Technical Report Documentation Page

1. Report No. FHWA/TX-10/0-5865-1	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Arterial Intelligent Transportation Systems—Infrastructure Elements and Traveler Information Requirements		5. Report Date August 2009	
		6. Performing Organization Code	
7. Author(s) C. Michael Walton, Khali Persad, Zhong Wang, Kristen Svicarovich, Alison Conway, Guohui Zhang		8. Performing Organization Report No. 0-5865	
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. 0-5865	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report September 2007–August 2009	
		14. Sponsoring Agency Code	
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.			
16. Abstract Applying Intelligent Transportation Systems (ITS) to arterial systems allows TxDOT to significantly enhance transportation system operation efficiency and improve traffic mobility. However, no guidelines are available to assist TxDOT staff in selecting the most beneficial arterial ITS elements and desirable ITS technologies. To address these gaps, this study was initiated by TxDOT to investigate the arterial ITS elements, technologies, arterial performance measures, information dissemination technologies, and financial considerations for arterial ITS deployments and to enhance the arterial traffic operation efficiency. A variety of techniques are available to monitor and manage the traffic on arterial roadways, and ITS applications can support many of these strategies. Evaluation of these ITS strategies and available technologies to meet TxDOT needs is the essence of this research project. The research addresses two TxDOT goals: making the current transportation system more efficient through innovative arterial ITS deployments, and maximizing the benefits of existing ITS infrastructure and new arterial ITS deployments. The research team first synthesized the state-of-the-art in arterial ITS technologies and management strategies. Then critical performance measures were investigated and identified through a survey study. Next, the most beneficial ITS elements were examined and desirable ITS technologies and solutions were identified for arterial management enhancement. Various traveler information dissemination modes were studied and evaluated, and the guideline was developed to prioritize arterials suitable for ITS implementations. Finally, a case study was conducted to demonstrate representative arterial ITS applications. It was found deploying ITS technologies can significantly improve arterial system operation efficiency. The study findings provide new knowledge and practical guidance to help TxDOT better utilize existing ITS infrastructure elements and to make wise investments in future arterial ITS applications.			
17. Key Words Intelligent Transportation Systems, ITS, Arterial systems, Arterial performance measures, Traveler information dissemination, Simulation.		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 272	22. Price

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

Arterial Intelligent Transportation Systems—Infrastructure Elements and Traveler Information Requirements

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Acknowledgments

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Chapter 1. Introduction

1.1 Background and Significance of Work

As a major component of Intelligent Transportation Systems (ITS), arterial management systems manage traffic along arterial roadways by using traffic surveillance technologies, traffic signals, and various means of communicating information to travelers. In the past decade, TxDOT's implementation of ITS on arterial roadways has focused on advanced signal controllers and innovative uses of video-based vehicle detection. With the rapid development of technologies, arterial ITS components are becoming more affordable and widely available. As a result, the ability of TxDOT to monitor and manage its arterial systems is technically feasible.

In general, deploying ITS on arterials is beneficial in the following aspects:

1) Improve arterial traffic operations and safety.

2) TxDOT may use information collected by traffic surveillance devices to smooth the traffic flow along major freeway corridors.

3) Under certain circumstances, TxDOT may use the arterial ITS devices to monitor critical transportation infrastructure and improve natural disaster evacuation for security purposes.

The first two benefits have been widely recognized. However, the third benefit may have equal importance to TxDOT. For example, in severe weather conditions, ITS devices can help TxDOT monitor critical transportation infrastructure in urban and rural areas for safety and security purposes. For the coastal districts such as Houston and Corpus Christi, arterial ITS devices would help TxDOT improve emergency evacuations.

A variety of techniques are available to monitor and manage the traffic on arterial roadways, and ITS applications can support many of these strategies. Evaluation of these ITS strategies and available technologies to meet TxDOT needs is the essence of this research project. The research addresses two TxDOT goals: making the current transportation system more efficient through innovative arterial ITS deployments, and maximizing the benefits of existing ITS infrastructure and new arterial ITS deployments. Working from a clear understanding of TxDOT needs and the necessity of implementable products, the research team had identified six focus areas:

1. The ITS strategies that would be most beneficial to improve arterial management,

2. Desired ITS technologies & solutions to improve arterial management,

3. Method to select and prioritize arterials suitable for ITS deployments,

4. Practical arterial performance measures,

5. Desired traveler information dissemination modes,

6. Financial considerations for arterial ITS deployment.

In addition, the research team evaluated the operational effects of arterial ITS deployments on the overall transportation system. In consultation with the TxDOT project

advisory committee, a case study was conducted in the Austin area. The results of this research provided new knowledge for the operation of 21st century ITS, and addressed three main emphasis areas included in the original research project statement:

1) Identify the elements of arterial management systems that would benefit most from ITS technologies and related real-time information;

2) Identify the available ITS technologies that would have the most immediate impact on arterial management systems; and

3) Identify performance measures and traveler information dissemination modes that provide the most clear arterial performance information to the traveling public.

1.2 Research Questions

The following is a brief review of the state of current knowledge in the six thrust areas identified by the research team for this research project, with discussion of the questions to be addressed by this project.

1. <u>What ITS strategies would be most beneficial to improve arterial management?</u>

Arterial management systems "manage traffic along arterial roadways, employing traffic detectors, traffic signals, and various means of communicating information to travelers" (USDOT, 2009). These systems make use of information collected by traffic surveillance devices to smooth the flow of traffic along travel corridors. They also disseminate important information about travel conditions to travelers via technologies such as dynamic message signs (DMS) or highway advisory radio (HAR).

Arterial ITS Elements

Arterial management elements can be used effectively to manage traffic and reduce the effects of congestion on arterial roadways. According to the definition of USDOT ITS Joint Program Office, there are six categories of ITS elements in arterial management systems (USDOT, 2009). They are:

- *Surveillance*, which includes traffic surveillance or infrastructure surveillance.

- *Traffic Control*, which can be used for transit signal priority, emergency vehicle preemption, adaptive signal control, advanced signal systems, variable speed limits, bicycle and pedestrian, or special events.

- *Lane Management*, which can be used for HOV/HOT facilities, reversible flow lanes, pricing, lane control, variable speed limits, and emergency evacuation.

- *Parking Management*, which includes data collection or parking information dissemination.

- *Information Dissemination*, which may use DMS, in-vehicle systems (IVS), and HAR.

- *Enforcement*, which can be used for speed enforcement or stop/yield enforcement.

Figure 1.1 provides a summary of arterial ITS elements as defined by the USDOT ITS Joint Program Office. These arterial ITS elements can be deployed in different jurisdictions (DOTs, City, Transit Authorities, etc.) in order to achieve a number of objectives.
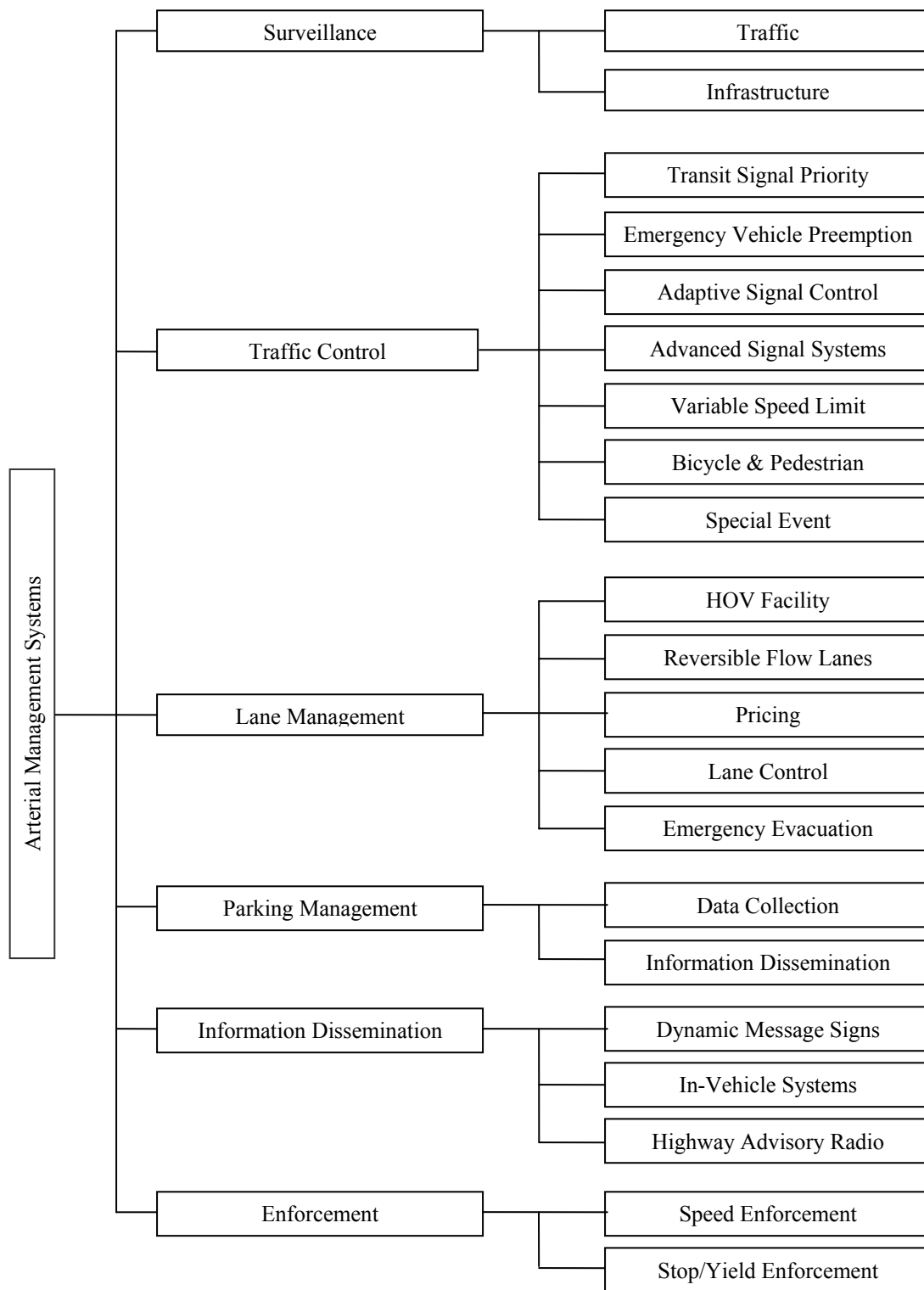
Figure 1.1: A List of Arterial ITS Elements (USDOT)

Benefits of Arterial ITS Elements

There is ample evidence that arterial ITS deployments can be beneficial to both travelers and transportation agencies. A study in Houston, Texas, found signal preemption reduced average emergency vehicle response times by 16% in one fire district and by 23% in another (Houston Metropolitan Transit Authority, 1991). Studies from six cities in Canada, Brazil, Spain, and Scotland indicated delay reductions from 5–42% after installation of adaptive signal control (Siemens Automotive, 1995; Zhou, et al., 1997; Peck, et al., 1995; Greenough and Kelman, 1999; Diakaki, et al., 2000). Signal coordination at 145 intersections in Syracuse, New York, reduced the total delay experienced by vehicles during the a.m.-peak, mid-day, and p.m.-peak periods by 14–19% (DMJM Harris, Inc., 2003). A 1999 Institute of Transportation Engineers (ITE) synthesis study on automated enforcement lists two U.S. cities with automated speed limit enforcement programs, with documented crash reductions of 40% in Paradise Valley, Arizona, and 51% in National City, California (Institute of Transportation Engineers, 1999).

Based on the review of previous studies, the observed benefits of arterial ITS deployments can be summarized as follows:

- Reduced travel time, number of stops, and delay

- Increased travel time reliability

- Increased vehicle throughput in the transportation network

- Reduced fuel and environmental cost

- Improved safety

- Improved critical infrastructure security

Interplay between Freeway Management and Arterial Management

In many metropolitan areas, the freeway system is functioning at or beyond the capacity for which it was designed. Many drivers are choosing to use arterial streets as an alternative. Applying ITS on arterials can be an effective way to manage this growing trend. By improving the interplay between freeway traffic management and arterial management, the freeway performance, arterial performance, and overall system performance would be improved. For example, a study of the integrated deployment of freeway ramp metering and adaptive signal control on adjacent arterial routes in Glasgow, Scotland, found a 20% increase in vehicle throughput on the arterials and a 6% increase on freeways. Arterial traffic increased 13% after implementation of ramp metering and an additional 7% with the initiation of adaptive signal control (Diakaki, et al., 2000). By improving the interplay between freeway traffic management and arterial management, the existing ITS infrastructure would be better utilized.

2. <u>Desired ITS technologies & solutions to improve arterial management</u>

The rapid development in technologies has made arterial ITS deployments widely available and more affordable. Today there are a variety of technologies that can be applied in arterial management such as wireless communications, computational technologies, floating vehicle data/floating cellular data, sensing technologies, inductive loop detection, video vehicle detection, etc. (Wikipedia, 2009).

Traffic Surveillance Technologies

Traffic surveillance technologies enable transportation agencies to monitor traffic flow and incidents on arterials. Typical traffic surveillance technologies include surveillance sensors and CCTV cameras. Sensing systems for ITS can be infrastructure-based, vehicle-based, or both. Infrastructure sensors are devices that are installed or embedded on the road, or surrounding the road (buildings, posts, and signs for example). The infrastructure sensors may be installed during road construction/maintenance or by sensor injection machinery for rapid deployment. While vehicle-based sensors are those devices installed on the road or in the vehicle, new technology development has also enabled cellular phones to become anonymous traffic probes for floating car data.

Arterial Performance Measurement Technologies

Accurate performance data is the foundation of arterial traffic management. Today various technologies have enabled traffic managers to better monitor arterial performance. Examples of these technologies include vehicle detection system for point-based performance using intersection detectors, supplemental detectors, or intelligent detectors, probe vehicles for link-based performance using toll-tag readers at arterial intersections, and trace vehicles for section-based performance using cell-phone tracking services. A study in Portland, Oregon demonstrated that actual arterial traffic conditions can be described using transit vehicle AVL (Automatic Vehicle Location) information (Tantiyanugulchai, 2003). The suggested arterial performance measures include travel time, travel speed, traffic volumes, and intersection delay.

Traffic Signal Control Technologies

Traffic signal control systems utilize control logic that can be divided into three categories: pre-timed signal control system, actuated signal control system, and traffic responsive signal control system. These signal systems may differ in the settings of controller system, optics, and lighting. Advanced coordinated signal systems have made it possible for drivers to go long distance without encountering a red light. The most sophisticated methods currently employed include the use centrally controlled monitors and computers to coordinate traffic signals based on emerging real time traffic patterns.

Traveler Information Dissemination Technologies

Current deployment technologies include Internet-based, phone-based, in-vehicle, and roadside-based systems. Internet- and telephone-based ATIS (Advanced Traveler Information System) have noted shortcomings. Internet-based systems are primarily for pre-trip planning, but users may not have access to information that is relevant to their trip, or the information may be stale by the time the trip is made. Telephone-based systems have similar weaknesses, plus requiring the user to know whom to call. Phone use also requires some "visioning" while talking, which is the reason why phone use impairs driver performance. Many states have moved to ban cell phone use while driving.

While a number of positive outcomes have been observed from the installation of roadside DMS, there are potential shortcomings as well. Figure 1.2 shows an example of roadside DMS. The infrastructure is static and expensive, and impact is limited to the immediate vicinity around the sign. The amount of information that can be provided is very limited. In fact,

many drivers never get the whole message unless they are already in congestion. Location and spacing guidelines for DMS are desirable.

Figure 1.2: Roadside Dynamic Message Signs

3. **Identify and prioritize arterials suitable for ITS deployments**

Arterial streets are usually two, three, or four lanes across in each direction, and they are designed to move large volumes of traffic at a relatively steady speed, although morning and afternoon rush hours can experience varying levels of congestion. The selection of arterials for ITS deployments will not only affect the usability of the arterial management systems for large segments of the travelers, but will also have profound impacts on the future development of the entire ITS system and adjacent freeway operations.

When ITS deployments are constrained by limited funding resources, arterials must be carefully selected and prioritized so that desired ITS benefits can be achieved. However, very few efforts have been found that attempt to address this issue. Given its importance, it is necessary to develop a method to assist TxDOT staff in selecting the arterials that would benefit most from the ITS implementations. The arterial selection criteria may include:

- Geometric characteristics

- Current level of service

- The number of beneficiaries of the new arterial management systems

- The amount of existing ITS infrastructure

- Implementation costs for new arterial management systems

- Connections with other major arterials and freeways

4. **Practical performance measures**

In general, ITS deployments would help transportation agencies deal with arterial performance measures in two ways:

- Improved arterial traffic operations such as increased travel speed, throughput, and reduced delay, etc.

- Improved arterial performance measurements, i.e., ITS applications would enhance arterial traffic monitoring and data collection.

The first benefit is the goal of traffic management, and the second benefit would help transportation agencies to achieve that goal. Therefore, it is important to define practical arterial performance measures and find methods to quantify these measures. Developing clear and relevant performance measures for arterials is challenging due to complicated traffic control parameters and users with numerous origins and destinations. However, with increasing data availability from ITS deployments, it is increasingly possible to develop and test new arterial performance measures. Important arterial performance measures include:

- Travel speed

- Travel time

- Travel delay

- Traffic volume

- Number of stops

The performance measures can be tailored to each of the constituencies expected to use a given performance measure. Constituencies include management center staff, administrators, other agencies, and traveling public. Some measures may be used for real-time control applications and may not be explicitly developed for a constituency group. Evaluation of the performance measures would help TxDOT staff improve transportation system management and provide more accurate information to travelers.

5. Desirable traveler information and dissemination modes

There is a significant amount of research verifying that traveler information could affect traffic conditions on roads and bring benefits to drivers. Following a nationwide ITS evaluation and field test, Lockheed Martin Federal Systems reviewed the results and confirmed that advanced traveler information systems (ATIS) could generate significant benefits by increasing transportation system efficiency and improving mobility (Lockheed Martin Federal Systems, 1996).

Desirable Information

Travel information can be categorized into two types: pre-trip information and en-route information. Pre-trip information informs travelers of travel options and typical traffic conditions. It can also include static information such as maps, roadside services, and planned disruptions. Such information assists users in deciding whether to make a trip and/or in selecting a mode, route, or departure time. En-route information provides travelers real-time information pertaining to traffic conditions, incidents, construction, weather conditions, hazardous road conditions, alternate routes, travel times to destinations, and other useful information while en-

route. This information allows travelers to switch to alternate routes or take a break during the trips.

Table 1.1 presents some findings from an Austin commuter survey conducted by the research team for research project 0-5079 in 2005 (Persad at el., 2005). It can be seen that when seeking traveler information to determine traffic conditions, commuters are particularly interested in accident locations, road congestion, weather conditions, and lane closures.

Table 1.1: Traveler Information Sought by Commuters in Austin, Texas

Content of Traveler Information	Likelihood of Seeking Information	Time of Day Information Is Important		
	Likely/Very Likely (%)	AM Rush Hours (%)	PM Rush Hours (%)	Both AM and PM (%)
Accident Location	80	12	6	75
Congested Roads	70	14	7	68
Weather Conditions	59	11	6	67
Road Work	48	18	7	64
Lane Closure	57	15	7	68
Road Hazard Warning	44	14	6	62
Estimated Trip Time	32	18	7	46
Alternate Route	NA	13	8	58

Information Dissemination Modes and Technology Trends

As discussed earlier in the section of ITS technologies for arterial management, there are a number of traveler information dissemination technologies available, each having its advantages and drawbacks. As with most technological developments, pioneers are proving the technology, and 'settlers' are starting to adopt it. In the early stages, the emphasis was primarily on providing travelers with information to improve their trip planning. The emphasis is now changing to supplementing static information with dynamic information to optimize individual travel. The evolution of information dissemination systems can be traced through three stages (Persad at el., 2006):

- <u>1990 to 2000:</u> This stage focused on improving information access and timeliness. Most of these systems relied on existing technologies and drivers' knowledge of the network.

- <u>2000 to 2010:</u> This stage focuses on en-route information systems, with increasing interactive content. Drivers are becoming part of the feedback loop.

- <u>2010 to 2020:</u> This stage will see the development of communication between the infrastructure and vehicles. Vehicles will be used to report conditions, and the infrastructure will process the data and use it to manage traffic and inform drivers. A variety of integrated in-vehicle devices will be available.

In a recent study conducted by the research team (0-5079: Use of Traveler Information to Enhance Toll Road Operations), it was found that information dissemination technologies are

evolving with the trends shown in Figure 1.3. Knowing the technology trends would enable TxDOT to make wise investments in the future.

Evolution and Trends for ATIS Technology
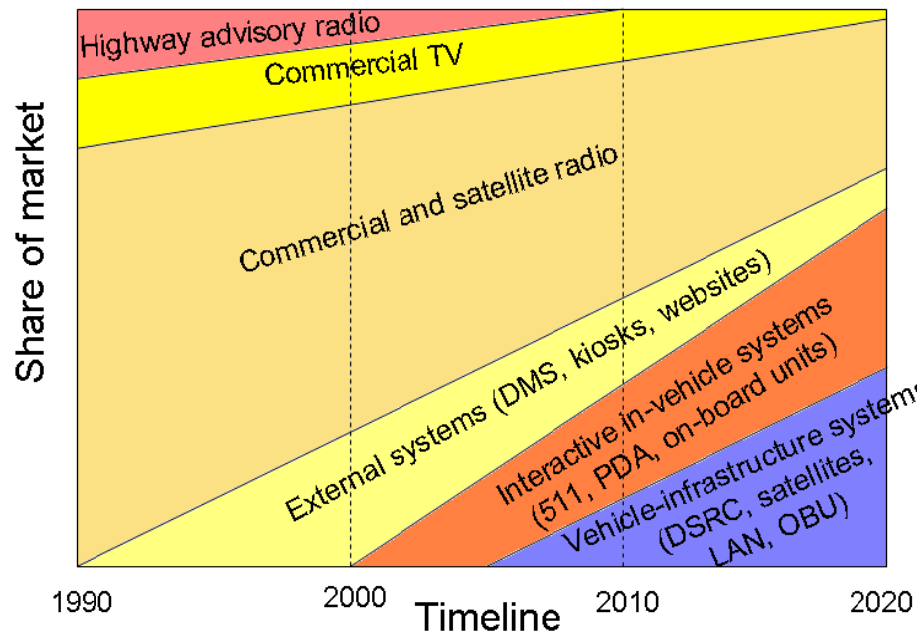
Figure 1.3: The Evolution of Information Dissemination Technology and Trends

6. Financial considerations for arterial ITS deployment

Funding has always been an issue for ITS deployments. All funding opportunities for arterial ITS deployments will be examined. The possible funding opportunities may include:

- SAFETEA-LU

- New/Ongoing Federal Initiatives

- North American Free Trade Agreement (NAFTA) Transportation Corridors and Related ITS Strategies

- Homeland Security/Evacuations

- Cost-Sharing of ITS Deployment with New Toll Road Construction

In order to improve the cost-effectiveness, the cost and returns of arterial ITS deployments must be evaluated. The costs of various arterial ITS components can be estimated based on their market prices. However, to quantify the returns, the operational effects of the arterial ITS deployments need to be evaluated.

Conclusions

Evaluation of arterial ITS strategies, technologies, and performance measures can enable TxDOT to improve transportation system performance and data collection through arterial ITS deployments. Combining the tasks related to identifying user requirements on traveler information with the development of a method to identify the most suitable arterials, along with a robust case study, can result in a powerful set of recommendations on arterial ITS applications. This careful and comprehensive set of tools and recommendations can enable TxDOT to improve transportation efficiency in Texas with the use of ITS on arterials.

1.3 Research Approach

The essence of this research is to evaluate the ITS strategies and technologies to meet TxDOT needs. The anticipated products have addressed two issues: arterial ITS benefits, and deployment requirements. Building on a clear understanding of TxDOT needs gained from years of experience working with TxDOT and other states, and the necessity of implementable research products, the research team had identified six focus areas for this research approach:

1. The most beneficial ITS strategies to improve arterial management,

2. Desired ITS technologies & solutions to improve arterial management,

3. Method to select and prioritize arterials suitable for ITS deployments,

4. Practical arterial performance measures,

5. Desired traveler information dissemination modes,

6. Financial considerations for arterial ITS deployment.

Table 1.2 illustrates the research team's understanding of TxDOT's needs and desired products for this project, along with the research conducted.

Table 1.2: Research Tasks as the Bridge between TxDOT Needs and Outcomes

TxDOT Needs	Research Required	Anticipated Outcomes
The most beneficial ITS strategies to improve arterial management	- Synthesize state-of-the art - Identify each arterial ITS element's potential benefits, targeting problems, and suitability	- A guide to assist TxDOT staff in selecting the arterial ITS elements that would benefit most from ITS deployments
Desired ITS technologies & solutions to improve arterial management	- Screen ITS technologies that can be applied for arterial management and evaluate their suitability - Develop and quantify evaluation criteria to assist TxDOT staff compare these technologies	- Guidelines that assist TxDOT staff in selecting the appropriate ITS technologies
Method to select and prioritize arterials suitable for ITS deployments	- Develop and quantify selection criteria - Develop a method to assist TxDOT staff compare and prioritize the candidate arterials	-Recommendations on how to select and prioritize arterials suitable for ITS deployments
Practical arterial performance measures	- Evaluate the performance measures that are used to monitor arterial operations - Identify the ITS technologies that can be used to improve the accuracy of performance measurement	- Arterial performance measures, and the technologies that can be used to improve the accuracy of arterial performance measurement
Desired traveler information dissemination modes	- Identify user requirements on traveler information - Identify technology trends of traveler information dissemination	- User requirement on traveler information, message design, technology trends of information dissemination
Financial considerations	- Analyze cost, potential sources of funding, implementation issues	-Deployment costs, funding and implementation plan.

1.4 Summary of Research Activities

To accomplish the project objectives in a comprehensive manner, the research team completed the following eight tasks in a two-year schedule.

Task 1: Synthesize national and international experience in Arterial Intelligent Transportation Systems

This task sought national and international experience and data to answer the following questions:

- What performance measures can be used to identify the arterial roads for ITS implementations?

- What ITS strategies can be taken for arterial road management? For each arterial ITS strategy, what are the targeting problems and potential benefits?

- What ITS technologies can be applied for each arterial ITS strategy?

- What lessons have been learned in deploying arterial ITS?

- What does these experience and data imply for Texas Arterial ITS implementations?

By integrating CTR's considerable in-house knowledge in the areas of ITS, traffic modeling, arterial study, and policy analysis with input from national and international experience, an early set of recommendations were generated for the TxDOT panel. The CTR team developed an annotated bibliography, covering performance measures to select arterial roads for ITS implementations, ITS strategies, and technologies.

Task 2: Define arterial performance measures and identify innovative strategies and technologies to improve arterial performance measurement

Developing clear and relevant performance measures for arterials is challenging due to complicated traffic control parameters and users with numerous origins and destinations. The objective of this task was to define arterial performance measures and identify innovative strategies and technologies to improve the accuracy of arterial performance measurement. The research team conducted the studies to:

- Evaluate the performance measures that are used to monitor arterial operations such as travel time, travel speed, traffic volumes, and intersection delay. With increasing data availability from ITS deployments, it is increasingly possible to develop and test new arterial performance measures.

- Tailor evaluation criteria to each of the constituencies expected to use a given performance measure—constituencies include management center staff, administrators, other agencies, and traveling public.

- Evaluate arterial performance measurement strategies and technologies:
  - Innovative vehicle detection system for point-based performance (using intersection detectors, supplemental detectors, or intelligent detectors)
  - Probe vehicles for link-based performance (using toll-tag readers at arterial intersections)

– Traced vehicles for section-based performance (using cell-phone tracking services).

Task 3: Identify the most beneficial ITS elements for arterial management

The objective of this task was to develop a guide to assist TxDOT staff in selecting the arterial management system elements that would benefit most from the implementation of ITS technologies. The research team conducted the studies to:

- Examine elements of arterial management systems, which include:
  – Arterial surveillance of operations and infrastructure
  – Traffic control (providing for transit priority, emergency vehicle preemption, adaptive signal control, etc.)
  – Lane management (HOV facilities, reversible flow lanes, emergency evacuation, etc.)
  – Parking management elements
  – Enforcement (speeding, red-light running, failure to stop/yield)
  – Integration with transit information systems
  – Incident management
  – Traveler information

- Develop a *matrix* that describes each element's configuration, potential benefits, targeting problems, implementation requirements, and cost estimation.

- Provide a description of how these ITS user services can be coordinated with those used to manage nearby freeway facilities and associated interchanges.

Task 4: Identify desirable ITS technologies and solutions for arterial management

The objective of this task was to develop a guideline to assist TxDOT staff in selecting the most effective ITS technologies to improve arterial management. The research team compared the available ITS technologies for each arterial management element. The advantages, disadvantages, and suitability of each technology option were identified. Specifically, the research team conducted the studies to:

- Evaluate available ITS technologies that can be applied for arterial management. A *matrix* was developed to describe each technology's advantages, disadvantages, implementation requirements, compatibility with existing infrastructure, implementation costs, and suitability for arterial management applications.

- Based on the evaluation results, the research team recommended a list of best ITS technology options.

Task 5: Evaluate traveler information dissemination modes for arterial management

The objective of this task was to develop a synthesis of user requirements and information dissemination modes for arterial management. Specifically, the research team conducted the studies to:

- Analyze the types of information that travelers want, including timing, location, and frequency. Existing efforts will be reviewed and synthesized.

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- Identify information sources and processing requirements.

- Evaluate traveler information dissemination modes such as internet web sites, dynamic message signs, highway advisory radio, in-vehicle systems, and personal wireless devices. Analyze each dissemination mode's suitability for arterial management applications.

- Identify the technological trends in traveler information dissemination so that TxDOT can better invest resources in traveler information systems.

Task 6: Develop a guideline to identify and prioritize arterials suitable for ITS implementations

The objective of this task was to develop a guideline so that TxDOT staff can use to identify and prioritize arterial roads suitable for ITS implementations. The choice of arterials for ITS implementations will not only affect the usability of the arterial management systems for large segments of the travelers but will also have profound impacts on the future development of the entire ITS system and adjacent freeway operations. The CTR team defined a set of arterial selection criteria. These criteria may include:

- Current level of service

- The number of beneficiaries of the new arterial management systems

- Existing ITS infrastructure and implementation costs for new arterial management systems

- Connections with other major arterials and freeways

Based on the evaluation results, a practical arterial selection method was developed and recommended to TxDOT.

