundaries, especially on high-volume arterials. The evaluation includes an examination of the traffic impacts at the system boundaries. Travel time studies and intersection delay studies will be used to capture these boundary conditions.

SCOOT Data Outputs – The SCOOT data outputs are intended for use in the evaluation of the transportation system impacts. But the reliability of this information is unknown: does SCOOT have the ability to objectively measure its own performance? This question is being examined in the data analysis phase of the evaluation.

T2000C System Failures – While the evaluation is primarily focused on the performance of the SCOOT system, the performance of the T2000C system also surfaced as an issue during the AUSCI project. The T2000C system failed in August 1999, disrupting the SCOOT data collection activities during the manual field data collection phase of the evaluation, and resulted in the loss of several days of SCOOT data. The system shutdown was caused by the failure of one of the two T2000C hard disk drives. When the system was brought back up, some of the existing timing plans were lost and had to be recreated. As mentioned in Section 3.3.1.3, the other disk drive failed in July 1998 during the SCOOT installation. Such system failures are not unusual for a system that is approximately six years old. In each case one of the T2000C system's disk drives had to be replaced.

Miscellaneous – Other remaining technical issues include the extent of future upgrades and modifications that the video detection or SCOOT system would require. How would these upgrades impact the performance of the system? Also, can the video detection system be used to collect system data as a parallel data collection resource? Finally, the impact of various weather conditions on the video detection system has not been fully explored. These questions are outside the scope of the evaluation effort.

6.3.1.8. Technical Issues Summary

The technical issues associated with the AUSCI project were identified through a combination of surveys, interviews, and observations of project participants. This document addresses Objective 4-1 from the AUSCI *Evaluation Test Plan – Identify technical issues associated with deploying the adaptive system*.

The main technical issues encountered over the course of the project are summarized below:

- **Ethernet Connection –** An Ethernet connection between the T2000C and SCOOT systems had to satisfy each system's timing requirements.
- **Intersection Controller Cabinet Modifications –** Every field cabinet in the SCOOT system had to be modified to accommodate the SCOOT and video detection system components.
- **SCOOT Features –** The SCOOT system was integrated with the T2000C system without any loss of SCOOT adaptive control features.
- **Software Integration –** The development of interfacing software and a common database was required to facilitate the software integration.
- **Timing Standard –** Differences between the T2000C's 1/30th of a second standard for gathering status information and SCOOT's 1/4th of a second required a conversion to make them compatible.
- **Stage/Phase Conversion –** Differences between the British use of stages and the American use of phases required development of a conversion table.
- **Adaptive System Validation –** Each SCOOT system link had to be field-validated, a process that took several months to complete.
- **System Expansion –** A review of the issues related to expanding the SCOOT system revealed that no barriers exist for expanding the SCOOT or video detection systems. Expansion would, however, require a detailed examination of the communication infrastructure and modifications to the T2000C system database.
- **Synchronization –** The SCOOT system continuously develops new timing plans, which the T2000C system then implements. A challenge is presented in synchronizing the two systems.
- **Video Detection System –** There was a variety of technical issues encountered with the video detection system; most were related to the fact that the system was under development and was not yet available to the market. The City agreed to the use of this prototype product and was willing to work with the video system supplier to test and refine as necessary. It is important to note that the video detection system has been working well as a final, fully deployed system.

In summary, the implementation of the AUSCI project has been a remarkable success for the level of sophistication, time required, and number of parties involved. Many of the technical challenges encountered were inherent to the integration of two different traffic control systems. The AUSCI project demonstrated that in Minneapolis, it was possible to attach the SCOOT adaptive control system to the existing T2000C signal control system. The integration was performed such that the two systems can coexist.

6.3.2. Objective 4-2 Identify Methods for Effective Maintenance and Operations

This section identifies the approaches most effective in maintaining, operating, controlling, and managing the adaptive signal control system. This information was gathered primarily through interviews of the City of Minneapolis traffic operations personnel.

Time Constraints – Limited time availability is a major factor facing Minneapolis traffic operations personnel. While time constraints prevent operations personnel from monitoring the details of day-to-day SCOOT operations, operators have found approaches that allow some of these tasks to be performed efficiently. For example, the City Traffic Engineer receives a daily report from ASTRID, SCOOT's reporting system, that provides the historic cycle lengths for regions within the SCOOT study area. Whenever a cycle length for a particular region appears higher than normal, the information is examined more closely. Typically, one intersection is found to drive the cycle lengths higher for the entire region. The detectors and traffic patterns at this intersection are then examined in order to track down the cause of the cycle length. Corrections are made as necessary. Approximately 15 minutes is required to retrieve and analyze the ASTRID report on a daily basis.

Video Detection System Diagnostics – A useful feature of the video detection system is its ability to perform a self-diagnosis. Through the browser software installed on the video detection system's computer, located in the control center, the operator can issue a *learn* request. The system then contacts each of the 138 video sensors and 63 hubs in the field and verifies that all sensors and hubs are online and working properly. The learn process is typically done every day and takes about ten minutes to complete.

Detector Inspection – The City also performs an inspection of the outputs from all detectors located in their system, including both the video detectors used by SCOOT and all other detectors located throughout the City. The T2000C system captures all detector outputs and stores them for analysis. The City Traffic Engineer enters the data into a spreadsheet and the volumes are compared to historic trends. Any unusual detector data points are examined in more detail. If an inductive loop detector is in question, field maintenance crews do the inspection. If a video detector is giving unusual outputs, the engineer examines the video image to diagnose the problem. Detectors used for traffic signal actuation (such as SCOOT detectors) are given higher priority than detectors used for volume data. The engineer spends approximately one hour per week examining detector information. Before the SCOOT system was installed, each of the 200 loop detectors was examined approximately once every four weeks. With 600 loop and video detectors now in operation, this inspection frequency has increased to approximately 12 weeks.

Video Detection System Maintenance – Some video detection system problems have been traced to dirt accumulation on the video sensor outer lens covers. In such cases, the City has had to dispatch a maintenance crew on short notice to clean the lens covers. The City is developing a plan to clean the lens covers on a regular basis. Approximately half the sensors are vulnerable to these problems because of the low mounting heights and will be cleaned twice each year. The remaining sensors will be cleaned about once per year. By setting up a maintenance schedule, the City can be proactive in their approach to the problem.

6.3.3. Objective 4-3 Identify Institutional Issues

Institutional issues are often the most challenging in implementing a multi-jurisdictional project that requires significant financial, staffing, and technical resources from both public and private sector partners. In this evaluation, emphasis was placed on identifying institutional issues that would be faced by other agencies attempting a project of this magnitude. As in previous sections, note that the term *issues* is used to describe both negative and positive aspects of the project, not just *problems*. Issues include challenges, opportunities and successes. The institutional analysis results are grouped into the following subject areas:

- Contractual Issues
- Insurance Issues
- Licensing Issues
- Liability/Risk Management Issues
- Proprietary Information
- International Business Relations
- Staff Turnover
- Funding
- Miscellaneous

6.3.3.1. Contractual Issues

Scope of Work – The AUSCI project began when the City of Minneapolis collaborated with Mn/DOT to develop a proposal for a federal work order. The FHWA authorized the concept development and preliminary design phase of the project. A detailed budget and scope of work had to be prepared before the FHWA could approve full funding for the project. It was the preparation of the project's scope of work that took a significant amount of time and is one of the project's more prominent institutional issues. One of the reasons this activity was so time-consuming was the challenge posed by the City's requirement that the adaptive control system be integrated with rather than replace portions of the existing signal control system. Several scope of work iterations were required because the City was adamant that the operation of their existing signal control system (the T2000C system) not be jeopardized. Keeping the T2000C system operational at all times was critical to the City because the SCOOT system controls just

56 intersections of the 740 intersections in the overall signalized network. Another significant cause of delay was the difficulty in obtaining a clear understanding of the proposed adaptive control system's operation because proprietary concerns prevented details about the SCOOT system's functionality from being fully revealed. Proprietary issues are discussed further in Section 3.3.3.5.

Joint Powers Agreement – Executing the joint powers agreement between the City of Minneapolis and Mn/DOT was a lengthy and complex process. Since the contracts had to meet both Mn/DOT and City legal contractual requirements, differences in the agencies' contractual requirements had to be resolved. Despite a desire to develop the agreement in a timely manner, the development process was delayed by the bureaucratic structure of each agency. Delays related to attorney review times were outside the control of the project participants. City staff had to prepare a council resolution referencing the AUSCI construction plans and detailing the intent of the agreement. Two committees of the Council reviewed the resolution prior to it being voted upon by the City Council. The Council action was publicly posted in the newspaper and, finally, signed by the mayor. Only once this process was completed were the City and Mn/DOT able to finalize the agreement. The entire process took a significant amount of time.

Order of Contract Execution – The City could not give approval to the joint powers agreement until the detailed construction plans were complete. This detailed information was necessary to develop accurate estimates of the amount of work and costs that the City would be required to contribute. While a local consultant developed the plans, some assistance from the project partners (Image Sensing Systems and Fortran) was required. These partners needed to be under contract in order to perform this work. Mn/DOT resolved this by executing the contracts with Image Sensing Systems and Fortran before the joint powers agreement between the City and Mn/DOT was approved.

6.3.3.2. Insurance Issues

Errors and Omissions Insurance – Differences in Canadian and United States (Mn/DOT) requirements for errors and omissions insurance proved to be an additional hurdle during the contract preparation process. This type of insurance is not normally required in Canada. The Canadian contractor (Fortran) does not typically carry insurance for engineering-related work because they typically perform work as a contractor, where bonding insurance is used. Fortran incurred unanticipated costs and delays to obtain this insurance. The problem was identified late in the contract negotiation process and threatened to cause significant delays. Mn/DOT executed a separate amendment to the contract reimbursing Fortran for the cost of purchasing this insurance.

6.3.3.3. Licensing Issues

Software Contract Requirements – One of the contract items with Fortran included a site license for the modified software used by the modified T2000C system and by SCOOT. Preparation of this license was challenging because Fortran could not meet Mn/DOT's standard contract requirements on software. This issue was complicated because the contract was written between Mn/DOT and Fortran, with the City being the end user. This issue was resolved by agreeing that the license would be assigned to the City, but that Mn/DOT would have access to the software.

Legacy System Licensing Issues – Licensing again surfaced as an issue when executing the joint powers agreement between Mn/DOT and the City of Minneapolis. The City completed a T2000C system upgrade in 1993, shortly before the AUSCI project started, but the licensing and escrowing contract-revisions for this upgrade were not completed when the AUSCI project began. Mn/DOT could not finalize the joint powers agreement with the City until this licensing was completed. This issue was a carryover from the previous project, but this did cause some delay to the AUSCI project.

Escrow Agreement – An escrow agreement for the system's software is important to the City. The City wishes to have access to the source code in order to make future upgrades if, for some reason, Fortran is not available to perform this work. Before the AUSCI project began, the City had an escrow agreement with Fortran for the original T2000C software. Changes to the source code were required when the SCOOT adaptive control system was integrated with the T2000C system. These changes necessitated a new escrow agreement between the City and Fortran. The terms of the original escrow agreement included a time clause that allowed for the code to become the City's property if there were no software upgrades for a certain period of time. Fortran would not agree to incorporation of this time clause in the new escrow agreement and it was removed as part of the re-negotiation with the City. In addition, the new escrow agreement does not include the part of the software package that involves the interface between the T2000C and SCOOT systems and of the SCOOT system itself. This exception was required because of a Fortran agreement with Siemens Traffic Control Limited that prevents disclosure of details about the SCOOT package. Ultimately, finalization of the escrow agreement required a significant amount of time.

6.3.3.4. Liability/Risk Management Issues

As participants in a large and complex project, all project partners were faced with a certain amount of risk. The City of Minneapolis risked the continued operation of their existing signal system. Fortran exposed themselves to risk by attempting an integration of two different signal control systems, an integration that had not been done before. Image Sensing Systems also undertook a risk by developing a new video detection product during the project. Finally, both the City and Mn/DOT risked dedicating time and resources to a project without a guarantee of positive user benefits. All of the project partners shared these risks. The following list of examples details how some of the project's risks were managed.

- Creation of a duplicate Minneapolis system in Toronto played a key role in allowing Fortran to mitigate some of the technical risks. By recreating the system, Fortran was able to troubleshoot many of the software integration issues before traveling to Minnesota for the actual installation.

- The City and Fortran mitigated risks in using the video detection system for system sampling detectors by requiring Image Sensing System to include language in their contract stating that the detection system would provide outputs comparable to a standard inductive loop detector. The detection system prototype had to pass acceptance testing demonstrating this capability prior to approval for use in the project.
- Mn/DOT requires professional liability insurance on all of their contracts. Having this insurance in place played a role in managing project risks for the project participants.

6.3.3.5. Proprietary Information

Another significant institutional issue was the proprietary nature of the SCOOT system, a system developed by the Transportation Research Laboratory – a division of the British Royal Crown. An understanding of the SCOOT features and functions was needed to develop the scope of work with Fortran. It was difficult for the City and Mn/DOT to determine their specifications without knowing what each of these features would provide. This contributed to the challenge of defining the scope of work. New SCOOT features became available in a newer generation of software during the project development and it was difficult to get the necessary level of detail on these features from the Transportation Research Laboratory.

Ultimately, representatives from Mn/DOT, the City, Fortran, and Westwood made a trip to the Transportation Research Laboratory in England to learn more about the SCOOT system. This trip included lectures on the SCOOT operations and examples of other SCOOT deployments. Since little information is published on the details of SCOOT operation, the visit was invaluable in providing an opportunity to talk face-to-face with the system developers and in providing an understanding of the SCOOT system's capabilities. The SCOOT system has several optional features that can be supplied as part of its deployment. Some that were considered for the Minneapolis deployment include ASTRID, a reporting feature, INGRID, an incident management feature, and a bus priority feature. In the end, the amount of detail that was actually required was not as significant as originally believed.

Proprietary concerns were also addressed among the project partners. Instead of one confidentiality statement in Mn/DOT's contract, bilateral confidentiality agreements were required between the project partners. These agreements were important because the project partners were involved in developing proprietary products and wanted assurance that the information would not be shared.

6.3.3.6. International Business Relations

Currency Exchange – The AUSCI project involved participants from both Europe and North America. The SCOOT software was developed by the Transportation Research Laboratories in England and is distributed by Siemens Traffic Control Limited. Fortran is a Canadian firm that performed the software development and modifications.

Preparing the agreements with Fortran and Siemens was challenging because of the time involved and the fluctuations in exchange rates between the British pound, the Canadian dollar, and the American dollar. Frequent revisions to the project costs were required because quotes were only good for a period of 30, 60, or 90 days. When unexpected delays pushed contract negotiations beyond the quote limit, new cost estimates had to be prepared.

International Legal Issues – Another challenge related to the companies involved in this project is the differing contractual requirements between the United States and Canada. In particular, the requirements for errors and omissions insurance, workers compensation, and affirmative action are different. As discussed in Section 3.3, Mn/DOT issued an amendment to the contract to cover the cost of errors and omissions insurance. Mn/DOT also waived the Minnesota affirmative action requirements because most of the work was done in Canada, and not the United States.

6.3.3.7. Staff Turnover

Untimely staff changes can have a significant impact to a multiple-year project, such as AUSCI. Fortunately, the staff turnovers that did occur during the project were relatively minor. Some delays, however, were related to changes in staff at Image Sensing Systems and SRF Consulting Group, Inc. The consistency in staffing at Westwood Professional Services (project consultant) and Fortran, and especially at the City and Mn/DOT, played an important role in the project's success.

6.3.3.8. Funding

Funding is a common limiting factor in implementing projects of this nature. The preliminary cost estimate indicated the budget was sufficient for the tasks required. During the detailed design phase, however, the preliminary estimates were refined and a higher estimate of the project cost began to emerge. Because FHWA's ability to provide these needed funds was limited, the City and Mn/DOT had to pick up the costs. Other cost increases were realized when the construction bids came in higher than original estimates. The video development and testing work was more involved and costs experienced by Image Sensing Systems were higher than anticipated, largely because the detection capabilities needed to be refined to accommodate diverse conditions such as low light and shadows. Finally, the scope of the evaluation effort was expanded to include additional field data collection activities. Cost sharing by the project partners enabled the project to reach completion.

6.3.3.9. Miscellaneous

Project Cost Reporting – The project costs were categorized into various project activities and reported to the Mn/DOT project manager on a monthly basis. Some project participants were not accustomed to this level of bookkeeping and felt the process was cumbersome and time-consuming.

SCOOT / Ramp Meter Interface – When the project was first conceived, there was discussion of incorporating Mn/DOT's ramp metering system with the SCOOT system. A tie-in with the ramp meters would have allowed the SCOOT system to know the metering rate at ramps that were in or near the study area. SCOOT could then have used this information to make signal timing adjustments based on the capacity of the metered ramps to accept additional traffic. The connection between the ramp metering system and the SCOOT system was never established; this was identified as a lost opportunity by the project participants.

6.3.3.10. Institutional Issues Summary

Identifying the institutional issues associated with the AUSCI project was accomplished through a combination of surveys, interviews and observations of project participants. The last institutional survey question asked respondents to identify the three key institutional issues as perceived from their organization's perspective (see survey form in the Appendix). The following list identifies how this question was answered. The number next to the item indicates how many people identified that item as a key institutional challenge.

1) Preparation of the scope of work with Fortran
    - Proprietary nature of SCOOT information (3)
    - Licensing issues (1)
    - Escrow issues (2)
2) Joint powers agreement (1)
3) Funding/cost increases (2)
4) International differences (2)
5) Project delays (1)

While the preparation of the agreement with Fortran was commonly identified as a key institutional issue, there were some factors that contributed to this lengthy process. Most notable was the fact that the project participants did not have a clear picture of the adaptive system's capabilities and how the adaptive system should be integrated with the existing system. It was during the contract negotiation phase that the project team worked out key design issues. The partnering process deployed here was actually a combination of a traditional design and a design-build process. Many of the technical details needed to be identified before the contract could be finalized. Ultimately, a better final product was realized because of the interaction between Fortran and the project team during the contract development process. Fortran's involvement in preparing the contract came at a critical time and supplied key information. This information was incorporated into the contract language and deliverables. In summary, the time spent developing the project's scope of work helped produce a better final product.

6.3.4. Objective 4-4 Identify the Effectiveness of Partnering

Partnering was a prominent institutional aspect of the AUSCI project. Partnering for this project involved not only partners from state and local public agencies, but also included private companies from Minnesota, Canada, and the United Kingdom. This combination of participants provided a number of challenges, including legal issues related to partners from different countries, the proprietary nature of the system, and the combination of partners from the public and private sectors. Considering the work that was involved, however, the project's implementation has been a remarkable success. Evaluation results from interviews and surveys indicate an overwhelmingly favorable response to the partnering process.

Public Sector Partners – The first step in the partnering process was a public/public partnership that was formed between the City of Minneapolis and Mn/DOT. These two agencies developed a project concept statement that was approved for funding by the FHWA under the Federal ITS Operational Test Program. In this arrangement, the City of Minneapolis has sole ownership of the system. This has been an important component contributing to the success of the project. It recognizes the City as the final stakeholder – the agency responsible for operating and maintaining the system after the project has been deployed.

Private Sector Partners – Fortran, a Canadian firm that supplied and supports the City's original traffic signal control system, agreed to partner in the project. The agreement formed with Fortran exemplifies partnering by giving the private partner an opportunity to develop, test, and demonstrate an integrated traffic control system in turn for a substantial pricing discount. The AUSCI project itself is unique because it is the first project of its kind to integrate SCOOT, an adaptive signal control system, with a legacy traffic responsive/time-of-day system. The success of AUSCI has given Fortran marketing exposure by demonstrating the company's ability to successfully integrate their traffic control system with SCOOT, as well as with a state-of-the art video detection system.

The other private partner in the project is Image Sensing Systems, the video detection system provider. Image Sensing Systems shared the costs of developing and deploying the next generation video detection system. The road network, the large number of intersections, and the communication infrastructure constituted an excellent beta test site for the new sensor development. Additionally, the AUSCI project has given Image Sensing Systems the opportunity to demonstrate the new sensor's ability to provide the detection system for a large-scale SCOOT deployment – a deployment that had previously only been done with inductive loop detectors.

Cooperative Spirit – One of the challenges of the project was addressing the numerous technical issues that surfaced during the project implementation, integration, and validation. Partnering enabled these challenges to be met in a cooperative spirit, because all project partners were working toward a common goal, a successful project deployment. The cooperative spirit that partnering can bring to a project did not happen automatically – rather, it was built over time. For example, bi-weekly meetings were held with representatives of Image Sensing Systems, Westwood Professional Services, the City, and Mn/DOT. A sense of partnership evolved through the working relationships that were established between the project personnel. These meetings allowed partners to resolve issues more quickly and effectively than would have been possible in a standard contract.

Partnering Risks – Project partners also perceived a risk because partnering introduced some loss of control over the project. For example, Fortran was responsible for gathering and integrating detector data (real-time volume and occupancy information) into a form suitable for the SCOOT detection requirements. The use of video detection (provided by Image Sensing Systems) introduced a degree of technical risk to the project. Fortran perceived a risk by not having typical loop detector data inputs to integrate. The partnering concept required the two firms to rely on one another.

Goals and Priorities – Partnering was effective in addressing another potential problem, differing goals and priorities for the two major public agencies involved, the City of Minneapolis and Mn/DOT. In the AUSCI project, these two public agencies have very different perspectives and different priorities for the project goals. For Mn/DOT, the AUSCI project is a high-profile ITS demonstration project; their goal is to demonstrate the utility of ITS technology, the merits of partnering, and the value of ITS applications as public sector investments. Benefits to the end-user are tantamount to the success of the project. For the City, however, the project is a modification to their main traffic signal control system; their main goal is to improve traffic flow without jeopardizing the operations of the existing system. Conflict of interest problems were generally avoided by an attitude of cooperation, particularly with Mn/DOT actively involving the City in the overall contract and decision-making process.

Partnering Drawbacks – Drawbacks to the partnering process were also identified. Since the AUSCI project included in-kind contributions from the private sector participants, there was a limited number of firms willing to participate in the project. A normal procurement contract would have resulted in more competition from the industry and the probable consideration of multiple proposals. Additionally, the contribution element of the partnering concept was identified as a way for government agencies to lower the project's price. Some private sector partners felt the partnering process reduced the amount of revenue they received.

Conflict of Interest – The relationship between Fortran and Image Sensing Systems was delicate because Fortran is the Canadian distributor for the Peek Video-Trak video detection system, which is a competitor to Image Sensing Systems. Image Sensing Systems was concerned with divulging proprietary information regarding the enhanced video detection system they were developing for the project. The issue did not seriously impact the project, however, largely because Fortran is located in Canada and was not directly involved with the majority of the video detection product development work. Partnering also played a role in mitigating this concern.

Joint Powers Agreement – The joint powers agreement between the City and Mn/DOT played a critical role in the partnership process. The agreement established the relationship between Mn/DOT and the City of Minneapolis, allowing the two agencies to work closely together throughout the project. The complicating element of the partnering effort was the development of contracts between Mn/DOT and the private sector project partners, Fortran and Image Sensing Systems. Since Mn/DOT was the lead partner, they had the contractual authority to make all project-related decisions even though the City was the ultimate owner of the system. Close coordination between the parties involved was required to ensure that the City's interests were adequately considered.

Member Contributions – The AUSCI project partners made significant financial and resource contributions to the project. The City of Minneapolis and Mn/DOT dedicated key staff members and funds to the project. Image Sensing Systems contributed to the development and deployment costs of the new video detection product. They supplied the video detection system for a cost that is comparable to a conventional inductive loop detection installation. Finally, Fortran dedicated key personnel to the complex process of integrating the original and adaptive systems, an integration that had never been attempted.

Partnering Summary – Partnering played a positive role in the AUSCI project by fostering strong communications between the private and public sector partners. Working closely together was an important theme that emerged from the partnering process. For example, the bi-weekly status meetings during the project's deployment helped develop a cooperative team spirit. The success of the project was dependent on the combined efforts of all involved.

6.3.5. Objective 4-5 Assess Operators' Perception of Value and Effectiveness of the Adaptive Signal System

The City of Minneapolis traffic operations personnel were interviewed to obtain their perception of value and effectiveness of the SCOOT system. In addition, the evaluator accompanied other evaluation team members for a SCOOT system drive-through in order to gain first-hand insight into traffic operations within the study area. The results presented here are more qualitative than other aspects of the evaluation.

Benefits of Adaptive Control – The Minneapolis traffic system operators indicate that the SCOOT system responds well to fluctuations in traffic. The impact is most noticeable when unpredictable changes to traffic flow occur. Special events, incidents, or construction activities may cause these changes. Whereas the original T2000C system had minimal capability to respond to variations in traffic, the SCOOT system's primary advantage comes in its ability to immediately detect and respond to these changes. While the changes may be most pronounced during these events, the operations personnel perceive an improvement during non-event time periods as well, including both peak and off-peak periods.

Critical Intersections – As with any multiple-intersection traffic system in a CBD area, the AUSCI project contains several key intersections. The traffic movement at these critical intersections is often the limiting factor in the performance of a traffic control strategy. For example, during the a.m. peak period, Hennepin Avenue at 6th Street is a critical intersection, and during the p.m. period the intersection of 1st Avenue and 7th Street is critical. The SCOOT system operators have the perception that the system adjusts well to varying traffic conditions at these and other critical intersections within the study area.

Public Reaction – Minneapolis traffic operations personnel frequently receive unsolicited comments and recommendations regarding the performance of the traffic signals located within the city limits. Since the SCOOT system was installed, the City staff has received some positive and no negative comments from the motoring public. A typical comment came from one motorist who stated "whatever you've done to the signals is good".

Drive-Through – A SCOOT system drive-through was conducted with the evaluator and other members of the evaluation team in the p.m. peak periods of December 13 and 14, 1999. The SCOOT system was turned on the first day and turned off the second day. During this drive-through, a specific route was driven once and the remaining time was spent observing various links and routes within the system. The travel time along the route varied by only 10 seconds, 8 minutes 30 seconds with SCOOT, and 8 minutes 40 seconds the next day without SCOOT. While this sample is obviously too small to draw any meaningful conclusions, it did provide some insight into the system operation. One important observation is that the SCOOT system treats the study area differently than the original T2000C system. The primary difference is in how traffic progresses through the corridor. Each system is broken into regions, and stops are often encountered when crossing the boundary of these regions. Stops were observed to occur at different locations, depending on which control strategy was in effect. Since the total travel times were so close, it was not possible to develop an impression of the SCOOT system's impact. The remaining time spent driving through the system did not yield any conclusive observations. Traffic congestion appeared to be higher in some areas and lower in others. But congestion is not a measure of performance and did not correlate to a particular control strategy. The consensus was that more observations of the system would be required before an impression of the SCOOT system's performance could be realized.

Overall Value – The City's representative was asked to comment on his perception of the *overall value* of the SCOOT system. The representative said the project has involved a combination of improvements to traffic operations within the study area, balanced by a significant effort to deploy the system.

Operators' Perception Summary – As owners of the SCOOT system, Minneapolis AUSCI project participants were interviewed regarding their perception of the adaptive system's value and effectiveness. The City's representatives have indicated a high level of satisfaction with the SCOOT system. System operators say the SCOOT system has been reliable and maintainable, running very well since it was installed over a year ago. While a brief drive-through of the system did not reveal any insights into SCOOT's performance, system operators have a strong perception that traffic operations in the study area have improved in all time periods, particularly during special events. This perception is bolstered by the input received from the traveling public.

6.3.6. Objective 4-6 Identify Transferability Issues Associated with Integrating an Adaptive Signal Control System with an Existing Urban Traffic Control System

Transferability issues are defined as those elements of the project that would apply anywhere a SCOOT adaptive signal control system is integrated with an existing signal control system. The objective is to identify what lessons learned in this project can be transferred to others attempting a similar project. The project's transferability is presented in the following topic areas: base conditions, existing infrastructure, system integration, system features and functions, policy and procedures, and transferability summary.

6.3.6.1. Base Conditions

When assessing the AUSCI project's transferability, it is important to examine the physical conditions that existed when the AUSCI project began. Into what setting was the AUSCI project deployed? These base conditions provide a frame of reference for others attempting a similar project.

In many respects, the Minneapolis CBD is similar to other urban centers. The AUSCI test area is a 56-intersection integrated network of one-way and two-way streets, dedicated busways, dedicated bikeways, freeway ramps, HOV facilities, and parking garages located in the western portion of the CBD. A proposal to bring light rail transit into the SCOOT area is also under consideration. An additional 120 intersections are under the T2000C's control in the remaining regions of the CBD. The blocks in the study area are typically 400 feet in length and width (refer to Figure 2-1). The major corridors in the study areas serve large numbers of rush-hour business and commercial center commuters, as well as attendees at major events in the CBD, including those at the Metrodome, Target Center Arena, and the Convention Center.

The T2000C timing plans were last updated in 1993. Westwood Professional Services did the update, a local consulting firm that also participated in the AUSCI project. The update was done with Transyt traffic simulation software. The City updates its timing plans on an as-needed basis, although funding availability often dictates the frequency of system-wide timing plan changes. Prior to 1993, the timing plans were last updated in 1978. It is important to assess the adequacy of the existing traffic control strategies when considering an upgrade to an adaptive signal control system. While 1993 provided a relatively recent timing plan update, the constantly changing traffic flows and demands associated with special events led, in part, to the decision to deploy an adaptive signal control system.

6.3.6.2. Existing Infrastructure

Some of the existing infrastructure in Minneapolis supported the integration of an adaptive signal control system, and some of the necessary infrastructure was not in place. The degree to which the in-place infrastructure could be utilized for the AUSCI project was an important factor in the decision to deploy the adaptive signal control system. The ability to utilize this infrastructure helped contain the project deployment costs. The following list highlights some of the considerations related to the existing infrastructure:

- Before the AUSCI project began, the City had an extensive communication network of City-owned and -operated twisted pair communication lines that served the intersection signal controllers in the CBD. This existing communication system was able to support the majority of the SCOOT and video detection system communication services.
- With some modifications, the hardware necessary to accommodate the SCOOT and video detection systems could fit inside the existing intersection signal control cabinets.
- The City uses Eagle controllers, but any NEMA controller could meet the SCOOT system's requirements.
- The City still had approximately 15 electromechanical controllers in use in the study area. These controllers had to be replaced to allow for integration with the SCOOT system.
- The City utilizes real-time communications between the Traffic Control Center and the field intersection signal control cabinets. This met SCOOT's second-by-second communication requirement. A centralized traffic system that updates once every cycle length, for example, would not support a SCOOT deployment.
- The City did lack one important infrastructure item – they did not have an in-place detection system that could support the SCOOT system requirements. The only in-place detectors in the region were a few inductive loop detectors. An extensive detection deployment was required to meet the SCOOT system's requirements of upstream detection on every link in the study area. Given the cost and disruption involved in installing loop detectors in the pavement, a video detection system was selected. The video sensors utilized much of the existing infrastructure when deployed in the study area. For example, the sensors were installed on existing street luminaire poles.

6.3.6.3. System Integration

System integration was accomplished by adding the SCOOT system to the current T2000C system, allowing the SCOOT system to operate with the in-place T2000C system. The systems are configured to enable selection of either the T2000C system or the SCOOT system to control the signal system. The SCOOT system operates on its own computer, where it continuously develops new timing plans. These new timing plan values are sent to the T2000C system which, in turn, converts the SCOOT timing into control commands and sends them to the traffic signal controllers. This approach required that SCOOT be disconnected from its typical UTC system and that linkage and interfacing software be developed to support a connection to the T2000C.

While Minneapolis is the only city to operate a T2000C UTC system in the United States, the lessons learned from this project are still applicable to other urban areas. Integrating SCOOT into any existing UTC system would require making many of the same decisions that were made in the AUSCI project. Consideration must be given to the degree of integration that is desired. The following questions should be considered:

- Should the UTC function reside with the SCOOT system, or should the existing system retain this function, as was done in the AUSCI project?
- Should the systems be fully integrated, or should they each retain a separate user interface, as was done in the AUSCI project?

6.3.6.4. System Features and Functions

Many features and functions of the SCOOT adaptive control system proved valuable in the AUSCI project and would be useful in other adaptive system implementations. For example, the ASTRID software module can report a variety of traffic parameters for inspection. The City of Minneapolis staff examines daily summaries of traffic parameters, such as cycle lengths, to monitor the system's performance. While the City received all of the features available from SCOOT version 2.4, additional features can be developed. For example, Fortran has developed many additional features and functions for the SCOOT system in Toronto. While these were not implemented in Minneapolis, they may be useful in other urban areas. Some of these functions are listed below:

- Real-time time/space diagrams
- Windows 95 or Windows NT Graphical User Interface (GUI)
- SQL database package
- Customized alarm functions
- Fastracs

6.3.6.5 Policy and Procedures

Several in-place policies and procedures facilitated a smooth project deployment. The City of Minneapolis made a strong commitment to the AUSCI project. This commitment was essential to ensure that the necessary staff and training were available, so that the system was correctly deployed and operated. The City must maintain this level of support in order to keep the system correctly calibrated and up-to-date. A history of strong support for advanced traffic management strategies is important in other deployments.

6.3.6.6 Transferability Summary

The lessons learned in the AUSCI project are largely transferable to others attempting a similar project. One of the most important lessons is that it is necessary for the project team to have a thorough knowledge of both the existing and proposed systems. This allows the project team to be realistic about the amount of effort involved in integrating an adaptive system and the potential benefits that can be derived. Although Minneapolis operates the only T2000C system in the United States, many of the key findings from this evaluation are transferable to other cities. Other cities with a UTC system would be faced with similar questions and would be able to use many of the AUSCI project tasks. Results from this evaluation could be useful in estimating the cost of a future adaptive system installation, by providing, for example, an estimate of the number of detectors required per approach, or the type of database development that is required.

6.4. CONCLUSIONS

The AUSCI project represents a model deployment of an adaptive signal control system within an existing centrally controlled system. The lessons learned in this project are transferable to other medium-sized metropolitan areas. The deployment issues, costs, and transportation system impacts are also useful to the City of Minneapolis in determining the future expansion of the adaptive system.

This document identifies the deployment issues of the adaptive signal control system. These issues were identified through a combination of surveys, interviews and observations of project participants. The following lessons were learned from this project:

- Staff availability and continuity are critical to the project schedule.
- Involved agencies and participating partners must actively support the project.
- Partnering fostered a cooperative spirit among project participants.
- Partnering was effective because all partners had a stake in the successful outcome of the project and shared in the project's risks.
- Project delays and funding requirements were much greater than anticipated.
- Preparation of the scope of work with Fortran was complicated by several factors: the City's concern about maintaining the existing signal control system, the proprietary nature of SCOOT software, and international differences in requirements, such as errors and omissions insurance.

- International issues related to participants from three countries played a larger role than originally foreseen.
- Given the success of this project, other agencies should fully explore the options for implementing a similar deployment.

Some technical and institutional issues did take more time to resolve than originally anticipated. This led to project delays and funding shortfalls when compared to the original program-level estimates. As the project proceeded, the true magnitude of the project tasks became known and the schedule and budget had to be revised accordingly. Without the history of how similar projects were deployed, there was no way to accurately predict the resources that would be needed. Part of what was learned in this operational test is the true level of effort required to deploy the system.

In summary, this project has been remarkably successful for the level of sophistication, time required and number of parties involved. Ultimately, all of the institutional and technical issues were overcome. Partnering was central to this success; it opened the channels of communication and created a cooperative atmosphere in which challenges could be effectively resolved.

7. REFERENCES

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APPENDIX A

AUSCI PERFORMANCE CHARACTERISTICS SURVEY

Name: ____________________________________

Agency: __________________________________

Date: _____________________________________

This survey is designed to identify the performance characteristics of the AUSCI system as identified in the *Evaluation Test Plan*. The responses from this survey will be summarized and included in the final Evaluation Report. Attach additional sheets if necessary.

