Technical Report Documentation Page

1. Report No. SWUTC/95/60010-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Benefits of Real-Time Travel Information in Houston, Texas		5. Report Date January 1995
		6. Performing Organization Code
7. Author(s) Kevin N. Balke, Gerald L. Ullman, William R. McCasland, Christopher E. Mountain and Conrad L. Dudek		8. Performing Organization Report No. Research Report 60010-1
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 0079
12. Sponsoring Agency Name and Address Southwest Region University Transportation Center Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		13. Type of Report and Period Covered
		14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the Office of the Governor of the State of Texas, Energy Office

16. Abstract

This report describes some of the possible benefits and uses of real-time travel time information in major cities in Texas. The report details the development of a system that used probe vehicles to directly measure travel times between key locations in the north corridor of Houston, TX. The report shows how the travel times from the probe vehicles can be used to detect incidents in the corridor. Although significantly higher false alarm rates were produced, detection rates using the probe-measured travel times were comparable to those that can be achieved with traffic data from loop detectors. A survey of a small sample of commuters showed that the information provided by the system was useful and credible. Because the system provided accurate and credible travel time information, TxDOT dramatically increased the use of their CMSs in the corridor to an average of 12.3 times per month. This resulted in an estimated fuel savings benefits ranging from between 33,800 to 67,000 liters/year (8,923 to 17,848 gallons/year).

17. Key Words Advanced Traveler Information System, Probe Vehicles, Incident Detection, Fuel Savings	18. Distribution Statement No Restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	132	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

BENEFITS OF REAL-TIME TRAVEL INFORMATION IN HOUSTON, TEXAS

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Research Report 60010-1
SWUTC Study Number 60010
Study Title: Field Studies of Route Diversion of Automobiles, Transit, and Commercial Vehicles Using Real-Time Information and Other IVHS Technologies in Texas

Sponsored by the
Southwest Region University Transportation Center

January 1995

TEXAS TRANSPORTATION INSTITUTE
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IMPLEMENTATION STATEMENT

The findings of this research show that accurate and timely information about traffic conditions and incidents can be obtained using IVHS concepts and technologies in corridors previously without any means of surveillance. The research proved that motorists equipped with cellular telephones could provide reasonable and believable estimates of link travel times. This information was shown to be useful in detecting incidents and influencing travel behavior in a corridor. Application of the system is estimated to save between 33,800 and 67,000 liters (8,923 and 17,848 gallons) of fuel annually in Houston.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project were Kevin N. Balke, P.E. #66529.

ACKNOWLEDGMENTS

The authors would like to thank Robert Otto, Office of the Governor; John Ferguson, City of Houston, Aviation Department; Paul Woodruff, Federal Express; Sgt. Bill Weaver, Houston Police Department; Rudy Bruhns, Greater Houston Taxi Company; Peggy Doyal, GLK Bus Services; and many others for participating in the development of this system. The authors would also like to express their appreciation to Mr. Al Kosik with the Texas Department of Transportation; Mr. Steve Levine, formerly with the Texas Department of Transportation; Mr. Darrell Borchardt, Ms. Katy Turnbull, and Mr. Dennis Smalley, all with the Texas Transportation Institute, for their technical assistance in developing the system.

This publication was developed as part of the University Transportation Centers Program which is funded 50% in oil overcharge funds from the Stripper Well settlement as provided by the State of Texas Governor's Energy Office and approved by the U.S. Department of Energy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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SUMMARY

This report describes some of the possible benefits and uses of real-time travel time information in major cities in Texas. The report details a system installed in the north corridor of Houston, Texas. This system, implemented in two phases, first used cellular telephones and then Automatic Vehicle Identification (AVI) systems. In Phase I, the Texas Transportation Institute provided probes with cellular telephones to track individual vehicles as they traveled through the corridor. As vehicles traveled through the corridor, they contacted a central communication center staffed with operators from several commercial traffic reporting services. The time between successive calls by probes provided estimates of link travel times. The cellular telephone system covered two freeways (I-45 North and US-59), one HOV lane (the I-45 HOV lane), and a toll facility (the Hardy Toll Road) in north Houston.

In Phase II, Automatic Vehicle Identification (AVI) systems replaced the cellular telephone system for collecting travel time information from probes. Instead of cellular telephones, vehicles with transponders served as probes. AVI readers and antennae installed next to, or over the travel lanes, automatically recorded the identification numbers of probes as they traveled through the corridor. As with the cellular telephone system, travel times were measured by computing the time required to travel between two reader stations. Beyond covering the Hardy Toll Road and I-45, Phase II expanded the surveillance capabilities to other facilities (such as I-10, US-59, I-610, and the Sam Houston Toll Road) in northwest Houston.

The report also shows how vehicles acting as probes can be used to detect incidents. Using the link travel times collected during incident-free conditions as a base, we applied the Standard Normal Deviate (SND) incident detection algorithm to determine the increase in link travel time needed to suggest when a link was operating abnormally (i.e. operating under incident conditions). To do this, we compared the measured travel times to travel times collected under known incident conditions. We found the SND algorithm achieved a detection rate comparable to those achieved by other incident detection algorithms that use data from loop detectors. The false alarm rates produced using this approach, however, were higher than those produced by other algorithms. Because of the limitations of the data, we were not able to learn the number of incidents that went undetected nor the delays associated with detecting the incidents using the telephone probe system.

A survey of a small sample of commuters who were provided with real-time information measured how users perceived the quality and reacted to the information available from the system. Most survey participants believed that the information provided by the system was accurate and believable. The majority of survey participants said that while they liked having both incident and travel time information, information about the location of incidents was more critical to their decisions. Many participants said that the information provided by the system directly influenced their travel behavior in the corridor by causing them to change routes or delaying their departure times.

The Texas Department of Transportation (TxDOT) has been and continues to be one of the primary users of the system. They use the travel time and incident information from the system to determine when an alternate route should be recommended on the Changeable Message Signs (CMS) located in the corridor system. The presence of the system has significantly increased the use of the CMS in the corridor. Prior to the start of the system, the CMSs in the North corridor were used an average of once per month to inform motorists of incidents; however, after completion of Phase I, CMS use for incident notification increased dramatically to an average of 12.3 times per month.

The primary purpose of this study was to examine whether or not the provision of real-time travel time information to motorists, transit agencies, and commercial vehicle companies traveling in an urban freeway corridor could result in significant fuel saving benefits. While it was impossible in this study to actually measure how information effected the fuel consumption of any of these groups, a simplified analytical method was used to assess the likely effects on fuel consumption of improved information under a variety of incident scenarios. The analysis procedures showed that the provision of information to drivers could result in a fuel savings of between 229 to 457 liters (61 to 121 gal.) for an incident lasting one hour. Given that TxDOT was able to provide accurate and timely information to motorists an additional 12.3 times with the system, the fuel savings for the system were estimated to range between 33,800 and 67,000 liters/year (8,923 to 17,848 gallons/year).

I. INTRODUCTION

One role of real-time motorist information systems is to provide drivers with current traffic and travel information. This information must be provided far enough in advance of critical decision points for drivers to evaluate alternative actions, make appropriate travel decisions, and implement selected actions that reduce their individual travel times to their ultimate destinations (1). Real-time motorist information systems are commonly used to inform motorists about 1) areas of recurring congestion where traffic demands exceed the capacity of the freeways for short periods (e.g., the peak period); 2) areas of non recurring congestion due to random or unpredictable incidents such as accidents, maintenance work, or special events; 3) environmental conditions such as rain, snow, or ice that may impede travel through a corridor; and 4) special operating conditions such as contraflow or reversible lane operations. Whatever their use, these systems have proved to be effective tools in managing traffic in a corridor as long as the information provided to the motorists, transit operators, and commercial fleet operators is reliable, accurate, and timely (1).

To provide motorists, transit agencies, and commercial fleet companies with accurate and timely information, most operators of real-time motorist information systems rely on traffic surveillance and control systems. Inductive loop detectors embedded in the pavement and closed-circuit television systems (CCTV) monitor traffic conditions on all or portions of a freeway network in real-time. Different media, including changeable message signs, highway advisory radios, and commercial radio broadcasts, relay traffic and travel information to drivers. Using information provided by these systems, drivers make decisions about what routes to travel, which mode to use (i.e., either their personal automobile or transit vehicle), and when they should depart to reach their destination. Unfortunately, traditional corridor surveillance capabilities and the extent of implementation in freeway corridors have not provided transportation agencies with the ability to provide up-to-date travel time information to motorists.

Intelligent Vehicle/Highway Systems (IVHS) enhance an agency's ability to monitor traffic conditions in a corridor and to disseminate traffic and travel information to individual drivers in their homes, offices, and vehicles. Improved surveillance and incident detection techniques allow freeway operators to identify congested areas faster and more accurately. Improvements in Automatic Vehicle Locating (AVL) and Automatic Vehicle Identification (AVI) systems make it possible to know a vehicle's instantaneous position in the traffic stream and to track its progress in a corridor. Several researchers (2, 3) suggest using these technologies to obtain real-time travel information without extensive construction. Vehicles equipped with this technology could act as moving sensors or "probes" to provide direct measurements of travel time, speed, and congestion location information in a corridor. However, it was unclear whether 1) this technology could provide reliable, accurate, and up-to-date information about travel conditions in a corridor, and 2) the information provided by this technology could be used to manage traffic in a corridor in real-time. This report summarizes research done toward addressing these two major questions.

BACKGROUND AND SIGNIFICANCE

With the completion of the Interstate Highway System, the attention of the nation's transportation agencies has shifted from constructing freeways to better operating and managing traffic on our existing facilities. The intent of Intelligent Vehicle/Highway Systems (IVHS) is to provide better use of our existing transportation facilities and systems. IVHS applies advanced computer, communication, and automotive technologies for improving mobility and transportation productivity, enhancing safety, and maximizing the use of existing transportation facilities and energy resources while protecting the environment (4). The Federal Highway Administration has proposed 29 user services that can be supported by IVHS (5). These users services are shown in Table I-1. Combinations of these user services form the five major elements of IVHS:

- Advanced Transportation Management Systems (ATMS),
- Advanced Traveler Information Systems (ATIS),
- Advanced Public Transportation Systems (APTS),
- Automatic Vehicle Control Systems (AVCS), and
- Commercial Vehicle Operations (CVO).

Advanced Traveler Information Systems (ATIS), one element of IVHS, assist all modes of travelers (not just highway users) in making both pre-trip and real-time decisions necessary for safe, convenient, and efficient travel. Advanced Driver Information Systems (ADIS) are one component of a comprehensive ATIS. With visual and/or auditory displays in the vehicle, ADIS provide drivers with current information about traffic conditions, congestion locations, vehicle position, and alternate routes to their destination (6).

Projects Nationwide

Several past and ongoing research efforts are exploring the feasibility and benefits of ATIS. These projects include PATHFINDER in Los Angeles, California; TRAVTEK in Orlando, Florida; and ADVANCE in Chicago, Illinois. PATHFINDER was one of the nation's first ADIS demonstrations project (7). In PATHFINDER, drivers of twenty-five specifically equipped vehicles were provided with recommendations of alternate routes to avoid congestion in a 21-kilometer (13-mile) stretch of the Santa Monica Freeway known as the Smart Corridor. A control center measured traffic flow in the corridor, and displayed congestion information on an electronic map mounted in the vehicle. Through these displays, the system helped motorists find the most efficient travel routes to their destination.

Table I-1. IVHS User Services.

Broad Service Areas	User Services
Travel and Traffic Management	• En-Route Driver Information • Traveler Services Information • Route Guidance • Incident Management • Emissions Testing and Mitigation • Traffic Control
Travel Demand Management	• Pre-Trip Travel Information • Ride Matching and Reservation • Demand Management and Operations
Public Transportation Management	• En-Route Transit Information • Public Transportation Management • Personalized Public Transit • Public Travel Security
Electronic Payment	• Electronic Payment Services
Commercial Vehicle Operations	• Commercial Vehicle Electronic Clearance • Automated Roadside Safety Inspection • Commercial Vehicle Administration Processes • On-Board Safety Monitoring • Commercial Fleet Management • Hazardous Material Incident Notification
Emergency Management	• Emergency Vehicle Management • Emergency Notification and Personal Security
Advanced Vehicle Safety Systems	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Collision Avoidance • Vision Enhancement for Crash Avoidance • Safety Readiness • Pre-Crash Restraint Deployment • Automated Vehicle Operation

TRAVTEK was a joint public sector-private sector project to develop, test, and evaluate an integrated driver information system and supporting infrastructure in metropolitan Orlando, Florida (8). TRAVTEK provided motorists with navigation, real-time traffic information, route selection and guidance, and motorist information services using 100 specially equipped Oldsmobile vehicles operating in a three thousand square kilometer (twelve hundred square mile) area surrounding the city of Orlando. Visitors to Orlando used 75 of the vehicles as rental cars. Local residents and special controlled field evaluation used the remaining 25 vehicles. The sources of real-time traffic and congestion information used in the system included loop detectors on the freeway and arterial street network, and the TRAVTEK vehicles themselves.

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) represents the most ambitions ATIS demonstration project currently planned for the United States. ADVANCE will carry out a large-scale field demonstration and evaluation of ATIS system concepts and technologies. When fully deployed, the ADVANCE system will involve approximately 5,000 vehicles operating within about a 500 square kilometer (200 square mile) test area in northwest suburban Chicago, Illinois. Onboard navigation and route guidance equipment in each of the 5,000 vehicles will provide motorists with information about alternate routes around congested areas. Completion of the first phase of ADVANCE is expected to occur by 1994 (9).

The Houston Project

One key element to the successful application of these or any other ATIS is the provision of accurate, reliable, and up-to-date information on travel conditions on the transportation network. Currently, the Texas Department of Transportation (TxDOT) and other transportation agencies are installing systems to collect, analyze, and distribute real-time travel time and incident information in Houston, Texas. Like most major metropolitan areas in the United States, traffic congestion is a major issue affecting the quality of life in Houston, Texas.

Even with recent expansion of the transportation infrastructure, Houston is still ranked as one of the most congested cities in the United States and is the most congested city in Texas (10). The Texas Transportation Institute (TTI) estimated that over $1.5 billion are lost annually in Houston due to congestion. Delays and excess fuel consumption resulting from congestion caused by incidents account for over half of this cost. Even slight reductions in the amount of congestion caused by incidents on the Houston freeways has the potential for significantly reducing the cost of delays and achieving significant fuel savings.

To combat the growing congestion problem in Houston, TxDOT is currently designing and installing a freeway surveillance and control system. This system will include, among other features, inductive loop detectors placed in every lane at 800 meter (½ mile) spacings and closed-circuit television cameras for monitoring travel conditions on the freeways in the metropolitan area. However, these systems are not expected to be fully operational for another three to five years. In 1989, TxDOT proposed that an AVI system could be used monitor travel conditions and provide motorists, transit vehicles, and commercial fleet operators with real-time incident and travel time information in Houston until the surveillance and control systems are operational. The purpose of this research was to investigate the concept of using probes to collect information about travel conditions in a corridor in real-time.

OBJECTIVES

The goal of this research effort was to show the possible travel time and fuel saving benefits by providing motorists, transit operators, and commercial vehicle operators with real-time travel information. In order to achieve this goal, we designed and installed a system for collecting real-time traffic and travel time information from vehicles operating in the North Corridor in Houston, Texas. The specific objectives of this research effort were as follows:

1. Design and implement a system for obtaining real-time travel time and incident information directly from motorists traveling in an uninstrumented corridor in Houston, Texas,

2. Examine the feasibility of using travel-time information obtained by the system to detect incidents in the implementation corridor, and

3. Document the user acceptance and potential fuel saving benefits of that could be achieved by implementing this type of system in a freeway corridor.

ORGANIZATION OF REPORT

The development and evaluation of a system for collecting and disseminating real-time travel information in Houston, Texas is presented in this report. We discuss the development of a system that uses the probe vehicle concept to collect and disseminate real-time travel time and incident information in Chapter II. Chapter III illustrates how we used the information obtained by the cellular telephone system to detect incidents in the system corridor. We also provide results from a study of motorists responses to the information collected by the systems and an evaluation of the potential fuel savings benefits from the system in Chapter IV. Chapter V summaries the results of the study.

II. THE HOUSTON SYSTEM

The Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI), together with many other public and private entities, developed a system that used the probe vehicle concept to collect travel time and incident data directly from vehicles traveling in the major commuting freeway corridors in northwest Houston, Texas. The agencies used a two-phased approach to implement the system. The first phase tested the feasibility of obtaining traffic and travel information from probes by using commuters equipped with cellular telephones. In the second phase, Automatic Vehicle Identification (AVI) systems automated the process of obtaining traffic and travel time information from the probe vehicles. A variety of motorist information mediums, including changeable message signs located at key diversion points in the corridor, facsimile transmissions, and dial-up computer information displays provided motorists, commercial fleet operators, and transit agencies with both traffic and incident information. The purpose of this chapter is to describe the design and use of this system. The chapter also describes the role of the private sector in the design and operation of the system, and how this system integrates with other IVHS and traffic management systems under development in Houston.

REAL-TIME TRAVEL INFORMATION SYSTEM (RTTIS)

The Real-Time Travel Information System (RTTIS) is a system that obtains real-time traffic information directly from commuters traveling in the major freeway corridors in northwest Houston, Texas. Conceptually, the design of the system is simple. Commuters traveling in the corridor served as moving sensors or probes. By monitoring the time it took commuters to travel between preestablished reference locations in the corridor, we estimated the travel time on that section of roadway. The probe vehicles transmit the travel time information to a central communications center where it is processed and disseminated to various users through multiple communication mediums. Figure II-1 provides a conceptual representation of the system operation.

Phase I

The system was implemented in two phases. In Phase I, which was a prototype of the ultimate system design, commuters equipped with cellular telephones provided the travel time and incident information. At reporting locations throughout the corridor, probe drivers manually called a central communications center on cellular telephones provided to them. The probes told the operators where they were currently located in the corridor. (Special signs located next to or over the travel lanes identified the reporting stations.) Operators at the central communications center entered the probe's identification number into a computer system that kept track of the active probes in the system. The time between successive calls by the probes provided an estimate of the travel time between reporting locations. This method of collecting travel time information provided a reasonable representation of the link travel times in a freeway corridor with no other form of surveillance information.

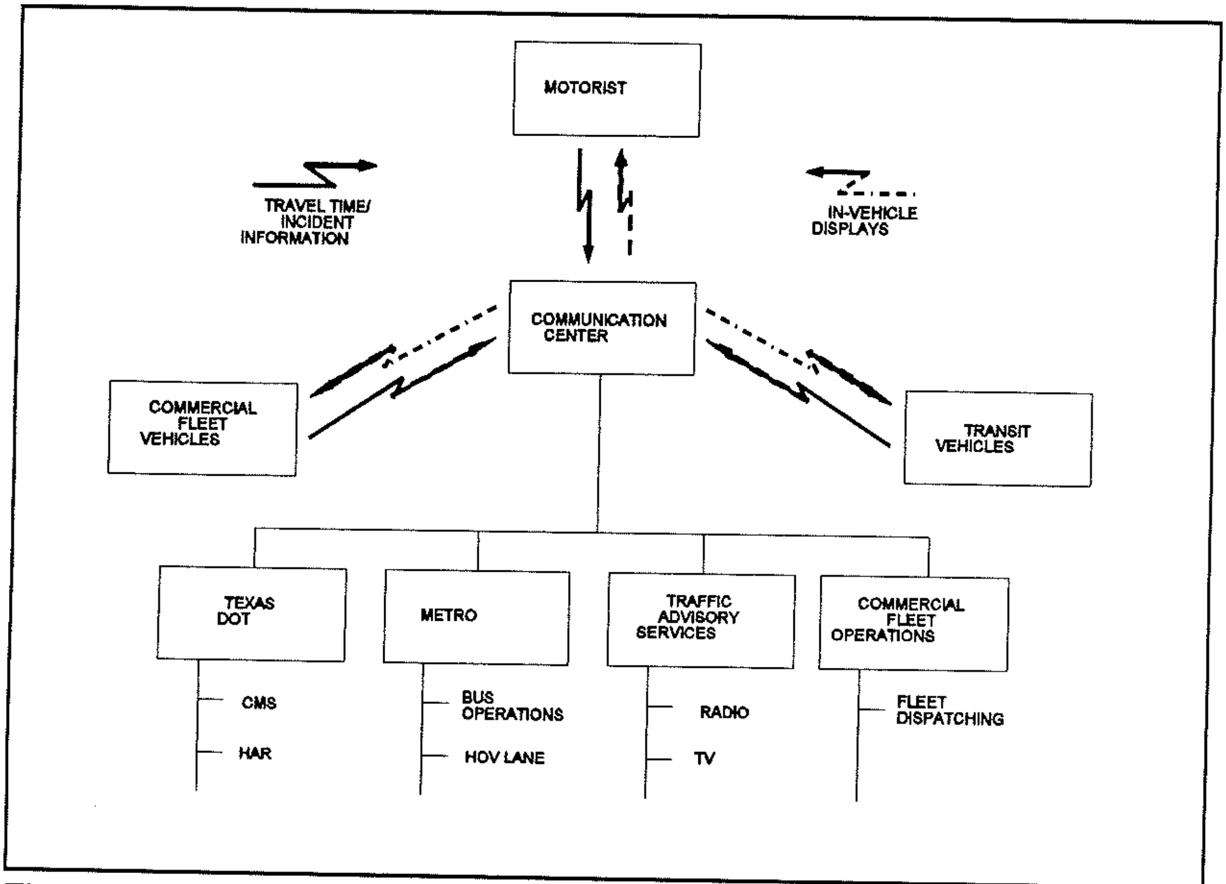

Figure II-1. Conceptual Design Of The Houston Real-Time Travel Information System.

Two freeways, a toll road and a high occupancy vehicle (HOV) lane in north Houston were selected to prove the feasibility of the system. These facilities are major commuting and intercity travel corridors in Houston, Texas. The system limits were the central business district (CBD) to the south and the residential developments of the Woodlands and Kingwood to the north. The total length of the corridor is approximately 40 kilometers (25 miles). Mixed land uses exist in the corridor, with significant residential areas and assorted parcels of commercial, retail, and light industrial developments scattered throughout. The corridor freeways also provide access to the Houston Intercontinental Airport, which serves approximately 8.2 million passengers per year (1990 estimate) and is in the center of the corridor.

As shown in Figure II-2, the corridor contains three major freeway-type facilities; I-45 (North) Freeway, US-59 (Eastex) Freeway, and a county toll facility (the Hardy Toll Road). I-45 is a controlled access facility with a cross section varying from four lanes at the north end of the corridor to eight lanes near the CBD. US-59 also changes cross section from a four-lane freeway at the north end of the corridor to a six-lane freeway near the CBD. Both freeways begin near the CBD and extends north in a "y" pattern. The study corridor ends at approximately the Harris County line. During the peak periods, congestion (Level of Service D or worse) exists on both facilities throughout the length of the corridor.

The Hardy Toll Road, operated by the Harris County Toll Authority, is a four-lane divided, access-controlled facility. The toll road begins at the I-610 Loop, north of the CBD, and extends north approximately 32 kilometers (20 miles). It terminates with a direct connection to I-45 near the Woodlands. Motorists pay a $1.50 toll to travel the entire length of the toll facility. Because of its excess capacity during the peak periods, the Hardy Toll Road is an excellent route for diverting traffic from both I-45 and US-59 during incident conditions. During peak traffic periods, Hardy Toll Road operates at Level of Service C or better.

A high-occupancy vehicle (HOV) lane is available for buses and two person carpools on I-45 for approximately 22 kilometers (13.5 miles). The HOV lane begins near the CBD and extends north to the Sam Houston Toll Road / Beltway 8 interchange. Located in the freeway median, concrete median barriers separate the HOV lane from the freeway main lanes. The width of the lane is approximately 6 meters (20 feet). It operates under one-way flow and is reversible to correspond with the peak direction of traffic flow in the corridor. The hours of operation are inbound towards the CBD from 4 a.m. to 1 p.m. and outbound from 2 p.m. to 10 p.m. On the average weekday, the HOV lane carries approximately 18,300 person trips, with the maximum peak hour, peak direction ridership at approximately 4700 persons per hour.

To obtain travel time information on these facilities, reporting stations spaced approximately 6.5 to 10 kilometers (4 to 6 miles) apart on each route were established so that, on the average, the time to travel between each reporting location under normal free flow conditions was approximately five minutes. Major cross street interchanges easily identifiable to commuters in the corridor represented suitable reporting locations in most cases. The reporting locations also represented major diversion opportunities in the corridor.

Phase II

In the second phase, an Automatic Vehicle Identification (AVI) system for collecting travel time information replaced the cellular telephone system. With the AVI system, travel time information was collected automatically from the probe vehicles. A transponder (or tag) encoded with a unique identification number was placed on each probe vehicle. As the vehicle traveled through the corridor, AVI antennae and readers installed next to or over the travel lanes transmit the identification numbers of the probes to the communication center. A computer algorithm

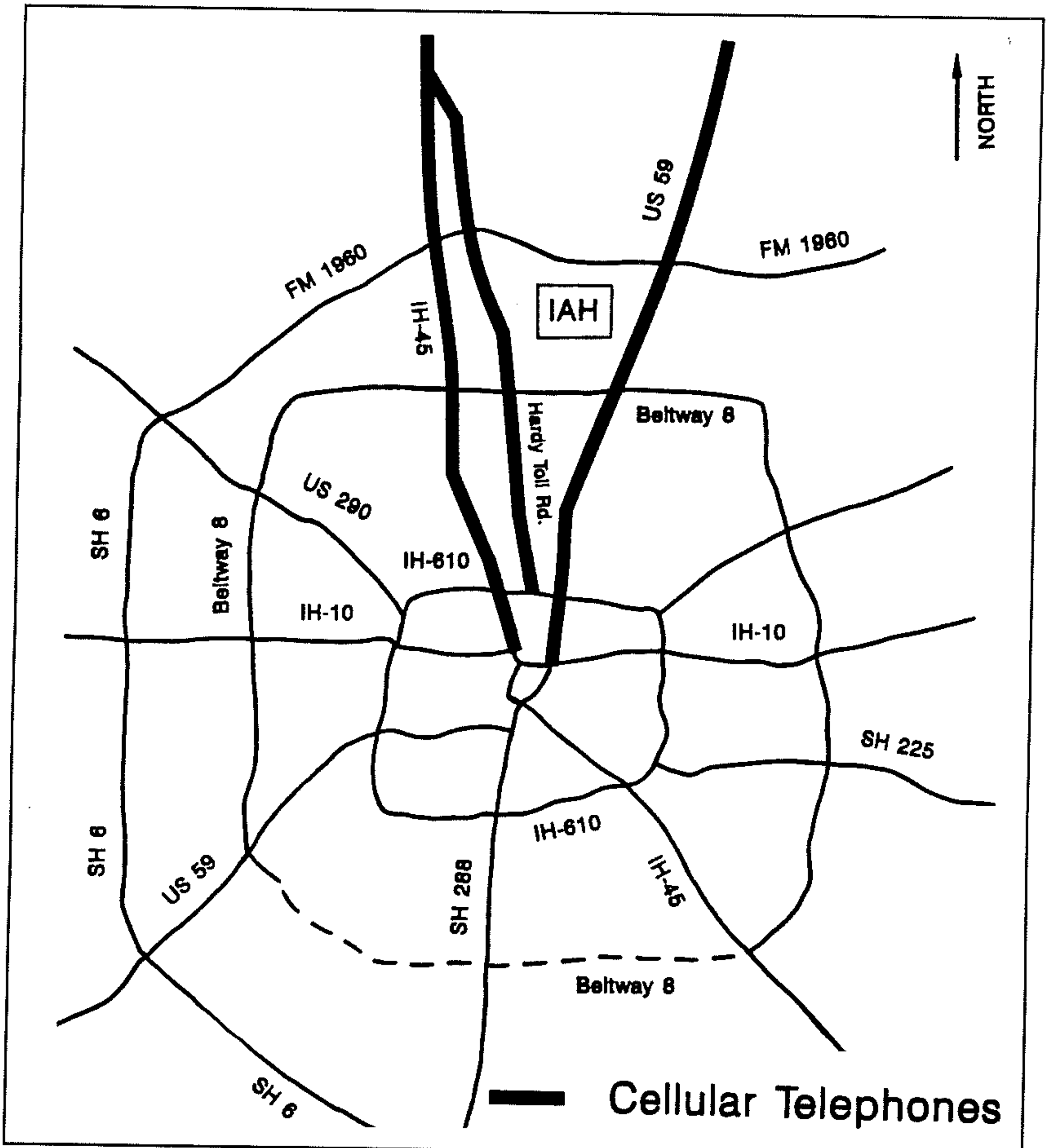

Figure II-2. Facilities Covered By The Real-Time Travel Information System (Phase I).

determined the times and average speed on a link were using the time between each successive transmission. In addition, we requested that motorists continue to use their cellular telephones to provide information on the location of congestion and incidents.

Besides replacing the cellular telephone system on I-45 North Freeway and the Hardy Toll Road, TxDOT expanded the AVI system in Phase II to provide coverage of two additional facilities: US-290 Northwest Highway and I-10 Katy Freeway. Both facilities are access controlled facilities and are major commuting corridors to the CBD. Both facilities also contain HOV lanes that provide priority treatment for carpool and transit vehicles during peak period.

The Harris County Toll Road Authority has installed AVI systems at toll booths on both the Hardy Toll Road and the Sam Houston Toll Road (Outer Loop). While these systems are primarily for automated toll collection, they are compatible with the travel time measuring systems installed in Phase II. As part of the Phase II implementation, TxDOT and the Harris County Toll Road Authority will be installing additional AVI antennae and readers at ramps leading to these toll facilities and at main lane locations other than the toll stations. With these additional reporting stations, full instrumentation of the facilities in Phase II system will occur by late 1995. Both TxDOT and the Toll Road Authority are working together to ensure that all of the AVI systems are compatible with one another, so that any vehicle equipped with AVI transponders can be monitored by the RTTIS network. Figure II-3 shows the total area of coverage provided in the Phase II system.

Besides these facilities, there are many arterial streets in the corridor that provide commuters with convenient alternate routes to divert around congestion. However, for the purposes of this demonstration project, travel time and incident information was not collected on these facilities. Future expansions of the system will consider including many streets in arterial street network.