Task 7: A case study to demonstrate how to develop arterial ITS applications

The objective of this task was to provide TxDOT with a methodology for developing arterial ITS applications. A case study was conducted in the Austin area based on the findings from Task 1–6. The CTR team developed guidelines to assist TxDOT staff in selecting the most beneficial arterial ITS elements, desirable ITS technologies, appropriate performance measures, and information dissemination modes for arterial ITS applications

- The research team collected data on traffic flows, vehicle speeds, and congestion on major arterials.

- The research team identified the arterials that are appropriate for ITS implementations. Characteristics of those arterials and suitability for arterial management systems were assessed.

- The researchers reviewed ITS strategies for arterial management and available technologies. The best ITS strategies and most effective ITS technologies were identified.

- The research team used traffic modeling techniques and simulated different arterial management scenarios. The simulation tool, VISSIM was used. The results were translated into an estimation of arterial ITS benefits. The methodology was documented along with required data inputs and simulation tools.

- Based on the results of the analysis, the research team examined the major arterials in the case study area and provided recommendations for implementation of arterial ITS.

1.5 Organization of Report

The reminder of this report is organized as follows: Chapter 2 presents a literature review and synthesis regarding the state-of-the-art in critical arterial ITS technologies and control strategies. Early recommendations are made based on the literature review. Chapter 3 presents the studies on arterial performance measurement evaluations. Then critical performance measures were investigated and identified through a survey study. Chapter 4 describes the identifications and evaluations of the most beneficial arterial ITS elements. Chapter 5 presents the research efforts and findings in the desirable ITS technologies and solutions for arterial management enhancement. Chapter 6 introduces various traveler information dissemination modes and their performance evaluations. The guideline was developed to prioritize suitable arterials for ITS implementations in Chapter 7. Chapter 8 presents a case study which demonstrates how to develop arterial ITS applications. Finally, Chapter 9 summarizes the important findings, conclusions, and recommendations from this study.

Chapter 2. Literature Review and Synthesis

2.1 Introduction

The primary objective of this literature review and synthesis was to seek national and international experience and data to answer the following questions:

- What performance measures can be used to identify the arterial roads for ITS implementations?

- What ITS strategies can be taken for arterial road management? For each arterial ITS strategy, what are the targeting problems and potential benefits?

- What ITS technologies can be applied for each arterial ITS strategy?

- What lessons have been learned in deploying arterial ITS?

- What does these experience and data imply for Texas Arterial ITS implementations?

Developing a strong foundation of the arterial ITS performance measures, strategies, technologies, and implementations is the basis of the research presented in this document. Both national and international experience within this field was reviewed and synthesized to provide a complete overview of the research done thus far as well as developments at the forefront of arterial management. The information gained can be built upon to aid TxDOT in the next step of this project, which is to take the performance measures outlined and identify innovative strategies and technologies to improve arterial performance measurement.

The work is broken down into Arterial ITS Implementations, Arterial ITS Technologies, Arterial ITS Strategies, Performance Measures, Arterial ITS Lessons Learned, and Arterial ITS Recommendations and Conclusions. Arterial ITS Implementations overviewed the main cities within the United States that are actively involved in Arterial ITS Management, have or are in the process of implementing new technologies, or are taking innovative steps to correct arterial congestion. The Metropolitan Model Deployment Initiatives (MMDI) for Phoenix, Arizona; Seattle, Washington; and San Antonio, Texas were then discussed along with the aspects of their respective projects that focused on arterial ITS. It is important to identify the leaders within arterial ITS because they will become resources as TxDOT develops its own guidelines for arterial ITS deployment.

Arterial ITS Technologies, discussed in Section 3, outline the main technologies being used in the field. The technologies have been broken down into Traffic Data Collection Systems, Traffic Control Technologies, and Information Dissemination Technologies. Each of the technologies was briefly described and some pictures were provided to show some of the lesser known technologies. Section 4 describes Arterial ITS Strategies and has been separated into three respective sections. The sections defined technologies and examples of arterial strategies implemented for Recurring Incidents, Non-Recurring Incidents, and the combination of technologies that can be used to aid in addressing both Recurring and Non-Recurring Incidents within an Arterial Management System. Performance Measures that could be used to evaluate congestion on arterials were then briefly summarized in Section 5. Following performance measures is a discussion of Lessons Learned in Arterial ITS as well as a Summary and Preliminary Recommendations formulated from the comprehensive literature review completed.

2.2 Arterial ITS Implementations

A large number of Arterial Management Systems have been implemented nationally. The cities most actively involved in the progress of Arterial ITS have been identified along with a brief synopsis of their contributions. In addition, the U.S. cities of Phoenix, Seattle, and San Antonio were discussed because of their involvement with the Metropolitan Model Deployment Initiative (MMDI), which implemented a variety of ITS technologies. The arterial ITS contributions are the focus of the information presented about the three MMDIs.

2.2.1 Main Arterial ITS Cities and States within the United States

Identifying cities with arterial ITS deployment within the United States was done by consulting the 2004-2006 Arterial Management Metropolitan Surveys conducted through ITS and the U.S. Department of Transportation. Current technologies were looked at along with what cities were deploying the technology. Attention was also paid to the size of the city; larger cities may have a lower percentage of arterial ITS deployment, but could have more technologies deployed than a smaller size city. The state of Texas rated high among the technologies evaluated. The cities of Austin, San Antonio, and Dallas/Fort Worth were all on the progressive side of ITS deployment. In particular, the city of San Antonio is leading the nation in variable speed limit technology with 13% of the roadway miles covered (ITS Deployment Statistics, 2006).

The metropolitan area of Los Angeles, Anaheim, and Riverside, California also rated high among deployed arterial ITS technologies. This metropolitan area leads the country with 254 dynamic message signs and also has 11% (987/9119 intersections) of their intersections under real-time traffic adaptive control (ITS Deployment Statistics, 2006). Several other cities are leading other categories for arterial ITS technology deployment, which can be summarized in more general terms with the most forward-thinking states. State DOTs that should be consulted concerning arterial ITS include Virginia, Florida, Arizona, Washington, North Carolina, New York, California, and Texas. These states have some of the best involvement with arterial ITS and may most likely provide the best information about their criteria for ITS performance measures and subsequent deployment.

2.2.2 Metropolitan Model Deployment Initiative (MMDI)

The Metropolitan Model Deployment Initiative began in October 1995 when Fedrico Pena, who was Secretary of Transportation, announced that Seattle, San Antonio, Phoenix, and New York City had been selected as cities for intelligent transportation systems (ITS) implementations (Wilbur, 1998). The program was jointly sponsored by the Federal Highway Administration (FHWA) and the Federal Transit Administration. The deployment sites featured examples of how technology information systems, along with better operation and management strategies, can improve transportation in metropolitan areas. The scope of the MMDI for the different cities varied slightly, but the ultimate goal was to have partnerships of public agencies and private companies combining their efforts to deploy "integrated, regional transportation management systems that provide improved operations, faster emergency response, and better incident management (Wilbur, 1998)." It was the goal of the studies to provide travelers in these areas with "up-to-the-minute traffic information, transit schedules and arrival times, parking availability and other transportation via the Internet, cable television, hand-held and in-vehicle devices, kiosks, and a variety of other devices (Wilbur, 1998)." Clearly all of the ITS

technologies implemented are not applicable for deployment on arterial roadways, but each of the studies did make a contribution to this area and those contributions were presented and discussed.

2.2.3 Description of Phoenix MMDI

The Phoenix MMDI was given the name AZTech and was a culmination of efforts from 19 public sector agencies and 13 private sector agencies over seven years (Zimmerman, 2000). Traffic management systems were deployed to help traffic signal coordination along major arterial roads and to implement a computer-aided incident management system. Of the 15 defined ITS projects, the two relating to arterial ITS will be discussed and technologies implemented within the system will also be noted. Getting the information to the system users was a main consideration of the projects and technologies that were used include Personalized Messaging System, Trailmaster Web Site and Roadway Closure and Restriction System (RCRS) Web page, commercialized Web Page, Traffic Check TV, In-Vehicle Navigation, Fastline PCD, Transit Status Information, and Information Kiosks (Zimmerman, 2000). These user interfaces are important because they are the means for ITS technologies to better serve the public.

Of interest to Arterial Management, three of the eight "Smart Corridors" were evaluated in the Phoenix area with different ITS technology implementations and they will be discussed in detail.

- *Scottsdale/Rural Road Corridor*: The corridor is 9.6 km and runs north/south connecting Tempe to Scottsdale. Arizona State University is also served by this major arterial. The corridor added 175 loop detectors and a closed circuit TV monitoring system. The two cities of Tempe and Scottsdale then coordinated three traffic signal timings out of the 21 mainline signals to increase speeds and reduce the frequency of stops, which was achieved. Also achieved was a reduction of crash risk by 6.7% for mainline travel as a result of the signal re-timing between the two cities (Zimmerman, 2000). However, the impact of the overall corridor performance including mainline and cross-streets was so small that it could not be reliably estimated. A simulation was then run to check the system and it was recommended that, to better serve the corridor, more corridor-wide signal re-timing should be considered at the jurisdictional boundary between the two cities (Zimmerman, 2000).

- *Southern/Baseline Smart Corridor*: This Smart Corridor consists of two parallel corridors that run on either side of the US-60 freeway and connect the City of Mesa and the City of Tempe. Sixty-five inductive loop traffic detectors and four changeable message signs were originally approved for the project (Zimmerman, 2000). However, the coordinated signal timing plan and the changeable messages signs were not in place during the evaluation period due to schedule impacts from the Mesa traffic control system (Zimmerman, 2000).

- *Bell Road Corridor*: This corridor was upgraded to automated traffic signal coordination like the previous corridors and both inductive loop detectors and closed circuit TV (CCTV) cameras were the technologies used for the upgrade. The corridor implemented 148 loop detectors as well as one CCTV monitoring system (Zimmerman, 2000). Although the Bell Road Corridor was initially considered it was found that the congestion subsided once a parallel freeway was opened. Therefore an evaluation of the

technologies wasn't conducted. Instead, the researchers looked at other corridors where traffic flow improvements could be measured.

These three corridor and in particular the Scottsdale/Rural Road Corridor should be looked at to see the technologies implemented and the successes/lessons learned from the arterial roadway network projects. As of 2006, Phoenix, Arizona has 53% of their signalized intersections covered by electronic surveillance and 70% of their signalized intersections are under centralized or closed loop control. They also have 27 installed Dynamic Message Signs; however, none of the city's 1,557 miles are covered by the Highway Advisory Radio (HAR) (ITS Deployment Statistics, 2006).

2.2.4 Description of Seattle MMDI

In Seattle, WA government interest in improving traffic congestion can be seen in the late 1980s as part of the FAME (Freeway and Arterial Management Effort) Program (O'Brien, 1991). It was this pre-existing interest in ITS, and the fact that Seattle is ITS-rich, that lead Seattle to be chosen as one of the four MMDI site locations (Jensen, 2000). Upon being selected, the Washington DOT entered into a public-private partnership with different organizations to implement various ITS technologies. This partnership would come to be known as Smart Trek. Evaluation of this system was done by focusing on three main areas, including institutional benefit, Advanced Traveler Information System (ATIS) customer satisfaction, and ITS integration modeling. The ITS integration modeling is more arterial specific and will be looked at with closer detail (Jensen, 2000).

ITS Integration Modeling: The goals of the ITS integration modeling were to evaluate the effects of "Advanced Traffic Management System (ATMS) arterial signal integration across multiple jurisdictions and traffic control system in a major metropolitan area and to provide the addition of arterial traffic information to Seattle arterial drivers via the Smart Trek ATIS system deployments (Jensen, 2000)." These evaluations are summarized in Table 2.1.

ATMS Signal Integration: The purpose of ATMS Signal Integration was to evaluate the effects of integrating signals across multiple jurisdictions. A coordinated fixed timing plan on along two major arterials (SR99 and SR522) in North Seattle was the focus of the evaluation. The test site, a 125-square-mile corridor, showed that traffic signal coordination has measurable benefits to both arterial streets and the surrounding roadways, as can be seen in Table 2.2 (Jensen, 2000).

ATIS for Arterial Data: The arterial data for ATIS was also tested in the North Seattle corridor; it provided arterial travel time estimates to drivers via ATIS system deployments (website, television, radio, etc.). It was shown that integration of arterial congestion data with freeway-based ATIS improved the effective utilization of ATIS services by travelers, even considering only a 6% usage rate of the ATIS system (Jensen, 2000). The improvements felt by the combination of data can be seen in Table 2.3.

Table 2.1: ITS Integration Modeling Evaluation Overview

Integration Option	Modeling Case Description	Modeling Results	
		System Traffic Flow	Emissions
ATMS Signal Integration	• Examine traffic flow and emissions effects of implementing multi-jurisdictional signal coordination within a major arterial corridor • Assumes coordinated and fixed signal timing plan • Compare to a baseline case of no traffic signal coordination	• Measurable benefits – 7% reduction in vehicle delay – no adverse impacts on cross-streets – no changes in benefits across varying demand and weather conditions	• No statistical change in emissions • Increases in emissions expected from slight increases in travel and higher speeds is offset by a reduction in vehicle stops
Arterial Data for ATIS	• Estimate arterial corridor traffic flow and emissions effects of providing arterial traveler info • Compare to baseline case which consists of freeway-based traveler information only • Assumes 6% ATIS market penetration	• Measurable benefits – 1.8% reduction in vehicle delay – 5.6% drop in number of stops – slight increase in vehicle throughput	• Across-the-board reductions in emissions – 2% reduction in CO – 2% reduction in NOx

Source: Seattle MMDI (Final Report)

Table 2.2: ATMS Signal Integration System Traffic Flow Impacts

Measures for Average AM Peak Period	Baseline	Signal Coordination	Change	% Change
Vehicle-Hours of Delay (annualized)	17,879	16,661	-1,218	-7.0%
Vehicle Throughput (annualized)	209,372	209,774	+402	+0.2%
Coefficient of Trip Time Variation	.242	.237	-.005	-2.1%
Vehicle-Km of Travel	3,438,000	3,455,000	+17,000	+0.4%
Total Number of Stops	1,200,000	1,167,000	-33,000	-2.7%

Source: Seattle MMDI (Final Report)

Table 2.3: Arterial Data for ATIS System Traffic Flow Impacts

Measure per Average AM Peak Period, North Corridor	Freeway ATIS	Freeway ATIS (+ Arterials)	Change	% Change
Vehicle-Hours of Delay	17,619	17,308	-311	-1.8%
Vehicle Throughput	209,382	209,575	+193	+0.0%
Coefficient of Trip Time Variation	.236	.247	+.011	+4.7%
Vehicle-Km of Travel	3,436,000	3,443,000	+7,000	+2.0%
Total Number of Stops	1,201,000	1,134,000	-67,000	-5.6%

Source: Seattle MMDI (Final Report)

From the modeling done for the Seattle MMDI, it was recommended that, where appropriate, cross-jurisdictional signal control integration utilizing ATMS systems should be implemented to reduce congestion and delay on overcrowded arterials. Also, ATIS websites should strongly consider additional data sensors for arterial corridors to allow traveler information to be collected and distributed (Jensen, 2000).

2.2.5 Description of San Antonio MMDI

The San Antonio MMDI had six transportation goals that they set out to achieve at the onset of the program. The arterial-related goals included goal number two, which was "to improve traffic management through the expansion of the existing TransGuide freeway management system and the integration of a portion of that expanded system with a newly deployed arterial management system (Carter, 2000)." And the final goal was to "offer an integrated, area-wide database of real-time traffic conditions. This database is intended to fuse information from multiple sources in order to provide travel speeds for freeways and major arterials (Carter, 2000)." San Antonio was selected for the MMDI because it had a preexisting system known as TransGuide that provided information about the infrastructure and system status. TransGuide was then used by the MMDI to improve the management of arterials, freeways, and emergency services as well as provide enhanced traveler information. However, focus will be given to the arterial management developed. The focus of the arterial management system in San Antonio is known as the Medical Center Corridor and aids in emergency management of arterials, which was then integrated with the TransGuide for the MMDI (Carter, 2000).

Arterial Focused ITS Deployed in San Antonio: The Medical Center Corridor was the main arterial development of this project and had a deployment cost of $525,000, with an annual cost of $47,000. The corridor is an 8.75-km arterial diversion corridor that has six DMS on the arterial route and a special incident response signal plan to divert vehicles. The following arterial-related ITS technologies were implemented in the San Antonio MMDI Project in addition to the corridor (Carter, 2000).

- 8.75-km Arterial Diversion Corridor integrated with parallel TransGuide freeway system.

- Six Dynamic Message Signs on arterial routes.

- 529 In-Vehicle Navigation (IVN) Systems distributed to public-agency-owned vehicles. The INV system provides route guidance and real-time information on traffic congestion, incidents, and highway-rail intersections.

- 36 indoor and 4 outdoor Kiosks that provide users with current roadway conditions along with static transit information.

- A Web Page that includes freeway travel speeds along with travel times and video images.

- Travel Data Server that fuses data from a broad range of sources into a single real-time database. The system provides static information on transit and operations; dynamic information about incidents and road closings, and real-time estimates of link specific travels speeds or times.

- 40,000 vehicle probes were voluntarily distributed. The probes are characterized as passive automatic vehicle identification tags that can be read at the 53 reading locations when the vehicle passes under the reader.

Results of Goals and Arterial-Focused ITS Deployment in San Antonio: It was seen in the case of Arterial Management, with a major incident in the Medical Center Corridor (MCC), that delay was reduced by 2.8% (Carter, 2000). Also as a result of the study, it was found that all of the MDDI studies that integrated freeway/arterial diversion corridors (the MCC), experienced significantly reduced delay, crash risk, and fuel consumption. Other findings from the deployed arterial ITS technologies include (Carter, 2000):

- Current user levels of the Web-based ATIS services were low, but are expected to increase.

- Kiosks were very ineffective within the system and were used less than the Web pages. Also, deploying the kiosks proved difficult.

- The IVN systems were found beneficial by the public agencies, but proper training, maintenance, and equipment selection is essential for their success.

- It was found that travelers want more arterial roadway information and that vehicle probes could be a way to deliver this information if enough probes are deployed within in the system.

- It was found that travelers can relate more accurately to shared information concerning travel times and camera images.

When compiling the information to create the travel speed and roadway condition database, one of the major issues was how to determine the travel speed. Several options were considered. The options included theoretical speed estimates, floating GPS-equipped vehicle readings, TransGuide freeway and incident management system, and the Automated Vehicle Identification (AVI) traffic probes. It was found that vehicle probes effectively collect travel speeds if the level of market penetration is adequate (enough people have the tags). Also, travel time information on VMS and on the Internet was found to be popular in San Antonio. However, the public feels that if the freeway and arterial information was integrated it would make for a better system. It can be recommended from this project to implement congestion strategies such as the MCC, the San Antonio Traffic Web Pages, and the Integrated Travel Data Server (functions for freeways only). Promising parts of the project that need more time to develop were the INV system for public agencies along with the Integrated Travel Data Server, which lacked arterial speeds at the time of evaluation due to vehicle tags not attaining an adequate market penetration. The ITS progress will continue to develop within San Antonio, Texas and can be looked to for innovative applications of current technologies (Carter, 2000). As of 2006, San Antonio had 99% of their signalized intersections covered by electronic surveillance and 68% of their signalized intersections under centralized or closed loop control. They also have 209 dynamic message signs throughout the city and 4% of their arterial miles are coved by the Highway Advisory Radio (HAR) (ITS Deployment Statistics, 2006).

2.2.6 Description of New York/New Jersey/Connecticut MMDI

Unlike San Antonio, Phoenix, or Seattle, the New York/New Jersey/Connecticut MMDI project focused on the institutional issues, not the deployment of ITS. As a result, the details of the New York/New Jersey/Connecticut MMDI are not discussed in depth here. For more information, refer to the *New York MMDI Lessons Learned Report* and the *Successful Practices for Deploying an Intelligent Transportation System* (Jensen, 2000).

2.3 Arterial ITS Technologies

Several types of ITS technologies are being applied to traffic networks across the United States and the world. ITS technologies that are applicable for use in arterial settings have been broken down into the following three sections: Traffic Data Collection Systems, Traffic Control Technologies, and Information Dissemination Technologies. Details are then given for each type of technology presented, including benefits and significant comments derived from the literature.

2.3.1 Traffic Data Collection Systems

One of the key components in ITS is the data that is being collected and used. Numerous technologies are used to gather data, each with its own advantages and disadvantages. Generally, the traffic data collection systems can be broken down into two categories: fixed location detectors and vehicle-based detectors. In the following section, each technology is listed within its respective category along with the benefits and problems encountered using the technology.

Fixed Location Traffic Data Collection Technologies

Inductive Loop Detectors (ILD): ILDs are the most traditional data collection technology and their operations are well understood within the industry due to the commonality of the technology. They have a flexible design to satisfy a large variety of applications that can be modified for accurate count data (as compared to other commonly used technologies). ILDs are insensitive to inclement weather. The weaknesses of ILDs include the installation and maintenance, which require lane closures, and the tendency for them to wear out/break due to pavement and ground conditions. The technology can measure volume, presence, occupancy, speed, headway, and can give gap traffic readings (Mimbela, 2007).

Magnetometer (two-axis fluxgate magnetometer): Magnetometers are less susceptible to the stress of traffic and yet still remain insensitive to weather. Like ILDs, a magnetometer's weakness includes the physical impact to the pavement and required lane closure for installation and maintenance. Magnetometers measure volume, presence, occupancy, speed, and headway, and can give gap traffic readings (Mimbela, 2007).

Magnetic (induction or search coil magnetometer): Magnetic sensors can be used in locations where ILDs are not feasible (ex: bridge decks). They are insensitive to inclement weather, and can be installed without road cuts by boring under the roadway. They cannot detect stopped vehicles without special sensor layouts or signal processing software. This technology measures volume, presence, occupancy, speed, and headway, and can give gap traffic readings (Mimbela, 2007).

Microwave Radar: Microwave radar provides the option of multiple lane operation, but cannot detect stopped vehicles. The technology can measure speed directly along with vehicle length (Mimbela, 2007). A photograph of microwave radar used for vehicle detection purposes can be seen in Figure 2.1 (Elmore Group, 2007).

Figure 2.1: A Microwave-Based Vehicle Detection Device
(Source: Elmore Group)

     Active Infrared: Active infrared can be described as multiple beams that are transmitted to provide accurate measurements of vehicle position, speed, and class. The technology can be used for multiple lane operations. The weaknesses of active infrared include decreased function in fog and blowing snow and continued lens cleaning maintenance. Active infrared can measure vehicle position, speed, and class (Mimbela, 2007).

     Passive Infrared: Passive infrared uses multiple passive sensors to measure speed. The weaknesses of passive infrared sensors include reduced sensitivity in heavy rain, snow, and dense fog. The technology measures vehicle speed, traffic counts, and vehicle presence (Mimbela, 2007). A Passive Infrared Radar traffic detector can be seen in Figure 2.2 (FABEMA, 2007).

Figure 2.2: Passive Infrared Radar Traffic Detector
(Source: FA BEMA Mobile Traffic Lights)

Ultrasonic: This technology has been used extensively in Japan and allows multiple lane operation and the detection of over height vehicles. It is sensitive to temperature change and extreme air turbulence, and many undercount in situations where vehicles are moving at moderate to high speeds due to the large pulse periods. The technology is used to measure presence, occupancy, and classification (Mimbela, 2007).

Acoustic: This technology allows for passive detection and has no sensitivity to precipitation and the option of multiple lane operation in some models. Vehicle count accuracy can be affected by cold temperatures and is not always recommended with slow moving vehicles in stop-and-go traffic. Acoustic detectors can measure vehicle detection, handle traffic counting, and give occupancy per lane of traffic in free-flow traffic at speeds of more than 30 MPH (Mimbela, 2007). An acoustic traffic detector can be seen in Figure 2.3 (SmarTek Systems, Inc., 2007).

Figure 2.3: The SAS-1 Acoustic Detector
(Source: SmarTek Systems, Inc.)

Video Image Processor (VIP): VIPs are most often used for signal processing and signal actuation. VIPs allow for a wide array of data to be collected across multiple lanes and detection zones that can be easily added or adjusted. The technology can determine vehicle class, vehicle presence, flow rate, occupancy, and speed (Mimbela, 2007).

Closed Circuit Television (CCTV): Closed Circuit Television is a way of using VIP for surveillance, and has strengths and weaknesses similar to the VIPs.

IPEX Cameras: An IPEX Camera has a wide angle and is used for surveillance that allows multiple users to pan and zoom without interfering with other user's desired view (Knee, 20004). This technology has strengths and weaknesses similar to the VIP.

Vehicle-Based Traffic Data Collection Technologies

Pavement Magnets with Onboard Magnetic Field Detectors: This technology warns drivers if travel speed is unsafe, and can determine travel times if distance between magnets is known. Pavement magnets with onboard magnetic field detectors can measure speed and travel time (Ivan, 1997).

Tracking Vehicles Using Satellites: This technology can follow vehicles through a highway network to measure travel times and traffic density (Ivan, 1997).

Wireless Communication Technologies: This is a newer technology that uses cell phone signals to track vehicles throughout a system. Currently, the refinement of the technology is still in the beginning stages. Issues have occurred with uncertainty surrounding how to attach the cell phone signals to vehicles. It is intended that this technology measure speed and travel time (Fontaine, 2007).

2.3.2 Traffic Control Technologies

Adaptive Signal Control/Adaptive Traffic Control Systems (ACTS): This ITS technology allows coordination control of traffic signals across a network. The signal length phases are adjusted according to the current traffic conditions. Benefits include a reduction of travel, average stop times, and delay, and an increase in speed on the arterials (ITS Benefits, 2007). The 2006 Metropolitan Survey found the cities of Richmond and Petersburg, Virginia to have the highest deployment of this technology with 55% in their network system. Nationally only 3% of signalized intersections are equipped with adaptive signal control, totaling 4,931 signalized intersections (ITS Deployment Statistics, 2006). Adaptive signal controls have also been implemented internationally in Canada, England, Spain, and Brazil, among others. Currently the adaptive signal control systems being used include SCOOT (United Kingdom), SCATS (Australia), OPAC (United States), RHODES (United States), and LA-ATCS (United States) (Martin, 2003). Another adaptive control software that provides benefits over typical traffic signal timing systems is known as ACS-Lite and was developed by the Federal Highway Association (ACS-Lite, 2007).

Advanced Signal Systems: This ITS technology uses coordinated signal operations across neighboring jurisdictions. It also develops a centralized control of traffic signals that may include some necessary technologies from adaptive signal control. The main benefits of advanced signal systems is a reduction in delay, emissions, crash frequency, travel times, and fuel consumption (ITS Benefits, 2007). The 2006 Metropolitan Survey found that this system was widely used by all 108 Metropolitan Areas surveyed; West Palm Beach, Boca Raton, and Delray, FL—along with Pittsburgh and Beaver Valley, PA—had 100% of their signalized intersections operating under closed loop or a central system control (ITS Deployment Statistics, 2006). However, it was noted that properly trained staff is needed to maintain the signal system, jurisdictions have to work together, and a sharing of information among different agencies is encouraged for successful implementations (ITS Lessons Learned, 2007).

Variable Speed Limits: This ITS technology uses sensors to monitor traffic conditions and in some cases weather conditions. The information collected then can be posted as enforceable speed limits on dynamic message signs. This technology is in its beginning stages and as of the 2006 Metropolitan Survey it was found that only eight metropolitan areas had deployed variable speed limits (ITS Deployment Statistics, 2006). Those metropolitan areas include Denver and Boulder, CO; Los Angeles, Anaheim, and Riverside, CA; New York, Northern New Jersey and Southwestern Connecticut, NY; Phoenix, AZ; Providence, Pawtucket

and Fall River, RI; Santa Barbara, CA; Seattle and Tacoma, WA; and Washington, DC (ITS Deployment Statistics, 2006). Variable speed limits being used in Washington State are shown in Figure 2.4 (WSDOT Projects, 2007).

Figure 2.4: Variable Speed Limit Sign used on I-90 on Snoqualmie Pass in Washington.
(Source: Washington State Department of Transportation)

2.3.3 Information Dissemination Technologies

Dynamic Message Signs (DMS)/Changeable Message Signs (CMS): This ITS technology is used to share network information with the customers and helps to provide users with more information about the arterial system. The signs are used to convey information about advisory recommendations concerning incident management and potential delays within the system (American Signal Company, 2002). The benefits seen with sign usage include reduction of crash fatalities, emissions, delay, and total number of stops, with an increase in throughputs. The technology is especially useful for non-recurring congestion (ITS Benefits, 2007). As of the 2006 Metropolitan Summary done by the ITS JPO, 51of the 108 metropolitan areas evaluated yearly have DMS deployed in their systems. The Los Angeles/Anaheim/Riverside Metropolitan Area topped the list with 254 DMS reported (ITS Deployment Statistics, 2006).

Portable Changeable Message Signs (PCMS): This ITS technology is mainly used for temporary purposes. These signs come in a variety of different set ups and can be mounted to a vehicle or towed by a trailer. These signs are LED dynamic and programmable for use for quick incident response or moving work zone operations on both freeways and arterials (American Signal Company, 2002).

In-Vehicle Systems (IVS)/ En-Route Traveler Information: Five main types of en-route traveler information were recognized and included in the 2006 Metropolitan Summary done by

ITS and the U.S. Department of Transportation: 1) Internet or wireless systems, 2) the national number 511, 3) other telephone systems, 4) the radio, and 5) IVS deployed by the metropolitan areas surveyed. It was found that radio was the most used en-route traveler information with 39 metropolitan areas using this information dissemination method (ITS Deployment Statistics, 2006).

Highway Advisory Radio (HAR): This ITS technology focuses on the use of radios to inform drivers of the highway and arterial conditions that could alter the normal traffic experienced by the road users. HAR is currently not widespread and is being used by only 42 metropolitan areas. Of the 108 metropolitan areas, only 2478 miles are covered by highway advisory radio, which accounts for only 2% of the roadway miles in these areas (ITS Deployment Statistics, 2006). The benefits of this dissemination technology have been reported as increased throughput and reduced vehicle-hours of delay (ITS Benefits, 2007). This is an evolving technology and could be used on a greater scale to help relieve traffic situations on arterials.

2.4 Arterial ITS Strategies

Several studies noted that combining ITS technologies can result in better performance of the network system in question. A way to break down the technologies to better service state and local governments looking at implementing ITS technologies is to group them into strategies. Three strategy types will be discussed along with technologies best suited for the situation. Case studies will also be presented to support the combination of technologies. The strategies being considered are ITS technologies best suited to relieve Recurring Incidents, ITS technologies best suited to relieve Non-Recurring Incidents, and ITS technologies that in combination can resolve both Recurring and Non-Recurring Incidents within the system.