1. Describe the **integratability** of the SCOOT system with the existing T2000C system. To what extent did the integration process place a restriction on the adaptive system? Were any SCOOT features or functions lost because of the integration? Were any T2000C features of functions lost? Briefly describe the major technical issues that were faced in the integration of the two systems.

2. Describe the **operability** or "usability" of the AUSCI system. This is a qualitative measure of how the system interfaces with its operators. Is the system intuitive to use? Is it user-friendly? What tasks are involved to operate the system? How often are these performed – daily, monthly, or annually? How has the usability of the T2000C system changed with the installation of the SCOOT system?

3. Identify the **most effective approaches** for operating, controlling, and managing the AUSCI system. For example, regarding control of the system, are the system operators subjected to time constraints that prevent them from utilizing every feature of the AUSCI system? What methods have proven effective in managing the system?

4. Describe the **adaptability** of the AUSCI system. Given your experience in observing the system in operation, give a qualitative description of how the system adapts to changing traffic conditions. Is this a noticeable improvement over the previous system?

5. Describe the **reliability** of the AUSCI system. What types of failures has the system experienced during the evaluation period between June 1 and August 31, 1999? Include both failures of the SCOOT system and of any supporting systems. What is the mean time between failures for each type of failure? What level of effort was required to correct the failure? What is your general impression of the system's reliability? How does it compare to the previous system?

6. Describe the **maintainability** of the AUSCI system. What tasks are involved in routine system maintenance? How often are these tasks performed - daily, monthly, or annually? What is the mean time required to make repairs? Can this work be scheduled, or is the maintenance work unscheduled? Include both regular system maintenance and ongoing validation work required to keep the system correctly calibrated. How does the AUSCI system's maintainability compare to the existing system?

7. Describe the **expandability** of the AUSCI system. First, give a qualitative discussion of the perceived barriers/opportunities to expand the system to include additional intersections and/or functions.

   Next, identify the physical limitations of each of the following:

   - Is there a limit on expanding SCOOT? How many additional detectors can be added? How many additional links?
   - Is there an interest in expanding the T2000C? What are the limits?
   - Does the control center itself place any restrictions on expansion?
   - Is there a limit on the communication infrastructure (i.e., the amount of reserve capacity in the City's communication network)?
   - Is there a limit on expanding the video detection system?

8. Describe the transferability of the AUSCI system. Give a qualitative discussion of the perceived feasibility/ease of transferring useful information to other urban areas attempting a similar project. To what extent is the Minneapolis UTC system unique? To what extent are the lessons learned transferable to others attempting a similar project?

   In order to make this evaluation useful to a wide audience, provide detailed information on the following existing conditions:

   a) Base conditions:

      - Current congestion levels
      - Details of the City's street network
      - Size of blocks
      - Location of one-way/two-way links
      - Details of the City's existing timing information
        - When were they prepared?
        - Who prepared them?
        - When were they last modified?
        - What is the extent of the system (number of intersections)?
        - How were they designed (using Passer, Transyt, etc.)?

b) Existing infrastructure:

Into what infrastructure is the new adaptive signal control system most easily integrated (i.e., type of cabinets, controllers, communications, etc.)?

c) Policy and procedures:

What policy and procedures should be in place for a smooth system deployment?

d) System features and functions:

Identify additional features and functions of the SCOOT adaptive control system that would be useful in future adaptive systems.

9. Assess the **capabilities** of the AUSCI system. The number of features or functions that the adaptive system can successfully provide will be used to assess the system's capabilities. Only the functions required by the adaptive signal control system will be evaluated. The system will also be examined to see that it performs all of the functions stated in the original project scope. Even though other features may be available, they will not be investigated if they were not specified in the original performance specifications.

   Below is a partial list of the system requirements. Please describe how effectively the AUSCI system met each requirement.

   1. Modify the T2000C central computer hardware to allow for the additional tasks to provide adaptive control.

   2. Modify the T2000C software, database and TELAN (Traffic Engineering Language) to accommodate the addition of the SCOOT module.

   3. Add a second smaller computer (the SCOOT computer) to run the SCOOT adaptive algorithm and interconnect it to the T2000C traffic control computer.

   4. Modify the SCOOT module interface so that it will link to the T2000C control software.

   5. Modify the CMU by adding I/O modules and/or detector modules to allow for the required "green" feedbacks and/or SCOOT detectors into the SCOOT optimization module.

   6. Perform a detector loop siting survey to define the locations of the SCOOT specific detectors.

7. Install the SCOOT detector loops and associated detector amplifiers and wire them into the traffic control cabinet and the CMU.

8. Integrate the two computers, the T2000C software and the SCOOT module, make them operational, test them, provide training to the City staff, enter the SCOOT database, perform acceptance testing, and supply appropriate documentation.

9. Perform the SCOOT validation at each intersection in the initial SCOOT controlled road network.

10. Perform fine-tuning of the validation parameters to achieve optimal performance under SCOOT control.

What additional features and functions does the AUSCI system provide? Provide a list of other prominent system features.

10. As owner of the AUSCI system, give a qualitative discussion of your perception of value for the system. What have been the positive aspects of the system? The negative aspects? What impacts to traffic operations have you perceived? Do these impacts vary by time-of-day, by location within the system, or by special events/incidents? What is your perception of the ease of system use? Ease of system maintenance? Finally, what is your overall perception of the system's value?

APPENDIX B

AUSCI MAINTENANCE LOG

Name: ____________________________________

Agency: __________________________________

Date: ____________________________________

Objective 1-1 of Test Plan 1 identifies issues associated with the system maintenance and reliability. This objective examines the average amount of time and effort to perform both preventative maintenance and maintenance related to component failure. Where applicable, maintainability will be expressed in terms of mean time required to make repairs and reliability will be expressed in terms of mean time between failures.

System maintenance will be examined on a monthly basis from June 1 to August 31, 1999. Please submit completed log sheets to Erik Minge with SRF Consulting Group on the first business day of each month. Use one log sheet for each occurrence.

Preventative/Scheduled Maintenance (describe work performed): _________________

____

____

____

____

Duration of downtime: ____

Time spent: ____

Personnel costs (including hours/job classification): _______________________________

____

Equipment costs: ____

____

Maintenance due to component failure (describe nature of failure - equipment, communication, data, etc.): ____

____

____

____

Time of failure: ____

Time when operation restored: ____

Duration of downtime: ____

Time to repair: ____

Action taken: ____

____

____

Impact to system: ____

____

____

Personnel costs (including hours/job classification): _____________________

____

Equipment costs: ____

____

APPENDIX C

AUSCI Operation Log

Name: ____________________________________

Agency: __________________________________

Date: ____________________________________

Objective 3-2 of Test Plan 3 identifies costs associated with the system operation. This objective examines the average amount of time and effort to operate the system under normal conditions and to perform ongoing system modification work.

System operations information will be examined on a monthly basis from June 1 to August 31, 1999. Please submit completed log sheets to Erik Minge with SRF Consulting Group on the first business day of each month. Use one log sheet for each occurrence.

Normal System Operations (describe work performed): __________________________

____

____

____

____

Duration of downtime: ____

Time spent: ____

Frequency: ____

Location(s): ____

Personnel Costs (including hours/job classification): ______________________________

____

Equipment costs: ____

____

Ongoing System Modification (describe work performed): ______________________

____

____

____

____

____

Duration of downtime: ____

Time spent: ____

Location(s): ____

Personnel Costs (including hours/job classification): _____________________

____

Equipment costs: ____

____

APPENDIX D

DATA COLLECTION FORMS

SRF CONSULTING GROUP, INC

DELAY STUDY FIELD SHEET

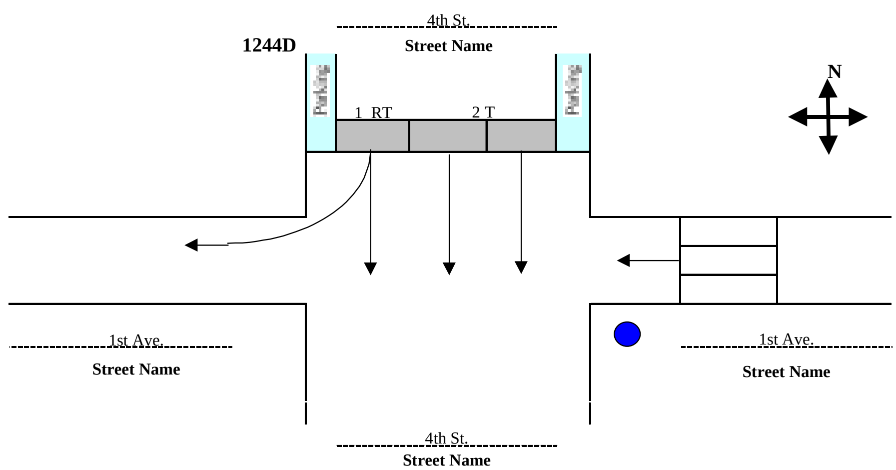
Project AUSCI **Name**

Date August 19, 1999 **Day** Thursday **Weather**

Intersection of 4th St. **And** 1st Ave. **Approach** 1244D

Time Period 6:30 AM - 10:30 AM

Time (Time of Day)	**Total Number of Vehicles Stopped in the Approach at Time:**			**Comment**
	0 Sec	20 Sec	40 Sec	
6:30 AM				
6:31 AM				
6:32 AM				
6:33 AM				
6:34 AM				
6:35 AM				
6:36 AM				
6:37 AM				
6:38 AM				
6:39 AM				
6:40 AM				
6:41 AM				
6:42 AM				
6:43 AM				
6:44 AM				
6:45 AM				
6:46 AM				
6:47 AM				
6:48 AM				



Note: Please count the approach with shaded boxes

SRF CONSULTING GROUP, INC

TRAVEL TIME STUDY FIELD SHEET

Project	AUSCI	**Name**	
Date	August 19, 1999	**Day**	Thursday
Route	4	**Weather**	
Time Period	6:30 a.m. - 10:30 a.m.		

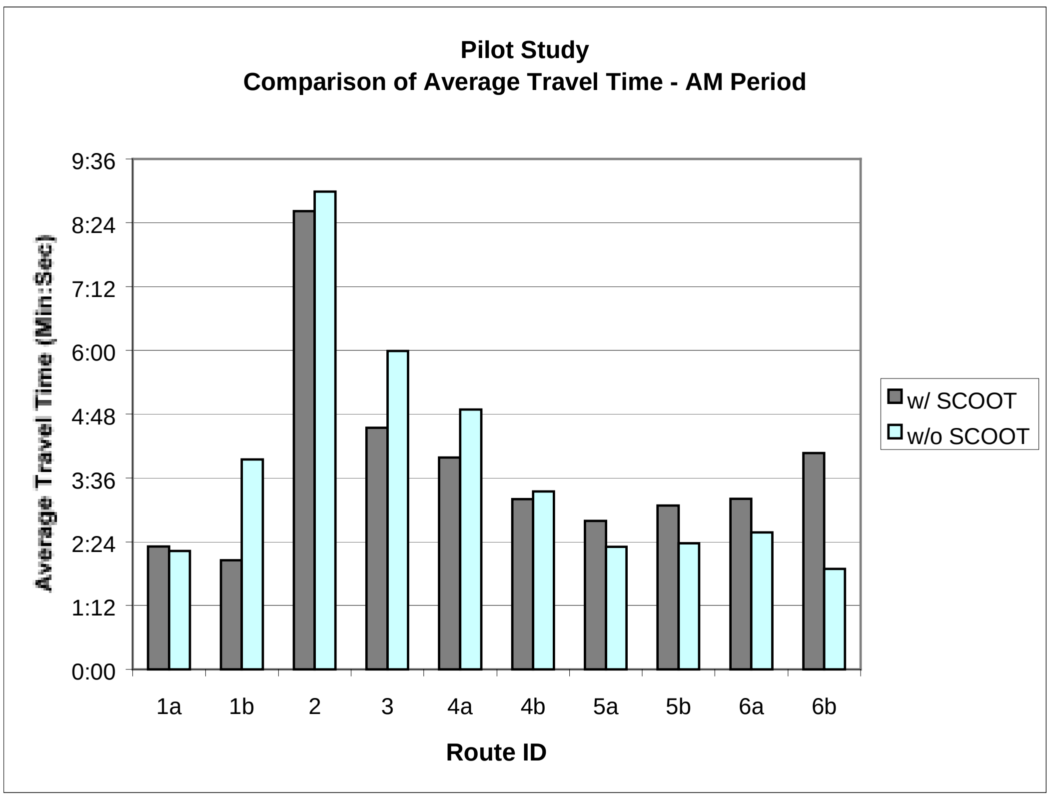
Start Time (Time of Day)	**Travel Time** (Elapsed Time)		**Comment**
	A to B (A = Hennepin/12nd St.) (B = Washington/2nd Ave. N)	**C to D** (C = Washington/3rd Ave. N) (D = 12nd St/Hawthorne)	

APPENDIX E

PILOT STUDY RESULTS

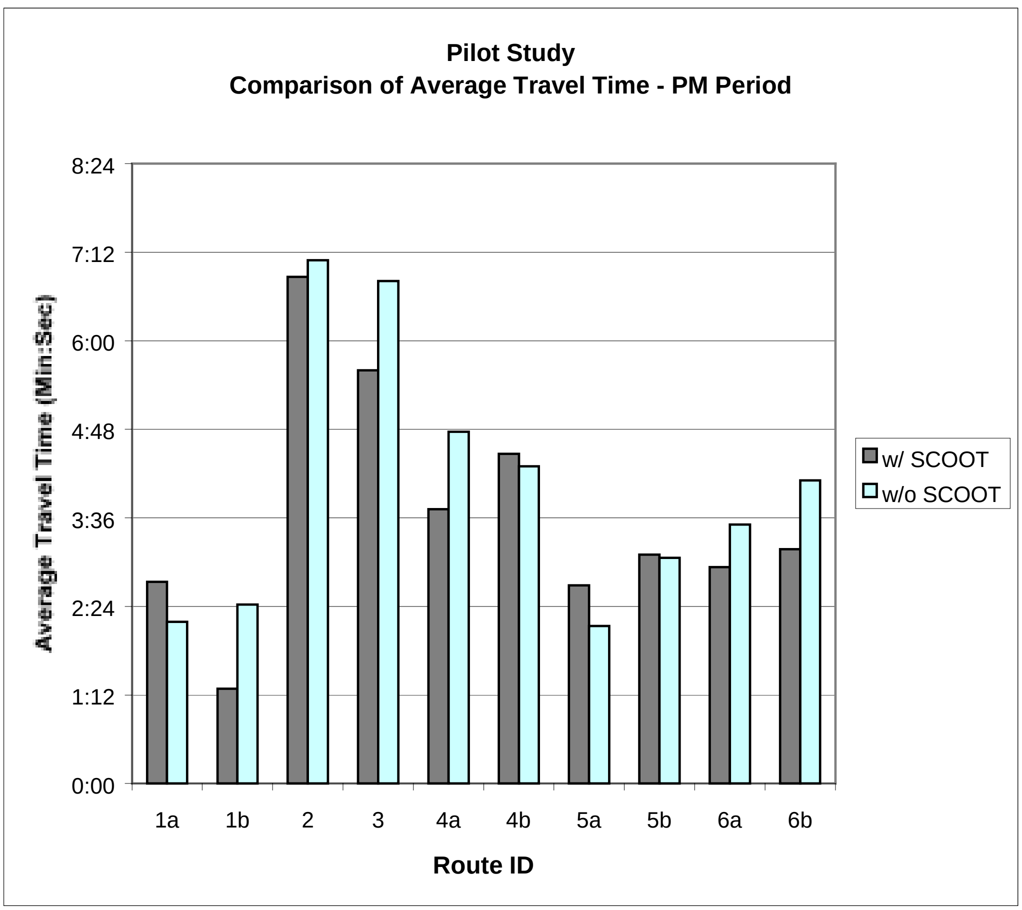
Pilot Study
Travel Time AM Period
Note: small sample size

Route ID	w/ SCOOT	w/o SCOOT	% Difference
Normal Condition			
1a	2:18	2:13	3.7%
1b	2:03	3:57	-48.1%
2	8:37	8:59	-4.1%
3	4:32	5:59	-24.1%
4a	3:59	4:53	-18.4%
4b	3:12	3:20	-4.2%
Average	4:07	4:53	**-15.9%**
Boundary Condition			
5a	2:47	2:18	21.4%
5b	3:05	2:22	30.3%
6a	3:12	2:34	24.6%
6b	4:04	1:53	115.0%
Average	3:17	2:17	**44.0%**
Average	3:47	3:51	**-1.7%**



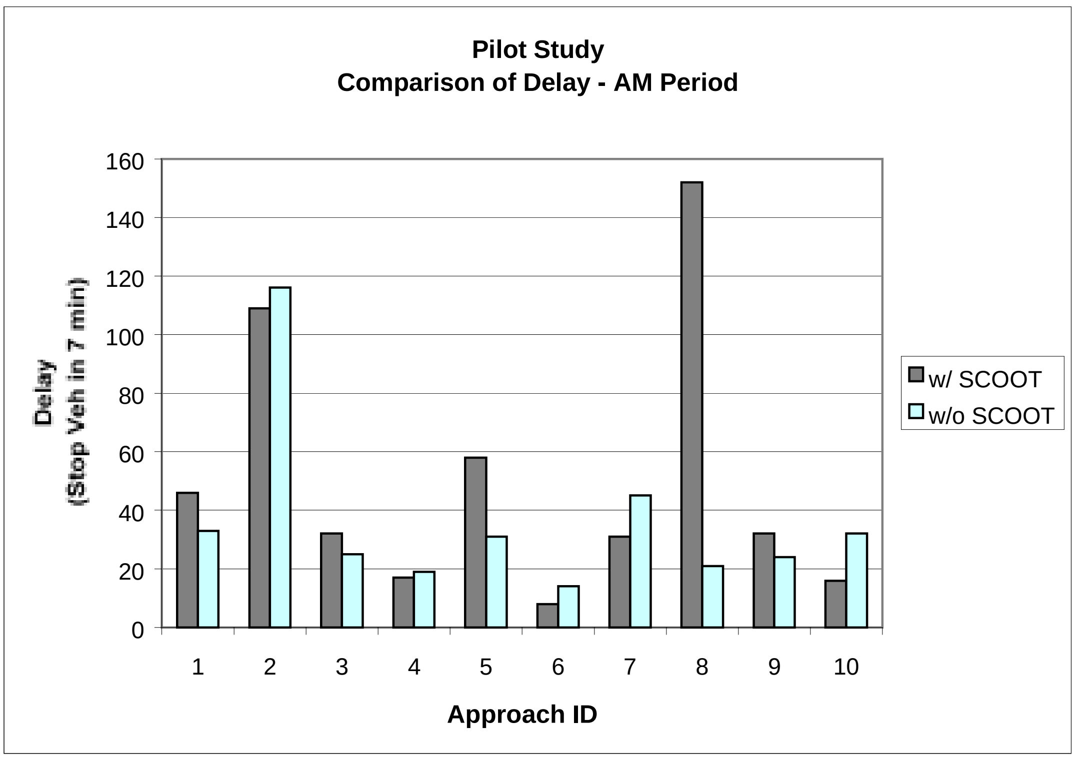
Pilot Study
Travel Time PM Period
Note: small sample size

Route ID	w/ SCOOT	w/o SCOOT	% Difference
Normal Condition			
1a	2:44	2:11	24.7%
1b	1:17	2:25	-47.1%
2	6:52	7:05	-3.2%
3	5:36	6:48	-17.7%
4a	3:43	4:46	-22.0%
4b	4:28	4:18	3.9%
Average	4:06	4:35	**-10.6%**
Boundary Condition			
5a	2:41	2:08	25.8%
5b	3:06	3:03	1.4%
6a	2:56	3:30	-16.4%
6b	3:10	4:06	-22.7%
Average	2:58	3:12	**-7.2%**
Average	**3:39**	**4:02**	**-9.5%**



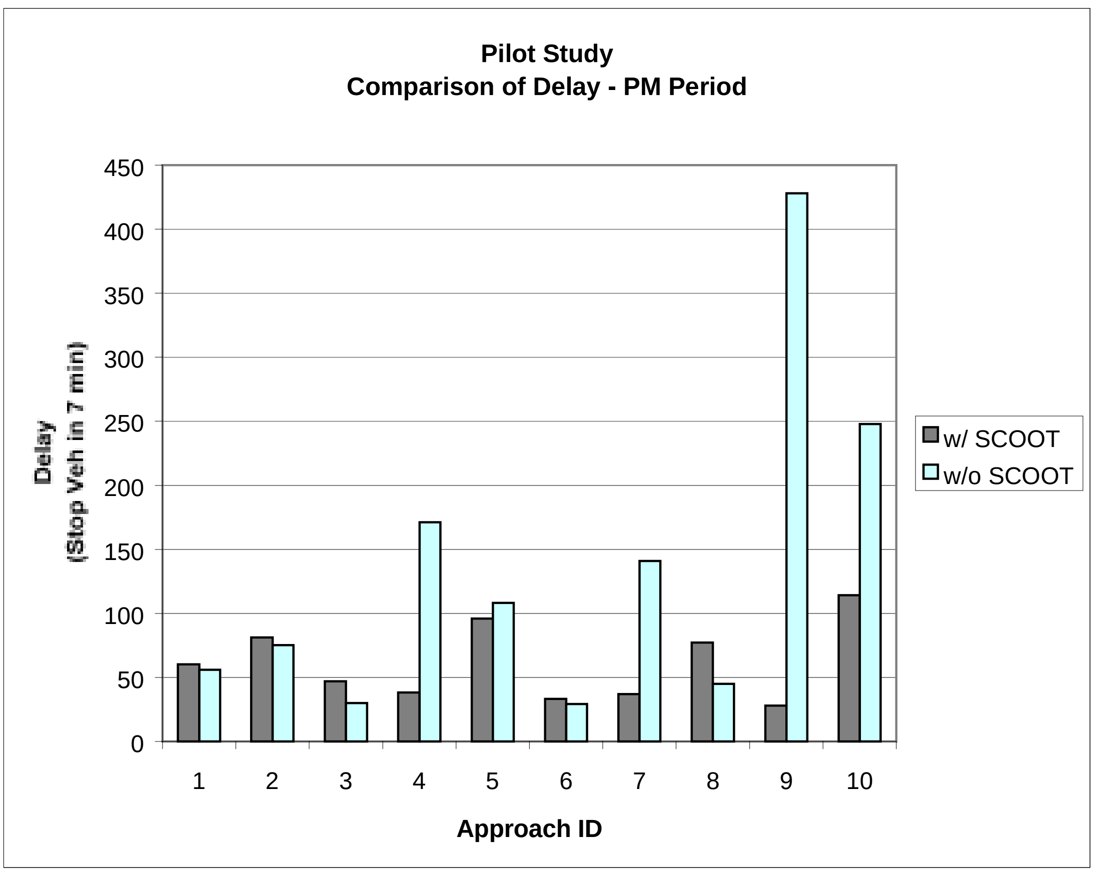
Pilot Study
Delay (Stopped Veh per 7min) AM Period
Note: small sample size

Approach	w/ SCOOT	w/o SCOOT	% Difference
Normal Condition			
1	46	33	39.4%
2	109	116	-6.0%
3	32	25	28.0%
4	17	19	-10.5%
5	58	31	87.1%
6	8	14	-42.9%
Average	45	40	**13.4%**
Boundary Condition			
7	31	45	-31.1%
8	152	21	623.8%
9	32	24	33.3%
10	16	32	-50.0%
Average	58	31	**89.3%**
Average	50	36	**39.2%**



Pilot Study
Delay (Stopped Veh per 7min) PM Period
Note: small sample size

Approach	w/ SCOOT	w/o SCOOT	% Difference
Normal Condition			
1	60	56	7.1%
2	81	75	8.0%
3	47	30	56.7%
4	38	171	-77.8%
5	96	108	-11.1%
6	33	29	13.8%
Average	59	78	**-24.3%**
Boundary Condition			
7	37	141	-73.8%
8	77	45	71.1%
9	28	428	-93.5%
10	114	248	-54.0%
Average	64	216	**-70.3%**
Average	**61**	**133**	**-54.1%**

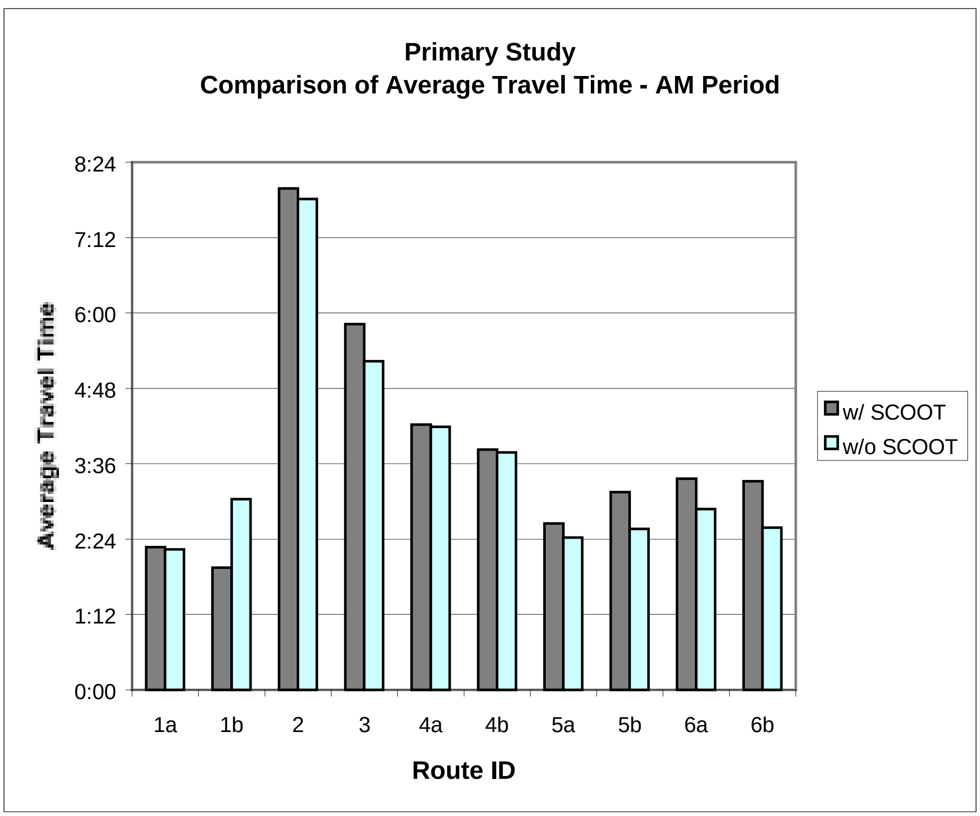


APPENDIX F

PRIMARY STUDY RESULTS
TRAVEL TIME

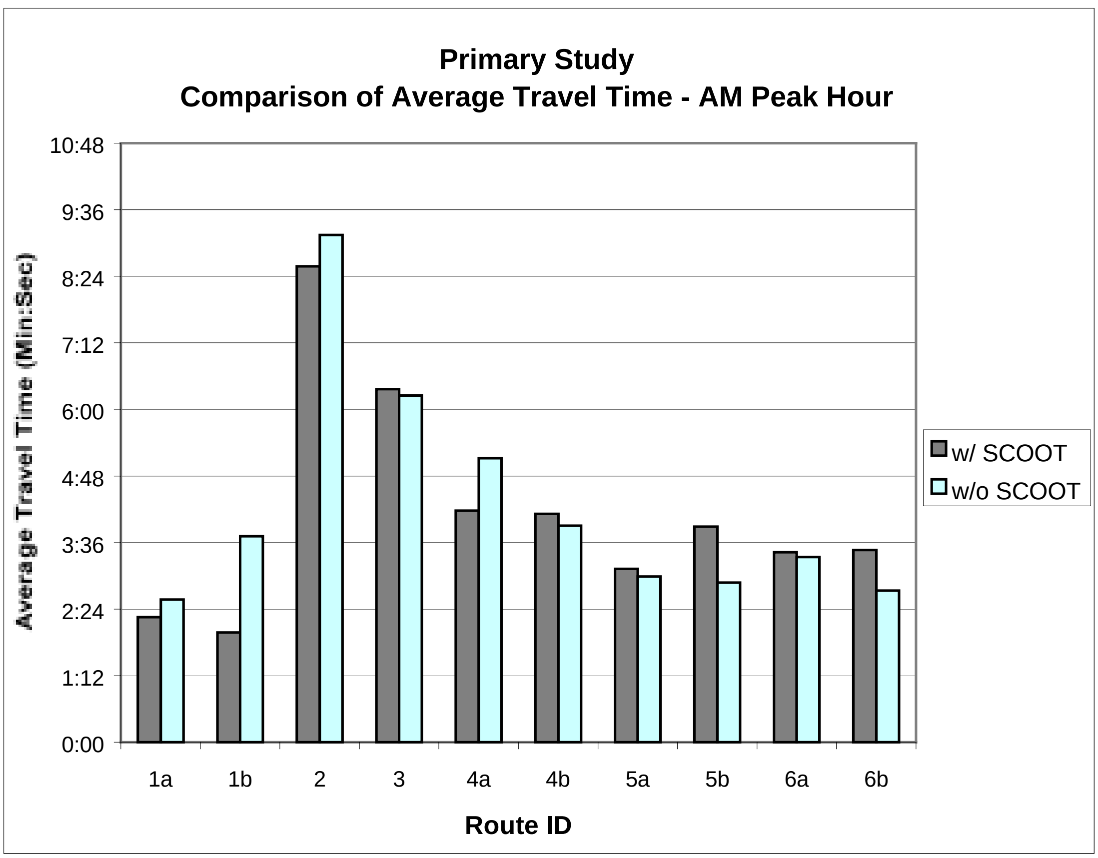
Primary Study
Travel Time AM Period

Route ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
Normal Condition				
1a	2:16	2:14	1.6%	No
1b	**1:56**	**3:02**	**-35.8%**	**Yes - SCOOT**
2	7:59	7:49	2.1%	No
3	**5:49**	**5:13**	**11.3%**	**Yes - T2000C**
4a	4:13	4:11	0.9%	No
4b	3:49	3:46	1.2%	No
Average	4:20	4:22	**-0.8%**	No
Boundary Condition				
5a	2:38	2:25	**9.3%**	No
5b	3:08	2:33	**22.9%**	**Yes - T2000C**
6a	3:21	2:52	**16.7%**	**Yes - T2000C**
6b	3:19	2:35	**28.4%**	**Yes - T2000C**
Average	3:07	2:36	**19.4%**	**Yes - T2000C**
Average	**3:51**	**3:40**	**4.9%**	



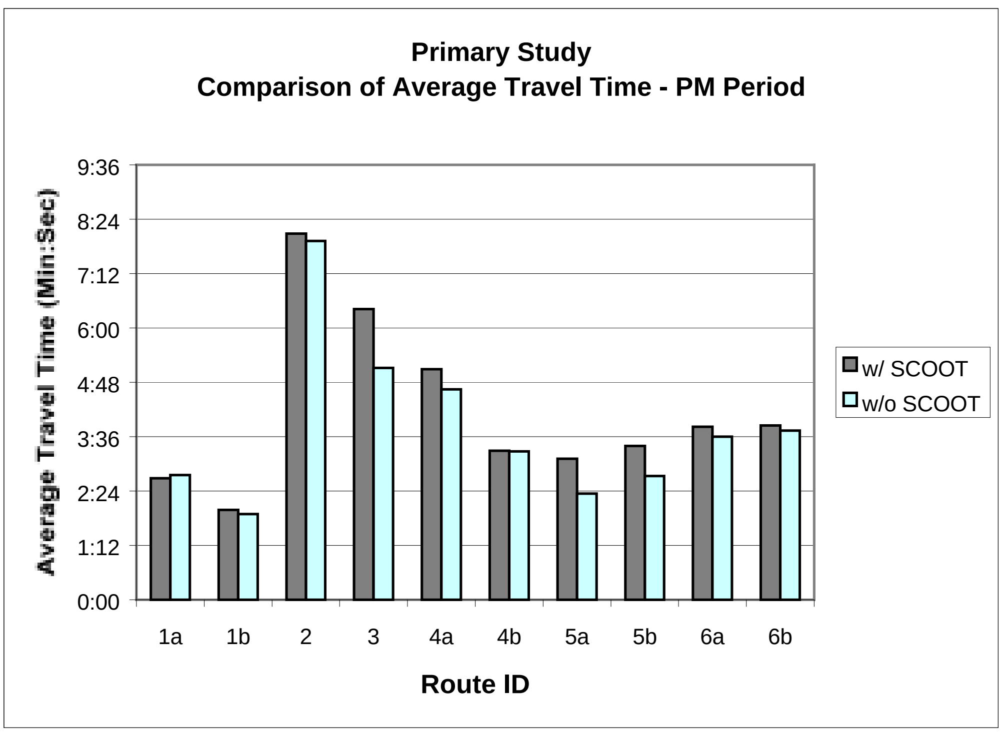
Primary Study
Travel Time AM Peak Hour

Route ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
Normal Condition				
1a	2:15	2:34	-12.5%	No
1b	**1:58**	**3:42**	**-46.8%**	**Yes - SCOOT**
2	8:34	9:08	-6.2%	No
3	6:22	6:15	1.8%	No
4a	**4:10**	**5:07**	**-18.5%**	**Yes - SCOOT**
4b	4:07	3:54	5.5%	No
Average	4:34	5:07	**-10.6%**	**Yes - SCOOT**
Boundary Condition				
5a	3:07	2:59	4.6%	No
5b	**3:53**	**2:52**	**35.1%**	**Yes - T2000C**
6a	3:25	3:20	2.6%	No
6b	**3:27**	**2:44**	**26.7%**	**Yes - T2000C**
Average	3:28	2:59	**16.4%**	**Yes - T2000C**
Average	**4:08**	**4:15**	**-3.0%**	



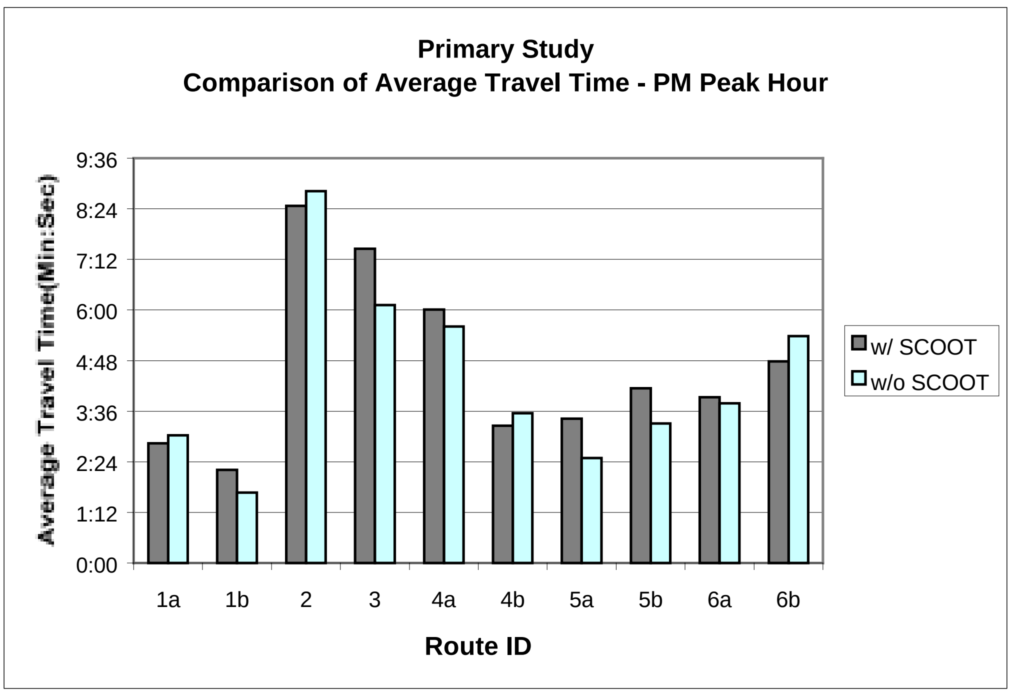
Primary Study
Travel Time PM Period

Route ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
Normal Condition				
1a	2:41	2:44	-2.3%	No
1b	1:59	1:53	4.9%	No
2	8:04	7:55	2.0%	No
3	**6:24**	**5:07**	**25.3%**	**Yes - T2000C**
4a	**5:05**	**4:38**	**9.6%**	**Yes - T2000C**
4b	3:17	3:16	0.6%	No
Average	4:35	4:15	**7.6%**	**Yes - T2000C**
Boundary Condition				
5a	**3:06**	**2:20**	**32.6%**	**Yes - T2000C**
5b	**3:23**	**2:44**	**24.2%**	**Yes - T2000C**
6a	**3:48**	**3:35**	**6.1%**	**Yes - T2000C**
6b	3:50	3:44	2.9%	No
Average	3:32	3:06	**14.1%**	**Yes - T2000C**
Average	**4:10**	**3:48**	**9.7%**	