Information Dissemination

The primary users of the information collected by the RTTIS are the Texas Department of Transportation, and the Metropolitan Transit Authority of Harris County. Both entities use the information to better manage the operations of their facilities. Motorists in the corridor receive pertinent travel time and incident information over a series of changeable message signs located throughout the corridor and through several commercial traffic reporting services. The Metropolitan Transit Authority also uses the information provided by the system to help them in operating the HOV lanes on I-45, US-290, and I-10.

Many private entities, such as commercial delivery companies and private transportation companies, expressed a desire to receive the information; however, this could not be accomplished within the time constraints of this study. As the system matures, we envision the dispatching center of each company may eventually be able to receive travel time and incident information directly through either on-line video display terminals or printouts. Each company's dispatching center will be responsible for using the information to make route choice and departure time decisions that maximize their company's goals and objectives.

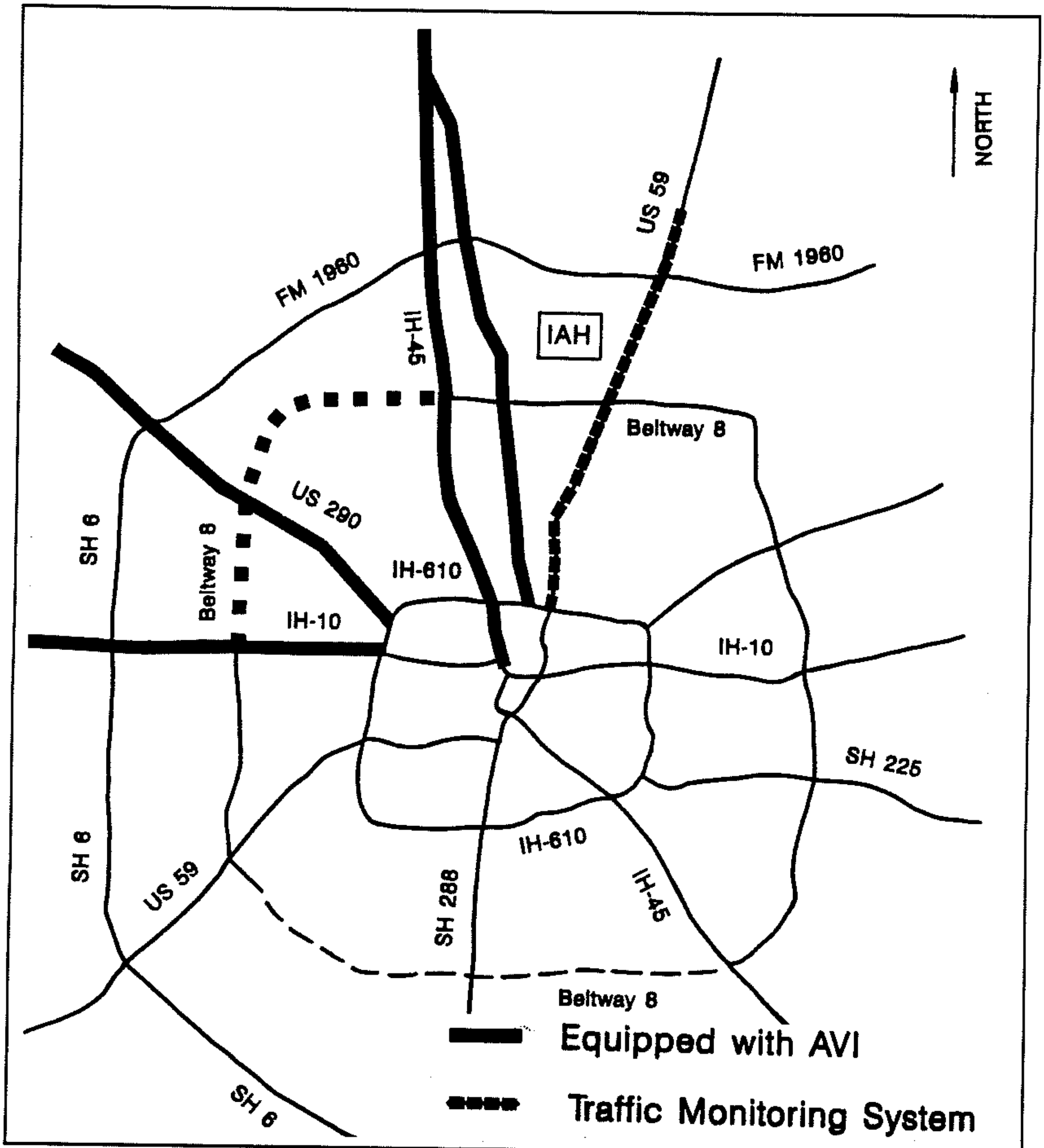

Figure II-3. Facilities Covered By The Real-Time Travel Information System (Phase II).

SYSTEM DEVELOPMENT AND IMPLEMENTATION ISSUES

As with most development efforts, TxDOT and TTI faced many challenges in the transition from conceptual design to implementation. Some major challenges included recruiting individuals to serve as probes in the system, developing procedures and methods for managing the flow of information through the system, and identifying the appropriate role of the private sector in the design and operation of the system. The following discusses each of these challenges in detail.

Recruitment of Probes

One major difficulty in developing the system was deciding the exact number of probes needed to provide adequate coverage in the corridor. On any given day, several probes will not be active in the system for a variety of reasons. Based on a queuing theory analysis, we estimated that between 200 and 300 probe vehicles would be needed to provide sufficient coverage of the routes in Phase I of the system implementation. Through careful selection of participants based on their anticipated departure times, it would be possible to obtain, on the average, five minute headways between probe vehicles to update the segment-by-segment travel times.

Based on these results, we used approximately 200 probes to provide surveillance on the four facilities in Phase I of RTTIS. Several large corporations with offices located in the CBD assisted in identifying individuals that would be interested in participating in the system. By posting messages on bulletin boards, and making announcements at employee group meetings, these corporations notified their employees of the project. Meetings were then held at the corporations' offices during lunch hours, where we provided prospective participates with more information. Follow-up letters and telephone calls were sent to complete the enlistment process. Approximately 60 percent of the participants were contacted in this manner. We then used newspaper advertisements and word-of-mouth to identify the remaining 40 percent of the participants.

To maintain the desired degree of coverage, individuals participating in Phase I agreed to serve as probes for one full year. In return, TTI provided each probe with a free cellular telephone. The probes kept the telephones at the end of the year. TTI also paid all connection and monthly access fees while Phase I of the system was operational. Probe participants were free to use the cellular telephone for personal calls; however, the individual was responsible for paying for those charges. All calls to the central communications center were free-of-charge, a contribution by Houston Cellular Telephone Company.

Information Management

Another major challenge with developing and installing the RTTIS was establishing procedures and methods for managing the flow of information through the system. In the Phase I system, four operators received calls from the probes in the field and entered travel time and incident information into a networked system of four computer terminals plus a master information-processing unit. Four dedicated telephone lines at the communications center handled all incoming calls from the probes. Incoming probe reports were processed on a first-come, first-serve basis through the next available telephone line. Simulation results and field experience showed that this method of processing calls limited the likelihood that a probe received a busy signal.

The master computer received information from each operator terminal, matched probe identification numbers and generated a single file containing segment-by-segment travel times and any incident reports. The communication computer, which was also part of the network, read the file and automatically distributed the information to the various users at regular intervals. The communication computer included an internal fax board so that users could receive travel time and incident reports at regular intervals. During initial operation, select users (TxDOT's interim Surveillance and Control Center, Traffic Advisory Services, Metro) received travel time and incident reports every 15 minutes; however, the system could provide information on a more frequent basis if needed by the users.

Private Sector Participation

From the very outset, the private sector played a significant role in designing and operating the system. An advisory panel, consisting of representatives from both the public sector and the private sector, described the traffic information needs of individual companies to assist in developing the system, particularly the information displays.

The private sector also played a significant role in the operations of the system. Early in the initial design stages, TxDOT decided not to charge an access fee to individual companies who wanted to use the information. Because the traffic advisory services benefited most directly from the information being provided by the system, TxDOT requested that each agency contribute to the operation of the central communications center. As a result, two of the operators in the central communications center were employees of two different traffic advisory agencies in Houston. A third traffic advisory service supplied communication equipment used to distribute the traffic information to the users.

INTEGRATION WITH OTHER IVHS COMPONENTS

Although designed to function as a stand alone system, the RTTIS is only one major component of the emerging Houston Intelligent Transportation System (HITS). HITS is a program designed to coordinate the IVHS and traffic management efforts and activities of TxDOT, Metro, the Harris County Toll Road Authority, and the City of Houston. The goal of HITS is to improve mobility of people and goods while reducing the environmental impacts on the transportation system though an accelerated and innovative program utilizing advanced information gathering, system control and communications technologies. It provides a framework for exchanging real-time transportation information between the various agencies responsible for operating and maintaining the elements of the Houston transportation system (13). Through HITS, the various agencies responsible for operating the different facilities in Houston share the travel information. While each element performs a specific function, all of the elements rely, in part, on the information provided by the RTTIS and others to operate more efficiently. Two such systems that rely on and augment the RTTIS are the Computerized Transportation Management System (CTMS) and the Houston *Smart Commuter* IVHS Demonstration Project.

The CTMS is an integrated traffic management and control system that will provide surveillance and control on the major freeway and arterial streets in the greater Houston Metropolitan Area. The system will provide for the real-time surveillance and monitoring of the freeway main lanes, HOV lanes, frontage roads, and major arterial streets. Information on current traffic conditions on the HOV lanes and freeway main lanes will be provided by changeable message signs and lane control signals. These signs will also help in the control and rerouting of traffic during incident conditions. To manage traffic entering the freeway to reduce congestion and improve the traffic flow along the arterial street system, TxDOT plans to install ramp metering systems and signal coordination systems (14). Together, the information provided by the RTTIS and the CTMS can be used to better manage traffic and provide comprehensive information on the operations of the freeway and adjacent arterial street system in Houston.

The RTTIS will also play a significant role in the Houston *Smart Commuter* IVHS Demonstration Project. The *Smart Commuter* Project, which is a joint effort of TxDOT, Metro, TTI, the Houston/Galveston Area Council (HGAC), the Federal Transit Administration (FTA), and the Federal Highway Administration (FHWA), and others, tests the potential of achieving greater use of the high-occupancy vehicle (HOV) lanes on two freeways in Houston (15). The premise of the project is that commuters are more likely to use public transportation and other high-occupancy modes if they have accurate and timely information about the travel conditions, bus routes and schedules, and potential instant carpool matches before beginning their trip. RTTIS will provide the travel time and incident information needed by the *Smart Commuter* Project.

Table II-1 lists the current and planned elements of the HITS. HITS is an evolutionary system where, over time, more sophisticated and technologically advanced components will be added to the system as they developed. The combination of these elements reflects the continued commitment of these agencies to improve transportation and the quality of life in Houston.

SUMMARY

Using the probe vehicle concept,we developed a system to obtain travel time and incident information directly from commuters traveling in a corridor in real-time in Houston, Texas. The system uses everyday commuters in the corridor to improve the quality and timeliness of the information provided motorists, commercial vehicles, and transit operators. With more accurate information, motorists, transit operators, and commercial vehicle dispatchers can make informed route, mode, and departure time decisions in response to incident conditions in the North Corridor of Houston. These decisions are expected to result in general travel time and fuel savings benefits for commuters, transit, and commercial vehicles operating in the corridor.

Besides providing information about the status of the operations of the facilities, the travel time information obtained by the RTTIS can also be used to help better manage operations on the freeways and HOV lanes in Houston. The following chapter examines the feasibility of using the travel time information collected by the probe vehicles to detect incidents.

Table II-1. Current and Planned Elements of the Houston Intelligent Transportation System.

Texas Department of Transportation	• Areawide Central Control Center • Freeway Surveillance and Control System • Ramp Metering/Ramp Closure System • Freeway Lane Control Signal System • Traffic Signal Coordination System • Changeable Message Signing System • Portable Highway Advisory Radio • Travel Time Information System • Infobanq • Automated Incident Management System • Motorist Assistance Patrol • Accident Investigation Sites • Cellular Telephone Hot Line
Metropolitan Transit Authority of Harris County (METRO)	• Automatic Vehicle Location System • Advanced Radio Communication System • Automated Telephone Information System • Real-Time Rideshare Matching • Automatic Passenger Delay Information System • Automatic Passenger Counting System • Advanced Automatic Scheduling and Run Cutting System • Smart Commuter Bus and Traffic Information System
City of Houston	• Arterial Street Signal System • Automated Airport Fee Collection System

III. INCIDENT DETECTION USING PROBE VEHICLES

One potential application of a system like the RTTIS is in the detection of freeway incidents. Reliable methods for automatically detecting lane-blocking incidents are essential for reducing the impacts of incidents on traffic operations. This chapter explores using the probe-measured travel times produced by the RTTIS for automatically detecting capacity-reducing incidents.

INCIDENT DETECTION ALGORITHM

There are many algorithms for detecting incidents on freeways; however, none of these algorithms use travel times as a traffic parameter. For this study, we used a modified format of the Standard Normal Deviate (SND) algorithm developed by Dudek and Messer (17) for detecting incidents in the RTTIS corridor. The SND algorithm compares the current travel time within a time slice to an average travel time for the same slice using the following formula:

$$SND = \frac{x - \bar{x}}{s} \qquad (1)$$

where,

- x = travel time measured by the probe vehicle at a given time
- $\bar{x}$ = average time on link for a given time-of-day interval, and
- s = standard deviation about the average travel time the given time-of-day interval.

Essentially, the SND algorithm establishes confidence intervals about a historical travel time for each link in the RTTIS system. Reorganizing Equation (1), the SND algorithm takes the form of the following equation:

$$x = \bar{x} + (SND)(s) \qquad (2)$$

Using this formulation, an incident alarm is declared if the probe-measured travel time (*x*) exceeds the confidence interval developed around the typical (or average) travel time on a link for a specific time-of-day [$\bar{x}$ + *(SND)(s)*].

To test the feasibility of this algorithm, typical travel time values were developed using the RTTIS travel time database. Because of the hourly and daily variations in travel times, average travel time values for every 15 minute intervals during the peak period of every week day were developed. We then used the incident logs from the RTTIS system to identify probes traveling the facilities during incident conditions. By merging the two data files, we simulated the performance of the algorithm to detect actual incident conditions in the field.

INCIDENT REPORTS

The RTTIS maintained a log of the incidents reported by the probes. The log contained first hand accounts of accidents, stalled vehicles, and other capacity-reducing events observed by the probe drivers. The type of information entered into an incident reported by the system operators included the following:

- the facility traveled by the probe,
- the date and time the incident was reported,
- the location of the probe at the time the incident was reported,
- the type of incident (whether it was an accident, a stalled vehicle, etc.),
- a brief description of the incident and the resulting traffic conditions, and
- the identification number of the probe reporting the incident.

Figure III-1 shows an example of the type of information contained in the incident log.

For analysis purposes, incident locations were coded according to the closest reporting station if the description of the incident was within one-half mile of an RTTIS reporting station. If the probe description placed the incident more than one-half mile from the RTTIS reporting station, we assumed the incident occurred at the reporting location immediately downstream of the incident.

Unfortunately inspection of the RTTIS incident files showed that many incident reports were missing a reporting station or the name of the highway facility where the incident occurred. In these situations, we compared the description of the incident to the description of other incident reports contained in the logs. If an incident had the same date, occurred in the same general period, and contained a similar physical description as another incident report that had an assigned reporting location, we assumed that the two reports were about the same incident.

Over the entire study period, the logs contained over 680 incident reports with no facility name or reporting station information. Using the above procedure, we identified appropriate facility names and reporting locations in over 92 percent of these incidents. The remaining 8 percent of the original RTTIS incident reports were not used in the analysis. The following is a list of the most common reasons that an incident reporting location could not be identified from the logs:

- the description provided by the probe driver was not specific enough to determine the location of the incident,
- the incident occurred outside the area covered by the RTTIS,

I-45 North Fwy	10/10/91	15:04	153	S	1	«Stalled Vehicle rt side I45 inbound @
I-45 North Fwy	10/10/91	15:04	153	S	2	south of Little York exit»
I-45 North Fwy	10/11/91	8:26	106	S	1	«Stalled Vehicle car and truck outbound
I-45 North Fwy	10/11/91	8:26	106	S	2	I-45 not blocking traffic right hand side
I-45 North Fwy	10/11/91	8:26	106	S	3	before Loop 610»
US-59 Eastex	10/14/91	7:08	407	S	1	«Stalled Vehicle southbound frontage rd.
US-59 Eastex	10/14/91	7:08	407	S	2	holding up traffic - exit ramp right hand
US-59 Eastex	10/14/91	7:08	407	S	3	side blocking traffic - 59 white van-car in
US-59 Eastex	10/14/91	7:08	407	S	4	front»
0	10/14/91	7:11	0	A	1	«Accident with a fuel spill, two left lanes
0	10/14/91	7:11	0	A	2	blocked. police on the scene.»
0	10/14/91	7:21	0	A	1	«Accident inside loop at 59 north of first
0	10/14/91	7:21	0	A	2	overpass - fuel spill - right lane blocked»
I-45 North Fwy	10/15/91	7:20	107	A	1	«Accident Cavalcade/Patton 1-45 center lane
I-45 North Fwy	10/15/91	7:20	107	A	2	cement mixer hit back of van - no injuries
I-45 North Fwy	10/15/91	7:20	107	A	3	»
I-45 North Fwy	10/15/91	17:40	156	S	1	«Stalled Vehicle stalled car rt hand outbound
I-45 North Fwy	10/15/91	17:40	156	S	2	shoulder between Richey & 1960 on 45n past
I-45 North Fwy	10/15/91	17:40	156	S	3	St 155»

Figure III-1. Example Of Information Contained In RTTIS Incident Log.

- the log entry did not describe an incident, but was a result of an internal system test or a description of a non incident event, and
- errors were made by the operators when entering the incident information.

Identification of Lane-Blocking Incidents

Not all freeway incidents reported by the probes impeded traffic flow so as to affect travel times on a link. Therefore, it was important to distinguish between incidents that did and did not influence travel times. An incident was assumed to affect travel times if it either blocked or partially blocked part of the freeway (including the through lanes, the exit ramps, or the entrance ramps) or caused "rubbernecking" by drivers. Rubbernecking refers to the action of drivers, as they pass an incident, to slow and observe (or "gawk" at) the incident scene. Whether an incident physically blocked the freeway itself or caused rubbernecking to occur, the impact of the incident on travel times is similar: the travel time on the link increases. Therefore, if either event occurred, we treated it as a lane-blocking incident.

Using the description of the incidents provided by the probe drivers, we subjectively decided whether an incident impacted traffic flow or not. To make this judgment, we used key words and phrases in the incident descriptions reported by the probe drivers that might suggest a lane-blocking incident. Examples of the more common types of phrases used to identify potential lane-blocking incidents from the incident descriptions provided by the probe drivers included the following:

- "traffic slow getting by,"
- "accident in middle of freeway,"
- "traffic backed up,"
- "blocking the left/right/middle lane,"
- "pushing someone slowly in the left/right/middle lane,"
- "traffic slows to rubberneck,"
- "bumper to bumper traffic," and
- "left/right/middle lane is closed."

Table III-1 shows the number of incidents on each facility. Figure III-2 shows the proportion of lane-blocking incidents documented on all four of the facilities covered by the RTTIS. Most of the incident reports (55 percent) were received by probes traveling the I-45 North Freeway. This is because most of the probes included in the system travel on this facility, and is not necessarily indicative of the distribution of incidents across the four facilities..

Table III-1. Number of Incidents Reported on Each RTTIS Facility.

Facility	AM Peak		PM Peak	
	Lane Blocking	All	Lane Blocking	All
I-45 North Freeway	248 (78%)	340	434 (57%)	767
I-45 HOV Lane	26 (62%)	42	46 (88%)	52
US 59 Eastex Freeway	85 (51%)	167	274 (28%)	962
Hardy Toll Road	13 (81%)	16	7 (33%)	21

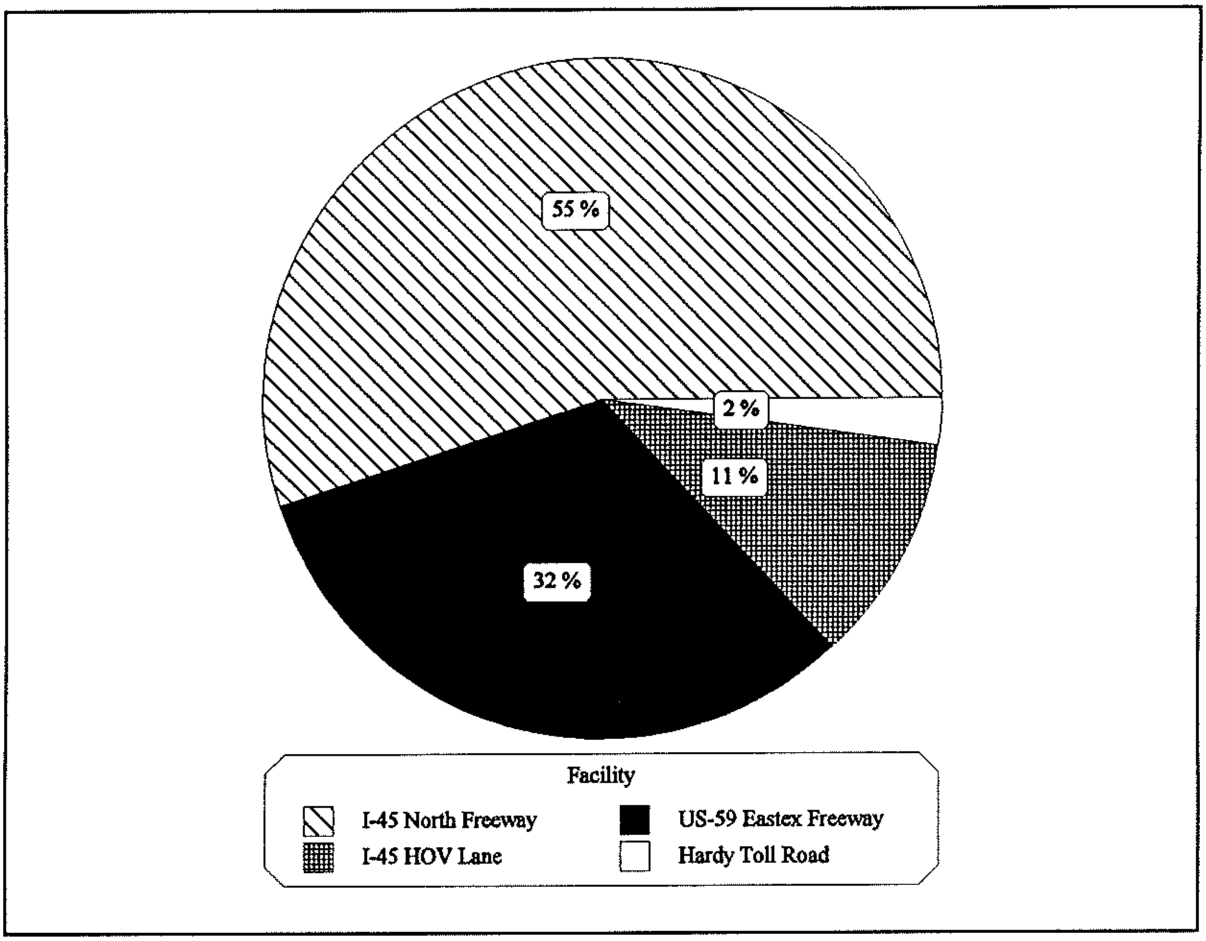

Figure III-2. Proportion Of Lane-Blocking Incidents Reported On Each Facility.

TRAVEL TIME REPORTS

The RTTIS maintained logs of the travel times reported by the probes. Using their cellular telephones, probe drivers called the RTTIS communication center as they passed preestablished reporting stations in the corridor. Using the difference in time between calls by the same probe, a computer at the communication center automatically calculated the travel times and the average speed of the probe between the reporting locations. We used travel times during non incident conditions to establish typically travel conditions on each facility.

The central computer system logged every probe-measured travel time collected by the RTTIS between October 1991 and August 1992. Each log entry contained the following information:

- the facility traveled by the probe,
- the date and time of the log entry,

- the beginning and ending reporting station that defined the traversed freeway link,
- the direction of travel (SB for southbound in the A.M. peak and NB for northbound in the P.M. peak),
- the distance of a given link (in miles)
- the computed travel time (in minutes), and
- the average speed of the probes on the link (in miles per hour).

Figure III-3 shows examples of the type of data contained in the travel time logs of RTTIS.

Elimination of Incident-Effected Travel Times

To find the typical travel time on a link, we removed the travel times affected by incidents and other atypical traffic situations from the database. Because the actual duration of an incident was difficult to determine from the logs, we established a time window around each known incident. For the purposes of this study, we assumed the incident affected the travel times of probes for one hour after receiving the initial incident report. Furthermore, since we did not know the exact time an incident actually occurred, we decided to remove any probe report that occurred thirty minutes before the time the incident appeared in the logs.

I-45 North Fwy	10/14/91	6:44	103	104	SB	4.9	4.57	64.38
I-45 North Fwy	10/14/91	6:46	105	106	SB	4.3	9.12	28.30
I-45 North Fwy	10/14/91	6:48	104	105	SB	3.6	3.78	57.09
I-45 North Fwy	10/14/91	6:52	105	106	SB	4.3	8.27	31.21
I-45 North Fwy	10/14/91	6:56	106	107	SB	2.9	3.73	46.61
I-45 North Fwy	10/14/91	6:56	101	102	SB	3.7	4.47	49.70
I-45 North Fwy	10/14/91	6:58	104	105	SB	3.6	3.07	70.43
I-45 North Fwy	10/14/91	7:01	106	107	SB	2.9	3.28	52.99
I-45 North Fwy	10/14/91	7:01	102	103	SB	3.8	4.23	53.86
I-45 North Fwy	10/14/91	7:01	105	106	SB	4.3	6.23	41.39
I-45 North Fwy	10/14/91	7:05	103	104	SB	4.9	5.23	56.18
I-45 North Fwy	10/14/91	7:07	106	107	SB	2.9	3.25	53.54
I-45 North Fwy	10/14/91	7:10	104	105	SB	3.6	5.03	42.91
I-45 North Fwy	10/14/91	7:15	105	106	SB	4.3	9.88	26.10
I-45 North Fwy	10/14/91	7:23	104	105	SB	3.6	4.17	51.84
I-45 North Fwy	10/14/91	7:27	105	106	SB	4.3	8.63	29.88
I-45 North Fwy	10/14/91	7:36	106	107	SB	2.9	6.72	25.91
I-45 North Fwy	10/14/91	7:45	106	107	SB	2.9	11.42	15.24

Figure III-3. Example Of Data Contained In RTTIS Travel Time Logs.

Besides affecting travel times for a certain period after the incident has occurred, incidents can also affect travel conditions on the link both immediately upstream and downstream of the initial location. The congestion and queuing normally associated with incidents in peak periods can cause travel times upstream of the incident to increase above normal. Similarly, because an incident can meter the amount of traffic that flows past an incident, travel times downstream of an incident may be higher than normal. For these reasons, we eliminated not only the travel times on the links where the incidents occurred, but also the travel times on the links immediately upstream and downstream of the link from where the incident was initially reported.

Elimination of Travel Time Outliers

Despite removing all of the known incident-effected travel times, we expected the remaining "non incident" travel time data set to contain several travel time measurements that fell outside a normal range. Several situations could cause isolated travel time measurements to be greater than "normal," including the following:

- An unreported incident may cause a probe to experience an "unusual" travel time.
- Poor visibility or bad-weather conditions may cause an unexpected delay of traffic.
- A probe driver may leave and reentered the freeway between reporting locations.
- The operator may incorrectly enter a probe identification number.

We generated scatter plots of the 39 links included in the RTTIS for each month of the non incident data. From each set, we calculated the mean and standard deviation of the travel time measurements on each link. We eliminated those travel times that exceeded three standard deviations about the mean travel time. We employed an iterative process where we recalculated the mean travel time and standard deviations each time.

We referred to the travel times remaining in the data set after eliminating the incident-affected travel times and the outliers as the "filtered" travel times. We used these observations to establish the base travel times on each link in the RTTIS. Table III-2 summarizes, by month, the number of observations eliminated from the original data set and those remaining in the filtered data set. Out of the 169,814 observations originally logged by the RTTIS over an 11-month period, incidents affected 17.7 percent of the travel times. We identified and removed an additional 3.4 percent of the travel times as outliers. Therefore, the filtered data set contained over 78 percent of the original RTTIS probe reported travel times.

Average Travel Times

The SND algorithm detects unusual traffic congestion by comparing measured travel times to travel times that are "typical" or "normal." Using the filtered travel time data, we computed average travel times for each link by time-of-day and day of the week. We used all 11 months of data to establish the historical travel times for each link. To simplify the analysis we grouped the travel time measurements into 15 minute intervals beginning at 5:45 A.M. and ending at 9:30 in the morning peak, and beginning at 3:00 P.M. and ending at 6:45 in the evening peak. Appendix A shows the typical travel time and standard deviation for each link in RTTIS.

Table III-2. Number of Travel Time Observations Used to Determine Base Travel Times.

Month	Number of Travel Time Observations			
	Recorded by Probes	Removed as Incident-Affected	Removed Outliers	Used to Calculate Base Travel Times
October '91	4738	450	187	4101
November '91	11804	1497	357	9950
December '91	10952	1349	382	9221
January '92	15277	2382	432	12463
February '92	15886	3091	465	12330
March '92	18707	2601	757	15349
April '92	19014	3665	567	14782
May '92	18521	4008	572	13941
June '92	19577	4093	655	14829
July '92	18917	4177	736	14004
August '92	16421	2752	589	13080
TOTALS	169814	30065	5699	134050

ALGORITHM EVALUATION

We used both the average travel times and the incident logs to examine the feasibility of using probe-measured travel time to detect incidents. The SND algorithm provided a mechanism for detecting when a particular probe measured travel time was outside a range that could be considered "typical" for the link at a specific time-of-day and day of the week. As shown in Figure III-4, the SND values correspond to a z-statistic for a normally distributed population.