2.4.1 Strategy: Recurring Incident ITS Technologies

A *recurring incident* is one that can be defined as having fixed location or time and occurs with regularity within the network system. Examples of recurring incidents include bottle necks and operations such as signal timing and capacity issues. Two recurring traffic incidents found within the literature reviewed will be described along with their implemented ITS technologies.

Denver, Colorado: The city of Denver began the Transportation Expansion Project along I-25 in Denver in mid-2001. Project completion was expected in fall of 2006. One of the projects requirements was that "an arterial detection system had to be installed to monitor real-time traffic conditions on the surface arterial street system, to guide motorist through the general construction area (Powell, 2004)." The design team selected a system using video detection cameras located upstream of major approaches. As of late May 2004, 293 of 300 intersection approaches using the advanced vehicle detection system (AVDS) were operational and could provide the public with live congestion information via the project website. Although the arterial monitoring developed as a result of the construction, it was foreseen that the system could have a permanent operation on selected intersections once the I-25 project was complete (Powell, 2004).

Calgary, Alberta, Canada: The recurring traffic incidents facing Calgary were rail cars blocking roads within the industrial part of the city. The recurring blockage resulted in delays for motorists and the development of long queues extending to a freeway exit ramp. Instead of removing the at-grade rail crossings, the city decided to implement ITS technologies to deal with the recurring traffic incidents that could last upward of 30 minutes. The system was installed in

April 2005 and the key components of the system included video-based vehicle detection, traffic signal control, and five portable changeable message signs (PCMS) (Bushman, 2005). It was found that "the use of ITS at this site has provided motorist with advanced warning of delay conditions and better traffic management by diverting traffic around the congested area and more efficiently servicing traffic queues formed as a result of train crossings (Bushman, 2005)."

Upon review of the ITS technologies available, technologies best suited for recurring incidents would include Adaptive Signal Control, Advanced Signal Systems, Dynamic Message Signs, Portable Changeable Message Signs, In-Vehicle Systems (IVS)/En-Route Traveler Information, fixed location traffic data collection technologies, vehicle-based traffic data collection technologies, and possibly Highway Advisory Radio. These technologies individually can help, as was seen in the Denver case with implementing video detection cameras. However, combining technologies, as was done in Calgary, often can provide a system more adaptable to recurring traffic incidents.

2.4.2 Strategy: Non-recurring Incidents

A *non-recurring incident* is one that can be describes as a onetime event like a traffic accident or an entertainment event. Described here are three non-recurring traffic incident examples found within the literature. The ITS technologies used to lessen the impacts of the non-recurring incidents will be discussed.

Phoenix International Raceway: Phoenix International Raceway (PIR) in Phoenix, Arizona is the site of large NASCAR races. The lack of arterial and freeway access to the raceway has caused problems for people getting to and from the events. Starting with the races in November 1999, the Maricopa County DOT, Maricopa County Sheriff's Office, Arizona Department of Transportation, the local Police, and the Regional Emergency Action Coordinating Team (REACT) teamed together to provide traffic management for the event. To make the most of the existing infrastructure, they used ADOT's existing freeway variable message signs (VMS) along with additional portable VMSs to provide directional assistance for those trying to get to the race. Then, using CCTVs and video from a helicopter, the traffic command center was able to view the action live and provide traffic advisories via the ADOT highway advisory radio. Over the three-day event, the coordination between agencies and use of ITS technologies was able to cut the average travel time from the PIR to Phoenix from 2 to 3 hours to between 25 and 30 minutes from 1998 to 2000 while increasing the number of visitors by almost 50,000 (Thompson, 2001).

ADVANCE, Chicago: Proposed in Chicago, Illinois in 1993, the Advanced Traveler Information System demonstration was tested as a way to help alert travelers to potential traffic problems due to unexpected events on the roadways. ADVANCE was an ATIS created by the Illinois University Transportation Research Consortium (IUTRC), Motorola, the Illinois Department of Transportation (IDOT), and the Federal Highway Administration in order to "identify non-recurring, capacity reducing incidents on the ADVANCE highway network (Ivan, 1993)." Using probe vehicle data, fixed detector data from inductive loop detectors and anecdotal sources from police, firefighters, and other call-in sources, a set of algorithms was derived to determine the likelihood of an incident. It was not discussed what was done with this data, but it is reasonable to assume that it could be used for practices such as emergency dispatch and incident management (Ivan, 1993).

Northern Virginia: In the northern Virginia urban area, the development of real-time traffic diversion using ITS was tested. It combines incident detection methods with traveler

information dissemination systems to identify accidents and reroute the traffic along alternate routes. Once an incident is identified, different alternative routes based on the quickest travel time and ability to handle the increased demand are activated until the incident is cleared and traffic returns to normal around the scene of the incident. A similar approach is being used by TxDOT in El Paso, Texas (Hobeika, 1993).

As can be seen from these three examples, there are several ITS technologies that apply generally to non-recurring incidents. They include the detection of the incidents through whatever detection system is most appropriate for the situation and the dissemination of information to the traveler about the incident and possible alternate routes through the use of VMS and/or traffic information media (radio, television, PDA's, etc).

2.4.3 Strategy: Combination of Recurring and Non-recurring Incidents

As demonstrated, combining technologies within the respective strategy of recurring or non-recurring incidents provides a more complete way to manage these varying types of incidents. In some cases, state and local government agencies have opted to combine the ITS technologies available to deal with these two types of incidents. Often one type of technology can service both incident types, as is the case with dynamic or changeable message signs, which can be used for both recurring and non-recurring traffic events. The arterial applications done within the context of the Phoenix, Seattle, and San Antonio MMDI implemented technologies in the arterial systems to deal with both recurring and non-recurring incidents. In this way, the state or local government agency can get the most results and improvements out of the selected combination of ITS technologies implemented. For specific examples of the combined technologies implemented within the MMDI see Section 2. One other example of combining ITS technologies to relieve recurring and non-recurring incidents is briefly described here.

Ottawa, Canada: The study in Ottawa looked at using micro-simulators to test different ITS technologies and come up with the best combination of technologies to relive the congestion being felt in the city. Although not applicable to our situation, ramp metering was looked at to relieve freeway congestion, an incident management plan was considered, variable message signs were evaluated, and a scenario where en-route traveler information was given using real-time traffic conditions (Khan, 2006). The different technologies were considered for freeway/arterial congestion improvements as an alternative to adding more capacity to the freeway, i.e., extra lanes. After testing the different technologies against the base case, it was concluded that "a package of measures is needed, some targeted at reducing travel demand, and others aimed at improving traffic operations and the efficiency of the transportation network (Khan, 2006)." This conclusion is one shared by several different studies. Combining ITS technologies for both recurring and non-recurring incidents provides the arterial coverage within the system.

2.5 Performance Measures

2.5.1 Congestion Performance Measures

Several congestion performance measures were found in the literature reviewed. The majority of the performance measures were found in the Texas Transportation Institute's (TTI) Urban Mobility Study and the National Cooperative Highways Research Program Report 398 entitled Quantifying Congestion. The performance measures that can be used to evaluate arterial operations are briefly described here.

- **Roadway Congestion Index:** "This index allows for comparison across metropolitan areas by measuring the full range of system performance by focusing on the physical capacity of the roadway in terms of vehicles (Boarnet, 1998). The index measures congestion by focusing on daily vehicle miles traveled on both freeway and arterial roads (Medley, 2003)."

- **Travel Rate Index:** "This index computes the 'amount of additional time that is required to make a trip because of congested conditions on the roadway (Schrank, 2001).' It examines how fast a trip can occur during the peak period by focusing on time rather than speed. It uses both freeway and arterial road travel rates (Medley, 2003)."

- **Travel Time Index:** "This index compares peak period travel and free flow travel while accounting for both recurring and incident conditions (Schrank, 2001). It determines how long it takes to travel during a peak hour and uses both freeway and arterial travel rates (Medley, 2003)."

- **Travel Delay:** "Travel delay is the extra amount of time spent traveling because of congested conditions (Schrank, 2001). The TTI study divided travel delay into two categories: recurring and incident (Schrank, 1997), (Schrank, 1998), (Medley, 2003)."

- **Buffer Index:** "The buffer index calculates the extra percentage if travel time a travelers should allow when making a trip in order to be on time 95% of the time (Lomax, 2001). This method uses the 95th percentile travel rate and the average travel rate, rather than average travel time, to address trip concerns (Medley, 2003)."

- **Misery Index:** "The misery index represents the worst 20 percent of trips that occur in congested conditions (Lomax, 2001). This index estimates the negative aspect of trip reliability by looking at only the travel rate of trips that exceed the average travel rate (Pearce, 2001). This index measure how bad the congestion is on the days congestion is the worst (Medley, 2003)."

- **Travel Rate:** "Travel rate estimated in minutes per mile is how quickly a vehicle travels over a certain segment of roadway (Lomax, 1997). It can be used for specific segments of roadway or averaged for an entire facility. Estimates of travel rate can be compared to a target value that represents unacceptable levels of congestion (Medley, 2003)."

- **Delay Rate:** "The delay rate is 'the rate of time loss for vehicles operating in congested conditions on a roadway segment or during a trip (Lomax, 1997).' This quantity can estimate system performance and compare actual and expected performance (Medley, 2003)."

- **Total Delay:** "Total delay is the sum of time lost on a segment of roadway for all vehicles (Lomax, 1997). This measure can show how improvements affect a transportation system, such as the effects on the entire transportation system or major improvements on one particular corridor (Medley, 2003)."

- **Relative Delay Rate:** "The relative delay rate can be used to compare mobility levels on roadways or between different modes of transportation (Lomax, 1997). This measure compares system operations to a standard or target. It can also be used to

compare different parts of the transportation system and reflect differences in operation between transit and roadway modes (Medley, 2003)."

- **Delay Ratio:** "The delay ratio can be used to compare mobility levels on roadways or among different modes of transportation (Lomax, 1997). It identifies the significance of the mobility problem in relation to actual conditions (Medley, 2003)."

- **Congested Travel:** "This measure concerns the amount and extent of congestion on roadways (Lomax, 1997). Congested travel is a measure of the amount of travel that occurs during congestion in terms of vehicle-mile (Medley, 2003)."

- **Congested Roadway:** "This measure concerns the amount and extent of congestion that occurs on roadways (Lomax, 1997). It describes the degree of congestion on the roadway (Medley, 2003)."

- **Accessibility:** "Accessibility is a measure of the time to complete travel objectives at a particular location (Lomax, 1997). Travel objectives are defined as trips to employment, shopping, home, or other destinations of interest. This measure is the sum of objective fulfillment opportunities where travel time is less than or equal to acceptable travel time. This measure can be used with any mode of transportation but is most often used when assessing the quality of transit service (Medley, 2003)."

- **Speed Reduction Index:** "This measure 'represents the ratio of the decline in speeds from free flow conditions (Lomax, 1997).' It provides a way to compare the amount of congestion on different transportation facilities by using a continuous scale to differentiate between different levels of congestion (Lomax, 1997). The index can be applied to entire routes, entire urban areas, or individual freeway segments for off-peak and peak conditions (Medley, 2003)."

- **Congestion Severity Index:** "This index is 'a measure of freeway delay per million miles of travel (Turner, 1992).' This measure estimates congestion using both freeway and arterial road delay and vehicle miles traveled (Medley, 2003)."

- **Lane-mile Duration Index:** "This index is a measure of recurring freeway congestion (Turner, 1992). This index measures congestion by summing the product of congested lane miles and congestion duration for segments of roadway (Medley, 2003)."

- **Level of Service (LOS):** "LOS differs by facility type and is defined by characteristics such as vehicle density and volume to capacity ratio (Turner, 1992). Congested conditions often fall into a LOS F range, where demand exceeds capacity of the roadway. Volume to capacity ratios could be compared to LOS to reach conclusions about congested conditions; however, there is no distinction between different levels of congestion once congested conditions are reached (Medley, 2003)."

- **Queues:** "Queues, or traffic back-ups, best represent the public's view of congestion (Levinson, 1996). Queues can be measured using aerial photography, which can often determine performance measures such as LOS and queued volume (Medley, 2003)."

2.5.2 Pair wise Comparison Method for Evaluation using Performance Measures

Using the performance measures described, *Pair wise Comparison Method for Evaluation of ITS Investments* (Dugas, 2003) presents a method for evaluating the goals of a project based on different performance measures. Intended to be used as a project evaluation tool, pairwise comparison allows different performance measures to be evaluated for the project as a whole and for the individual elements. Then, using a cycle of comparison matrices, eigenvalues, eigenvectors, a final table of priority vectors for each device, and a specific goal, the project as whole is evaluated. This allows the devices to be ranked by each performance measure and overall in the level of effectiveness. Thus each device can be compared to one another for overall effectiveness, taking into account the priority of the goals set out for the project (Dugas, 2003).

2.5.3 User Performance Measures

User performance measures tend to be somewhat more subjective than the conventional transportation system performance measures. And they can be developed from user satisfaction surveys (focus groups, web surveys, phone surveys, etc.) as seen in the MMDIs as well as *551 Virginia Evaluation Report* released in January of 2004 (Swan, 2004). One example of incorporating user performance measures into the typical system performance measures is described in Florida's HEFT Test Corridor, discussed here.

Florida Department of Transportation, HEFT Test Corridor: The Florida Department of Transportation (FDOT) has created a DMS deployment framework that has been kept as generic as possible so that the process can be used not only for DMS but also for an ITS device deployment. Florida has recognized the DMS systems as "one of the most proven, visible, and effective ITS solutions (Murthy, 2003)." However, the Department's current "performance measures primarily focus on the highway geometric and traffic engineering parameters such as delay, speed, traffic volume, capacity, safety rations, skid resistance indexes, super elevation, horizontal and vertical curves, degree of curvature, etc. (Murthy, 2003)." These parameters don't completely reflect the user wants and needs within the system and the user performance measures differ greatly from what was described earlier. The study's focus was then to incorporate user DMS performance measures with FDOT performance measures and "develop a framework of Continuous Improvement Process (CIP) for DMS deployment and integrated operation with Traffic Management Centers and other corresponding ITS elements (Murthy, 2003)." Internal benchmarking, along with measures of effectiveness (MOEs), was used in combination to evaluate DMS within the system.

The Homestead Extension of Florida's Turnpike (HEFT) was used as a test corridor and the DMS internal benchmarking was "used to determine suitable locations for DMS deployment and identify appropriate DMS operational criteria that are exclusively applicable to the Turnpike System (Murthy, 2003)." Although this DMS deployment was done on a turnpike, the development of internal benchmarking as a performance measure that incorporates user wants and needs with FDOT's system performance measures could be a way to evaluate ITS deployment on arterial roadways.

2.6 Arterial ITS Lessons Learned

There are plenty of lessons learned from actual applications of Arterial Management Systems nationwide. Following are those lessons that are directly applicable to arterial ITS (ITS Lessons Learned, 2007):

- **Maintain, reinforce, and expand existing programs to improve traffic signal operation:** From Wisconsin's Department of Transportation self-assessment and peer review process, they determined that there are three things other agencies can do to develop a strong traffic management program: craft a program of sustainable funding for traffic operations, build a true statewide program, and create a standard for personnel certification and qualification.

- **Test new signal timing plans, even on a shoestring budget:** Based on research published by the Federal Highway Administration (FHA), it was shown that for signal timing plans done with a limited budget, the signal timing parameters should be installed at each controller, the plans should be tested at a benign traffic period like the mid-morning after the morning peak period, and then the plan can be placed in operation for the period it was designed for. Also, whenever possible a travel time and stopped-time delay study should be performed to determine the full effects of the new timing plans.

- **Conduct a site survey when developing a new signal timing plan:** Another lesson learned from the research published by the FHA is that a site survey is one of the most important steps in the signal retiming process. The outline of a good site survey includes conducting the site survey after all the existing data have been collected and organized, so that the accuracy of the existing data can be verified. The intersections should be visited during the time period for which the plans are developed. During those visits, the following information should be collected or verified: geometric layout with lane configurations, sight distance, and curb restrictions, phasing diagram, detector diagrams, existing controller settings, and traffic flow.

- **Adopt a performance-based, proactive approach to traffic signal operations in order to maximize operational efficiency:** Based on a study done in Minneapolis, Minnesota, it was found that a performance-based approach is good, because it provides a baseline for knowing how the system is working. Also a proactive approach should be taken, so that problems are addressed before they occur.

- **Maintain adequate funding and personnel levels to maximize efficient operation of traffic signal systems operations:** It was also recommended to the city of Minneapolis, Minnesota that, to prevent and/or address some of the problems found (failed detectors, malfunctioning signals, etc.), the funding for traffic signal operations should be improved. It was also stated that more personnel should be hired to maintain adequate personnel levels, so that problems found can be addressed in a timely manner.

- **Use a regional approach for traffic signal systems operations to realize cost efficiencies:** From the self-assessment that the National Transportation Operations Coalition (NTOC) performed for the Minneapolis Department of Public Works, it was found that building a regional program for system operation and investments allows better use of funds by eliminating duplicate systems and promoting improved traffic flow across the region.

- **Partner with neighboring agencies, either formally or informally, to address institutional challenges and benefit from cross-jurisdictional traffic signal coordination:** Along the same lines as the lesson learned in Minneapolis, case studies

in Philadelphia, Pennsylvania; Montgomery County, Maryland; Monroe County, New York; Tucson, Arizona; and the City of Greenwood Village, Colorado showed that signal coordination across jurisdictions is achievable no matter what size the community is or the number of jurisdictions involved. Some of the keys to success included addressing comfort levels when establishing formal or informal agreements among agencies, exploring alternative arrangements for cooperation that suit the local landscape, and taking advantage of facilitation by regional governmental organizations.

- **Hire properly trained staff to deploy and maintain traffic signal systems:** From the 2002 FHWA synthesis of best practices of traffic signal system procurement techniques, the following experiences were revealed: continuing education must be recognized and budgeted to ensure success, the abilities of an agency to deploy and maintain a traffic signal system must be considered before deployment, telecommunication expertise is critical to success, and close cooperation with maintenance staff is required for a successful deployment.

- **Establish a working group among public sector partners to address liability issues:** In Phoenix, it was shown that to reduce liability issues, a group can be formed to define and document a series of thresholds under which signal plans can be altered, and to establish written coordination policies and plans to cover signalized corridors bordering multiple jurisdictions.

- **Implement a communication structure across jurisdictions that facilitates the flow of data and allows agencies to coordinate traffic signal timing:** From the MMDIs in Phoenix and Seattle, it was learned that cross jurisdictional communications allow for real-time traffic operations information and update signal plans that can result in reduced traveler delays and decreases in crash risk.

- **Develop a user-oriented system for displaying travel time messages on dynamic message signs:** Based on case studies in Chicago, Houston, Nashville, and Portland, Oregon, where current travel times are posted using DMS, an outline was developed to provide guidance on how to ensure that travel time data is meeting the wants/needs of the driving public. It includes defining the target audience to help determine travel time destinations and messaging format, accommodating difficulties in accurately estimating travel times by displaying travel time ranges, displaying travel times in a concise, easily comprehendible format, deploying DMS prior to key decision points where commuters can decide to take alternate route, and soliciting driver feedback to determine what information is most desired on DMS.

- **Optimize travel time messaging operations by improving the way in which data is collected, analyzed, and displayed:** Those same four cities (Chicago, Houston, Nashville, and Portland, Oregon) have also provided lessons that are useful in planning and designing how information is going to be collected, analyzed, and presented.

- **Follow accepted guidelines to create concise, effective messages to communicate to the public using Dynamic Message Signs (DMS):** The Changeable Message Sign Operation and Messaging Handbook was written for those who are in charge of the operation and/or message design for CMSs. The lessons learned include practical guidance on the design of dynamic message signs such as providing motorists with

early warning messages, and designing DMS messages to be brief, to the point, have impact, and use consistent message elements and presentation order.

- **Adopt an adequate and thorough procurement process that covers purchases of both standardized "commodity" type equipment and highly complex integrated ITS components:** In the Silicon Valley Smart Corridor in San Jose, California, it was learned that there should be different process for the procurement of different elements of ITS projects. Separating standard "commodity" items from more complex ITS components so that time and effort are not wasted on the procurement of "commodity" items that is necessary for more complex and expensive ITS elements.

- **Deploy ITS systems strategically to achieve benefits:** The San Antonio MMDI Medical Center Corridor showed that, even without a large deployment area, a large impact can be made provided that it is done strategically; using signal timing plans and variable message signs appropriately.

- **Integrate freeway and alternative route operations to achieve greater benefits:** The integration of highways and arterial management systems as part of the San Antonio MMDI is shown to be mathematically greater than the sum of the benefits of the systems alone.

2.7 Summary and Preliminary Recommendations

This literature review has found that arterial ITS applications have the potential to reduce travel time, increase travel time reliability, increase vehicle throughput in the transportation network, and reduce fuel and environmental cost. These benefits are achieved because ITS deployments such as signal optimization and traveler information system can improve traffic operations on arterials and change driver behavior, especially route choice. As reported in different studies and in different regions, adaptive signal control systems deployed in five metropolitan areas have reduced delay 19 to 44 percent (Sussman et al. 2000). Traffic signal retiming programs have resulted in travel time and delay reductions of 5 to 20 percent, and fuel savings of 10 to 15 percent (Halkias and Schauer, 2004). When properly implemented, arterial ITS will result in a better usage of system capacity. The MUTCD provides guidance for arterial ITS implementation. With the rapid development of technologies, arterial ITS components are becoming more affordable and widely available. As a result, the ability of TxDOT to monitor and manage its arterial systems is technically feasible.

It has been found in several studies that combining ITS technologies can result in better performance of the network system. For arterial ITS implementations, different strategies can be taken to deal with recurring and non-recurring incidents. Specific examples of ITS strategies for recurring incidents, non-recurring incidents, and combination of recurring and non-recurring incidents were further discussed in this literature review.

Different agencies such as state DOTs, MPOs, and city transportation divisions may have concerns on different arterial performance measures. It is important to define practical arterial performance measures and find methods to quantify these measures. Developing clear and relevant performance measures for arterials is challenging due to complicated traffic control parameters and users with numerous origins and destinations. In addition to some frequently used arterial performance measures—such as travel speed, travel time, travel delay, traffic

volume, and number of stops—a number of indices that can be used to measure arterial performance were listed and discussed in this document.

Finally, the lessons that have been learned in arterial ITS implementations were summarized. Valuable lessons have been learned in arterial ITS system planning, design, installation, and operation. These lessons are especially beneficial for developing arterial ITS implementation guidelines.

Based on a thorough literature review, the following preliminary recommendations were formulated:

1. Improved traffic data collection on arterials would lay a solid foundation for managing arterials operations. So it is recommend using various means of data collection technologies such as detectors, video detection, GPS detection, cell phone detection, toll tag detection, and so on to improve arterial data collection.

2. Signal optimization is the most effective way to improve arterial traffic operations. The software and hardware are already mature and widely available for this purpose.

3. Desirable characteristics of arterial traveler information system include (a) Provide route and decision guidance (b) Be timely, accurate, available, and cost effective, and (c) Be easy to access and safe to use.

4. The ideal message design should reduce driver's uncertainty regarding traffic conditions instead of overwhelming him or her with unneeded data. Visual displays are only desirable for drivers unfamiliar with the area. An auditory method is adequate and effective when drivers are familiar with the network.

5. Arterial management can be integrated with TxDOT's traffic management plan so that the freeway traffic operations can be enhanced through improving the interactions between arterial and freeways.

6. There are opportunities for public/private partnerships, mainly in data gathering and data fusion. However, the initial infrastructure is more likely to be provided by the public sector.

7. The technologies for vehicle registration/identification, toll collection, and ATIS are similar, and possibilities for integration should be pursued. This integration would benefit arterial data collection as well.

Chapter 3. Critical Arterial Performance Measure Investigations and Identifications

At the national level, management of arterial roadways is part of the ITS architecture proposed by the United States Department of Transportation's (USDOT) Research and Innovative Technology Administration (RITA). However, due to the complexity and diversity of performance measurement, insufficient attention has been placed on arterial roadways. In order to deal with increasing congestion, arterial performance measures must be comprehensively studied and investigated to provide in-depth insight on arterial traffic operation improvements resulting from ITS technology implementations. The objectives of this task were to select arterial performance measures and then verify their significance to stakeholder groups along with identifying arterial data collection technologies. The arterial performance measures were first selected after a thorough review of the literature. After the arterial performance measures were selected, a number of regional transportation agencies in Texas, including Metropolitan Planning Organizations (MPOs), Department of Transportation (DOT) Districts, and Regional Mobility Authorities (RMAs), were surveyed to gauge the state of the practice concerning arterial performance measurement as well as developing trends. The performance measures selected along with their descriptions and formulations can be found in Appendix A: *Arterial Performance Measures—Descriptions and Calculations*.

3.1 State of the Practice

William Edwards Deming's *Deming Total Quality Management* movement, which was implemented in Japan during the 1950s, is responsible for the modern use of performance measures (NCHRP *Synthesis 311*, 2003). Deming developed a set of fourteen key principles for management and his model saw a great deal of success in executing Japan's 1951 Census (Clauson, 2000). Deming's principles served as the foundation for performance measurement systems in the years to follow and became an important tool. Over the last twenty years, an increase in attention has been focused on the development of performance measures in the transportation industry. The development of performance measures in transportation has been aided by the NCHRP Report 446 (2000): A Guidebook for Performance-Based Transportation Planning. The eight steps for developing a performance based strategic planning program are outlined in the literature (Office of Management and Budget, 1993). Pickrell and Neumann (2000) outlined the major reasons for adopting performance measures, including accountability, efficiency, effectiveness, communications, clarity, and improvement. Performance measures can also be used to address some of the concerns urban arterials raise on the impact of, "goods movement, delays, safety, costs, environmental impacts, and energy consumption" (Committee on Urban Arterial Systems, 1981).

The existing studies helped to shape the focus of this task. Of particular interest was identifying a way to limit the amount of arterial performance measures used for a particular agency. The lessons learned from previous studies were accounted for in the research performed and served as a foundation for the selection of arterial performance measures and helped to mold the research.

3.2 Regional Transportation Agencies

After identification of the 18 prevailing arterial performance measures, representative transportation agencies were then selected to obtain information about use of the performance measures. Three categories of regional agencies in the State of Texas were contacted and included the 25 Metropolitan Planning Organizations, the 25 Texas Department of Transportation (TxDOT) Districts, and the 8 Regional Mobility Authorities. The decision to survey these transportation agencies was supported by the *NCHRP Report 398* (Lomax, 1997), *NCHRP Synthesis 311* (2003) and the report *Collecting, Processing, Archiving and Dissemination of Traffic Data to Measure and Improve Traffic Performance* (Dahlgren, 2002). Because these agencies take a regional approach to planning, performance measures are used more often for evaluating investments and prioritizing projects as well as allocation of funding. A variety of regional planning organizations were selected to improve reliability and eliminate bias.

3.3 Critical Arterial Performance Analysis

The survey studies were conducted and these transportation agencies were given the Arterial Roadway Performance Measure Survey form to fill out with both their revealed and stated preference responses concerning the 18 selected arterial performance measures. Also, the agencies were asked to use a nominal or classification scale to denote which arterial performance measures they currently use and which arterial performance measures they would be interested in using. Survey results were collected both by email and through telephone interviews. A portion of the survey with an example agency is shown in Table 3.1.

Table 3.1: Example of Arterial Roadway Performance Measure Survey

Agency/Contact	Arterial Performance Measure						
	Arterial Vehicle Miles Traveled	Volume	Speed/ Travel Rate	Travel Time	Duration of Congestion	Percent of System Congested	Level Of Service
Agency XYZ	X	XX	XX	X		X	XX
Legend							
X—Agency is interested in/might use the performance measure							
XX—Agency currently uses the performance measure							
Blank—Agency is not interested in/would not use the performance measure.							

These agencies had three choices in response to each arterial performance measure. Agencies interested in using the performance measure if it was made available to them, checked off the corresponding performance measure using one X. Agencies that currently are using the arterial performance measures marked the measure using two XX's. The third choice made available to the agencies was to leave the cell blank which denoted that the agency was not interested in or would not use the performance measure if it was made available to them. In order to provide an ultimate ranking of the arterial performance measures for agency type and agency classification size, a formula was developed to combine the revealed and stated preference responses.

Arterial Performance Measure Rank = 0*[blank response] +1*[X] +2*[XX]

where, [X] denotes the total amount of X responses. The formula provides an overall ranking of arterial performance measures based on the weighted calculation and it has been used in the result analysis section.

The stakeholders were identified from the *January 2007 Regional ITS Architecture and Deployment Austin Region Report*. Reponses from twelve stakeholders in the Austin metropolitan area were received which gave their evaluation of each performance measure. The results of the Austin stakeholder feedback can be found in the *Austin Agencies vs. Arterial Performance Measures Matrix* shown in Table 3.2. The survey was conducted to capture opinions in the cities of San Antonio and Corpus Christi. Of the nine agencies contacted in San Antonio the research team collected four responses and of the nine agencies contacted in Corpus Christi the research team was only able to collect three responses. The agencies contacted along with the responses received can be viewed in Table 3.3 for San Antonio stakeholder survey responses and Table 3.4 Corpus Christi stakeholder survey responses. Figure 3.1 shows the arterial performance measure rankings with the highest scores indicating the most interest shown in the particular arterial performance measure. Looking at this table one can begin to identify which performance measures are most likely to be used by the different stakeholder agencies for future ITS technology deployment evaluation.