Primary Study
Travel Time PM Peak Hour

Route ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
Normal Condition				
1a	2:50	3:01	-6.2%	No
1b	**2:12**	**1:39**	**32.3%**	**Yes - T2000C**
2	8:28	8:49	-4.0%	No
3	**7:26**	**6:06**	**21.8%**	**Yes - T2000C**
4a	6:00	5:36	7.2%	No
4b	3:15	3:33	-8.3%	No
Average	5:02	4:47	**5.0%**	No
Boundary Condition				
5a	**3:25**	**2:29**	**37.5%**	**Yes - T2000C**
5b	**4:08**	**3:18**	**25.3%**	**Yes - T2000C**
6a	3:55	3:47	3.7%	No
6b	4:47	5:22	-11.0%	No
Average	4:04	3:44	**8.8%**	**Yes - T2000C**
Average	**4:39**	**4:22**	**6.3%**	



Primary Study
Travel Time
Analysis per Day and per Approach

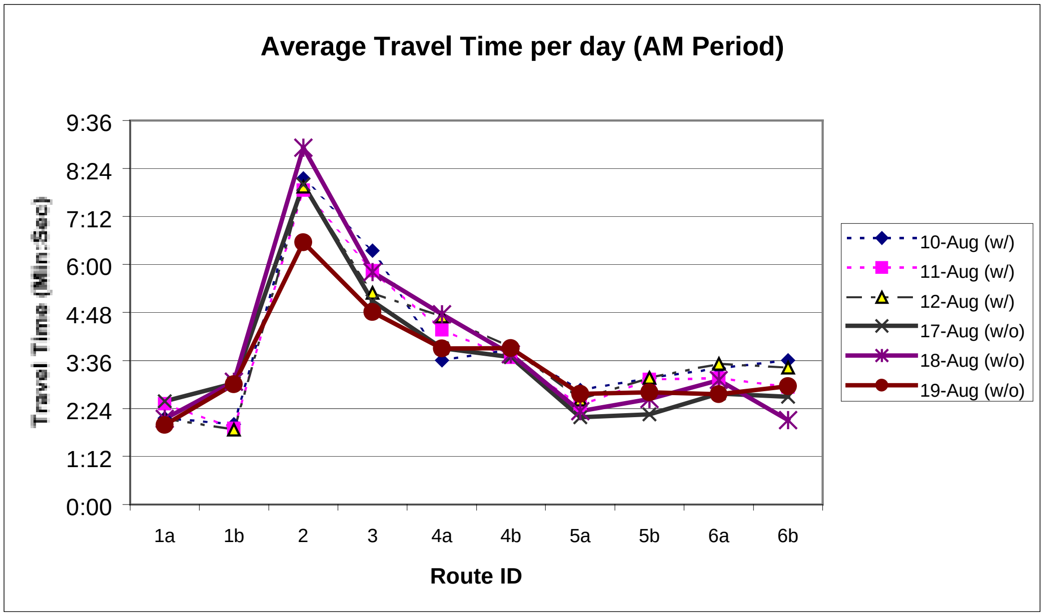
Travel Time

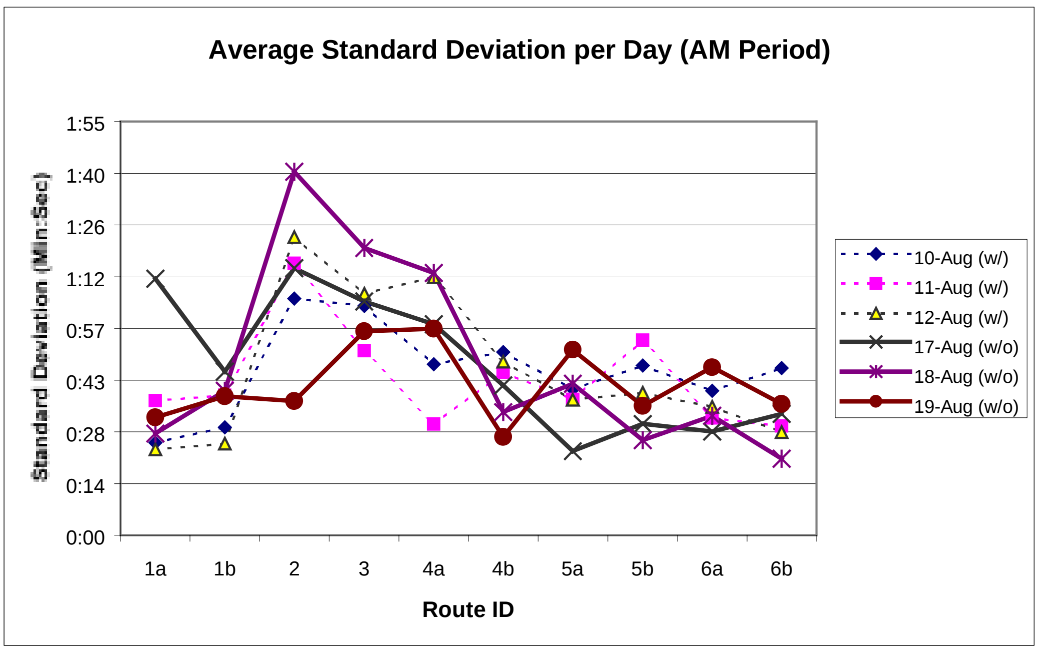
AM Period

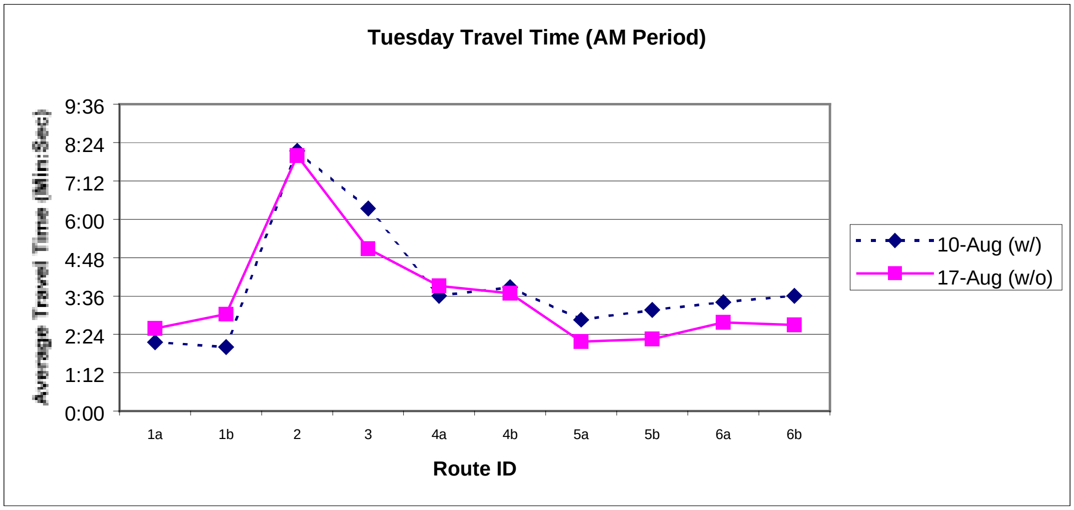
SCOOT Status	With SCOOT				Without SCOOT			
Route ID	10-Aug	11-Aug	12-Aug	Sub Avg.	17-Aug	18-Aug	19-Aug	Sub Avg.
1a	2:09	2:30	2:09	2:16	2:34	2:08	1:59	2:14
1b	2:00	1:54	1:51	1:55	3:01	3:04	3:00	3:02
2	8:09	7:51	7:56	7:59	7:59	8:55	6:33	7:49
3	6:20	5:50	5:17	5:49	5:04	5:48	4:48	5:13
4a	3:36	4:21	4:42	4:13	3:54	4:44	3:54	4:11
4b	3:52	3:40	3:55	3:49	3:40	3:45	3:54	3:46
5a	2:51	2:27	2:37	2:38	2:10	2:20	2:45	2:25
5b	3:09	3:07	3:09	3:08	2:15	2:38	2:48	2:33
6a	3:24	3:09	3:30	3:21	2:46	3:06	2:45	2:52
6b	3:36	2:55	3:25	3:19	2:41	2:06	2:57	2:35
Average	3:55	3:46	3:51	**3:51**	3:37	3:51	3:32	**3:40**

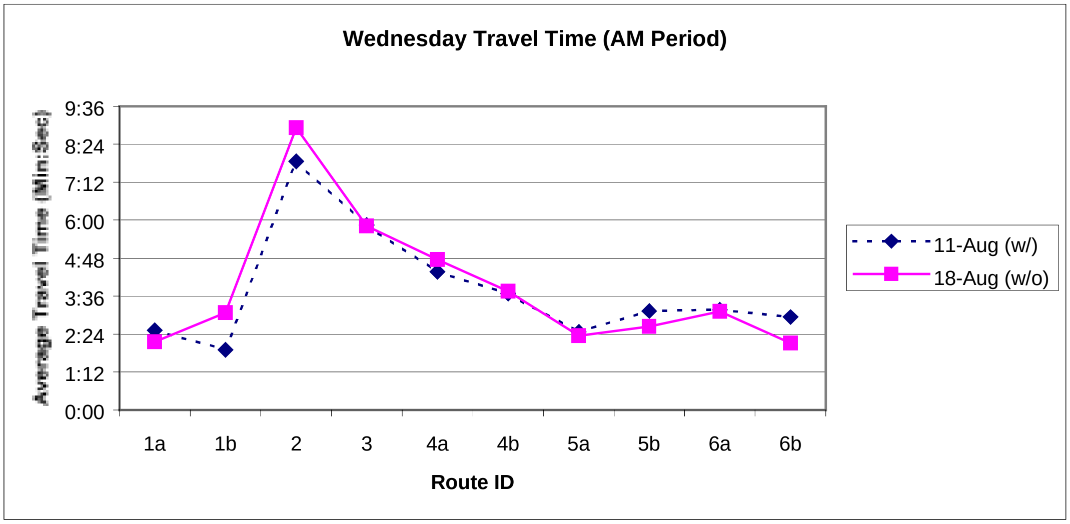
Travel Time Standard Deviation

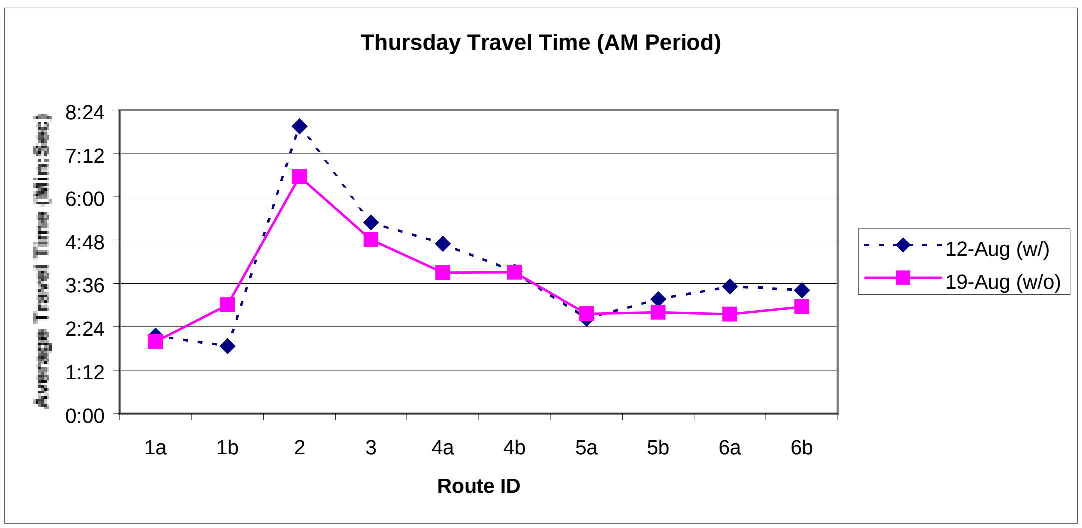
SCOOT Status	With SCOOT				Without SCOOT			
Route ID	10-Aug	11-Aug	12-Aug	Sub Avg.	17-Aug	18-Aug	19-Aug	Sub Avg.
1a	0:25	0:37	0:23	0:31	1:11	0:28	0:32	0:47
1b	0:30	0:39	0:25	0:32	0:45	0:40	0:38	0:40
2	1:05	1:15	1:23	1:14	1:14	1:41	0:37	1:32
3	1:03	0:51	1:07	1:05	1:05	1:20	0:56	1:12
4a	0:47	0:30	1:11	0:58	0:58	1:13	0:57	1:06
4b	0:50	0:45	0:48	0:47	0:41	0:34	0:27	0:34
5a	0:40	0:37	0:37	0:38	0:23	0:42	0:51	0:42
5b	0:47	0:54	0:39	0:46	0:30	0:26	0:36	0:34
6a	0:40	0:32	0:35	0:37	0:28	0:33	0:46	0:37
6b	0:46	0:30	0:28	0:39	0:33	0:21	0:36	0:37
Average	1:59	1:50	1:52	**1:54**	1:48	2:03	1:28	**1:47**

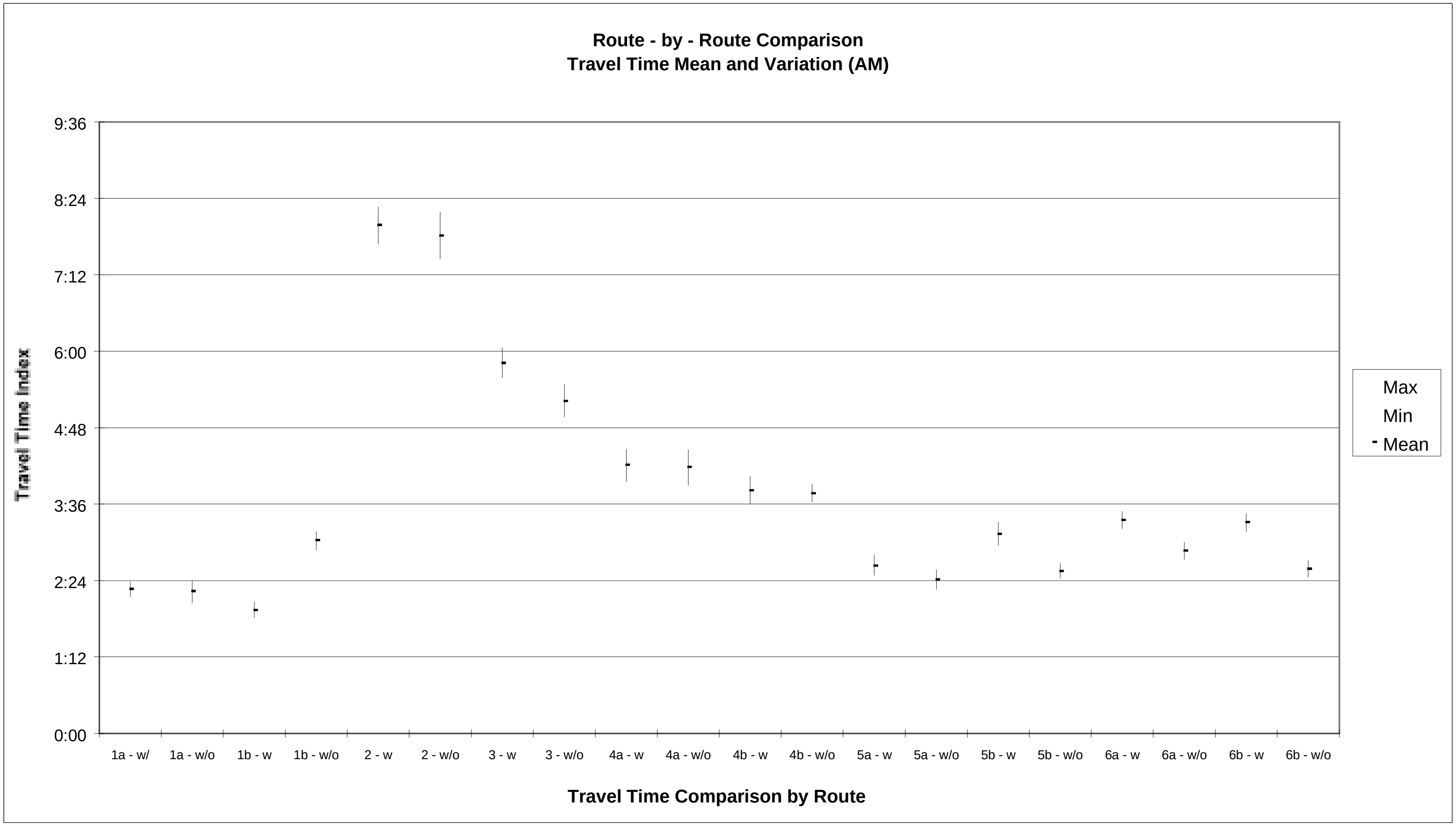

Average Travel Time per day (AM Period)
Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)


Average Standard Deviation per Day (AM Period)
Standard Deviation (Min:Sec)
1:55
1:40
1:26
1:12
0:57
0:43
0:28
0:14
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)


Tuesday Travel Time (AM Period)
Average Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
10-Aug (w/)
17-Aug (w/o)


Wednesday Travel Time (AM Period)
Average Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
11-Aug (w/)
18-Aug (w/o)


Thursday Travel Time (AM Period)
Average Travel Time (Min:Sec)
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
12-Aug (w/)
19-Aug (w/o)


Route - by - Route Comparison
Travel Time Mean and Variation (AM)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
Travel Time Index
1a - w/
1a - w/o
1b - w
1b - w/o
2 - w
2 - w/o
3 - w
3 - w/o
4a - w
4a - w/o
4b - w
4b - w/o
5a - w
5a - w/o
5b - w
5b - w/o
6a - w
6a - w/o
6b - w
6b - w/o
Travel Time Comparison by Route
Max
Min
Mean

Primary Study

Summary of Hypothesis Test for Travel Time (AM)

z-Test: Two-Sample for Means

H0 = Travel Time did not reduce for the sysem with SCOOT

H1 = Travel Time reduced for the sysem with SCOOT

	Route 1a		**Route 1b**		**Route 2**		**Route 3**	
	w/ SCOOT	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*
Mean	2:17	2:12	1:55	3:02	7:58	7:38	5:48	5:14
Percentage Differnece	1.60%		-35.80%		2.10%		11.30%	
Variance	0.0005	0.0011	0.0005	0.0008	0.0027	0.0041	0.0021	0.0025
Observations	79	84	77	85	69	70	84	85
Hypothesized Mean Difference	0		0		0		0	
z Stat	**0.74**		**-11.47**		**1.39**		**3.20**	
P(Z<=z) two-tail	0.46		0.00		0.17		0.00	
z Critical two-tail	1.96		1.96		1.96		1.96	
Result	z Stat < zc	Accept H0	abs(z Stat) > zc	Reject H0	z Stat < zc	Accept H0	z Stat > zc	Reject H0

	Route 4a		**Route 4b**		**Route 5a**		**Route 5b**	
	w/ SCOOT	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*
Mean	4:13	4:10	3:49	3:47	2:37	2:24	3:10	2:32
Percentage Differnece	0.90%		1.20%		9.30%		22.90%	
Variance	0.0016	0.0021	0.0011	0.0006	0.0007	0.0009	0.0010	0.0006
Observations	56	62	56	62	70	90	70	89
Hypothesized Mean Difference	0		0		0		0	
z Stat	**0.27**		**0.27**		**1.93**		**5.67**	
P(Z<=z) two-tail	0.79		0.79		0.06		0.00	
z Critical two-tail	1.96		1.96		1.96		1.96	
Result	z Stat < zc	Accept H0	z Stat < zc	Accept H0	z Stat < zc	Accept H0	z Stat > zc	Reject H0

	Route 6a		**Route 6b**		**Route 1a,1b,2,3,4a,4b (All routes within study area)**		**Route 5a,5b,6a,6b (All routes crossing study boundary)**	
	w/ SCOOT	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*	*w/ SCOOT*	*w/o SCOOT*
Mean	3:22	2:53	3:20	2:32	4:19	4:16	3:08	2:35
Percentage Differnece	16.70%		28.40%		0.8%		20.9%	
Variance	0.0007	0.0007	0.0008	0.0007	0.01	0.01	0.001	0.001
Observations	81	85	81	86	421	448	302	350
Hypothesized Mean Difference	0		0		0		0	
z Stat	**4.85**		**7.91**		0.24		9.89	
P(Z<=z) two-tail	0.00		0.00		0.81		0	
z Critical two-tail	1.96		1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	z Stat > zc	Reject H0	z Stat < zc	Accept H0	z Stat > zc	Reject H0

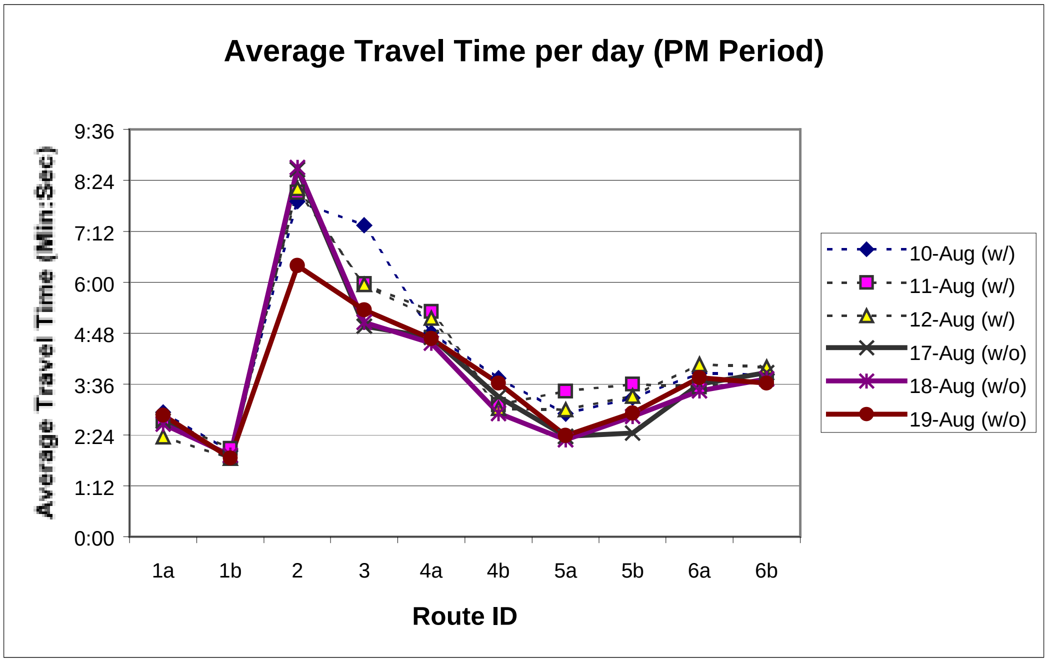
Primary Study
Travel Time
Analysis per Day and per Approach

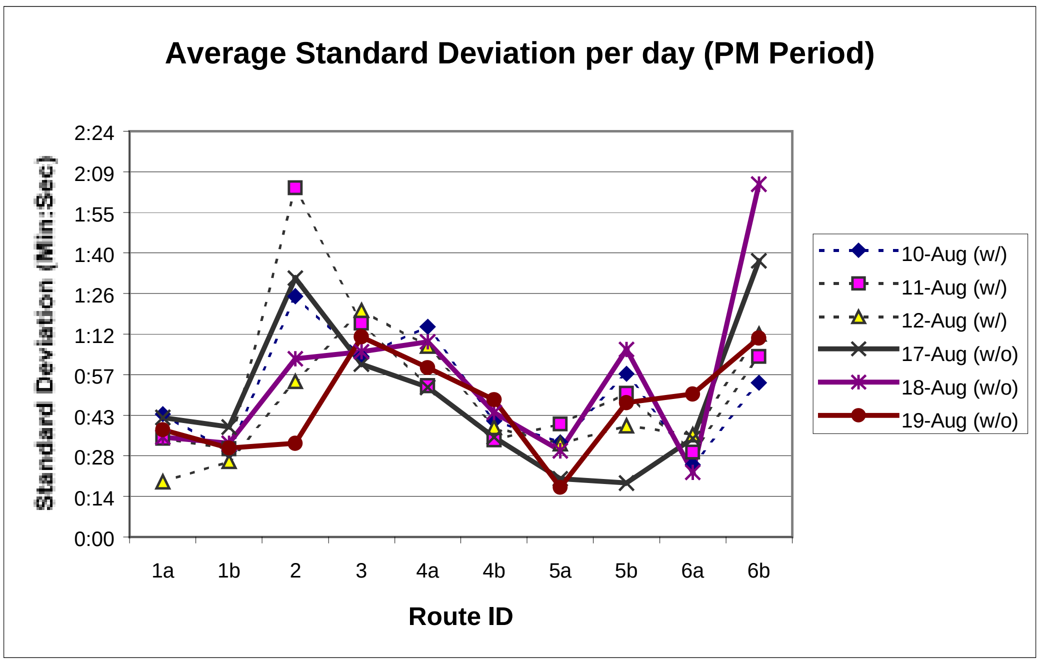
Travel Time PM Period

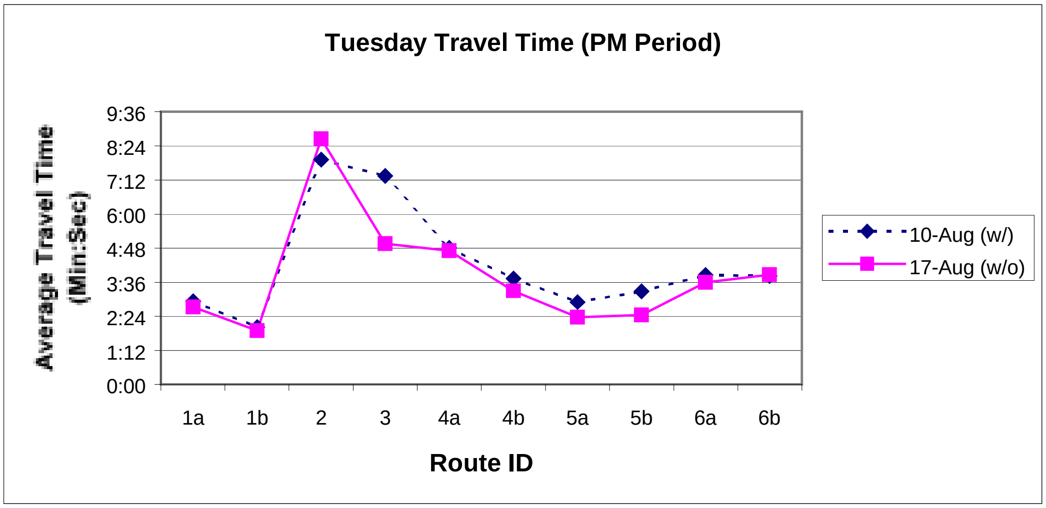
SCOOT Status	With SCOOT				Without SCOOT			
Route ID	10-Aug	11-Aug	12-Aug	Sub Avg.	17-Aug	18-Aug	19-Aug	Sub Avg.
1a	2:55	2:46	2:21	2:41	2:43	2:39	2:51	2:44
1b	2:00	2:05	1:51	1:59	1:53	1:55	1:51	1:53
2	7:54	8:07	8:12	8:04	8:39	8:42	6:23	7:55
3	7:20	5:57	5:56	6:24	4:57	5:03	5:20	5:07
4a	4:48	5:18	5:09	5:05	4:42	4:33	4:40	4:38
4b	3:44	3:06	3:01	3:17	3:17	2:54	3:37	3:16
5a	2:54	3:25	2:59	3:06	2:21	2:17	2:23	2:20
5b	3:16	3:35	3:18	3:23	2:26	2:50	2:55	2:44
6a	3:51	3:32	4:03	3:48	3:35	3:26	3:44	3:35
6b	3:49	3:43	3:59	3:50	3:51	3:43	3:37	3:44
Average	4:15	4:09	4:05	**4:10**	3:51	3:48	3:44	**3:48**

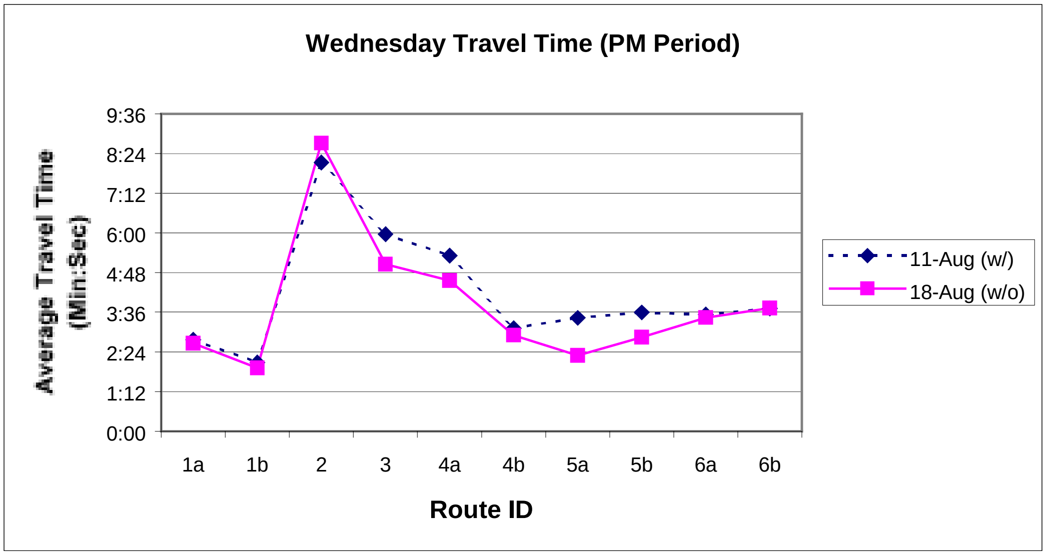
Travel Time Standard Deviation

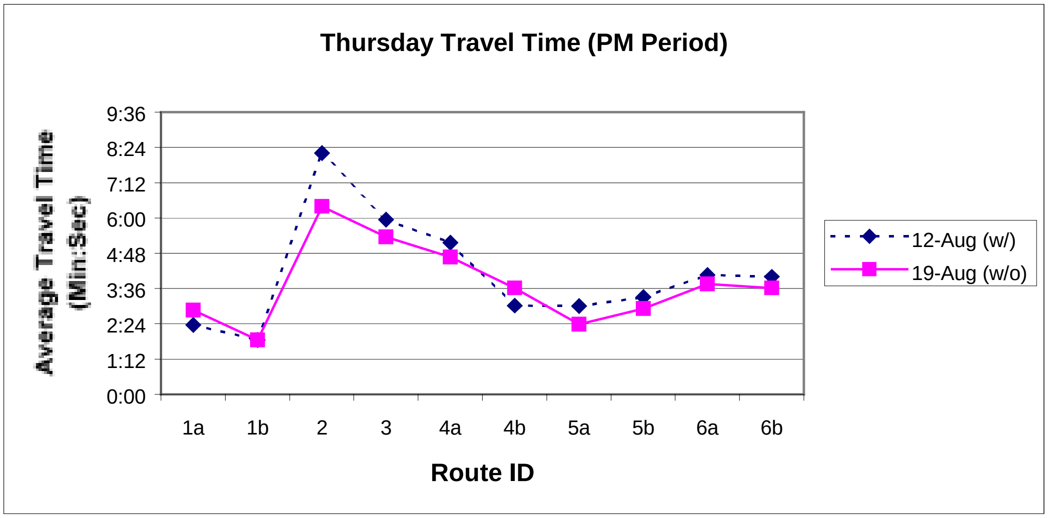
SCOOT Status	With SCOOT				Without SCOOT			
Route ID	10-Aug	11-Aug	12-Aug	Sub Avg.	17-Aug	18-Aug	19-Aug	Sub Avg.
1a	0:43	0:34	0:19	0:35	0:42	0:35	0:38	0:38
1b	0:30	0:31	0:26	0:29	0:39	0:33	0:31	0:35
2	1:25	2:03	0:55	1:30	1:31	1:03	0:33	1:32
3	1:04	1:15	1:20	1:21	1:01	1:05	1:11	1:06
4a	1:14	0:53	1:07	1:05	0:53	1:09	1:00	1:00
4b	0:41	0:34	0:38	0:41	0:35	0:44	0:48	0:45
5a	0:33	0:40	0:33	0:37	0:20	0:30	0:17	0:23
5b	0:57	0:50	0:39	0:49	0:19	1:06	0:47	0:49
6a	0:25	0:30	0:36	0:34	0:35	0:22	0:50	0:38
6b	0:54	1:04	1:12	1:09	1:37	2:05	1:10	1:37
Average	2:02	2:00	1:58	**2:00**	1:57	1:59	1:35	**1:50**

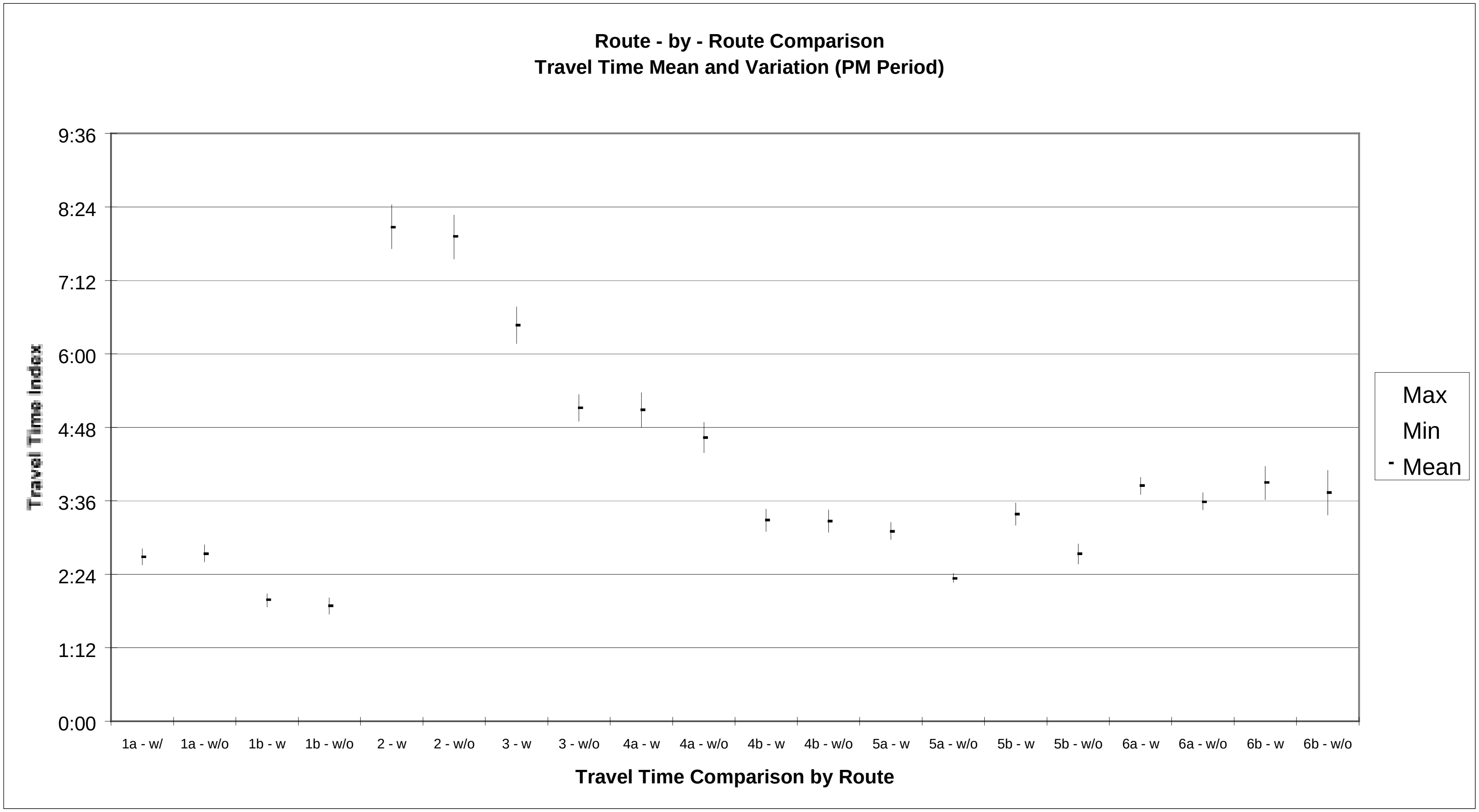

Average Travel Time per day (PM Period)
Average Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)