The z-statistic defines the interval that includes a specific percentage of the travel time measures. In other words, 97.72 percent of travel time measurements can be expected to fall within the interval defined by the 2.0 SND value. An SND value of 4.0 contains 99.9968 percent of travel times about the "typical" travel time for a specific link.

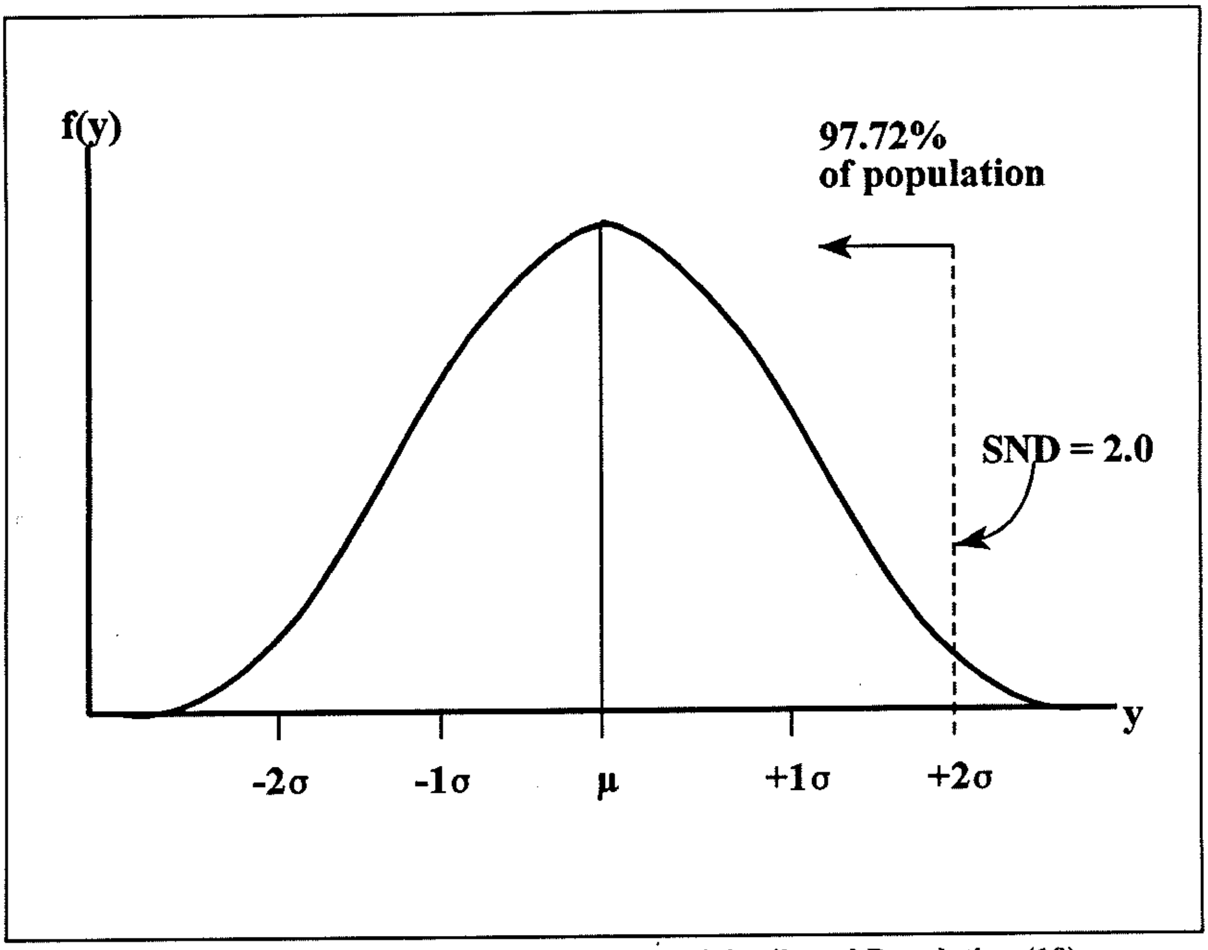

Figure III-4. SND Values For A Normally Distributed Population (18).

We used each travel time measurement contained in the RTTIS logs to test the feasibility of using the probe-measured travel times to detect incidents. We computed threshold travel times using the mean and standard deviation of the "typical" travel times in the SND model. We tested travel times at five critical SND values:

- SND = 2.0,
- SND = 2.5,
- SND = 3.0,

- SND = 3.5, and
- SND = 4.0.

The probe-measured travel times were then compared to the computed threshold travel times. If the probe-measured travel time exceeded the computed threshold travel time, then an incident alarm flag was set.

To find out whether incident conditions existed at the time, we compared the time that the probe traversed the link to the master incident data log. A match was successful if the travel time and incident files both satisfied the following conditions:

- The incident and the probe travel time occurred on the same link on the same day, and
- The time a probe traversed a link was within approximately one hour of the time the incident was logged in the RTTIS. We permitted some allowances for extending this time window whenever multiple probe entries at close intervals appeared beyond this one hour limit.

We considered the algorithm to have successfully detected an incident if it met the following criteria:

- The probe traversed the link at a time when the RTTIS log showed the presence of an incident, and
- The travel time of the probe exceeded the threshold travel time established by the SND algorithm.

Conversely, we classified an incident flag as a false alarm when no entry existed in the RTTIS incident log.

Algorithm Performance

We computed on the false alarm and incident detection rates generated at each of the five critical SND values on all four of the facilities covered by RTTIS. The detection rate is defined as the percentage of successfully detected incidents out of the total number of incidents occurring on a facility. The false alarm rate is defined as the percentage of false incident alarms out of the total number of probe measured travel times for each facility. Table III-3 summarizes the total detection rate achieved by using the algorithm for all types of incidents (i.e., both lane blocking and non lane blocking incidents) on each facility in both the A.M. and P.M. peaks. Table III-4 provides a similar summary for the lane-blocking incidents only that occurred on each facility. Table III-5 shows the false alarm rates that occurred using the SND algorithm and the travel time measurements provided by the probe vehicles. Appendix B and C provide summaries of the algorithm performance for each link in the RTTIS.

Table III-3. Rates For Detecting All Incidents (Lane Blocking and Non-Lane Blocking) Using SND Algorithm In AM And PM Peak Periods.

Facility	Number of Incidents	Detection Rate				
		SND = 2.0	SND = 2.5	SND = 3.0	SND = 3.5	SND = 4.0
AM PEAK PERIOD						
I-45 North Frwy	340	238 (70%)	198 (58%)	149 (44%)	109 (32%)	77 (23%)
I-45 HOV	42	18 (43%)	14 (33%)	12 (29%)	11 (26%)	5 (12%)
Hardy Toll Rd	16	7 (44%)	6 (38%)	6 (38%)	5 (31%)	4 (25%)
US-59 Eastex Frwy	167	57 (34%)	44 (26%)	32 (19%)	18 (11%)	12 (7%)
PM PEAK PERIOD						
I-45 North Frwy	767	401 (52%)	334 (44%)	264 (34%)	206 (27%)	176 (23%)
I-45 HOV	52	14 (27%)	11 (21%)	6 (12%)	5 (10%)	4 (8%)
Hardy Toll Rd	21	5 (24%)	2 (10%)	2 (10%)	2 (10%)	2 (10%)
US-59 Eastex Frwy	962	563 (59%)	445 (46%)	336 (35%)	264 (27%)	209 (22%)

These tables show that both the detection rate and false alarm rate decrease as the critical SND value increases. We expected this because, at high SND values, the travel time must be significantly higher in order for an incident alarm to be sounded. Therefore, the incident must have a severe impact on travel times to be detected at higher SND values. On the other hand, because high SND values require that travel times be significantly higher before an incident alarm is sounded, the chances are very low that a random travel time will cause the alarm to sound when no incident condition exists (i.e., a false alarm). Therefore, the false alarm rate also reduces as the SND value increases.

These tables also show that the detection rates (and to some degree the false alarm rates) for both the I-45 HOV lane and the Hardy Toll Road are lower than those achieved for the other two facilities. This is because incidents that occur on these two facilities do not disrupt traffic as much as they do on both I-45 and US-59. Both the Hardy Toll Road and the I-45 HOV lane do not operate as close to capacity as the main lanes of I-45 and US-59. Because the I-45 HOV lane and the Hardy Toll Road do not operate near capacity, the congestion caused by an incident is generally not as severe, allowing drivers to "make up" some (if not all) of time lost due to the incident. Therefore, the impact of the incident on travel times may have been masked due to the higher level of service on these facilities.

Table III-4. Rates For Detecting Lane-Blocking Incidents Using SND Algorithm In AM And PM Peak Periods.

Facility	Number of Incidents	Detection Rate				
		SND = 2.0	SND = 2.5	SND = 3.0	SND = 3.5	SND = 4.0
AM PEAK PERIOD						
I-45 North Frwy	248	176 (71%)	148 (60%)	113 (46%)	83 (33%)	58 (23%)
I-45 HOV	26	7 (27%)	6 (23%)	5 (19%)	4 (15%)	3 (11%)
Hardy Toll Rd	13	6 (46%)	5 (38%)	5 (38%)	5 (38%)	4 (31%)
US-59 Eastex Frwy	85	12 (14%)	9 (11%)	8 (9%)	5 (6%)	3 (4%)
PM PEAK PERIOD						
I-45 North Frwy	434	210 (48%)	181 (42%)	140 (32%)	105 (24%)	89 (21%)
I-45 HOV	46	14 (30%)	11 (24%)	6 (13%)	5 (11%)	4 (9%)
Hardy Toll Rd	7	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
US-59 Eastex Frwy	274	158 (58%)	124 (45%)	94 (34%)	75 (27%)	61 (22%)

Another possible explanation for the lower detection rates on the HOV lane of I-45 and the Hardy Toll Road was the frequency of probe reports on these facilities. Table III-6 shows that average number of probe reports received during each peak period on each facility. As can be seen from this table, the number of probes traveling on both the I-45 HOV lane and the Hardy Toll Road was lower than the number of probes on I-45 North and US-59 Eastex Freeways. Because of the lower number of probes, the likelihood of detecting an incident on the HOV lane or the Hardy Toll Road was not as great as it was for detecting incidents on main lanes of the two freeways.

Table III-5. False Alarm Rates Using SND Algorithm On All Facilities In AM And PM Peak Periods.

Facility	Number of Incidents	Detection Rate				
		SND = 2.0	SND = 2.5	SND = 3.0	SND = 3.5	SND = 4.0
AM PEAK PERIOD						
I-45 North Frwy	37135	1933 (5.2%)	1268 (3.4%)	848 (2.3%)	594 (1.6%)	442 (1.2%)
I-45 HOV	5855	255 (4.4%)	163 (2.8%)	121 (2.1%)	90 (1.5%)	66 (1.1%)
Hardy Toll Rd	14598	540 (3.7%)	333 (2.3%)	218 (1.5%)	152 (1.0%)	104 (0.7%)
US-59 Eastex Frwy	39972	1770 (4.4%)	1144 (2.9%)	782 (2.0%)	551 (1.4%)	411 (1.0%)
PM PEAK PERIOD						
I-45 North Frwy	29945	1619 (5.4%)	1159 (3.9%)	870 (2.9%)	654 (2.2%)	535 (1.3%)
I-45 HOV	5285	259 (4.9%)	167 (3.2%)	104 (2.0%)	80 (1.5%)	50 (1.0%)
Hardy Toll Rd	6183	262 (4.2%)	153 (2.5%)	92 (1.5%)	46 (0.7%)	21 (0.3%)
US-59 Eastex Frwy	30902	1152 (3.7%)	737 (2.4%)	498 (1.6%)	371 (1.2%)	272 (0.9%)

Table III-6. Average Number Of Probe Reports Per Period On Each Facility.

Facility	AM Peak	PM Peak
I-45 North Freeway	3345	2722
I-45 HOV Lane	532	480
Hardy Toll Road	1327	562
US-59 Eastex Freeway	3634	2809

We should note while the system was able to detect only a portion of the incidents occurring on these facilities, the detection rates are significantly better than those that existed prior to implementing the system. Prior to installing the RTTIS system, the only mechanism available to TxDOT for detecting incidents was the Motorist Assistance Patrols. While it was not possible to assess how quickly incidents were detected using the RTTIS system, discussions with TxDOT personnel led us to believe that the RTTIS allowed TxDOT and the Motorist Assistance Patrols to find out about potential incidents much faster than they normally would via telephone reports.

Comparison with Other Incident Detection Algorithms

Several algorithms have been developed for automatically detecting incidents on freeways. Some algorithms directly compare measured traffic conditions to preestablished thresholds while other use statistical procedures to detect significant changes in traffic patterns over time. Still other use complex theoretical models to predict future traffic conditions using current traffic measures and historical trends. While there are many factors that affect their performance (such as how well they are calibrated), the general structure of each algorithm has the greatest impact of its performance in terms of detection rate, false alarm rate, and detection time (19).

Table III-7 compares the performance of the SND algorithm that used the probe-measured travel times to the reported performance of some commonly used incident detection algorithms that use loop detector data. Because of the lack of loop detector data, we did not attempt to do direct on-line or off-line comparisons of the other algorithms, but instead relied solely on reported performance.

Table III-7. Comparison Of Probe Algorithm To Other Incident Detection Algorithms.

Algorithm	Detection Rate	False Alarm Rate
SND -- Probe Travel Times	70%	5.2%
California	82%	1.73%
Modified California #8	68%	0.177%
SND -- Loop Detectors	92%	1.3%
McMaster	68%	0.0018%

We found that, in terms of detection rates, the performance of the SND algorithm using the probe-measured travel times was comparable with the performance of the other incident detection algorithms. Both the basic California Algorithm and the SND model using loop detector data have reported higher detection rates than those achieved using the probe data. The SND algorithm using probe travel time measurements performed at least as well as the Modified California Algorithm #8 and the McMaster algorithm, both of which are being used in freeway management centers in North America.

However, the SND algorithm with the probe travel times experience a considerably higher false alarm rate than the other algorithms. The false alarm rates of most incident detection algorithms that used loop detector data is below 2 percent. The best performing SND algorithm that used the probe travel times (in terms of detection rate) experienced a false alarm rate of over 5 percent. This level of false alarms is not generally acceptable for algorithms that use detector data.

Because of the limitations of the RTTIS incident logs, we were not able to learn both the number of undetected incidents or the average detection times of the SND algorithm using probe measured travel times. Both measures are critical in assessing total performance of an incident detection algorithm.

SUMMARY

Using both the incident and travel time information logged by RTTIS in Houston, Texas, we showed the travel times provided by probe vehicles can be used to detect incidents on freeways and toll roads. We used a modified version of the Standard Normal Deviate (SND) algorithm developed by Dudek and Messer for detecting incidents. We used historical travel time measurements from RTTIS to establish the average and standard deviation travel times on each link in the system. These values were then used to establish threshold values for probe travel times. An incident condition existed when a probe measured travel time exceeded the SND threshold travel times. Grouping travel times into 15 minutes intervals for each day of the week, we assessed the performance of the algorithms by varying the SND values that established the detection thresholds.

Using this approach, we could detect approximately 70 percent of the known incidents when a 2.0 SND value was selected. We achieved a false alarm rate of approximately 5 percent. As the SND value increased, both the detection rate and false alarm rate declined, as expected. The performance of the algorithm compared favorably with the reported performance of other incident detection algorithms that use volume and occupancy measurements from loop detectors.

IV. BENEFITS OF REAL-TIME INFORMATION

One benefit of providing drivers with real-time information is that they can make informed route choice, departure time, and mode choice decisions based on the actual traffic and travel conditions that exist in a corridor. Because drivers waste fuel by sitting idle in congestion, providing motorists with real-time information that allows drivers to alter their routes can result in significant fuel savings. However, drivers will only use the information if they perceive it as accurate and timely. In this chapter, we explore motorists' perceptions and reactions to the real-time information provided by the system. We also explore the fuel saving benefits of providing drivers with real-time incident and travel time information.

MOTORISTS' PERCEPTIONS AND REACTIONS

In order for a system like the RTTIS to effect changes in travel patterns that can produce a fuel savings benefits, the information provided by the system must be accurate and credible. If drivers perceive the information as not being accurate or timely, they will not react to the information by diverting to alternate routes. Therefore, it is critical to determine if drivers' perceive the information being provided by the RTTIS as accurate and timely. To do this, we conducted a survey to gauge motorists' perceptions and reactions to information provided by RTTIS.

To gauge motorists' perceptions about the system, we selected fifteen probe drivers to participate in a survey. These probe drivers all used I-45 between I-10 and Beltway 8 as part of their regular commute. During the normal commute, these probe drivers would call the central communications center at the normal reporting locations, and identify themselves as survey participants. We provided them with the current travel time, incident, and congestion information that was available through the RTTIS. We allowed the probe drivers to react to this information any way they deemed appropriate, which included diverting to alternate facilities. Probe drivers were also free to ask for similar information about the travel conditions of the other facilities covered by the system (i.e., I-45 HOV lanes and the Hardy Toll Road); however, this was not provided unless requested by the driver. While we were conducting the survey, several incidents that affected travel times occurred on the facilities covered by the system.

We provided the survey participates with information for approximately ten days. After the ten-day period, we surveyed each participant by telephone. The purpose of the telephone survey was to assess the following:

- how participants perceived the accuracy, desirability, and usefulness of the information,
- if having access to the information caused the participants to alter their travel patterns (specially, to divert to an alternate facility), and
- what problems (if any) existed with the quality or accuracy of the information.

Format of Information

Throughout the ten days, we used different formats for providing the travel time and incident information. For four days, we provided the probes with both travel time and incident information. During another three days in the study, we provided only incident information to the probes. On the remaining three days, we provided both incident and delay information to the probes. For the purposes of this study, we computed delays by comparing the measured travel times to historical averages for each link.

As part of the post-study survey, we asked the participants to tell us which format they liked best for presenting the information. Most of the survey participants did not perceive much difference in way the information was presented. Most of the participants reported wanting both the travel time and incident information. Because most of the commuters already had an idea of the normal commuting times for the time of day that they traveled the facility, many said that by providing them with travel time information they could compute their own anticipated delays.

Almost all of the participants in the survey stated that the most critical information was knowing when and where incidents occurred in the freeway. Because of their previous experience with incidents in the corridor, many survey participants said that they would have an idea of what to expect (in terms of congestion and delays) if they knew where the incidents were located. Depending upon the location of the incident, they could then make adjustments to their travel patterns, based on their local experience.

Usefulness and Accuracy of Information

A critical issue examined in the survey was how motorists perceived the usefulness and the accuracy of the information provided by the RTTIS. Of those surveyed, over 70 percent (11 of 15) of the motorists said that they found the information provided by the system to be useful to them in their normal everyday commute. Eighty-two percent (12 of 15) of those that participated in the survey found the information to accurately reflect actual conditions in the corridor. Therefore, we concluded from these responses that the type of traffic and travel information obtained by using commuters equipped with cellular telephones acting as probes was both accurate and beneficial to the motoring public.

Effect on Trip-Making

The primary purpose of implementing a system like RTTIS is to provide drivers with information about incidents and congestion far enough in advance and in ample time so that they can alter their travel behavior to avoid the congestion. With accurate and timely information, drivers can select alternate routes, modes, or departure times, which reduce their travel time to their destination and reduce fuel consumption. Therefore, one issue examined in the user survey was the effect of real-time information on the trip-making patterns of drivers in the corridor.

As part of the survey, we asked users if having access to the travel time and incident information affected their trip making patterns (i.e., caused them to change their departure times, mode of travel, or route). Fifty-three percent (8 of 15) of the respondents said that they changed their trip-making patterns because of having access to the information. Thirty-three percent (5 of 15) of the respondents said that they changed their routes in direct response to the information. Several times, incidents on I-45 caused congestion on the main lanes. In these situations, some drivers reported taking the HOV lane or the Hardy Toll Road after receiving a report that there was an incident ahead of them. While the number of individuals that participated in the survey was limited, these findings show that drivers will alter their travel patterns if they have accurate and timely information about travel conditions ahead of them.

TXDOT UTILIZATION OF REAL-TIME TRAVEL TIME INFORMATION

Background

TxDOT has been and continues to be one of the primary users of the real-time travel time information obtained from RTTIS. Prior to the initiation of Phase I of the system, TxDOT had installed several changeable message signs (CMS) at strategic diversion points within the corridor. With these signs, TxDOT wanted to notify motorists when incident conditions existed downstream and when it would be beneficial for those motorists to divert to an alternative route. However, without surveillance equipment installed in the corridor, TxDOT could not provide this type of information. Consequently, TxDOT utilized the signs for certain preplanned activities (maintenance operations involving lane closures in the corridor, special event information) and for major incidents that were reported from other sources.

Phase I of RTTIS provided TxDOT with real-time estimates of peak-period travel times on I-45, US-59, and the Hardy Toll Road. In addition, the commuter probes provided more timely and accurate notification of incident locations. This enabled TxDOT to display CMS messages to motorists in the corridor that indicated 1) the existence of a downstream incident on any of the facilities, and 2) whether it was advisable for motorists to divert to the alternative facilities in the corridor. Most commonly, delays due to an incident on I-45 meant that motorists could save travel time by diverting to the Hardy Toll Road.

From an operations standpoint, current travel times were important to TxDOT in determining when an alternative route should be recommended via the CMS as well as in the actual design of the messages. TxDOT recommended an alternative facility whenever the travel time on the incident route became more than 10 minutes longer than on the alternative, taking into consideration the additional travel time required to reach the alternative (20). For example, TxDOT estimated that travel from I-45 to the Hardy Toll Road involved an additional 7 minutes.

Consequently, TxDOT enacted the signs and recommended diversion for any incident that resulted in travel times on I-45 that were 17 minutes or more longer than on the Hardy Toll Road. Current travel times were also important to TxDOT CMS operations for information dissemination purposes. TxDOT indicated by CMS the amount of time savings possible by diverting from the roadway where an incident was located. Generally speaking, TxDOT displayed the savings in travel time to the nearest five-minute increment (i.e., 10 minutes, 15 minutes, 20 minutes of delay savings, etc.).

Evaluation Results

TxDOT provided TTI access to the monthly records of CMS utilization in the corridor. At the time of this evaluation, data were available from January 1991 through June 1994. Given that Phase I of RTTIS lasted from October 1991 through September 1992, Figure IV-1 presents the average monthly TxDOT CMS utilization for incidents for the nine months prior to initiating Phase I (January to September 1991), for the 12 months during which Phase I was operating (October 1991 to September 1992), for the 12-month period following the completion of Phase I (October 1992 to September 1993), and then for a nine-month period when the AVI traffic monitoring system began to come on-line and provide travel time data (October 1993 to June 1994). It should be noted that there was a substantial lag between the time Phase I concluded and Phase II (using the AVI technology) became fully operational. This fact is quite evident in Figure IV-1. Prior to the start of RTTIS, TxDOT officials were able to use the North corridor CMS to inform motorists of an incident approximately once per month. Once Phase I became operational, CMS use for incident notification increased dramatically to an average of 12.3 times per month. After Phase I terminated (and only limited traffic conditions information were again available), this utilization dropped to 4.3 times per month. Finally, as Phase II of RTTIS was brought on-line in the corridor, CMS use again increased (although it had not yet fully returned to Phase I levels by June 1994).

An even more vivid illustration of the importance of real-time information to TxDOT CMS operations can be seen if data are compared only for the times when Phase I of RTTIS operated with a full complement of commuter participants. Although the system began operations in October 1991, it did not obtain all 200 commuter participants until late December 1991. If utilization data are compared only for the months of January through September of each year, an even more significant impact of the RTTIS information is evident. Figure IV-2 presents the average monthly CMS utilization for incident conditions in the corridor based on a January-to-September time frame. Whereas the CMS utilization prior to Phase I of RTTIS was still approximately once per month, utilization during the months of full participation in Phase I increased to over 15 times per month (nearly four times per week). Furthermore, the period immediately following the completion of the first phase showed an average utilization rate of only 3 times per month, only one-fifth of the utilization achieved during the months that Phase I was operational.

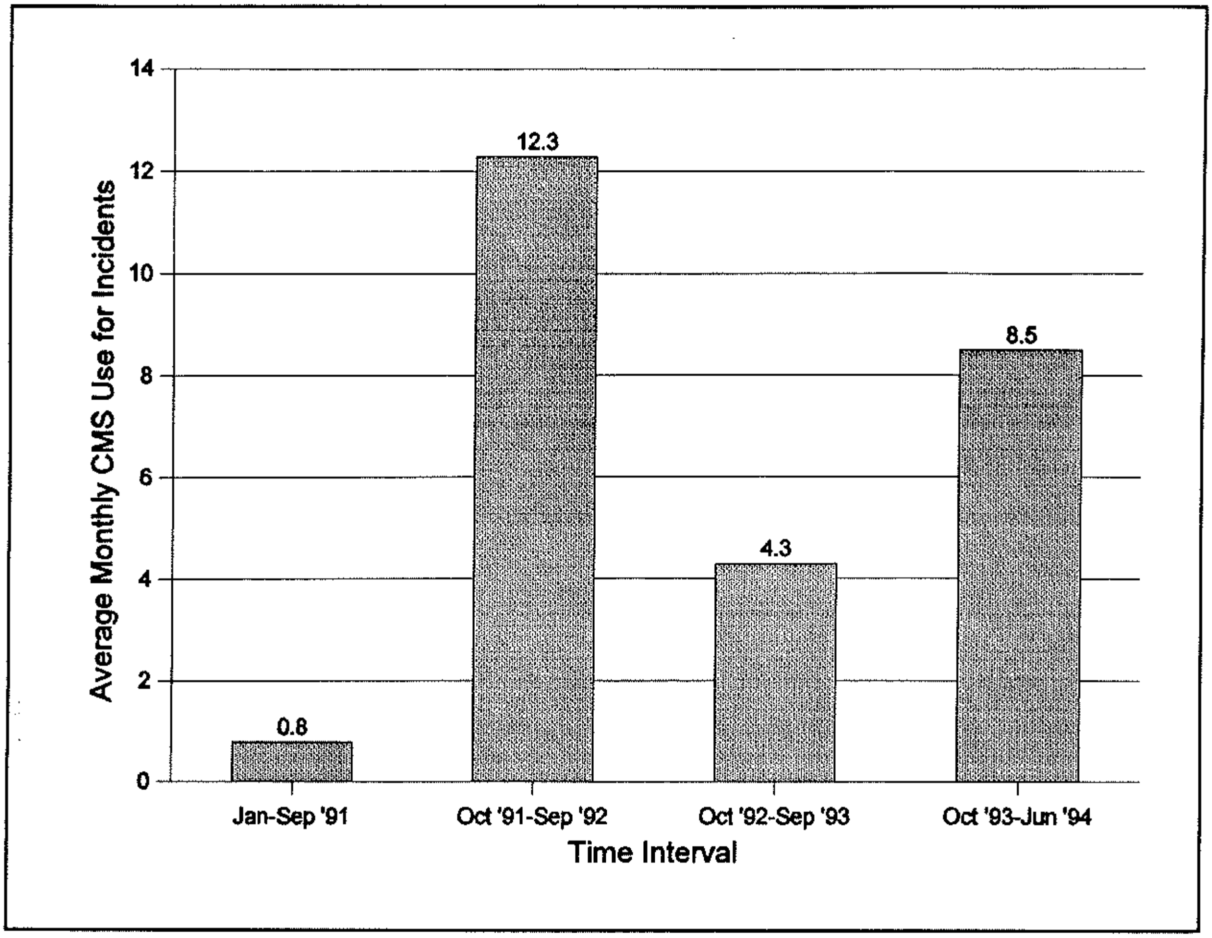

Figure IV-1. TxDOT Monthly CMS Utilization.

These data indicate that the full Phase I system provided TxDOT with a greater quantity and quality of travel time data. This allowed TxDOT to use the CMS for incident notification more often to communicate back to motorists. With respect to the display of actual travel time savings to motorists in the corridor, Table IV-1 presents the distribution of time savings values displayed via the CMSs during the year of Phase I of RTTIS operation.

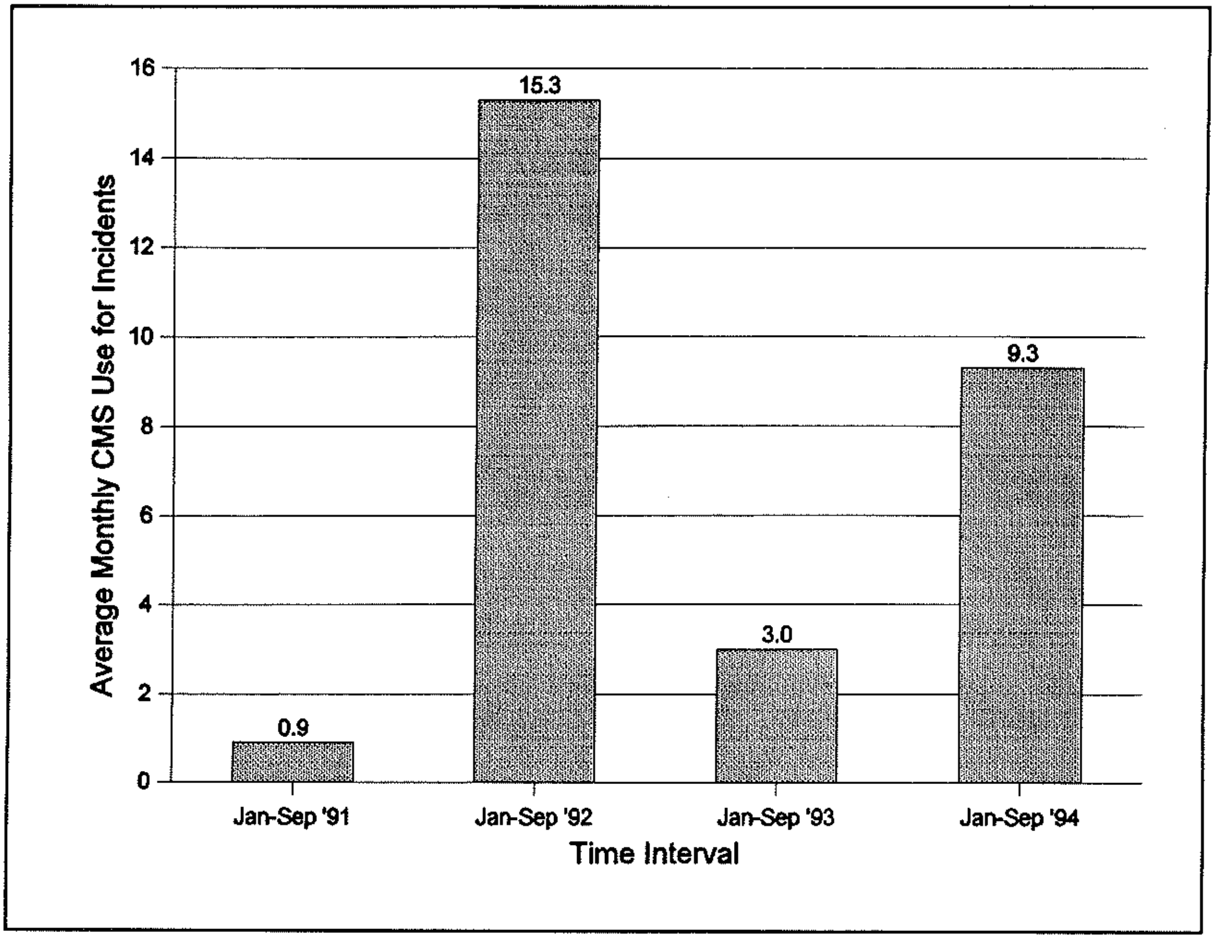

Figure IV-2. TxDOT Monthly CMS Use With And Without Full Commuter Participation.