Table 3.2: Austin Agencies vs. Arterial Performance Measures Matrix

Agencies		Arterial Vehicle Miles Traveled (VMT)	Volume	Speed/ Travel Rate	Travel Time	Duration of Congestion	Percent of System Congested	LOS	Total Delay	Density (veh per hour per lane)	Volume/ Capacity Ratio	Buffer Index	Control Delay	Total Intersection Delay	Corridor Mobility Index	Delay Rate	Road Congestion Index	Travel Rate Index	Travel Time Index
Metropolitan Planning Organization (MPO)		XX	XX		XX	X	X	XX	XX		XX		XX	X	X		X		
Local City Governments	Urban Transportation System	XX	XX	XX	XX	X	X	XX	XX	X	XX	X		XX	X	XX	X	X	
	Emergency Medical Services (EMS)		X	X	X						X					X			
	Fire Department		X	X	X						X					X			
	Police Department	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Municipalities		XX	XX	XX	XX	X	X	XX	XX	X	XX	X		XX	X	XX	X	X	
Private Entities	Private Travelers			X	X	X	X	X	X	X	X		X	X					
Regional Mobility Authority (RMA)		XX	XX		XX	X	X	XX	XX		XX		XX	X	X		X		
Transit Authority		XX	XX	XX	XX	XX	X	XX*		X	XX*			X	X	X		X	X
TxDOT	TxDOT Austin District	X	X	X	X	X	X		X	X	X			X			X		
Major Universities and Schools			XX	X	X			X		X	X				X	XX			X
Transportation Research Institutes		XX	XX	XX	XX	XX	X	XX	X	XX	X	X	XX	X	X	XX	XX	X	X

Totals																			
X		2	4	6	6	7	9	3	4	7	7	4	2	7	8	4	6	5	4
XX		6	7	4	6	3	0	6	4	1	5	0	3	2	0	4	1	0	0
Blank		4	1	2	0	2	3	3	4	4	0	8	6	3	4	4	5	7	8

Legend
X - Agency is interested in/might use the performance measure
XX- Agency currently uses the performance measure
Blank - Agency is not interested/would not use the performance measure

* While we use this measure due to its ready availability, it is suboptimal because of its singular focus on vehicular capacity, rather than people capacity

Table 3.3: San Antonio Agencies vs. Arterial Performance Measures Matrix

San Antonio Stakeholder Survey Responses

Agencies		Arterial Performance Measures																	
		Arterial Vehicle Miles Traveled (VMT)	Volume	Speed/ Travel Rate	Travel Time	Duration of Congestion	Percent of System Congested	LOS	Total Delay	Density (veh per hour per lane)	Volume/Capacity Ratio	Buffer Index	Control Delay	Total Intersection Delay	Corridor Mobility Index	Delay Rate	Road Congestion Index	Travel Rate Index	Travel Time Index
San Antonio/Bexar County MPO - Contacted Jeanne Geiger		x	x	x	x	x	x	x	x	x	xx	x	x	x	x	x	x	x	x
Bexar County Public Works - Contacted Renee Green		No Response.																	
Local City Governments	City of San Antonio Department of Public Works - Contacted Elidia Banda	xx	xx	xx	xx	x		xx	xx	x	xx			xx		x	x	x	x
	San Antonio Fire Department - Contacted Mario Guerra	No Response.																	
	SA Police Department - Contacted Patrick Murnin		x	xx	xx	x			x	x	x	x					x		
	San Antonio Office of Emergency Management - Contacted Nim Kidd	No Response.																	
Transit Authority - Via Metropolitan Transit - Contacted Michael Ledesma		No Response.																	
Alamo Regional Mobility Authority - Contacted Patrick Irwin		No Response.																	
TxDOT	TxDOT San Antonio District - Contacted Brian Fariello		xx	x	x	x	x	xx	xx		x			xx					x

Legend
X - Agency is interested in/might use the performance measure
XX- Agency currently uses the performance measure

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Table 3.4: Corpus Christi Agencies vs. Arterial Performance Measures Matrix

Corpus Christi Stakeholder Survey Responses

Agencies		Arterial Vehicle Miles Traveled (VMT)	Volume	Speed/ Travel Rate	Travel Time	Duration of Congestion	Percent of System Congested	LOS	Total Delay	Density (veh per hour per lane)	Volume/Capacity Ratio	Buffer Index	Control Delay	Total Intersection Delay	Corridor Mobility Index	Delay Rate	Road Congestion Index	Travel Rate Index	Travel Time Index
Corpus Christi MPO - Contacted Tom Niksala		X	XX	XX	XX	XX		XX	XX	X	XX			XX					
Local City Governments	City of Corpus Christi - Traffic Department - Contacted Gabriel Lee	No Response.																	
	Corpus Christi Police Department - Contacted Mike McKinney		X	X	X	X			X	X				X	X	X	X	X	X
	Corpus Christi Fire Department - Contacted Richard Hooks	No Response.																	
	Corpus Christi Local Emergency Planning Committee - Contacted Marcela Cuevas	No Response.																	
	Corpus Christi Office of Emergency Management - Contacted Randy Sijansky	No Response.																	
Corpus Christi RMA - Contacted Oscar Vargas		XX	XX	XX	XX	XX	X	XX	XX	X	XX	X	X	XX	X	X	X	X	X
Transit Authority - "The B" - Contacted Public Affairs Office		No Response.																	
TxDOT	Corpus Christi TXDOT District - Contacted Craig Clark	No Response.																	

Legend
X - Agency is interested in/might use the performance measure
XX- Agency currently uses the performance measure

Arterial Performance Measure Ranking

Measure	Value	Rank
Volume	18	T1
Travel Time	18	T1
Volume/Capacity Ratio	17	3
LOS	15	4
Speed/Travel Rate	14	T5
Arterial VMT	14	T5
Duration of Congestion	13	7
Total Delay	12	T8
Delay Rate	12	T8
Total Intersection	11	10
Percent of System	9	T11
Density (veh per hour per lane)	9	T11
Control Delay	8	T13
Road Congestion Index	8	T13
Corridor Mobility Index	8	T13
Travel Rate Index	5	16
Buffer Index	4	T17
Travel Time Index	4	T17
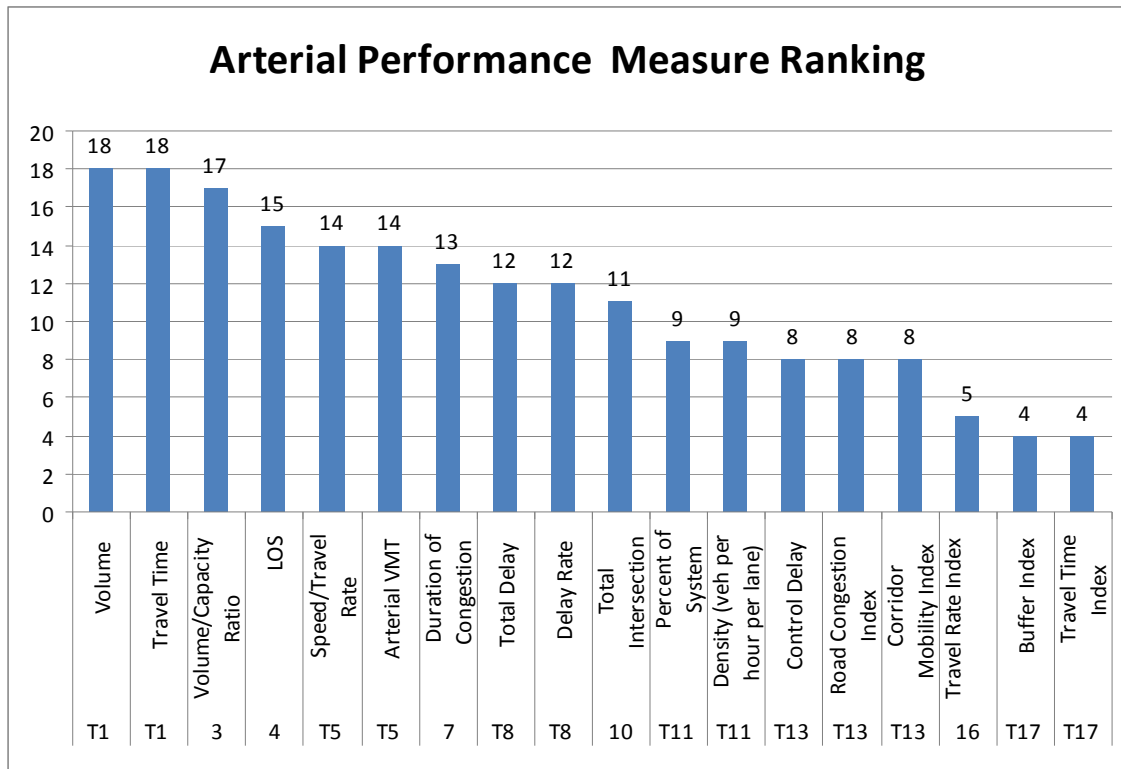
Note: T—tied

Figure 3.1: Arterial Performance Measure Ranking

The next output is the *Arterial Performance Measures vs. Arterial Data Collection Matrix* shown in Table 3.5.

Table 3.5: Arterial Performance Measures vs. Arterial Data Collection Matrix

Arterial Performance Measures	VMT	Average Speed/Travel Rate	V/C Ratio	Capacity (veh/h)	Cycle Length	Effective Green Time	Analysis Period (Time)	Person Volume	Segment or Trip Length	No. of Lanes	Vehicle Density	Miles Congested	Volume (Daily Traffic)	Delay Rate	Free Flow Rate
Arterial VMT	X														
Buffer Index		X													
Control Delay			X		X	X	X								
Corridor Mobility Index		X						X							
Delay Rate		X							X					X	
Density (veh per hour per lane)							X			X	X		X		
Duration of Congestion							X								
LOS			X								X				
Percent of System Congested									X			X			
Road Congestion Index													X		
Speed/Travel Rate		X					X		X						
Total Delay							X	X	X					X	
Total Intersection Delay			X		X	X	X								
Travel Rate Index	X	X													X
Travel Time							X								
Index							X								
Volume/Capacity Ratio				X				X					X		
Volume								X					X		
Totals	2	5	3	1	2	2	8	4	4	1	2	1	4	2	1

This matrix took the formulations from the different arterial performance measures and broken them down into the specific types of data that would need to be collected in order to complete the calculations. By identifying data that is required by the most number of arterial performance measures, the objective was to possibly select arterial data collection technologies that capture this data. Technologies can be identified that best suit the agency goals when evaluating their arterial roadway network providing the agency more "bang for their buck." A ranking of the Arterial Data Collection can be found in Figure 3.2.
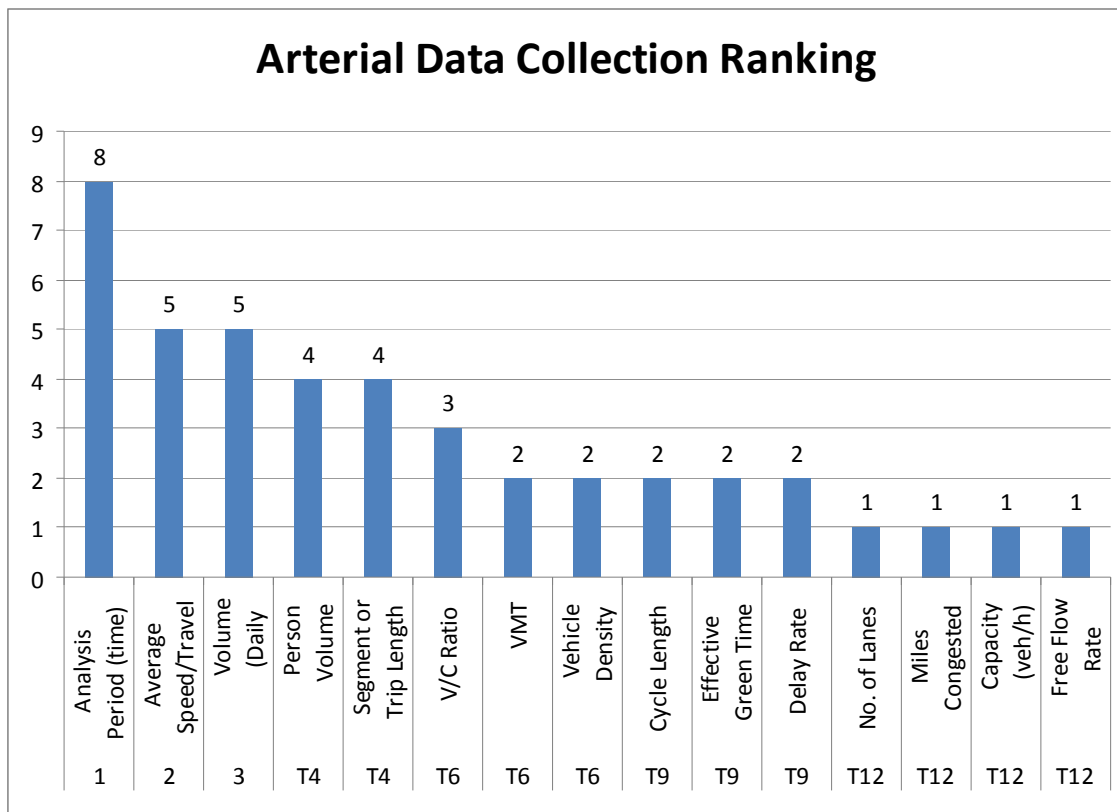
Note: T—tied.

Figure 3.2: Arterial Data Collection Ranking

Most studies of traffic related problems begin with the collection of a good foundation of roadway and traffic conditions. In other words, data collection is the fundamental part for arterial performance monitoring and management. From the *Arterial Performance Measures vs. Arterial Data Collection Matrix,* it can be seen that the majority of the performance measures can be quantified on the basis of two common types of data: vehicle count and speed. There are a number of technologies that can be used to collect volume and speed data. In general, these technologies can be categorized into three types:

- **Road-based,** for example, inductive loops, magnetometers, and Piezo electric detectors.

- **Road-side**, for example, microwave detectors, acoustic detectors, passive/active infrared detectors, ultrasonic detectors, and VIDS.

- **Vehicle probe system**, for example, toll-tag/RFID based system and cell phone/AVL based system.

    Loop detectors are the most commonly used technologies by TxDOT in collecting traffic data. A comparison of the loop detector and alternative data collection/monitoring technologies is presented in Table 3.6.

Table 3.6: Evaluation of Loop Detectors and Alternative Data Collection Devices

Technology[A]	Installation Cost ($K)[B]		O & M ($K)[B]		Lifetime (years)[B]	Output Data[C]					Multiple Lane/Zone Detection[C]	Bandwidth[C]	Accuracy at Intersection (%)[D]	Overhead Accuracy on Freeways[D]		Effect of Weather[D]
	Corridor	Intersection	Corridor	Intersection		Count	Presence	Speed	Occupancy	Classification				Count	Speed	
Road Based																
Induction Loop	3.0 - 8.0	8.6 -15.3	0.4 - 0.6	0.9 - 1.4	5	X	X	X	X	X	-	Low to Moderate	98	98	96	Low
Magnetometer	-	-	-	-	-	X	X	X	X	-	-	Low	-	-	-	-
Piezo Electric Detectors	-	-	-	-	-	X	X	-	-	X	-	-	-	-	-	-
Road Side																
Microwave	9.0 - 13.0	18.0	0.1 - 0.6	0.1	10	X	X	X	X	X	X	Moderate	-	92	98	Moderate
Acoustic	3.7 - 8.0	5.0 -15.0	0.2 - 0.4	0.2 - 0.4	-	X	X	X	X	-	X	Low to Moderate	-	90	55	Moderate*
Passive/Active Infrared	6.0 - 1.2		-	-	-	X	X	X	X	X	X	Low to Moderate	97	97	90	Moderate
Radar	-	-	-	-	-	X*	X*	X*	-	-	X*	-	95	99	98	Low
Ultrasonic	-	-	-	-	-	X	X	X	-	-	-	Low	-	98	-	Moderate
VIDS	21.7 - 29.0	16.0 - 25.5	0.2 - 0.4	0.2 - 1.0	10	X	X	X	X	X	X	Low to High	95	95	87	Moderate*
Vehicle Probe																
Toll Tag/RFID Based	> 50	-	-	-	10	X	X	X	X	X	X	Low to High	-	-	-	Low
Cell Phone/AVL Based	-	-	-	-	-	X	X	X	X	X	X	Low to High	-	-	-	Moderate

[A] Definitions: Video Image Detection Systems (VIDS)

[B] ITS Unit Costs Database (as of Sept 30, 2006)

[C] A Summary of Vehicle Detection and Surveillance Technologies used in ITS (2000)

[D] Evaluation of Some Existing Technologies for Vehicle Detection (1999) (at optimal conditions)

[E] Evaluation of Some Existing Technologies for Vehicle Detection (1999)

* From product description

3.4 Summary of Findings

To quantify arterial traffic operation performance, a series of performance measures have been proposed and applied in traffic systems. Identifying critical arterial performance measures is essential to standardize arterial roadway management and enhance overall traffic system operation strategies. In this task, an arterial roadway performance measure survey was conducted. Various transportation agencies including MPOs, TxDOT Districts, and RMAs in Texas were contacted to participate in the survey. Eighteen different arterial performance measures were included. The top arterial performance measures were evaluated for the frequency of response in the revealed preference, stated preference, and combined preference surveys. Six arterial performance measures stood out for receiving the most positive feedback as effective tools characterize to arterial roadways, including Arterial Vehicle Miles Traveled, Level of Service, Speed/Travel Rate, Travel Time, the Volume/Capacity Ratio, and Volume. The survey results also indicate the top five stated preference arterial performance measures include Duration of Congestion, Total Delay, Travel Time, and in a tie for fourth, Percent of System Congested, Density, and the Roadway Congestion Index. As allocation of funding becomes more dependent on the performance of a roadway network, transportation agencies may look to these measures for evaluation of their arterial roadways. The survey results were summarized for each type of transportation agency as follows.

3.4.1 Metropolitan Planning Organizations

Volume and the Volume/Capacity Ratio (52%) were used most often by MPOs followed by Level of Service (48%), Travel Time (44%), and Arterial Vehicle Miles Traveled (32%). The top arterial performance measures that MPOs do not use, but would like to use if the measure was made available were Duration of Congestion, Total Delay, Total Intersection Delay, and Corridor Mobility Index. Each of these was preferred by 48% of the MPOs. This interest might suggest that MPOs are seeking out better ways to characterize delay as well as the mobility component. These types of arterial performance measures if captured properly could provide more valuable information to everyday roadway users. Density was also of interest to a considerable portion of MPOs, with 44% wanting to use this arterial performance measure. The top five measures identified through combined preference ranking for Texas MPOs include Volume, Volume/Capacity Ratio, Level of Service (LOS), Travel Time, and Arterial Vehicle Miles Traveled (VMT).

3.4.2 Texas Department of Transportation Districts

The results of the revealed preference survey from the TxDOT Districts show that the most commonly used arterial performance measure was Volume and that 56% of TxDOT Districts use this measure. Volume was followed in response frequency by Level of Service used by 40% of TxDOT Districts, and then Speed/Travel Rate, Volume/Capacity Ratio, and Total Intersection Delay were all in a tie for third and were used by 24% of the districts. In the stated preference portion of the survey it was found that Travel Time (52%), Duration of Congestion (48%), and Total Delay (44%) would be used by TxDOT Districts if the arterial performance measure was made available. Speed/Travel Rate, Percent of System Congested, and Road Congestion Index were tied in fourth in frequency of response at 40%. Using the weighted formula, both the revealed and stated preference responses were combined to form an overall ranking for TxDOT

Districts. The top five arterial performance measures ranked in the following order: Volume, Level of Service, Speed/Travel Rate, Travel Time, and Total Intersection Delay.

3.4.3 Regional Mobility Authorities

Currently only eight RMAs exist in the State of Texas. Of the eight RMAs contacted, seven responded and of those seven, only three agencies were able to provide responses. That being said, only one agency is capturing arterial performance measures. They are monitoring Volume, Speed/Travel Rate, and Travel Time on arterial roadways. It was found from the stated preference responses that Duration of Congestion, Total Delay, the Volume/Capacity Ratio, Corridor Mobility Index, and Travel Time Index were requested most by the RMAs with 37.5% of the RMAs requesting that they have these arterial performance measures made available to them. Combining the revealed and stated preference survey responses, the arterial performance measures of Volume, Speed/Travel Rate, and Travel Time had the most interest by RMAs, followed by the measures of Duration of Congestion, Total Delay, Volume/Capacity Ratio, Corridor Mobility Index, and the Travel Time Index. RMAs have recognized the primary sets of data (Volume and Speed/Travel Rate) that can be used to calculate performance measures and characterize a transportation system, but their involvement in arterial performance is not to be expected in the near future.

Chapter 4. Identifications of the Most Beneficial Arterial ITS Elements

4.1 Introduction

The work completed in this task involved examining the elements of arterial management systems. The different elements of arterial management systems were taken from the US DOT ITS Joint Program Office, which has identified six categories:

- *Surveillance*, which includes traffic surveillance and infrastructure surveillance.

- *Traffic Control*, which can be used for transit signal priority, emergency vehicle preemption, adaptive signal control, advanced signal systems, variable speed limits, bicycle and pedestrian, or special events

- *Lane Management*, which can be used for HOV facilities, reversible flow lanes, pricing, lane control, variable speed limits, and emergency evacuation.

- *Parking Management*, which includes data collection or parking information dissemination.

- *Information Dissemination*, which uses DMS, in-vehicle systems (IVS), and HAR

- *Enforcement*, which can be used for speed enforcement or stop/yield enforcement.

For each of the categories information concerning positive and negative impacts on traffic operations, TxDOT planning goals/target problem, implementation requirements/costs, and reported benefits were identified. The arterial management systems that achieve the TxDOT planning goals/target problem are displayed in Table 4.1, which is then followed by a summary of the 21 different subcategories. Information about the Reported Impacts of Arterial ITS Elements and the Implementation Requirements and Cost Matrix for Arterial ITS Elements can be found in the Appendix B and Appendix C.

It should be noted that TxDOT's Strategic Planning goals for 2007-2011 have been kept in mind while collecting the information required. TxDOT's planning goals are:

1) Reduce congestion
2) Enhance safety
3) Expand economic opportunity
4) Improve air quality
5) Increase the value of transportation assets

4.2 Evaluation of Arterial ITS Elements

Based on the evaluation of each arterial ITS elements, it was found that the arterial ITS strategies can be used to achieve the following TxDOT strategic goals:

Table 4.1: Arterial Elements and TxDOT Strategic Goals

Arterial ITS Elements		TxDOT Strategic Goals				
		Reduce congestion	Enhance safety	Expand economic opportunity	Improve air quality	Increase the value of transportation assets
Surveillance	Traffic	X	X		X	X
	Infrastructure		X			X
Traffic Control	Transit Signal Priority	X	X		X	X
	Emergency vehicle Preemption	X	X			
	Adaptive Signal Control	X	X		X	X
	Advanced Signal Systems	X	X		X	X
	Variable Speed Limit	X	X		X	X
	Bicycle & Pedestrian		X			
	Special Event	X	X	X	X	X
Lane Management	HOV Facility	X	X	X	X	X
	Reversible Flow Lanes	X	X		X	X
	Pricing	X	X	X	X	X
	Lane Control	X	X		X	X
	Emergency Evacuation	X	X		X	X
Parking Management	Data Collection	X	X	X	X	X
	Information Dissemination	X	X	X	X	X
Information Dissemination	Dynamic Message Signs	X	X	X	X	X
	In-Vehicle Systems	X		X	X	X
	Highway Advisory Radio	X	X	X	X	X
Enforcement	Speed Enforcement		X			
	Stop/Yield Enforcement		X			

4.2.1 Surveillance

a) *Traffic Surveillance*
Traffic surveillance technologies play an essential role in incident detection, traffic management, and traffic data collection.

- Positive impacts on traffic operations:
  - Reduce emissions
  - Reduce number of stops
  - Reduce peak period delay
  - Reduce traffic demand
  - Reduce vehicle delay
  - Reduced crash fatalities
- Negative impacts on traffic operations:
  - Little guidance for detector placement
  - Challenge exists with single loop detectors on length based classification
  - Inductive loop installation can deteriorate pavement
  - Some detectors are weather sensitive

b) *Infrastructure surveillance*
Among surface transportation's modal systems, the highway infrastructure is relatively robust and redundant. Nevertheless, the consequences—both direct and indirect—of damage on critical links could be significant. There are certain contexts across Texas in which the loss of key links could have major economic and mobility impacts and result in immediate loss of life. Infrastructure surveillance, in this situation, plays an essential role in improving infrastructure security and damage control.

- Positive impacts on traffic operations:
  - Improve transportation security/homeland security
  - Disseminate weather information
  - Disseminate incident information
  - Disseminate construction information
  - Disseminate AMBER alerts
  - Can monitor public transit
  - Potential for vehicle to vehicle interaction
  - Potential for vehicle to infrastructure interaction

- Negative impacts on traffic operations:
  - Technology is ineffective with poor detector placement
  - Government must be mindful of overstepping privacy boundaries with surveillance.

4.2.2 Traffic Control

a) *Transit Signal Priority*

Transit Signal Priority (TSP) is an operational strategy that facilitates the movement of transit vehicles (usually those in service), either buses or streetcars, through traffic-signal controlled intersections. Objectives of TSP include improved schedule adherence and improved transit travel time efficiency while minimizing impacts to normal traffic operations.

- Positive impacts on traffic operations:
  - Improve on-time arrival
  - Real-time passenger information displays regarded as useful by passengers
  - Reduce accidents
  - Reduce bus emissions
  - Reduce bus travel time
  - Reduce car travel times
  - Reduce fuel consumption
  - Reduce person delay
  - Reduce transit vehicle stops
  - Reduce emissions
  - Reduce stopped-time of bus
  - Reduce vehicle delay
  - Can result in removing vehicles from system and maintain level of service
  - Smoother and more comfortable ride for passengers
  - Reduced recovery time at end of run
  - Modal shift from auto to transit on some corridors
- Negative impacts on traffic operations:
  - Increase delay for other traffic
  - Increased emissions of other vehicles
  - Increase fuel consumption for other vehicles
  - Increase passenger vehicle time

b) Emergency Vehicle Preemption

Signal preemption systems for emergency vehicles use sensors to detect an approaching emergency vehicle and provide a green signal to the vehicle.

– Positive impacts on traffic operations:

  – Reduce emergency vehicle crash rate

  – Reduce emergency vehicle travel time

  – Reduce response time

  – Reduce delays at signalized intersections

– Negative impacts on traffic operations:

  – Increase average travel time when priority was requested

  – Increased travel times around emergency facilities due to signal preemption

c) Adaptive Signal Control

Adaptive signal control systems coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions.

– Positive impacts on traffic operations:

  – Improve travel time

  – Increase speeds

  – Increase vehicle throughput

  – Lower travel times than optimized fixed-time signal control

  – May lower operator and maintenance costs associated with traffic signal timing

  – Reduce crash frequency

  – Reduce delay compared to fixed-timed signal control

  – Reduce delay on main streets and cross-streets

  – Reduce fuel use

  – Reduce number of stops

  – Reduce ramp queues

  – Reduce transit delay

  – Reduce travel time for detours around an incident

  – Reduce vehicle emissions

– Negative impacts on traffic operations:

  – Neutral/no impact on traffic

  – Boundary effects worsened travel times

- Video sensor positioning is a time consuming task

- No change in peak period travel times

- Detector demanding technology

- Performance degrades significantly when detectors fail

- Drivers may not notice improvement

d) *Advanced Signal Systems*

Advanced signal systems include coordinated signal operations across neighboring jurisdictions, as well as centralized control of traffic signals which may include some necessary technologies for the later development of adaptive signal control.

- Positive impacts on traffic operations:
  - Cost savings

  - Improve fuel economy

  - Improve travel times

  - Improve trip time reliability

  - Increase average speed

  - Increase peak period speeds

  - Increase throughput

  - Reduced emissions

  - Reduce crash frequency

  - Reduce delay

  - Reduce frequency of fatal crashes

  - Reduce pavement wear

  - Reduce peak period delay

  - Reduce tire and brake wear

  - Reduce total stops

  - Reduce travel times for detours around an incident

- Negative impacts on traffic operations:
  - Energy consumption in corridor showed an increase

  - Emission reduction was little to none

e) *Variable Speed Limit*

Variable speed limit systems use sensors to monitor prevailing traffic and/or weather conditions, posting appropriate enforceable speed limits on dynamic message signs.

- Positive impacts on traffic operations:
  - Increase average speeds
  - Decrease travel times
  - Reduce number of crashes
  - Reduce number of speed violations
  - Beneficial in weather related conditions
  - Reduce variation in speeds
  - Reduce emissions
  - Reduce work zone accidents
- Negative impacts on traffic operations:
  - May cause driver confusion
  - May result in drivers not complying with set speed limits

f) Bicycle & Pedestrian

Pedestrian detectors, pedestrian activated lighted crosswalks, specialized pedestrian signals (e.g., 'countdown' WALK/DON'T WALK signals), and bicycle-actuated signals can improve the safety of all road users at signalized intersections and un-signalized crossings.

- Positive impacts on traffic operations:
  - Reduce pedestrians crossing during the steady DON'T WALK
  - Reduce vehicle-pedestrian conflicts reduced
- Negative impacts on traffic operations:
  - Pedestrians may walk into detection zone without intent to cross
  - Sensors have difficulty detecting bicyclist traveling faster than 10-15mph
  - Countdown signals reduce pedestrian compliance with walk phase
  - Some age groups don't respond well to countdown signals

g) Special Event

Arterial management systems can also smooth traffic flow during special events with unique operating schemes, incorporating elements such as special traffic signal operating plans, temporary lane restrictions, traveler guidance, and other measures.

- Positive impacts on traffic operations:
  - Reduce congestion
  - Minimize quality of life impacts on residents and businesses
  - Increase safety

- – Minimize regional traffic effects form events

- – Maximize efficiency through the system

- – Negative impacts on traffic operations:

- – May increase travel time for a portion of traffic.

4.2.3 Lane Management

a) *HOV Facility*

Sensors detecting the traffic conditions support the use of dynamic message signs and moveable barriers (e.g., gates) to control the operation of HOV facilities.

- – Positive impacts on traffic operations:

  - – Reduce travel times

  - – More reliable travel times

  - – Reduce emissions

  - – Reduce wear on personal vehicles

  - – Enhance bus transit operations

  - – Increases use of ridesharing, carpooling, and vanpooling

  - – Time savings are seen by ride sharers during peak periods

- – Negative impacts on traffic operations:

  - – HOV lanes are underutilized

  - – Many HOV lanes suffer degraded operations (speeds < 45mph)

  - – Travel time savings aren't statistically significant

  - – Reduced access design has shown increase in total passenger hours, fuel consumption and vehicle emission levels

  - – Can create bottlenecks in system if not implemented properly

b) *Reversible Flow Lanes*

Traffic sensors and lane control signs can be used to implement reversible flow lanes allowing travel in the peak direction during rush hours.

- – Positive impacts on traffic operations:

  - – Reduce congestion

  - – Relieve peak commuter periods

  - – Aid in emergency evacuations

  - – Aid in roadway construction work zones

  - – Reduced travel time

- Increased traffic flow

- Enhance operation of transit and HOV operations

- Negative impacts on traffic operations:

    - May cause commuter confusion

    - Increase number of accidents

    - Problems with pedestrians not know where traffic was approaching

    - Reduced capacity for flow in the minor direction

c) Pricing
Traffic sensors, electronic payment, video, GPS, and automated enforcement technologies can support the implementation of congestion pricing strategies, varying the cost of transportation facilities based on demand or the time of day.