Average Standard Deviation per day (PM Period)
Standard Deviation (Min:Sec)
2:24
2:09
1:55
1:40
1:26
1:12
0:57
0:43
0:28
0:14
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)


Tuesday Travel Time (PM Period)
Average Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
10-Aug (w/)
17-Aug (w/o)


Wednesday Travel Time (PM Period)
Average Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
11-Aug (w/)
18-Aug (w/o)


Thursday Travel Time (PM Period)
Average Travel Time (Min:Sec)
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a
1b
2
3
4a
4b
5a
5b
6a
6b
Route ID
12-Aug (w/)
19-Aug (w/o)


Route - by - Route Comparison
Travel Time Mean and Variation (PM Period)
Travel Time Index
9:36
8:24
7:12
6:00
4:48
3:36
2:24
1:12
0:00
1a - w/
1a - w/o
1b - w
1b - w/o
2 - w
2 - w/o
3 - w
3 - w/o
4a - w
4a - w/o
4b - w
4b - w/o
5a - w
5a - w/o
5b - w
5b - w/o
6a - w
6a - w/o
6b - w
6b - w/o
Travel Time Comparison by Route
Max
Min
Mean

Primary Study

Summary of Hypothesis Test for Travel Time (PM)

z-Test: Two-Sample for Means

H0 = Travel Time did not reduce for the sysem with SCOOT

H1 = Travel Time reduced for the sysem with SCOOT

	Route 1a		**Route 1b**		**Route 2**		**Route 3**	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	2:39	2:45	1:57	1:53	8:05	7:42	6:23	5:08
Percentage Difference	-2.3%		4.9%		2.0%		26.4%	
Variance	0.001	0.001	0.000	0.001	0.004	0.004	0.003	0.002
Observations	78	84	79	83	71	71	82	102
Hypothesized Mean Difference	0		0		0		0	
z Stat	**-0.97**		**0.74**		**1.44**		**6.75**	
P(Z<=z) two-tail	0.33		0.46		0.15		0.00	
z Critical two-tail	1.96		1.96		1.96		1.96	
Result	abs(z Stat) > zc	Accept H0	z Stat < zc	Accept H0	z Stat < zc	Accept H0	z Stat > zc	Reject H0

	Route 4a		**Route 4b**		**Route 5a**		**Route 5b**	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	5:06	4:38	3:15	3:15	3:06	2:20	3:23	2:43
Percentage Difference	9.6%		0.6%		32.6%		24.2%	
Variance	0.002	0.002	0.001	0.001	0.001	0.000	0.001	0.001
Observations	60	64	59	64	78	107	80	107
Hypothesized Mean Difference	0		0		0		0	
z Stat	**2.51**		**0.05**		**9.43**		**5.47**	
P(Z<=z) two-tail	0.01		0.96		0.00		0.00	
z Critical two-tail	1.96		1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	z Stat < zc	Accept H0	z Stat > zc	Reject H0	z Stat > zc	Reject H0

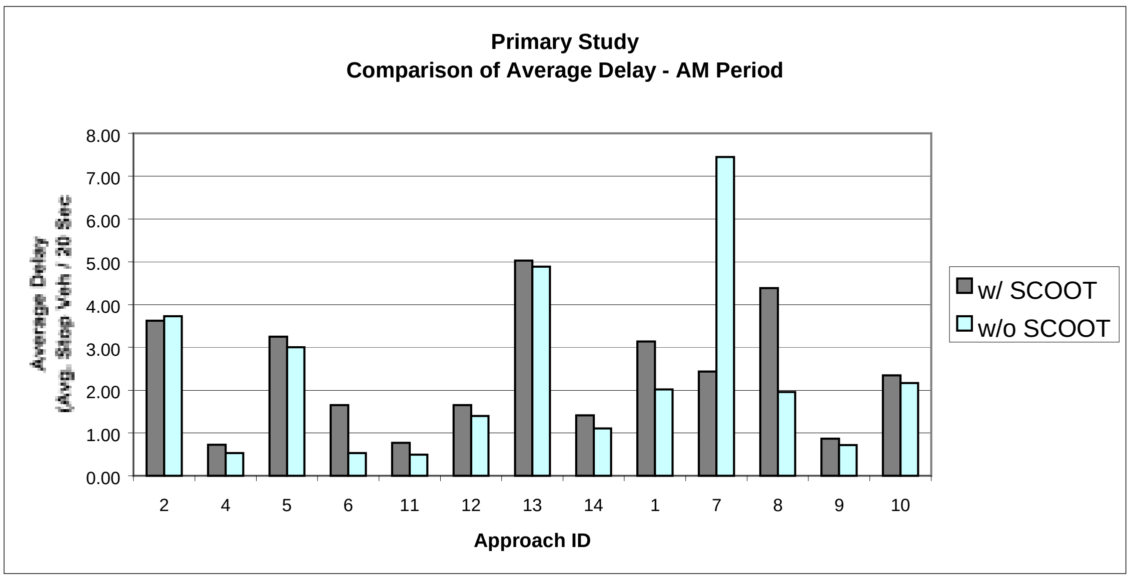
	Route 6a		**Route 6b**		**Route 1a,1b,2,3,4a,4b (All routes within study area)**		**Route 5a,5b,6a,6b (All routes crossing study boundary)**	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	3:51	3:36	3:55	3:43	4:34	4:12	3:33	3:00
Percentage Difference	7.1%		4.4%		8.8%		18.0%	
Variance	0.001	0.001	0.002	0.005	0.01	0.01	0.001	0.002
Observations	71	77	72	77	429	468	301	368
Hypothesized Mean Difference	0		0		0		0	
z Stat	**2.46**		**0.81**		**2.40**		**7.04**	
P(Z<=z) two-tail	0.01		0.42		0.02		0	
z Critical two-tail	1.96		1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	z Stat < zc	Accept H0	z Stat > zc	Reject Ho	z Stat > zc	Reject H0

APPENDIX G

PRIMARY STUDY RESULTS
DELAY

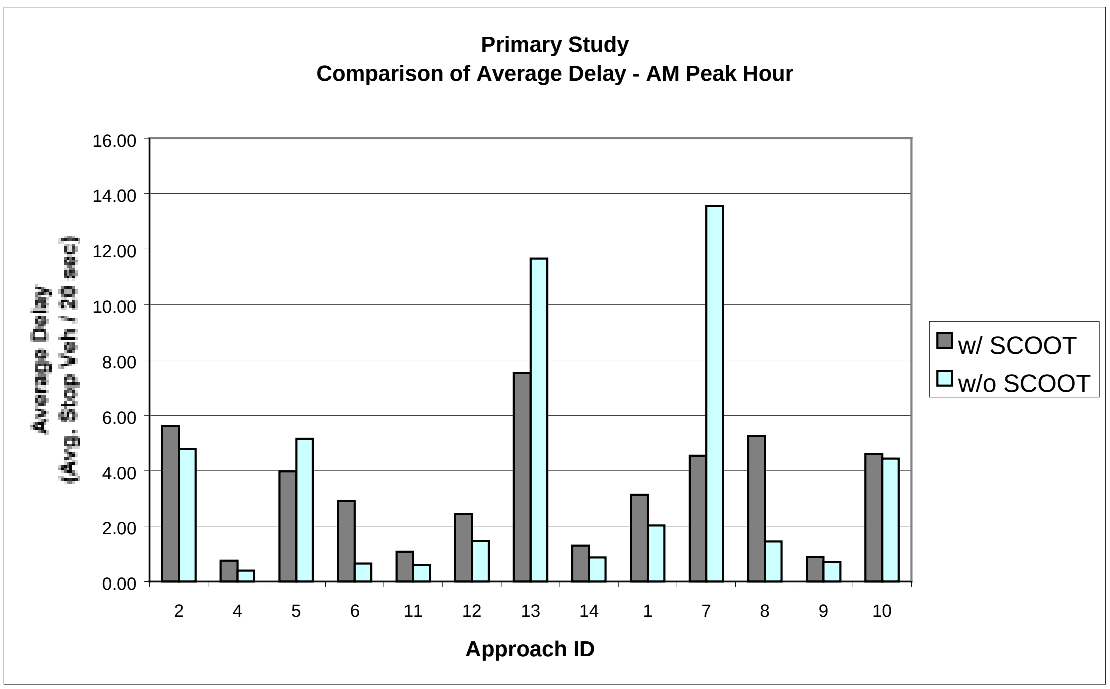
Primary Study
Delay (Avg Stop Veh / 20 sec) AM Period

Approach ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
Normal Condition				
2	3.62	3.73	-2.9%	No
4	**0.72**	**0.53**	**37.4%**	**Yes - T2000C**
5	3.25	3.00	8.2%	No
6	**1.66**	**0.53**	**215.0%**	**Yes - T2000C**
11	**0.77**	**0.49**	**58%**	**Yes - T2000C**
12	**1.64**	**1.40**	**18%**	**Yes - T2000C**
13	5.03	4.89	**3%**	No
14	**1.41**	**1.11**	**27%**	**Yes - T2000C**
Average	3.62	3.13	**15.6%**	
Boundary Condition				
1	**3.13**	**2.02**	**55.5%**	**Yes - T2000C**
7	**2.43**	**7.45**	**-67.4%**	**Yes**
8	**4.38**	**1.95**	**124.4%**	**Yes - T2000C**
9	**0.86**	**0.72**	**20.3%**	**Yes - T2000C**
10	**2.35**	**2.17**	**8.3%**	**Yes - T2000C**
Average	3.29	3.58	**-8.0%**	
Average	2.40	2.31	**4.3%**	



Primary Study
Delay (Avg Stop Veh / 20 sec) AM Peak Hour

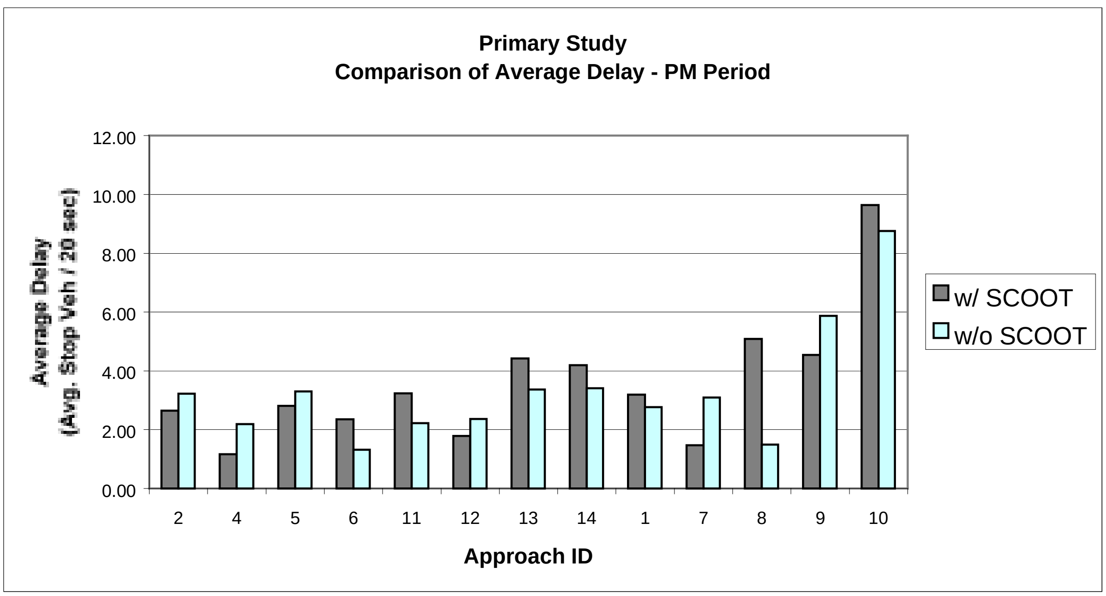
Approach ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
Normal Condition				
2	5.61	4.78	17.4%	No
4	**0.75**	**0.40**	**86.4%**	**Yes - T2000C**
5	**3.97**	**5.15**	**-22.9%**	**Yes**
6	**2.90**	**0.65**	**348.5%**	**Yes - T2000C**
11	**1.07**	**0.59**	**80%**	**Yes**
12	**2.44**	**1.47**	**66%**	**Yes**
13	**7.52**	**11.66**	**-35%**	**Yes**
14	**1.30**	**0.86**	**51%**	**Yes**
Average	3.1951	3.1949	**0.01%**	
Boundary Condition				
1	**3.13**	**2.02**	**55.5%**	**Yes - T2000C**
7	**4.53**	**13.55**	**-66.5%**	**Yes**
8	**5.24**	**1.45**	**262.1%**	**Yes - T2000C**
9	0.89	0.70	27.7%	No
10	4.61	4.43	4.0%	No
Average	3.68	4.43	-16.8%	
Average	**3.38**	**3.67**	**-7.8%**	



Primary Study
Delay (Avg Stop Veh / 20 sec)

PM Period

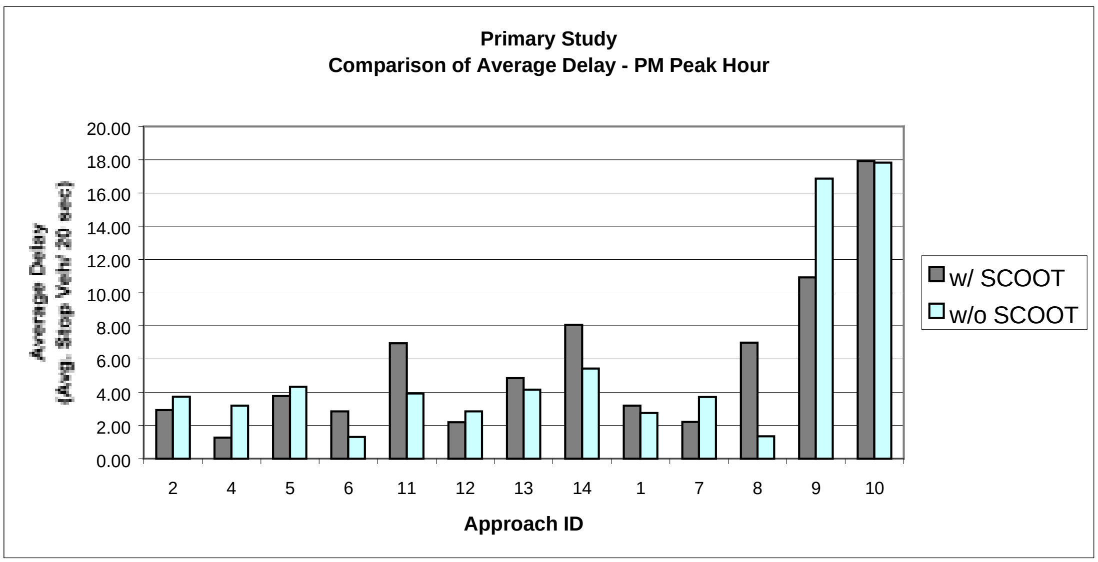
Approach ID	With SCOOT	Without SCOOT	% Diff	Stat Diff
Normal Condition				
2	**2.65**	**3.22**	**-18%**	**Yes**
4	**1.17**	**2.19**	**-46%**	**Yes**
5	**2.81**	**3.31**	**-15%**	**Yes**
6	**2.36**	**1.33**	**78%**	**Yes - T2000C**
11	**3.23**	**2.22**	**46%**	**Yes - T2000C**
12	**1.79**	**2.36**	**-24%**	**Yes**
13	**4.42**	**3.37**	**31%**	**Yes - T2000C**
14	**4.20**	**3.41**	**23%**	**Yes - T2000C**
Average	2.83	2.68	**5.7%**	
Boundary Condition				
1	3.20	2.77	16%	No
7	**1.47**	**3.10**	**-52%**	**Yes**
8	**5.09**	**1.49**	**241%**	**Yes - T2000C**
9	**4.55**	**5.86**	**-22%**	**Yes**
10	**9.63**	**8.76**	**10%**	**Yes - T2000C**
Average	4.79	4.40	**8.9%**	
Average	3.58	3.34	**7.3%**	



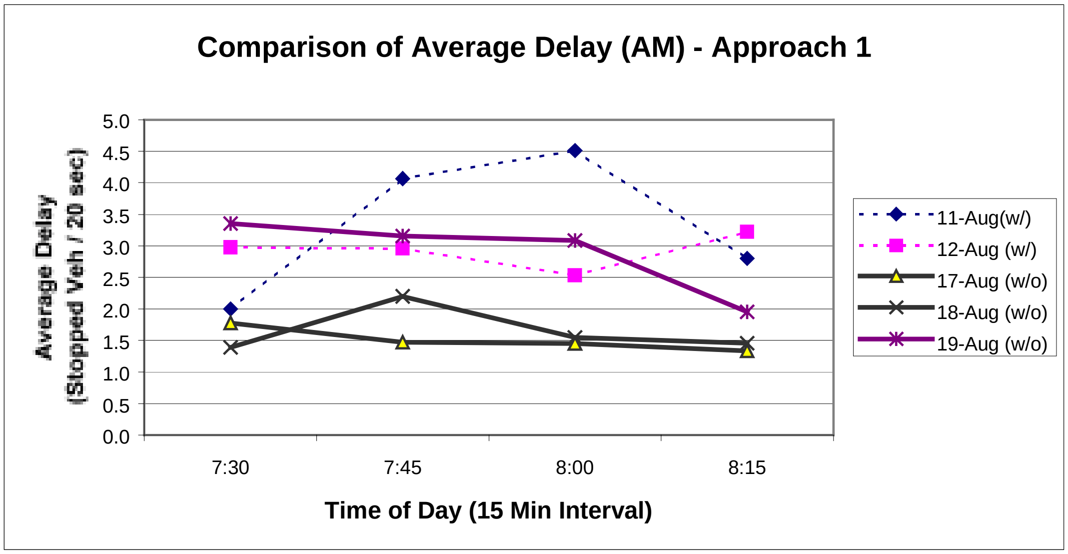
Primary Study
Delay (Avg Stop Veh / 20 sec)

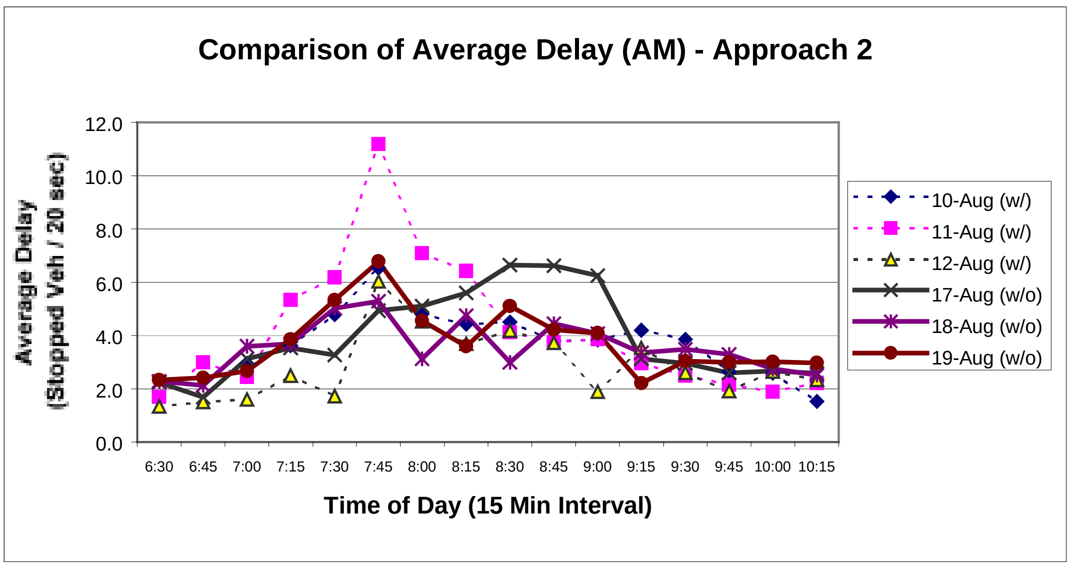
PM Peak Hour

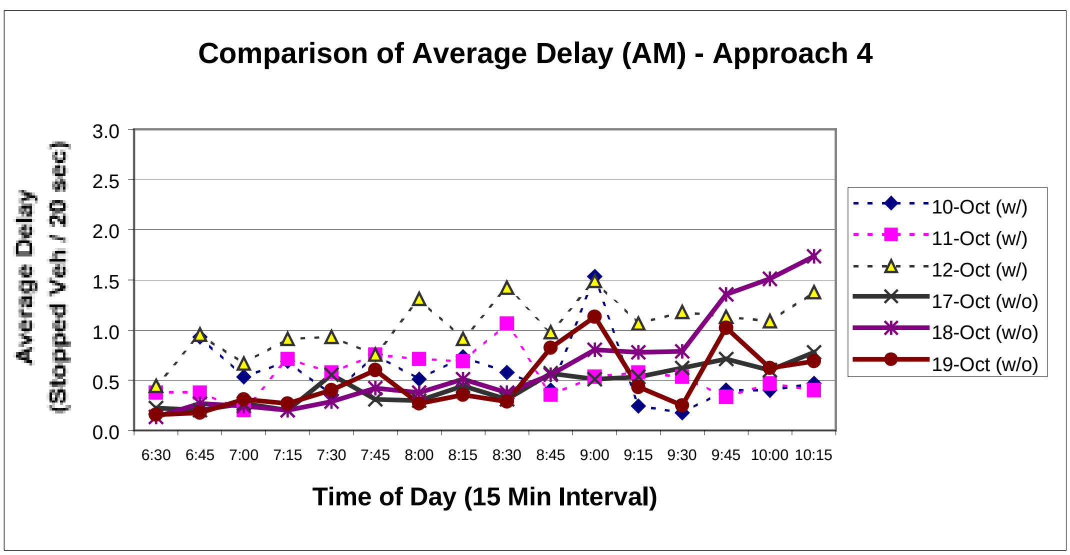
Approach ID	With SCOOT	Without SCOOT	% Diff	Statistical Difference
Normal Condition				
2	**2.93**	**3.75**	**-21.8%**	**Yes**
4	**1.26**	**3.18**	**-60.4%**	**Yes**
5	**3.78**	**4.33**	**-12.7%**	**Yes**
6	**2.83**	**1.32**	**115.1%**	**Yes - T2000C**
11	**6.9**	**3.9**	**77%**	**Yes - T2000C**
12	**2.19**	**2.86**	**-23%**	**Yes**
13	**4.84**	**4.14**	**17%**	**Yes - T2000C**
14	**8.07**	**5.44**	**48%**	**Yes - T2000C**
Average	4.11	3.62	**13.5%**	
Boundary Condition				
1	3.20	2.77	**15.5%**	No
7	**2.21**	**3.73**	**-40.6%**	**Yes**
8	**6.99**	**1.35**	**417.0%**	**Yes - T2000C**
9	**10.92**	**16.86**	**-35.2%**	**Yes**
10	17.91	17.83	**0.5%**	No
Average	8.25	8.51	**-3.0%**	
Average	5.70	5.50	**3.7%**	



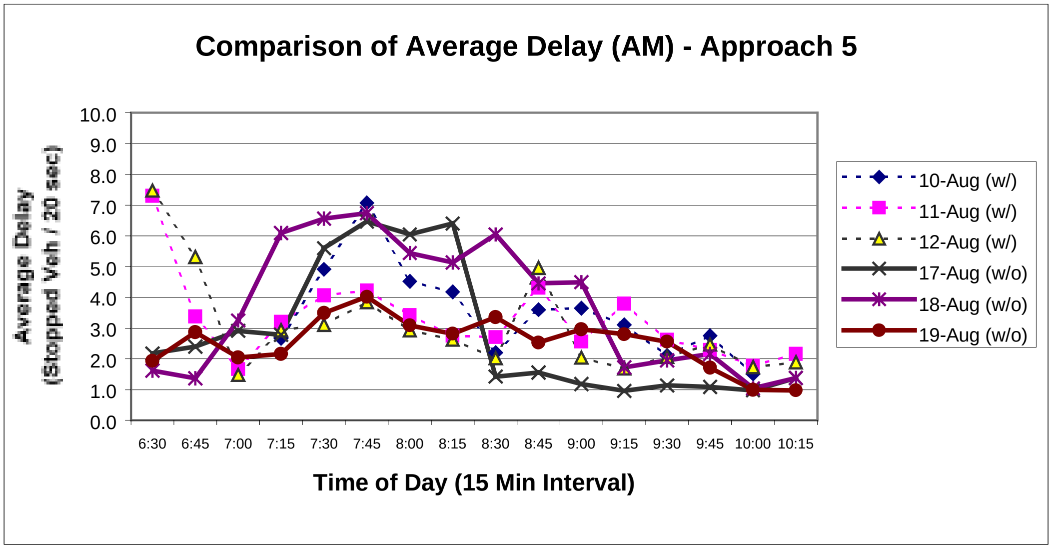
Approach - by -Approach Average Delay Comparison (AM)

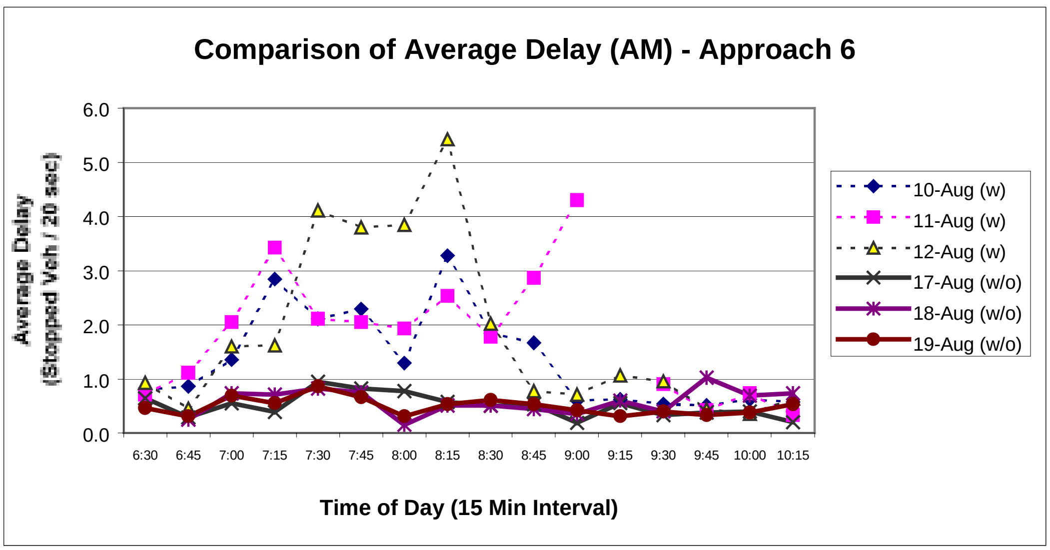


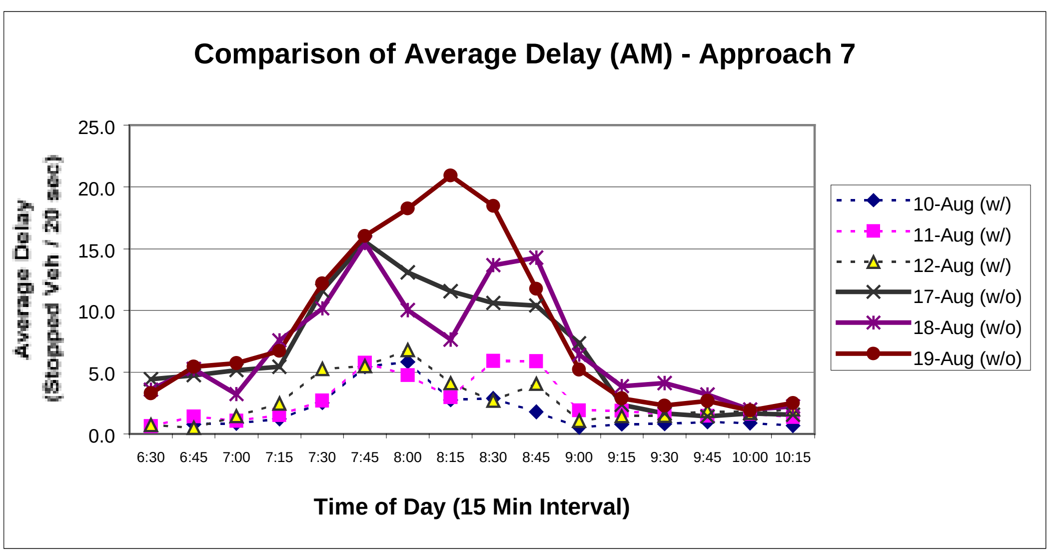




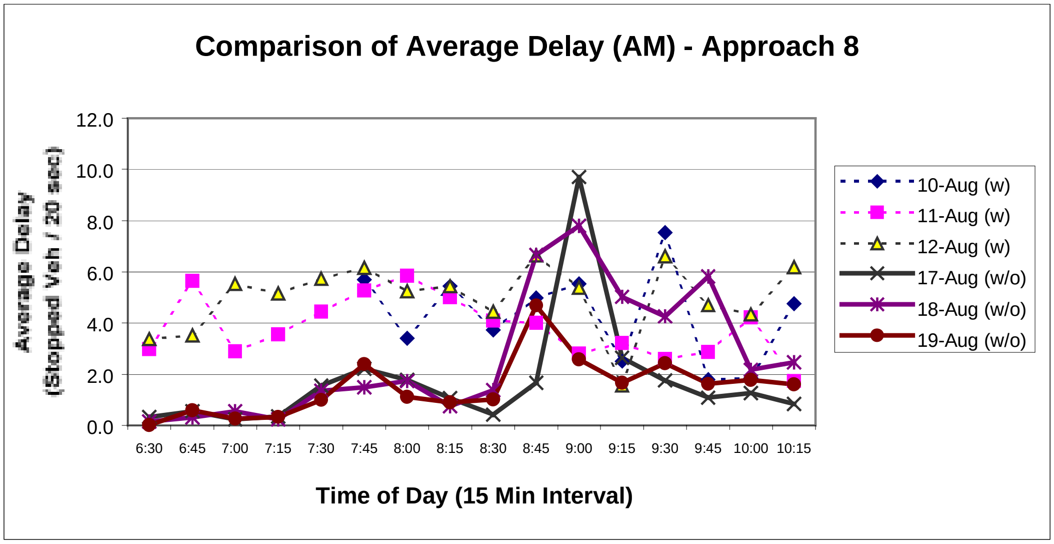
Approach - by - Approach Average Delay Comparison (AM)

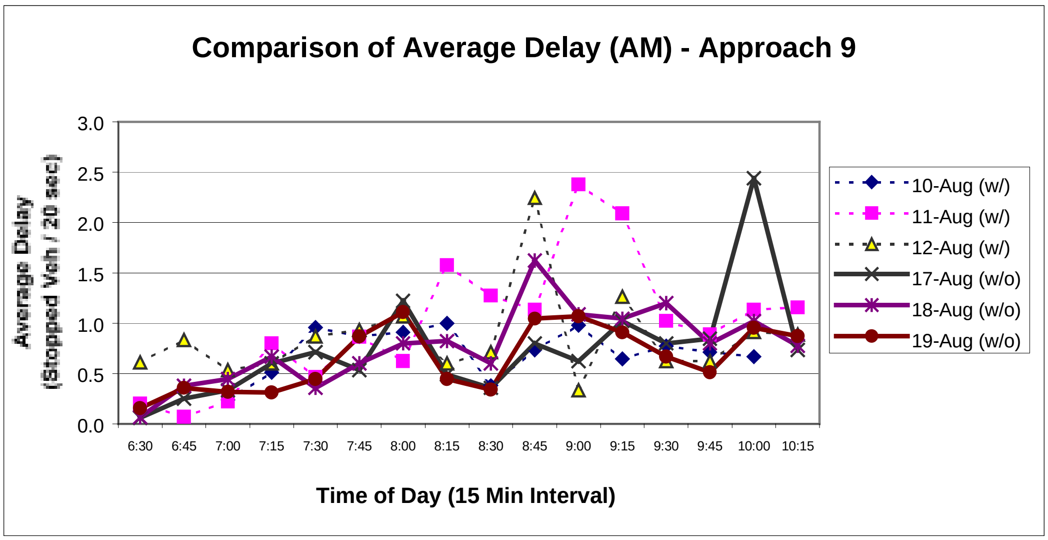


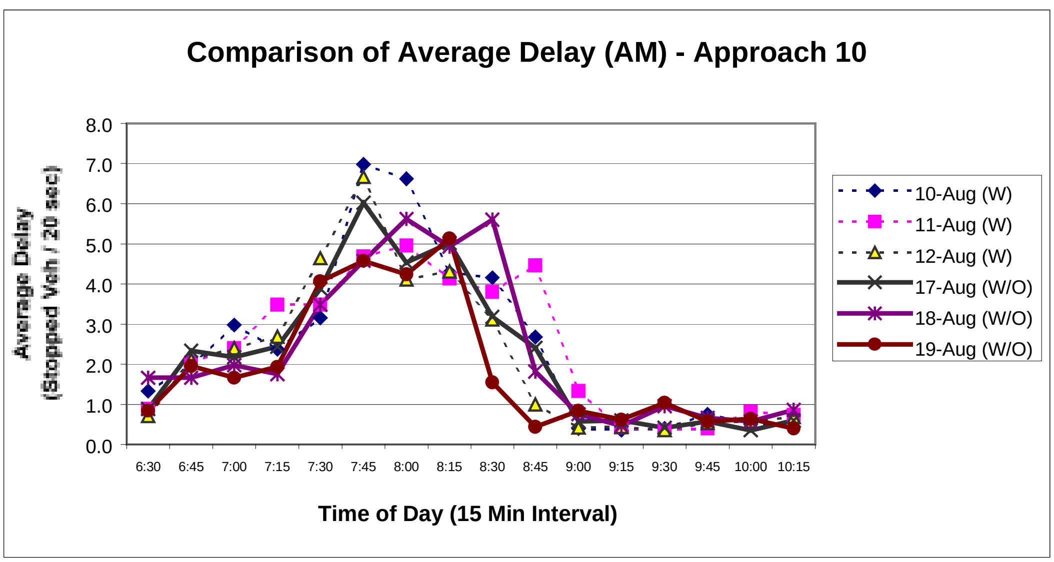


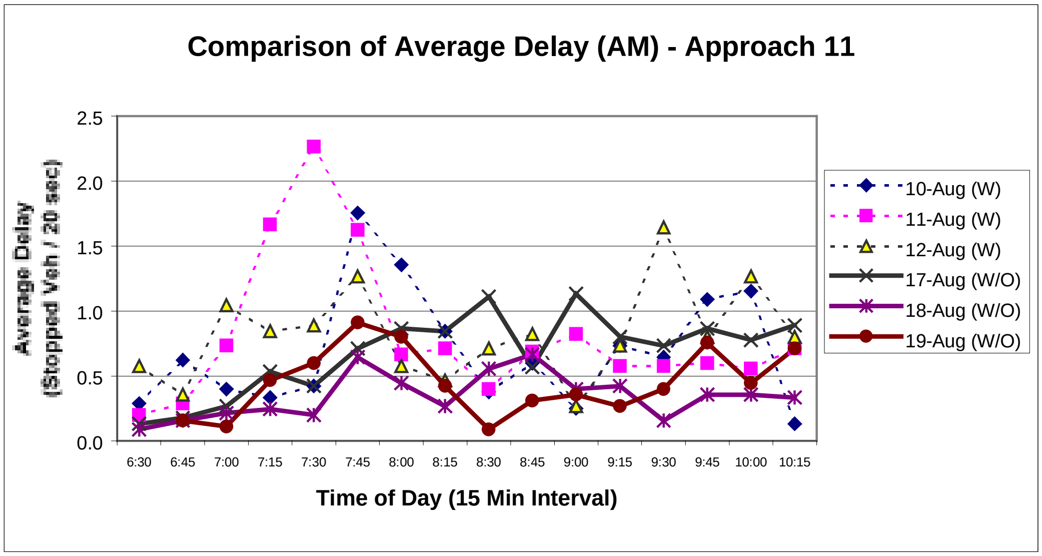


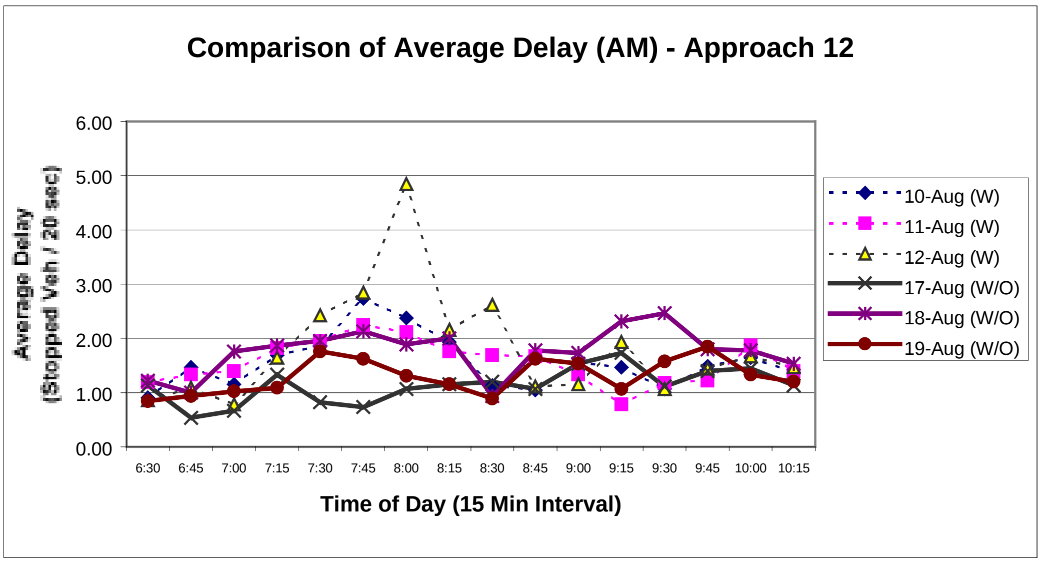
Approach - by - Approach Average Delay Comparison (AM)