Table IV-1. Distribution of Time Savings CMS Messages Displayed in Corridor

Time Savings Value	Percent of Messages
No Time Savings Displayed	5
"...Save 10 Minutes"	45
"...Save 15 Minutes"	30
"...Save 20 Minutes"	20

The percentages in Table IV-1 reflect the maximum time savings value displayed during a given incident. For several of the incidents, the travel time data were timely and accurate enough for TxDOT to initially display a 10-minute travel time savings to the Hardy Toll Road, and then to increase the displayed value to a 15- or 20-minute savings as congestion increased and pushed up delays on the incident route. Approximately one-half of the incidents (45 percent) resulted in a 10-minute travel time savings to motorists who diverted. Another one-third of the incidents (30 percent) generated a 15-minute time savings via an alternative route, and one-fifth (20 percent) of the incidents resulted in congestion that offered motorists a 20-minute travel time savings to divert. In only five percent of the incidents did TxDOT not display travel time savings information to motorists.

Combined with the results of the commuter probe survey described earlier, these data in Figures IV-1 and IV-2 and in Table IV-1 imply that Phase I of RTTIS demonstrated that the provision of accurate and timely travel information was useful to the traffic management efforts in the North Corridor. These data do not account for how information was used by the various traffic information services in the Houston area. The traffic information services also had direct access to this information, and combined with their own information collection network, disseminated it to their various media customers. Unfortunately, the complexity of the traffic service agency operations precluded any means of objectively measuring the impact of the information from Phase I.

POTENTIAL FUEL SAVINGS OF REAL-TIME TRAVEL TIME INFORMATION

One of the major questions posed by the researchers at the onset of this study was the following: Can the provision of real-time travel time information to motorists, transit agencies, and commercial vehicle companies traveling in an urban freeway corridor result in significant fuel savings benefits? Through the activities documented in this report, the benefits of this information for incident detection on a facility where no traffic surveillance is available have been illustrated, as has the usefulness of this information both to individual motorists and to TxDOT in operating its CMSs in the corridor. In this final section of the chapter, the fuel savings benefits of the system are explored.

The scope and financial limitations of the study precluded actual measurements of fuel consumption of any particular group of information users. Likewise, the effects of this real-time travel time information upon motorist travel patterns in the corridor under incident conditions could not be objectively measured under the funding constraints of this research. In actuality, such an evaluation may not have been particularly fruitful had it been attempted. Incidents are rare events that have dramatically different impacts depending on their location, time-of-day, duration, and other factors. Consequently, it would have been very difficult to establish a database that allowed for an accurate comparison of the effects of real-time information upon traffic operations in general and fuel consumption in particular.

Given that a direct comparison of actual fuel consumption in the corridor with and without the RTTIS system was not possible, efforts turned to analytical methods that could be used to assess the likely fuel consumption effects of improved information under a variety of possible incident scenarios and potential responses of the driving population in the corridor. The assumptions and computational procedures incorporated into this analysis, as well as the results of the evaluation, are described below.

Assumptions and Computational Procedures

Unit Fuel Consumption Estimates Under Normal Conditions

Estimates of fuel consumption normally used to assess geometric and operational alternatives come from data collected during the 1960s and 1970s by Claffey (21). Although it is known that vehicular and roadway characteristics have changed dramatically since that time, updated fuel consumption factors have not been published (although research is currently underway to accomplish this). Therefore, these data were assumed to represent the best available and served as the basis of this evaluation.

Vehicle fuel consumption analyses includes the following three components:

- fuel consumed while traveling at a uniform speed,
- additional fuel consumed in accelerating and decelerating, and
- fuel consumed while stopped and idling.

The relationship that exists between fuel consumption and uniform running speed is depicted in Figure IV-3. As can be seen, this relationship is not linear. Rather, fuel consumption is at its lowest when speeds are between 50 and 55 km/h (30 and 35 mph). Fuel consumption is higher at faster running speeds, and is dramatically higher for very slow speeds (i.e., less than 10 km/h [16 mph]). Therefore, assuming typical running speeds for freeways and arterials (i.e., 80 to 95 km/h [50 to 60 mph] for uncongested freeways versus 45 to 65 km/h [30 to 40 mph] for arterial streets), one sees that the uniform speed component of fuel consumption is greater for freeway travel than for an equivalent distance traveled on an arterial street.

For Phase I of RTTIS, the normal running speed on the freeway was assumed to be 90 km/h (56 mph) during the hours the RTTIS was operating. Since the completion of reconstruction along portions of I-45 north of I-610, speeds of this magnitude are not unreasonable even during peak periods as long as an incident does not occur to restrict capacity. In comparison, the normal running speed between intersections on arterials in the corridor was taken to be 65 km/h (40 mph). It is known that speeds vary from one arterial to the next. However, these differences occur primarily because of differences in traffic signal timings at the intersections. Between traffic signals, it is believed that speeds are not all that much different. Using these assumed typical speeds for the freeway and arterial roadways in the corridor, fuel consumption is assumed to be equal to 0.212 and 0.170 liters/km (0.090 and .072 gal/mi), respectively.

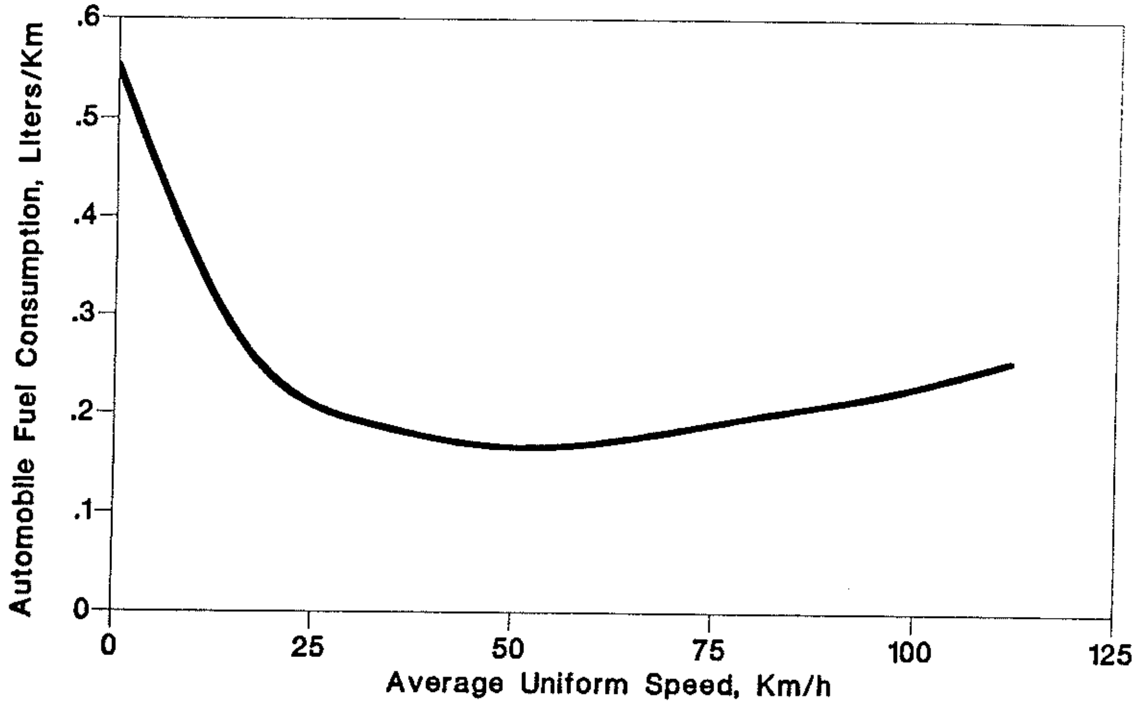

Figure IV-3. Uniform Speed Fuel Consumption Rates For Automobiles (21).

The lower fuel consumption rate on the arterial street is offset somewhat by the signalized intersections spaced along the roadway that periodically stop traffic flow. At these intersections, drivers must decelerate, spend some amount of time stopped, and then accelerate if they encounter a traffic signal when a red indication is displayed. According to the literature (21), the amount of extra fuel consumed during this particular maneuver depends on the operating speed the vehicle decelerates from and then accelerates back to before and after stopping at the intersection, as well as the amount of time the vehicle spends stationary at the intersection waiting for the light to turn green. If an average signal timing configuration (defined in terms of the probability each vehicle has of stopping times the average time each stopped vehicle must wait) and intersection spacing is assumed for a typical arterial, fuel consumption can be converted into a rate per kilometer (identical to the units used to define fuel consumption at a uniform vehicle speed). Figure IV-4 presents a graph of additional fuel consumption due to stopping and idling versus the product of stopping probability per intersection and intersection spacing. The values in this figure are based on the assumed 65 km/h (40 mph) running speed between intersections in the North corridor. As Figure IV-4 illustrates, intersection spacing and stopping probability has a much more pronounced effect upon this additional fuel consumption than does the delay occurred each time a vehicle stops.

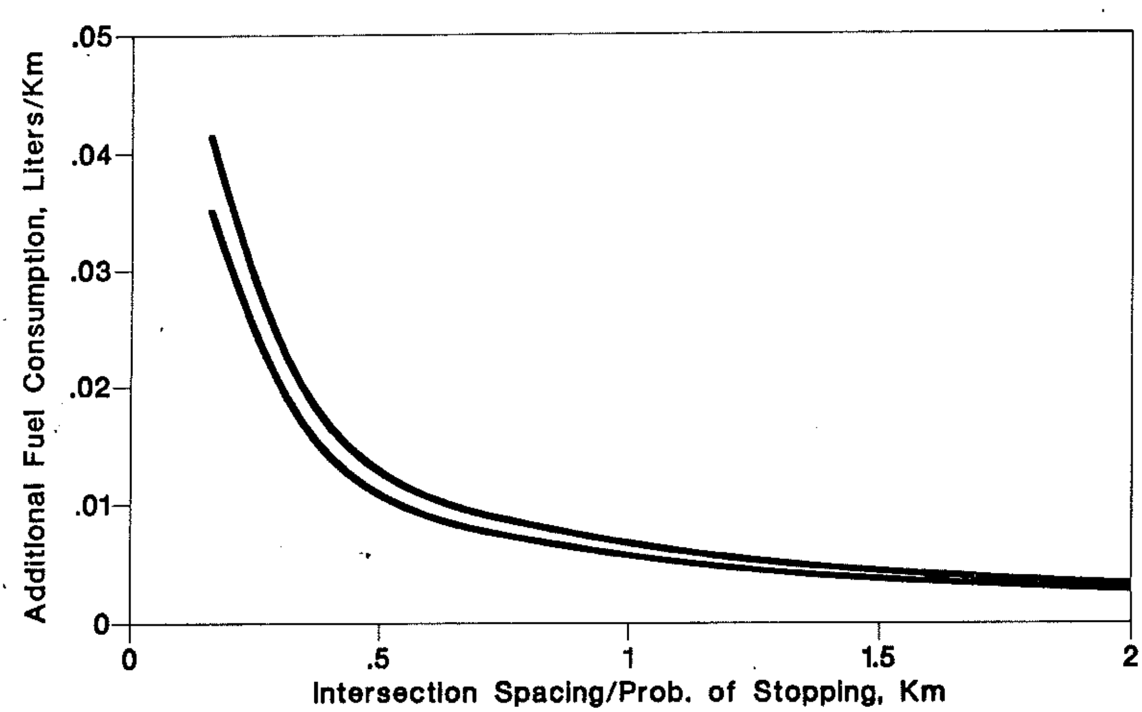

Figure IV-4. Additional Fuel Consumed On Arterials At Signalized Intersections (21).

Based on unpublished roadway inventory and travel time data collected by TTI in the North corridor, an intersection spacing of 1.2 kilometers (0.75 miles) was assumed for this analysis. During peak periods, it was also assumed that every vehicle would be required to stop at each intersection. From Figure IV-4, these assumptions equate to an additional 0.005 liters/km (0.002 gal/mi) of fuel consumed per vehicle. Adding this value to the uniform speed consumption rate for arterials identified earlier results in an estimated 0.175 liters/km (0.074 gal/mi) for travel on the arterials, compared to the 0.212 liters/km on the freeway. Thus, even considering the stops and delays caused by signalized intersections, fuel consumption is still estimated to be lower on the arterials in the corridor than on the freeway under normal operating conditions.

Unit Fuel Consumption Rates Under Incident Conditions

When an incident occurs on a freeway segment and reduces capacity to less than the existing traffic demand on that facility, traffic begins to queue upstream of the incident site. Travel conditions through the queue are characterized by very low speeds and extensive speed-changing activity (i.e. stop-and-go vehicle operations). Often, speeds within a section of freeway queue will average no more than 8 to 15 km/h (3 to 5 mph). From Figure IV-3, speeds of this magnitude will result in substantially higher fuel consumption rates than for normal freeway speeds. The repetitive acceleration-deceleration process in the queue increases this fuel consumption rate even further.

Data regarding roadway capacity data suggest that incidents that block one or two lanes of a three-lane section of freeway (such as exists predominantly on I-45) reduce available capacity by 50 to 79 percent, respectively (22). Even accidents on the shoulder decrease capacity by approximately 26 percent due to rubbernecking (22). However, it is the lane-blocking incidents that typically degrade traffic conditions on I-45 to the point of warranting diversion messages displayed via the CMS. Therefore, it was assumed that each incident when real-time information in the corridor was displayed involved a 50 percent reduction in capacity. Then, the following equation from freeway surveillance and control research of the 1960s was used to estimate the average speed in queue as a function of reduction in roadway capacity due to the incident (23):

$$u_q = \frac{u_f}{2}\left[1 - \sqrt{\frac{\%\ capacity\ \ reduction}{100}}\right] \qquad (1)$$

where

u_q	=	average speed of traffic in the queue
u_f	=	free-flow speed of traffic (assumed to be 105 km/h [65 mph])

From this relationship, an average speed in queue of 14 km/h (9 mph) is estimated for the typical incident on I-45. In Figure IV-3, this speed results in an average fuel consumption rate of 0.375 liters/km (0.159 gal/mi) of queue. Meanwhile, unpublished data from queues observed upstream of work zone lane closures suggest that vehicles experience approximately two 0-to-16-to-0 km/h speed changes per kilometer of queue (24). From the literature, these two speed changes consume an additional 0.008 liters/km (0.003 gal/mi) of fuel, for a total consumption rate of 0.383 liters/km (0.163 gal/mi) of queue on the freeway under incident conditions.

Differences in Driver Behavior With and Without Real-Time Information

With the various unit fuel consumption rates estimated, efforts now turn to determining the incremental effect of real-time travel time information upon fuel consumption under incident conditions. Traditionally, operational analyses of oversaturated conditions caused by non-recurrent congestion have been hampered because of a lack of understanding regarding dynamic driver diversion behavior. It is known that driver decisions are affected by the traffic conditions encountered. Conversely, the traffic conditions that result upstream of an incident or other bottleneck depend on the traffic demands approaching the incident site. Unfortunately, methods of incorporating the time-dependent effect that queue growth has upon these diversion decisions has been quite difficult to model realistically.

However, the TTI researchers contend that it may not be necessary to accurately depict the overall decision-making strategy for the entire driver population in the corridor as long as the resulting impact on overall traffic behavior can be represented. Recent research results have shown that queue lengths and congestion upstream of temporary freeway bottlenecks do not propagate upstream continuously over the duration of a temporary bottleneck such as an incident. Rather, the queues reach an equilibrium as travel patterns at the entrance and exit ramps within and immediately upstream of the freeway change in response to the new freeway congested traffic conditions. Field experiences statewide suggest that freeway queues at temporary work zone lane closures stabilize at around 3 to 5 km (2 to 3 miles). These estimates were verified in research study sites in San Antonio. Under high-volume conditions, freeway queues can grow to that length in only a short period of time, after which the queue fluctuates only a small amount around that stable length.

This stabilization process implies that significant diversion occurs regardless of whether or not real-time information is disseminated to motorists. However, the diversion without real-time information is likely to occur in the immediate vicinity of the incident location as motorists actually encounter the congestion. This type of diversion still typically leads to secondary congestion on the frontage road and other nearby arterials (resulting in significantly higher fuel consumption). By providing real-time information, it is theorized that some motorists will divert farther upstream of the congestion and thereby avoid both the freeway as well as the secondary arterial congestion due to the incident. Figure IV-4 depicts the difference in non-real-time versus real-time information access upon driver diversion patterns. The top portion of the figure shows that additional congestion resulting in stop-and-go operations (and increased fuel consumption) will be encountered by motorists making any number of normal or diversion maneuvers in the vicinity of the congestion. Conversely, the lower portion of Figure IV-4 shows that a motorist with real-time information about the downstream congestion can divert earlier and avoid the congestion on the freeway and nearby arterials.

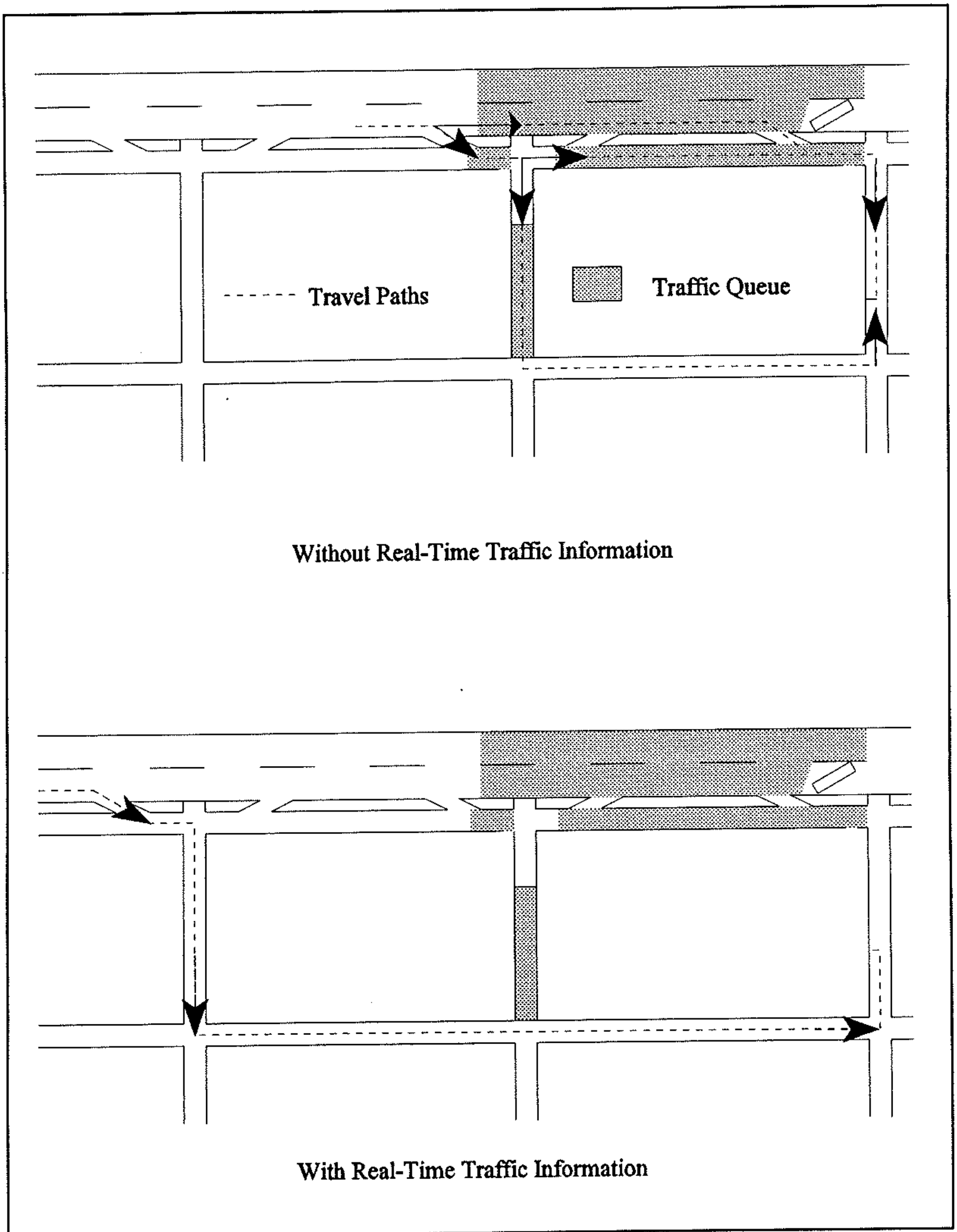

Figure IV-5. Effect of Real-Time Traffic Information on Motorist Travel Patterns

Another point to raise concerning motorist diversion behavior relates to the effect of diversion upon total travel distance. Traditionally, diversion is envisioned as increasing travel distance, assuming that motorists leave the freeway to bypass congestion and then return back to the freeway downstream of the congestion. Although this particular maneuver may be representative of those motorists making long-distance trips through the corridor, research regarding commuter diversion behavior (25) in urban freeway corridors suggests that motorists who divert from the freeway do not return to the freeway beyond the incident but rather continue along the arterial to their destination. This is the type of diversion pattern depicted in Figure IV-4. Assuming that motorists have some knowledge of the roadway network in the vicinity of the incident, travel distances under diversion conditions may not increase significantly.

Although estimating the fuel consumption impacts of a freeway queue of some finite length was fairly straightforward, calculations of the impacts of secondary congestion on an arterial is more difficult conceptually. For purposes of this analysis, the fuel consumption rate in congestion per length of arterial was assumed to be equivalent to that computed for the freeway. Furthermore, for simplicity of analysis, it was assumed that the length of secondary congestion that would have been encountered on nearby arterials by any motorists who diverted once they encountered congestion would be the same as if they had continued along the freeway (i.e., 8 km). Based on these assumptions, then, the fuel consumption savings achievable through the provision of accurate and timely travel time information to motorists is due to the fact that the motorists do not travel that distance in congestion, but rather on a segment of uncongested arterial roadway. This reduction in fuel consumption for the trip will be offset slightly if it involved an increase in travel distance. The total fuel consumption saved is then simply summed over all of the motorists predicted to divert because of the real-time information. Mathematically, this analysis process is as presented in equation 2:

$$Savings = (No.\ Vehicles\ Diverting)\,([FC_c - AC_u]QL - AC_u[\Delta TL]) \qquad (2)$$

where

FC_c	=	fuel consumption rate in congested conditions (liters/km of queue)
AC_u	=	arterial fuel consumption rate in uncongested conditions (liters/km)
QL	=	equilibrium queue length on the freeway
ΔTL	=	increase in travel distance due to diversion

The average lane-blocking incident (for which TxDOT could provide real-time information) was assumed to last one hour, for the analysis of the North Corridor in Houston. Diverting traffic was estimated as a percentage of normal freeway volume (determined from previous traffic counts to be between 4000 and 5600 vph over the roadway section of interest). A conservative 5 to 10 percent diversion rate due to information was assumed to occur in the corridor, which implies a total diversion of between 240 and 480 vehicles per one-hour incident for analysis purposes. As previously stated, queue lengths were assumed to stabilize at 5 km (3 mi). Finally, the estimated additional travel distance required of diverting traffic was assumed be an average of 0.5 km (0.3 mi). Table IV-2 summarizes the various assumptions included in the analysis.

Table IV-2. Values Assumed in Fuel Savings Analysis.

Variable/Parameter	Value(s)
Number of Vehicles Diverting	240 to 480
Equilibrium Queue Length	8 km
Extra Travel Distance of Diverting Drivers	0.5 km
Fuel Consumption in Congested Conditions [FC_c]	0.383 liters/km
Fuel Consumption on Arterial in Uncongested Conditions [AC_u]	0.175 liters/km

1 gal/mi = 2.353 liters/km
1 mi = 1.61 km

Presentation and Interpretation of Results

Using equation 2 and the assumed values shown in Table IV-2, researchers calculated the possible fuel savings benefits for an average one-hour incident as between 229 and 457 liters/incident (61 to 121 gal./incident). Based on the monthly CMS frequency of utilization during and immediately after Phase I of RTTIS (from Figures IV-1 and IV-2), it appears that the system allowed TxDOT to provide accurate and timely information to motorists up to an additional 12.3 times per month than was possible without RTTIS. Multiplying these monthly rates by the average fuel savings computed for each incident yields a yearly fuel savings reduction of between 33,800 and 67,600 liters/year (8,923 and 17,848 gal/year).

These estimates are based on a very simplistic analysis process, and so must be interpreted with caution. It is evident from the evaluation that the final estimate is quite sensitive to several of the assumptions made, assumptions for which little or no supporting data are available. For example, the effect of driver diversion patterns upon total trip length are not known at this time, yet from equation 2 the value of this factor can have a significant effect upon the final estimate. Likewise, the impact of real-time information upon the number of drivers that choose to divert has yet to be fully evaluated in the field. Laboratory studies (26, 27, 28) indicate that a high percentage (i.e., up to 50 percent) of drivers will divert in response to time savings values of the magnitude reported by TxDOT on the CMS. However, whether this level of diversion is achieved under actual operating scenarios is unknown at this time. Finally, it is important to remember that these fuel consumption estimates are based upon data from vehicles over 20 years old. Dramatic improvements in vehicle fuel economy that have occurred since then suggest that the results of this analysis may overestimate the true fuel savings benefits achieved with the RTTIS system.

V. SUMMARY OF CONCLUSIONS

Even with recent expansion of the transportation infrastructure, Houston ranks as one of the most congested cities in the United States and is the most congested city in Texas. Currently, the Texas Department of Transportation (TxDOT) and other transportation agencies are installing systems to collect, analyze, and distribute real-time travel time and incident information. One such system is the Real-Time Traffic Information System (RTTIS). This system provides motorists, transit operators, and commercial vehicle operators with real-time travel time and incident information on the high mobility transportation facilities in north and northwest Houston. The objectives of this research were as follows:

1. To design and implement a system for obtaining real-time travel time and incident information directly from motorists traveling in an uninstrumented corridor in Houston,

2. To examine the feasibility of using the information collected by the system to detection incidents,

3. To document the user acceptance and potential fuel saving of implementing this type of system in a freeway corridor.

The report also shows how vehicles acting as probes can provide real-time travel time and incident information to detect incidents. We used the data collected by the cellular telephone system to compute typical travel conditions on each link covered by the system. We modified the SND algorithm developed originally by Dudek and Messer to determine when a probe travel time exceeded the travel time under incident free conditions. Using this approach, we achieved detection rates that were comparable to those achieved by other incident detection algorithms that used loop detector data. The false alarm rates produced using this approach, however, were higher than those produced by other algorithms. Because of the limitation of the data, we were not able to learn how many incidents went undetected or the detection times using the telephone probe system.

A survey of a small sample of system users measured how users perceived the quality and reacted to the information provided by RTTIS. Most survey participants believed that the information provided by the system was accurate and believable. The majority of survey participants said that while they liked having both incident and travel time information, receiving information about incidents was more critical to them. Many said that the information provided by the system directly influenced their travel behavior in the corridor by causing them to change routes or delaying their departure times.

TxDOT has been and continues to be one of the primary users of RTTIS. They use the travel time and incident information from the RTTIS to determine when an alternate route should be recommended via the CMS. The presence of the RTTIS has significantly increased the use of the CMS on the freeway system. Prior to the start of RTTIS, the CMSs in the North corridor were used an average of once per month to inform motorists of incidents; however, after completion of Phase I of RTTIS, CMS use for incident notification increased dramatically to an average of 12.3 times per month.

The primary purpose of this study was to examine whether or not the provision of real-time travel time information to motorists, transit agencies, and commercial vehicle companies travelling in an urban freeway corridor could result in significant fuel saving benefits. While it was impossible in this study to actually measure how information effected the fuel consumption of any of these groups, a simplistic analytical method was used to assess the likely fuel consumption effects of improved information under a variety of incident scenarios. The analysis procedures showed that the provision of information to drivers could result in a savings benefits for an average incident of one hours of between 229 and 457 liters/incident (61 to 121 gal./incident). Given that TxDOT was able to provide accurate and timely information to motorists an additional 12.3 times with RTTIS, the annual fuel savings benefits for the system were estimated to range between 33,800 and 67,000 liters/year (8,923 to 17,848 gal./year).

VI. REFERENCES

1. C.L. Dudek and R.D. Huchingson. *Manual on Real-Time Motorist Information Displays.* FHWA Report No. FHWA-IP-86-16. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., August 1986.

2. D. Brand. Workshop Report on In-Vehicle Motorist Information Systems for Real-Time Route Guidance. In *Proceedings of the Engineering Foundation Conference on Management Control of Urban Traffic Systems.* Henniker, N.H., June 14-19, 1987.

3. P. Davies and C. Hill. Driver Route Choice Assisted by Automatic Vehicle Identification. Presented at the First International Conference on Application of Advanced Technologies in Transportation Engineering, San Diego, CA., February 5-8, 1989.

4. *Mobility 2000 Presents Intelligent Vehicles and Highway Systems.* Executive Summary. Texas Transportation Institute, College Station, TX., July 1990.