- Positive impacts on traffic operations:

    - Generates money for transit improvements

    - No impact on local businesses

    - Positive impact on local businesses

    - Reduce emissions

    - Reduce inner city traffic

    - Taxi cab drivers cover more miles per hour, service more riders, and decrease operating costs per passenger-mile

    - Reduced number of inner city accidents

    - Reduced noise levels

    - Acceptance increased with familiarity

    - Shift of trips from peak to off-peak hours

    - Reduced maintenance and rehabilitation on roadway infrastructure

- Negative impacts on traffic operations:

    - Negative impact on local businesses

    - Public not supportive of tactic

d) Lane Control
Lane control signs, supported by surveillance and detection technologies, allow the temporary closure of lanes to avoid incidents or construction on arterial roadways.

- Positive impacts on traffic operations:

    - Overhead signs can be used to manage traffic flow

- Overhead signs can be used to reduce congestion

- Overhead signs can be used to communicate incidents and other information

- Speed management control can reduce crashes, injuries and fatalities

- Reduce work zone collisions

- Improve throughput

- Reduce emissions

- Improve reliability of travel times

- Extend pavement life

- Negative impacts on traffic operations:

    - Drivers inundated with information can become overwhelmed

    - Conflicts can arise between jurisdictions

    - Incompatibilities exist between static and dynamic message signs

    - Information sharing across jurisdictions can be problematic

e) *Variable Speed Limits*
   Variable speed limit systems use sensors to monitor prevailing traffic and/or weather conditions, posting appropriate enforceable speed limits on dynamic message signs.

- Positive impacts on traffic operations:

    - Increase average speeds

    - Decrease travel times

    - Reduce number of crashes

    - Reduce number of speed violations

    - Beneficial in weather related conditions

- Negative impacts on traffic operations:

    - Difficult to enforce speed limit

f) *Emergency Evacuation*
- Positive impacts on traffic operations:

    - Annual contracts should be in place before hurricane season to provide additional personnel and equipment in an emergency

    - Contraflow lanes can be used during an evacuation to help aid in congestion

    - Contraflow lanes can be restricted to daytime use only

    - Websites can disseminate information about evacuation

– Courtesy patrols are beneficial during an evacuation period

– The 511 Traffic and Travel Information telephone system can be used to disseminate information during an evacuation

– Dissemination of evacuation information helps to relieve stress of evacuees

– Communication between evacuation communities needs to be seamless

– Negative impacts on traffic operations:

– Lack of preplanning will lead to an ineffective evacuation

– Contraflow lanes are unusual and cause driver confusion during evaluations

– The termination of contraflow lanes can cause confusion

– Vehicles using contraflow lanes are limited to those not towing trailers

4.2.4 Parking Management

a) Data Collection

Parking management systems, most commonly deployed in urban centers or at modal transfer points such as airports, monitor the availability of parking and disseminate the information to drivers, reducing traveler frustration and congestion associated with searching for parking.

– Positive impacts on traffic operations:

– Reduce traffic volumes related to parking space searches

– Reduce search time

– Easier parking management

– Customized information

– Parking information provided before and during trip

– Improved use and management of existing parking spaces

– Greater security

– Negative impacts on traffic operations: Not reported

b) Information Dissemination

Parking management systems with information dissemination capabilities, most commonly deployed in urban centers or at modal transfer points such as airports, monitor the availability of parking and disseminate the information to drivers, reducing traveler frustration and congestion associated with searching for parking.

– Positive impacts on traffic operations:

– Reduce traffic volumes related to parking space searches

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- Encourage motorist to use more distant facilities that are underused while core parking is congested

- As information dissemination continues usually greater positive impacts are realized

- Reduce airport parking delays

- Drivers utilize pre-trip information with respect to parking choice and increased transit use

- Negative impacts on traffic operations: Not reported

4.2.5 Information Dissemination

a) *Dynamic Message Signs (DMS)*

Organizations operating ITS can share information collected by detectors associated with arterial management systems with road users through technologies within the arterial network, such as dynamic messages signs or highway advisory radio. ITS operators may also send information to in-vehicle devices capable of displaying traveler information. Coordination with regional or multimodal traveler information efforts, as well as freeway and incident management programs, can increase the availability of information on arterial travel conditions.

- Positive impacts on traffic operations:

  - Increase throughput

  - Increase travel speeds

  - Reduce delay and risks caused by crashes, stalls, disabled vehicles and construction

  - Improve safety

  - Reduce crash fatalities during peak periods

  - Reduce emissions

  - Reduce fuel consumption

  - Reduce stop time

  - Reduce total number of stops

  - Reduce travel time

  - Reduce vehicle-hours of delay

- Negative impacts on traffic operations:

  - Elderly drivers respond slower and less accurately to DMS

  - Driver can be overloaded with information

  - Message must be meaningful, accurate, timely, and useful to gain driver trust

  - Driver confidence can be easily lost if DMS isn't maintained properly

b) *In-Vehicle Systems (IVS)*

Organizations operating ITS can share information collected by detectors associated with arterial management systems with road users through technologies within the arterial network, such as dynamic messages signs or highway advisory radio. ITS operators may also send information to in-vehicle devices capable of displaying traveler information. Coordination with regional or multimodal traveler information efforts, as well as freeway and incident management programs, can increase the availability of information on arterial travel conditions.

- Positive impacts on traffic operations:

  - Aid drivers in selecting mode

  - Aid drivers in selecting route

  - Aid drivers in selecting departure time

  - Better reaction time with speech-based system

  - Enhanced mobility

  - Enhanced productivity

  - Speech-based interface allows drivers to keep their hands on the wheel and eyes on the road

- Negative impacts on traffic operations:

  - Can be distracting to driver

  - Hands-free cell phones have at least as great a risk factor as hand-held phones

  - Driving while using a cell phone may add a significant increment of risk to the driving task

  - Making a call during a trip may more than triple the risk of a crash

c) *Highway Advisory Radio (HAR)*

Organizations operating ITS can share information collected by detectors associated with arterial management systems with road users through technologies within the arterial network, such as dynamic messages signs or highway advisory radio. ITS operators may also send information to in-vehicle devices capable of displaying traveler information. Coordination with regional or multimodal traveler information efforts, as well as freeway and incident management programs, can increase the availability of information on arterial travel conditions.

- Positive impacts on traffic operations:

  - Increase throughput

  - Reduce total number of stops

  - Reduce vehicle-hours of delay

  - Broadcast range may vary from one to six miles

  - Nearly all HAR systems use AM radio which most vehicles have

- – HAR broadcasts 24hours a day without commercial interruptions

- – No additional equipment is needed to receive HAR broadcasts

- – HAR can disseminate a variety of different types of traveler information

- – Negative impacts on traffic operations:

  - – HAR must maintain accurate, up-to-date messages that are comprehensive yet succinct

  - – The quality of AM signal must be clear in order for customers to listen

  - – Installation in some instances can be costly for antennas as well as staffing

  - – In urban areas the broadcasts can get interrupted due to large buildings

  - – HAR can become inoperable due to radio interference when large number of communication devices are operating simultaneously

4.2.6 Enforcement

a) *Speed Enforcement*

Automated enforcement technologies can assist with the enforcement of speed limit compliance. Still or video cameras, activated by detectors, can record vehicles traveling faster than the speed limit.

- – Positive impacts on traffic operations:

  - – Reduce crash frequency

  - – Reduce crash injuries

  - – Reduce fatalities

  - – Reduce speed

  - – Reduce vehicles exceeding the speed limit

  - – Reduced speeds in school zones

  - – Spill over effects with reduced speeds experienced in the entire network

- – Negative impacts on traffic operations:

  - – Reduce speed

  - – Drivers try to beat the system and use radar detectors so they can continue speeding

  - – Drivers will wear masks to avoid having their pictures taken. Masks may impair driving.

  - – Photo-radar equipment must be durable enough to remain outdoors

  - – Detection of speeding drivers isn't always successful

b) *Stop/Yield Enforcement*

Automated enforcement technologies can assist with the enforcement of traffic signal compliance. Still or video cameras, activated by detectors, can record vehicles traveling through a red signal.

– Positive impacts on traffic operations:

  – Reduce crash frequency

  – Reduce number of persons killed and seriously injured

  – Reduced personal injury accident rate

  – Reduce right-angle crashes

  – Reduce right-angle injury crashes

  – Reduce speed

  – Reduce traffic signal violations

  – Reduce vehicles exceeding speed limit

– Negative impacts on traffic operations:

  – Reduce speed

  – Increased number of rear-end crashes

  – Increase number of total crashes

  – Increased number of total injury crashes

  – Eventually number of violations will decrease which reduces revenue

The reported impacts of ITS elements and their implementation requirements and costs are detailed in Appendix B and C.

4.3 Summary and Recommendations

The information gathered shows that implementation of ITS technologies can have significant positive impacts on arterial management systems. Some elements of the arterial management systems seem to benefit more from the implementation of ITS technologies than others. Based on the research completed, the following preliminary recommendations have been formulated:

1) Traffic Control, which includes the subcategories of Transit Signal Priority, Emergency Vehicle Preemption, Adaptive Signal Control, Advanced Signal Systems, and Variable Speed Limits all have shown significant benefits to the arterial systems and are in line with TxDOT's strategic planning goals.

2) Lane Management-Pricing has been an underutilized tool in managing congestion and should be investigated further to aid in relieving arterial traffic.

3) Information Dissemination, primarily in the form of Dynamic Message Signs (DMS) provides drivers with information regarding traffic conditions and is effective when

drivers are unfamiliar with the area. Highway Advisory Radio is beneficial when drivers are familiar with the network, but is underutilized.

4) Speed Enforcement and Stop/Yield Enforcement both have shown they can enhance safety within an arterial network and the technology is mature and widely available for this purpose.

Chapter 5. ITS Technologies and Solutions for Arterial Management Enhancement

5.1 Introduction

The objective of this task was to identify desirable ITS technologies and solutions for arterial management. The research team evaluated available ITS technologies that are applicable for arterial roadway management. Both Non-Intrusive and Intrusive data collection technologies were identified, as well as technology systems for Signal Priority. Matrices for each of the data collection technologies were created that outline each technology's advantages, disadvantages, implementation requirements, compatibility with existing infrastructure, implementation costs, and suitability for arterial management applications. Based on the evaluation of individual systems, desirable system attributes were identified for each technology.

5.1.1 List of Acronyms

ANPR – Automatic Number Plate Recognition
AVC – Automatic Vehicle Counter/Classifier
CCTV – Closed Circuit Television
EVP – Emergency Vehicle Priority
FHWA – Federal Highway Administration
FTP – File Transfer Protocol
GSM – Global System for Mobile Communications
HAR – Highway Advisory Radio
IP Camera – Internet Protocol Camera
ITS – Intelligent Transportation Systems
LAN – Local Area Network
LED – Light-Emitting Diode
LPR Camera – License Plate Recognition Camera
MTBF – Mean Time Between Failures
MTTR – Meantime to Repair
MVP – Machine Vision Processor
MW – Microwave
NTSC – National Television Standards Committee
PC – Personal Computer
PDA – Personal Digital Assistant
PIR – Passive Infrared
PTZ – Pan-Tilt-Zoom
RTCP – Remote Traffic Counting Package
RTMS – Remote Traffic Microwave Sensor
SMR – Street Receiver Module
TSP – Transit Signal Priority
UK – United Kingdom
US – Ultrasonic
VBV – Vehicle by Vehicle
WIM – Weigh-in-Motion

5.2 Non-Intrusive Technologies

Several methods exist to characterize traffic surveillance technologies. Technologies can be classified as road-based or vehicle-based, or they can be characterized by their installation requirements. In this study, data collection/surveillance technologies are classified according to the latter into two categories: non-intrusive technologies and intrusive technologies. This first section focuses on non-intrusive technologies. A non-intrusive technology is a detector that captures information about an arterial system in which the detector is "installed above or on the sides of roads and bridges with minimum disruption to traffic flow (Martin, 2003)." The non-intrusive detector technologies examined in this document include the following:

- Active Infrared Detection

- Passive Infrared Detection

- Microwave Detection

- Ultrasonic Detection

- Passive Acoustic Detection

- Video Detection

For each technology, available systems were identified and system attributes evaluated. Additionally, a synthesis table identifying advantages/disadvantages, data collected, implementation requirements, installation and maintenance costs, and compatibility with existing infrastructure for each technology type is provided. After evaluation of the different available technologies was completed, recommended system attributes were identified for each type of detection device. To provide a more complete summary of the Non-Intrusive Detection Technologies available in today's market, several domestic and international companies were profiled.

5.2.1 Active Infrared Detection

Active Infrared Detectors are similar to microwave radar detectors and are capable of capturing vehicle presence, count, speed, length, and queue (Klien, 2006). The detectors can be mounted in both the overhead and sidefire positions, and in the active system, the detection zones are identified with infrared energy. The energy is then reflected from the vehicle traveling through the detection zone and the system then records the appropriate information. Active infrared detectors can be installed at the same intersection without interference from transmitted or received signals (Klien, 2006).

Table 5.1: Available Active Infrared Detection Technology Systems

Company	Available Technology	Technology Description
Clearview Traffic	Marksman 500 above ground vehicle count and classifier	The Marksman 500 is an above ground radar vehicle classifier that is Bluetooth enabled. The sensor has been designed to ease the problems associated with collection of temporary traffic data. The system provides a safe and reliable solution and minimizes the use of ladders for mounting by providing an automated adjustment sensor positioning and a cable-less site set-up. The M500 provides accurate count, speed, and classification data and provides a memory capacity of up to 250,000 vehicles. The M500 has its own internal power supply which is supplied by a 6V battery which provides approximately 30 days of data recording (Golden River, 2007).
Noptel Oy	Noptel Distance Sensors for Traffic Control	The pulsed time-of-flight technology allows high-speed measurement of distances from poorly reflecting surfaces with excellent resolution. One typical application for a laser sensor is vehicle detection when the vehicle is approaching an LPR camera or driving away from it. A typical sensor installation is 5 to 7 meters above ground looking forward and down at the road. When the vehicle enters the trigger area defined by the parameters, the sensor sends a pulse to the camera. This technology can be used for vehicle profile measurement, vehicle classification, speed measurement, speed violation control, portable speed cameras, traffic light control, intersection control, left turn sensor, signal violation control, criminal vehicle interception, vehicle detection, and tunnel entrance control (Noptel, 2008).
OSI LaserScan	AS500 Series AutoSense™	The AS500 Series provides timing, position, and speed of vehicles passing though the field of view. The technology is designed to be installed on a pole arm or support structure (OSI, 2007).
TEC Traffic Systems	TOM Laser Vehicle Classification	This product is a laser scanner that is mounted on a gantry above the road. The six widened laser beam creates a curtain of laser that records a 3-dimensional profile of vehicles moving underneath. Data are derived from measuring the travel time of a light pulse from the TOM 2000 to the road surface and back. The high profile is used to calculate the type of vehicle (TEC Traffic Systems, 2006).
TEC Traffic Systems	3M Opticom Priority Control System	This system enhances time-critical travel by allowing emergency vehicles to request and receive green lights as they go to and from the scene of an accident. The technology is a proven infrared technology that solves the stagnation caused by waiting traffic and secures safe crossings at intersections (TEC Traffic Systems, 2006).
TEC Traffic Systems	SAM-S Laser Height Detection	This product is a form of laser technology that can detect vehicles which are too high to pass under tunnels, bridges or other constructions of limited height. The technology is one-sided detection that works under all weather conditions and covers multiple lanes of traffic (TEC Traffic Systems, 2006).

Company	Available Technology	Technology Description
TSEU	AIM S—Above Ground Stop Line Detector	This detector is suitable for one or two lane application and is an active infrared detector designed to detect the presence of vehicles within the detection zone. The AIM-S is mounted on a single head pole at the side of the carriage way, ahead of the stopline. The unit gives output when one or more vehicles are present. Typical applications of this detector include stopline detection, queue detection, filter lane detection, etc. This detector can replace an induction loop system and has high immunity to false detects and lock up (TSEU, 2005).
TSEU	AIM G—Above Ground Gantry Detector	This detector is an active infrared detector designed to detect vehicles within the detection zone. Typically this detection is used for vehicle counting, queue detection, speed indication, etc. This detector can replace an induction loop system, is highly reliable, and has high immunity against false detects and lock up. The AIM-G is suitable for monitoring a single lane of traffic when mounted directly overhead (TSEU, 2005).
TSEU	AIM R—Above Ground Roadside Detector	This detector is an active infrared detector that is designed to detect the presence of vehicles within the detection zone. Typical applications include vehicle counting, queue detection, etc. The system is capable of replacing an induction loop system and can operate on one or two lanes. The detector is highly reliable, and has a low occurrence of false detects and lock ups (TSEU, 2005).
Weiss-Electronic	Infrared Detector IRD90x/2	The IRD901/2 has a range up to 35m whereas the IRD903/2 has a range up to 60m. Both detection devices request or extend green-phases of traffic light installations and are used for vehicle and pedestrian detection. The passive infrared detector series operates according to the principle of contactless temperature measurement. The mounting unit enables pole mounting by means of a tension band or wall mounting and both can be adjusted (Weiss-Electronic, 2001).
Weiss-Electronic	Infrared Detector IRD1001	This product requests or extends the green-phase of traffic light installations, detects vehicles and pedestrians, completes vehicle counts and measures time of occupancy. The detector uses passive infra-red and measures temperature. The range of wave lengths with this passive infrared radiation is within the range of 8-12µm. The radiation of this wave length is only singly weakened by environmental influences like fog or rain. As a special feature of this detector is that, not only movements are detected, but also the presence of an object for up to three minutes (Weiss-Electronic, 2001).
Weiss-Electronic	Radar Detector RD_L	This product is used for traffic light installations and speed warning installations. It can be used at high distance range and has easy installation and maintenance. The detector can be mounted fire side or above the road and sensitivity can be adjusted with a distance range of up to 100m. The detector also has a wide range of working temperatures allowing the outside use of the device (Weiss-Electronic, 2001).

Company	Available Technology	Technology Description
Weiss-Electronic	**Combined Radar Detection RD2200**	This product collects traffic data and does incident detection on multilane urban and interurban roads. The production does provisions of per-lane presence, volume, occupancy, speed, and vehicle classification per lane in up to eight user-defined detection zones simultaneously. The hardware can be installed either with over head mounting or side-fire. The RD2200 can detect a stationary as well as fast moving vehicle which is then relayed to a data collection control unit. The unit operates in either of two microwave bands and the installed radar detector is calibrated via laptop PC (Weiss-Electronic, 2001).

Table 5.2: Active Infrared Detection Technology Information Synthesis (Martin, 2003)

Technology	Advantage	Disadvantage	Data Collected by Technology					Implementation Requirements	Unit Cost (US $ in 2008)*	O/M Cost (US $ in 2008 per year)*	System Life (years)	Compatibility with existing Infrastructure
			Classification (length)	Count/Volume	Occupancy	Presence	Speed					
Active Infrared	Unlimited data rates; A variety of communication channels; Non-interference with metalized windshields	Detectors are affected by snow and rain because the short wavelengths cannot penetrate	X	X	---	---	X	Installation is done using a bucket truck and is fairly straight forward.	$7,000-8,100	$700	7-10	As long as support infrastructure is present. The technology can be implemented without having to install other mounting structures.

X Indicates that data is collected by technology

--- Indicates that data is not collected by technology.

* Initial costs were estimated using 2003 data. The cost was projected forward to 2008 with a 3% inflation rate.

Technology Recommendations

Each of the companies listed above have their own niche within the transportation detector market. Some of the companies specifically focus on active infrared detection, whereas other companies have active infrared as one product in a list of other technologies. If one is interested specifically in active infrared detection, it is recommended that they contact a company that has several products that utilize infrared detection for traffic data collection. An active infrared data collection system should be able to capture count/volume, speed, and vehicle classification. Something also to keep in mind, which will be a common theme throughout all of the recommendations, is the communication factor with companies located outside of the United States. A company may offer a great technology, but may not be able to implement their system if the proper lines of communication cannot be achieved. In addition, to communication it is important to check that the European hardware as well as software is compatible to systems being used in Texas. It is advised to seek out information about organizations that have worked with one of the companies profiled to see if they have any specific recommendations or insight about working with a particular company. Many times a company may be able to provide contact information for work they have previously performed.

5.2.2 Passive Infrared Detection

Passive infrared detectors do not transmit energy of their own, but instead recognize the energy emitted by other sources. The detector is used to capture volume, speed, class measurement, occupancy, and presence. It can also be used to detect pedestrians. A passive infrared detector recognizes energy emitted from vehicles, the road surface, and other objects that are in their view path. The energy captured is then converted into signals that are interpreted as the presence of mainly vehicles. The sensors are typically mounted overhead but also have a sidefire mounting option (Klein, 2006).

Table 5.3: Available Passive Infrared Detection Technology Systems

Company	Available Technology	Technology Description
GENEQ Inc.	Model IR 250	This passive infrared detector is used for data acquisition. The detector can capture presence, count, speed, and length. The technology uses a combination of static and dynamic detection channels to form two or more detection zones. The detector can be mounted overhead or sidefire and is capable of replacing a pair of inductive loops. The detectors can operate accurately under all conditions including heavy traffic congestion and down to a standstill (GENEQ, 2008).
GENEQ Inc.	TT 290 Series	Tri-Tech detectors use three different detection principles to capture vehicle classification, counting, speed, presence, and, occupancy. The technology uses MW detection, US detection, and PIR detection (GENEQ, 2008).
Siemens ITS	EAGLE Passive Infrared Detector Advanced Long-Range Motion PIR 3 Series	EAGLE PIR detectors capture thermal radiation and discriminate between the slightest changes in thermal radiation. The detector can be used to detect vehicles for request of green phase, extension of green phase, or time gap recognition. The highlights of the technology include lane-selective field of view, economical loop replacement, dynamic processing logic, user-selectable detector functions, and internal self-check facility (Siemens, 2008).
Xtralis ASIM	IR 200V Series Dynamic PIR vehicle detectors	This product detects vehicles approaching an intersection for request and extension of the green phase in flexible time intersections. This infrared detector detects all kinds of vehicles entering the field of view and remains activated as long as motion is detected within the field of view. Various models exist with a lane selective detection up to 100m. All models are available with a comprehensive choice of supply voltages and output options (Xtralis, 2007).
Xtralis ASIM	IR 240 Series Dynamic low cost, multipurpose PIR detectors	This product detects vehicles approaching an intersection for request and extension of the green phase in flexible time intersection control applications. This passive infrared detector detects all types of vehicles or pedestrians entering the field of view and remains activated as long as motion is detected within the field of view. This model includes lane selective detection up to 30m as well as volumetric coverage of the approach or detection of pedestrians on a crossing are available with DC supply only and relay or transistor outputs. This detector requires continued movement to maintain the output activated and a vehicle coming to a halt in the field of view is not detected as being present (Xtralis, 2007).
Xtralis ASIM	DT 270 Series Dual technology PIR (Passive Infrared) and US (Ultrasonic) detectors	This product does static detection of vehicles or people entering the detection cone of the ultrasonic part for active counting and presence detection in flexible time intersection control applications. Typical nominal ranges for distance measurement are within 12m. The detectors are available with a comprehensive choice of supply voltages and output options. The detector is easy to install and highly reliable due to the active distance measurement and adaptive internal signal processing. Stationary vehicles can be detected for a virtually unlimited period of time (Xtralis, 2007).

Company	Available Technology	Technology Description
Xtralis ASIM	IR 250 Series Multi channel PIR vehicle detectors	This detector is used for counting, occupancy, speed, and length assessment in traffic data acquisition systems. The detector is used for a combination of static and dynamic detection channels in a single detector. Mounting of the device can be done on bridges, gantries or other stable structures above the lane to be observed with a nominal detection range of 6 to 16 meters. The detector is low in power DC supply only and two-way communication over an RS 485 data bus. Models with different focal lengths of the optics are available (Xtralis, 2007).
Xtralis ASIM	TT 290 Series Technology PIR/US/MW detectors	This detector can be used for counting, occupancy, speed, and vehicle classification in traffic data acquisition systems. Nominal mounting height is 5 to 8 meters depending on model and the device can be mounted on bridges, gantries, and other stable structures above the lanes. The combination of the three technologies enables better detection of different traffic data sets. The standard TT 292 is for two vehicle classes with DC power supply. The TT 293, 295, and 298 are for up to eight vehicle classes and include multi channel PIR curtains across the width of the lane for best performance (Xtralis, 2007).

Table 5.4: Passive Infrared Detection Technology Information Synthesis (Martin, 2003)

Technology			Data Collected by Technology									
	Advantage	Disadvantage	Classification (length)	Count/Volume	Occupancy	Presence	Speed	Implementation Requirements	Unit Cost (US $ in 2008)*	O/M Cost (US $ in 2008 per year)*	System Life (years)	Compatibility with existing Infrastructure
Passive Infrared Detection	Detectors are not affected by inclement weather; Produce no energy signal	Can undercount if changes in background occur; Technology is best used where trends in the counts are already known	X	X	X	X	X**	Installation is fairly quick taking 15 minutes to attach the detector. Sidefire installation can be more time consuming because of calibration issues.	$800-2,300	$700	7-10	A sidefire mount can be difficult to implement if the supporting infrastructure isn't present. Capturing the appropriate detection zone can be difficult with a sidefire mount.

X Indicates that data is collected by technology
--- Indicates that data is not collected by technology.
* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.
** Detectors with multiple detection zones can measure speed.

Technology Recommendation

Passive infrared detection technology can capture vehicle classification, count, occupancy, presence, and speed. When selecting a company to provide passive infrared technology it is important that their technology can deliver these five major data sets. Some companies offer a combination of detectors to capture the data sets. It is recommended that the company providing the technology can integrate it into the current TxDOT ITS architecture and possess the communication skill to achieve this ultimate goal.

5.2.3 Microwave Detection

Microwave sensors, or Doppler detectors use a Doppler radar signal to bounce microwaves off an object and measure the frequency of the returning microwaves. These technologies typically operate at frequencies of 1-10 GHz (Martin, 2003). The devices work when an object is moving in the sensor's field, the microwave that hits the object and returns to the sensor is at a different frequency than the original signal that was transmitted. In this way the detector recognizes the change and detects the object depending if the returning frequency is higher or lower than the original. This detection device works in all weather and traffic conditions and offers a greater distance of converge and are reliable at those distances (Martin, 2003).

Table 5.5: Available Microwave Detection Technology Systems

Company	Available Technology	Technology Description
AGD Systems Ltd. (UK), AGD Systemes SARL (France)	AGD 200 (Non-UK Applications)	Product has been designed to detect and monitor vehicles at signalized intersections and other applications where the detection of moving vehicles is required in a long zone extending from the detector. The detector is CW Doppler radar which operates in the X-band. It is able to discriminate between approaching and receding traffic. The detector can be used for the detection of vehicle moving in one direction up to 100 meters from its mounting position and can be used for the call and/or extension of a signal phase on a single or two lane approaches to a particular signal. It is recommended that where detection in more than two lanes is required; more than one detector should be used. Other applications of detector include all red extensions as well as normal traffic installations or anywhere that detection of moving vehicles is required (AGD, 2008).
AGD Systems Ltd. (UK), AGD Systemes SARL (France)	AGD305 Traffic Control	Product was designed to detect and monitor vehicles at signalized intersections and other applications where detection of moving targets is required in a long zone extending from the detector. The detector is a CW Doppler radar that operates in the K-band (24GHz). The detector has a custom designed planar radar antenna able to detect moving vehicles up to 100 meters. The detector has a set of user selectable switches to adapt to the detector's performance for a given installation. This allows the user to adjust the low speed threshold and other detection parameters to achieve optimal detection performance. The AGD305 can be supplied with a Livewire interface in place of the standard switch for a greater control of detection performance. Bluetooth connection is available on request (AGD, 2008).
AGD Systems Ltd. (UK), AGD Systemes SARL (France)	AGD315 Digital Radar Traffic Detector	Product has been designed for the detection and monitoring of vehicles in queues, distance specific speed measurement, ramp monitoring, and occupancy measurement. The product operates in the K-band (24GHz). It is able to discriminate between approaching and receding traffic and the detection of stationary vehicles. The AGD315 has a custom designed planar antenna and employs a unique frequency modulated technique which enables the detection of moving or stationary vehicles at specific distances from the radar. The detector is configured via a special cable connected to the Livewire port on the rear face of the unit for set-up or optionally can be supplied with the Livewire interface fully Bluetooth enabled. Connection to host system is via relay or RS485 interfaces and the AGD Janus range features a number of alternative ITS connectivity solutions (AGD, 2008).
Applied Traffic Limited	AT-SR3 AVC— Temporary/Permanent Radar Detection Device	The AT-SR3 AVC radar traffic monitoring system is used to make covert recordings of traffic flow data and the accompanying free issue PC analysis software enables the operator to make detailed analysis of the data. The radar device can record every vehicle without hindering the flow of traffic and the unit is secured quickly and safely by one person to an available post using specially designed clamps. The radar system is used to accurately measure the vehicle speed, the length and the gap between vehicles, on a vehicle by vehicle (VBV) format. Every vehicle is stored with the date and time of the recording. The product is powered by 6 volt batteries and will operate for 10 days and the 1MB memory can be used to store up to 209,700 vehicles individually. The data is then transferred to a PC using a PDA and then can be analyzed. The system has been developed to support most Palm and Compaq iPAC PDAs (Applied Traffic Limited, 2007).
Applied Traffic Limited	AT-SR4 Bluetooth® Radar Counter Classifier—Short-Term Traffic Counts	Similar to the AT-SR3 AVC, the AT-SR4 is equipped with Bluetooth communications (Applied Traffic Limited, 2007).