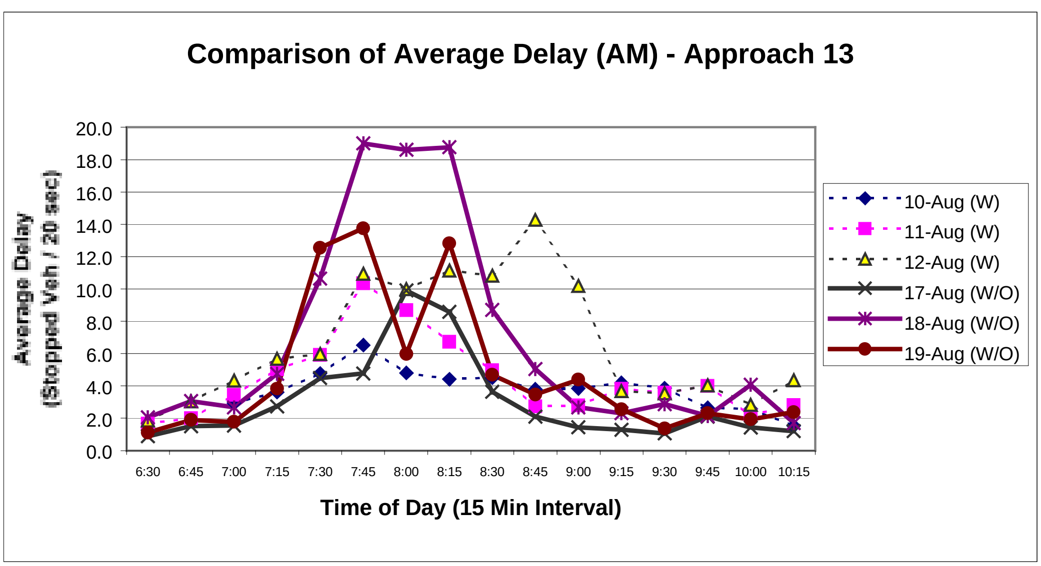


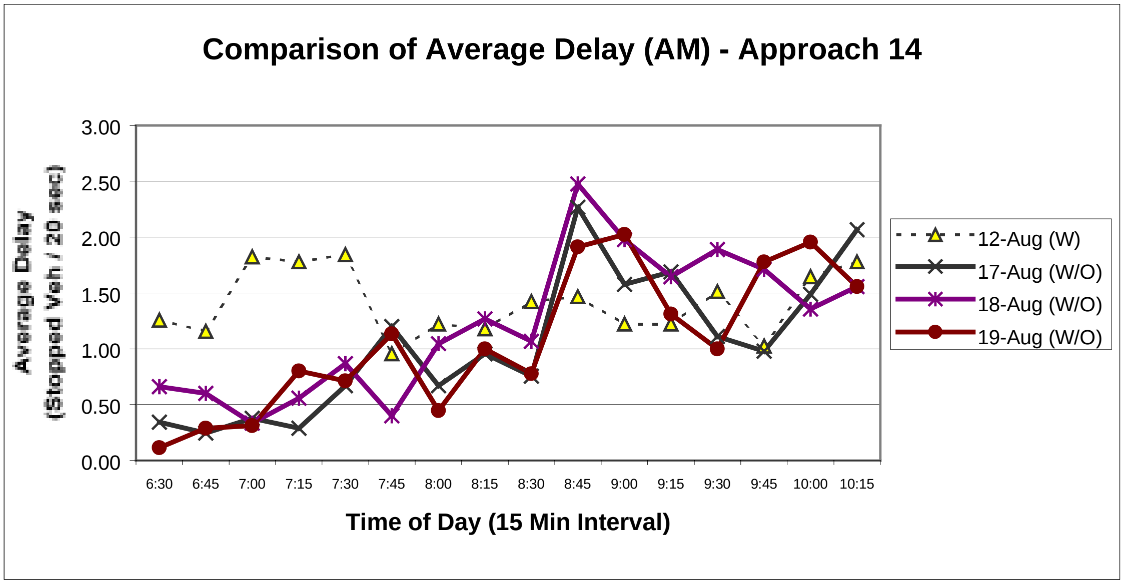





Comparison of Average Delay (AM) - Approach 11
Average Delay (Stopped Veh / 20 sec)
2.5
2.0
1.5
1.0
0.5
0.0
6:30 6:45 7:00 7:15 7:30 7:45 8:00 8:15 8:30 8:45 9:00 9:15 9:30 9:45 10:00 10:15
Time of Day (15 Min Interval)
10-Aug (W)
11-Aug (W)
12-Aug (W)
17-Aug (W/O)
18-Aug (W/O)
19-Aug (W/O)


Comparison of Average Delay (AM) - Approach 12
Average Delay (Stopped Veh / 20 sec)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6:30 6:45 7:00 7:15 7:30 7:45 8:00 8:15 8:30 8:45 9:00 9:15 9:30 9:45 10:00 10:15
Time of Day (15 Min Interval)
10-Aug (W)
11-Aug (W)
12-Aug (W)
17-Aug (W/O)
18-Aug (W/O)
19-Aug (W/O)


Comparison of Average Delay (AM) - Approach 13
Average Delay (Stopped Veh / 20 sec)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
6:30 6:45 7:00 7:15 7:30 7:45 8:00 8:15 8:30 8:45 9:00 9:15 9:30 9:45 10:00 10:15
Time of Day (15 Min Interval)
10-Aug (W)
11-Aug (W)
12-Aug (W)
17-Aug (W/O)
18-Aug (W/O)
19-Aug (W/O)


Comparison of Average Delay (AM) - Approach 14
Average Delay
(Stopped Veh / 20 sec)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
6:30
6:45
7:00
7:15
7:30
7:45
8:00
8:15
8:30
8:45
9:00
9:15
9:30
9:45
10:00
10:15
Time of Day (15 Min Interval)
12-Aug (W)
17-Aug (W/O)
18-Aug (W/O)
19-Aug (W/O)

Summary of Hypothesis Test - Delay (AM)

z-Test: Two-Sample for Means

H0 = Delay did not reduce for the sysem with SCOOT

H1 = Delay reduced for the sysem with SCOOT

	Approach 1		Approach 2		Approach 4	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	3.10	2.02	3.62	3.75	0.72	0.52
Percentage Difference	53.8%		-3.3%		37.6%	
Variance	14.09	6.98	33.20	28.23	2.21	1.31
Observations	366	514	2044	2040	2110	2106
Hypothesized Mean Difference	0		0		0	
z Stat	**4.76**		**-0.70**		**4.82**	
P(Z<=z) two-tail	0.00		0.48		0.00	
z Critical two-tail	1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	abs(z Stat) < - zc	Accept H0	z Stat > zc	Reject H0

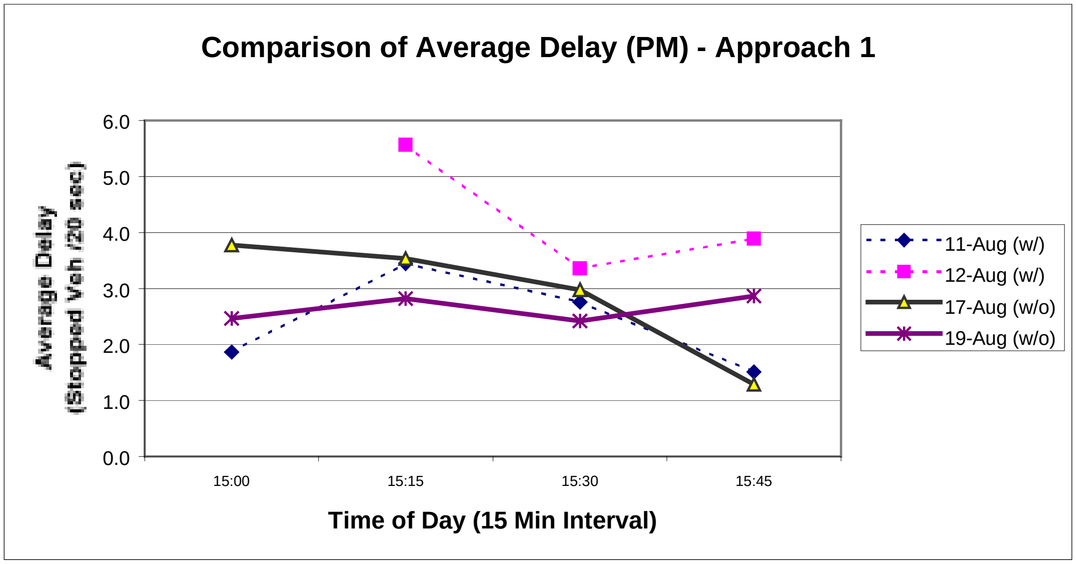
	Approach 5		Approach 6		Approach 7	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	3.25	3.00	1.65	0.53	2.45	7.56
Percentage Difference	8.1%		210%		-67.6%	
Variance	30.11	23.67	13.36	1.37	17.83	94.09
Observations	1927	2156	2018	2006	1996	2043
Hypothesized Mean Difference	0		0		0	
z Stat	**1.49**		**13.10**		**-21.79**	
P(Z<=z) two-tail	0.14		0.00		0.00	
z Critical two-tail (zc)	1.96		1.96		1.96	
Result	z Stat < zc	Accept H0	z Stat > zc	Reject H0	abs (z Stat) > - zc	Reject H0

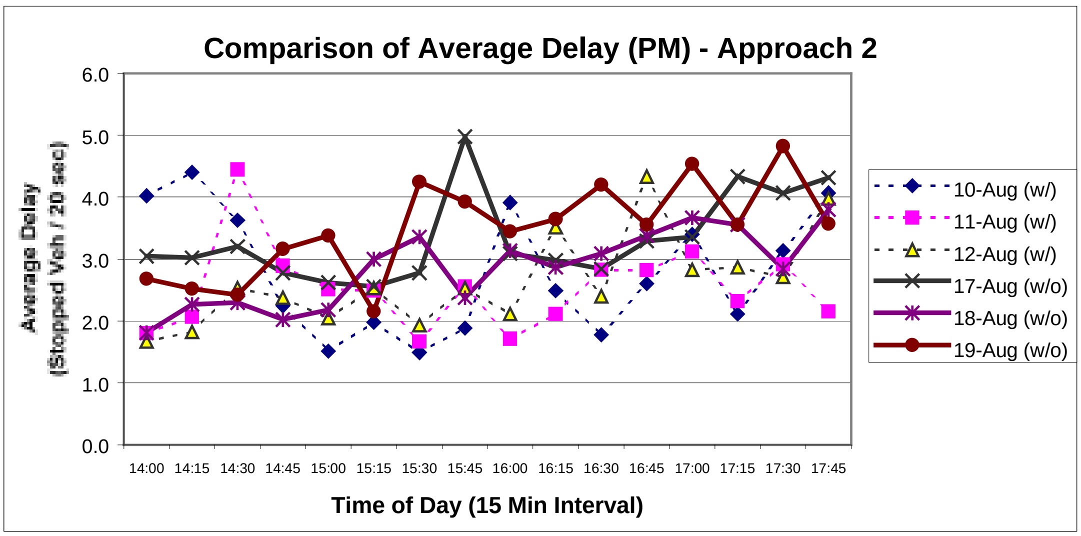
	Approach 8		Approach 9		Approach 10	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	4.39	1.95	0.89	0.73	2.37	2.14
Percentage Difference	124.8%		22.3%		10.5%	
Variance	39.55	11.96	3.23	4.46	12.42	9.81
Observations	1843	2146	1850	2135	2125	2149
Hypothesized Mean Difference	0		0		0	
z Stat	**14.84**		**2.63**		**2.20**	
P(Z<=z) two-tail	0.00		0.01		0.03	
z Critical two-tail (zc)	1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	z Stat > zc	Reject H0	z Stat > zc	Reject H0

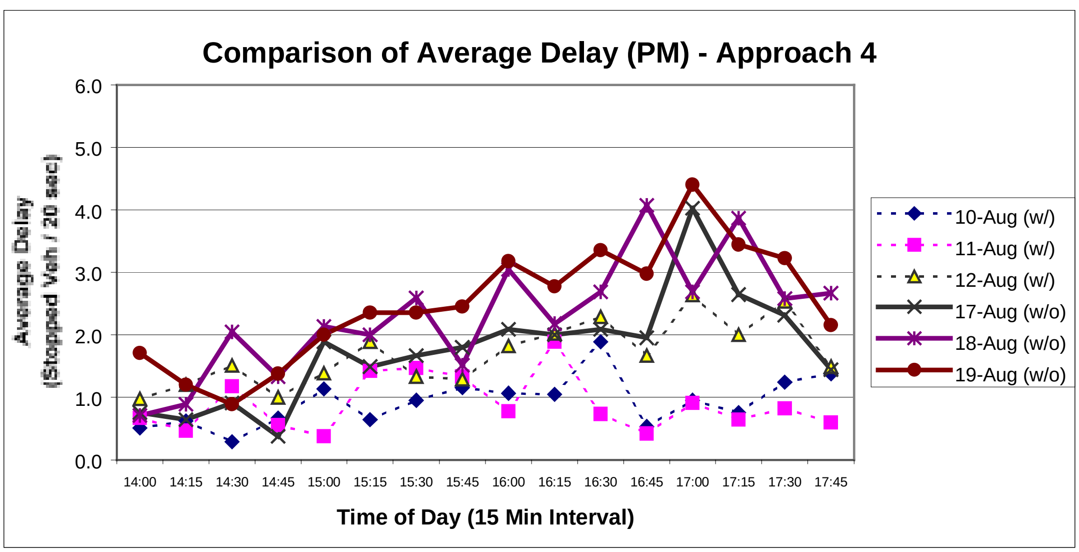
	Approach 11		Approach 12		Approach 13	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	0.77	0.48	1.64	1.39	5.04	4.91
Percentage Difference	60.8%		17.9%		2.8%	
Variance	3.77	1.42	6.18	4.22	27.72	47.14
Observations	2159	2159	2159	2167	2061	2145
Hypothesized Mean Difference	0		0		0	
z Stat	**5.97**		**3.61**		**0.72**	
P(Z<=z) two-tail	0.00		0.00		0.47	
z Critical two-tail (zc)	1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	z Stat > zc	Reject H0	z Stat < zc	Accept H0

	Approach 14	
	w/	*w/o*
Mean	1.40	1.11
Percentage Difference	26.0%	
Variance	4.58	3.42
Observations	720	2161
Hypothesized Mean Difference	0	
z Stat	**3.25**	
P(Z<=z) two-tail	0.00	
z Critical two-tail (zc)	1.96	
Result	z Stat > zc	Reject H0

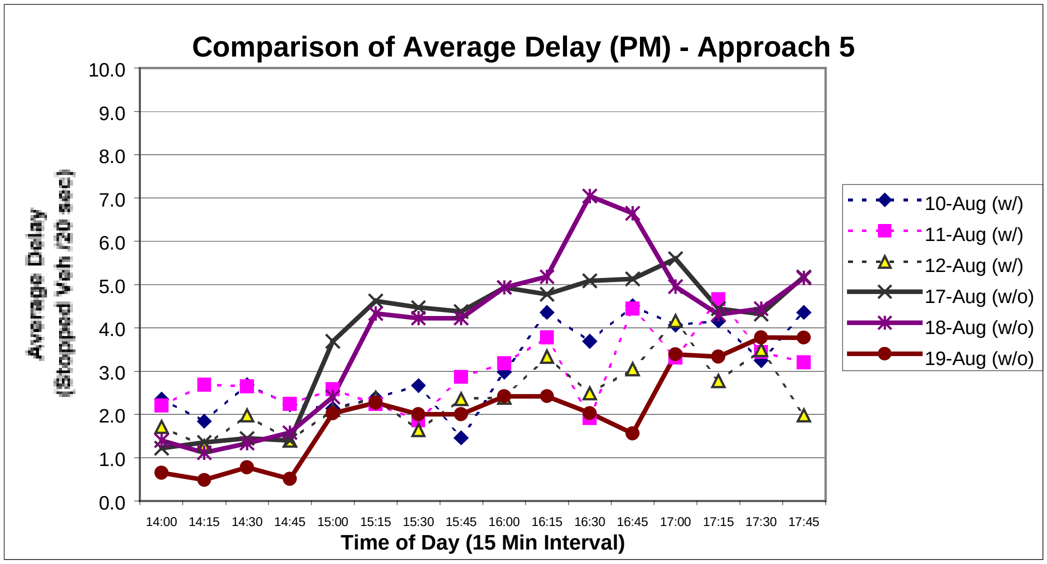
Approach - by - Approach Average Delay Comparison (PM)

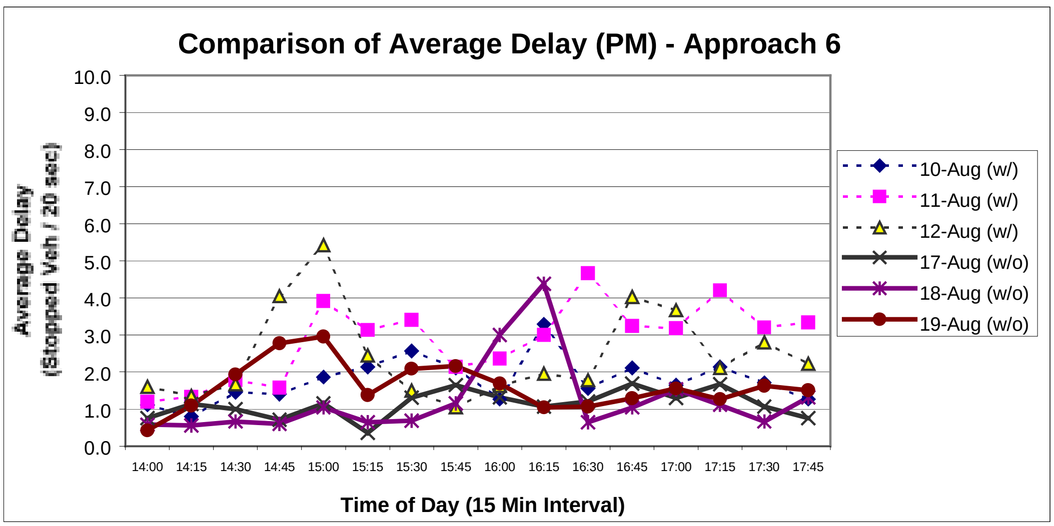


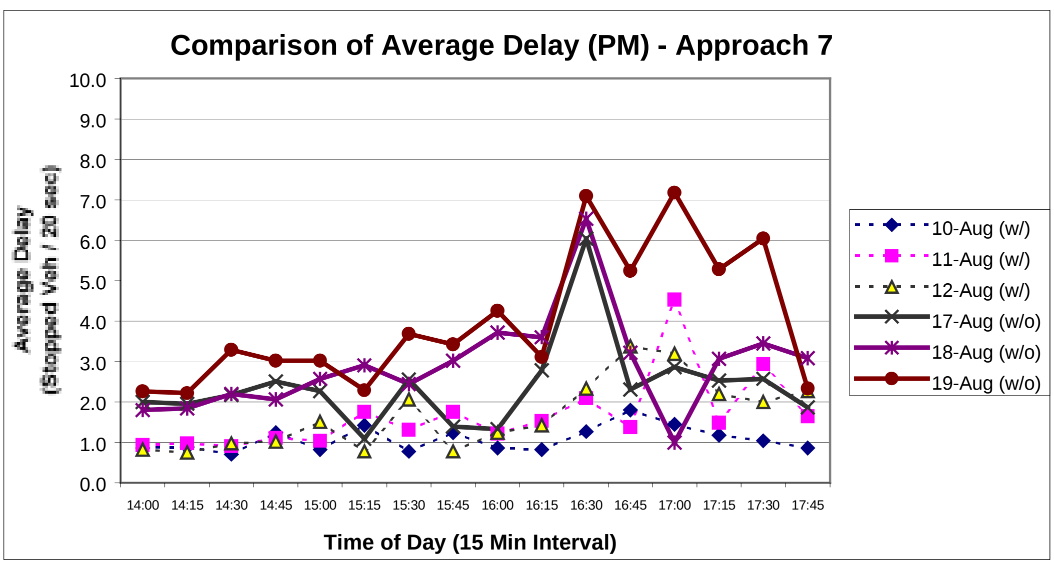




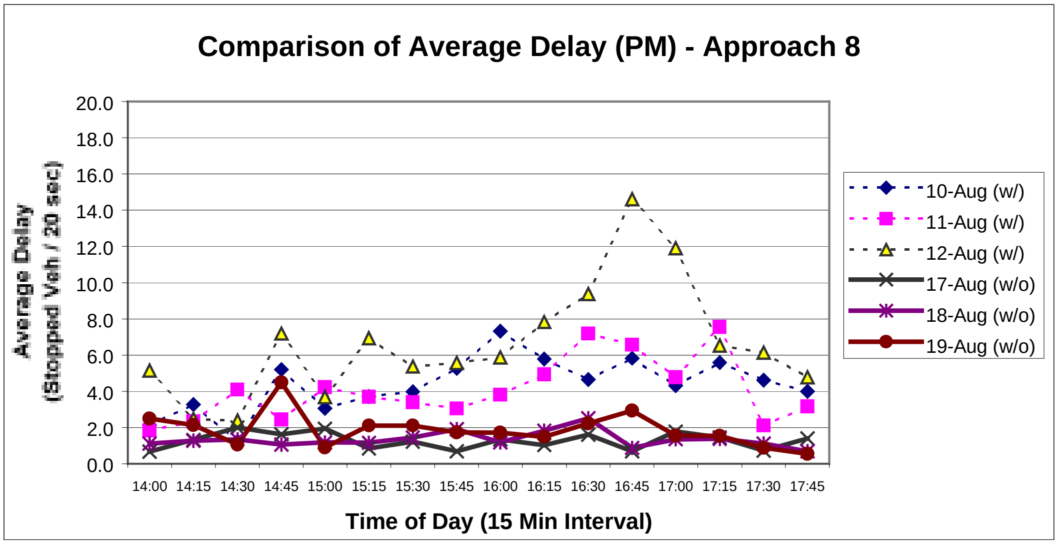
Approach - by - Approach Average Delay Comparison (PM)

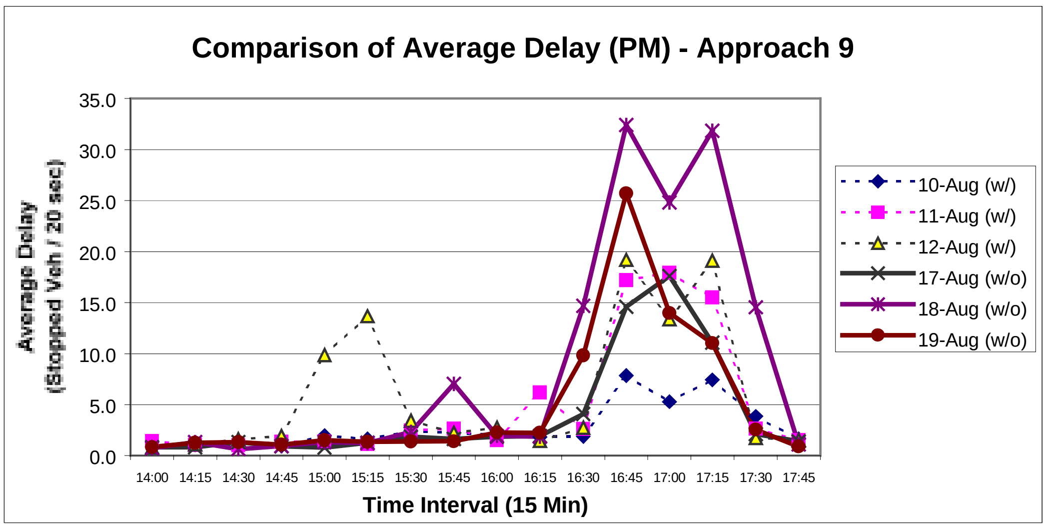


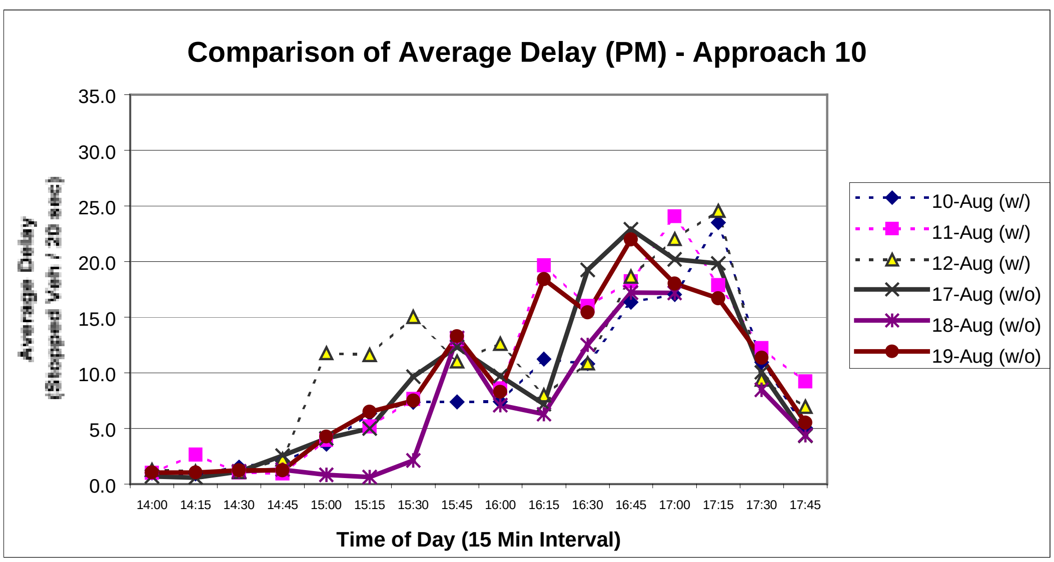


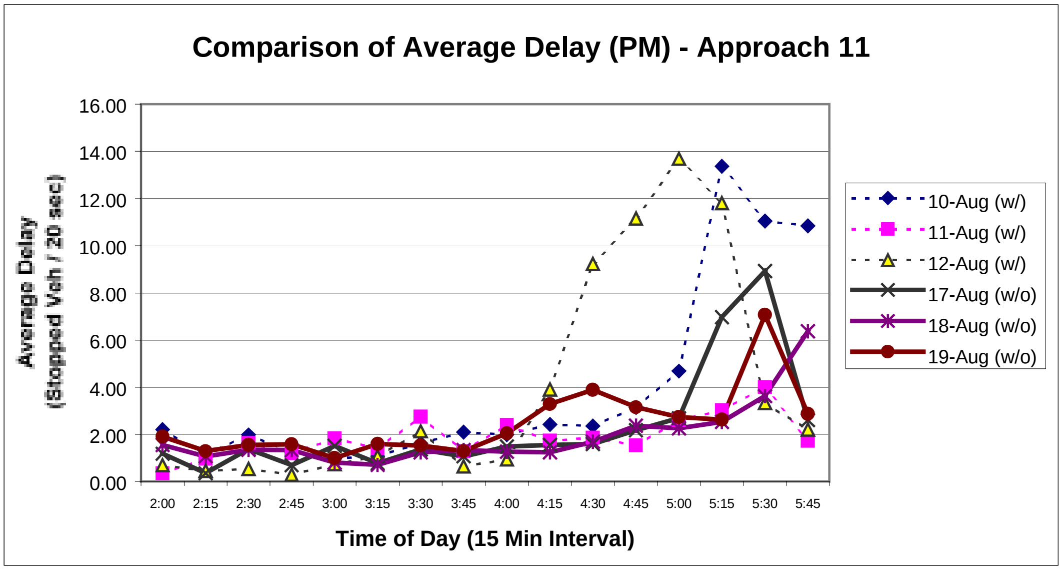


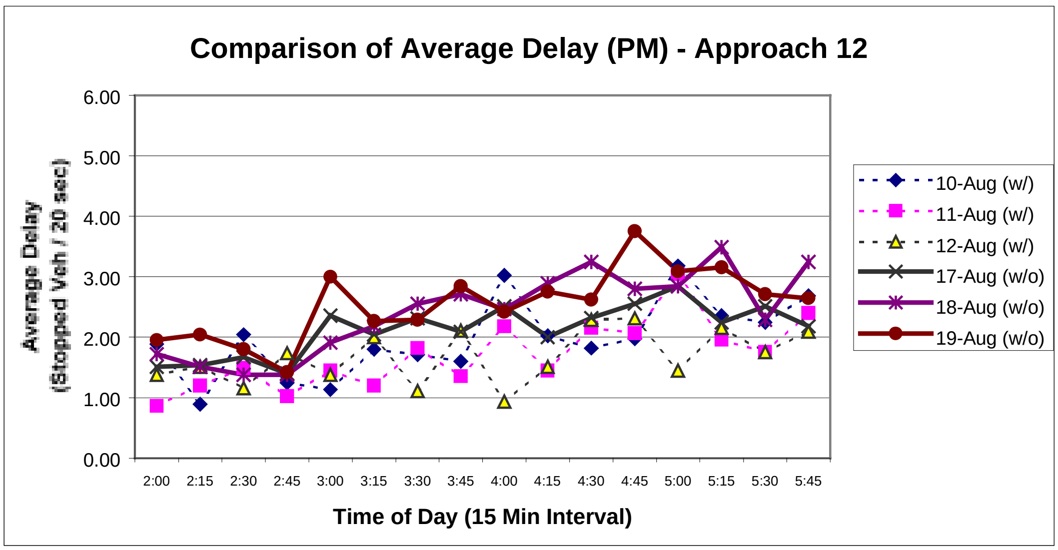
Approach - by - Approach Average Delay Comparison (PM)

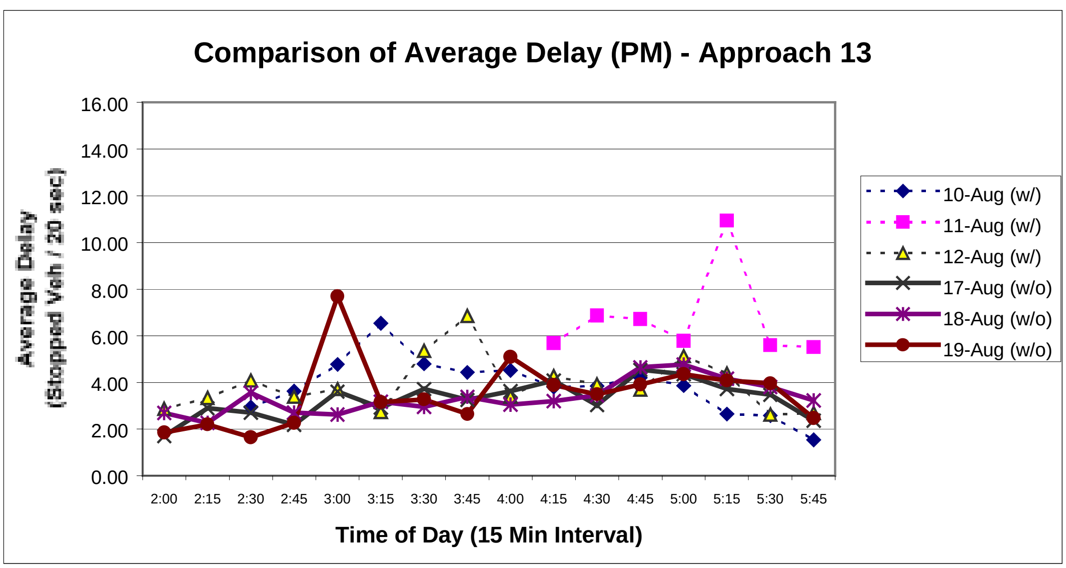


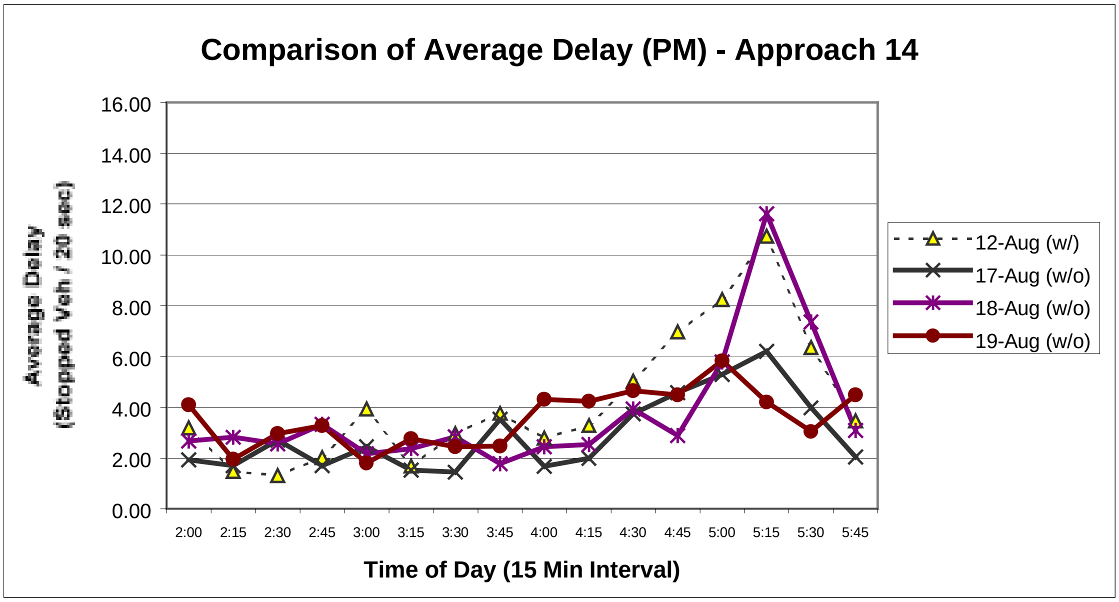





Comparison of Average Delay (PM) - Approach 11
Average Delay (Stopped Veh / 20 sec)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2:00 2:15 2:30 2:45 3:00 3:15 3:30 3:45 4:00 4:15 4:30 4:45 5:00 5:15 5:30 5:45
Time of Day (15 Min Interval)
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)