5. *IVHS Architecture Bulletin 2.* U.S. Department of Transportation and the Intelligent Transportation Society of America, Washington, D.C., September 1994.

6. J.H. Rillings and R.J. Betsold. Advanced Driver Information System. In *IEEE Transactions on Vehicle Technology.* Volume 40, No.1. Institute of Electrical and Electronics Engineers, Inc., Piscataway, N.J., February 1991.

7. P. Wasielewski. Overview of PATHFINDER. Presented at the Research and Development Conference, California Department of Transportation, Sacramento, CA., September 1988.

8. J.H. Rillings and J.W. Lewis. TravTek. In *Vehicle Navigation & Information Systems Conference Proceedings.* Society of Automotive Engineers, Inc., Warrendale, PA., October 1991.

9. B.C. Smith, P. Pollock, F. Koppleman, C Bhat, P. Nelson, and D. Rorem. A Conceptual Overview of ADVANCE. In *Surface Transportation and the Information Age.* Proceedings of the IVHS AMERICA 1992 Annual Meeting, Volume Two, IVHS AMERICA, Washington D.C., 1992.

10. J.W. Hanks, Jr. and T.J. Lomax. *Roadway Congestion In Major Urban Areas: 1982 to 1987.* Report No. FHWA/TX-90-1131-2. Texas Transportation Institute, Texas A&M University System, College Station, TX., October 1989.

11. K.Banning, R. Stokes, J. Mounce, and D. Morris. *Simulation Analysis of Proposed Improvements for Eastex Freeway (US-59N), Houston.* Texas Transportation Institute, Texas A&M University System, College Station, TX., February 1983.

12. R. Stokes, J. Mounce, D. Morris, and R. Peterson. *Simulation Analysis of Proposed Improvements for the Southwest Freeway (US-59S), Houston.* Texas Transportation Institute, Texas A&M University System, College Station, TX., August 1982.

13. Draft Executive Summary. *Houston Intelligent Transportation System.* Prepared for Metropolitan Transit Authority of Harris County and the Texas Department of Transportation by the Texas Transportation Institute. College Station, TX., April 1991.

14. *State Department of Highways and Public Transportation District 12 Computerized Transportation Management System: 10-Year Project Development Plan 1989-1998.* Texas Department of Transportation, July 1988.

15. K.F. Turnbull and D.L. Christiansen. Houston SMART Commuter IVHS Demonstration Project. Present at the IVHS AMERICA 1992 Annual Meeting. Newport Beach, CA., May 1992.

16. C.L. Dudek and C.J. Messer. Incident Detection on Urban Freeways. In *Transportation Research Record 495.* Transportation Research Board, National Research Council, Washington D.C., 1974.

17. C.E. Mountain. *Incident Detection Using the Standard Normal Deviate Model and Travel Time Information From Probe Vehicles.* Master of Science Thesis. Texas A&M University, College Station, TX., December 1993.

18. L. Ott. *An Introduction to Statistical Methods and Data Analysis.* Second Edition. PWS Publishers, Boston, MA. 1984.

19. K. Balke. *An Evaluation of Existing Incident Detection Algorithms.* Research Report 1232-20. Texas Transportation Institute, Texas A&M University System, College Station, TX. November 1993.

20. Personal Communication with Mr. Carlton Allen, TxDOT-Houston, September 14, 1994.

21. P.J. Claffey. Running Costs of Motor Vehicles as Affected By Road Design and Traffic. *National Cooperative Highway Research Program Report* No. 111. Transportation Research Board, Washington, D.C. 1971.

22. R.A. Reiss and W.M. Dunn, Jr. *Freeway Incident Management Handbook.* Report No. FHWA-SA-91-056. Federal Highway Administration, Washington, D.C. July 1991.

23. C.J. Messer and C.L. Dudek. *Development of a Model for Predicting Travel Time on an Urban Freeway.* Report No. 165-8. Texas Transportation Institute, College Station, Texas. January 1974.

24. J.L. Memmott and C.L. Dudek. *A Model to Calculate the Road User Costs at Work Zones.* Report No. FHWA/TX-83/20+292-1. Texas Transportation Institute, College Station, Texas. September 1982.

25. Stephanedes, Y.J., Kwon, E., and P. Michalopoulos. Demand Diversion for Vehicle Guidance, Simulation, and Control in Freeway Corridors. Transportation Research Record No. 1220. Transportation Research Board, Washington, D.C 1989. pp. 12-20.

26. R.D. Huchingson and C.L. Dudek. Delay, Time Saved, and Travel Time Information for Freeway Traffic Management. *Transportation Research Record* No. 722. Transportation Research Board, Washington, D.C. 1979. pp. 36-40.

27. R.D. Huchingson, J.R. Whaley, and N.D. Huddleston. Delay Messages and Delay Tolerance and Houston Work Zones (Abridgement). *Transportation Research Record* No. 957. Transportation Research Board, Washington, D.C. 1984. pp. 19-21.

28. G.L. Ullman, C.L. Dudek, and K.N. Balke. *Effect of Freeway Corridor Attributes Upon Motorist Diversion Responses to Real-Time Travel Time Information.* Report No. FHWA/TX-92/1232-13. Texas Transportation Institute, College Station, Texas. October 1992.

APPENDIX A.

HISTORICAL LINK TRAVEL TIMES

Table A-1. Average Travel Times by Time-of-Day and Day-of-Week for Link 101.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.6 (0.5)	3.5 (0.2)	3.6 (0.9)	3.6 (0.4)	3.3 (0.3)	3.5 (0.6)
6:00	3.8 (0.7)	3.6 (0.3)	3.8 (1.3)	3.5 (0.4)	3.6 (0.4)	3.6 (0.7)
6:15	4.3 (1.3)	5.0 (2.8)	3.8 (0.6)	3.7 (0.4)	3.8 (0.8)	4.1 (1.5)
6:30	4.6 (1.6)	4.4 (1.4)	3.8 (0.5)	3.8 (0.6)	3.7 (0.6)	4.1 (1.2)
6:45	5.3 (3.6)	4.4 (1.4)	4.2 (1.1)	3.7 (0.7)	3.7 (0.8)	4.3 (2.0)
7:00	4.5 (1.2)	4.6 (1.9)	4.0 (0.9)	3.8 (0.7)	3.7 (0.6)	4.2 (1.2)
7:15	5.0 (1.7)	4.2 (1.0)	4.4 (1.0)	3.9 (0.9)	3.7 (0.8)	4.2 (1.2)
7:30	4.3 (1.0)	4.5 (0.8)	5.4 (1.3)	5.3 (3.6)	4.3 (1.3)	4.7 (2.0)
7:45	5.0 (2.0)	4.5 (1.5)	4.6 (1.2)	4.8 (1.4)	4.4 (1.2)	4.6 (1.4)
8:00	4.4 (1.5)	4.2 (1.1)	4.2 (1.2)	4.1 (1.1)	4.0 (1.1)	4.2 (1.2)
8:15	3.6 (0.8)	3.8 (0.6)	3.9 (1.0)	4.1 (1.9)	3.5 (0.2)	3.8 (1.1)
8:30	3.9 (0.7)	3.5 (0.4)	3.4 (0.3)	4.3 (1.8)	3.4 (0.1)	3.6 (0.8)
8:45	3.3 (-)	3.6 (0.4)	3.5 (0.5)	3.4 (0.3)	3.2 (0.3)	3.4 (0.4)
9:00	4.1 (0.9)	3.5 (0.6)	3.6 (0.5)	3.4 (0.4)	3.6 (0.4)	3.6 (0.6)
9:15	3.6 (0.3)	3.6 (0.6)	3.3 (0.2)	3.4 (0.2)	3.3 (0.3)	3.4 (0.4)
9:30 AM	3.7 (0.1)	3.7 (0.4)	3.3 (0.6)	3.3 (0.3)	3.6 (0.5)	3.5 (0.5)
Average	4.4 (1.9)	4.2 (1.4)	4.0 (1.0)	3.9 (1.1)	3.7 (0.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-2. Average Travel Times by Time-of-Day and Day-of-Week for Link 102.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	4.0 (1.2)	3.7 (0.3)	3.7 (0.3)	3.8 (0.9)	3.6 (0.5)	3.8 (0.8)
6:00	3.8 (0.6)	4.0 (1.0)	3.7 (0.5)	3.8 (0.5)	3.7 (0.3)	3.8 (0.7)
6:15	4.5 (1.0)	4.4 (1.2)	4.1 (0.8)	4.3 (0.8)	4.0 (0.6)	4.3 (0.9)
6:30	4.9 (1.0)	5.2 (1.1)	4.7 (0.8)	4.5 (0.8)	4.4 (0.8)	4.8 (1.0)
6:45	5.7 (1.2)	5.5 (1.4)	5.0 (1.2)	4.8 (1.1)	4.4 (0.8)	5.1 (1.2)
7:00	5.9 (1.2)	5.6 (1.3)	5.2 (1.3)	4.6 (1.0)	4.6 (1.0)	5.2 (1.3)
7:15	5.1 (0.8)	5.1 (1.5)	4.8 (1.1)	4.6 (0.9)	4.5 (1.0)	4.8 (1.1)
7:30	5.2 (0.4)	4.9 (0.7)	8.1 (9.3)	4.6 (0.7)	4.6 (0.9)	5.4 (3.9)
7:45	5.1 (1.0)	5.0 (1.2)	4.8 (0.9)	5.2 (1.6)	4.5 (1.0)	4.9 (1.2)
8:00	4.4 (1.3)	4.6 (1.8)	4.5 (1.0)	4.4 (1.4)	3.9 (0.8)	4.4 (1.3)
8:15	4.2 (1.2)	4.0 (0.7)	4.1 (0.8)	3.9 (0.6)	4.0 (0.5)	4.0 (0.8)
8:30	4.1 (0.8)	3.7 (0.7)	3.7 (0.6)	3.7 (0.9)	3.5 (0.4)	3.7 (0.7)
8:45	3.4 (0.7)	3.6 (0.4)	3.7 (0.5)	3.6 (0.4)	3.5 (0.2)	3.5 (0.5)
9:00	4.3 (2.1)	3.6 (0.2)	3.7 (0.4)	3.7 (0.4)	3.5 (0.5)	3.7 (0.7)
9:15	3.2 (0.4)	3.5 (0.6)	4.0 (0.8)	3.8 (0.8)	3.5 (0.4)	3.6 (0.6)
9:30 AM	3.3 (0.4)	3.5 (0.4)	3.6 (0.6)	3.4 (0.3)	3.9 (1.1)	3.6 (0.8)
Average	4.8 (1.3)	4.7 (1.4)	4.5 (1.5)	4.3 (1.0)	4.2 (0.9)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-3. Average Travel Times by Time-of-Day and Day-of-Week for Link 103.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average
5:45	5.0 (1.0)	4.4 (0.4)	4.8 (1.6)	4.5 (0.2)	5.3 (2.4)	4.8 (1.3)
6:00	6.6 (2.9)	6.4 (3.1)	6.7 (3.6)	6.1 (3.1)	5.0 (2.0)	6.2 (3.1)
6:15	5.4 (1.1)	5.4 (1.0)	5.2 (0.7)	5.0 (0.6)	5.0 (0.6)	5.2 (0.8)
6:30	6.1 (2.5)	6.3 (1.7)	5.7 (0.9)	5.5 (1.3)	5.4 (0.7)	5.8 (1.6)
6:45	6.2 (1.6)	6.3 (1.9)	6.2 (1.2)	5.7 (0.9)	5.6 (1.1)	6.0 (1.4)
7:00	7.1 (1.8)	7.7 (2.8)	7.5 (2.0)	6.8 (1.4)	6.4 (1.4)	7.0 (2.0)
7:15	7.6 (2.1)	7.6 (2.4)	8.2 (2.7)	7.2 (2.3)	6.6 (1.6)	7.4 (2.2)
7:30	7.1 (1.7)	7.7 (2.1)	7.2 (1.4)	7.0 (2.2)	6.3 (1.8)	7.0 (1.9)
7:45	6.1 (1.6)	6.8 (2.0)	6.2 (1.2)	6.1 (1.3)	6.1 (2.9)	6.2 (2.0)
8:00	5.6 (1.6)	6.0 (2.3)	5.3 (1.7)	5.5 (1.7)	5.0 (1.7)	5.5 (1.8)
8:15	5.7 (1.8)	5.2 (1.3)	5.4 (1.8)	6.1 (5.1)	5.8 (3.6)	5.6 (3.0)
8:30	4.7 (0.8)	4.8 (0.8)	4.6 (1.0)	4.5 (0.8)	4.6 (1.1)	4.6 (0.9)
8:45	4.5 (0.5)	4.3 (0.8)	4.7 (0.6)	4.5 (0.4)	4.4 (0.6)	4.5 (0.6)
9:00	4.0 (0.6)	6.1 (5.3)	4.7 (0.5)	4.7 (0.6)	4.4 (0.4)	4.9 (2.8)
9:15	4.6 (0.9)	4.4 (0.4)	4.4 (0.5)	4.3 (0.6)	4.3 (0.6)	4.4 (0.6)
9:30 AM	4.6 (0.4)	4.6 (0.4)	4.3 (0.4)	4.2 (0.6	4.6 (1.3)	4.4 (0.8)
Average	6.2 (2.0)	6.3 (2.3)	6.1 (2.0)	5.9 (2.2)	5.6 (1.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-4. Average Travel Times by Time-of-Day and Day-of-Week for Link 104.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.7 (1.0)	3.5 (0.8)	3.5 (0.6)	3.5 (0.8)	3.5 (1.0)	3.6 (0.8)
6:00	4.8 (6.7)	3.7 (1.1)	3.7 (0.7)	3.7 (1.0)	4.3 (4.8)	4.1 (3.8)
6:15	4.0 (0.9)	4.0 (1.0)	4.0 (1.3)	3.8 (0.7)	3.7 (0.6)	3.9 (0.9)
6:30	4.5 (1.7)	4.3 (1.1)	4.3 (0.9)	4.3 (1.2)	3.7 (0.6)	4.2 (1.2)
6:45	4.2 (1.5)	4.3 (1.1)	4.0 (1.3)	3.8 (0.9)	3.6 (0.6)	4.0 (1.1)
7:00	4.5 (1.7)	4.3 (1.3)	3.9 (1.0)	4.0 (1.1)	3.9 (1.3)	4.1 (1.3)
7:15	4.4 (1.5)	4.6 (1.8)	4.5 (1.1)	4.4 (1.4)	4.0 (1.4)	4.4 (1.4)
7:30	4.2 (2.0)	4.8 (2.2)	4.1 (1.2)	3.8 (1.2)	3.7 (0.9)	4.1 (1.6)
7:45	3.5 (0.8)	3.6 (1.0)	3.5 (0.8)	3.3 (0.5)	3.4 (1.0)	3.4 (0.8)
8:00	4.2 (3.9)	3.5 (0.8)	3.5 (0.6)	3.6 (1.5)	3.6 (0.9)	3.6 (1.9)
8:15	3.3 (0.6)	3.9 (4.2)	4.2 (5.0)	3.6 (2.7)	3.3 (0.7)	3.6 (3.1)
8:30	3.3 (0.5)	4.4 (4.6)	3.2 (0.4)	3.5 (1.0)	3.4 (0.7)	3.6 (2.2)
8:45	3.2 (0.3)	3.1 (0.3)	3.2 (0.3)	3.3 (0.4)	3.4 (0.7)	3.3 (0.4)
9:00	3.3 (0.3)	3.4 (0.7)	3.3 (0.4)	3.5 (0.8)	3.8 (1.4)	3.4 (0.8)
9:15	3.3 (0.5)	3.4 (0.5)	4.0 (2.3)	3.7 (1.0)	3.3 (0.5)	3.5 (1.2)
9:30 AM	3.5 (0.6)	3.2 (0.4)	3.3 (0.8)	3.3 (0.3)	3.5 (0.6)	3.4 (0.6)
Average	4.2 (2.8)	4.1 (1.7)	3.9 (1.5)	3.8 (1.2)	3.7 (1.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-5. Average Travel Times by Time-of-Day and Day-of-Week for Link 105.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	4.8 (1.2)	4.2 (0.5)	4.3 (0.5)	4.0 (0.5)	4.1 (0.6)	4.3 (0.7)
6:00	4.6 (0.7)	4.5 (0.6)	4.5 (0.5)	4.5 (0.5)	4.8 (4.2)	4.6 (1.8)
6:15	5.3 (1.2)	5.4 (1.3)	5.0 (0.8)	5.0 (0.7)	5.0 (1.2)	5.1 (1.0)
6:30	6.4 (1.8)	6.4 (1.1)	6.6 (2.1)	6.0 (1.1)	5.8 (1.7)	6.2 (1.6)
6:45	6.4 (1.7)	6.4 (1.4)	6.2 (1.2)	6.1 (1.0)	5.6 (1.2)	6.1 (1.4)
7:00	6.7 (1.9)	6.5 (1.5)	6.4 (1.3)	6.3 (1.4)	6.0 (2.8)	6.4 (1.9)
7:15	7.8 (2.4)	8.1 (2.4)	7.7 (1.8)	7.6 (2.3)	6.8 (2.2)	7.6 (2.3)
7:30	8.3 (2.8)	8.9 (2.4)	8.9 (3.0)	8.6 (2.3)	7.0 (2.7)	8.2 (2.7)
7:45	7.3 (3.1)	6.7 (1.8)	8.0 (3.1)	7.6 (2.6)	5.9 (2.6)	7.0 (2.8)
8:00	6.0 (2.9)	5.1 (1.4)	6.7 (3.0)	5.9 (1.8)	5.3 (1.8)	5.7 (2.2)
8:15	5.1 (1.7)	4.8 (1.2)	5.4 (1.8)	4.8 (1.2)	4.6 (1.1)	4.9 (1.5)
8:30	4.8 (1.5)	4.6 (0.7)	5.0 (1.4)	4.6 (1.2)	4.4 (0.7)	4.7 (1.2)
8:45	4.5 (1.0)	5.2 (3.2)	4.4 (0.9)	4.5 (1.2)	4.1 (0.4)	4.4 (1.4)
9:00	4.1 (0.3)	4.3 (0.8)	5.0 (2.3)	4.2 (0.5)	4.3 (1.0)	4.4 (1.3)
9:15	4.2 (0.5)	4.9 (2.9)	4.9 (3.3)	4.0 (0.8)	4.0 (0.4)	4.5 (2.2)
9:30 AM	4.1 (0.6)	4.3 (0.3)	4.5 (1.4)	4.2 (0.2)	4.8 (2.4)	4.4 (1.4)
Average	6.1 (2.2)	5.9 (1.9)	5.9 (2.0)	5.8 (1.8)	5.5 (2.3)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-6. Average Travel Times by Time-of-Day and Day-of-Week for Link 106.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.3 (1.6)	2.9 (0.5)	2.8 (0.6)	2.9 (0.7)	2.8 (0.6)	2.9 (0.9)
6:00	2.9 (0.7)	3.0 (1.0)	2.9 (0.6)	2.9 (0.9)	2.8 (0.4)	2.9 (0.7)
6:15	3.2 (1.3)	3.2 (1.9)	3.1 (0.7)	3.1 (0.7)	3.0 (0.6)	3.1 (1.1)
6:30	3.4 (0.7)	3.5 (1.3)	3.6 (2.2)	3.4 (0.8)	3.2 (0.6)	3.4 (1.3)
6:45	3.9 (1.0)	3.4 (1.0)	3.7 (0.7)	3.7 (1.0)	3.4 (0.7)	3.6 (0.9)
7:00	4.2 (1.4)	3.8 (1.3)	4.0 (1.0)	4.1 (1.6)	3.5 (0.9)	3.9 (1.3)
7:15	4.7 (1.2)	4.9 (2.5)	4.6 (1.3)	4.4 (1.2)	4.1 (1.3)	4.5 (1.6)
7:30	5.5 (1.8)	5.4 (1.6)	5.1 (1.6)	5.6 (1.6)	5.0 (1.5)	5.3 (1.6)
7:45	5.2 (1.6)	6.1 (1.6)	6.8 (4.5)	5.8 (1.3)	5.6 (2.3)	5.8 (2.5)
8:00	4.8 (1.5)	4.7 (1.2)	5.2 (1.6)	5.0 (1.4)	4.6 (2.0)	4.8 (1.6)
8:15	3.8 (1.4)	4.2 (1.3)	5.0 (2.1)	4.2 (1.4)	4.3 (2.6)	4.3 (1.8)
8:30	3.8 (1.4)	3.6 (1.5)	4.4 (1.7)	3.5 (1.3)	3.7 (1.8)	3.8 (1.6)
8:45	3.3 (0.6)	4.0 (3.9)	3.0 (0.6)	2.8 (0.5)	3.0 (1.4)	3.1 (1.4)
9:00	2.6 (0.4)	2.9 (0.7)	2.9 (0.7)	2.9 (1.0)	2.9 (1.2)	2.8 (0.8)
9:15	2.8 (0.4)	3.1 (1.0)	2.9 (0.4)	2.7 (0.4)	2.9 (0.4)	2.9 (0.7)
9:30 AM	2.9 (0.5)	2.9 (0.8)	2.9 (0.5)	2.7 (0.3)	2.8 (0.5)	2.8 (0.5)
Average	3.9 (1.5)	3.8 (1.7)	3.9 (1.8)	3.8 (1.4)	3.7 (1.5)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-7. Average Travel Times by Time-of-Day and Day-of-Week for Link 205.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	5.0 (1.2)	4.8 (1.1)	4.8 (1.4)	5.0 (1.5)	4.8 (1.2)	4.9 (1.3)
6:00	4.8 (1.0)	5.4 (2.0)	4.7 (0.8)	4.6 (0.9)	4.7 (1.0)	4.8 (1.2)
6:15	5.0 (1.6)	4.8 (1.3)	4.8 (0.8)	4.6 (0.6)	4.7 (0.5)	4.8 (1.0)
6:30	5.6 (1.8)	5.9 (2.7)	5.4 (1.6)	5.4 (1.4)	5.8 (1.8)	5.6 (1.9)
6:45	5.0 (0.8)	5.1 (0.8)	5.2 (1.2)	5.0 (1.0)	5.0 (0.8)	5.1 (0.9)
7:00	5.0 (0.5)	5.0 (0.7)	5.1 (0.7)	4.7 (0.5)	4.8 (0.4)	5.0 (0.6)
7:15	5.0 (0.5)	5.3 (2.7)	4.9 (0.8)	5.0 (0.7)	4.9 (0.7)	5.0 (1.4)
7:30	5.1 (0.8)	5.1 (0.8)	5.1 (0.7)	5.0 (0.6)	4.9 (0.4)	5.0 (0.7)
7:45	5.0 (1.2)	4.9 (1.3)	5.0 (1.9)	5.2 (2.6)	4.5 (0.4)	4.9 (1.7)
8:00	4.6 (0.8)	4.7 (1.0)	4.8 (1.3)	4.5 (0.8)	4.3 (0.6)	4.6 (0.9)
8:15	4.6 (0.6)	5.0 (2.8)	4.9 (1.4)	4.5 (1.1)	4.3 (0.6)	4.7 (1.6)
8:30	4.4 (0.1)	5.2 (1.8)	4.3 (0.2)	4.2 (0.4)	4.9 (1.1)	4.7 (1.2)
8:45	4.4 (-)	5.0 (0.9)	4.8 (0.5)	4.8 (0.7)	4.6 (1.1)	4.7 (0.5)
9:00	- (-)	- (-)	4.9 (0.6)	5.0 (-)	5.2 (-)	4.9 (0.5)
9:15	4.3 (-)	4.2 (0.2)	5.2 (-)	4.3 (-)	-	4.4 (0.4)
9:30 AM	- (-)	4.8 (0.4)	4.6 (0.3)	4.4 (0.1)	4.5 (0.6)	4.6 (0.5)
Average	5.0 (1.0)	5.1 (1.7)	5.0 (1.2)	4.9 (1.2)	4.8 (0.9)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-8. Average Travel Times by Time-of-Day and Day-of-Week for Link 206.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.9 (1.4)	3.9 (2.0)	3.7 (1.1)	3.8 (1.0)	4.2 (1.3)	3.9 (1.4)
6:00	3.9 (1.3)	3.9 (1.0)	3.8 (0.9)	4.0 (1.0)	3.8 (1.3)	3.9 (1.1)
6:15	4.0 (1.8)	3.4 (1.2)	3.3 (1.1)	3.0 (0.3)	3.5 (1.2)	3.4 (1.2)
6:30	3.5 (1.5)	3.3 (1.3)	3.1 (0.8)	3.1 (0.5)	3.1 (0.7)	3.3 (1.1)
6:45	3.6 (0.8)	3.5 (0.9)	3.6 (0.9)	3.9 (1.2)	3.7 (0.9)	3.6 (1.0)
7:00	3.3 (0.5)	3.4 (0.8)	3.3 (0.8)	3.4 (0.9)	3.2 (0.5)	3.3 (0.7)
7:15	3.3 (0.5)	3.5 (1.3)	3.4 (0.8)	3.5 (0.8)	3.3 (0.4)	3.4 (0.8)
7:30	3.3 (0.6)	3.5 (0.9)	3.4 (0.7)	3.5 (0.8)	3.3 (0.4)	3.4 (0.7)
7:45	3.3 (0.5)	3.4 (0.8)	3.2 (0.6)	3.6 (3.3)	3.2 (0.5)	3.3 (1.6)
8:00	3.3 (0.8)	3.1 (0.5)	3.1 (0.4)	3.8 (2.6)	3.1 (0.6)	3.3 (1.3)
8:15	3.5 (1.0)	3.2 (0.7)	3.4 (0.8)	3.3 (0.7)	3.9 (3.8)	3.5 (1.9)
8:30	4.6 (2.5)	3.5 (0.4)	4.5 (2.1)	4.0 (1.3)	3.5 (0.4)	4.0 (1.4)
8:45	2.5 (-)	2.7 (0.2)	2.9 (0.2)	2.9 (0.1)	5.2 (-)	3.0 (0.7)
9:00	- (-)	2.4 (-)	3.0 (0.5)	2.3 (-)	- (-)	2.8 (0.5)
9:15	3.2 (-)	- (-)	2.6 (-)	2.9 (-)	2.5 (-)	2.8 (0.3)
9:30 AM	- (-)	2.8 (0.3)	2.9 (0.5)	3.1 (0.6)	2.9 (0.4)	2.9 (0.4)
Average	3.5 (1.0)	3.5 (1.0)	3.4 (0.8)	3.6 (1.5)	3.4 (1.2)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-9. Average Travel Times by Time-of-Day and Day-of-Week for Link 301.