Company	Available Technology	Technology Description
Counters & Accessories Ltd.	Radar Recorder	The technology uses a state of the art planar antenna, and radar techniques to measure the speed of approaching and receding vehicles. The Radar Recorder is supplied complete with connection cables, mounting bracket and clips, battery and charger. The data collection software for the Palm Pilot is provided. The unit is 6V, very low powered which allows for 8 days of data achievable from a single battery. The radar mounted at 1m height on a busy two-lane road (12,000 vehicles per day) will, on volume, produce accuracy results around 98% on near side and 96% on farside. As the height of the placement of the radar is increased the accuracy of the volume will also be increased. The radar range is up to 120 meters (Counters & Accessories Ltd., 2006).
DataCollect	MWD1 Radar Detection	The MWD1 radar detector uses microwave detection for non-intrusive above ground detection. The narrow antenna beam width allows a lane selective measurement in overhead applications. The detector measures speed, length for vehicle classification, and net time gap (DataCollect, 2006).
DataCollect	SDR radar classifier	The SDR is designed to meet demands for a solid and reliable non intrusive traffic measuring device. The device is easy to set up on the roadside with a PDA (palm). The data collected can be monitored online and is more real than data collected b visible sensors on the road. The SDR can measure and store all passing vehicles in 2 directions and with their arrival date and time, speed, length, and direction up to 1.6 million vehicles (DataCollect, 2006).
DataCollect	SDR Fusion	The SDR Fusion combines a speed panel with the SDR traffic classifier technology. The Fusion can measure 2 directions of traffic simultaneously recording traffic count, speed, and length classification, but also control a speed panel via Bluetooth communication. The user can display speeds related to the type of vehicle. In a truck speed limit zone (downhill road) only the truck driver would get their appropriate speed limit information (DataCollect, 2006).
EIS Electronic Integrated Systems, Inc.	RTMS (Remote Traffic Microwave Sensor)	The RTMS radar is a sensor which detects presence and measures traffic parameters in multiple independent lanes. The RTMS detector provides information on presence, volume, occupancy, speed, and classification information in up to 8 user-defined detection zones up to 60 m (200 ft) away. Output information is provided to existing controllers via contact pairs and to computer systems via a RS-232 serial communication port. The RTMS is designed for side-fired operation and is usually mounted on existing side-of-the-road poles, is easy to install and remove, and is fully programmable to support a variety of applications. Technology has a 15 year lifespan and is by far the detector with the lowest cost of ownership (EIS, 2008).
EIS Electronic Integrated Systems, Inc.	RTCP (Remote Traffic Counting Package)	The RTCP is a traffic counting solution for permanent and temporary counting stations and data is time stamped and stored from multi-lane roads. The system is side-fired from existing light poles and requires no lane closure with installation. The RTCP is accurate in all-weather operations and covers up to 8 lanes in 15-200 ft range. The information collected includes volume, occupancy, speed, and classification by length/headway. No maintenance is required and it has a 10 year MTBF (mean time between failures) (EIS, 2008).
EIS Electronic Integrated Systems, Inc.	WATER (Wide Area Traffic/Event Reporting)	This is a quickly deployed, low cost, wide area traffic measurement, and reporting system. The RTMS-based system measure traffic at many detection stations and transmits their data in real-time to a traffic operations center for analysis. No lane closures during installation are required and no maintenance is required either. The system is installed on existing roadside poles via side-fired RTMS. One can collect data from up to 50 detection stations and the coverage radius is 15 km in the line of sight. Additionally the system is interfaced with dial-up or leased-line modems (EIS, 2008).

Company	Available Technology	Technology Description
Excel Technology	XLrvd RADAR Vehicle Detector	This vehicle detector is suitable to most roadway applications. Its output is vehicle speed and therefore the device may be used for mentoring and logging purposes. The device can also be used as a vehicle detector and can be interfaced with existing traffic control equipment to provide temporary vehicle actuation when loops have failed. Adjustment of detection performance parameters enables wider usage on bikeways where pedestrian detection is required. Vehicle length and speed detection can be achieved with a controlled orientation towards the target object and a side fire direction from the roadside may be used dependent of the application (Excel, 2007).
Fortran Traffic Systems Ltd.	Accuwave™ LX-150 Microwave Detector	This technology features true presence detection and replaces loops and loop detectors for advanced detection on approach and actuated interaction and ramps. The detector can handle multiple lanes and equally effective on gravel, asphalt and concrete. The system is also RS 232 ready for setup and monitoring. The detection range is typically 80 feet (Fortran, 2007).
International Road Dynamics Inc.	RTMS (Remote Traffic Microwave Sensor)	RTMS is a low-cost, advanced sensor for the detection and measurement of traffic on roadways. It's all-weather accurate and virtually maintenance-free with long-term worry-free reliability. The RTMS is a small roadside pole-mounted radar operating in the microwave band and proves per-lane presences as well as volume, occupancy, speed and classification information in up to 8 user-defined detection zones, simultaneously. A single RTMS can replace multiple inductive loop detectors (IRD, 2008).
International Road Dynamics Inc.	TMS-SA Microwave Traffic Counter/Classifier	The TMS-SA is a compact detector that can be used for temporary or permanent purposes. The technology uses a Doppler radar and it counts vehicles, measures their speed, and classifies up to four length categories. It has a memory up to a million vehicles and the setup and download data can be done via Bluetooth wireless technology. The TMS-SA has a speed range of 6 to 168 mph and has a speed accuracy of 97%, a counting accuracy of 98%, and a length accuracy of 90% (IRD, 2008).
OLVIA JSC	Spectr 1	This product is used to collect statistics about traffic parameters and controlling the traffic. The technology can detect and register both stationary and moving vehicles around the clock. The main function of the microwave traffic detector is traffic intensity control and can control up to 8 lanes. The device collects information about traffic intensity, total quantity of transport, traffic lane occupancy, average speed in each traffic lane, and quantity of long vehicles (OLVIA, 2007).
PEEK Traffic Limited	Microwave Vehicle Detector (AGD200)	This product is used for detecting vehicles at intersections and has a user adjustable range, speed threshold, and direction of detection. The technology used CW microwave techniques (PEEK, 2008).
Quixote Transportation Technologies, Inc.	trans-Q™ Radar Traffic Classifier	The trans-Q radar is a non-intrusive radar classifier for measuring traffic data. The trans-Q is designed for non-contact measurement and utilizes radar technology to detect traffic count, speed, and length. The trans-Q is easy to set-up on the roadside with a PDA and does not disturb traffic flow. The sensor detects all passing vehicles in two directions and data is easily retried with a corded PDA or wireless Bluetooth connection (Quixote, 2007).
Traffic Technology Ltd	SDR Radar Traffic Classifier	This product is a traffic classifier that was designed to be a reliable non-intrusive traffic measuring device. The SDR is easy to set up with a PDA without interrupting traffic flow. Data can be monitored online and is uninfluenced and more "real" than data collected by visible sensors on the road. The SDR measures and stores all passing vehicles in two directions with records their arrival date, time, speed, length, and direction (Traffic Technology Ltd., 2007).

Company	Available Technology	Technology Description
Traffic Technology Ltd	**SDR Basic Radar Recorder**	The SDR Basic is an entry level covert radar monitoring device. The SDR range of radar traffic data recorders have been designed to eliminate the need for "in road" working, no tubes or loops. The Data is stored in the 128MB memory and can be downloaded via RS232, optional Bluetooth, or GPRS communications. The recorder captures vehicle count, speed, and direction (Traffic Technology Ltd., 2007).
Traffic Technology Ltd	**SDR Midi Radar Recorder**	The SDR midi is a mid range radar device and has the same functions as the SDR basic. The SDR midi captures vehicle count, speed, direction, and vehicle classification (2 length bands) and is supplied complete with Excel analysis software (Traffic Technology Ltd., 2007).
Traffic Technology Ltd	**SDR Pro Radar Recorder**	The SDRpro is the leading radar traffic classifier. The detector is capable of detecting bi-directional vehicle flow, speed, and vehicle type by length. The SDRpro provides a complete low cost alternative to tube and loop based classification sites. The SDR pro can be installed at the side of the road or above the road on a bridge or gantry. When purchased the product includes communication options for Bluetooth or web hosted GPRS and is complete with Excel analysis software (Traffic Technology Ltd., 2007).
TSEU	**ADD - Above Ground Dynamic Vehicle Detector**	This product is used to detect vehicles and replace multiple loop induction systems. The ADD has a minimum speed detection threshold set to 8 kph and a low speed threshold is also available at 5 kph. This detector when installed has a range of 40 to 60 m from the stop line and the ADD beam can detect vehicle across two normal lanes of traffic (TSEU, 2005).
Xtralis ASIM	**TT 290 Series Technology PIR/US/MW detectors**	This detector can be used for counting, occupancy, speed, and vehicle classification in traffic data acquisition systems. Nominal mounting height is 5 to 8 meters depending on model and the device can be mounted on bridges, gantries, and other stable structures above the lanes. The combination of the three technologies enables better detection of different traffic data sets. The standard TT 292 is for two vehicle classes with DC power supply. The TT 293, 295, and 298 are for up to eight vehicle classes and include multi channel PIR curtains across the width of the lane for best performance (Xtralis, 2007).
Xtralis ASIM	**MW 233 Doppler radar vehicle detectors for AC supply**	This product is a K-Band Doppler radar traffic technology designed to detect vehicles moving into or through the field of view in short to medium range. The MW233 functions like the 232 except that it is designed of an AC power supply (Xtralis, 2007).
Xtralis ASIM	**MW 231 & 232 Doppler radar vehicle detectors for DC supply**	This K-band Doppler radar traffic detector is designed for the detection of vehicles moving into or through their field of view in short to medium range. The MW 232 has a number of user-selectable functions not available in the MW 231. The MW 232 can react to approaching traffic on one or in both directions. The minimum threshold speed of 4 km/h or 8 km/h can be selected. In addition the timer function automatically activates the output to simulate the arrival of a vehicle if there was no detection for a period of 2.5 minutes (Xtralis, 2007).

Table 5.6: Microwave Detection Technology Information Synthesis (Martin, 2003)

Technology			Data Collected by Technology					Implementation Requirements	Unit/Installation Cost (US $ in 2008)*	O/M Cost (US $ in 2008 per year)*	System Life (years)	Compatibility with existing Infrastructure
	Advantage	Disadvantage	Classification (length)	Count/Volume	Occupancy	Presence	Speed					
Microwave Radar: Doppler & True Presence	Good in most weather conditions; Can directly measure speed; Can operate over multiple lanes	Doppler sensors cannot detect stopped vehicles; Doppler sensors have been found to perform poorly at intersections as volume counters	X	X	X	X	X	Implementation can be done without closing lanes. The device is typically mounted on existing infrastructure. The detection zones can be set by the operator. Once set and calibrated, very little else needs to be done to the detection unit.	$1,200-3,800	$100-200	5-10	RTMS radar uses RS 232 serial communication port and typical detectors can work over several lanes of traffic.

X Indicates that data is collected by technology

--- Indicates that data is not collected by technology.

* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

With so many different companies providing technologies in microwave detection it is important to consider the extras that come along with the standard technology. Microwave detection can capture vehicle classification, count, occupancy, presence, and speed and all technologies available should provide those data sets. It is recommended that the company specialize in microwave detection and offer several options depending on the complexity of the intersection or roadway. The technology should have a long life span preferably around 10-15 years and should be adaptable depending on the power supplies available at the site. A combination of technologies can also be used in microwave detection to capture a greater range of data sets.

5.2.4 Ultrasonic Detection

Ultrasonic detectors can detect volume and presence. An ultrasonic detector is simply an active acoustic detector. The ultrasonic detector transmits sound waves toward the detection zone between frequencies of 20 to 300 KHz. The detector then senses the waves returned from reflecting off of the vehicle. Two types of ultrasonic detectors exist: pulsed ultrasonic detectors and continuous wave (CW) ultrasonic detectors (Martin, 2003).

Table 5.7: Available Ultrasonic Detection Technology Systems

Company	Available Technology	Technology Description
Excel Technology	ETG Ultrasonic Vehicle Detector	The ETG Ultrasonic Vehicle detector was developed for bus station application where loops could not be installed and radar reflected interference caused a high rate of error. The Ultrasonic detector was calibrated to the distance from the bus station ceiling to the roadway. Most unites were directed perpendicular to the roadway however a few sites required a side fired application (Excel, 2007).
Xtralis ASIM	DT 270 Series Dual technology PIR (Passive Infrared) and US (Ultrasonic) detectors	This product does static detection of vehicles or people entering the detection cone of the ultrasonic part for active counting and presence detection in flexible time intersection control applications. Typical nominal ranges for distance measurement are within 12 m. The detectors are available with a comprehensive choice of supply voltages and output options. The detector is easy to install and highly reliable due to the active distance measurement and adaptive internal signal processing. Stationary vehicles can be detected for a virtually unlimited period of time (Xtralis, 2007).
Xtralis ASIM	TT 290 Series Technology PIR/US/MW detectors— Infrared, Ultrasonic, and Microwave Detector	This detector can be used for counting, occupancy, speed, and vehicle classification in traffic data acquisition systems. Nominal mounting height is 5 to 8 meters depending on model and the device can be mounted on bridges, gantries, and other stable structures above the lanes. The combination of the three technologies enables better detection of different traffic data sets. The standard TT 292 is for two vehicle classes with DC power supply. The TT 293, 295, and 298 are for up to eight vehicle classes and include multi channel PIR curtains across the width of the lane for best performance (Xtralis, 2007).

Table 5.8: Ultrasonic Detection Technology Information Synthesis (Martin, 2003)

Technology			Data Collected by Technology									
	Advantage	Disadvantage	Classification (length)	Count/Volume	Occupancy	Presence	Speed	Implementation Requirements	Cost per Unit (US $ in 2008)*	O/M Cost (US $ in 2008 per year)*	System Life (years)	Compatibility with existing Infrastructure
Ultrasonic Detection	Can be used over multiple lanes; Easy installation	Temperature change and extreme air conditions can effect performance	---	**X**	---	**X**	---	Units are typically easy to mount. Calibration takes no longer than 10-15 minutes.	$600	$200	7	Can be installed overhead or sidefire on overhead structure or gantry.

X Indicates that data is collected by technology
--- Indicates that data is not collected by technology.
* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

       Ultrasonic detection is often used in combination with other technologies to capture a wide array of traffic data. This is because ultrasonic detectors are typically only able to capture vehicle count and presence. As was mentioned before, communication is a key factor in contacting the distributor or supplier of the specific company in question. Compatibility with the existing system is important as well as technical support if this technology is in fact implemented. Typically ultrasonic detection is used for vehicle detection more so than actual traffic data collection unless combined with other technologies.

5.2.5 Passive Acoustic Detection

       Acoustic detection which can be passive or active (Ultrasonic Detectors) is done with a sensor that is typically mounted to existing roadside structures. The detector monitors a traffic system by detecting the acoustic signals that vehicles create and radiate while operating. A passive acoustic detector does not radiate a signal whereas an active detector radiates a signal and is classified as an Ultrasonic Detector (Martin, 2003).

Table 5.9: Available Passive Acoustic Detection Technology Systems

Company	Available Technology	Technology Description
International Road Dynamics Inc.	**SAS-1**	The SAS-1 operates in the adverse environments found on roadside structures. It is easy to use and can detect multiple lanes of traffic for real-time operations or to collect traffic counts with 3 levels of classification. The wireless option eliminates home run cables and it is the ideal back-fit for failed loop detectors. This product is distributed by IRD but is manufactured by SmarTek Systems which is also profiled (IRD, 2008).
SmarTek Systems	**SAS-1 Passive Acoustic Vehicle Detector**	This product is a non-intrusive, true presence vehicle detector providing multi-lane traffic count, occupancy, per vehicle speed information and can store up to 60 days of data. The sensor provides up to five lanes of dual-loop, speed trap equivalence when installed from a side fire position. The detection zone is equivalent to a 6 foot inductive loop (SmarTek Systems, 2007).

Table 5.10: Passive Acoustic Detection Technology Information Synthesis (Martin, 2003)

| Technology | Advantage | Disadvantage | Data Collected by Technology | | | | | Implementation Requirements | Cost per Unit (US $ in 2008)* | O/M Cost (US $ in 2008 per year)* | System Life (years) | Compatibility with existing Infrastructure |
			Classification (length)	Count/Volume	Occupancy	Presence	Speed					
Passive Acoustic Detection	Easy installation; Wireless option available; Non-intrusive; Insensitive to precipitation; Provides up to five lanes of dual-loop detection	Technology is affected by snow, extreme cold, acoustic noise, wind, light, and low traffic volume	X	X	X	X	X	Easy to install. Typically mounted in sidefire position. Unit is compact in size and has a modest weight for installation using a bucket truck.	$5,800	$200-500	7	Uses windows software.

X Indicates that data is collected by technology
--- Indicates that data is not collected by technology.
* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

Passive acoustic detection is a technology that can capture vehicle classification, count, occupancy, presence, and speed. However, the patent for the technology is held by one company who currently produces the product. The technology can detect both static and dynamic vehicles and can monitor five lanes of traffic. Some of the disadvantages which are listed in the following table are the main drawbacks to this technology and may be the reason more companies have not entered the market in passive acoustic detection technology.

5.2.6 Video Detection

Video detection technology can capture a wide range of data, including traffic volume, presence, occupancy, density, speed, and vehicle classification. Also, they can do vehicle identification, incident detection and be used for origin destination information. Some of the main drawbacks to the cameras are their susceptibility to environmental factors. For example, if video cameras are used in busy freeway areas, how to keep the lens clean to ensure high-resolution images becomes a main problem. It closely associated with the environmental conditions and where the camera is placed. Additionally, video detection requires more attention for mounting and is susceptible to unfavorable camera vibrations due to strong wind. The camera installation mounting height varies depending on the specific devices, locations, and practical conditions. Based on the TxDOT experience, for standard signalized intersections, the mounting height is usually closer to 25-35 ft, sometimes it may be 40 ft when mounted on extensions from mast arms or at the top of the signal poles.

Table 5.11: Available Video Detection Technology Systems

Company	Available Technology	Technology Description
ACISA— Aeronaval de Construcciones e Instalaciones, S.A.	**Visioway ® OpenCounter**	This is an "all in one" video based traffic data collection system that is made up of a zoom camera as well as an embedded system that processes the image in real time. The product can be used for a variety of traffic management applications. The video detectors can be used as vehicle presence detectors (collecting vehicle counts, measure speed, classify vehicles and collect traffic data), tracking detectors (detecting traffic violations i.e. illegal turns and wrong-way drivers), and traffic jam detectors (activated when vehicles are stopped in a percentage of an area) (ACISA, 2008). The equipment used can be accessed by a control center or by a laptop computer using only a web browser (i.e. Firefox, Internet Explorer). The video server transmits digital streaming video taken in real time that can be visualized using a viewer application (ACISA, 2008).
Austrian Research Centers	**Smart Eye—TDS / Traffic Data Sensor**	The Smart Eye—TDS does single vehicle detection on up to four lanes (inbound and outbound traffic), provides time stamped data (date and time), velocity, length of vehicle, time gap in milliseconds, classification (car/truck), and occupancy in milliseconds. Smart eye is offered in a variety of modules, depending on project and application. The basic system "smart eye TDS" is required and then traffic light control or trigger applications as well as traffic data acquisition for statistical analysis can also be added to the system (Smart Systems, 2008). The smart eye system allows easy configuration and maintenance of all systems simultaneously and the software can be installed on any standard personal or notebook computer for convenient remote maintenance. The following databases are supported: Microsoft™ - SQL 2003/2005; My SQL Database, Microsoft™ Access; and CSV-Fileformat (Smart Systems, 2008).
Citilog Inc.	**MediaRoad**	Video detection uses image processing algorithms to extract information from standard video-surveillance camera images. MediaRoad can be used as both an automatic incident detection technology as well as a traffic data collection technology. The information collected includes flow, speed, occupancy, vehicle headway, vehicle classification, and travel time. MediaRoad has been implemented in the Beijing Ring Road, A13, and A14 Motorways, and in Calgary, Canada (Citilog, 2008).
Citilog Inc.	**VisioPaD**	VisioPaD is a video-based Automatic Incident Detection System that uses standard existing cameras to identify incidents and accidents on roadways and provides quick alarms to Traffic Control Centers. VisioPaD provides traffic operators with an alarm after an incident occurs even before the consequences of an incident can be noticed by traditional monitoring. Citilog's software-based system uses existing video signals from any closed circuit television (CCTV), fixed, pan-tilt-zoom (PTZ), analog, IP and any other camera, thus requiring no new hardware or infrastructure additions. VisioPaD also automatically adjusts to camera shifts, changes in the video feed, to all weather conditions, to variations in lighting and all traffic conditions to maximize video clarity at all time of the day or night. It is currently being used in Fort Lauderdale, Florida and has been deployed by the Illinois Department of Transportation as a security measure (Citilog, 2008).
Citilog Inc.	**MediaTD**	MediaTD is software created for traffic data collection which includes vehicle counts, vehicle classification, occupancy, headway, and speed. MediaTD uses video detection which is an alternative to loop installation and does not required roadwork when installing the detectors. The system is flexible and can adapt to changing conditions on roadways including lane reassignment, temporary lane closure or work zone activities. The system uses standard fixed cameras, color, or black and white and is easily set up and can be tracked remotely using a laptop or a computer connected to a network (Citilog, 2008).

Company	Available Technology	Technology Description
Citilog Inc.	MediaCity	Media city is a video-based detection solution that collects real-time information to identify the presence of vehicles at signal-controlled intersections. The MediaCity software is compatible with CCCTV, Analog or IP cameras and works under all conditions. MediaCity can improve safety and reduce congestion at intersections by providing customizable data to traffic controllers about the presence or absence of vehicles within a specified zone and can detect both moving and stopped vehicles. The system's basic functions include vehicle presence detection, stopped vehicle detection, directional detection, and pedestrian detection. In addition, traffic data is collected along with queue length and queue monitoring (Citilog, 2008).
Clearview Traffic	M800 Journey Time Monitoring Systems	The Marksman 87x series of camera system uses cameras fixed to gantries or other roadside furniture to identify vehicles at key points in the network using Automatic Number Plate Recognition (ANPR). Each camera is connected to a roadside cabinet which houses the ANPR software. The data is transferred every few minutes, hours, or daily and then the software calculates journey time and/or Origin and Destination matrices for onward transmission to the client and storage for later analysis. A small Marksman system can deliver valuable information about changes and trends in journey times. In a typical city there might be seven major routes into the city center and installing ten outstations with 15 cameras can give enough through coverage of all major routes. The system is particularly useful for bus lane performance and tolling systems. The system has been installed in major European cities including Helsinki, London, Rotterdam, Birmingham, Newcastle, and Glasgow (Golden River, 2007).
Econolite	Autoscope Solo Terra	The Autoscope Solo Terra sensor is a color video detection and surveillance system that quickly installs. It reduces maintenance with ClearVision faceplate coating and offers convenient Terra Technology that uses IP-based addressing with a unique Ethernet MAC address. Terra Technology employs an Autoscope Terra duel-core processor with sophisticated image processing and Advanced RISC Machine (ARM) general-purpose processing in a small SoC package for low power consumption. Multi-treaded software processes video images in real-time to detect traffic, extract data, identify incidents, and transmit detector outputs while simultaneously streaming full-motion MPEG-4 video (Econolite, 2008).
Econolite	Autoscope Solo Pro II	This sensor offers field-proven reliability and flexibility to meet more detection objectives. This product is ideal for freeway, intersection, bridge, tunnel, railroad, traffic monitoring, and indecent prevention applications. With the Autoscope Communications Server Software Developer's Kit (SDK), a programmer can easily create new client applications for display, incident alarms, and traffic parameter databases. The system uses twisted-pair wiring which is faster and easier to install than higher-cost coaxial cables. Remote connections as simple as a phone line or wireless radio can bring compressed video and data back to a traffic management center (Econolite, 2008).
Econolite	Autoscope AIS Color	The product is a high resolution, color image sensor, especially optimized as a video source for the Autoscope stand-alone MVP (machine vision processor) product suite. The Image Sensor produces consistent video quality in all weather, lighting, and traffic congestion levels common to the traffic industry. It has high sensitivity for accurate vehicle detection at night and other times of low light levels. During setup, the 22x zoom auto-iris lens quickly adjusts to a field view best suited for the detection objectives and a coax modem used with a laptop computer can adjust the zoom of the camera (Econolite, 2008).

Company	Available Technology	Technology Description
Econolite	Autoscope Atlas	The Autoscope Atlas is a technology used for intersection detection. The system is a video detection system that uses a dual-camera video processor that can be used to replace loops for stopline vehicle detection for intersection control. The Atlas processor card slides easily into a rack to provide detection for four approaches to an intersection providing more cost-effective vehicle detection than ever before (Econolite, 2008).
Siemens ITS	SITRAFFIC Concert	This product is a traffic management control center developed by Siemens that collects, bundles, and evaluates traffic data and then distributes the information to various users in the form of traffic information. Concert integrates all traffic flows (parking traffic, local public transport, and individual traffic) and also different traffic areas (inner city, highway, county). The detectors used in this system include the classical loop detectors, overhead detectors, and video detectors. Specific information on all of these detector types could not be found via the website (Siemens, 2008).
Siemens ITS	TRAFFIC EYE® Universal	This product provides an overhead detector system that can be easily installed at any location. The autonomous system doesn't require any cabling, neither for power supply nor for the transmission of traffic data. Power is supplied by a solar panel with battery back-up and data communication is handled via the mobile telephone network (GSM). Up to six detectors deliver reliable measurements of traffic density, speed, and number of vehicle independent of weather conditions. Because of the passive detection technology, vehicles are not affected by radiation (Siemens, 2008).
SmarTek Systems	SVS-1 Vehicle Detection for Intersections	This is a video detector that delivers reliable stop line vehicle detection at an affordable price. The system can configure up to 6 off-the-shelf NTSC video cameras with up to 30 zones in each. Map the zones to 10 relays per camera via Boolean logic (SmarTek, 2007).
Tattile srl (Traffic Division)	VEGA ANPR Automatic Number Plate Reader	This product is an all in one camera, analyzer, and illuminator. ANPR for both front and rear car plate numbers and the camera can process up to 20 number plates per second. The camera has a range of 4.7 up to 11.5 meters (Tattile, 2008).
Tattile srl (Traffic Division)	VEGA ANPR Wireless Automatic Number Plate Reader	This product is an all in one camera, analyzer, modem, and illuminator. The camera captures both frontal and rear car plate numbers and can process up to 20 number plates per second. The range of the camera is 4.7 to 11.5 meters and a PC and Shelter system is not required. The system is configurable in stand-alone/on-line modality and requires 9W low power consumption (Tattile, 2008).
Tattile srl (Traffic Division)	VEGA long range ANPR Automatic Number Plate Reader	The product is an all in one camera, analyzer, and illuminator that captures both frontal and rear car plate numbers. The system can process up, to 20 number plates per second and has a long range operation up to 15 meters. The camera is configurable in stand-along/on-line modality and requires only 8W low power consumption (Tattile, 2008).
Tattile srl (Traffic Division)	VEGA Plus ANPR Automatic Number Plate Reader	This product is an all in one camera, analyzer, and illuminator that captures both frontal and rear car plates. It is the best choice for free flow ANPR and processes up to 15 number plates per second. The range of action is up to 22 m and has an Ethernet interface for supervised architecture along with web server functionality for set-up via Browser. The system is configurable in stand-alone/on-line modality and requires a low power consumption of less than 20 W (Tattile, 2008).
Tattile srl (Traffic Division)	ALGOR ANPR Automatic Number Plate Reader with context Camera	This product is an all in one camera, analyzer, illuminator, and context camera. The camera is black and white for ANPR of both frontal and rear number plates and can process up to 15 number plates per second in the free-run mode and up to 25 number plates per second in triggered mode. The camera has a range of action up to 25 m and is configurable in stand-alone/on-line modality (Tattile, 2008).

Company	Available Technology	Technology Description
Tattile srl (Traffic Division)	**DENER ANPR Automatic Number Plate Reader with context Camera**	This product is a camera, analyzer, illuminator, loop detector, and context camera. The camera is black and white and captures both front and rear number plates. However, a color camera is available for complete scene documentation. The range of action is up to 25 meters and it can process up to 15 plates per second in free-run mode and up to 25 plates per second in triggered mode. The loop detectors are used for vehicle classification and the whole system runs on a low voltage power consumption of only 25W (Tattile, 2008).
Tattile srl (Traffic Division)	**RIGEL ITS—Intelligent Transportation System**	This traffic analyzer is based on intelligent cameras and can detect traffic jams, stopped vehicles, wrong way vehicles, smoke and fire detection, vehicle counting and classification, average speed evaluation, statistic reports, and obscuring detection. The camera has a high resolution JPEG Event/Alarm Storage, a Giga Ethernet interface for LAN and low voltage power consumption.
Tattile srl (Traffic Division)	**SIRIO High Resolution Intelligent Camera with modem for Wireless solutions**	This product is an intelligent digital video camera with integrating algorithms which does automatic event detection. The system supports Giga Ethernet communication ports for LAN/WLAN networks. In addition the system can be remotely managed via PC, PDA, Smart Phone, Cellular, or Internet. Alarm notification is also available via SMS and MMS with included pictures or video where applicable. Local storage of information is captured on an SD memory card and remote storage is done on a FTP server or central station. The system is known for its quick installation and startup using solar panel or batteries (Tattile, 2008).
Telindus Surveillance Solutions	**Cellstack Integration Suite**	The Cellstack Integration Suite is a management system that is well suited to a multi-service IT environment. It allows the network designer to create a video surveillance network suitable for all user types and enables the network administrator to manage the network on a daily basis. The product line includes: Manager, Operator, Event Handling System, Gateway, Vision, Vision WebGate, MultiVision, and Media Player (Telindus, 2008).
Traffic Data Collection Systems Ltd	**HI-TRAC® 110 High-Speed Traffic Counter/Classifier System—Inductive Loop Detector and Piezo Electric Sensors, available with CCTV camera option.**	This product is an automatic vehicle counting and classifying system with loop profiling. The system takes inputs for up to 16 inductive loop sensors and 8 piezo electric sensors. The technology has both laptop and modem communication ports and has classification of up to 110 unique vehicle types. The data stored is done vehicle-by-vehicle (VBV) and has an option for CCTV camera connection for text insertion or license plate number recognition. It has a 4-lane operation as a standard and is expandable up to 8-lanes. The system provides a low cost means of recording vehicle count and classification without interruption to traffic flows (TDC, 2008).
Traficon	**TrafiCam®**	TrafiCam integrates both camera and detector into a compact unit that detects vehicles waiting at or approaching an intersection. The TrafiCam is an all-in-one sensor that is non-intrusive and is installed above ground. The technology is water and weatherproof as well as compact and easy to install and configure. The cam has a multiple direction sensitive detection zones and detection outputs and has an optional wireless communication option (Traficon, 2008).
Weiss-Electronic	**Video Detector Atlas**	This detector is a two-camera video detector that does traffic-dependent control of traffic light installations. One 19" rack is used for the two cameras and the cameras can be installed for overhead detection. The Atlas video detector is a newly developed detector in euro-card format allowing the connection of two cameras. The Atlas card has 4 inputs and 8 switching outputs, which can be freely, attached to the virtual detection zones. The unit has non-volatile memory data storage and a LED status-display for supply voltage, communication, video, and data processing (Weiss-Electronic, 2001).