Comparison of Average Delay (PM) - Approach 12
Average Delay (Stopped Veh / 20 sec)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2:00 2:15 2:30 2:45 3:00 3:15 3:30 3:45 4:00 4:15 4:30 4:45 5:00 5:15 5:30 5:45
Time of Day (15 Min Interval)
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)


Comparison of Average Delay (PM) - Approach 13
Average Delay (Stopped Veh / 20 sec)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2:00 2:15 2:30 2:45 3:00 3:15 3:30 3:45 4:00 4:15 4:30 4:45 5:00 5:15 5:30 5:45
Time of Day (15 Min Interval)
10-Aug (w/)
11-Aug (w/)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)



Comparison of Average Delay (PM) - Approach 14
Average Delay
(Stopped Veh / 20 sec)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2:00
2:15
2:30
2:45
3:00
3:15
3:30
3:45
4:00
4:15
4:30
4:45
5:00
5:15
5:30
5:45
Time of Day (15 Min Interval)
12-Aug (w/)
17-Aug (w/o)
18-Aug (w/o)
19-Aug (w/o)

Summary of Hypothesis Test - Delay (PM) **10/11**

z-Test: Two-Sample for Means

H0 = Delay did not reduce for the sysem with SCOOT

H1 = Delay reduced for the sysem with SCOOT

	Approach 1		Approach 2		Approach 4	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	3.07	2.74	2.65	3.23	1.17	2.19
Percentage Difference	12.1%		-17.8%		-46.5%	
Variance	13.86	7.98	18.40	18.58	4.96	9.28
Observations	300	363	2145	2143	2141	2155
Hypothesized Mean Difference	0		0		0	
z Stat	**1.27**		**-4.38**		**-12.5**	
P(Z<=z) two-tail	0.20		0.00		0.0	
z Critical two-tail (zc)	1.96		1.96		2.0	
Result	z Stat < zc	Accept H0	z Stat < - zc	Reject H0	abs(z Stat) > zc	Reject H0

	Approach 5		Approach 6		Approach 7	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	2.82	3.34	2.31	1.33	1.47	3.13
Percentage Difference	-15.7%		73.3%		-53.1%	
Variance	15.92	22.61	16.68	6.60	6.51	18.68
Observations	2115	2141	2071	2149	2167	2040
Hypothesized Mean Difference	0		0		0	
z Stat	**-3.91**		**9.25**		**-15.06**	
P(Z<=z) two-tail	0.00		0.00		0.00	
z Critical two-tail (zc)	1.96		1.96		1.96	
Result	abs(z Stat) > zc	Reject H0	z Stat > zc	Reject H0	abs(z Stat) > zc	Reject H0

	Approach 8		Approach 9		Approach 10	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	5.14	1.51	4.57	5.92	9.84	8.79
Percentage Difference	240.4%		-22.8%		12.0%	
Variance	59.00	5.01	60.96	157.42	117.31	103.59
Observations	2136	2067	2132	2138	1942	1937
Hypothesized Mean Difference	0		0		0	
z Stat	**20.93**		**-4.21**		**3.14**	
P(Z<=z) two-tail	0.00		0.00		0.00	
z Critical two-tail (zc)	1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	abs(z Stat) > zc	Reject H0	z Stat > zc	Reject H0

	Approach 11		Approach 12		Approach 13	
	w/	*w/o*	*w/*	*w/o*	*w/*	*w/o*
Mean	3.23	2.21	1.79	2.37	4.43	3.37
Percentage Difference	46.1%		-24.6%		31.5%	
Variance	37.10	16.83	6.91	8.26	21.75	12.29
Observations	2162	2157	2164	2159	1659	2160
Hypothesized Mean Difference	0		0		0	
z Stat	**6.46**		**-6.95**		**7.73**	
P(Z<=z) two-tail	0.00		0.00		0.00	
z Critical two-tail (zc)	1.96		1.96		1.96	
Result	z Stat > zc	Reject H0	Abs.(z Stat) > zc	Reject H0	z Stat > zc	Reject H0

	Approach 14	
	w/	*w/o*
Mean	5.04	3.42
Percentage Difference	47.4%	
Variance	42.46	20.78
Observations	1028	2151
Hypothesized Mean Difference	0	
z Stat	**7.18**	
P(Z<=z) two-tail	0.00	
z Critical two-tail (zc)	1.96	
Result	z Stat > zc	Reject H0

APPENDIX H

PRIMARY STUDY RESULTS
SCOOT DATA

Primary Study
SCOOT Data

Network Average Number of Vehicle Stops (per 5 min) AM Period

	Week 1		Week 2			Week 3		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily	227.9	213.7	237.6	257.8	230.9	204.5	212.5	206.7
Weekly		220.8			242.1			207.9

Percentage Difference

Week 1-Week 2

w/ SCOOT	w/o SCOOT	% Diff
220.8	242.1	**-8.8%**

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff
207.9	242.1	**-14.1%**

Network Average Volume (per 5 min) AM Period

	Week 1	w/ SCOOT	Week 2	w/o SCOOT		Week 3	w/ SCOOT	
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily	388.9	377	373	395	368	368	365	363
Weekly		383			379			366

Percentage Difference

Week 1-Week 2

w/ SCOOT	w/o SCOOT	% Diff
383	379	**1.1%**

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff
366	379	**-3.5%**

Primary Study
SCOOT Data

Network Average Number of Vehicle Stops (per 5 min) AM Peak Hour

	Week 1		Week 2			Week 3		
	11-Aug	12-Oct	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily	301.6	305.8	347.7	353.7	327.2	292.5	301.2	288.0
Weekly		303.7			342.9			293.9

Percentage Difference

Week 1-Week 2

w/ SCOOT	w/o SCOOT	% Diff
303.7	342.9	**-11.4%**

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff
293.9	342.9	**-14.3%**

Network Average Volume (per 5 min) AM Peak Hour

	Week 1	w/ SCOOT	Week 2	w/o SCOOT		Week 3	w/ SCOOT	
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily	505	505	506	512	486	497	493	481
Weekly		505			501			490

Percentage Difference

Week 1-Week 2

w/ SCOOT	w/o SCOOT	% Diff
505	501	**0.7%**

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff
490	501	**-2.2%**

Network Average Delay (per 5 min) AM Peak Hour

	Week 1		Week 2			Week 3		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily	23.9	24.1	29.3	29.9	26.4	23.2	22.9	21.9
Weekly		24.0			28.5			22.7

Percentage Difference

Week 1-Week 2

w/ SCOOT	w/o SCOOT	% Diff
24.0	28.5	**-15.8%**

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff
23.0	28.5	**-19.3%**

Primary Study
SCOOT Data

Network Average Number of Vehicle Stops (per 5 min) PM Period

	Week 1		Week 2 w/o SCOOT			Week 3 w/ SCOOT		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			253	259	253	239	255	265
Weekly					255			253

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat
253	255	-0.8%	Yes

Network Average Volume (per 5 min) PM Period

	Week 1	w/ SCOOT	Week 2 w/o SCOOT			Week 3 w/ SCOOT		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			412	419	414	419	438	450
Weekly					415			435

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat
435	415	5.0%	Yes

Primary Study
SCOOT Data

Network Average Number of Vehicle Stops (per 5 min) PM Peak Hour

	Week 1	w/ SCOOT	Week 2	w/o SCOOT		Week 3	w/ SCOOT	
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			333	336	313	309	332	361
Weekly					327			334

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat
334	327	2.1%	

Network Average Volume (per 5 min) PM Peak Hour

	Week 1	w/ SCOOT	Week 2	w/o SCOOT		Week 3	w/ SCOOT	
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			513	515	493	524	551	580
Weekly					507			552

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat
552	507	8.9%	Yes

Network Average Delay (per 5 min) PM Peak Hour

	Week 1		Week 2	w/o SCOOT		Week 3	w/ SCOOT	
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			27	26	25	27	29	31
Weekly					26			29

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat
29	26	11.5%	Yes

Primary Study
SCOOT Data

Network Average Number of Vehicle Stops (per 5 min) Midday

	Week 1		Week 2			Week 3		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			190.4	205.8	205.6	173.8	175.6	179.1
Weekly					200.6			176.1

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat Diff
176.1	200.6	**-12.2%**	Yes

Network Average Volume (per 5 min) Midday

	Week 1 w/ SCOOT		Week 2 w/o SCOOT			Week 3 w/ SCOOT		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			309.3	329	331	318	320	320
Weekly					323			319

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat Diff
319	323	**-1.3%**	No

Primary Study
SCOOT Data

Network Average Number of Vehicle Stops (per 5 min) Early Morning

	Week 1		Week 2			Week 3		
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			32.8	34.6	52.2	29.7	32.1	43.4
Weekly					39.9			35.1

Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat Diff
35.1	39.9	**-12.0%**	Yes

Network Average Volume (per 5 min) Early Morning

	Week 1	w/ SCOOT	Week 2	w/o SCOOT		Week 3	w/ SCOOT	
	11-Aug	12-Aug	17-Aug	18-Aug	19-Aug	24-Aug	25-Aug	26-Aug
Daily			59.9	62	86	62	66	87
Weekly					69			71

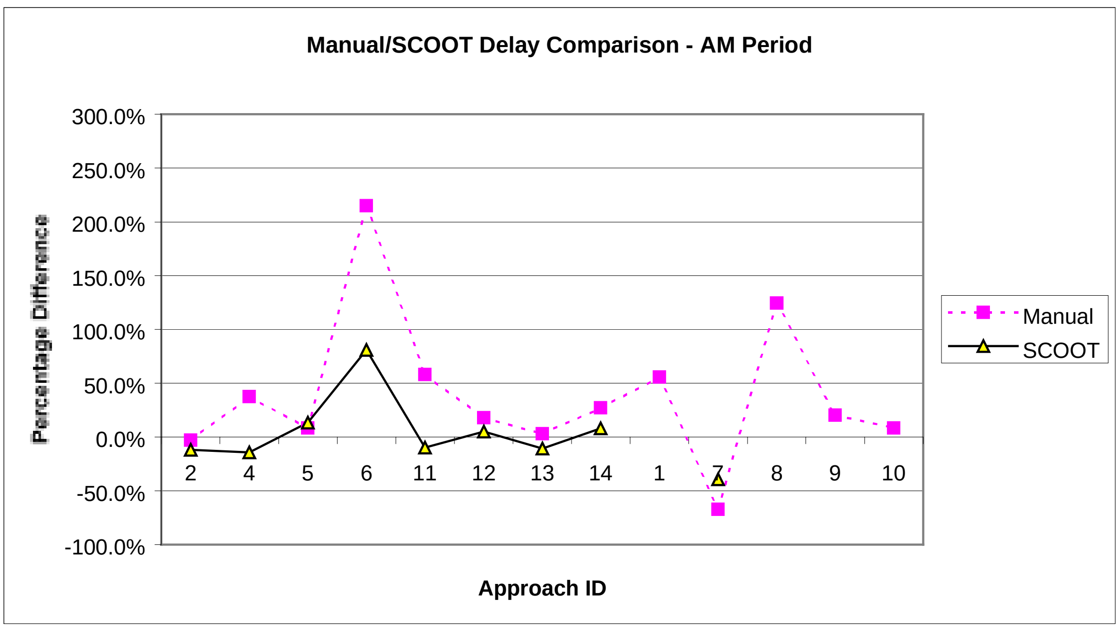
Percentage Difference

Week 2-Week 3

w/ SCOOT	w/o SCOOT	% Diff	Stat Diff
71	69	**3.4%**	No

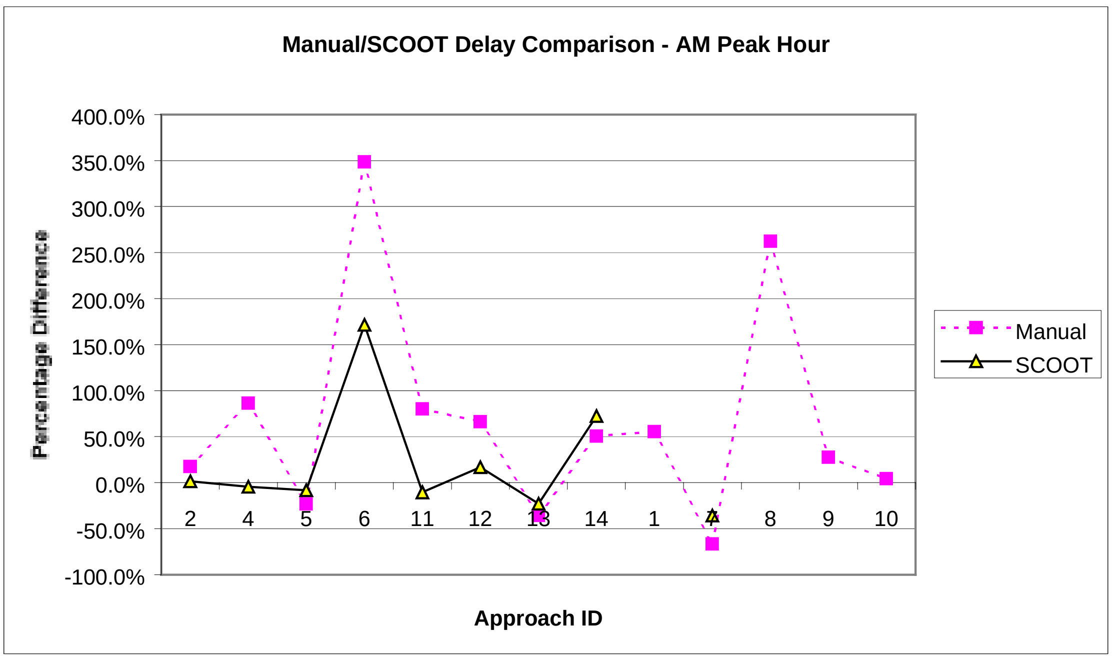
Primary Study
Delay - Manual Data compared to SCOOT Data (AM Period)

Route ID	w/ SCOOT		w/o SCOOT		% Difference	
	Manual Data	SCOOT Data	Manual Data	SCOOT Data	Manual Data	SCOOT Data
Normal Condition						
2	3.62	4.39	3.73	4.97	-2.9%	-11.8%
4	0.72	1.30	0.53	1.51	37.4%	-14.2%
5	3.25	6.83	3.00	6.03	8.2%	13.3%
6	1.66	1.88	0.53	1.04	215.0%	80.9%
11	0.77	1.03	0.49	1.14	58.0%	-9.9%
12	1.64	3.00	1.40	2.86	17.8%	4.9%
13	5.03	3.10	4.89	3.47	2.9%	-10.7%
14	1.41	1.84	1.11	1.71	26.9%	8.0%
Average	2.3	2.9	2.0	2.8	15.6%	2.8%
Boundary Condition						
1	3.13		2.02		55.5%	
7	2.43	3.05	7.45	5.01	-67.4%	-39.1%
8	4.38		1.95		124.4%	
9	0.86		0.72		20.3%	
10	2.35		2.17		8.3%	
Average	2.51	3.05	3.07	5.01	-18.4%	-39.1%
Average	**2.34**	**2.93**	**2.33**	**3.08**	**0.6%**	**-4.8%**



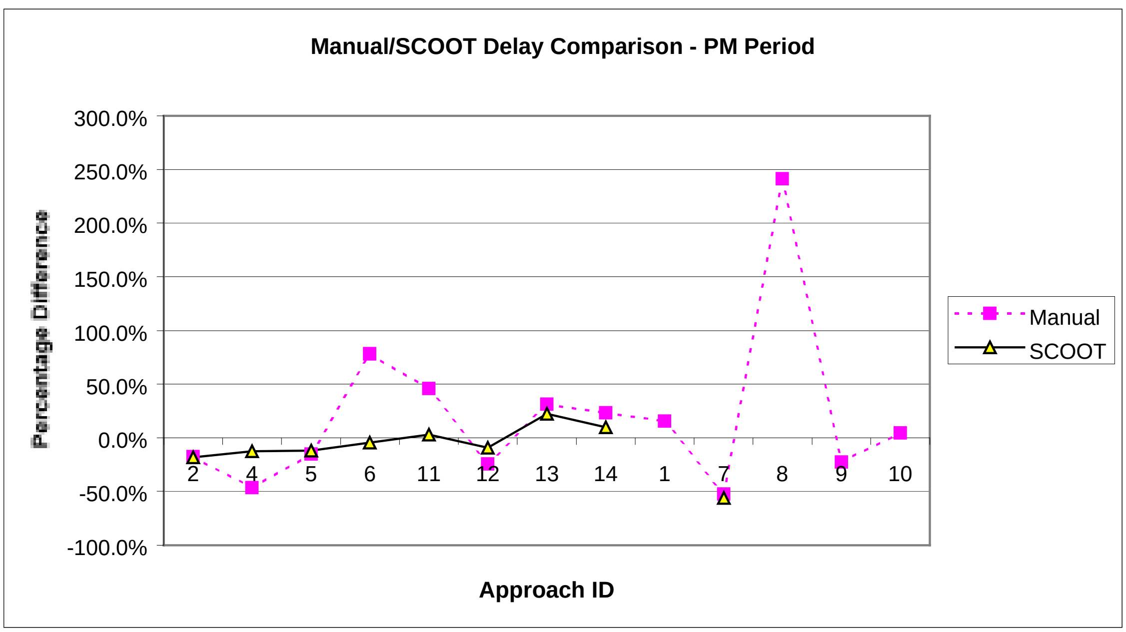
Primary Study
Delay - Manual Data compared to SCOOT Data (AM Peak Hour)

Route ID	w/ SCOOT		w/o SCOOT		% Difference	
	Manual Data	SCOOT Data	Manual Data	SCOOT Data	Manual Data	SCOOT Data
Normal Condition						
2	5.61	6.78	4.78	6.69	17.4%	1.4%
4	0.75	1.42	0.40	1.48	86.4%	-4.4%
5	3.97	9.98	5.15	10.91	-22.9%	-8.5%
6	2.90	2.78	0.65	1.02	348.5%	171.5%
11	1.07	1.33	0.59	1.49	80%	-11%
12	2.44	4.38	1.47	3.75	66%	17%
13	7.52	4.61	11.66	5.98	-35%	-23%
14	1.30	2.42	0.86	1.40	51%	72%
Average	3.31	5.24	2.74	5.03	20.5%	4.3%
Boundary Condition						
1	3.13		2.02		55.5%	
7	4.53	5.43	13.55	8.48	-66.5%	-35.9%
8	5.24		1.45		262.1%	
9	0.89		0.70		27.7%	
10	4.61		4.43		4.0%	
Average	3.82	5.43	5.03	8.48	-24.1%	-35.9%
Average	**3.56**	**5.28**	**3.89**	**5.72**	**-8.3%**	**-7.7%**



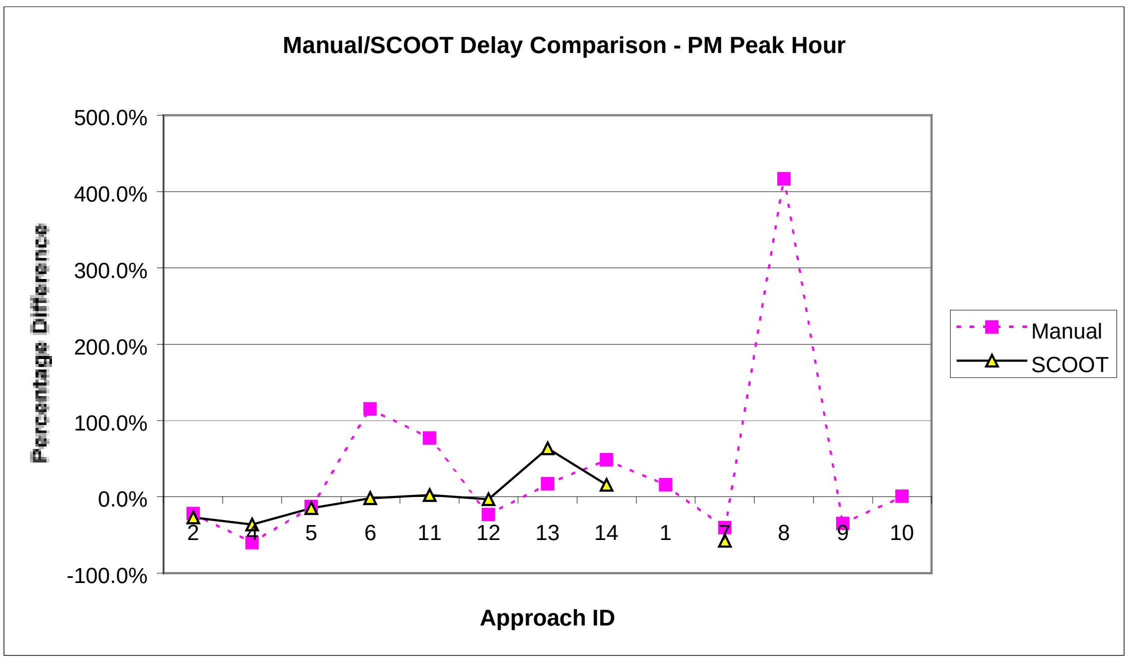
Primary Study
Delay - Manual Data compared to SCOOT Data (PM Period)

Route ID	w/ SCOOT		w/o SCOOT		% Difference	
	Manual Data	SCOOT Data	Manual Data	SCOOT Data	Manual Data	SCOOT Data
Normal Condition						
2	2.65	2.45	3.22	3.00	-17.8%	-18.3%
4	1.17	2.00	2.19	2.29	-46.5%	-12.7%
5	2.81	3.36	3.31	3.82	-15.0%	-12.0%
6	2.36	3.58	1.33	3.75	78.2%	-4.5%
11	3.23	3.9	2.22	3.8	46%	3.0%
12	1.79	2.8	2.36	3.1	-24%	-9.2%
13	4.42	2.7	3.37	2.2	31%	22.3%
14	4.20	3.2	3.41	3.0	23%	9.6%
Average	2.83	3.00	2.68	3.11	5.7%	-3.4%
Boundary Condition						
1	3.20		2.77		15.5%	
7	1.47	1.51	3.10	3.44	-52.5%	-56.1%
8	5.09		1.49		241.1%	
9	4.55		5.86		-22.5%	
10	9.63		9.22		4.5%	
Average	4.79	1.51	4.49	3.44	6.7%	-56.1%
Average	**3.58**	**2.84**	**3.37**	**3.15**	**6.2%**	**-9.8%**



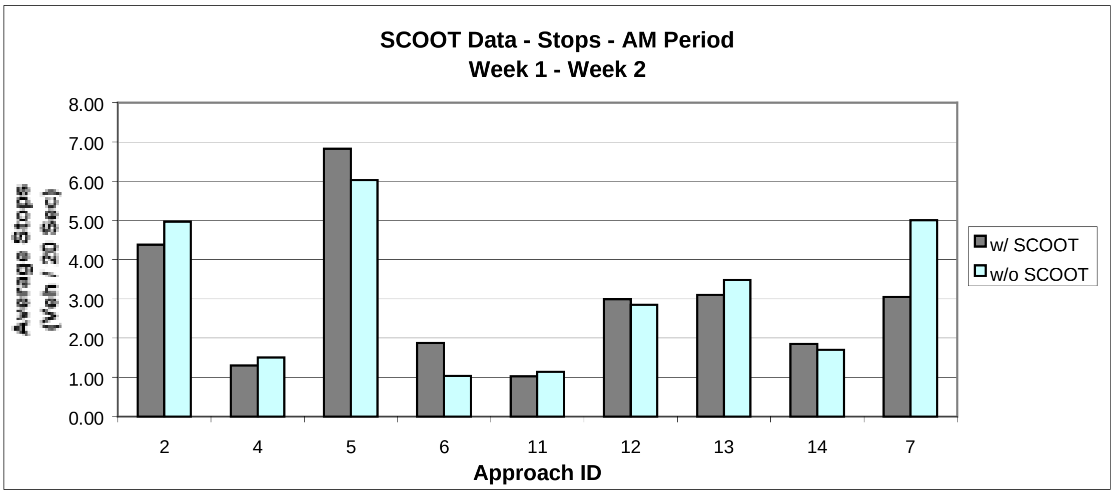
Primary Study
Delay - Manual Data compared to SCOOT Data (PM Peak Hour)

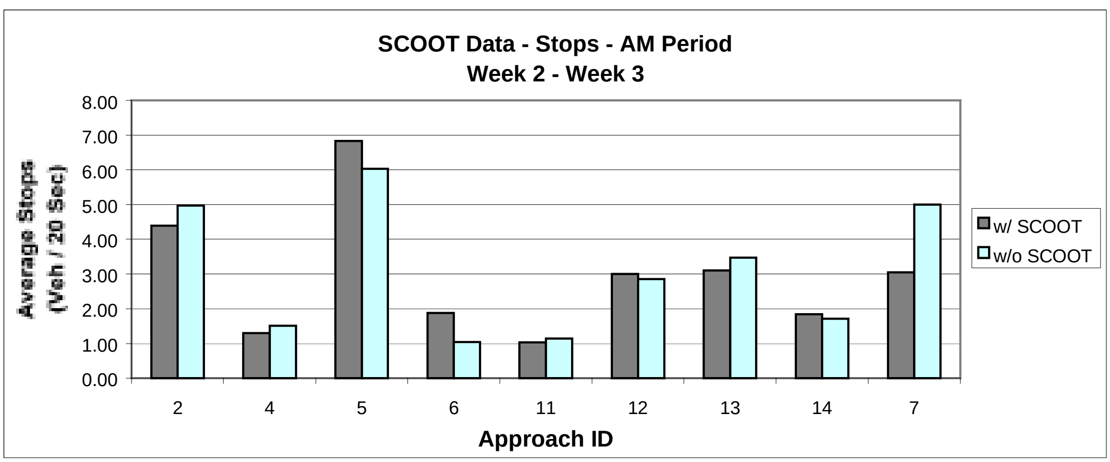
Route ID	w/ SCOOT		w/o SCOOT		% Difference	
	Manual Data	SCOOT Data	Manual Data	SCOOT Data	Manual Data	SCOOT Data
Normal Condition						
2	2.93	2.49	3.75	3.41	-21.8%	-27.0%
4	1.26	1.74	3.18	2.74	-60.4%	-36.4%
5	3.78	3.54	4.33	4.16	-12.7%	-15.0%
6	2.83	4.12	1.32	4.19	115.1%	-1.7%
11	6.9	6.32	3.9		77%	2%
12	2.19	3.43	2.86		-23%	-3%
13	4.84	3.65	4.14		17%	63%
14	8.07	4.35	5.44		48%	16%
Average	4.11	3.70	3.62	3.62	13.5%	2.2%
Boundary Condition						
1	3.20		2.77		15.5%	
7	2.21	1.82	3.73	4.28	-40.6%	-57.5%
8	6.99		1.35		417.0%	
9	10.92		16.86		-35.2%	
10	17.91		17.83		0.5%	
Average	8.25	1.82	8.51	4.28	-3.0%	-57.5%
Average	**5.70**	**3.49**	**5.50**	**3.75**	**3.7%**	**-6.9%**



Primary Study - SCOOT Data
Stops (Avg Stop Veh / 20 sec) **AM Period**

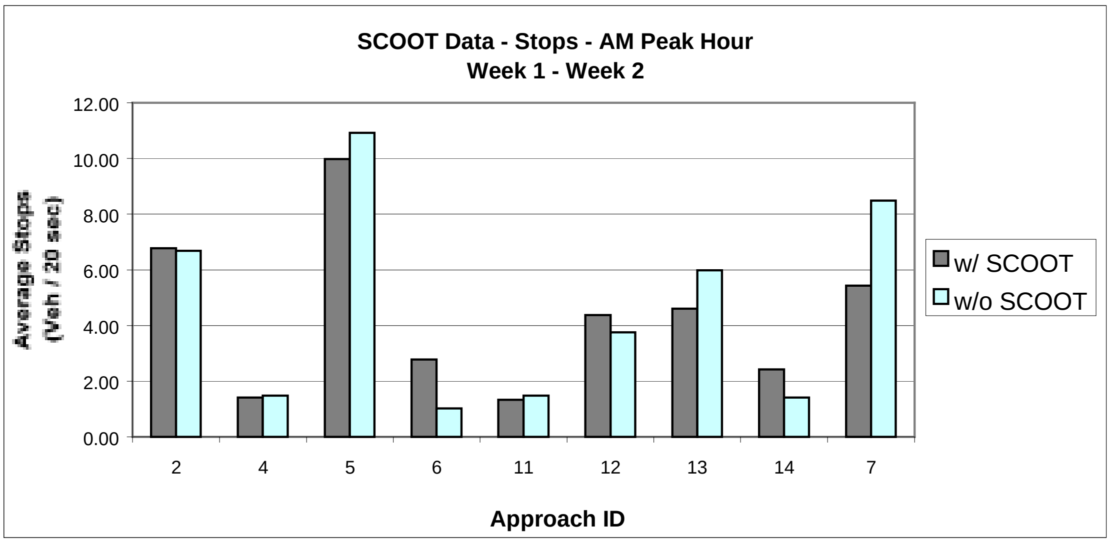
Approach ID	Week 1 (Aug 10-12) to Week 2 (Aug 17-19) w/ SCOOT	w/o SCOOT	% Diff	Stat Diff	Week 2 (Aug 17-19) to Week 3 (Aug 24-26) w/ SCOOT	w/o SCOOT	% Diff	Stat Diff
Normal Condition					Normal Condition			
2	**4.39**	**4.97**	**-11.8%**	**Yes-SC**	4.81	4.97	-3.3%	No
4	**1.3**	**1.5**	**-14.2%**	**Yes-SC**	**1.1**	**1.5**	**-24.9%**	**Yes-SC**
5	6.83	6.03	13.3%	No	**6.96**	**6.03**	**15.5%**	**Yes-T2**
6	**1.88**	**1.04**	**80.9%**	**Yes**	**1.59**	**1.04**	**53.4%**	**Yes-T2**
11	**1.03**	**1.14**	**-9.9%**	**Yes-SC**	**1.0**	**1.1**	**-13.0%**	**Yes-SC**
12	3.00	2.86	4.9%	No	2.9	2.9	2.4%	No
13	3.10	3.47	-10.7%	No	**2.8**	**3.5**	**-20.5%**	**Yes-SC**
14	1.84	1.71	8.0%	No	1.715	1.708	0.4%	No
Average	2.92	2.84	2.8%		2.86	2.84	0.7%	
Boundary Condition					Boundary Condition			
7	**3.05**	**5.01**	**-39.1%**	**Yes-SC**	**2.59**	**5.01**	**-48.3%**	**Yes**
Average	2.93	3.08	-4.8%		2.83	3.08	-8.1%	

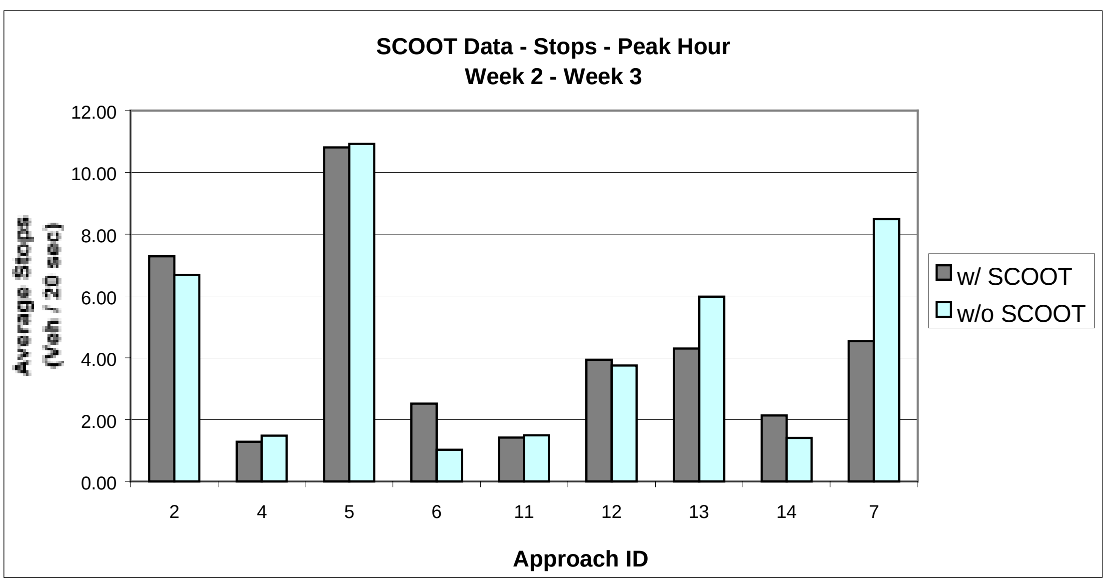




Primary Study - SCOOT Data
Stops (Avg Stop Veh / 20 sec) **AM Peak Hour**

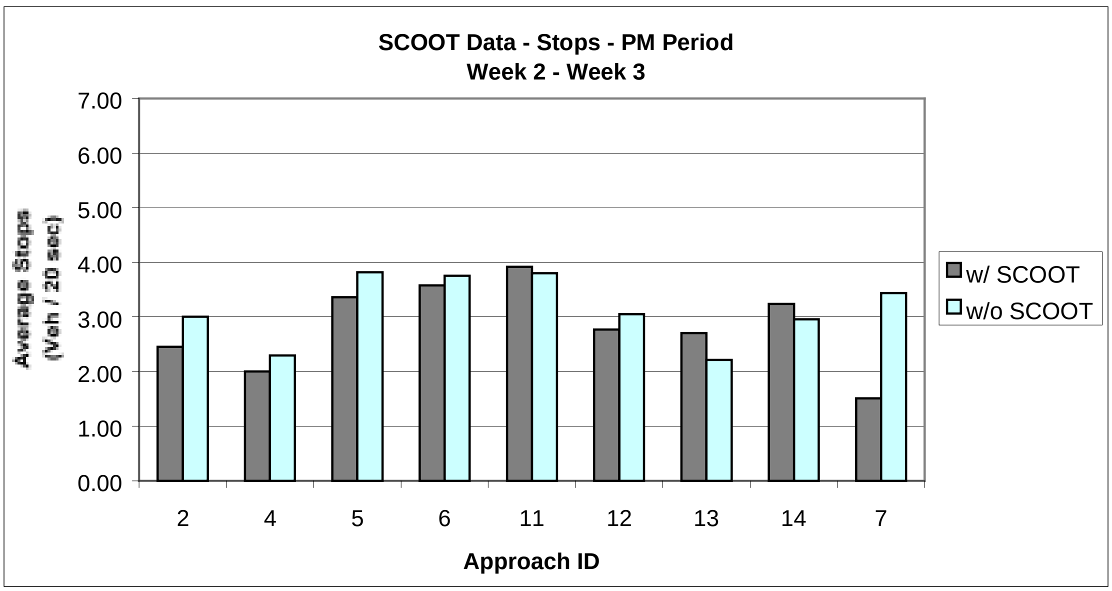
	Week 1 (Aug 10-12) to Week 2 (Aug 17-19)				Week 2 (Aug 17-19) to Week 3 (Aug 24-26)			
Approach ID	With	Without	% Diff	Stat Diff	With	Without	% Diff	Stat Diff
	Normal Condition				Normal Condition			
2	6.78	6.69	1.4%	No	7.28	6.69	8.9%	No
4	1.4	1.5	-4.4%	No	1.3	1.48	-13.6%	No
5	9.98	10.91	-8.5%	No	10.81	10.91	-0.9%	No
6	**2.78**	**1.02**	**171.5%**	**Yes**	**2.52**	**1.02**	**145.7%**	**Yes-T2**
11	1.33	1.49	-10.6%	No	1.41	1.49	-5.1%	No
12	**4.38**	**3.75**	**16.6%**	**Yes**	3.94	3.75	4.9%	No
13	**4.61**	**5.98**	**-22.8%**	**Yes-SC**	**4.29**	**5.98**	**-28.1%**	**Yes-SC**
14	**2.42**	**1.40**	**72.4%**	**Yes**	**2.13**	**1.40**	**51.7%**	**Yes-T2**
Average	4.21	4.09	3.0%		4.21	4.09	2.9%	
	Boundary Condition				Boundary Condition			
7	**5.43**	**8.48**	**-35.9%**	**Yes-SC**	**4.53**	**8.48**	**-46.6%**	**Yes-SC**
Average	4.35	4.58	-5.0%		4.24	4.58	-7.3%	