	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.7 (0.5)	3.9 (1.1)	3.5 (0.7)	3.7 (0.8)	3.3 (0.3)	3.7 (0.7)
6:00	3.5 (0.6)	3.4 (0.5)	3.5 (0.6)	3.4 (0.6)	3.3 (0.5)	3.4 (0.6)
6:15	3.5 (0.4)	3.6 (0.5)	3.6 (0.4)	3.6 (0.5)	3.7 (1.0)	3.6 (0.6)
6:30	3.7 (0.5)	3.5 (0.5)	3.5 (0.5)	3.5 (0.5)	3.4 (0.4)	3.5 (0.5)
6:45	3.6 (0.6)	3.6 (1.0)	3.4 (0.6)	3.4 (0.6)	3.5 (0.5)	3.5 (0.7)
7:00	3.7 (1.1)	3.5 (0.5)	3.5 (0.5)	3.5 (0.5)	3.3 (0.5)	3.5 (0.7)
7:15	3.8 (1.2)	3.9 (1.4)	3.6 (0.8)	3.5 (0.8)	3.5 (0.7)	3.7 (1.0)
7:30	4.2 (1.4)	4.2 (1.2)	4.0 (1.1)	4.3 (1.3)	3.8 (0.8)	4.1 (1.2)
7:45	3.9 (0.9)	3.9 (0.9)	3.6 (0.6)	3.6 (0.7)	4.0 (1.4)	3.8 (0.9)
8:00	3.8 (1.0)	4.0 (1.1)	3.8 (1.0)	3.8 (0.9)	3.7 (1.1)	3.8 (1.0)
8:15	3.8 (1.1)	3.8 (1.5)	4.4 (2.1)	3.6 (0.6)	4.4 (2.0)	4.0 (1.6)
8:30	3.7 (1.2)	3.4 (0.4)	3.4 (0.4)	3.4 (0.7)	3.6 (0.6)	3.5 (0.6)
8:45	5.2 (1.3)	4.1 (1.4)	3.0 (-)	3.7 (-)	3.2 (-)	4.0 (1.2)
9:00	3.3 (0.1)	3.4 (-)	4.4 (0.5)	- (-)	6.5 (0.6)	4.4 (1.4)
9:15	3.5 (-)	- (-)	- (-)	3.2 (-)	- (-)	3.3 (0.2)
9:30 AM	- (-)	- (-)	- (-)	3.6 (0.8)	3.0 (0.4)	3.4 (0.7)
Average	3.7 (0.9)	3.7 (0.9)	3.6 (0.8)	3.6 (0.7)	3.6 (0.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-10. Average Travel Times by Time-of-Day and Day-of-Week for Link 302.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average
5:45 AM	6.1 (0.3)	6.0 (0.4)	5.5 (1.0)	5.5 (0.2)	5.8 (0.7)	5.8 (0.6)
6:00	6.2 (0.9)	6.4 (0.6)	5.8 (0.8)	6.2 (0.7)	6.2 (0.7)	6.2 (0.8)
6:15	6.1 (0.6)	7.1 (7.5)	6.1 (0.5)	6.0 (0.7)	6.0 (0.5)	6.3 (3.6)
6:30	6.5 (0.8)	6.6 (0.7)	6.7 (1.0)	6.6 (0.8)	6.4 (0.7)	6.6 (0.8)
6:45	6.6 (0.6)	6.6 (0.5)	6.5 (0.5)	6.5 (0.6)	6.4 (0.7)	6.5 (0.6)
7:00	6.8 (0.5)	6.7 (0.6)	6.9 (0.8)	6.5 (0.6)	6.6 (0.6)	6.7 (0.7)
7:15	6.8 (0.8)	6.6 (0.7)	6.8 (1.0)	6.6 (0.6)	6.5 (0.6)	6.7 (0.8)
7:30	7.0 (0.8)	6.6 (1.2)	7.6 (4.0)	6.5 (0.9)	6.2 (0.7)	6.8 (2.0)
7:45	6.7 (0.8)	7.4 (1.8)	6.6 (0.8)	6.7 (0.7)	6.4 (0.6)	6.7 (1.0)
8:00	6.4 (0.6)	6.7 (1.3)	6.5 (0.5)	6.5 (0.9)	6.3 (0.5)	6.5 (0.9)
8:15	6.3 (0.6)	6.5 (0.6)	6.5 (0.8)	6.5 (0.4)	6.3 (1.0)	6.4 (0.7)
8:30	6.4 (0.5)	6.6 (0.8)	6.4 (0.3)	6.7 (0.7)	6.1 (0.9)	6.4 (0.6)
8:45	5.8 (1.2)	6.7 (1.1)	5.6 (-)	5.8 (1.3)	5.9 (1.3)	6.1 (1.0)
9:00	7.0 (-)	6.8 (-)	5.2 (-)	- (-)	7.3 (-)	6.6 (0.9)
9:15	6.9 (0.1)	- (-)	7.1 (-)	7.3 (-)	6.4 (-)	6.9 (0.4)
9:30 AM	- (-)	- (-)	- (-)	6.8 (-)	7.3 (-)	7.1 (0.3)
Average	6.6 (0.7)	6.7 (2.8)	6.6 (1.4)	6.5 (0.7)	6.4 (0.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-11. Average Travel Times by Time-of-Day and Day-of-Week for Link 303.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	2.6 (0.2)	3.5 (1.3)	- (-)	2.6 (-)	3.2 (0.5)	3.0 (0.8)
6:00	2.6 (0.7)	2.6 (0.7)	2.9 (0.8)	3.4 (1.0)	3.0 (0.7)	2.9 (0.8)
6:15	2.6 (0.8)	2.7 (1.1)	2.6 (0.4)	2.5 (0.4)	2.4 (0.6)	2.6 (0.8)
6:30	2.6 (0.5)	2.5 (0.4)	2.7 (0.5)	2.5 (0.4)	2.5 (0.3)	2.6 (0.4)
6:45	2.6 (0.8)	2.5 (0.4)	2.5 (0.5)	2.5 (0.5)	2.4 (0.3)	2.5 (0.5)
7:00	2.6 (0.7)	2.5 (0.5)	2.6 (0.5)	2.6 (0.9)	2.5 (0.5)	2.6 (0.7)
7:15	2.8 (0.6)	2.6 (0.4)	2.6 (0.7)	2.7 (0.7)	2.6 (0.8)	2.6 (0.6)
7:30	2.9 (0.6)	2.8 (0.6)	2.8 (0.9)	2.8 (0.7)	2.7 (0.6)	2.8 (0.7)
7:45	2.8 (0.7)	2.7 (0.8)	2.7 (0.6)	2.7 (0.6)	2.6 (0.6)	2.7 (0.7)
8:00	3.1 (3.5)	2.6 (0.6)	2.5 (0.5)	2.4 (0.4)	2.4 (0.4)	2.6 (1.5)
8:15	2.6 (0.6)	2.8 (0.8)	2.6 (1.0)	2.4 (0.6)	2.6 (1.3)	2.6 (0.9)
8:30	2.4 (0.5)	2.4 (0.7)	2.3 (0.5)	2.1 (0.3)	2.8 (1.4)	2.4 (0.8)
8:45	5.3 (5.7)	2.4 (0.5)	2.2 (0.2)	2.4 (0.6)	2.6 (0.7)	2.9 (2.2)
9:00	3.2 (1.8)	2.1 (0.2)	3.0 (-)	- (-)	- (-)	2.7 (1.2)
9:15	2.1 (0.1)	- (-)	- (-)	2.8 (-)	- (-)	2.3 (0.4)
9:30 AM	- (-)	- (-)	- (-)	- (-)	2.5 (-)	2.5 (-)
Average	2.7 (1.2)	2.6 (0.6)	2.6 (0.6)	2.6 (0.7)	2.5 (0.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-12. Average Travel Times by Time-of-Day and Day-of-Week for Link 304.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average
5:45 AM	5.2 (0.4)	4.3 (-)	- (-)	4.2 (0.8)	- (-)	4.6 (0.7)
6:00	4.5 (0.9)	4.1 (0.7)	4.3 (0.8)	4.0 (0.6)	4.2 (0.4)	4.3 (0.8)
6:15	4.7 (0.5)	4.8 (0.8)	4.6 (0.5)	4.7 (0.5)	4.8 (1.8)	4.7 (0.9)
6:30	4.4 (0.6)	4.5 (0.6)	4.5 (0.5)	4.6 (0.7)	4.4 (0.6)	4.5 (0.6)
6:45	4.7 (0.8)	4.8 (0.9)	4.8 (0.8)	4.7 (0.8)	4.6 (0.8)	4.7 (0.8)
7:00	4.8 (0.8)	4.8 (1.6)	4.6 (0.8)	4.6 (0.7)	4.6 (0.8)	4.7 (1.0)
7:15	5.0 (0.7)	4.9 (1.0)	4.9 (1.0)	5.2 (1.6)	4.8 (0.7)	5.0 (1.0)
7:30	4.7 (0.6)	4.7 (0.6)	4.7 (0.8)	4.7 (0.6)	4.6 (0.7)	4.7 (0.6)
7:45	4.7 (0.6)	4.5 (0.5)	4.7 (0.6)	4.5 (0.6)	4.8 (1.7)	4.6 (0.9)
8:00	4.8 (0.6)	5.0 (1.2)	4.8 (0.6)	4.8 (0.6)	4.7 (0.6)	4.8 (0.8)
8:15	4.9 (0.6)	4.8 (0.7)	5.0 (0.9)	4.8 (0.4)	4.9 (0.5)	4.8 (0.7)
8:30	4.9 (0.7)	5.0 (0.7)	4.7 (0.5)	5.2 (0.4)	4.6 (0.4)	4.9 (0.6)
8:45	4.9 (0.4)	4.7 (0.5)	5.0 (0.1)	5.0 (0.1)	4.4 (0.8)	4.7 (0.5)
9:00	5.2 (2.2)	5.3 (0.3)	3.9 (-)	4.5 (0.4)	- (-)	4.9 (1.2)
9:15	5.1 (0.2)	5.4 (-)	- (-)	4.4 (-)	- (-)	5.0 (0.4)
9:30 AM	5.3 (-)	- (-)	- (-)	5.0 (-)	- (-)	5.2 (0.2)
Average	4.8 (0.7)	4.8 (1.0)	4.7 (0.8)	4.8 (0.9)	4.7 (0.9)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-13. Average Travel Times by Time-of-Day and Day-of-Week for Link 305.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	2.3 (0.4)	2.3 (-)	- (-)	- (-)	2.4 (-)	2.3 (0.2)
6:00	2.7 (0.6)	2.7 (0.6)	3.0 (0.8)	2.6 (1.1)	3.4 (1.0)	2.8 (0.8)
6:15	2.4 (0.5)	2.5 (0.6)	2.7 (0.5)	2.8 (1.1)	2.5 (0.6)	2.5 (0.7)
6:30	2.4 (0.4)	2.5 (0.6)	2.6 (1.3)	2.3 (0.5)	2.4 (0.6)	2.4 (0.7)
6:45	2.5 (0.5)	3.0 (1.7)	2.7 (0.9)	2.5 (0.5)	2.5 (0.5)	2.7 (1.0)
7:00	2.7 (0.6)	2.7 (0.7)	2.9 (0.7)	2.8 (0.8)	2.7 (0.9)	2.8 (0.7)
7:15	2.9 (1.2)	2.7 (0.9)	3.0 (2.1)	2.8 (1.0)	2.7 (0.7)	2.8 (1.2)
7:30	2.9 (1.3)	2.9 (1.2)	3.0 (1.4)	2.9 (1.0)	2.7 (0.8)	2.9 (1.2)
7:45	2.9 (1.1)	3.2 (1.0)	3.2 (1.5)	3.4 (1.7)	2.8 (0.9)	3.1 (1.3)
8:00	2.6 (0.6)	2.7 (1.0)	2.7 (0.6)	2.8 (1.0)	2.6 (0.7)	2.7 (0.8)
8:15	2.9 (1.0)	2.9 (0.9)	2.7 (0.5)	2.7 (0.6)	2.9 (0.9)	2.8 (0.8)
8:30	3.0 (0.8)	2.7 (0.5)	2.8 (0.6)	2.7 (0.5)	3.0 (1.3)	2.8 (0.8)
8:45	2.4 (0.4)	2.4 (0.2)	2.6 (0.5)	2.4 (0.2)	2.8 (0.9)	2.5 (0.5)
9:00	3.0 (-)	2.9 (1.0)	- (-)	3.1 (-)	2.6 (0.6)	2.9 (0.7)
9:15	2.4 (0.1)	2.8 (-)	3.2 (-)	2.3 (-)	2.3 (-)	2.5 (0.3)
9:30 AM	2.4 (-)	- (-)	- (-)	2.5 (-)	- (-)	2.5 (0.1)
Average	2.7 (1.0)	2.8 (1.0)	2.9 (1.2)	2.8 (1.0)	2.7 (0.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-14. Average Travel Times by Time-of-Day and Day-of-Week for Link 401.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	2.3 (0.3)	2.4 (0.4)	2.3 (0.4)	2.4 (0.4)	2.4 (0.6)	2.3 (0.4)
6:00	2.7 (0.6)	2.6 (0.6)	2.5 (0.5)	2.6 (0.5)	2.5 (0.6)	2.6 (0.6)
6:15	3.0 (2.0)	2.8 (1.1)	2.7 (0.7)	2.5 (0.6)	2.5 (0.5)	2.7 (1.1)
6:30	3.4 (1.2)	2.8 (0.9)	2.8 (0.8)	2.5 (0.6)	2.6 (0.7)	2.8 (0.9)
6:45	3.4 (1.2)	3.0 (1.0)	3.0 (1.1)	3.0 (1.0)	2.6 (0.6)	3.0 (1.0)
7:00	3.7 (1.4)	3.1 (1.4)	3.0 (0.9)	2.9 (0.8)	2.7 (0.8)	3.0 (1.1)
7:15	3.5 (1.2)	3.5 (2.0)	2.7 (0.6)	2.8 (0.8)	2.4 (0.5)	3.0 (1.2)
7:30	3.6 (1.4)	3.0 (1.0)	2.8 (0.8)	2.8 (0.7)	2.5 (0.5)	2.9 (1.0)
7:45	3.1 (1.9)	3.0 (2.1)	2.7 (1.1)	2.5 (1.3)	2.4 (1.4)	2.8 (1.6)
8:00	2.6 (1.0)	2.4 (0.6)	2.3 (1.0)	2.5 (1.9)	2.3 (1.1)	2.4 (1.1)
8:15	2.3 (0.5)	2.2 (0.3)	2.3 (0.3)	3.2 (3.7)	2.2 (0.3)	2.5 (1.9)
8:30	2.2 (0.4)	2.0 (0.2)	2.2 (0.3)	2.1 (0.2)	2.2 (0.2)	2.2 (0.3)
8:45	2.2 (0.4)	2.5 (0.8)	2.1 (0.2)	4.7 (7.3)	2.2 (0.2)	2.7 (2.9)
9:00	2.0 (0.1)	2.1 (0.2)	2.2 (0.2)	3.0 (1.7)	2.1 (0.3)	2.3 (0.8)
9:15	2.0 (0.1)	2.3 (0.5)	2.1 (0.2)	3.0 (2.5)	2.2 (0.2)	2.4 (1.3)
9:30 AM	1.8 (0.3)	2.2 (0.2)	2.0 (-)	2.1 (0.4)	2.1 (-)	2.0 (0.3)
Average	3.1 (1.4)	2.8 (1.2)	2.7 (0.8)	2.7 (1.3)	2.5 (0.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-15. Average Travel Times by Time-of-Day and Day-of-Week for Link 402.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.6 (1.6)	3.0 (0.5)	3.0 (0.3)	3.0 (0.5)	3.0 (0.3)	3.1 (0.8)
6:00	4.0 (0.9)	3.8 (1.4)	3.6 (0.6)	3.6 (0.7)	3.1 (0.6)	3.6 (0.9)
6:15	4.4 (0.9)	4.1 (1.8)	4.1 (2.2)	3.9 (0.7)	3.8 (1.4)	4.0 (1.5)
6:30	4.7 (1.3)	4.5 (1.7)	4.5 (2.4)	4.2 (1.3)	4.2 (3.1)	4.4 (2.1)
6:45	4.5 (1.2)	4.4 (1.1)	4.1 (1.0)	4.2 (1.2)	4.0 (0.9)	4.2 (1.1)
7:00	5.1 (1.3)	4.9 (1.9)	4.7 (1.3)	4.2 (0.9)	4.1 (1.0)	4.6 (1.4)
7:15	4.8 (1.2)	4.3 (1.1)	4.6 (1.1)	4.0 (1.0)	3.7 (0.9)	4.3 (1.1)
7:30	4.2 (1.1)	4.3 (2.2)	4.0 (1.2)	3.6 (0.6)	3.6 (1.1)	3.9 (1.4)
7:45	3.6 (1.0)	3.9 (2.6)	4.2 (3.2)	3.5 (1.2)	3.3 (0.7)	3.7 (2.0)
8:00	3.6 (2.0)	3.2 (1.2)	3.0 (0.8)	3.0 (0.5)	3.1 (1.2)	3.2 (1.3)
8:15	3.1 (1.2)	2.8 (0.4)	2.8 (0.4)	3.8 (5.2)	2.8 (0.5)	3.1 (2.6)
8:30	3.0 (0.9)	2.8 (0.3)	2.8 (0.2)	3.5 (2.0)	2.8 (0.4)	3.0 (1.1)
8:45	2.6 (0.4)	2.8 (0.4)	2.8 (0.4)	2.8 (0.1)	2.8 (0.5)	2.7 (0.4)
9:00	3.0 (0.3)	5.2 (5.6)	2.9 (0.6)	3.0 (1.0)	2.6 (0.2)	3.1 (2.0)
9:15	2.6 (0.1)	2.5 (0.4)	2.6 (0.4)	2.7 (0.4)	2.8 (0.2)	2.6 (0.3)
9:30 AM	2.5 (0.3)	2.7 (0.1)	3.4 (1.1)	3.4 (2.1)	2.7 (0.1)	3.0 (1.5)
Average	4.3 (1.3)	4.1 (1.7)	4.1 (1.8)	3.8 (1.4)	3.7 (1.5)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-16. Average Travel Times by Time-of-Day and Day-of-Week for Link 403.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average
5:45 AM	3.3 (0.9)	3.0 (0.3)	3.0 (0.4)	3.0 (0.5)	3.0 (0.4)	3.1 (0.5)
6:00	3.2 (0.4)	3.3 (0.8)	3.2 (0.5)	3.1 (0.5)	3.0 (0.6)	3.2 (0.6)
6:15	3.3 (0.6)	3.3 (0.8)	3.2 (0.5)	3.2 (0.7)	3.1 (0.5)	3.2 (0.6)
6:30	3.3 (0.6)	3.3 (0.8)	3.2 (0.4)	3.2 (0.8)	3.1 (0.8)	3.2 (0.7)
6:45	3.3 (0.8)	3.3 (0.6)	3.3 (0.6)	3.3 (1.0)	3.1 (0.4)	3.3 (0.7)
7:00	3.4 (0.8)	3.3 (0.6)	3.4 (0.5)	3.5 (1.3)	3.2 (0.6)	3.4 (0.9)
7:15	3.4 (0.6)	3.3 (0.6)	3.3 (0.6)	3.8 (2.5)	3.2 (0.6)	3.4 (1.3)
7:30	3.0 (0.4)	3.2 (0.5)	3.0 (0.4)	3.5 (2.1)	2.9 (0.4)	3.1 (1.1)
7:45	2.9 (0.4)	2.9 (0.4)	2.9 (0.4)	2.9 (0.4)	2.8 (0.4)	2.9 (0.4)
8:00	2.9 (0.6)	3.0 (1.1)	3.0 (0.6)	2.8 (0.4)	2.8 (0.4)	2.9 (0.7)
8:15	3.0 (0.4)	2.8 (0.3)	2.9 (0.3)	2.8 (0.5)	2.8 (0.3)	2.8 (0.4)
8:30	2.7 (0.2)	2.7 (0.2)	2.9 (0.4)	2.8 (0.6)	2.8 (0.3)	2.8 (0.4)
8:45	2.7 (0.2)	2.8 (0.3)	2.9 (0.4)	2.7 (0.3)	2.8 (0.4)	2.8 (0.3)
9:00	3.0 (0.5)	2.8 (0.2)	2.8 (0.5)	2.8 (0.5)	3.2 (1.2)	3.0 (0.8)
9:15	2.9 (0.2)	3.1 (0.5)	2.6 (0.3)	2.8 (0.2)	2.7 (0.2)	2.8 (0.2)
9:30 AM	2.8 (-)	2.8 (0.1)	2.6 (0.4)	3.0 (0.6)	2.8 (0.1)	2.8 (0.4)
Average	3.2 (0.6)	3.2 (0.7)	3.2 (0.5)	3.3 (1.3)	3.1 (0.6)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-17. Average Travel Times by Time-of-Day and Day-of-Week for Link 404.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	5.0 (1.2)	4.5 (0.6)	4.7 (0.6)	4.7 (1.0)	4.3 (0.4)	4.6 (0.8)
6:00	5.2 (1.0)	5.1 (1.2)	5.0 (1.0)	5.5 (3.1)	5.1 (1.9)	5.2 (1.7)
6:15	6.7 (1.7)	6.8 (2.5)	6.9 (1.9)	6.3 (1.7)	6.3 (1.9)	6.6 (2.0)
6:30	6.8 (1.9)	6.8 (2.2)	6.5 (1.6)	7.0 (3.7)	6.0 (1.6)	6.6 (2.3)
6:45	6.8 (2.0)	6.5 (2.1)	6.2 (1.6)	6.4 (2.6)	5.8 (1.8)	6.3 (2.1)
7:00	7.2 (2.3)	7.1 (3.0)	6.7 (2.0)	6.8 (4.3)	6.2 (1.9)	6.8 (2.9)
7:15	8.0 (2.6)	7.5 (2.2)	7.1 (2.2)	7.1 (3.4)	6.5 (1.9)	7.3 (2.6)
7:30	7.6 (2.9)	7.7 (3.3)	6.9 (2.2)	7.2 (4.9)	5.9 (2.0)	7.0 (3.4)
7:45	6.0 (2.3)	6.0 (2.2)	5.6 (1.8)	5.4 (3.7)	4.8 (1.1)	5.6 (2.5)
8:00	5.0 (1.8)	5.4 (2.4)	4.5 (1.2)	4.3 (0.7)	4.4 (1.1)	4.8 (1.6)
8:15	4.7 (1.2)	4.8 (1.8)	4.4 (0.9)	4.2 (0.7)	4.3 (0.5)	4.5 (1.2)
8:30	4.4 (1.1)	4.7 (1.3)	4.3 (0.6)	4.4 (2.0)	4.2 (0.6)	4.4 (1.3)
8:45	4.4 (0.7)	4.1 (0.4)	4.1 (0.5)	4.5 (1.8)	4.1 (0.3)	4.3 (1.0)
9:00	4.2 (0.3)	4.1 (0.4)	4.5 (1.2)	5.1 (2.6)	4.0 (0.2)	4.3 (1.3)
9:15	3.8 (0.3)	3.4 (0.7)	4.1 (0.2)	4.0 (0.5)	3.9 (0.4)	3.9 (0.4)
9:30 AM	4.0 (0.2)	4.1 (0.3)	4.2 (0.7)	4.0 (0.3)	4.2 (0.2)	4.1 (0.3)
Average	6.5 (2.2)	6.4 (2.5)	6.1 (1.9)	6.2 (3.3)	5.7 (1.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-18. Average Travel Times by Time-of-Day and Day-of-Week for Link 405.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	5.7 (1.7)	4.3 (0.4)	5.1 (3.3)	4.3 (0.4)	4.1 (0.6)	4.8 (1.8)
6:00	5.4 (1.1)	5.2 (0.8)	5.0 (0.7)	4.8 (0.8)	5.0 (1.1)	5.1 (0.9)
6:15	6.7 (1.8)	6.7 (1.5)	6.6 (1.2)	6.8 (4.4)	6.5 (1.5)	6.6 (2.3)
6:30	7.1 (1.3)	7.4 (2.3)	6.9 (1.2)	6.8 (1.2)	6.8 (1.4)	7.0 (1.6)
6:45	6.8 (1.4)	7.3 (1.7)	7.0 (1.2)	6.8 (2.6)	6.5 (1.2)	6.9 (1.7)
7:00	7.0 (1.3)	7.0 (1.2)	7.3 (1.2)	6.9 (1.2)	6.7 (1.9)	7.0 (1.4)
7:15	6.9 (1.4)	7.1 (1.5)	7.2 (1.4)	7.0 (2.9)	6.6 (1.4)	7.0 (1.8)
7:30	7.0 (1.4)	7.3 (1.6)	7.1 (1.1)	6.8 (1.1)	7.0 (1.7)	7.0 (1.4)
7:45	6.7 (2.4)	6.6 (1.7)	6.3 (1.5)	6.0 (1.2)	5.9 (1.6)	6.3 (1.7)
8:00	5.8 (1.3)	5.9 (3.2)	5.2 (1.5)	5.1 (1.5)	5.1 (1.9)	5.4 (2.0)
8:15	5.0 (1.3)	4.9 (1.2)	4.5 (1.1)	4.4 (1.3)	4.1 (0.7)	4.6 (1.2)
8:30	4.8 (1.6)	4.3 (0.9)	4.4 (1.0)	4.1 (0.8)	4.0 (1.0)	4.3 (1.2)
8:45	3.8 (0.8)	4.0 (0.8)	3.7 (0.5)	3.7 (0.7)	3.9 (0.6)	3.8 (0.7)
9:00	3.6 (0.4)	3.7 (0.8)	3.6 (0.8)	3.7 (0.6)	3.5 (0.4)	3.6 (0.6)
9:15	3.4 (0.4)	3.2 (0.4)	4.6 (1.6)	3.5 (0.8)	3.4 (0.4)	3.6 (0.9)
9:30 AM	3.8 (0.6)	3.2 (0.4)	3.6 (0.6)	3.3 (0.6)	4.7 (2.3)	3.7 (1.1)
Average	6.4 (1.7)	6.6 (2.0)	6.4 (1.6)	6.2 (2.2)	6.1 (1.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-19. Average Travel Times by Time-of-Day and Day-of-Week for Link 406.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
5:45 AM	3.3 (1.0)	2.7 (0.3)	2.7 (0.2)	2.5 (0.2)	2.6 (0.4)	2.8 (0.6)
6:00	3.0 (0.9)	2.7 (0.5)	2.7 (0.4)	2.6 (0.3)	2.7 (0.3)	2.7 (0.5)
6:15	3.2 (1.2)	3.3 (2.6)	2.8 (0.5)	2.8 (0.6)	2.8 (0.5)	3.0 (1.4)
6:30	3.1 (0.7)	3.1 (0.7)	3.1 (0.6)	3.0 (0.6)	3.1 (0.7)	3.1 (0.7)
6:45	3.5 (1.2)	3.5 (1.2)	3.7 (2.3)	3.4 (2.0)	3.4 (1.0)	3.5 (1.6)
7:00	4.0 (2.6)	4.0 (1.3)	3.9 (1.2)	3.9 (1.9)	3.6 (1.1)	3.9 (1.7)
7:15	5.0 (1.9)	5.5 (1.8)	5.7 (2.5)	5.3 (2.1)	5.0 (1.9)	5.3 (2.1)
7:30	5.9 (2.0)	7.1 (2.4)	6.4 (2.1)	6.0 (2.1)	5.6 (2.2)	6.2 (2.2)
7:45	6.5 (2.2)	7.6 (2.6)	7.4 (2.8)	7.1 (3.4)	6.7 (2.9)	7.1 (2.9)
8:00	5.5 (2.5)	5.5 (1.6)	5.6 (2.2)	5.1 (1.8)	4.8 (2.0)	5.3 (2.0)
8:15	4.5 (2.4)	4.4 (2.1)	4.4 (1.6)	4.2 (1.6)	3.8 (1.6)	4.2 (1.9)
8:30	3.6 (1.4)	3.8 (2.2)	3.4 (1.1)	3.4 (1.3)	3.7 (1.6)	3.6 (1.6)
8:45	4.1 (3.1)	3.4 (1.3)	3.5 (1.1)	3.1 (0.6)	3.4 (0.9)	3.6 (1.8)
9:00	3.3 (0.7)	3.5 (1.1)	3.5 (0.7)	3.5 (0.9)	3.2 (0.4)	3.4 (0.8)
9:15	3.0 (0.4)	3.3 (0.5)	3.4 (1.0)	3.8 (1.2)	3.6 (0.8)	3.5 (0.9)
9:30 AM	2.8 (0.8)	3.7 (0.5)	2.9 (0.7)	3.6 (0.1)	3.2 (0.5)	3.2 (0.6)
Average	4.2 (2.2)	4.5 (2.2)	4.5 (2.3)	4.3 (2.3)	4.0 (1.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-20. Average Travel Times by Time-of-Day and Day-of-Week for Link 151.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	3.1 (0.6)	2.7 (0.4)	3.1 (0.6)	2.9 (0.4)	3.0 (0.6)	3.0 (0.6)
15:15	3.0 (0.6)	3.0 (0.9)	3.0 (0.5)	3.0 (0.6)	3.2 (0.7)	3.0 (0.7)
15:30	3.3 (0.8)	3.3 (1.4)	3.2 (0.7)	3.2 (0.7)	3.2 (0.6)	3.2 (0.8)
15:45	3.2 (0.7)	3.2 (1.2)	3.3 (0.9)	3.4 (1.0)	4.2 (4.4)	3.4 (1.8)
16:00	3.3 (1.5)	3.3 (1.0)	3.3 (1.0)	3.3 (1.0)	3.6 (0.7)	3.4 (1.1)
16:15	3.9 (2.0)	3.6 (0.9)	3.4 (0.8)	3.7 (1.1)	3.9 (1.2)	3.7 (1.3)
16:30	3.7 (1.0)	3.7 (1.4)	3.8 (1.3)	3.6 (1.1)	3.5 (0.8)	3.7 (1.1)
16:45	3.7 (1.0)	4.2 (1.3)	4.2 (1.2)	3.9 (1.2)	3.8 (1.5)	4.0 (1.2)
17:00	3.9 (1.1)	4.0 (1.2)	4.0 (1.1)	4.2 (1.3)	3.8 (1.0)	4.0 (1.2)
17:15	4.7 (1.8)	4.5 (1.1)	4.8 (1.2)	4.6 (1.0)	4.4 (1.6)	4.6 (1.4)
17:30	4.4 (1.2)	4.4 (1.7)	4.6 (1.3)	4.5 (1.2)	3.9 (1.8)	4.4 (1.4)
17:45	3.6 (1.0)	4.0 (1.1)	4.0 (1.1)	3.9 (1.4)	3.0 (0.8)	3.8 (1.2)
18:00	3.2 (0.9)	3.0 (1.0)	3.6 (1.4)	3.5 (1.4)	2.9 (0.6)	3.2 (1.1)
18:15	2.9 (0.5)	2.8 (0.6)	3.3 (0.9)	3.1 (0.9)	2.8 (0.5)	3.0 (0.7)
18:30	2.8 (0.6)	2.9 (0.4)	2.8 (0.5)	2.6 (0.4)	2.9 (0.5)	2.8 (0.5)
18:45 PM	2.7 (0.5)	2.8 (0.4)	3.1 (1.2)	2.8 (0.5)	2.8 (0.5)	2.8 (0.7)
Average	3.6 (1.3)	3.6 (1.2)	3.6 (1.2)	3.7 (1.2)	3.6 (1.4)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-21. Average Travel Times by Time-of-Day and Day-of-Week for Link 152.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	4.3 (0.6)	4.3 (0.6)	4.3 (0.5)	5.3 (5.4)	4.9 (1.4)	4.6 (2.5)
15:15	6.0 (7.5)	4.9 (3.7)	4.6 (0.8)	4.8 (3.3)	4.7 (2.6)	5.0 (4.3)
15:30	4.6 (1.4)	4.4 (0.6)	5.5 (5.3)	4.6 (1.3)	4.8 (2.3)	4.7 (2.5)
15:45	5.1 (3.0)	4.6 (0.8)	4.6 (1.2)	5.2 (4.7)	4.6 (0.6)	4.9 (2.9)
16:00	4.9 (2.2)	4.7 (1.1)	5.0 (2.6)	4.6 (1.0)	5.6 (6.2)	4.9 (2.8)
16:15	4.6 (0.6)	4.9 (2.1)	5.5 (3.9)	4.8 (1.3)	4.7 (0.6)	4.9 (2.1)
16:30	4.8 (1.9)	5.2 (3.4)	4.8 (1.0)	4.7 (0.9)	4.7 (1.4)	4.8 (1.9)
16:45	4.6 (0.7)	4.7 (0.9)	5.6 (3.5)	4.6 (0.8)	5.0 (2.3)	4.9 (2.0)
17:00	5.1 (1.5)	5.2 (1.2)	5.0 (1.1)	4.8 (1.1)	4.8 (0.7)	5.0 (1.2)
17:15	5.2 (1.2)	5.1 (0.9)	5.1 (0.9)	5.2 (1.8)	5.0 (1.2)	5.2 (1.3)
17:30	5.4 (0.9)	5.1 (0.9)	4.8 (0.8)	5.0 (0.7)	4.9 (0.8)	5.1 (0.8)
17:45	5.4 (1.5)	5.1 (1.0)	4.8 (0.8)	5.0 (1.4)	4.7 (1.2)	5.0 (1.2)
18:00	5.8 (1.8)	4.6 (0.8)	4.8 (1.1)	4.9 (1.5)	4.2 (0.6)	4.9 (1.4)
18:15	5.1 (1.6)	4.4 (0.6)	4.8 (1.0)	4.5 (0.6)	4.3 (0.5)	4.6 (1.0)
18:30	4.9 (1.2)	4.5 (0.9)	4.5 (0.8)	4.6 (0.9)	4.2 (0.6)	4.6 (0.9)
18:45 PM	4.3 (0.6)	4.2 (0.6)	4.4 (0.8)	4.3 (0.6)	4.4 (0.6)	4.3 (0.6)
Average	5.0 (2.3)	4.8 (1.7)	4.9 (2.1)	4.8 (1.9)	4.8 (2.1)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-22. Average Travel Times by Time-of-Day and Day-of-Week for Link 153.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	3.8 (1.2)	3.8 (1.4)	3.7 (0.7)	3.7 (0.8)	3.8 (1.0)	3.7 (1.0)
15:15	3.7 (1.5)	3.8 (1.4)	4.3 (4.3)	4.4 (2.3)	4.3 (3.6)	4.1 (2.9)
15:30	3.4 (0.6)	4.2 (5.2)	3.5 (1.4)	3.6 (0.9)	3.6 (1.2)	3.7 (2.6)
15:45	4.1 (1.1)	3.9 (1.0)	4.2 (3.7)	4.1 (1.6)	4.0 (1.7)	4.1 (2.0)
16:00	3.5 (0.4)	3.8 (1.4)	3.8 (1.6)	3.5 (0.6)	4.0 (1.0)	3.7 (1.1)
16:15	3.7 (0.7)	3.8 (1.4)	4.2 (3.7)	3.9 (1.1)	4.4 (1.4)	4.0 (2.0)
16:30	4.6 (5.1)	3.7 (0.8)	3.7 (0.8)	4.1 (2.4)	4.1 (1.6)	4.0 (2.6)
16:45	3.6 (0.6)	3.6 (0.7)	3.9 (1.9)	3.8 (1.0)	3.7 (0.7)	3.7 (1.1)
17:00	4.1 (1.6)	4.5 (2.8)	4.2 (1.2)	4.4 (1.6)	4.7 (2.9)	4.3 (2.0)
17:15	4.7 (2.1)	4.5 (1.3)	4.5 (2.2)	4.9 (2.1)	4.9 (1.8)	4.7 (1.9)
17:30	5.3 (3.0)	5.3 (2.9)	5.0 (2.3)	5.3 (2.2)	4.4 (1.2)	5.1 (2.5)
17:45	5.5 (2.9)	5.2 (1.9)	5.0 (2.7)	5.0 (1.6)	4.2 (1.1)	5.0 (2.2)
18:00	4.8 (2.4)	4.2 (1.5)	4.6 (2.6)	4.3 (2.6)	3.9 (1.3)	4.4 (2.1)
18:15	4.7 (2.4)	4.0 (1.2)	4.0 (2.0)	3.7 (1.1)	3.3 (0.4)	4.0 (1.7)
18:30	4.0 (1.7)	3.6 (1.0)	3.6 (0.7)	3.5 (0.5)	3.6 (1.4)	3.7 (1.1)
18:45 PM	3.5 (0.9)	3.8 (1.4)	3.2 (0.4)	3.5 (0.7)	3.2 (0.5)	3.4 (0.9)
Average	4.2 (2.4)	4.1 (2.0)	4.1 (2.3)	4.2 (1.7)	4.1 (1.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-23. Average Travel Times by Time-of-Day and Day-of-Week for Link 154.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	5.1 (0.9)	8.5 (9.8)	4.7 (0.3)	8.9 (10.1)	18.4 (17.4)	10.1 (11.7)
15:15	4.6 (0.4)	4.7 (0.3)	4.3 (0.5)	4.3 (0.6)	4.7 (1.0)	4.6 (0.7)
15:30	5.8 (5.1)	4.7 (0.4)	4.6 (0.5)	5.0 (0.5)	5.7 (1.4)	5.2 (2.4)
15:45	4.4 (0.3)	5.3 (3.4)	4.6 (0.7)	5.4 (3.3)	4.7 (0.6)	4.9 (2.3)
16:00	6.8 (10.3)	4.9 (0.6)	5.3 (2.3)	4.9 (1.2)	5.6 (2.2)	5.4 (4.4)
16:15	5.4 (1.8)	4.9 (0.7)	5.1 (0.9)	5.3 (1.7)	6.8 (5.2)	5.3 (2.3)
16:30	5.6 (1.0)	5.3 (0.8)	6.1 (1.7)	6.2 (1.9)	7.6 (3.7)	6.3 (2.4)
16:45	6.7 (3.6)	6.7 (5.9)	6.5 (1.8)	7.7 (6.4)	7.1 (1.8)	6.9 (4.5)