Company	Available Technology	Technology Description
Weiss-Electronic	Video Detector RackVision	This product detects number of vehicles, does length classification, vehicle speed, occupancy time, and net time cap. It also is capable of incident detection concerning traffic jams, accidents, and wrong driver. The advantage is that it does overhead detection, is fast and easy to install, and has remote configuration. In addition, the system has manufacturer-independent implementation and has easy linking-up of several systems via ribbon cable (Weiss-Electronic, 2001).
Wireless Technology Inc.	Intelligent Traffic Systems Wireless Video Monitoring	This system makes the transmission of video imagery and pixilated data easy to capture. ITS Video Imagining can provide long or short range video and serial data transmission and works in conjunction with transportation system that measure traffic waves and control traffic signals and signage. Video signals received via wireless transmission can be re-transmitted to receivers located across the highways located within a 10 mile radius. The system includes the Video Transmitter CFS-2400P and the Video Receiver CFS-2400P (WTI, 2008).
Iteris Inc.	Vantage VIVDS	The Vantage video imaging vehicle detection system (VIVDS) were developed by Iteris Inc. It is a video system for detection of vehicle movement along roadways using image data analysis to measure the required traffic parameters, e.g. vehicle traffic intensity, speed and occupation of traffic lanes or classification of vehicles according to their length. At the same time the system can detect an obstacle in traffic flow (accident, immobilized vehicle, bulky object on the road etc.) and inform the operators at a dispatching centre. In a similar way it informs a dispatching centre on a low visibility state. It captures and analyzes video images through sophisticated algorithms and enables transmission of both video images and data using a wide range of communication technologies. The Vantage detection systems are ideally-suited for intersection control, traffic data collection on roadways and incident management applications on highways, as well as surveillance applications. The Vantage product line offers several models and configurations resulting in a wide range of video detection product solutions. (Iteris Vantage, 2000; Middleton and Parker, 2002, Iteris, 2008)

Table 5.12: Video Detection Technology Information Synthesis (Martin, 2003)

Technology	Advantage	Disadvantage	Data Collected by Technology					Implementation Requirements	Cost per Unit (US $ in 2008)*	O/M Cost (US $ in 2008 per year)*	System Life (years)	Compatibility with existing Infrastructure
			Classification (length)	Count/Volume	Occupancy	Presence	Speed					
Video Detection	Monitors multiple lanes/zones; Easy to modify detection zone; Captures a variety of data; Provides a wide-area detection	Detector is affected by inclement weather, shadows, day to night transition, vehicle/road contrasts, water, and any other adverse external environmental factors. For example, if video cameras are used in busy freeway areas to capture volumes, how to keep the lens clean to ensure high-resolution images becomes a main problem. It closely associated with the environmental conditions and where the camera is placed. Additionally, video detection requires more attention for mounting and is susceptible to unfavorable camera vibrations due to strong wind.	X	X	X	X	X	Camera must have a sturdy structure for proper mounting.	$1,600-4,600	$200-500	10	Most cameras will work in a variety of systems.

X Indicates that data is collected by technology
--- Indicates that data is not collected by technology.
* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

Video detection is a technology that has several different companies that provide a series of different products. With video detection more so than any other detection technology, the consumer will run into companies that are offering a total detection package over the particular hardware components. It is recommended that if a consumer is specifically looking at video detection hardware that they find a product that can be easily incorporated into their software and has a lifespan of at least 10 years. With that said, buying into a complete video detection system may be the best decision for the consumer. Several companies offer software and management systems to best utilize the video hardware. However, it is important for the consumer to consider where they see their organization in a 10 year span and to consider the health of the company they're purchasing their system from. Ultimately, one wants to avoid buying into a system that isn't user friendly, requires an excessive amount of technical support, and one that is not going to be compatible to upgrades or a change in the technology provider.

Another consideration when dealing with video technology is the technologies capabilities of automatic number plate recognition (ANPR). ANPR is a technology that is being used liberally in Europe and is making its way into different facets of the American traffic data collection market. Although this may not be a technology that a city or state sees as something they want today, it is an important consideration when buying technology that will be used in the future.

5.3 Intrusive Technologies

Intrusive detection technologies are those installed in-roadway, which means they "are installed within or across the pavement on roads and bridges (Martin, 2003)." Intrusive detectors have been widely used for the past few decades, however they have some drawbacks. In order to install the detectors and complete maintenance, traffic flow must be interrupted. Intrusive technologies are seen to have high failure rates under certain roadway conditions and they are fairly inflexible (Martin, 2003). The Intrusive detector technology highlighted in this document includes the following:

- Inductive Loop Detection

- Piezoelectric Detection

- Magnetic Detection

For each technology, available systems were identified and system attributes evaluated. Additionally, a synthesis table identifying advantages/disadvantages, data collected, implementation requirements, installation and maintenance costs, and compatibility with existing infrastructure for each technology type is provided. After evaluation of the different available technologies was completed, recommended system attributes were identified for each type of detection device. To provide a more complete summary of the Intrusive Detection Technologies available in today's market, several domestic and international companies were profiled.

5.3.1 Inductive Loop Detection

Inductive loop detectors are a well known detection technology. The device works, "when a vehicle passes over a loop or stays in a loop area, loop inductance is reduced and oscillator frequency is increased. A vehicle's presence is determined when frequency change

exceeds the threshold set by the sensitivity setting (Martin, 2003)." Three types of loop detectors currently exist and were captured in the technologies listed in the companies profiled. The three types include saw-cut, trenched-in, and preformed, each with its own positive and negative characteristics (Martin, 2003).

Table 5.13: Available Inductive Loop Detection Technology Systems

Company	Available Technology	Technology Description
AGD Systems Ltd. (UK), AGD Systemes SARL (France)	**AGD510 Traffic Control**	This product has been designed for the detection and monitoring of vehicles for traffic applications. The detector has an RS232 interface standard, which enables easy installation and maintenance as well as access to historic information. The detector can be used to provide reliable detection input in traffic control applications and provides all connections though an eleven way circular connector integrated with the rear of the housing. Connection to a power supply and sensing loop of a suitable load will enable the detector's fast-tune facility and initiate operation of the detector. Frequency selection is four bands (AGD, 2008).
AGD Systems Ltd. (UK), AGD Systemes SARL (France)	**AGD 520 Traffic Control**	This product has been designed for the detection and monitoring of vehicles for traffic applications. The detector is a compact multiplexed dual channel boxed inductive loop detector. The detector has two detection channels and output of the detector is via one set of relay contacts per channel. Detector operation can be observed via four station LED's on the front panel of the detector. The detector's high multiplex speed makes the detector suitable for speed and length measurement and it has an RS232 interface as standard which enables easy installation and maintenance as well as access to historic information. Frequency selection is four bands (AGD, 2008).
AGD Systems Ltd. (UK), AGD Systemes SARL (France)	**AGD 540 Traffic Control**	This product has been designed for the detection and monitoring of vehicles for traffic applications. The detector is a high speed four channel multiplexed inductive loop detector in Eurocard format. The high speed multiplexed operation of the detector is suited to applications where accurate speed measurement is required on high speed roads. Frequency selection is four bands per channel (AGD, 2008).
Applied Traffic Limited	**AT-HI TRAC 110 AVC**	The AT-HI TRAC 110 high-speed traffic data collection system provides a low cost means of recording vehicle count and classification without interruption to traffic flow. The unit interfaces with up to 8 piezo electric detectors and 16 induction loop detectors installed in the highway. Incident detection and event monitoring functions can be incorporated along with message sign activation and CCTV interface for text insertion and license plate recognition. The HI-TRAC 110 is accompanied by the HI-COMM software package which provides data retrieval via model (landline or GSM) or laptop as well as data analysis facilities and system diagnostic functions. In the standard configuration, two Piezo electric detectors and one induction loop detector are installed in the highway per lane of detection. The piezo electric sensors measure axle speeds and inter-axle spacing. The induction loop detects vehicle presence and measure the vehicle length (Applied Traffic Limited, 2007).
Applied Traffic Limited	**T5-VPC**	The T5-VPC Vehicle Profiling classifier has been designed to take advantage of the current developments in technology enabling the production of a very competitively priced, high performance product that includes high-speed processing, flash memory, and low power consumption. The T5-VPC is a highly accurate loop profiling classifier that is compatible with existing installations allowing easy swap out of older systems. It has the capability to simply expand up to 16 lanes of operation allowing the T5 to easily handle any loop based traffic counting scenario (Applied Traffic Limited, 2007).

Company	Available Technology	Technology Description
Applied Traffic Limited	**S5 SLC**	The S5 SLC Single Loop Classifier is the same as the T5 except that it has been designed to operate from a single loop array and allows the S5 to not only count traffic on a single loop, but also classify and record vehicle speed. This represents as massive step forward in counter classifier design. The S5 will produce 85th percentile speed reports and classify vehicles on single loop count sites. It has the capability to simply expand up to 32 lanes of operation (Applied Traffic Limited, 2007).
Clearview Traffic	**M68x 8/16 Loop Vehicle Count and Classifier**	The Marksman 68x range was introduced in 2007 and was designed to meet the demand of any location. The 8 or 16 loop M68x range can be either solar powered, battery alone with a charge life of up to 8 weeks or mains powered via a battery charger. The M68x has full VBV recording capabilities and up to 10 million records can be stored in this upgradeable non volatile memory as standard. The M68x captures vehicle type classification, gap, speed, length, and headway. In addition, the system has user friendly 'Front End' management software and internal modem drivers (Golden River, 2007).
Clearview Traffic	**M72x Highway Detection System**	The Marksman M72x is a highly reliable detection system that provides accurate data processing and incorporates fast and reliable Ethernet communications. The system provides 16 loops for detection and reports individual vehicle parameters including full vehicle by vehicle (VBV) recording capabilities and up to 10 million records can be stored in this upgradeable non volatile memory as standard. Vehicle type classification, speed, length, interval, or VBV recordings are included in the data capture for the traffic operator (Golden River, 2007).
Clearview Traffic	**Marksman 661/662 8/16 Loop Classifier**	The Marksman 661 is normally used to monitor 4 lanes of traffic however the Marksman 662 can be used to monitor eight lanes of traffic. The loop sensor can report vehicle counts, speed, lengths, and gap/headway in each lane. The data can be collected on each vehicle compiling minute-by-minute interval files for transfer by packet based communications systems. Over 20,000 Marksman's traffic recorders are in the field around the world and operating to an extremely high level in all traffic conditions (Golden River, 2007).
Clearview Traffic	**TMU/M665 Real Time Traffic Monitoring**	This product is a high-speed multi-channel loop detector that provides enhanced performance for the measurement of vehicle count, speed, and vehicle classification. The system uses the General Packet Radio Service (GPRS), which is a packet based protocol that runs alongside the traditional GSM service being used on mobile telephones to allow low cost internet browsing and emails. The technology allows for real-time traffic reports every 1-5 minutes and a single unit covers 8 lanes. The loop detectors when installed give better than 99% capture rates and 99% accuracy nearly all the time. Also, the unit runs on solar energy and needs no power supply (Golden River, 2007).
Counters & Accessories Ltd.	**Loop Profiler**	The loop profiler can be purchase with 1 to 4 lane cars which provides information for each lane of traffic being monitored. The recorder is compatible with PC and Palm Pilot allowing easy set-up of surveys and downloading of data. The recorder can be low or solar powered and can identify up to 10 types of vehicles with and accuracy of classification, speed, and length of up to 95% (Counters & Accessories Ltd., 2006).
Counters & Accessories Ltd.	**Loop Recorder**	The Loop Recorder can contain up to 4 twin detector cards enough for 8 lanes of vehicles. The Loop Recorder includes a counting option for all know counting situations including direction counting using two loops in one lane. The unit supports 2 and 3 lane N+1 loop arrays for counting situations on roadways where lane changing is prevalent. It can also be using to count bicycles with a special bicycle monitoring loop by using a bicycle detector card in place of standard detector card. The system has an accuracy of 95% (Counters & Accessories Ltd., 2006).

Company	Available Technology	Technology Description
Counters & Accessories Ltd.	**Traffic Monitor**	The Traffic Monitor has an advance profiling detector which allows for sophisticated classification from loops as well as industry leading speed accuracy. The optional piezo inputs also allow for more detailed class analysis. The data streams from all locations can be used by other systems as a source of information or it can be displayed directly on a website to make local congestion information available to the public. A flexible approach has been made to suit the user requirements as far as information dissemination, GSM communications, and SMS alerts are available utilizing the widespread and reliable GSM network and as a fallback for the GPRS network. A GPRS packet or an SMS message is sent by the system when the user definable conditions like congestion are met by the traffic at that location. The system collects VBV records on time of arrival, vehicle speed, vehicle length, vehicle class, chassis characteristics, gap from pervious vehicle, and headway from previous vehicle. The accuracy of the data is recorded as 95% reliable (Counters & Accessories Ltd., 2006).
Idris— Diamond Consulting Services	**The Idris® Advantage**	This product has five principle applications which include tolling, shadow tolling design, build, finance & operate (DBFO), data collection/ census gathering, intelligent vehicle detection, and incident detection. The system gathers data concerning volume, speed, length, and vehicle classification. The technology is looped based and uses single sensor technology in a single or multilane system with high speed communications. Idris touts its technology as one you can count on with better than 99.99% count accuracy in free flow traffic, better than 99.9% count accuracy in congestion and better than 99.8% axle class accuracy in express lane tolling (Idris, 2003).
Idris— Diamond Consulting Services	**Idris Loop Technology**	Idris advanced loop technology will accurately separate vehicles regardless of volume, speed, or position on the road in both constrained and multi-lane express lane environments. This allows for a complete vehicle classification system based solely on in-road loops. The accuracy of the technology, the ease of commissioning, life span and low maintenance costs make the system robust, reliable, and suitable for all types of traffic applications. The detectors achieve a better than 99.99% count accuracy in free flow traffic, a better than 99.9% count accuracy in congestion, and a better than 99.8% axle class accuracy in express lane tolling (Idris, 2003).
Never-Fail Loop Systems	**Model A (Asphalt overlay)**	This product is designed for installation into host asphalt or under asphalt overlay. Loops are constructed form polypropylene conduit and are filled with hot rubberized asphalt which allows the loop to remain flexible once cooled, prevent incursion of moisture, and set the turns of wire firmly in place (Never-Fail, 2001).
Never-Fail Loop Systems	**Model C (Concrete Overlay)**	This product is designed for installation into concrete, concrete overlay, or bridge decks. The product is tested prior to shipment and is shipped ready to install with patented expansion/contraction joints. In addition, the detector is ready for direct burial into sub-base or tie down to rebar which results in reduced maintenance cost (Never-Fail, 2001).
Never-Fail Loop Systems	**Model F (Cut-in application)**	This product is designed for saw-cut installation (Never-Fail, 2001).
Never-Fail Loop Systems	**Model F-38 (Any application)**	This product is designed for application in a cut-in situation, hot asphalt overlay, concrete overlay, and in the temporary above ground application. The detector can be laid down on rebar without spaces and wires are sealed in rubber asphalt filled polypropylene conduit in insure a reduced maintenance cost (Never-Fail, 2001).
Never-Fail Loop Systems	**LD 100 Series (single channel loop detectors)**	This product is a series of single channel inductive loop detectors. Typically the application of this technology is used in the parking and access control environments (Never-Fail, 2001).

Company	Available Technology	Technology Description
Never-Fail Loop Systems	**LD 200 Series (dual channel loop detectors)**	This product is a dual channel induction loop detector. Typical applications include safety loops, arming loops, and entry/exit loops (Never-Fail, 2001).
Never-Fail Loop Systems	**LD 250/450/850 (2/4/8 channel loop detectors)**	This product is a multi-channel inductive loop detector. The detectors are compatible with most Nema Card detectors on the market and are easy to set-up and install. Optional features include a RS485 communications port. Typically this detector system is used for traffic control, toll systems, and vehicle counting (Never-Fail, 2001).
Nortech Detection	**IR 100 Incident Detection Roadside Unit**	The IR100 incorporates reliable highly accurate 4 channel vehicle detector units for capturing traffic data and a processor/communications module that time tags data and generates occupancy alarms for transmission to the host computer system. The processor card calculates individual lane occupancy values on a second-by-second basis and produces incident alerts based on alarm variable downloaded from the host computer. The system can monitor 24 loops and will provide average flow data relating to traffic volume, speed, headway, and percent occupancy (Nortech, 2008).
Nortech Detection	**IR 100 Intelligent Vehicle Loop Detector Unit**	The IR100 incorporates reliable, highly accurate 4 channel vehicle detector units for capture of traffic data and a processor/communications model that time tags and stores the vehicle data until polled by the host computer system. The IR100 will accurately time stamp individual loop data or provide average flow data relating to traffic volume, speed, headway, and percent occupancy. The IR100 can monitor 23 loops at vehicles speeds of 200KmH. It also is equipped to have internal communication with bus for bus actuated signals (Nortech, 2008).
Patriot Detection—Loops and Traffic Systems	**CG16MMA—Asphalt Pave Over Preformed Inductive Loop**	This product is used for asphalt pave over and utilizes a highly abrasion-resistant polyurethane cover and high tensile strength braided synthetic fiber reinforcement. The loop wire is 16 gauge tffn/thhn stranded single conductors and one continuous wire is used in order to manufacture the loop and lead-in. No splices are used (Patriot, 2008).
Patriot Detection—Loops and Traffic Systems	**CG16MMC—Concrete Overlay Preformed Inductive Loop**	This product is used for concrete overlay and utilizes a highly abrasion-resistant polyurethane alloy cover and high tensile strength braided synthetic fiber reinforcement. The loop wire is 16 gauge tffn/thhn stranded single conductors and one continuous wire is used in order to manufacture the loop and lead-in. No splices are used (Patriot, 2008).
Patriot Detection—Loops and Traffic Systems	**CG9.5MM Cut-In, Asphalt Pave Over, Concrete Overlay, Temporary Above-Ground Installation**	This product can be used for all inductive loop applications. This product uses a highly abrasion-resistant Nylon alloy cover and high tensile strength braided synthetic fiber reinforcement which is flexible over a wide temperature range. The loop wire is 20 gauge silver coated with a Teflon jacket single stranded conductor wire and one continuous wire is used in order to manufacture the loop and lead-in. No splices are used (Patriot, 2008).
PEEK Traffic Limited	**MTS4E**	This product is a 4 channel loop detector unit that uses the industry-proven MTS loop-scanning technique. The detector can be used for simple vehicle activation at signal controllers, complex vehicle profiling for classification applications, and incident detection. The detector has a serial communications port on the rear connector that facilities remote interrogations of the unit for detect and fault data (PEEK, 2008).
Siemens ITS	**SITRAFFIC Concert**	This product is a traffic management control center developed by Siemens that collects bundles and evaluates traffic data and then distributes the information to various users in the form of traffic information. Concert integrates all traffic flows (parking traffic, local public transport, and individual traffic) and also different traffic areas (inner city, highway, county). The detectors used in this system include the classical loop detectors, overhead detectors, and video detectors. Specific information on all of these detector types could not be found via the website (Siemens, 2008).

Company	Available Technology	Technology Description
Traffic Data Collection Systems Ltd	**HI-TRAC® 90 High-Speed Weigh-in-Motion & Classification System**	This product works as a Weigh-in-Motion (WIM) and Automatic Counter/Classifier (AVC). The technology has a built in GSM modem and antenna and can classify over 100 unique vehicle types. The product can also be used for incident detection and event monitoring and has a 2-lane WIM operation and a 4 lane AVC operation. The unit interfaces for up to 4 Piezo electric sensors and 8 induction loop sensors. The HI-TRAC 90 is accompanied by the HI-COMM 100 software package that provides data retrieval via modem or laptop as well as data analysis facilities and system diagnostic functions (TDC, 2008).
Traffic Data Collection Systems Ltd	**HI-TRAC® 110 High-Speed Traffic Counter/Classifier System**	This product is an automatic vehicle counting and classifying system with loop profiling. The system takes inputs for up to 16 inductive loop sensors and 8 piezo electric sensors. The technology has both laptop and modem communication ports and has classification of up to 110 unique vehicle types. The data stored is done vehicle-by-vehicle (VBV) and has an option for CCTV camera connection for text insertion or license plate number recognition. It has a 4-lane operation as a standard and is expandable up to 8-lanes. The system provides a low cost means of recording vehicle count and classification without interruption to traffic flows (TDC, 2008).
Traffic Data Collection Systems Ltd	**HI-TRAC® EMU Event Monitoring Unit & Vehicle Classification System**	This product is a loop volumetric counter, a loop speed & length classifier as well as a loop profiling classifier. The technology can be incorporated for a weigh-in-motion system and also can function to do traffic alerts, event monitoring, and incident detection. The information captured is done on a vehicle-by-vehicle storage. The product utilizes 8 lanes of loop volumetric counting, 4 lanes of loop-loop speed and length counting, 2 lanes of piezo-loop-piezo weigh-in-motion, and 4 lanes of loop-piezo-loop automatic vehicle classification/weigh-in-motion (TDC, 2008).
Traffic Tech	**Sub-Surface Ezyloops**	These loops are electromagnetic traffic detection loops that are pre-formed and encapsulated in a protective, adhesive membrane so that they may be laid within the road pavement as a single unit. The sub-surface loops can be laid at a depth of between 2 inches and 6 inches during the construction or maintenance of the road surface. The loops can easily be made to any shape or size and because of the thin profile of the loops no detrimental affects to the pavement integrity occur because of installation (Lake Traffic Solutions, 2008).
Truvelo	**Truvelo Traffic Data Logger TCL/TDL**	This product is typically coupled with inductive loops and capacitive weight sensors and is used to provide accurate, reliable, high speed weigh-in-motion data. The data from the TDL-500 has been used to aid in cost effective road pavement design, research, predicting levels of pollution in tunnels based on actual vehicle weights, road pavement maintenance planning, axle load monitoring, screening, and recording of relative load movements. The road sensors consist of two inductive loops and one capacitive weight sensor per lane to cover a maximum of four lanes of traffic. The TDL-500 combines the sensor information into a default data string consisting of vehicle number, arrival date and time, gap time, lane number, travel direction, vehicle straddling present, trailer present , vehicle chassis height, vehicle speed, vehicle length, vehicle class, number of axles, axle weight, axle distance, equivalent standard axle load, weight violations and bridge overloading. The standard vehicle classification format is the American FHWA, but can be programmed by the operator (Truvelo, 2006).

Company	Available Technology	Technology Description
TSEU	MXED—UK 2 & 4 Channel Detector	This product requires as standard Eurocard and is available in 2 or 4 channel versions. However, all versions are suitable for speed measurement and have a wider range of loop inductance. The tuning of the detector is automatic and fast and once tuned the detector will track all environmental drift continuously. Since vehicles produce an increase in inductance as they pass over a loop and will cause most detectors to lock up. The MXED detector incorporates a feature to prevent this and normal operation is unaffected (TSEU, 2005).
TSEU	MXE—Worldwide 2 & 4 Channel Detector	This detector requires a standard Eurocard and is available in a 2 or 4 channel version both suitable for speed measurement. The operator can select sensitivity and presence times from first or last vehicle movement. The tuning of the detector is automatic and fast (TSEU, 2005).
Weiss-Electronic	Classification Detector CD9054	The detector is used for vehicle classification and speed measurement. However vehicle length, distance, time of occupancy, time gap, and driving direction are also collected. The detector operates with two induction loops per lane and is not influenced by weather conditions (Weiss-Electronic, 2001).
Weiss-Electronic	Classification Detector MC2014	This detector is capable of vehicle classification and speed measurement for increased demands. The detector operates with two induction loops per lane. A version of the MC2014 is the MC2014SL which is the single loop detector especially designed for motorway ramps and can distinguish between vehicles. Detection of speed and directional logic are not possible with the MC2014SL. If two loops are used the detector can also collect data concerning length, distance, time of occupancy, time gap, and driving direction (Weiss-Electronic, 2001).
Weiss-Electronic	Classification Detector MC2024	This product is used for vehicle classification and speed measurement, but also can be used to capture vehicle length, distance, time of occupancy, time gap, and driving direction. The detector automatically adjusts itself to the attached loop/feed-cable combination and variations on temperatures have no influence on data acquisition. Short measuring intervals and a new procedure for speed measurement provide the high accuracy of the measured data and the high detection speed (Weiss-Electronic, 2001).
Weiss-Electronic	Loop Detector IG645/3-IG745/3S	This product is primarily used for signal output for traffic light installations. The loop detector does bus classification as well as car-lorry classification. Another option is that the detector can be used for traffic jam detection as well as speed measurement. The 4 channel loop detector was specifically designed for traffic applications (Weiss-Electronic, 2001).
Weiss-Electronic	Loop Detector IG224/4	This detector gives a signal output for traffic light installations. The detector is cable of counting traffic, vehicle classification, detection of traffic jams, and speed measurement. This product is the card plug for the rack system (Weiss-Electronic, 2001).

Table 5.14: Inductive Loop Detection Technology Information Synthesis (Martin, 2003)

Technology			Data Collected by Technology									
	Advantage	Disadvantage	Classification (length)	Count/Volume	Occupancy	Presence	Speed	Implementation Requirements	Installation Cost per Unit (US $ in 2008)*	O/M Cost (US $ in 2008 per year)*	System Life (years)	Compatibility with existing Infrastructure
Induction Loop Detection	Established technology; Lower cost compared to non-intrusive detectors; Can operate in sub optimal weather conditions; Has a flexible design	Implementation causes traffic interruption; Detectors can fail with poor road surfaces; Multiple detectors are typically required; System is susceptible to stress of traffic and temperature; Decreases pavement lifetime; Routine maintenance is required	X	X	X	X	X	Installation can take up to two days. Loop installation and maintenance is disruptive to traffic flow compared to other technologies. The loop system is a function of the software used in the loop input devices which include traffic controllers and local control units.	$600-1200	$580-1,900	5-15	Typically loop detectors have a flexible design which works well in a variety of applications.

X Indicates that data is collected by technology

--- Indicates that data is not collected by technology.

* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

Inductive loop detectors are a technology that is widely available and has been used for decades. Numerous companies produce products that feature inductive loop detection. Loop detectors can capture vehicle classification, count, occupancy, presence, and speed. Similar to video detection, technologies are available that simply address the hardware involved in data collection, all the way up to companies that offer an all-in-one system that not only provide the hardware but the software to accompany it and present the data collected. Inductive loop detectors are available in different types depending on the pavement the detector is being installed in. In addition, lifespan and warranty are important factors one should consider when considering different loop detectors. A warranty of 10 to 15 years is recommended. This is important because maintaining the pavement infrastructure for as long as possible is imperative to the systems longevity. Faulty loop detectors can threaten the integrity of pavement and cause premature road surface problems if the detectors have to be replaced. In addition, to the systems that offer an all in one hardware and software system it should be noted that often times loop detectors are used in collaboration with piezoelectric detectors to capture weigh-in-motion data. Companies that specialize in this combination of technologies have been noted, but are more prevalent when piezoelectric detectors are discussed.

5.3.2 Piezoelectric Detectors

A piezoelectric detector is an electromechanical system that reacts based on changes in compression. The piezoelectric detectors are insensitive to electromagnetic fields, radiation, and work under a wide range of temperatures. Piezoelectric detectors are a mature technology, but have one main drawback; they cannot be used to measure static objects. Typically a piezoelectric detector is a metal strip placed on or near the road surface. The detectors are used for vehicle detection, counting, and classification and are often seen in weigh-in-motion applications for trucks (Martin, 2003).

Table 5.15: Available Piezoelectric Detection Technology Systems

Company	Available Technology	Technology Description
Applied Traffic Limited	**AT-HI TRAC 110 AVC**	The AT-HI TRAC 110 high-speed traffic data collection system provides a low cost means of recording vehicle count and classification without interruption to traffic flow. The unit interfaces with up to 8 piezo electric detectors and 16 induction loop detectors installed in the highway. Incident detection and event monitoring functions can be incorporated along with message sign activation and CCTV interface for text insertion and license plate recognition. The HI-TRAC 110 is accompanied by the HI-COMM software package which provides data retrieval via model (landline or GSM) or laptop as well as data analysis facilities and system diagnostic functions. In the standard configuration, two Piezo electric detectors and one induction loop detector are installed in the highway per lane of detection. The piezo electric sensors measure axle speeds and inter-axle spacing. The induction loop detects vehicle presence and measures the vehicle length (Applied Traffic Limited, 2007).
Counters & Accessories Ltd.	**Traffic Monitor**	The Traffic Monitor has an advance profiling detector which allow for sophisticated classification from loops as well as industry leading speed accuracy. The optional piezo inputs also allow for more detailed class analysis. The data streams from all locations can be used by other systems as a source of information or it can be displayed directly on a website to make local congestion information available to the public. A flexible approach has been made to suit the user requirements as far as information dissemination, GSM communications an SMS alerts are available utilizing the widespread and reliable GSM network and as a fallback for the GPRS network. A GPRS packet or an SMS message is sent by the system when the user definable conditions like congestion are met by the traffic at that location. The system collects VBV records on time of arrival, vehicle speed, vehicle length, vehicle class, chassis characteristics, gap from previous vehicle and headway from previous vehicle. The accuracy of the data is recorded as 95% reliable (Counters & Accessories, 2006).
Traffic Data Collection Systems Ltd	**HI-TRAC® 110 High-Speed Traffic Counter/Classifier System**	This product is an automatic vehicle counting and classifying system with loop profiling. The system takes inputs for up to 16 inductive loop sensors and 8 piezo electric sensors. The technology has both laptop and modem communication ports and has classification of up to 110 unique vehicle types. The data stored is done vehicle-by-vehicle (VBV) and has an option for CCTV camera connection for text insertion or license plate number recognition. It has a 4-lane operation as a standard and is expandable up to 8-lanes. The system provides a low cost means of recording vehicle count and classification without interruption to traffic flows (TDC, 2008).
Traffic Data Collection Systems Ltd	**HI-TRAC® EMU Event Monitoring Unit & Vehicle Classification System**	This product is a loop volumetric counter, a loop speed & length classifier as well as a loop profiling classifier. The technology can be incorporated for a weigh-in-motion system and also can function to do traffic alerts, event monitoring and incident detection. The information captured is done on a vehicle-by-vehicle storage. The product utilizes 8 lanes of loop volumetric counting, 4 lanes of loop-loop speed and length counting, 2 lanes of piezo-loop-piezo weigh-in-motion, and 4 lanes of loop-piezo-loop automatic vehicle classification/weigh-in-motion (TDC, 2008).