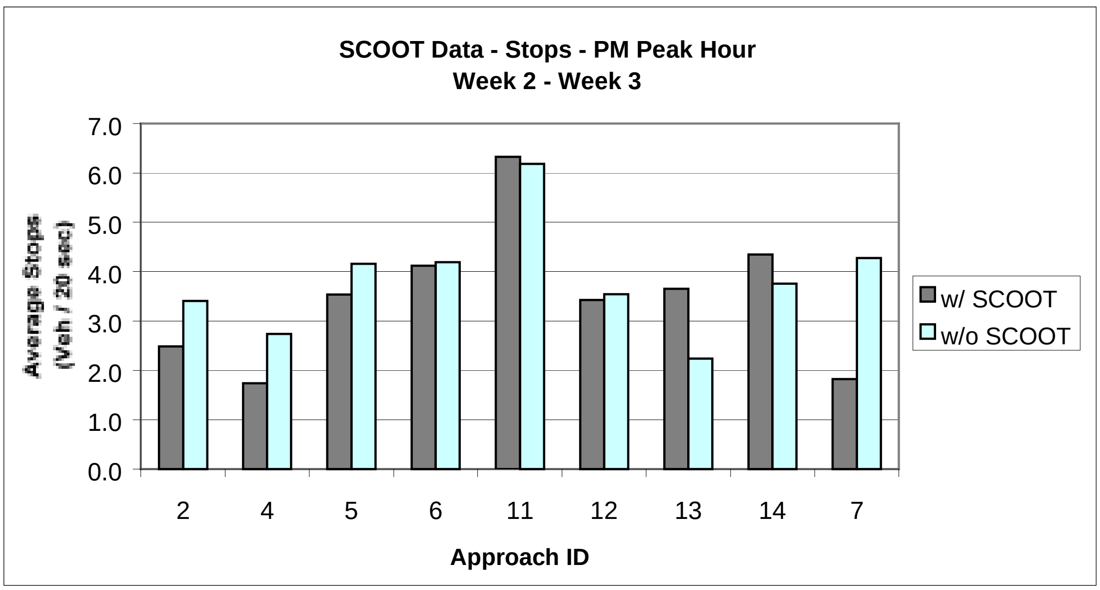
Primary Study - SCOOT Data
Stops (Avg Stop Veh / 20 sec) **PM Period**

	Week 1 (Aug 10-12) to Week 2 (Aug 17-19)				Week 2 (Aug 17-19) to Week 3 (Aug 24-26)			
Approach ID	With	Without	% Diff	Stat Diff	With	Without	% Diff	Stat Diff
	Normal Condition				Normal Condition			
2	N/A	N/A	N/A	N/A	**2.45**	**3.00**	**-18.3%**	**Yes-SC**
4	N/A	N/A	N/A	N/A	**2.0**	**2.3**	**-12.7%**	**Yes-SC**
5	N/A	N/A	N/A	N/A	**3.36**	**3.82**	**-12.0%**	**Yes-SC**
6	N/A	N/A	N/A	N/A	3.58	3.75	-4.5%	No
11	N/A	N/A	N/A	N/A	3.9	3.8	3.0%	No
12	N/A	N/A	N/A	N/A	**2.8**	**3.1**	**-9.2%**	**Yes-SC**
13	N/A	N/A	N/A	N/A	**2.7**	**2.2**	**22.3%**	**Yes-T2**
14	N/A	N/A	N/A	N/A	**3.2**	**3.0**	**9.6%**	**Yes-T2**
Average					3.0	3.1	-3.4%	
	Boundary Condition				Boundary Condition			
7	N/A	N/A	N/A	N/A	**1.51**	**3.44**	**-56.1%**	**Yes-SC**
Average					2.84	3.15	-9.8%	



Primary Study - SCOOT Data
Stops (Avg Stop Veh / 20 sec) **PM Peak Hour**

	Week 1 (Aug 10-12) to Week 2 (Aug 17-19)				Week 2 (Aug 17-19) to Week 3 (Aug 24-26)			
Approach ID	With	Without	% Diff	Stat Diff	With	Without	% Diff	Stat Diff
	Normal Condition				Normal Condition			
2	N/A	N/A	N/A	N/A	**2.5**	**3.4**	**-27.0%**	**Yes-SC**
4	N/A	N/A	N/A	N/A	**1.7**	**2.7**	**-36.4%**	**Yes-SC**
5	N/A	N/A	N/A	N/A	**3.5**	**4.2**	**-15.0%**	**Yes-SC**
6	N/A	N/A	N/A	N/A	4.1	4.2	-1.7%	No
11	N/A	N/A	N/A	N/A	6.32	6.18	2.3%	No
12	N/A	N/A	N/A	N/A	3.43	3.54	-3.3%	No
13	N/A	N/A	N/A	N/A	**3.65**	**2.24**	**63.3%**	**Yes-T2**
14	N/A	N/A	N/A	N/A	**4.35**	**3.76**	**15.7%**	**Yes-T2**
Average					3.7	3.8	-1.9%	
	Boundary Condition				Boundary Condition			
7	N/A	N/A	N/A	N/A	**1.8**	**4.3**	**-57.5%**	**Yes-SC**
Average					3.49	3.83	-8.8%	

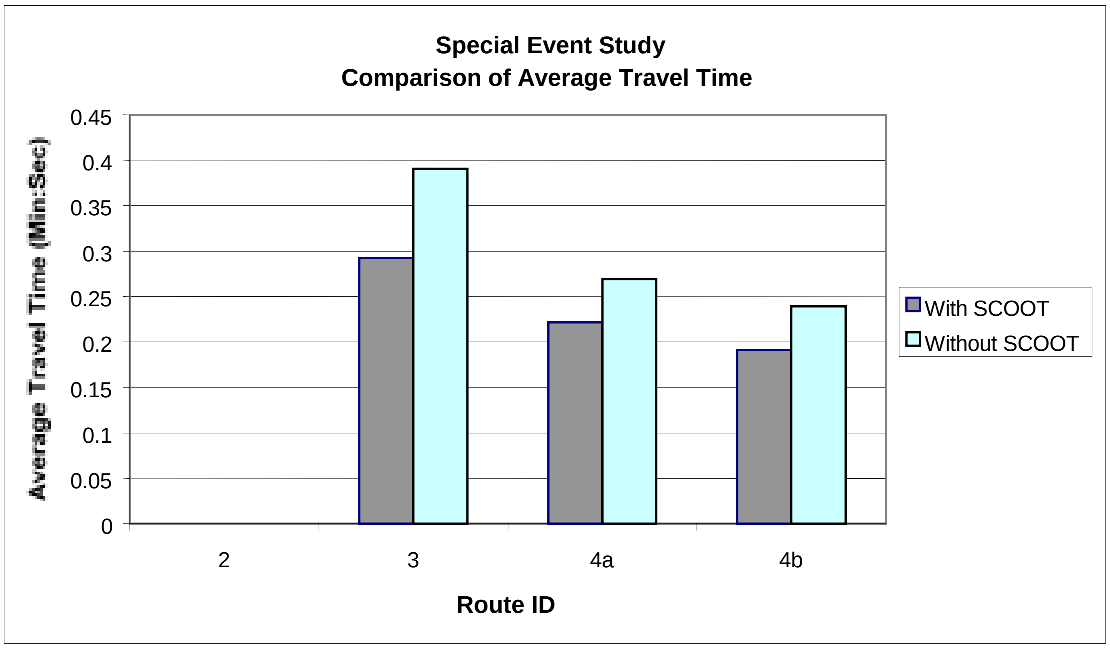


APPENDIX I

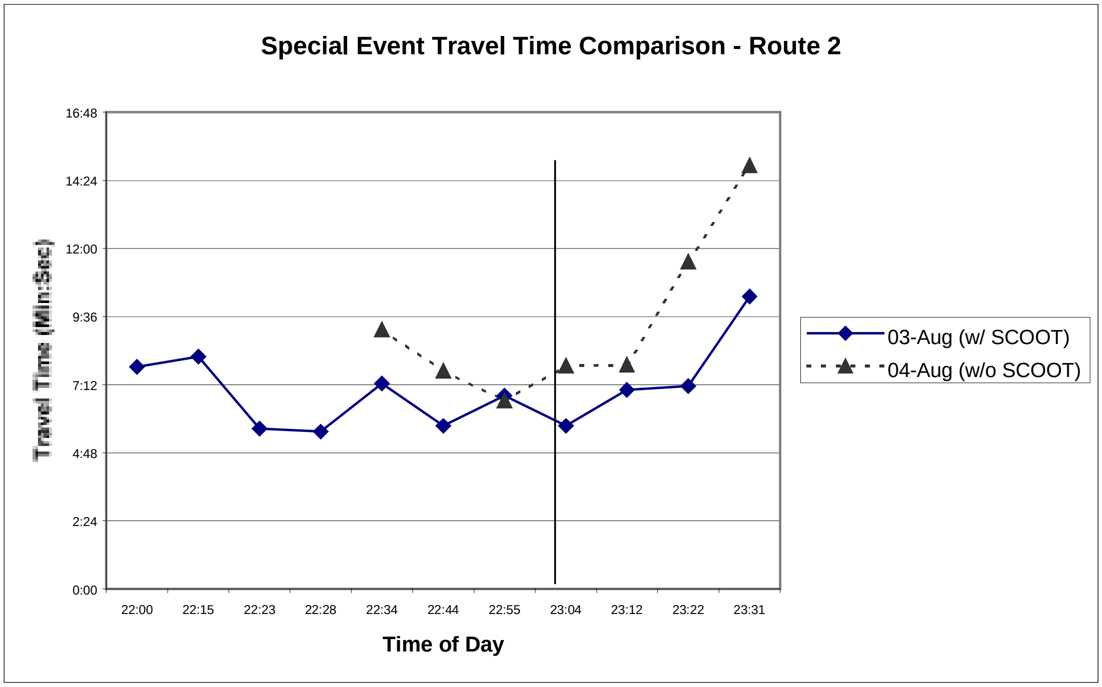
SPECIAL EVENT RESULTS

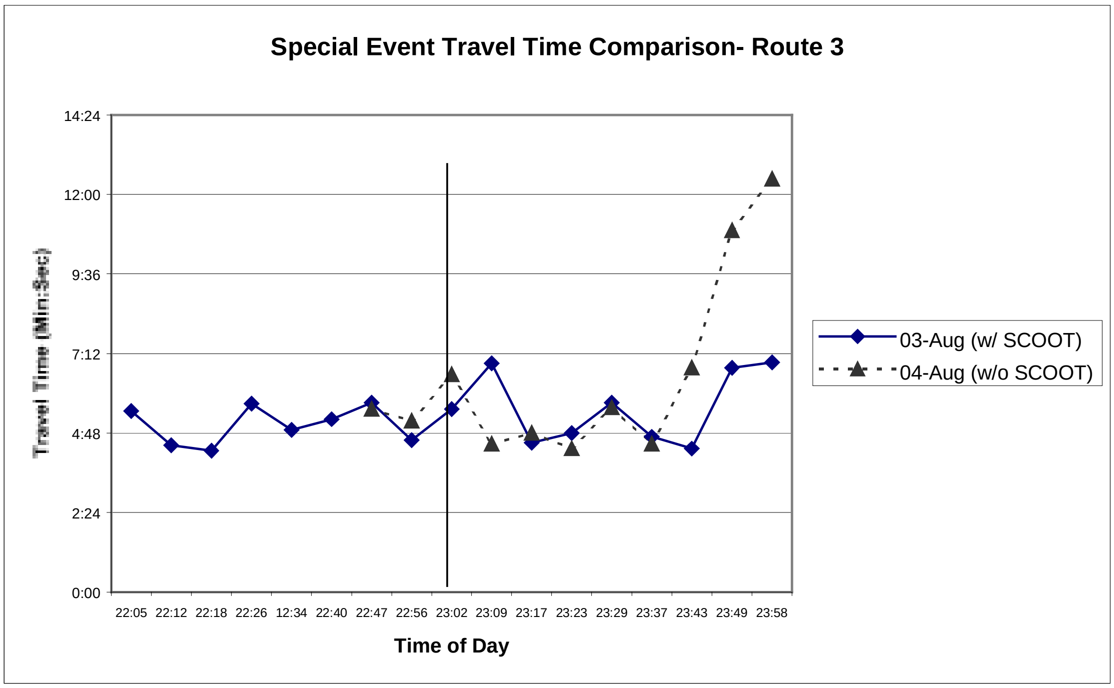
Special Event Study
Travel Time

Route ID	w/ SCOOT	w/o SCOOT	% Diff	Statistical Difference
2	7:01	9:22	-25.1%	
3	5:19	6:27	-17.6%	
4a	4:35	5:44	-20.0%	
4b	3:40	3:54	-5.9%	
Average	5:09	6:22	**-19.1%**	**Yes - SCOOT**

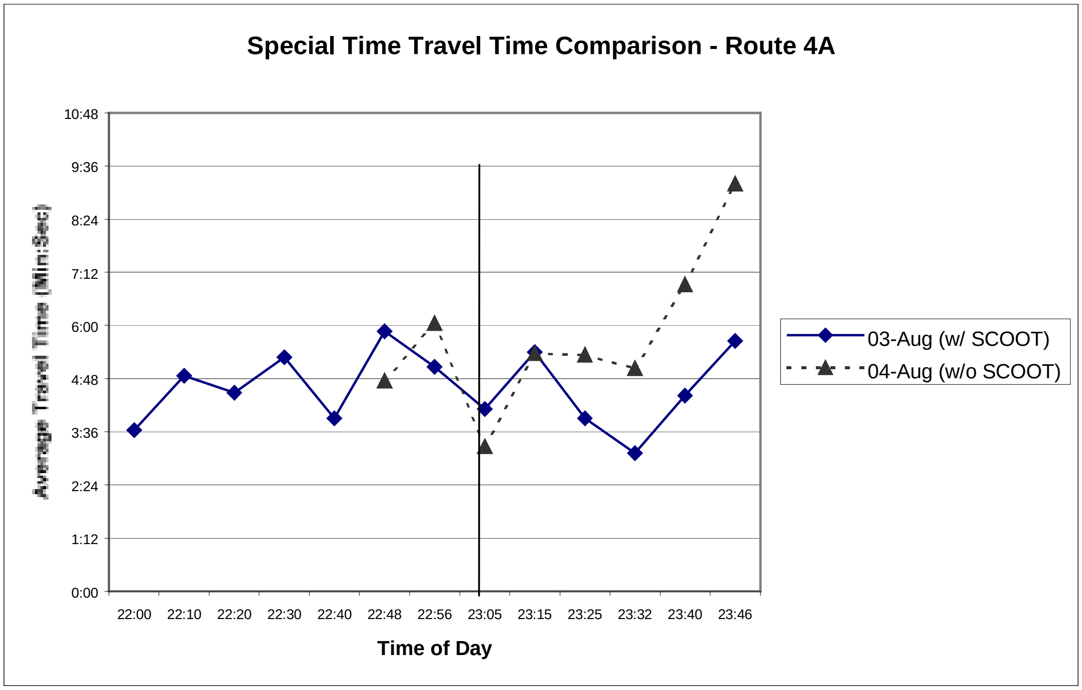


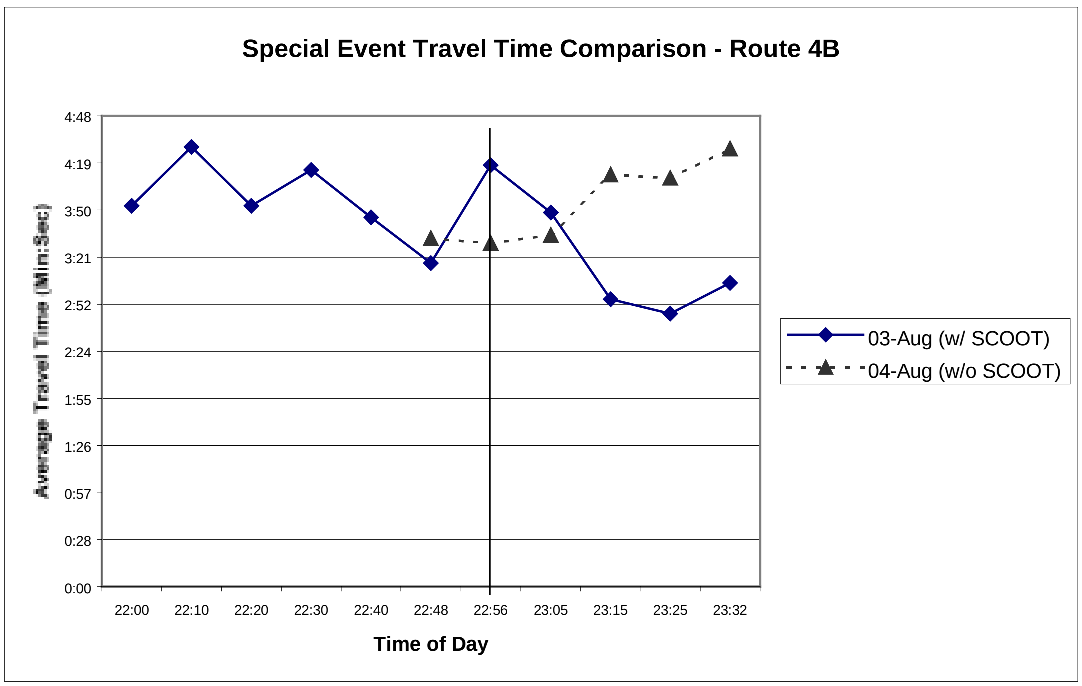
Route - By - Route Travel Time Comparison (Special Event)





Route - By - Route Travel Time Comparison (Special Event)





Special Event

Travel Time Detailed Results

Aug-3-99	10:00 PM - 12:00 AM	Event ended at 11:00 PM	With SCOOT
Aug-4-99	9:30 PM - 11:30 PM	Event ended at 10:30 PM	Without SCOOT

Route 2				Route 3			
Aug 3 (w/ SCOOT)		Aug 4 (w/o SCOOT)		Aug 3 (w/ SCOOT)		Aug 4 (w/o SCOOT)	
Starting Time	A to B	Starting Time	A to B	Starting Time	A to B	Starting Time	A to B
10:00 PM	7:50			10:05 PM	5:28		
10:15 PM	8:11			10:12 PM	4:26		
10:23 PM	5:39			10:18 PM	4:16		
10:28 PM	5:33			10:26 PM	5:41		
10:34 PM	7:15	10:00 PM	9:08	12:34 PM	4:54		
10:44 PM	5:45	10:11 PM	7:41	10:40 PM	5:13		
10:55 PM	6:49	10:22 PM	6:38	10:47 PM	5:43	10:05 PM	5:31
11:04 PM	5:45	10:28 PM	7:52	10:56 PM	4:35	10:12 PM	5:10
11:12 PM	7:01	10:39 PM	7:54	11:02 PM	5:31	10:19 PM	6:34
11:22 PM	7:09	10:50 PM	11:32	11:09 PM	6:54	10:27 PM	4:28
11:31 PM	10:19	11:04 PM	14:55	11:17 PM	4:30	10:33 PM	4:48
				11:23 PM	4:48	10:40 PM	4:20
				11:29 PM	5:43	10:46 PM	5:34
				11:37 PM	4:41	10:53 PM	4:28
				11:43 PM	4:20	10:59 PM	6:46
				11:49 PM	6:46	11:08 PM	10:55
				11:58 PM	6:56	11:20 PM	12:28
Average	7:01		9:22		5:19		6:27
% Difference		**-25.1%**				**-17.6%**	

Route 4A				Route 4B			
Aug 3 (w/ SCOOT)		Aug 4 (w/o SCOOT)		Aug 3 (w/ SCOOT)		Aug 4 (w/o SCOOT)	
Starting Time	A to B	Starting Time	A to B	Starting Time	C to D	Starting Time	C to D
10:00 PM	3:38			10:00 PM	3:53		
10:10 PM	4:52			10:10 PM	4:29		
10:20 PM	4:29			10:20 PM	3:53		
10:30 PM	5:17			10:30 PM	4:15		
10:40 PM	3:54			10:40 PM	3:46		
10:48 PM	5:52	10:05 PM	4:45	10:48 PM	3:18	10:05 PM	3:33
10:56 PM	5:04	10:15 PM	6:03	10:56 PM	4:18	10:15 PM	3:30
11:05 PM	4:07	10:25 PM	3:16	11:05 PM	3:49	10:25 PM	3:35
11:15 PM	5:24	10:35 PM	5:22	11:15 PM	2:56	10:35 PM	4:12
11:25 PM	3:54	10:45 PM	5:20	11:25 PM	2:47	10:45 PM	4:10
11:32 PM	3:07	10:55 PM	5:02	11:32 PM	3:06	10:55 PM	4:28
11:40 PM	4:25	11:05 PM	6:55				
11:46 PM	5:39	11:17 PM	9:12				
Average	4:35		5:44		3:40		3:54
% Difference		**-20.0%**				**-5.9%**	

APPENDIX J

SUPPLEMENTAL STUDY RESULTS

Supplemental Study
Weighted Travel Time (seconds)
AM Summary

	w/ SCOOT			w/o SCOOT			w/ SCOOT			w/o SCOOT		
	Travel Time	**Avg Vol**	**Weighted TT**	**Travel Time**	**Avg Vol**	**Weighted TT**	**Travel Time**	**Avg Vol**	**Weighted TT**	**Travel Time**	**Avg Vol**	**Weighted TT**
Link(1)	(all data)	T2000C		(all data)	T2000C		(Modified)	T2000C		(Modified)	T2000C	
1 **Washington: Hennepin to 1st Ave**	**34.3**	**14.6**	**0.3**	**33**	**13.1**	**0.27**						
2 **1st Ave: Washington to 3rd St.**	**20.2**	**138.5**	**1.7**	**18.4**	**128.3**	**1.45**						
3 1st Ave: 3rd to 4th St.	29.5	82.1	1.5	38.3	76.0	1.79	29.5	82.1	1.6	38.3	76.0	2.0
4 1st Ave: 4th to 5th St.	16	114.4	1.1	16.1	105.5	1.04	16	114.4	1.2	16.1	105.5	1.1
5 1st Ave: 5th to 6th St.	26	109.0	1.7	21.5	103.0	1.36	26	109.0	1.9	21.5	103.0	1.5
6 1st Ave: 6th to 7th St.	11.3	86.5	0.6	20.4	82.2	1.03	11.3	86.5	0.7	20.4	82.2	1.1
7 1st Ave: 7th to 8th St.	13.6	87.2	0.7	13	87.1	0.70	13.6	87.2	0.8	13	87.1	0.8
8 1st Ave: 8th to 9th St.	20.2	57.9	0.7	30.9	55.3	1.05	20.2	57.9	0.8	30.9	55.3	1.2
9 1st Ave: 9th to 10th St.	27.6	57.9	1.0	14.9	55.3	0.51	27.6	57.9	1.1	14.9	55.3	0.6
10 1st Ave: 10th to 11th St.	15.1	54.2	0.5	10.8	52.8	0.35	15.1	54.2	0.5	10.8	52.8	0.4
11 1st Ave: 11th to 12th St.	13.7	22.1	0.2	12.8	21.7	0.17	13.7	22.1	0.2	12.8	21.7	0.2
12 12th St: 1st Ave to Hennepin	34.4	11.3	0.2	26.9	10.2	0.17	34.4	11.3	0.3	26.9	10.2	0.2
13 Hennepin: 12th to 11th St.	21.2	117.8	1.5	32.4	121.6	2.42	21.2	117.8	1.7	32.4	121.6	2.7
14 Hennepin: 11th to 10th St.	18.6	110.4	1.2	12.4	111.8	0.85	18.6	110.4	1.4	12.4	111.8	0.9
15 Hennepin: 10th to 9th St.	11.9	100.1	0.7	12	98.4	0.72	11.9	100.1	0.8	12	98.4	0.8
16 Hennepin: 9th to 8th St.	13.5	114.3	0.9	25.9	116.8	1.86	13.5	114.3	1.0	25.9	116.8	2.0
17 Hennepin: 8th to 7th St.	20.2	80.4	1.0	16.6	80.8	0.82	20.2	80.4	1.1	16.6	80.8	0.9
18 Hennepin: 7th to 6th St.	19.7	91.6	1.1	14.3	93.2	0.82	19.7	91.6	1.2	14.3	93.2	0.9
19 Hennepin: 6th to 5th St.	26.1	82.4	1.3	16	81.5	0.80	26.1	82.4	1.4	16	81.5	0.9
20 Hennepin: 5th to 4th St.	26	60.5	0.9	33.5	62.8	1.29	26	60.5	1.0	33.5	62.8	1.4
21 Hennepin: 4th to 3rd St.	17.8	61.3	0.7	23.2	62.3	0.89	17.8	61.3	0.7	23.2	62.3	1.0
22 **Hennepin: 3rd St to Washington**	**37**	**8.7**	**0.2**	**27.1**	**8.6**	**0.14**						
Total		1663.2			1628.4			1501.4			1478.3	
Average Travel Time (Seconds)	21.5	75.6	0.89	21.4	74.0	0.93	20.1	79.0	1.0	20.6	77.8	1.08
Percent Diference				0.7%	2.1%	-4.1%				-2.4%	1.6%	-5.7%
Statistical Difference (t-test)				No (CI=75%)	No (CI=76%)	No (CI<70%)				No (CI<70%)	No	No (CI<72%)

(1) links identified in bold were removed from the calculation in order to reduce the impact of turning movement within the route.
(2) The Confidence Interval (CI) inidicates the confidence level at which the difference becomes statistically significant (95% used here).

Supplemental Study

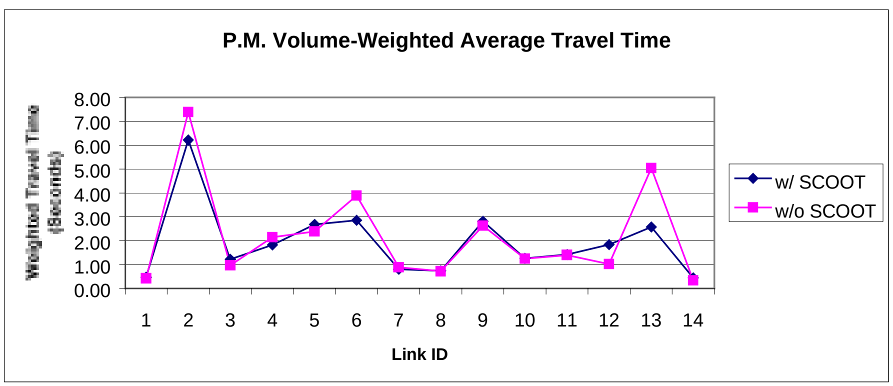
Volume-Weighted Average Travel Time

PM Summary

Link(1)		w/ SCOOT			w/o SCOOT			w/ SCOOT			w/o SCOOT		
		Travel Time (all data)	Avg Vol (all data)	Weighted TT (all data)	Travel Time (all data)	Avg Vol (all data)	Weighted TT (all data)	Travel Time (modified)	Avg Vol (modified)	Weighted TT (modified)	Travel Time (modified)	Avg Vol (modified)	Weighted TT (modified)
1	**Washington: Hennepin to 1st Ave**	**31.1**	**18.2**	**0.47**	**28.3**	**18.6**	**0.42**						
2	**1st Ave: Washington to 3rd St.**	**44**	**169.2**	**6.21**	**52.6**	**176.5**	**7.39**						
3	1st Ave: 3rd to 4th St.	15.8	92.2	1.22	12.4	97.0	0.96	15.8	92.2	1.52	12.4	97.0	1.19
4	1st Ave: 4th to 5th St.	19.3	112.9	1.82	22.8	117.9	2.14	19.3	112.9	2.27	22.8	117.9	2.67
5	1st Ave: 5th to 6th St.	25.6	125.5	2.68	22.6	132.4	2.38	25.6	125.5	3.34	22.6	132.4	2.97
6	1st Ave: 6th to 7th St.	31.3	109.2	2.85	42.7	114.2	3.88	31.3	109.2	3.56	42.7	114.2	4.83
7	1st Ave: 7th to 8th St.	23.4	41.3	0.81	24.1	46.4	0.89	23.4	41.3	1.01	24.1	46.4	1.11
8	**8th St: 1st Ave to Hennepin**	**51.2**	**17.3**	**0.74**	**46**	**19.6**	**0.72**						
9	**Hennepin: 8th to 7th St.**	**34.7**	**97.2**	**2.82**	**34.1**	**96.9**	**2.63**						
10	Hennepin: 7th to 6th St.	14.1	106.7	1.26	14.6	107.2	1.25	14.1	106.7	1.57	14.6	107.2	1.55
11	Hennepin: 6th to 5th St.	16.9	100.7	1.42	16.8	104.9	1.40	16.9	100.7	1.77	16.8	104.9	1.75
12	Hennepin: 5th to 4th St.	25.5	86.2	1.84	14.4	89.0	1.02	25.5	86.2	2.29	14.4	89.0	1.27
13	Hennepin: 4th to 3rd St.	30.6	101.0	2.58	60.5	104.5	5.04	30.6	101.0	3.22	60.5	104.5	6.27
14	**Hennepin: 3rd St to Washington**	**42.1**	**12.5**	**0.44**	**35.4**	**12.2**	**0.34**						
Total			1190.0			1237.3			875.6			913.5	
Average		29.0	85.0	1.94	30.5	88.4	2.18	22.5	97.3	2.28	25.7	101.5	2.62
Percent Difference					-5.1%	-3.8%	-10.9%				-12.3%	-4.2%	-13.0%
Statistical Difference (t-test) (2)					No (CI=73%)	No (CI=94%)	No (CI=93%)				No (CI=94%)	No	Yes (CI=96%)

(1) Links identified in bold were removed from the calculation in order to reduce the impact of turning movement within the route.

(2) The Confidence Interval (CI) inidicates the confidence level at which the difference becomes statistically significant (95% used here).