17:00	8.1 (4.6)	8.9 (7.9)	8.7 (8.4)	8.3 (4.1)	10.1 (9.5)	8.7 (6.9)
17:15	8.0 (1.6)	7.8 (3.0)	7.1 (1.5)	8.1 (2.6)	8.0 (2.0)	7.8 (2.3)
17:30	7.8 (1.8)	7.7 (3.2)	7.8 (3.6)	8.7 (4.9)	7.8 (3.5)	8.0 (3.6)
17:45	8.3 (2.1)	7.4 (1.6)	7.6 (1.7)	7.5 (1.6)	8.1 (6.1)	7.7 (2.9)
18:00	7.2 (2.1)	6.6 (1.3)	8.4 (4.4)	6.7 (1.5)	6.5 (1.4)	7.0 (2.4)
18:15	6.8 (2.0)	6.8 (1.7)	6.3 (1.6)	6.6 (2.6)	5.6 (1.4)	6.5 (2.0)
18:30	5.2 (1.2)	5.2 (1.6)	5.3 (1.3)	5.8 (2.2)	5.0 (1.3)	5.3 (1.6)
18:45 PM	5.8 (1.9)	5.2 (1.3)	4.9 (1.2)	4.5 (0.6)	4.8 (0.7)	5.0 (1.3)
Average	6.8 (3.3)	6.5 (3.7)	6.5 (3.3)	6.9 (3.7)	7.1 (4.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-24. Average Travel Times by Time-of-Day and Day-of-Week for Link 155.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	3.6 (0.5)	4.3 (0.5)	3.9 (0.6)	3.6 (0.2)	4.5 (1.7)	3.8 (0.8)
15:15	4.4 (2.0)	3.6 (0.2)	3.6 (0.4)	3.6 (0.1)	5.4 (1.3)	4.2 (1.2)
15:30	3.6 (0.5)	4.1 (0.8)	3.8 (0.3)	4.3 (0.8)	5.8 (2.8)	4.6 (1.8)
15:45	3.6 (0.2)	4.3 (1.6)	3.9 (0.3)	4.4 (0.8)	6.8 (2.2)	4.8 (1.8)
16:00	3.6 (0.4)	4.1 (1.0)	4.1 (0.8)	4.0 (0.8)	6.9 (2.3)	4.5 (1.6)
16:15	4.7 (3.2)	4.6 (1.0)	4.3 (0.9)	4.8 (1.2)	8.1 (2.3)	4.9 (2.0)
16:30	4.8 (1.8)	4.8 (1.4)	5.3 (1.9)	6.3 (3.7)	7.6 (2.4)	5.8 (2.6)
16:45	5.1 (1.4)	5.2 (1.4)	5.7 (2.6)	6.2 (2.2)	8.1 (2.2)	6.1 (2.3)
17:00	7.2 (5.3)	5.2 (1.6)	5.9 (3.0)	5.4 (1.2)	8.2 (2.7)	6.3 (3.3)
17:15	7.0 (3.2)	6.5 (2.9)	6.5 (1.7)	7.8 (5.4)	10.8 (6.4)	7.5 (4.3)
17:30	6.4 (2.7)	6.1 (2.6)	6.0 (2.7)	6.0 (2.0)	7.8 (3.2)	6.4 (2.7)
17:45	7.4 (5.1)	5.7 (4.7)	5.0 (1.2)	5.6 (1.5)	8.0 (3.2)	6.3 (3.8)
18:00	5.7 (2.5)	5.3 (1.9)	6.0 (2.3)	6.2 (2.3)	7.2 (2.8)	5.9 (2.3)
18:15	5.3 (1.9)	5.6 (3.0)	6.2 (3.5)	6.2 (4.5)	7.3 (5.4)	6.0 (3.7)
18:30	5.0 (2.3)	4.7 (1.4)	5.0 (4.0)	4.7 (1.1)	5.2 (2.3)	4.9 (2.4)
18:45 PM	4.0 (0.7)	3.8 (0.9)	4.0 (0.8)	4.0 (0.8)	4.6 (0.8)	4.0 (0.8)
Average	5.6 (3.2)	5.2 (2.3)	5.3 (2.4)	5.7 (2.7)	7.5 (3.5)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-25. Average Travel Times by Time-of-Day and Day-of-Week for Link 156.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	3.7 (0.2)	3.5 (0.3)	3.7 (0.2)	3.4 (0.3)	3.6 (0.1)	3.6 (0.2)
15:15	3.6 (0.4)	3.7 (0.1)	3.6 (0.1)	3.6 (0.4)	3.6 (0.6)	3.6 (0.5)
15:30	3.7 (0.1)	3.5 (0.2)	4.4 (1.9)	3.5 (0.3)	7.2 (7.7)	4.9 (4.7)
15:45	3.2 (0.2)	3.5 (0.2)	3.7 (0.3)	3.7 (0.7)	4.3 (1.3)	3.7 (0.8)
16:00	3.8 (0.5)	3.5 (0.4)	5.2 (7.7)	4.1 (1.7)	4.4 (1.0)	4.2 (3.9)
16:15	4.0 (1.0)	3.8 (0.9)	4.0 (1.5)	4.2 (1.4)	4.1 (0.5)	4.0 (1.2)
16:30	3.9 (0.8)	4.0 (1.0)	4.0 (1.0)	3.9 (1.1)	4.5 (1.2)	4.0 (1.0)
16:45	3.8 (0.5)	4.1 (2.1)	3.9 (1.8)	3.9 (1.4)	4.8 (2.1)	4.1 (1.7)
17:00	4.6 (4.0)	3.7 (0.5)	4.1 (1.6)	5.1 (4.7)	4.6 (1.5)	4.4 (3.1)
17:15	3.7 (0.6)	3.7 (0.4)	4.4 (2.2)	3.8 (0.7)	3.8 (0.4)	3.9 (1.3)
17:30	3.9 (0.7)	3.9 (1.1)	4.2 (2.0)	3.8 (0.7)	4.3 (2.1)	4.0 (1.4)
17:45	4.2 (1.5)	3.9 (0.9)	4.0 (1.2)	3.7 (0.5)	4.2 (1.4)	4.0 (1.1)
18:00	4.0 (0.9)	3.8 (0.6)	4.5 (1.2)	3.8 (1.0)	4.0 (1.0)	4.0 (0.9)
18:15	4.1 (1.2)	3.7 (0.5)	3.7 (0.6)	3.7 (0.4)	3.8 (0.6)	3.8 (0.8)
18:30	3.7 (0.4)	3.7 (0.4)	4.1 (1.4)	3.9 (1.5)	4.1 (0.6)	3.9 (1.0)
18:45 PM	3.6 (0.3)	3.7 (0.4)	3.5 (0.2)	3.6 (0.3)	3.6 (0.5)	3.6 (0.4)
Average	4.0 (1.4)	3.8 (0.9)	4.1 (2.4)	3.9 (1.6)	4.3 (1.9)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-26. Average Travel Times by Time-of-Day and Day-of-Week for Link 251.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	3.1 (0.6)	2.7 (-)	6.1 (4.8)	2.7 (-)	3.1 (1.0)	3.9 (2.6)
15:15	2.8 (0.2)	2.8 (0.7)	3.2 (0.8)	2.6 (0.6)	2.4 (-)	2.9 (0.6)
15:30	3.4 (0.6)	3.1 (0.7)	3.0 (0.6)	3.4 (1.0)	2.9 (0.5)	3.1 (0.6)
15:45	3.1 (0.5)	3.2 (0.9)	3.4 (0.5)	3.0 (0.5)	2.9 (0.6)	3.1 (0.6)
16:00	4.1 (2.0)	3.8 (1.4)	3.7 (1.4)	3.6 (1.2)	4.0 (1.6)	3.8 (1.6)
16:15	3.7 (1.0)	3.5 (1.5)	3.6 (0.9)	3.6 (1.0)	3.9 (1.2)	3.7 (1.2)
16:30	3.6 (0.9)	3.3 (0.5)	3.6 (0.7)	3.5 (1.0)	3.5 (0.6)	3.5 (0.8)
16:45	3.4 (0.8)	3.4 (0.7)	3.5 (0.6)	3.9 (3.1)	3.4 (0.6)	3.6 (1.6)
17:00	3.4 (0.7)	3.4 (0.5)	3.4 (0.5)	3.2 (0.4)	3.3 (0.7)	3.3 (0.6)
17:15	3.5 (0.9)	3.5 (0.5)	3.5 (0.7)	3.5 (0.9)	3.3 (0.7)	3.5 (0.8)
17:30	3.2 (0.4)	3.3 (0.7)	3.3 (0.8)	3.5 (1.0)	3.2 (0.7)	3.4 (0.8)
17:45	3.6 (1.1)	3.4 (0.6)	3.2 (0.3)	3.2 (0.6)	3.2 (0.4)	3.3 (0.7)
18:00	3.3 (0.7)	3.1 (0.5)	3.2 (0.7)	3.2 (0.7)	3.0 (0.5)	3.2 (0.6)
18:15	2.8 (0.3)	3.2 (0.6)	3.0 (0.6)	2.9 (0.4)	2.9 (0.3)	3.0 (0.5)
18:30	3.2 (0.6)	3.1 (0.6)	2.9 (0.5)	2.8 (0.4)	2.9 (0.3)	3.0 (0.4)
18:45 PM	2.6 (0.1)	2.5 (0.7)	2.5 (0.1)	2.8 (0.5)	3.1 (0.6)	2.7 (0.5)
Average	3.5 (1.0)	3.4 (0.9)	3.5 (0.9)	3.5 (1.4)	3.4 (0.9)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-27. Average Travel Times by Time-of-Day and Day-of-Week for Link 252.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	4.0 (0.2)	3.8 (-)	4.3 (1.5)	6.1 (-)	4.2 (0.2)	4.3 (1.0)
15:15	4.2 (0.2)	3.6 (0.8)	4.0 (0.4)	4.7 (0.8)	4.1 (1.2)	4.1 (0.7)
15:30	4.6 (1.5)	4.4 (0.2)	4.0 (0.4)	3.6 (0.1)	5.0 (1.8)	4.5 (1.3)
15:45	4.6 (0.6)	4.4 (0.6)	4.3 (0.5)	4.4 (0.7)	4.5 (0.7)	4.4 (0.6)
16:00	5.0 (1.6)	5.3 (1.6)	4.8 (0.8)	5.0 (1.4)	5.0 (1.2)	5.0 (1.4)
16:15	6.1 (2.2)	5.1 (1.5)	5.4 (1.5)	5.6 (1.7)	5.6 (1.9)	5.5 (1.8)
16:30	4.9 (1.0)	4.8 (0.6)	4.6 (0.5)	4.8 (0.6)	4.7 (0.5)	4.8 (0.6)
16:45	5.1 (0.7)	5.1 (0.6)	5.1 (0.9)	5.0 (0.7)	5.0 (1.3)	5.0 (0.9)
17:00	5.0 (0.7)	4.9 (0.7)	5.0 (0.9)	4.9 (0.9)	5.0 (0.8)	5.0 (0.8)
17:15	5.2 (0.8)	5.0 (0.6)	5.1 (0.7)	5.2 (0.7)	5.0 (0.7)	5.1 (0.7)
17:30	5.4 (0.9)	5.1 (0.7)	5.4 (1.1)	5.1 (0.8)	4.7 (0.5)	5.2 (0.8)
17:45	4.9 (0.8)	5.0 (0.6)	5.1 (1.6)	5.0 (1.1)	5.2 (0.9)	5.0 (1.0)
18:00	4.9 (0.8)	5.0 (0.8)	4.8 (0.8)	4.9 (0.9)	4.6 (0.5)	4.9 (0.8)
18:15	4.9 (0.7)	4.7 (1.0)	4.5 (0.6)	4.6 (0.6)	4.9 (0.9)	4.7 (0.8)
18:30	4.8 (0.5)	4.4 (0.2)	4.4 (0.6)	4.4 (0.4)	4.1 (0.3)	4.4 (0.5)
18:45 PM	4.6 (0.5)	4.3 (0.4)	4.1 (0.3)	4.4 (0.1)	5.2 (0.9)	4.4 (0.5)
Average	5.1 (1.1)	5.0 (0.9)	5.0 (1.0)	5.0 (1.0)	4.9 (1.0)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-28. Average Travel Times by Time-of-Day and Day-of-Week for Link 355.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	- (-)	2.6 (-)	3.9 (1.0)	2.5 (-)	3.8 (0.9)	3.5 (0.9)
15:15	2.3 (0.3)	2.8 (1.1)	- (-)	2.5 (0.1)	2.4 (0.3)	2.5 (0.6)
15:30	3.4 (1.7)	2.6 (0.5)	3.1 (1.7)	2.8 (0.8)	3.3 (1.2)	3.2 (1.1)
15:45	2.4 (0.6)	3.1 (1.1)	3.2 (1.2)	2.6 (0.7)	2.7 (0.8)	2.8 (0.9)
16:00	2.5 (0.7)	2.6 (0.5)	2.6 (0.8)	2.4 (0.6)	2.4 (0.5)	2.5 (0.6)
16:15	2.8 (1.0)	2.9 (1.0)	2.9 (1.0)	2.5 (0.6)	2.9 (1.3)	2.8 (1.0)
16:30	2.7 (0.6)	2.7 (0.8)	2.8 (1.1)	2.7 (0.6)	2.3 (0.4)	2.6 (0.8)
16:45	2.8 (0.7)	2.5 (0.7)	2.5 (0.6)	2.7 (0.8)	2.7 (0.8)	2.6 (0.7)
17:00	2.6 (0.7)	2.8 (0.9)	2.8 (0.8)	2.6 (0.6)	2.6 (0.6)	2.6 (0.7)
17:15	2.6 (0.6)	2.7 (0.7)	2.7 (0.7)	2.8 (0.9)	2.5 (0.5)	2.7 (0.7)
17:30	2.8 (1.1)	2.6 (0.6)	2.6 (0.7)	2.6 (0.7)	2.5 (0.5)	2.6 (0.8)
17:45	2.5 (0.8)	2.7 (1.1)	2.9 (0.5)	2.7 (0.7)	2.6 (0.7)	2.7 (0.8)
18:00	2.5 (0.5)	2.9 (0.6)	2.6 (0.6)	2.7 (0.7)	2.6 (0.7)	2.6 (0.6)
18:15	2.9 (0.7)	2.5 (0.8)	2.6 (0.7)	2.6 (0.7)	2.8 (0.6)	2.6 (0.7)
18:30	2.2 (0.2)	2.5 (0.4)	3.0 (0.4)	2.5 (0.6)	2.4 (-)	2.5 (0.5)
18:45 PM	- (-)	2.5 (0.2)	2.9 (-)	2.2 (-)	- (-)	2.5 (0.3)
Average	2.6 (0.7)	2.7 (0.8)	2.7 (0.8)	2.7 (0.7)	2.6 (0.7)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-29. Average Travel Times by Time-of-Day and Day-of-Week for Link 356.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	- (-)	- (-)	6.3 (-)	- (-)	3.9 (-)	5.1 (1.7)
15:15	5.4 (1.2)	5.4 (2.0)	- (-)	4.4 (0.1)	4.5 (0.3)	4.9 (1.0)
15:30	4.1 (0.1)	4.4 (0.1)	4.6 (0.1)	- (-)	4.3 (0.7)	4.3 (0.4)
15:45	4.8 (1.0)	4.8 (1.0)	5.2 (0.2)	4.6 (0.5)	4.9 (1.1)	4.8 (1.0)
16:00	4.8 (0.9)	4.5 (0.4)	4.7 (0.6)	4.4 (0.5)	4.7 (0.6)	4.6 (0.6)
16:15	4.8 (0.7)	4.8 (0.5)	4.4 (0.3)	5.0 (1.1)	4.7 (0.6)	4.8 (0.7)
16:30	4.7 (0.6)	4.7 (0.8)	4.7 (0.7)	4.7 (0.6)	4.5 (0.6)	4.6 (0.6)
16:45	4.7 (1.0)	4.4 (0.5)	4.5 (0.5)	4.5 (0.6)	4.4 (0.8)	4.5 (0.7)
17:00	4.4 (0.6)	4.6 (0.6)	4.7 (0.8)	4.6 (0.6)	4.9 (0.9)	4.6 (0.7)
17:15	4.5 (0.7)	4.6 (0.9)	4.6 (0.6)	4.7 (0.7)	4.7 (0.9)	4.6 (0.8)
17:30	4.8 (0.6)	5.0 (1.4)	4.9 (1.0)	5.1 (1.1)	5.0 (1.6)	5.0 (1.2)
17:45	4.9 (1.2)	4.9 (0.7)	5.0 (0.6)	5.4 (1.9)	4.6 (0.7)	4.9 (1.2)
18:00	4.9 (0.8)	5.0 (0.9)	4.5 (0.7)	5.5 (2.2)	4.6 (0.8)	4.9 (1.3)
18:15	4.8 (1.2)	4.6 (0.7)	4.4 (0.3)	4.7 (0.8)	4.4 (0.7)	4.6 (0.8)
18:30	4.4 (0.2)	4.7 (0.6)	3.7 (1.1)	4.8 (0.6)	- (-)	4.6 (0.6)
18:45 PM	- (-)	- (-)	3.7 (-)	4.7 (0.3)	- (-)	4.4 (0.6)
Average	4.7 (0.8)	4.7 (0.9)	4.6 (0.7)	4.8 (1.1)	4.7 (0.9)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-30. Average Travel Times by Time-of-Day and Day-of-Week for Link 357.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
15:15	- (-)	- (-)	- (-)	2.2 (0.1)	2.8 (0.7)	2.5 (0.6)
15:30	2.6 (0.5)	2.7 (0.2)	2.5 (0.4)	- (-)	2.1 (0.5)	2.5 (0.5)
15:45	2.6 (0.4)	3.4 (1.3)	3.0 (1.1)	2.5 (0.4)	2.6 (0.5)	2.8 (0.8)
16:00	3.1 (1.7)	2.7 (0.5)	3.1 (1.0)	2.6 (0.3)	3.3 (3.6)	3.0 (2.3)
16:15	2.7 (0.4)	3.0 (0.2)	3.2 (1.1)	2.7 (0.5)	2.6 (0.4)	2.7 (0.6)
16:30	2.8 (0.8)	2.6 (0.4)	2.8 (0.3)	3.2 (0.8)	2.8 (0.5)	2.8 (0.6)
16:45	2.8 (0.5)	3.0 (0.5)	3.2 (0.7)	2.9 (0.5)	3.1 (0.8)	3.0 (0.6)
17:00	3.2 (1.4)	2.9 (0.7)	3.0 (1.0)	2.7 (0.7)	2.9 (0.7)	2.9 (0.9)
17:15	3.1 (1.1)	3.0 (0.8)	3.2 (1.5)	2.9 (0.6)	3.2 (1.0)	3.1 (1.0)
17:30	3.3 (1.3)	2.9 (0.6)	4.0 (3.3)	3.5 (1.7)	3.3 (1.2)	3.4 (2.0)
17:45	3.6 (1.2)	3.1 (0.7)	3.4 (2.2)	3.4 (1.4)	5.3 (5.4)	3.8 (3.0)
18:00	3.4 (1.6)	3.4 (2.1)	3.0 (0.7)	3.5 (2.0)	3.3 (1.8)	3.3 (1.5)
18:15	3.8 (1.9)	3.0 (0.8)	3.0 (0.4)	3.4 (2.2)	2.8 (0.7)	3.2 (1.5)
18:30	3.0 (0.3)	3.5 (2.6)	2.5 (0.5)	2.6 (0.5)	2.6 (-)	3.0 (1.8)
18:45 PM	2.7 (-)	2.8 (-)	2.7 (0.8)	2.6 (0.4)	- (-)	2.7 (0.5)
Average	3.2 (1.2)	3.0 (1.0)	3.3 (1.8)	3.0 (1.2)	3.2 (2.2)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-31. Average Travel Times by Time-of-Day and Day-of-Week for Link 358.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
15:15	- (-)	- (-)	- (-)	- (-)	6.1 (0.2)	6.1 (0.2)
15:30	6.0 (0.8)	6.6 (1.2)	6.1 (-)	- (-)	6.8 (0.5)	6.3 (0.8)
15:45	6.4 (0.6)	6.4 (0.5)	7.4 (0.7)	6.5 (0.4)	6.0 (0.6)	6.5 (0.7)
16:00	6.6 (0.6)	6.7 (1.1)	6.2 (0.5)	6.2 (0.7)	6.4 (0.8)	6.5 (0.8)
16:15	6.6 (0.9)	6.0 (0.6)	6.3 (0.4)	6.3 (0.6)	6.5 (0.6)	6.4 (0.7)
16:30	6.2 (0.7)	6.4 (0.6)	6.2 (0.4)	6.4 (0.6)	7.0 (1.0)	6.4 (0.7)
16:45	6.8 (0.6)	6.3 (0.6)	6.8 (0.9)	6.8 (0.8)	6.8 (1.0)	6.7 (0.8)
17:00	6.6 (0.7)	6.2 (0.4)	6.4 (0.5)	6.6 (0.9)	6.4 (0.7)	6.4 (0.7)
17:15	6.9 (1.8)	6.5 (0.7)	6.5 (0.7)	6.5 (0.6)	6.5 (0.5)	6.6 (1.0)
17:30	7.1 (1.6)	6.8 (0.8)	7.1 (1.8)	7.1 (1.9)	6.6 (0.7)	6.9 (1.4)
17:45	7.6 (1.8)	6.7 (1.0)	7.9 (2.6)	7.4 (1.6)	6.9 (1.2)	7.3 (1.8)
18:00	6.6 (0.4)	6.4 (0.6)	6.7 (1.4)	6.7 (0.8)	6.7 (1.0)	6.6 (0.9)
18:15	7.2 (1.6)	6.6 (1.3)	6.4 (0.9)	6.8 (1.0)	6.8 (1.4)	6.8 (1.2)
18:30	6.3 (0.2)	6.5 (0.6)	6.3 (0.5)	6.9 (1.0)	7.8 (0.2)	6.7 (0.8)
18:45 PM	5.2 (-)	6.0 (0.6)	- (-)	- (-)	- (-)	5.8 (0.6)
Average	6.8 (1.3)	6.5 (0.8)	6.8 (1.4)	6.8 (1.1)	6.6 (0.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-32. Average Travel Times by Time-of-Day and Day-of-Week for Link 359.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
15:15	- (-)	- (-)	- (-)	- (-)	2.8 (-)	2.8 (-)
15:30	4.0 (0.3)	4.8 (-)	- (-)	- (-)	4.1 (0.7)	4.1 (0.5)
15:45	4.0 (0.1)	3.9 (0.2)	3.3 (0.3)	4.0 (-)	3.9 (0.9)	3.8 (0.5)
16:00	3.6 (0.6)	4.3 (0.4)	3.8 (0.7)	3.3 (0.5)	3.4 (0.4)	3.6 (0.6)
16:15	3.6 (0.6)	3.6 (0.4)	3.7 (0.7)	5.2 (5.3)	3.7 (0.4)	3.9 (2.2)
16:30	4.6 (2.3)	3.9 (0.5)	3.5 (0.5)	4.0 (0.9)	3.8 (0.6)	3.9 (1.0)
16:45	3.9 (0.4)	4.0 (0.5)	3.8 (0.5)	4.1 (0.4)	3.6 (0.5)	3.9 (0.5)
17:00	4.2 (1.5)	4.0 (0.4)	3.9 (0.5)	3.7 (0.5)	3.9 (0.4)	3.9 (0.7)
17:15	4.0 (0.5)	3.9 (0.8)	4.0 (0.7)	3.9 (0.5)	4.1 (0.8)	4.0 (0.7)
17:30	3.7 (0.4)	4.0 (0.6)	3.7 (0.5)	3.8 (0.4)	4.1 (0.4)	3.9 (0.5)
17:45	3.8 (0.6)	3.6 (0.5)	4.0 (0.7)	4.1 (0.6)	3.9 (0.4)	3.9 (0.6)
18:00	4.0 (0.4)	3.8 (0.4)	4.0 (0.7)	3.5 (0.3)	3.8 (0.4)	3.8 (0.5)
18:15	3.9 (0.5)	3.8 (0.5)	3.7 (0.4)	4.0 (0.6)	4.1 (0.5)	3.8 (0.5)
18:30	3.7 (0.6)	3.6 (0.5)	3.8 (0.6)	4.0 (0.5)	4.2 (0.7)	3.8 (0.6)
18:45 PM	4.0 (-)	3.5 (0.6)	3.1 (0.2)	3.9 (0.3)	3.6 (-)	3.6 (0.5)
Average	3.9 (0.8)	3.8 (0.6)	3.8 (0.6)	4.0 (1.6)	3.9 (0.6)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-33. Average Travel Times by Time-of-Day and Day-of-Week for Link 451.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	2.7 (0.4)	2.8 (0.8)	3.1 (0.6)	3.3 (0.8)	2.4 (0.3)	2.8 (0.6)
15:15	3.0 (0.6)	3.5 (2.0)	6.1 (6.7)	2.8 (0.5)	3.2 (0.8)	3.4 (2.8)
15:30	3.1 (1.2)	3.2 (1.7)	3.7 (3.2)	2.9 (0.7)	3.9 (3.0)	3.4 (2.3)
15:45	3.5 (1.4)	3.3 (1.1)	3.5 (1.3)	3.7 (1.8)	3.9 (1.0)	3.6 (1.4)
16:00	3.3 (0.9)	3.3 (2.4)	3.5 (1.5)	3.7 (1.3)	3.8 (1.1)	3.5 (1.6)
16:15	3.3 (1.1)	3.2 (0.7)	3.4 (1.3)	3.5 (1.0)	3.8 (1.0)	3.5 (1.1)
16:30	3.0 (0.6)	3.0 (0.8)	3.1 (1.9)	3.7 (1.2)	3.7 (1.0)	3.3 (1.2)
16:45	3.1 (0.6)	3.4 (1.0)	3.4 (1.8)	3.5 (1.4)	3.8 (1.3)	3.4 (1.3)
17:00	3.6 (0.9)	3.8 (1.4)	3.8 (2.4)	3.6 (1.2)	4.2 (1.4)	3.8 (1.6)
17:15	4.1 (2.4)	3.9 (2.6)	4.5 (3.8)	3.4 (1.1)	3.9 (1.2)	3.9 (2.5)
17:30	4.0 (2.5)	4.2 (2.1)	4.6 (4.3)	4.8 (4.3)	3.9 (1.1)	4.3 (3.2)
17:45	3.4 (1.2)	4.1 (2.7)	3.5 (1.1)	3.5 (1.0)	3.6 (1.5)	3.6 (1.6)
18:00	3.6 (1.3)	3.2 (1.0)	3.0 (0.8)	3.2 (1.4)	3.3 (0.8)	3.3 (1.1)
18:15	3.6 (1.2)	3.2 (0.8)	3.3 (1.0)	3.4 (1.5)	3.2 (0.7)	3.3 (1.1)
18:30	3.1 (1.0)	3.0 (0.6)	2.9 (0.6)	2.8 (0.5)	3.2 (0.9)	3.0 (0.8)
18:45 PM	2.7 (0.3)	3.1 (0.6)	2.8 (0.6)	3.1 (0.5)	3.7 (-)	3.0 (0.6)
Average	3.4 (1.4)	3.5 (1.8)	3.7 (2.5)	3.6 (1.7)	3.8 (1.3)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-34. Average Travel Times by Time-of-Day and Day-of-Week for Link 452.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	4.0 (0.7)	4.6 (1.2)	3.8 (-)	3.6 (0.3)	3.9 (0.4)	4.0 (0.8)
15:15	4.0 (0.7)	4.2 (0.8)	4.7 (1.2)	4.2 (0.4)	4.8 (0.8)	4.4 (0.9)
15:30	4.3 (0.8)	4.2 (0.9)	4.6 (1.2)	4.7 (1.3)	5.0 (1.2)	4.5 (1.1)
15:45	5.4 (1.0)	5.4 (0.9)	5.7 (2.0)	5.6 (0.9)	6.5 (4.7)	5.7 (2.4)
16:00	5.5 (1.6)	5.6 (1.1)	6.1 (2.3)	5.8 (2.1)	6.7 (1.4)	5.9 (1.8)
16:15	5.8 (1.5)	5.9 (1.5)	6.3 (2.4)	6.2 (1.5)	6.9 (1.3)	6.2 (1.8)
16:30	5.9 (1.1)	5.5 (1.4)	5.9 (1.8)	6.1 (1.5)	7.0 (1.6)	6.1 (1.6)
16:45	6.4 (1.3)	6.2 (1.6)	7.0 (1.8)	6.6 (1.7)	6.9 (1.5)	6.6 (1.6)
17:00	6.6 (1.6)	6.2 (1.5)	6.9 (4.2)	6.6 (1.6)	7.1 (1.8)	6.6 (2.6)
17:15	7.3 (1.7)	7.3 (2.6)	7.9 (3.8)	7.4 (1.6)	7.2 (1.4)	7.4 (2.5)
17:30	7.2 (2.4)	6.9 (1.7)	7.9 (4.3)	7.0 (1.6)	7.3 (4.8)	7.3 (3.0)
17:45	7.1 (1.5)	6.9 (1.7)	7.9 (4.6)	7.1 (3.5)	5.8 (1.5)	7.2 (3.2)
18:00	6.5 (1.8)	6.0 (1.9)	6.2 (2.9)	5.8 (1.8)	4.6 (1.5)	5.9 (2.2)
18:15	5.0 (1.7)	4.9 (1.6)	5.4 (2.4)	5.0 (1.6)	4.9 (2.0)	5.0 (1.8)
18:30	4.9 (1.9)	4.4 (1.2)	4.1 (0.9)	4.5 (1.7)	3.9 (0.7)	4.4 (1.4)
18:45 PM	3.8 (1.0)	3.8 (1.0)	3.9 (0.4)	3.6 (0.9)	3.4 (0.6)	3.7 (0.9)
Average	6.2 (1.8)	6.0 (1.9)	6.6 (3.4)	6.2 (2.0)	6.5 (2.3)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-35. Average Travel Times by Time-of-Day and Day-of-Week for Link 453.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	4.4 (0.7)	3.6 (0.7)	4.6 (1.1)	4.1 (0.2)	4.2 (0.3)	4.2 (0.7)
15:15	4.2 (0.7)	5.0 (2.5)	4.8 (1.1)	4.1 (0.4)	4.6 (1.1)	4.5 (1.5)
15:30	4.4 (0.7)	4.3 (0.4)	4.4 (0.7)	4.5 (1.0)	4.9 (2.1)	4.5 (1.0)
15:45	4.4 (0.8)	4.6 (0.6)	4.7 (1.1)	4.5 (0.8)	4.6 (0.6)	4.6 (0.8)
16:00	4.5 (0.5)	4.9 (3.1)	4.8 (1.3)	4.4 (0.6)	4.8 (0.7)	4.7 (1.7)
16:15	4.5 (0.7)	4.6 (1.0)	4.6 (0.6)	4.6 (0.7)	4.9 (1.1)	4.6 (0.9)
16:30	4.7 (1.0)	4.7 (1.0)	4.8 (1.3)	4.9 (1.8)	4.9 (0.8)	4.8 (1.2)
16:45	4.9 (1.5)	4.6 (0.5)	4.6 (0.5)	4.7 (0.7)	5.1 (4.0)	4.8 (2.0)
17:00	5.3 (3.8)	4.7 (0.6)	5.0 (0.8)	4.9 (1.1)	4.9 (0.7)	4.9 (1.8)
17:15	5.0 (0.8)	5.0 (1.2)	5.0 (1.0)	5.1 (1.7)	5.1 (1.1)	5.1 (1.2)
17:30	4.8 (0.6)	4.8 (0.7)	4.9 (1.7)	4.9 (1.0)	4.8 (0.7)	4.9 (1.0)
17:45	5.0 (1.4)	4.7 (0.7)	5.2 (2.2)	5.0 (1.6)	5.2 (3.2)	5.0 (1.8)
18:00	4.7 (0.7)	4.8 (1.8)	4.9 (1.9)	4.9 (1.4)	5.5 (4.8)	4.9 (2.3)
18:15	4.8 (1.0)	4.2 (0.4)	5.5 (4.1)	4.6 (1.2)	4.6 (0.7)	4.8 (2.2)
18:30	4.6 (1.1)	4.7 (1.6)	5.6 (4.2)	4.5 (0.9)	4.3 (0.4)	4.8 (2.2)
18:45 PM	4.3 (0.6)	4.2 (0.5)	4.5 (0.6)	4.2 (0.7)	4.2 (1.1)	4.3 (0.7)
Average	4.8 (1.4)	4.7 (1.3)	4.9 (1.7)	4.8 (1.2)	4.9 (2.0)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-36. Average Travel Times by Time-of-Day and Day-of-Week for Link 454.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average
15:00 PM	3.3 (0.3)	3.2 (0.1)	3.2 (0.4)	3.0 (0.2)	3.3 (0.7)	3.2 (0.4)
15:15	3.0 (0.1)	3.3 (0.8)	3.0 (0.2)	3.0 (0.2)	3.2 (0.3)	3.1 (0.4)
15:30	3.2 (0.8)	3.2 (0.6)	3.3 (0.6)	3.1 (0.4)	3.3 (0.4)	3.2 (0.6)
15:45	3.2 (0.6)	3.2 (0.4)	3.4 (0.7)	3.2 (0.7)	4.0 (1.8)	3.4 (1.0)
16:00	3.2 (0.5)	3.2 (0.6)	3.5 (0.9)	3.4 (2.1)	3.7 (0.8)	3.4 (1.2)
16:15	3.4 (0.7)	3.5 (0.8)	3.5 (1.2)	3.4 (1.0)	4.3 (1.2)	3.6 (1.0)
16:30	3.6 (0.7)	3.7 (0.8)	3.7 (1.1)	4.0 (1.7)	4.7 (1.3)	3.9 (1.2)
16:45	3.9 (1.2)	3.8 (1.0)	3.8 (0.9)	4.5 (2.0)	5.0 (1.4)	4.2 (1.5)
17:00	3.9 (1.3)	3.8 (1.1)	4.0 (1.1)	4.2 (1.0)	5.2 (1.7)	4.3 (1.4)
17:15	4.0 (1.0)	4.3 (2.2)	4.2 (2.1)	4.4 (1.5)	5.7 (2.1)	4.4 (1.9)
17:30	4.2 (1.4)	4.9 (3.9)	4.2 (1.8)	4.6 (2.0)	6.3 (3.2)	4.8 (2.6)
17:45	4.1 (1.7)	4.8 (4.1)	4.7 (2.4)	4.7 (2.4)	6.2 (3.6)	4.8 (3.0)
18:00	4.7 (2.1)	4.1 (1.6)	4.2 (2.0)	4.5 (2.6)	5.8 (2.6)	4.6 (2.2)
18:15	3.8 (1.3)	4.1 (3.6)	4.5 (2.9)	3.9 (1.3)	4.6 (2.0)	4.2 (2.4)
18:30	3.5 (1.1)	3.8 (2.5)	3.6 (1.6)	4.1 (2.1)	4.0 (1.9)	3.8 (1.9)
18:45 PM	3.2 (0.8)	3.2 (0.4)	3.7 (1.5)	3.3 (0.5)	4.4 (2.2)	3.5 (1.2)
Average	3.8 (1.3)	4.0 (2.3)	3.9 (1.7)	4.1 (1.8)	5.0 (2.2)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-37. Average Travel Times by Time-of-Day and Day-of-Week for Link 455.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	2.7 (0.3)	2.8 (0.4)	2.8 (0.3)	3.3 (1.2)	2.8 (0.6)	2.9 (0.7)
15:15	3.0 (0.7)	3.3 (0.4)	3.0 (0.4)	2.7 (0.2)	2.3 (0.6)	2.9 (0.6)
15:30	3.8 (2.8)	3.0 (0.8)	3.0 (0.4)	3.2 (0.7)	3.2 (0.6)	3.2 (1.5)
15:45	3.1 (0.9)	2.9 (0.5)	3.4 (2.6)	3.6 (1.7)	3.3 (0.7)	3.3 (1.5)
16:00	3.1 (0.4)	3.1 (0.5)	3.3 (0.7)	3.5 (2.4)	3.6 (1.0)	3.3 (1.3)
16:15	3.2 (0.9)	3.4 (1.7)	3.5 (1.4)	3.3 (0.7)	3.6 (0.5)	3.4 (1.2)
16:30	3.7 (1.9)	3.7 (1.4)	3.8 (2.5)	3.9 (3.0)	4.2 (1.0)	3.8 (2.1)
16:45	3.9 (0.9)	4.2 (2.6)	3.8 (1.3)	4.3 (1.7)	5.6 (4.4)	4.3 (2.4)
17:00	4.6 (2.0)	4.6 (2.8)	4.2 (1.0)	4.3 (1.0)	5.5 (1.7)	4.7 (1.9)
17:15	5.5 (2.3)	5.5 (3.2)	5.2 (1.5)	5.5 (2.1)	6.6 (2.4)	5.6 (2.4)
17:30	6.0 (2.4)	6.0 (2.4)	5.9 (2.3)	6.4 (3.1)	7.4 (2.5)	6.3 (2.6)
17:45	5.6 (2.0)	5.5 (1.9)	6.2 (3.4)	5.9 (3.2)	7.4 (3.3)	6.0 (2.8)
18:00	5.2 (2.4)	4.8 (1.4)	5.2 (3.3)	5.3 (2.8)	7.3 (3.5)	5.4 (2.8)
18:15	4.5 (2.0)	4.1 (1.2)	5.2 (4.8)	5.1 (2.9)	6.3 (2.8)	5.1 (3.1)
18:30	3.8 (1.5)	3.3 (0.8)	4.1 (2.7)	4.4 (2.3)	6.0 (2.8)	4.2 (2.3)
18:45 PM	3.4 (1.2)	2.7 (0.4)	3.0 (0.7)	3.7 (1.7)	3.2 (0.6)	3.2 (1.1)
Average	4.5 (2.1)	4.3 (2.2)	4.5 (2.6)	4.7 (2.6)	5.4 (2.8)	