Supplemental Study

T2000C Volume

AM Period

Street Name	Detector ID	w/ SCOOT			w/o SCOOT			Overall
		14-Dec	16-Dec	Avg. Vol / 5 min	15-Dec	17-Dec	Avg. Vol / 5 min	Avg. Vol/5min
Washington: Hennepin to 1st Ave (1)	D656 - 5,6,7	13.0	16.3	14.6	12.8	13.4	13.1	13.9
1st Ave: Washington to 3rd St. (1)	D631 -7,8	130.1	146.9	138.5	125.9	130.8	128.3	133.4
1st Ave: 3rd to 4th St.	D630 -1,2,3	79.7	84.5	82.1	75.0	76.9	76.0	79.0
1st Ave: 4th to 5th St.	D629 - 4,5,6	112.9	116.0	114.4	104.1	107.0	105.5	110.0
1st Ave: 5th to 6th St.	D628 -1,2,3	107.2	110.9	109.0	103.4	102.7	103.0	106.0
1st Ave: 6th to 7th St.	D627 - 5,6,7	86.2	86.8	86.5	83.4	81.0	82.2	84.3
1st Ave: 7th to 8th St.	D626 - 1,2,3	85.0	89.5	87.2	90.2	84.0	87.1	87.2
1st Ave: 8th to 9th St.	D625 - 4,5,6	56.1	59.7	57.9	57.8	52.8	55.3	56.6
1st Ave: 9th to 10th St. (estimated)	(see above)	56.1	59.7	57.9	57.8	52.8	55.3	56.6
1st Ave: 10th to 11th St.	D637 - 4,5,6	51.8	56.6	54.2	56.3	49.4	52.8	53.5
1st Ave: 11th to 12th St. (1)	D724 - 1,2,3	20.8	23.3	22.1	22.8	20.6	21.7	21.9
12th St: 1st Ave to Hennepin (1)	D635 - 1,2	10.9	11.7	11.3	10.5	9.9	10.2	10.8
Hennepin: 12th to 11th St.	D646 - 1,2,3	116.0	119.6	117.8	124.1	119.1	121.6	119.7
Hennepin: 11th to 10th St.	D647 - 1,2,3	104.4	116.4	110.4	111.8	111.8	111.8	111.1
Hennepin: 10th to 9th St.	D648 - 1,2,3	101.0	99.2	100.1	99.9	96.8	98.4	99.2
Hennepin: 9th to 8th St.	D649 - 1,2,3	115.8	112.8	114.3	118.0	115.6	116.8	115.6
Hennepin: 8th to 7th St.	D650 - 1,2,3	83.8	76.9	80.4	83.2	78.4	80.8	80.6
Hennepin: 7th to 6th St.	D651 - 1,2,3	93.4	89.7	91.6	97.5	88.8	93.2	92.4
Hennepin: 6th to 5th St.	D652 - 1,2,3	84.3	80.5	82.4	82.8	80.1	81.5	81.9
Hennepin: 5th to 4th St.	D653 - 1,2	61.0	60.0	60.5	62.9	62.8	62.8	61.7
Hennepin: 4th to 3rd St.	D654 - 1,2,3	61.2	61.4	61.3	64.3	60.3	62.3	61.8
Hennepin: 3rd St to Washington (1)	D655 - 1,2	8.7	8.7	8.7	8.8	8.5	8.6	8.7
Average		74.5	76.7	75.6	75.2	72.9	74.0	74.8
Percent Difference					-0.8%	5.2%	2.1%	
Z-Test							No	

Note

1. Volumes on left-turning links have been modified to approximate left-turn volumes. (Multiply total volume by left turn percentage)

Supplemental Study

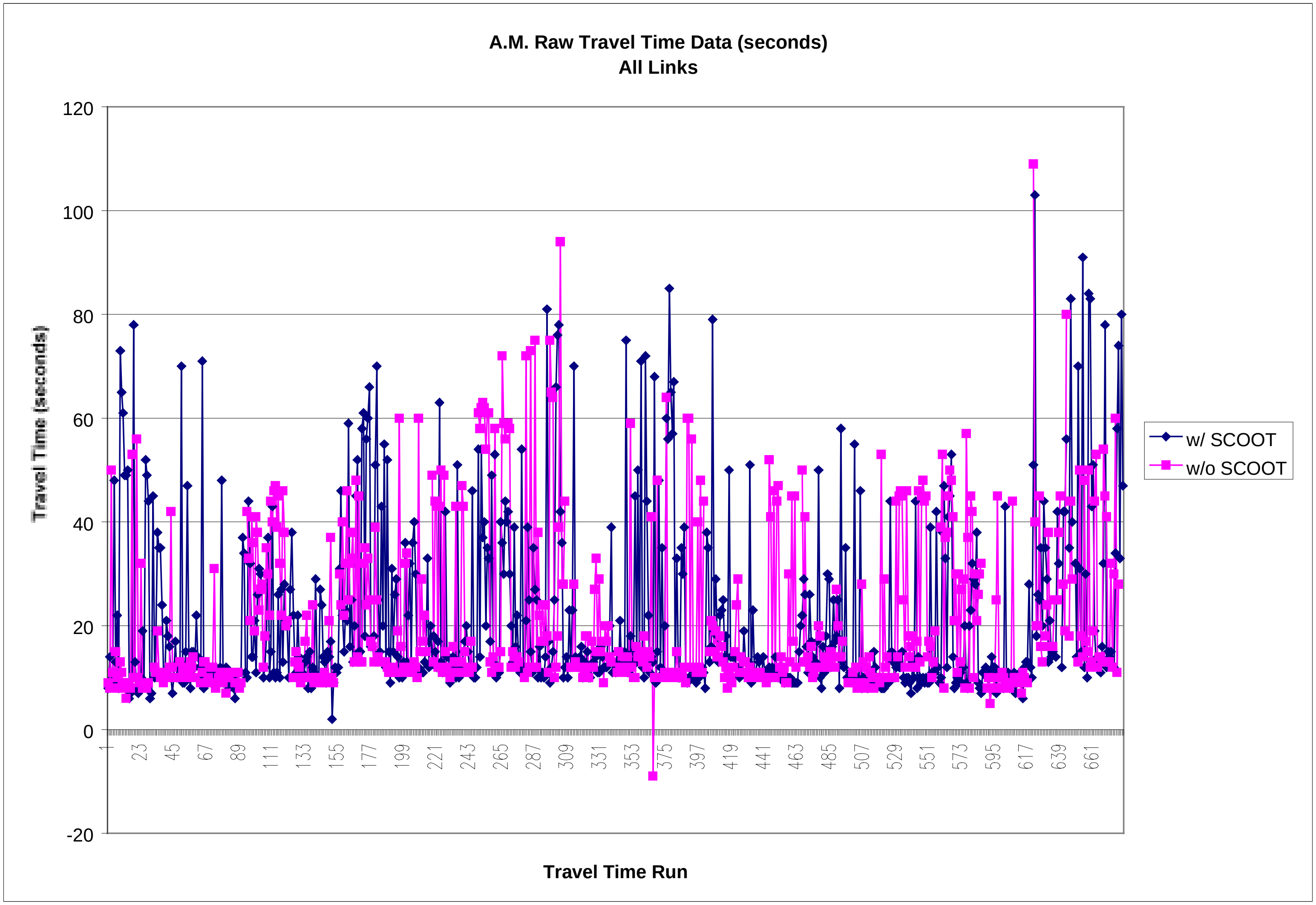
T200C Volume

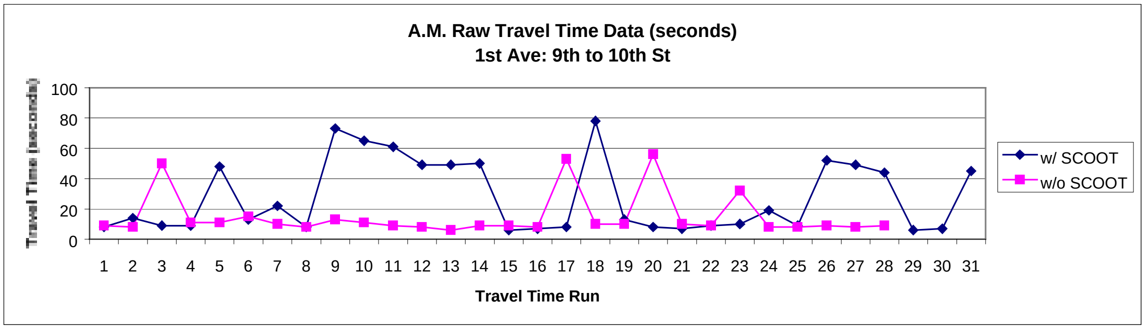
PM Period

Street Name	Detector ID	w/ SCOOT 13-Dec	w/ SCOOT 15-Dec	w/ SCOOT Avg. Vol / 5 min	w/o SCOOT 14-Dec	w/o SCOOT 16-Dec	w/o SCOOT Avg. Vol / 5 min	Overall Avg. Vol/5 min
Washington: Hennepin to 1st Ave (1)	D656 - 5,6,7	17.6	18.8	18.2	18.5	18.7	18.6	18.4
1st Ave: Washington to 3rd St.	D631 -7,8	161.7	176.6	169.2	172.5	180.4	176.5	172.8
1st Ave: 3rd to 4th St.	D630 -1,2,3	85.5	99.0	92.2	90.2	103.8	97.0	94.6
1st Ave: 4th to 5th St.	D629 - 4,5,6	103.1	122.6	112.9	108.8	127.1	117.9	115.4
1st Ave: 5th to 6th St.	D628 -1,2,3	117.4	133.5	125.5	127.4	137.4	132.4	129.0
1st Ave: 6th to 7th St.	D627 - 5,6,7	99.6	118.8	109.2	108.1	120.3	114.2	111.7
1st Ave: 7th to 8th St. (1)	D626 - 1,2,3	38.0	44.6	41.3	44.0	48.7	46.4	43.8
8th St: 1st Ave to Hennepin (1)	D625 - 1,2,3	16.4	18.2	17.3	19.4	19.7	19.6	18.4
Hennepin: 8th to 7th St.	D650 - 1,2,3	91.0	103.4	97.2	94.5	99.4	96.9	97.1
Hennepin: 7th to 6th St.	D651 - 1,2,3	101.4	111.9	106.7	104.4	109.9	107.2	106.9
Hennepin: 6th to 5th St.	D652 - 1,2,3	95.6	105.7	100.7	102.4	107.5	104.9	102.8
Hennepin: 5th to 4th St.	D653 - 1,2	85.8	86.6	86.2	87.5	90.6	89.0	87.6
Hennepin: 4th to 3rd St.	D654 - 1,2,3	98.0	104.1	101.0	99.0	110.0	104.5	102.8
Hennepin: 3rd St to Washington (1)	D655 - 1,2	12.4	12.7	12.5	12.0	12.4	12.2	12.4
Average		80.3	89.8	85.0	84.9	91.9	88.4	86.7
Percent Difference					-5.5%	-2.3%	-3.8%	
Z-Test							No	

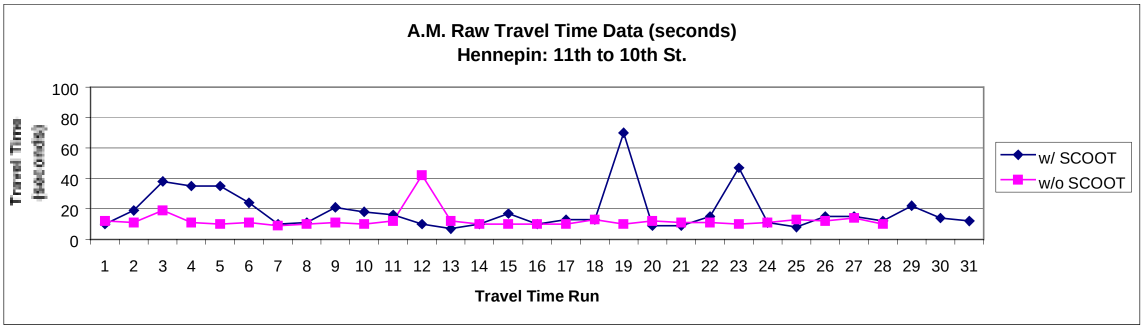
Note

(1) Volumes on left-turning links have been modified to approximate left-turn volumes. (Multiply total volume by left turn percentage)

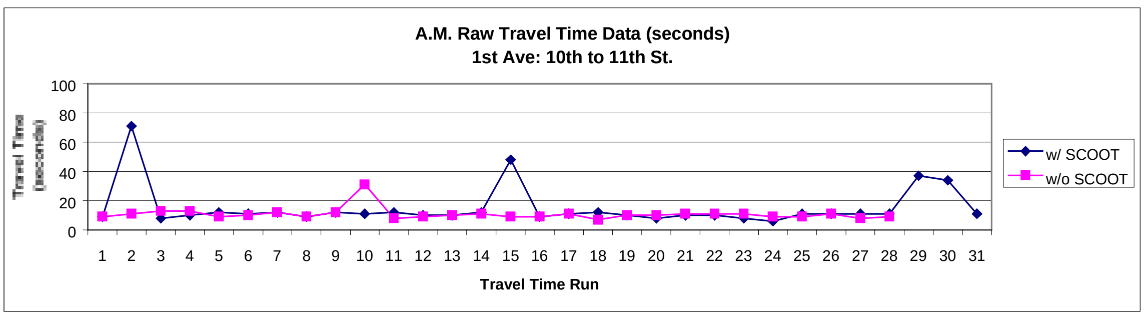

A.M. Raw Travel Time Data (seconds)
All Links
Travel Time (seconds)
Travel Time Run
w/ SCOOT
w/o SCOOT
120
100
80
60
40
20
0
-20
1
23
45
67
89
111
133
155
177
199
221
243
265
287
309
331
353
375
397
419
441
463
485
507
529
551
573
595
617
639
661



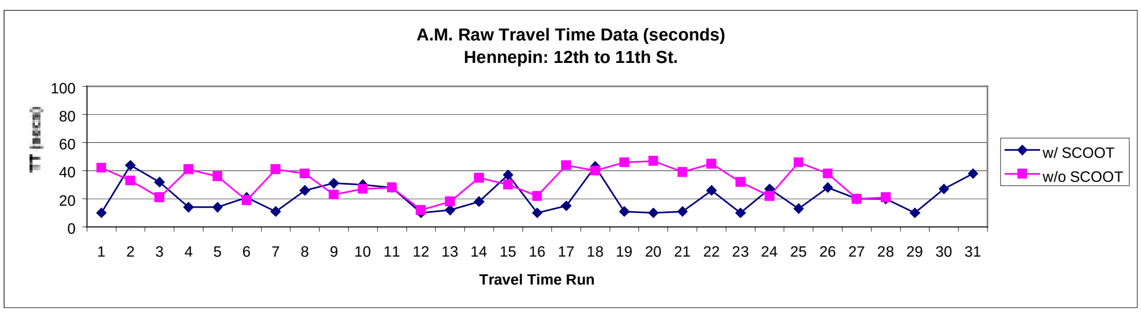
A.M. Raw Travel Time Data (seconds)
1st Ave: 9th to 10th St
Travel Time (seconds)
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Travel Time Run
w/ SCOOT
w/o SCOOT



A.M. Raw Travel Time Data (seconds)
Hennepin: 11th to 10th St.
Travel Time (seconds)
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Travel Time Run
w/ SCOOT
w/o SCOOT



A.M. Raw Travel Time Data (seconds)
1st Ave: 10th to 11th St.
Travel Time (seconds)
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Travel Time Run
w/ SCOOT
w/o SCOOT



A.M. Raw Travel Time Data (seconds)
Hennepin: 12th to 11th St.
TT (secs)
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Travel Time Run
w/ SCOOT
w/o SCOOT

LINK ID **17-Feb-00**

AM

Link(1)	**Street Name**	**SCOOT DET**	**T2000C ID**
1	**Washington: Hennepin to 1st Ave**	AU	D656 - 5,6,7
2	**1st Ave: Washington to 3rd St.**	Y-M (1124)	D631 -7,8
3	1st Ave: 3rd to 4th St.	X-G (1234)	D630 -1,2,3
4	1st Ave: 4th to 5th St.	W-A (1244)	D629 - 4,5,6
5	1st Ave: 5th to 6th St.	V-G (1354)	D628 -1,2,3
6	1st Ave: 6th to 7th St.	U-A (1364)	D627 - 5,6,7
7	1st Ave: 7th to 8th St.	T-G (1374)	D626 - 1,2,3
8	1st Ave: 8th to 9th St.	S-A (1384)	D625 - 4,5,6
9	1st Ave: 9th to 10th St.	AC	
10	1st Ave: 10th to 11th St.	AB-A (1414)	D637 - 4,5,6
11	1st Ave: 11th to 12th St.	AA (1424)	D724 - 1,2,3
12	12th St: 1st Ave to Hennepin	Z- (1434)	D635 - 1,2
13	Hennepin: 12th to 11th St.	AK- (1435)	D646 - 1,2,3
14	Hennepin: 11th to 10th St.	AL-C (1425)	D647 - 1,2,3
15	Hennepin: 10th to 9th St.	AM-J (1415)	D648 - 1,2,3
16	Hennepin: 9th to 8th St.	AN-C (1495)	D649 - 1,2,3
17	Hennepin: 8th to 7th St.	AO-J (1385)	D650 - 1,2,3
18	Hennepin: 7th to 6th St.	AP-C (1375)	D651 - 1,2,3
19	Hennepin: 6th to 5th St.	AQ-J (1365)	D652 - 1,2,3
20	Hennepin: 5th to 4th St.	AR-C (1355)	D653 - 1,2
21	Hennepin: 4th to 3rd St.	AS-J (1245)	D654 - 1,2,3
22	**Hennepin: 3rd St to Washington**	AT-C (1235)	D655 - 1,2

PM

Link(1)	**Street Name**	**SCOOT ID**	**T2000C ID**
1	**Washington: Hennepin to 1st Ave**	AU	D656 - 5,6,7
2	**1st Ave: Washington to 3rd St.**	Y-M (1124)	D631 -7,8
3	1st Ave: 3rd to 4th St.	X-G (1234)	D630 -1,2,3
4	1st Ave: 4th to 5th St.	W-A (1244)	D629 - 4,5,6
5	1st Ave: 5th to 6th St.	V-G (1354)	D628 -1,2,3
6	1st Ave: 6th to 7th St.	U-A (1364)	D627 - 5,6,7
7	1st Ave: 7th to 8th St.	T-G (1374)	D626 - 1,2,3
8	**8th St: 1st Ave to Hennepin**	S-A (1384)	D625 - 1,2,3
9	**Hennepin: 8th to 7th St.**	AO-J (1385)	D650 - 1,2,3
10	Hennepin: 7th to 6th St.	AP-C (1375)	D651 - 1,2,3
11	Hennepin: 6th to 5th St.	AQ-J (1365)	D652 - 1,2,3
12	Hennepin: 5th to 4th St.	AR-C (1355)	D653 - 1,2
13	Hennepin: 4th to 3rd St.	AS-J (1245)	D654 - 1,2,3
14	**Hennepin: 3rd St to Washington**	AT-C (1235)	D655 - 1,2

Turn Percentage

Link(1)	Street Name	SCOOT ID	T2000C ID	Turn %
1	**Washington: Hennepin to 1st Ave**	Y-M (1124)	D631 WBL	24.3
11	1st Ave: 11th to 12th St.	Z- (1434)	D635 SBL	30.5
12	12th St: 1st Ave to Hennepin	AK- (1435)	D646 EBL	20.2
22	**Hennepin: 3rd St to Washington**	AU	D656 NBL	16.2
1	**Washington: Hennepin to 1st Ave**	Y-M (1124)	D631 WBL	19.9
7	1st Ave: 7th to 8th St.	S	D625 SBL	32.7
8	**8th St: 1st Ave to Hennepin**	AO-J (1385)	D650 EBL	20.6
14	**Hennepin: 3rd St to Washington**	AU	D656 NBL	16.1

Note:

1. SCOOT Detector ID is the detectors that located at the up stream of the link in City map.

Suplemental Study
Delay

7th Street at 1st Avenue (Approach 17) P.M. Period

Delay Measure	w/ SCOOT	w/o SCOOT	Percent Difference
Vehicles stopped at sample interval (stops/hour)	873	373	134.4%
Delay (veh-hr/hr)	3.9	1.7	134.4%
Number of vehicle stops/5min	34	21	66.7%
Number of non-stopping vehicles/5min	78.2	76.0	2.9%
Approach volume/5min	84	78	8.1%
Approach volume/hour	1009	933	8.1%

1st Avenue at 7th Street (Approach 18)

Delay Measure	w/ SCOOT	w/o SCOOT	Percent Difference
Vehicles stopped at sample interval (stops/hour)	551	859	-35.9%
Delay (veh-hr/hr)	2.4	3.8	-35.9%
Number of vehicle stops/5min	32	30	5.3%
Number of non-stopping vehicles/5min	88.1	89.9	-2.0%
Approach volume/5min	94	98	-4.1%
Approach volume/hour	1122	1170	-4.1%

Notes:
1) With SCOOT is 3:45 to 5:45 p.m. 12/13/00
2) Without SCOOT is 3:45 to 5:45 p.m. 12/14/00

Supplemental Study
Manual Data/SCOOT Data Comparison
Four-Hour Detailed Analysis
3:45 - 5:45 p.m. 12/13/99 (SCOOT ON)
3:45 - 5:45 p.m. 12/14/99 (SCOOT OFF)

Travel Time

SCOOT Status	Manual Data Travel Time (sec/link)
w/ SCOOT (13th)	21.6
w/o SCOOT (14th)	23.8
% Diff	-9.3%
T-Test	No

Stops

	SCOOT Data			Manual Data				
	Stops (stops/hour)(1)			Stops (stops/hour)(2)			Percentage (stops/total)	
SCOOT Status	1st/7th	7th/1st	Total	1st/7th	7th/1st	Total	1st/7th	7th/1st
w/ SCOOT (13th)	415	349	763	384	408	792	33.8%	40.5%
w/o SCOOT (14th)	700	363	1063	360	252	612	30.8%	26.5%
% Diff	-40.7%	-4.1%	-28.2%	6.7%	61.9%	29.4%		
T-Test	Yes	No	Yes	No	Yes	Yes		

Delay

	SCOOT Data						Manual Data					
	Total Delay (veh-hour/hour)(3)			Average Delay (sec/veh)(4)			Total Delay (veh-hour/hour)(5)			Average Delay (sec/veh)(6)		
SCOOT Status	1st/7th	7th/1st	Total	1st/7th	7th/1st	Total	1st/7th	7th/1st	Total	1st/7th	7th/1st	Total
w/ SCOOT (13th)	2.3	3.4	5.6	6.9	13.0	19.9	2.4	3.9	6.3	7.9	13.9	22
w/o SCOOT (14th)	4.6	2.1	6.7	12.9	8.4	21.3	3.8	1.7	5.5	11.7	6.4	18
% Diff	-50.8%	57.7%	-16.5%	-46.5%	54.8%	-6.6%	-35.9%	134.4%	15.6%	-32.9%	117.2%	20.2%
T-Test	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No			

Volume

	SCOOT Data			Manual Data			T2000C Data		
	Flow (Lpu/Hour)			Volume (Veh/Hour)			Volume (Veh/hour)		
SCOOT Status	1st/7th	7th/1st	Total	1st/7th	7th/1st	Total	1st/7th	7th/1st	Total
w/ SCOOT (13th)	937	561	1498	1122	1009	2131	1192	938	2130
w/o SCOOT (14th)	1005	512	1517	1170	933	2103	1287	898	2185
% Diff	-6.8%	9.6%	-1.3%	-4.1%	8.1%	1.3%	-7.4%	4.5%	-2.5%
T-Test	No	No	No	No	No	No	No	No	No

Notes:
(1) SCOOT number of Stops - defined as the number of vehicles stopped per hour
(2) Manual number of Stops - defined as the total number of vehicles in the traffic stream that come to a stop
(3) SCOOT Total Delay - defined as the total delay in vehicle-hours/hour
(4) SCOOT Average Delay - calculated by dividing the SCOOT Total Delay by the T2000C Volume data
(5) Manual Total Delay - defined as the total number of vehicles stopped during each sampling interval x the sampling interval
(6) Manual Average Delay - defined as the number of stops divided by the approach volume

APPENDIX K

AUSCI Cost Categories

City of Minneapolis	Phase I	Phase II	Subtotal by ID	Total by Category
Project Management Costs				171,808
1540 City of Minneapolis Project Management	5,308	166,500	171,808	
Evaluation Costs				3,600
1541 Evaluation Participation		3,600	3,600	
Pre-Installation/Design Costs				19,000
1260 Detector Zone Siting		2,000	2,000	
1780 Software Addition for Detectors		10,000	10,000	
1500 City Computer Room Preparation		7,000	7,000	
Field Controller/Cabinet Equipment Costs				238,000
1670 Manuf. & Deliver Controller/Cabinet (20%)		48,000	48,000	
1671 Deliver Controller/Cabinet Equipment (80%)		190,000	190,000	
Field Controller/Cabinet Installation Costs				606,210
1242 City New Controller/Cabinet Work		92,000	92,000	
1235 & 1430 Modify Intersections and Cabinets		276,890	276,890	
1740 & 1440 Install In-Cabinet Video Hardware		44,500	44,500	
1690 & 1691 Install Controller/Cabinet Equipment		192,820	192,820	
System Acceptance Test				11,600
1790 Detector Calibration for Video		9,600	9,600	
1290 System Acceptance Testing (SAT)		2,000	2,000	
SCOOT Validation Costs				14,850
1210 City Detector Zone Calibration (80%)		11,600	11,600	
1750 Detector Zone Calibration Training (20%)		3,250	3,250	
Operation Costs				700
1720 Operate AUSCI System		700	700	
Initial SCOOT Operation Training Costs				4,500
1280 Training in England		2,500	2,500	
1757 SCOOT Training		2,000	2,000	
T2000C Modification Training Costs				500
1759 T2000C Modification Training		500	500	
Initial Video Detection System Installation Training Costs				250
1120 Sensor Installation Training / Assistance		250	250	
Initial Video Detection System Operation Training Costs				990
1770 Video Sensor Training		990	990	
SCOOT Validation Training Costs				2,000
1750 Detector Zone Calibration Training (20%)		2,000	2,000	
Subtotal	**5,308**	**1,068,700**	**1,074,008**	**1,074,008**

Fortran Traffic Systems Limited	Phase I	Phase II	Subtotal by ID	Total by Category
Project Management Costs				261,100
1010 Fortran Project Management		206,600	206,600	
1011 Fortran Project Management (Contrib.)		54,500	54,500	
Evaluation Costs				25,000
1012 Evaluation Participation (Contrib.) - (3)		25,000	25,000	
Insurance Costs				15,000
1580 Insurance		15,000	15,000	
SCOOT/T2000C License and Escrow Costs				335,671
1401 Procure Software License		245,197	245,197	
1402 Procure Software License (Contrib.)		41,299	41,299	
1420 Fortran Escrow and License Agreements		29,340	29,340	
1421 Fortran Escrow and License Agmts. (Contrib.)		19,835	19,835	
Pre-Installation/Design Costs				120,342
1259 Preliminary Design	37,220		37,220	
1260 Detector Zone Siting		26,616	26,616	
1261 Detector Zone Siting (Contrib.)		20,872	20,872	
1550 T2000 & SCOOT Database Development (20%)		11,685	11,685	
1551 T2000 & SCOOT Database Dev. (20% - Contrib.)		4,731	4,731	
1560 Define Hardware Requirements		7,687	7,687	
1561 Define Hardware Requirements (Contrib.)		1,922	1,922	
1570 Software Specifications		7,687	7,687	
1571 Software Specifications (Contrib.)		1,922	1,922	
SCOOT Hardware/Software Costs				673,456
1020 Modify SCOOT/T2000 S/W & Doc. - Toronto		186,227	186,227	
1021 Mod SCOOT/T2000 S/W, Doc - Toronto (Contr)		50,863	50,863	
1030 Configure Hardware in Toronto		12,894	12,894	
1031 Configure Hardware in Toronto (Contrib.)		11,904	11,904	
1170 Modify SCOOT/T2000 Software & Documentation - England, Siemens		185,889	185,889	
1171 Modify SCOOT/T2000 Software & Documentation - England, Siemens (Contrib.)		46,472	46,472	
1380 Integrate Software – Toronto		48,821	48,821	
1381 Integrate Software – Toronto (Contrib.)		12,205	12,205	
1400 Procure Hardware		105,181	105,181	
1403 Procure Hardware (Contrib.)		13,000	13,000	
System Acceptance Costs				64,408
1060 Factory Site Acceptance Test		35,526	35,526	
1061 Factory Site Acceptance Test (Contrib.)		8,882	8,882	
1290 System Acceptance Testing (SAT)		8,000	8,000	
1301 System Acceptance Testing (SAT)–Minn Contrib.		12,000	12,000	

SCOOT Validation Costs				178,108
1220 Calibration (20%)		126,773	126,773	
1221 Calibration (20%) (Contrib.)		51,335	51,335	
SCOOT Installation Costs				47,703
1130 Install, Test, & Commission in Minn.		36,562	36,562	
1131 Install, Test, & Commission in Minn. (Contrib.)		11,141	11,141	
Operation Costs				103,267
1510 Operations Support		68,315	68,315	
1511 Operations Support (Contrib.)		34,952	34,952	
Initial SCOOT Operation Training Costs				35,000
1757 SCOOT Training		35,000	35,000	
T2000C Modification Training Costs				3,000
1759 T2000C Modification Training		3,000	3,000	
Subtotal	**37,220**	**1,824,835**	**1,862,055**	**1,862,055**

Mn/DOT (Guidestar) Project Manager	**Phase I**	**Phase II**	**Subtotal by ID**	**Total by Category**
Project Management Costs				
1075 Travel for Mn/DOT and City	4,652	13,733	18,385	18,385
1490 Mn/DOT Project Management	22,325	107,940	130,265	130,265
Evaluation Costs				13,165
1492 Mn/DOT Evaluation (phase II: 7,783)		13,165	13,165	
Initial SCOOT Operation Training Costs				5,595
1280 Training in England for Mn/DOT and City - Registration Fees		5,595	5,595	
Subtotal	**26,977**	**140,433**	**167,410**	**167,410**

Mn/DOT (Guidestar) Program Office	**Phase I**	**Phase II**	**Subtotal by ID**	**Total by Category**
Project Management Costs				11,686
1300 Public Relations Activities (Budget: 30,000)		11,686	11,686	
Subtotal	**0**	**11,686**	**11,686**	**11,686**

Image Sensing Systems, Inc.	Phase I	Phase II	Subtotal by ID	Total by Category
Project Management Costs				150,074
1494 ISS Project Management		60,000	60,000	
1495 ISS Project Management (Contrib.)		90,074	90,074	
Evaluation Costs				6109
1390 ISS Evaluation Participation (Contrib.)		6109	6109	
Pre-Installation/Design Costs				55,000
1080 Video Sensor System Design		50,000	50,000	
1104 Complete Supervisor/Data Collection Sys. Spec.		5,000	5,000	
Video System Hardware/Software Costs				1,800,296
1082 Sensor System Engineering		280,000	280,000	
1083 Sensor System Engineering (Contrib.)		885,210	885,210	
1110 Fab/Deliver Video Sensor Units (20%)		83,387	83,387	
1113 Fab/Del. Video Sensor (20%) (Contrib.)		218,227	218,227	
1111 Fab & Deliver Video Sensor Units (80%)		200,000	200,000	
1114 Fab & Del. Video Sensor (80%) (Contrib.)		93,472	93,472	
1180 Install Supervisor at Traffic Control Center		40,000	40,000	
System Acceptance Costs				70,000
1100 Install Prototypes		40,000	40,000	
1101 Install Prototypes (Contrib.)		10,000	10,000	
1102 Demonstrate SCOOT Detection & Comm. Sys		20,000	20,000	
Operation Costs				4,018
1189 Video Sensor System Ongoing Support (Contrib.)		4,018	4,018	
Initial Video Detection Installation Training Costs (1)				73,947
1120 Sensor Installation Training/Assistance		20,000	20,000	
1121 Sensor Installation Assistance (Contrib.)		53,947	53,947	
Initial Video Detection Operation Training Costs (1)				33,008
1186 Supervisor Training & Doc. (Contrib.)		33,008	33,008	
Subtotal	**0**	**2,192,452**	**2,192,452**	**2,192,452**

Note:

(1) The installation and operation training costs associated with the video detection system are predominantly non-recurring project costs related to the "first-of-a-kind" sensor developed for this project. Training costs for a typical video application are approximately $1,500.

SRF Consulting Group, Inc.	Phase I	Phase II	Subtotal by ID	Total by Category
Evaluation Costs				263,867
1599 Develop Preliminary Evaluation Plan	20,105		20,105	
1600 SRF Project Management	4,895	39,662	44,557	
1530 Develop Evaluation Final Plan		68,786	68,786	
1320 Perform Evaluation Tests		71,814	71,814	
1310 Perform Intermediate & Final Analysis		46,350	46,350	
1340 Interim & Final Evaluation Report		12,255	12,255	
Subtotal	**25,000**	**238,867**	**263,867**	**263,867**

Video/Surveillance Systems Construction Contractor	Phase I	Phase II	Subtotal by ID	Total by Category
Video Surveillance System Installation Costs				185,982
1270 Surveillance System Field Construction		141,802	141,802	
1760 Field Construction (45%)		44,180	44,180	
Video Sensor System Installation Costs				137,348
1115 & 1116 Field Install Video Detector Units		113,720	113,720	
1760 Field Construction (20%)		23,628	23,628	
Communication System Installation Costs				111,270
1680 Install Additional Cable As Necessary		75,839	75,839	
1760 Field Construction (35%)		35,431	35,431	
Subtotal	**0**	**434,600**	**434,600**	**434,600**

Westwood Professional Services, Inc.	Phase I	Phase II	Subtotal by ID	Total by Category
Project Management Costs				135,102
1491 Westwood Project Management	11,677	92,252	103,929	
1610 Westwood Contract Negotiation Assist.		9,872	9,872	
1620 Westwood Technical Document Review		3,837	3,837	
1460 Project Design & Implementation Report		6,115	6,115	
1640 Westwood Direct Non-Salary Costs		11,349	11,349	
Evaluation Costs				15,406
1461 Evaluation Participation		15,406	15,406	
Pre-Installation/Design Costs				204,557
1149 Preliminary Design	74,920		74,920	
1150 Final P.S.&E. For Video, Surveillance System		58,069	58,069	
1190 Final Plans for Cabinets/Controllers		19,478	19,478	
1590 Westwood Site Review for Camera Locations		10,614	10,614	
1260 Detector Zone Siting		12,946	12,946	
1200 Base Layouts For Detectors		25,004	25,004	
1660 P.S.& E. For Comm. Cable		3,526	3,526	
Video System Installation Costs				76,993
1410 Westwood Video System Construction Inspection		76,993	76,993	
SCOOT Installation Costs				7,366
1450 Prepare Operator's Plan		709	709	
1710 & 1711 Detector Documentation		6,657	6,657	
System Acceptance Costs				6,832
1060 Factory Site Acceptance Test		2,399	2,399	
1250 Westwood System Acceptance Testing Support		4,433	4,433	
SCOOT Validation Costs				2,736
1700 & 1701 Assist in Video Detector Aim & Testing		2,736	2,736	
Operation Costs				638
1470 Operational Test System Support		638	638	
Initial SCOOT Operations Training Costs				6,144
1630 Westwood SCOOT Training		6,144	6,144	
Subtotal	**86,597**	**369,177**	**455,774**	**455,774**

SUMMARY **Project Cost by Participant (1)**	**Phase I**	**Phase II**	**Total**
City of Minneapolis	5,308	1,068,700	1,074,008
Fortran Traffic Systems Limited	37,220	1,824,835	1,862,055
Mn/DOT (Guidestar) Project Manager	26,977	140,433	167,410
Mn/DOT (Guidestar) Program Office	0	11,686	11,686
Image Sensing Systems	0	2,192,452	2,192,452
SRF Consulting Group, Inc.	25,000	238,867	263,867
Video/Surveillance Systems Construction Contractor	0	434,600	434,600
Westwood Professional Services, Inc.	86,597	369,177	455,774
Total	**181,102**	**6,280,750**	**6,461,852**

Notes:
(1) Project costs include in-kind contributions.

APPENDIX L
INSTITUTIONAL ISSUES SURVEY FORM

Name: ____________________________________

Agency: __________________________________

Date: ____________________________________

This survey is designed to identify institutional issues associated with the AUSCI project deployment as identified in Objective 4-3 of the *Evaluation Test Plan*. The responses from this survey will be summarized and included in the final *Evaluation Report*. The institutional issues have been broken down into topic areas representing the roles of the different public and private stakeholders. Please respond to the institutional issues outlined below that pertain to the experience you have had in the AUSCI project to date.

1. Describe your current position and the role you and your organization have played in the AUSCI project to date.

2. Describe the challenges involved in moving AUSCI from the idea stage to deployment. Which individuals or organizations were critical in making this happen?

3. Describe the challenges that each of the following legal issues presented to the AUSCI project. How was each of these issues handled?
   - Contractual Issues
   - Insurance Issues
   - Licensing Issues
   - Liability/Risk Management Issues
   - Proprietary Information
   - International Business Relations

4. Describe your interaction with the other public agencies, private sector organizations, and project managers involved in AUSCI. What challenges have presented themselves? How have these challenges been overcome? What factors contributed to successful interaction?

5. Discuss the process of negotiating the private sector contracts involved in this project. What were some of the challenges that emerged and how were they resolved? Also, what were some of the enabling factors that facilitated the negotiations? How did the partnership process affect the contractual negotiations?

6. Discuss the process involved in developing and executing the Joint Powers Agreement. What issues arose and how were they resolved?

7. What has been the response of the stakeholders to the partnership process and concept? How have the private sector partners fit into the process?

8. Have staffing turnovers caused impacts to the AUSCI project? If so, which staff turnovers had the most significant impact and why?

9. Describe the impact of funding issues to the AUSCI project.

10. Describe any other institutional challenges that you think may occur before completion of the project.

11. Describe any other institutional issues that do not fit into the categories presented above.

12. Of the institutional issues you have identified above, select the three key institutional issues from your organization's perspective.

APPENDIX M
TECHNICAL ISSUES SURVEY FORM

Name: ____________________________________

Agency: ___________________________________

Position: __________________________________

Date: _____________________________________

This survey is designed to identify technical issues associated with the AUSCI project deployment as identified in Objective 4-1 of the *Evaluation Test Plan*. The responses from this survey will be summarized and included in the final *Evaluation Report*. Please provide a list of deployment issues that you have recognized during the design and implementation of the AUSCI project to date. Also, include the method for resolution where applicable. Several examples have been provided to guide your input.

1. Hardware Integration

Identify technical issues associated with integrating the existing signal control system hardware with the adaptive system's hardware. This includes required infrastructure improvements, such as communication modifications.
(Example: The cable for the interconnect was incorrectly specified for Minneapolis installations. A supplemental agreement was written to order the correct interconnect cable.)

2. Software Integration

Identify technical issues associated with integrating the existing signal control system software with the adaptive system's software.
(Example: A translation of the existing signal system operation which uses North American phases was required to match the SCOOT system which uses European stages.)

3. Data Collection Integration

Identify technical issues associated with integrating the adaptive system's data outputs with the existing data collection methods.

4. Adaptive System Installation

Identify technical issues associated with installing the adaptive system.

5. Adaptive System Calibration/Validation

Identify technical issues related to the initial system setup, as well as the ongoing system validation required to keep the system in tune with the changing operating environment.

6. Video Detection System Installation

Identify technical issues associated with installing the video detection system in the field and within the existing control center environment.
(Example: The brackets for the video sensors did not fit on the light poles along Hennepin Avenue. This was resolved by ordering new brackets with a modified design.)

7. Video Detection System Calibration

Identify technical issues related to the initial video detection system calibration as well as to any ongoing system calibration.

8. Adaptive System Expandability

Technical issues related to expandability include limits on the number of detector inputs, software limitations, etc. Please provide the following information as it pertains to your role in the project:

- SCOOT expansion limitations (i.e. number of detectors and links);
- T2000C expansion limitations (i.e. number of detectors and intersections);
- City of Minneapolis control center expansion limitations/required infrastructure improvements;
- City of Minneapolis communication system expansion limitations;
- Video detection system expansion limitations.

9. Remaining Technical Issues

Describe any technical challenges that may occur before completion of the project.

10. Other Technical Issues

Describe any other technical issues that do not fit into the categories presented above.