xx (xx) = Average Travel Time (Standard Deviation)

Table A-38. Average Travel Times by Time-of-Day and Day-of-Week for Link 456.

Time of Day	Monday	Tuesday	Wednesday	Thursday	Friday	**Average**
15:00 PM	2.2 (-)	- (-)	2.4 (-)	2.9 (1.4)	2.0 (0.1)	2.4 (0.8)
15:15	2.8 (1.2)	2.8 (0.4)	2.5 (0.9)	2.0 (-)	2.2 (0.3)	2.5 (0.8)
15:30	2.1 (0.2)	4.9 (5.7)	2.2 (0.2)	2.7 (0.9)	2.5 (0.6)	3.1 (3.3)
15:45	2.4 (0.8)	3.1 (3.6)	2.3 (0.3)	2.4 (0.8)	2.3 (0.5)	2.5 (1.9)
16:00	2.3 (0.2)	2.4 (0.4)	2.3 (0.3)	2.5 (0.5)	2.5 (0.6)	2.4 (0.4)
16:15	2.3 (0.5)	2.3 (0.4)	2.5 (1.1)	2.4 (0.6)	3.0 (1.7)	2.5 (1.0)
16:30	2.4 (0.6)	2.6 (1.0)	2.4 (0.5)	2.5 (0.7)	2.6 (0.5)	2.5 (0.7)
16:45	2.8 (1.0)	3.1 (2.1)	2.6 (0.5)	2.8 (0.8)	3.0 (0.8)	2.8 (1.2)
17:00	2.9 (0.8)	3.2 (1.6)	2.9 (0.8)	3.3 (1.5)	3.5 (0.9)	3.2 (1.2)
17:15	3.3 (0.8)	3.6 (1.7)	3.2 (0.7)	3.7 (2.0)	3.8 (0.8)	3.5 (1.3)
17:30	3.2 (0.7)	3.7 (1.5)	3.3 (1.1)	3.5 (1.4)	3.9 (0.8)	3.5 (1.2)
17:45	3.1 (0.8)	3.4 (0.9)	3.4 (1.4)	3.6 (1.3)	4.0 (1.3)	3.5 (1.2)
18:00	3.0 (0.8)	3.4 (2.2)	2.9 (1.0)	3.7 (3.6)	3.9 (1.0)	3.3 (2.1)
18:15	2.9 (0.7)	2.6 (0.6)	3.0 (1.4)	3.2 (1.3)	3.6 (1.5)	3.1 (1.2)
18:30	2.7 (0.7)	2.8 (0.8)	2.7 (1.0)	3.3 (2.0)	3.6 (2.1)	3.0 (1.6)
18:45 PM	2.6 (0.7)	2.3 (0.3)	2.6 (1.4)	2.5 (0.4)	3.0 (1.3)	2.6 (1.0)
Average	2.8 (0.8)	3.1 (1.9)	2.8 (1.0)	3.2 (1.6)	3.3 (1.2)	

xx (xx) = Average Travel Time (Standard Deviation)

APPENDIX B.

INCIDENT DETECTION RATES BY FACILITY

Table B-1. Incident Detection Rates for I-45 North Freeway in AM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
101	2	4	2 (100%)	4 (100%)	2 (100%)	3 (75%)	2 (100%)	3 (75%)	2 (100%)	3 (75%)	2 (100%)	3 (75%)
102	6	7	4 (66%)	4 (57%)	4 (66%)	4 (57%)	4 (66%)	4 (57%)	4 (66%)	4 (57%)	3 (50%)	3 (43%)
103	0	2	0 (-)	0 (0%)	0 (-)	0 (0%)	0 (-)	0 (0%)	0 (-)	0 (0%)	0 (-)	0 (0%)
104	15	18	2 (13%)	2 (11%)	2 (13%)	2 (11%)	1 (7%)	1 (9%)	1 (7%)	1 (9%)	1 (7%)	1 (9%)
105	129	166	102 (79%)	130 (78%)	81 (63%)	103 (62%)	66 (51%)	82 (49%)	50 (39%)	63 (38%)	38 (29%)	49 (30%)
106	96	143	66 (69%)	98 (68%)	59 (61%)	86 (60%)	40 (42%)	59 (41%)	26 (27%)	38 (26%)	14 (15%)	21 (15%)
Total	248	340	176 (71%)	238 (70%)	148 (60%)	198 (58%)	113 (46%)	149 (44%)	83 (33%)	109 (32%)	58 (23%)	77 (22%)

XX/(XX)) = Frequency/(Percent)

Table B-2. Incident Detection Rates for I-45 North Freeway in PM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
151	105	126	41 (39%)	54 43(%)	34 (32%)	45 (36%)	14 (13%)	27 (21%)	14 (13%)	23 (18%)	6 (6%)	13 (10%)
152	142	257	77 (54%)	149 (58%)	69 (49%)	129 (50%)	58 (41%)	110 (43%)	39 (27%)	86 (33%)	36 (25%)	81 (32%)
153	105	218	64 (61%)	125 (57%)	56 (53%)	100 (46%)	44 (47%)	83 (38%)	40 (38%)	63 (29%)	36 (34%)	53 (24%)
154	55	109	13 (24%)	44 (40%)	12 (22%)	39 (36%)	8 (15%)	30 (28%)	7 (13%)	24 (22%)	6 (11%)	19 (17%)
155	21	46	13 (62%)	25 (54%)	8 (38%)	17 (37%)	5 (24%)	11 (24%)	3 (14%)	7 (15%)	3 (14%)	7 (15%)
156	6	11	2 (33%)	4 (36%)	2 (33%)	4 (36%)	2 (33%)	3 (27%)	2 (33%)	3 (27%)	2 (33%)	3 (27%)
Total	434	767	210 (48%)	401 (52%)	401 (52%)	181 (42%)	334 (44%)	140 (32%)	264 (34%)	105 (24%)	206 (27%)	176 (23%)

XX/(XX)) = Frequency/(Percent)

Table B-3. Incident Detection Rates for I-45 HOV in AM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
205	8	12	1 (13%)	1 (8%)	1 (13%)	1 (8%)	1 (13%)	1 (8%)	1 (13%)	1 (8%)	1 (13%)	1 (8%)
206	18	30	6 (33%)	17 (57%)	5 (28%)	13 (43%)	4 (22%)	11 (37%)	3 (17%)	10 (33%)	2 (11%)	4 (13%)
Total	26	42	7 (27%)	18 (43%)	6 (23%)	14 (33%)	5 (19%)	12 (29%)	4 (15%)	11 (26%)	3 (12%)	5 (12%)

XX/(XX)) = Frequency/(Percent)

Table B-4. Incident Detection Rates for I-45 HOV in PM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
251	20	22	7 (35%)	7 (32%)	6 (30%)	6 (27%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)	1 (5%)
252	26	30	7 (27%)	7 (23%)	5 (19%)	5 (17%)	5 (19%)	5 (17%)	4 (15%)	4 (13%)	3 (12%)	3 (10%)
Total	46	52	14 (30%)	14 (27%)	11 (24%)	11 (21%)	6 (13%)	6 (12%)	5 (11%)	5 (10%)	4 (9%)	4 (8%)

XX/(XX)) = Frequency/(Percent)

Table B-5. Incident Detection Rates for Hardy Toll Road in AM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
301	0	0	0	0	0	0	0	0	0	0	0	0
302	1	1	1 (100%)	1	1 (100%)	1	1 (100%)	1	1 (100%)	1	0	0
303	8	9	4 (50%)	5 (56%)	3 (38%)	4 (44%)	3 (38%)	4 (44%)	3 (38%)	3 (33%)	3 (38%)	3 (33%)
304	3	5	1 (33%)	1 (20%)	1 (33%)	1 (20%)	1 (33%)	1 (20%)	1 (33%)	1 (20%)	1 (33%)	1 (20%)
305	1	1	0	0	0	0	0	0	0	0	0	0
Total	13	16	6 (46%)	7 (44%)	5 (38%)	6 (38%)	5 (38%)	6 (38%)	5 (38%)	5 (31%)	4 (31%)	4 (25%)

XX/(XX)) = Frequency/(Percent)

Table B-6. Incident Detection Rates for Hardy Toll Road in PM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
355	0	0	0	0	0	0	0	0	0	0	0	0
356	4	7	0	1 (64%)	0	1 (14%)	0	1 (14%)	0	1 (14%)	0	1 (14%)
357	0	3	0	2 (66%)	0	0	0	0	0	0	0	0
358	0	8	0	2 (25%)	0	1 (13%)	0	1 (13%)	0	1 (13%)	0	1 (13%)
359	3	3	0	0	0	0	0	0	0	0	0	0
Total	7	21	0	5 (24%)	0	2 (10%)	0	2 (10%)	0	2 (10%)	0	2 (10%)

XX/(XX)) = Frequency/(Percent)

Table B-7. Incident Detection Rates for US-59 in AM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
401	13	15	5 (38%)	5 (33%)	5 (38%)	5 (33%)	4 (31%)	4 (27%)	3 (23%)	3 (20%)	2 (15%)	2 (13%)
402	2	3	1 (50%)	1 (33%)	1 (50%)	1 (33%)	1 (50%)	1 (33%)	1 (50%)	1 (33%)	1 (50%)	1 (33%)
403	2	6	0	3 (50%)	0	3 (50%)	0	3 (50%)	0	3 (50%)	0	3 (50%)
404	1	7	0	3 (43%)	0	2 (29%)	0	2 (29%)	0	1 (14%)	0	1 (14%)
405	49	75	6 (12%)	18 (24%)	3 (6%)	12 (10%)	3 (6%)	11 (15%)	1 (2%)	4 (5%)	0	3 (4%)
406	18	61	0	27 (44%)	0	21 (34%)	0	11 (18%)	0	6 (10%)	0	2 (3%)
Total	85	167	12 (14%)	57 (34%)	9 (11%)	44 (26%)	8 (9%)	32 (19%)	5 (6%)	18 (11%)	3 (4%)	12 (7%)

XX/(XX)) = Frequency/(Percent)

Table B-8. Incident Detection Rates for US-59 in PM Peak.

Link	Number of Incidents		Detection Rate									
			SND = 2.0		SND = 2.5		SND = 3.0		SND = 3.5		SND = 4.0	
	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All	Lane Blocking	All
451	79	233	59 (75%)	155 (67%)	52 (66%)	137 (59%)	46 (58%)	117 (50%)	42 (53%)	99 (42%)	36 (46%)	84 (36%)
452	91	270	53 (58%)	155 (57%)	40 (44%)	106 (39%)	26 (29%)	66 (24%)	19 (21%)	50 (19%)	14 (15%)	38 (14%)
453	26	130	9 (35%)	67 (52%)	7 (27%)	56 (43%)	5 (19%)	42 (32%)	5 (19%)	40 (31%)	5 (19%)	29 (22%)
454	16	150	6 (38%)	91 (67%)	4 (25%)	67 (45%)	1 (0.39%)	49 (33%)	1 (0.39%)	35 (23%)	1 (0.39%)	28 (19%)
455	43	148	18 (42%)	75 (51%)	12 (28%)	63 (43%)	10 (23%)	51 (34%)	6 (14%)	34 (23%)	3 (7%)	24 (16%)
456	19	31	13 (68%)	20 (65%)	9 (47%)	16 (52%)	6 (32%)	11 (35%)	2 (11%)	6 (19%)	2 (11%)	6 (19%)
Total	274	962	158 (58%)	563 (59%)	124 (45%)	445 (46%)	94 (34%)	336 (35%)	75 (27%)	264 (27%)	61 (22%)	209 (22%)

XX/(XX)) = Frequency/(Percent)

APPENDIX C.

FALSE ALARM RATE BY FACILITY.

Table C-1. False Alarm Rates for I-45 North Freeway in AM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
101	2257	122 (5.41%)	81 (3.59%)	56 (2.48%)	27 (1.20%)	14 (0.62%)
102	3397	144 (4.24%)	90 (2.65%)	47 (1.38%)	25 (0.74%)	15 (0.44%)
103	5278	204 (3.87%)	121 (2.29%)	81 (1.53%)	53 (1.00%)	40 (0.76%)
104	8940	528 (5.91%)	367 (4.11%)	255 (2.85%)	196 (2.19%)	153 (1.71%)
105	8861	593 (6.69%)	374 (4.22%)	244 (2.75%)	177 (2.00%)	129 (1.46%)
106	8402	342 (4.07%)	235 (2.80%)	165 (1.96%)	116 (1.38%)	91 (1.08%)
Total	37135	1933 (5.21%)	1268 (3.41%)	848 (2.28%)	594 (1.60%)	442 (1.19%)

XX/(XX))=Frequency/(Percent)

Table C-2. False Alarm Rates for I-45 North Freeway in PM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
151	6848	476 (6.95%)	321 (4.69%)	232 (3.39%)	157 (2.29%)	121 (1.77%)
152	7433	395 (5.30%)	288 (3.86%)	229 (3.07%)	188 (2.52%)	151 (2.03%)
153	7126	346 (4.86%)	255 (3.58%)	188 (2.64%)	137 (1.92%)	110 (1.54%)
154	4038	171 (4.23%)	121 (3.00%)	85 (2.11%)	67 (1.66%)	55 (1.36%)
155	2664	123 (4.62%)	87 (3.27%)	65 (2.44%)	44 (1.65%)	36 (1.35%)
156	1815	108 (5.95%)	87 (4.79%)	71 (3.91%)	61 (3.36%)	32 (2.87%)
Total	29945	1619 (5.41%)	1159 (3.87%)	870 (2.91%)	654 (2.18%)	525 (1.75%)

XX/(XX))=Frequency/(Percent)

Table C-3. False Alarm Rates for I-45 HOV in AM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
205	2911	148 (5.08%)	98 (3.37%)	72 (2.47%)	52 (1.79%)	40 (1.37%)
206	2944	107 (3.63%)	65 (2.21%)	49 (1.66%)	38 (1.29%)	26 (0.88%)
Total	5855	255 (4.36%)	163 (2.78%)	121 (2.07%)	90 (1.54%)	66 (1.13%)

XX/(XX))=Frequency/(Percent)

Table C-4. False Alarm Rates for I-45 HOV in PM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
251	2649	124 (4.68%)	80 (3.02%)	48 (1.81%)	39 (1.47%)	31 (1.17%)
252	2636	135 (5.12%)	87 (3.30%)	56 (2.12%)	41 (1.56%)	19 (0.72%)
Total	5285	259 (4.90%)	167 (3.16%)	104 (1.97%)	80 (1.51%)	50 (0.95%)

XX/(XX))=Frequency/(Percent)

Table C-5. False Alarm Rate for Hardy Toll Road in AM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
301	2309	97 (4.20%)	60 (2.60%)	41 (1.78%)	24 (1.04%)	16 (0.69%)
302	2480	83 (3.35%)	52 (2.10%)	36 (1.45%)	27 (1.09%)	19 (0.77%)
303	3062	127 (4.15%)	83 (2.71%)	49 (1.60%)	31 (1.01%)	20 (0.65%)
304	3374	83 (2.46%)	43 (1.27%)	27 (0.80%)	22 (0.65%)	16 (0.47%)
305	3373	150 (4.45%)	95 (2.82%)	65 (1.93%)	48 (1.42%)	33 (0.98%)
Total	14598	540 (3.70%)	333 (2.28%)	218 (1.49%)	152 (1.09%)	104 (0.71%)

XX/(XX))=Frequency/(Percent)

Table C-6. False Alarm Rates for Hardy Toll Road in PM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
355	1727	78 (4.52%)	46 (2.66%)	29 (1.68%)	16 (0.93%)	9 (0.57%)
356	1279	46 (3.60%)	23 (1.80%)	13 (1.02%)	7 (0.55%)	3 (0.23%)
357	1171	61 (5.21%)	44 (3.76%)	28 (2.39%)	15 (1.28%)	4 (0.34%)
358	1070	50 (4.67%)	26 (2.43%)	14 (1.31%)	5 (0.47%)	2 (0.19%)
359	936	27 (2.88%)	14 (1.50%)	8 (0.85%)	3 (0.32%)	3 (0.32%)
Total	6183	262 (4.24%)	153 (2.47%)	92 (1.49%)	46 (0.74%)	21 (0.34%)

XX/(XX))=Frequency/(Percent)

Table C-7. False Alarm Rate for US-59 in AM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
401	5389	266 (4.94%)	172 (3.19%)	122 (2.26%)	90 (1.67%)	73 (1.35%)
402	5736	239 (4.17%)	147 (2.56%)	98 (1.71%)	68 (1.19%)	52 (0.91%)
403	6546	273 (4.17%)	186 (2.84%)	127 (1.94%)	100 (1.53%)	76 (1.16%)
404	7443	353 (4.74%)	234 (3.14%)	167 (2.24%)	114 (1.53%)	85 (1.14%)
405	7680	287 (3.74%)	182 (2.37%)	128 (1.67%)	88 (1.15%)	61 (0.79%)
406	7178	352 (4.90%)	223 (3.11%)	140 (1.95%)	91 (1.27%)	64 (0.89%)
Total	39972	1770 (4.43%)	1144 (2.86%)	782 (1.96%)	551 (1.38%)	411 (1.03%)

XX/(XX))=Frequency/(Percent)

Table C-8. False Alarm Rate for US-59 in PM Peak.

Link	Number of Algorithm Iterations	Number of False Alarms				
		SND=2.0	SND=2.5	SND=3.0	SND=3.5	SND=4.0
451	5436	239 (4.40%)	165 (3.04%)	114 (2.10%)	85 (1.56%)	65 (1.20%)
452	6033	163 (2.70%)	81 (1.34%)	51 (0.85%)	40 (0.66%)	27 (0.45%)
453	5960	180 (3.02%)	127 (2.13%)	81 (1.36%)	62 (1.04%)	47 (0.79%)
454	5656	202 (3.57%)	128 (2.26%)	87 (1.54%)	61 (1.08%)	47 (0.83%)
455	4396	177 (4.03%)	111 (2.53%)	80 (1.82%)	59 (1.34%)	42 (0.96%)
456	3802	191 (5.02%)	125 (3.29%)	85 (2.24%)	64 (1.68%)	44 (1.16%)
Total	3092	1152 (3.73%)	737 (2.38%)	498 (1.61%)	371 (1.20%)	272 (0.88%)

XX/(XX))=Frequency/(Percent)