Table 5.16: Piezoelectric Detection Technology Information Synthesis (Bushman, 1998)

Technology			Data Collected by Technology								
	Advantage	Disadvantage	Classification (length)	Count/Volume	Occupancy	Presence	Speed	Implementation Requirements	Life Cycle Cost (US $ per year in 2008*)	System Life (years)	Compatibility with existing Infrastructure
Piezoelectric Detection	Work well in all weather types; Can be used in coordination with other detectors	Pavement must be cut for installation; Cannot measure static objects	X	X	---	---	X	Implementation takes 1 to 2 hours per lane for installing two piezo sensors and an inductive loop. Installation time can vary depending on site characteristics.	$6,000	4	Piezoelectric detectors are often used in collaboration with induction loop detection and video detection.

X Indicates that data is collected by technology
--- Indicates that data is not collected by technology.
* Initial costs came from 1998 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

Typically piezoelectric detectors are used for weigh-in-motion systems for vehicle classification. One drawback of the technology is that it cannot measure static objects. The detectors are often used in combination with inductive loop detectors to capture traffic data. A typical piezoelectric detector can capture vehicle classification, count, and speed. When the piezoelectric detector is combined with a loop detector several other pieces data can be collected. The system lifecycle and warranty are important factors when looking at piezoelectric detectors since once again the technology is most often imbedded in the roadway surface.

5.3.3 Magnetic Detection

A magnetometer (magnetic detection) is an in-road sensor that detects the magnetic disturbances in the earth's field as a vehicle (ferrous metal) passes over the detector. Typically the detector is used to identify vehicle presence. The detectors are often used on bridges where inductor loops cannot be installed due to lack of pavement depth (Martin, 2003).

Table 5.17: Available Magnetic Detection Technology Systems

Company	Available Technology	Technology Description
Global Traffic Technologies, LLC	**Canoga™ 702 Non-invasive Microloop™ Sensors**	The Canoga 702 Non-invasive Microloop sensors are a matched component of the Canoga Traffic Sensing System. The Canoga 702 Microloop is a transducer that converts changes in the vertical component of the earth's magnetic field to changes in inductance. Vehicles containing vertical components of ferromagnetic material "focus" the earth's field, increasing the magnetic field at the sensor when vehicles move over the sensor. The sensor is installed into a 3 inch plastic conduit installed 18-24 inches below the road surface. Installing the sensors in a conduit leaves the road surface intact (Global Traffic Technologies, 2008).
Global Traffic Technologies, LLC	**Canoga™ 701 Microloop™ Sensors**	The Canoga 701 Microloop Sensors are a matched component of the Canoga Traffic Sensing System. The detector is a transducer that converts changes in the vertical component of the earth's magnetic field to changes in inductance. Vehicles containing vertical components of ferromagnetic material "focus" the earth's field, increasing the magnetic field at the sensor when the vehicles move over the sensor. The sensors are located vertically in 1-inch holds and placed 18-24 inches below the roadway surface (Global Traffic Technologies, 2008).
Quixote Transportation Technologies, Inc.	**Groundhog®**	The Groundhog is a wireless permanent traffic analyzer that detects vehicle count, speed, and classification. The sensor collects data without any external sensors, loops, or tubes. The technology is self-contained and is an in-pavement sensor that utilizes Vehicle Magnetic Imaging technology. The Groundhog then reports wirelessly to a site controller and provides accurate traffic data with much less maintenance and replacement cost that traditional loop technology (Quixote, 2007).
Quixote Transportation Technologies, Inc.	**NC-100/200™**	The NC-100/200 is a portable traffic analyzer that collects vehicle count, speed, and classification data. The device is placed directly in the traffic lane to provide accurate data, but can be installed and removed quickly and easily. The NC-100/200 utilizes Vehicle Magnetic Imaging technology and is easily exported to Highway Data Management (HDM) software, where it can be presented in the form of reports, charts, and graphs (Quixote, 2007).
Quixote Transportation Technologies, Inc.	**Hi-Star® NC-97—Magnetic Detection**	The Hi-Star is a portable traffic analyzer designed to collect vehicle count, speed, and classification using Vehicle Magnetic Imaging technology (Quixote, 2007).
TEC Traffic Systems	**3M Non-Invasive Microloop - Magnetic Detection**	This product uses cylindrical probes which are installed in specially designed carriers located in a horizontal conduit 60 cm below the road surface. The product is installed by a horizontal directional drilling from the side of the road. The probes are put into place with predetermined spacing and lead-in cabling. The non-invasive prove is a small cylindrical passive transducer that transforms changes in magnetic field intensity into inductance changes that can be sensed by vehicle detectors such as the 3M Canoga Vehicle Detector (TEC Traffic Systems, 2006).

Table 5.18: Magnetic Detection Technology Information Synthesis (Martin, 2003)

Technology			Data Collected by Technology								
	Advantage	Disadvantage	Classification (length)	Count/Volume	Occupancy	Presence	Speed	Implementation Requirements	Unit/Installation Cost (US $ in 2008)*	System Life (years)	Compatibility with existing Infrastructure
Magnetic Detection	Less disruption to traffic flow than induction loops; Less susceptible that loops to traffic stress; Can be used where loops are not feasible	Installation requires cutting of pavement; Installation requires lane closures; Detection zones can be small; Detectors will not detect a stopped vehicle	**X****	**X**	**X**	**X**	**X****	Cuts must be made in the pavement which requires lane closures. Typically installation will take one day. However, under bridge installation is quick and non-intrusive.	$300-1,200	15	The Canoga detectors only are compatible within the Canoga Traffic System Technology.

X Indicates that data is collected by technology
--- Indicates that data is not collected by technology.
* Initial costs came from 2003 data. The cost was then projected forward to 2008 with a 3% inflation rate.
** Speed and classification measurement will require two units

Technology Recommendation

Magnetic detectors can capture vehicle classification, count, occupancy, presence, and speed. However, two units must be implemented to capture vehicle classification and speed. This technology is offered by a set of companies that typically require the consumer to buy into their entire system to capture traffic data. Magnetic detectors can be used in either a temporary or permanent set up and are often installed on bridges where loop detectors are not a feasible option. Magnetic detectors should have a life span around 15 years and preferably be compatible with hardware and software that is not company/distributor specific.

5.4 Signal Priority

Transit Signal Priority (TSP) along with Emergency Vehicle Preemption (EVP) is the process of giving priority to transit/emergency vehicles at signalized intersections. Because a transit vehicle holds more people, those people are given priority through the intersection which increases the passenger throughput at an intersection. Also because emergency vehicles are carrying passengers on their way to a hospital they too are given priority in the system. There are two types of TSP: active priority and passive priority (Li, 2008). Active priority occurs when the bus is detected as it approaches the intersection and the signals are changed accordingly. This is the most effective and widely used TSP. The other option is passive priority where the traffic control devices are adjusted to the bus schedule along the route. This can be done using a combination of fixed-timed and schedule-based control strategies. The main advantage of passive priority is that it has a lower cost, but isn't as effective at achieving TSP (Li, 2008).

Table 5.19: Available Signal Priority Technology Systems

Company	Available Technology	Technology Description
Idris—Diamond Consulting Services	Idris® Intelligent Vehicle Detection	Idris loop technology can distinguish between vehicle types and recognizes vehicle chassis features. The detectors have a high accuracy in congested or free flow traffic conditions are have a high meantime between failure (MTBF) and low meantime to repair (MTTR). The system detects vehicles using the signatures from inductive loops and the message is then processed and passed to the traffic controller. The technology can be used by decreasing the number of private vehicles on the roads and increasing the viability and attractiveness of the public transportation sector. The system can give priority to vehicles such as buses and could reduced congestion and pollution within cities (Idris, 2003).
Nortech Detection	T100 Vehicle ID Transmitter/Receiver	Track 100 is a vehicle identification system designed to control vehicles. The transmitter is battery powered and is fitted to the undercarriage of the vehicle. The receiver is connected to an inductive loop in the roadway surface. The transmitter emits a low power signal that is recognized by the receiver, which responds with a control output. The system indentifies vehicles fitted with the device and ignores all other vehicles. The system can be used to automatically open a control barrier, gate, or to implement priority traffic control. The receiver operates to a distance above the roadway of two meters and has been tested to speeds of 140km/h. The Track 100 Receiver responds to a unique modulated signal with no chance of false triggering by noise or other radio sources (Nortech, 2008).
Nortech Detection	T200 Vehicle ID Transmitter/Receiver	Track 200 is a vehicle identification system designed to control vehicles. The transmitter is battery powered and is fitted to the undercarriage of the vehicle. The receiver is connected to an inductive loop in the roadway surface. The transmitter emits a low power signal that is recognized by the receiver, which responds with a control output. The system indentifies vehicles fitted with the device and ignores all other vehicles. The system can be used to automatically open a control barrier, gate, or to implement priority traffic control. The receiver operates to a distance above the roadway of two meters and has been tested to speeds of 140km/h. The Track 200 Receiver can differentiate between 4 different unique codes selectively transmitted from the vehicle (Nortech, 2008).
Nortech Detection	Track 2000 Vehicle ID Transmitter	The Track 2000 has been designed to identify moving vehicles and consists of a transmitter that can be fitted to the undercarriage of a vehicle and a receiver that is connected to a conventional inductive loop antenna buried in the roadway. The receiver is capable of processing an unlimited number of pre-programmed unique transmitter codes that it outputs in Wiegand, RS 232, or Clock & Data format. The receiver operates to a distance of 1.2 meters above the roadway and the system has been tested at speeds of 200km/h (Nortech, 2008).
Novax Industries Corporation	BUSPlus™	Bus Plus is a priority traffic signal management system that allows buses priority through selected intersections with minimal delay. This system can reduce commute times, lower transit operating costs, and ultimately promotes public transit as a viable automobile alternative. Bus Plus can use up to 3 different levels of priority for buses and can optimize conflict management for different directions of travel. An infrared vehicle tracking system is used to achieve this result. Only three major components: IR Bus Tags, Wayside, and Master Units are required with minimal hard wiring for Bus Plus operation (Novax, 2003).
Novax Industries Corporation	BusPlus™ Emitter	The BusPlus vehicle transponder transmits coded infrared signals to Wayside Units. The unit is waterproof and can be mounted high on the side of the vehicle. The transponder transmits a continuous coded signal that is picked up with the bus passes a Wayside Unit. The emitter has a detection zone of 2 meters at a 6 meter distance (Novax, 2003).

Company	Available Technology	Technology Description
Novax Industries Corporation	**BusPlus™ Wayside Unit**	The Wayside Unit detects the priority signal transmitted by the infrared vehicle emitter mounted to the transit vehicle. Two Wayside Units are required for each direction of approach to the intersection. One works as a check-in of the priority transit vehicle and the other works as a check-out of the vehicle. The unit is typically place 500-2000 feet ahead of the intersection to allow adequate time for the traffic control equipment to respond (Novax, 2003).
Novax Industries Corporation	**BusPlus™ Master Unit**	The Bus Plus Master resides in or near the intersection traffic signal controller cabinet. The unit processes the request for priority from up to four directions of BUSPlus Wayside Units (Novax, 2003).
Novax Industries Corporation	**METROTag™**	METROTag is a transit signal priority system that provides priority for buses and other transit vehicles to pass through traffic signal controlled intersections with minimal delay. The system is based on highly accurate in-ground inductive loop system that is used to achieve TSP (Novax, 2003).
Novax Industries Corporation	**METROTag™ Transponder**	The METROTag Transponder provides the means to transfer a signal from a moving vehicle to an inductive loop imbedded in the roadway. The transponder is mounted to the under carriage of the front of the transit vehicle and an onboard microprocessor, the MetroTag transmits a continuous field which is 100% compatible for use with the existing 'Street Receiver Module' (SMR) technology (Novax, 2003).
Novax Industries Corporation	**METROTag™ SMR**	The SMR resides in or near the intersection traffic signal controller cabinet. It processed the requests for priority from up to two directions from in-ground inductive loops and communicates the necessary information to the traffic signal controller (Novax, 2003).
Novax Industries Corporation	**TransPOD™**	Technology offers priority demand for transit and emergency response vehicles, conditional signal priority based on schedule, headway, or other variables and is compatible with near or far-side stops. TransPOD integrates seamlessly with other GreenLight innovations such as eMVeePOD™ and InfoPOD™. TransPOD requires no on-street detection equipment which minimizes installation and maintenance cost. eMVeePOD in particular provides emergency response vehicles with preemption at traffic-signal-controlled intersections and can deliver information to responders almost instantly (Novax, 2003).
TEC Traffic Systems	**3M Opticom Priority Control System**	This system enhances time-critical travel by allowing emergency vehicles to request and receive green lights as they go to and from the scene of an accident. The technology is a proven infrared technology that solves the stagnation caused by waiting traffic and secures safe crossings at intersections (TEC Traffic Systems, 2006).

Table 5.20: Signal Priority Technology Information Synthesis (Smith, 2005)

Technology						
	Advantage	Disadvantage	Implementation Requirements	Unit Cost if existing software and controller equipment exist (US $ in 2008 per intersection)*	Cost if software and controller need to be replaced (US $ in 2008 per intersection)*	Compatibility with existing Infrastructure
Signal Priority: TSP & EVP	Improved schedule adherence and reliability; Reduced travel time for buses; Increased transit quality of service	Delays to non-priority traffic	Can vary from new software and controller equipment to a simple upgrade of a transmitter.	$5,500	$21,900-32,800	Software must be verified and tested to insure the new system is operating correctly.

* Initial costs came from 2005 data. The cost was then projected forward to 2008 with a 3% inflation rate.

Technology Recommendation

Signal Priority encapsulates both Transit Signal Priority and Emergency Vehicle Preemption. Companies that offer this technology are not involved in data collection but rather increasing the passenger throughput at intersections. Because Austin and San Antonio are cities that rely on transit to get passengers to and from their origins and destinations, this technology was evaluated in its contribution to arterial roadways. Choosing a company that provides a diverse line of products concerning signal priority is the best option for consumers. Companies that offer signal priority based on infrared technology as well as inductive loop technology provide the consumer with the widest array of technologies that can be incorporated into their preexisting systems. In addition, the number of unique detection identification options should also be a consideration when choosing a company to provide signal priority.

Chapter 6. Arterial Traveler Information Dissemination

6.1 Introduction

The purpose of this task was to develop a comprehensive list of information dissemination modes with potential deployment for arterial applications, to evaluate these modes, and to determine their appropriateness to meet user needs and for arterial applications. Specific goals of this task included:

- Evaluate traveler information dissemination modes such as internet web sites, dynamic message signs, highway advisory radio, in-vehicle systems, and personal wireless devices.

- Identify information sources and processing requirements.

- Analyze each dissemination mode's suitability for arterial management applications.

- Identify the technological trends in traveler information dissemination.

- Analyze the types of information that travelers want, including timing, location, and frequency.

- Provide recommendations for future information dissemination.

This chapter provides a summary of available information dissemination modes and technologies, data requirements, costs/benefits, advantages/disadvantages, and suitability for arterial applications. The report also identifies technology trends in information dissemination. Results of a 2005 Austin Commuter Survey which examined driver preferences for information types, frequencies, locations, and dissemination modes are also examined in this report. After evaluating the results of the technology review and the commuter survey, conclusions and recommendations for future information dissemination for arterial applications were developed.

6.2 Information Dissemination Modes

A number of information dissemination modes are currently employed to provide drivers with traffic information. Traditionally, radio and television reports have provided drivers with incident, construction, congestion, and weather information during peak demand periods. In more recent years, dedicated television and radio stations have been employed to provide constant traffic information. While television information is almost exclusively used pre-trip to plan travel routes, times, and modes, radio information provides en route updates that allow drivers to change pre-trip decisions based on current traffic and incident information. Stated preference surveys performed in Los Angeles (Abdel-Aty, et al., 1996), San Francisco (Yim and Miller, 2000), Seattle, Detroit (Rutherford, et al. 2005), and Austin (Walton, et al. 2006) have all found that drivers generally prefer en route information to pre-trip. A number of advanced pre-trip, in-vehicle, and roadside technologies have been developed and deployed in recent years to provide better information to drivers. Major technology applications of Advanced Traveler Information Systems (ATIS) include highway advisory radio (HAR), dynamic message signs (DMS), and web and telephone information systems. In addition to these technologies generally

referred to as ATIS in the US, a number of advanced radio and satellite applications have become commercially available in the past 2 years.

Field observations, surveys, and simulation studies have all been performed to examine the benefits of deployment of ATIS both for users and for the overall highway network. Studies in Detroit, Seattle, Spokane, San Francisco, Cincinnati, Hawaii, the Netherlands (Rutherford, et al. 2005), China (Jou, et al. 2005), and San Antonio (Metropolitan Model Deployment Initiative, 2000) have all examined the benefits of deploying multiple ATIS technologies. Studies in London (Chatterjee et al. 2002), Paris (Yim, and Ygnace, 1995), Amsterdam (Traveler Information Services and Technologies Page, 2003), Denmark (European Commission Directorate General Energys and Transport, 2003), Nebraska, Japan (Rutherford, et al. 2005), and Wisconsin (Ran et al., 2004) have all specifically focused on identifying VMS benefits and usefulness. A separate Detroit study examined the usefulness of HAR, and a different Cincinnati study (Rutherford, et al. 2005) as well as a Boston study (Englisher, et al. 1996) examined the usefulness of phone-based systems. A Pennsylvania study (Rutherford, et al. 2005) focused on identifying the benefits and usefulness of web-based ATIS. Although most ATIS applications have been deployed on freeways, research in Phoenix and Seattle indicates that additional benefits could be achieved by integrating arterials (USDOT Federal Highway Administration, 2000). Results from Seattle's Metropolitan Model Deployment Initiative (MMDI) indicate that adding arterial information to the ATIS systems examined could improve delay; while delay reductions due to ATIS on freeways were estimated to be 1.5 percent, inclusion of arterial information was estimated to increase savings to 3.4 percent.

The availability of traveler information can help drivers to make route, travel time, and mode choice decisions. The quality, frequency, and timeliness of data is important. Currently, nearly all information sources are limited by the availability of detailed traffic information. Although incident information is often available for arterials through accident reports, traffic flow information, such as speeds, travel times, and congestion levels are usually only made available for freeways. This is a result of the fact that most monitoring equipment, including loop detectors, cameras, and other types of road sensors, are located on freeways. Research indicates that, in general, users are willing to pay for improved traffic information (Khattak, et al., 2003). Growth in commercially available systems for personalized traffic information will be discussed in the following sections. The following sections provide detailed information about individual information dissemination modes and technologies, their data requirements, their costs/benefits and advantages/disadvantages, and their suitability for arterial applications:

6.2.1 Pre-Trip Information

Television

Television is a primary source of pre-trip traffic information. Traffic reports may be provided during local news broadcasts, as special reports during major events such as extreme weather, or continuously on a dedicated traffic channel. Content is determined by the provider, but may include congestion or speed information, incident locations and details, construction and lane closures, recommended alternative routes, and CCTV views of major roadways. In Austin, TxDOT provides video data directly to four media stations (Brydia, et al. 2007). Previously, these media stations were able to pan/tilt/zoom cameras, however, due to excessive movement of cameras, particularly during the morning peak, these capabilities have been limited. Anyone within broadcast range can pick up the signal. However, four news stations, including 3 network

affiliates and one cable channel, receive video transmissions through an external access video switch, which allows them to choose a specific camera and stay on that camera for as long as required. While in Austin, a dedicated cable channel broadcasts traffic information and camera views constantly, in San Antonio, the city's local access channel broadcasts traffic only during peak periods and emergencies. Currently, traffic information provided on television can include both freeway and arterial information. While speed and travel time information is likely only provided for freeways due to limits in data availability, incident, construction, and general congestion information may be provided for arterial roadways. However, traffic information provided on television is often generalized and provides little local detail (TxDOT Highway Conditions Reporting System Website, 2008). Television broadcasts cannot be personalized to meet a user's needs. A 1998 Detroit study found that television, radio, and even VMS are all poor methods for providing custom traffic information. Additionally, the short time period available for traffic reports often limits both the total amount and the detail of traffic information provided.

Radio

Radio can provide pre-trip traffic information, but it is more likely used to receive en route updates. The different types of radio information available will be discussed in detail in the next section.

Internet

Web-based traffic information can be provided in a number of formats through a variety of information providers. Government-operated websites may provide direct access to primary traffic, incident, and weather information. Websites for local media outlets may also provide traffic information, whether obtained directly from a government source or through a third party ISP who collects and integrates its own information from sources such as incident reports, traffic cameras, and aerial surveillance. ISPs may also operate their own independent websites. Information can be provided in text or graphical formats. Table 6.1 shows the types of traffic information available on a number of traffic information websites for Austin and San Antonio.

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Table 6.1: Web-Based Traffic Information Available in Austin and San Antonio

Web Site	Information Type											
	Incidents	Construction/ Lane Closure	Congestion Level	Travel Times	Speed	Personalized Route	Historic Traffic	Weather	Cameras	DMS	Events	Transit
Government												
TxDOT HCRS (18)	X	X						X				
TxDOT Austin District (19)		X						X	X			
TxDOT Austin Roads (20)									X	P		
City of Austin Roadworks (21)		X										
San Antonio TransGuide (16)	X	X	X	X	X	X			X	X		
San Antonio Street Closures (22)		X										
News Stations												
KEYE (23)	Direct Link to Traffic.com											
KVUE (24)	X	X	X					X	X		X	
KXAN (25)	X	X	X					X	L			X
Web Only Providers												
Traffic.com (26)	X	X	X								X	X
Yahoo Maps (27)	X				X							
Google Maps (28)	X	X	X				X					

Generally, the government sites provide limited information such as construction and lane closures. In Austin, different information from TxDOT can be found on three websites. In San Antonio, the TransGuide website provides very detailed traffic information, including congestion level, travel times, and speeds in addition to construction and incident information. TransGuide even offers a "Personalized Route Selector" to estimate the travel time for a user-prescribed route. The majority of local media traffic sites receive information both from TxDOT and from proprietary third party ISPs such as NAVTEQ. Information provided by these ISPs may include historic traffic, event, and transit information not provided on other websites. Just as on television, available information is limited by data availability; generally, speed and travel time information is provided only for freeways, while incident and construction information is also provided for arterials. Internet-based traffic information systems can provide users with a method of obtaining more personalized traffic information by choosing locations and information types. Website design as well as update frequency can affect the usefulness of web-based traffic information to drivers. If expected website functions do not work, information is difficult to find, or information is wrong or outdated, web-based traffic information systems will likely not be used. Although in general, traffic information seems to be sought slightly more frequently in morning peak periods, currently, web-based traffic information is most likely sought previous to afternoon peak travel (USDOT Federal Highway Administration, 2008). This is likely due to the fact that people do not have time to start up a home computer before leaving

for work in the morning. As both the quality and market penetration of mobile devices such as cell phones, PDAs, and in-vehicle navigation systems continue to improve, it is very likely that web-based system will be used not only for pre-trip travel information, but also for en route decision making. However, as en route use increases, safety concerns caused by driver distraction, like those identified for cell phone use, are likely to emerge.

Telephone

Telephone systems can also be used either pre-trip or en route to receive traffic information. In 2000, the Federal Communications Commission (FCC) dedicated 511 as a nation-wide telephone number available to states and other jurisdictions to provide traffic information to users. Although exact content varies according to location, the 511 Deployment Coalition, which includes representatives from a number of organizations including AASHTO, APTA, ITS America, and USDOT, has developed implementation guidelines and recommendations on content (511 Deployment Coalition Website, ITS America, 2005). Typical 511 content for highways includes information on construction, incidents, special events, and congestion. Transit schedules, fares, and status reports and weather information may also be provided. Generally, callers using 511 use voice or push-button commands to access this information. Forty-three 511 Services are currently operational in 33 U.S. states and 2 Canadian provinces (511 Deployment Coalition Website, ITS America, 2005). Costs of deploying 511 systems vary considerably; as a result it is not possible to provide generic cost estimates (Kelly, 2005). Benefits to users, deploying agencies, and the overall highway network have been identified. These include: time savings, convenience, and peace of mind for users, reductions in 911 calls and increased partnership opportunities for system operators, and reductions in network congestion. Like websites, telephone systems with a variety of options can provide users with personalized content.

However, there are some disadvantages to telephone based systems. 511 systems can be expensive to operate. Users must also be made aware of the existence of such systems; research performed in 2004 indicates that even in some cities where 511 is fully operational, drivers are not aware of the service (Kelly, 2005). Additionally, users attempting to access telephone based information systems while driving may pose a safety hazard on the road. A study performed using a driving simulator found that those attempting to access 511 while driving were less aware of their surroundings and slower to react to situations that required immediate response (Cell Phone Driving Laws, 2008). Results indicate that the effects on driver behavior of using a voice-command 511 system are the same as having any cell phone discussion. Additionally, new laws are limiting the use of cellular phones in cars. Currently, five states and the District of Columbia ban hand-held cell phone use in vehicles, and jurisdictions in six additional states also have bans (Deployment Statistics, ITS Joint Program Office. 2007). As additional hand-held cell phone bans continue to take effect, in-vehicle 511 use may be reduced.

6.2.2 In-Vehicle Information

Radio

The majority of drivers currently seek traffic information from broadcast radio reports. Like on television, content is determined by the provider, but may include congestion information (such as slow moving locations or queue lengths), incident locations and details, construction and lane closure locations, and recommended alternative routes. The length and

frequency of reports varies considerably depending on station format. Unlike television, radio cannot use graphical representations such as maps or camera views to display information. However, radio reports are often more frequent than television reports and can be received en route to help drivers make decisions using more timely information. In recent years, a number of new types of radio traffic information have been developed, including Highway Advisory Radio (HAR) and satellite radio.

Highway Advisory Radio (HAR)

HAR is a radio channel that exclusively broadcasts highway information. HAR systems usually broadcast on an AM band with a range between one and 6 miles (Traveler Information Services and Technologies Page, 2003). Information provided may include incidents, construction information, traffic reports, emergencies, events, parking, tourist information, and weather. According to the ITS Joint Programs Office's (JPO) 2006 Metropolitan summary, 4,004 miles of US freeways and 2,453 miles of arterials are currently covered by HAR (ITS Cost Database, 2007). Most applications of HAR are on toll roads, bridges, and tunnels, and on other "closed" systems like national parks and airports (Traveler Information Services and Technologies Page, 2003). HAR is also often employed in long-term construction zones. Table 6.2 shows the component costs identified by the ITS JPO for HAR system hardware (News Channels Schedule, 2008). It is clear from this table that both capital and operations costs can vary depending on the size of the area covered and the type and quality of information provided. Specifically, labor costs can be very high to keep information up-to-date and accurate (Traveler Information Services and Technologies Page, 2003).

Table 6.2: HAR System Component Costs
(Source: ITS Cost Database)

Element	Life	Capital Cost		O&M Cost	
	Years	$K, 2007 Dollars		$K/year, 2007 Dollars	
		Low	High	Low	High
Highway Advisory Radio	20	15.00	35.00	0.60	1.00
Highway Advisory Radio Sign	10	5.00	9.00	0.25	0.25
Roadside Probe Beacon	5	5.00	8.00	0.50	0.80

HAR can provide some benefits compared to other technologies (Traveler Information Services and Technologies Page, 2003). HAR offers more localized and frequent information than a commercial radio station, and longer messages than a DMS (which will be discussed in detail in the next section). However, there are some implementation challenges. Because of the very small range of individual systems, it is difficult to make travelers aware of them. Static or variable message signs are usually used to provide station information to users. The broadcast message that runs on a loop must be designed to be succinct, informative, and understandable. Additionally, the quality and strength of the signal received by car radios may be difficult to maintain or control. Since HAR is generally employed on "closed systems" it may not be entirely applicable for some arterial applications, however, it is useful to provide information during major construction periods and on arterials located in "closed" systems.

Satellite Radio

In recent years, satellite radio has gained a considerable market share among radio listeners. Both XM Radio and Sirius Satellite radio services offer continuous traffic information stations for some urban areas. XM Radio provides exclusive traffic stations for 21 major metropolitan areas in the US, including both Dallas and Houston (Traffic and Weather, Sirius Satellite Website, 2008). Sirius offers traffic information for 20 cities, although 18 of the 20 cities share a station with one other city, including Dallas and Houston, whose traffic reports are offered on one station (Calafell and Pyne, 2001). Traffic-only satellite radio stations improve upon broadcast stations by offering constantly available traffic reports. Satellite radios range in cost from about $50 to $500, and monthly service fees range from $10 to $13.

Radio Data System—Enhanced Other Networks (RDS-EON)

Radio Data System—Enhanced Other Networks (RDS-EON) have been in use in Europe for over a decade (Total Traffic Network Traffic Message Channel Website, 2008). Traffic messages are broadcast from a public service station using a 57 KHz FM "sub-carrier." The signal is received by a RDS-EON equipped radio, with which most European cars are equipped. When the signal is received, the radio is re-tuned or the CD player disabled so the listener can receive the broadcast traffic message. RDS-EON provides timely traffic information, but many messages may not be of use to all users. Drivers may become annoyed if frequent, uninteresting messages continue to interrupt their regular radio listening.

Radio Data System—Traffic Management Channel (RDS-TMC)

Radio Data System—Traffic Message Channel (RDS-TMC) is also widely deployed in Europe (Total Traffic Network Traffic Message Channel Website, 2008). In an RDS-TMC system, coded traffic information is transmitted along with a normal FM radio broadcast. An on-board TMC receiver decodes the transmitted information, including event, duration, direction, and severity information. Two different protocols are used to transmit event and status information. The decoded messages can be displayed as text, speech, or graphically. In 2006, Clear Channel Radio began using an RDS-TMC system, called the Total Traffic Network, to transmit traffic data with some of its high definition (HD) radio broadcasts (NavTraffic, 2008). Clear Channel collects traffic information from a network of traffic cameras, speed sensors, police scanners, and mobile reporters. TMC messages are broadcast and received by compatible in-vehicle and portable navigation systems. Received information is displayed on the navigation system's map. Compatible navigation system costs range from $300 to $700. The service, which is purchased through navigation system providers, costs about $60/yr. The Total Traffic Network now provides traffic information for major highways in 95 major North American markets, including most of San Antonio's major freeways and I-35 in Austin. There are currently more than 500,000 active subscribers to the Total Traffic Network.

Satellite Navigation

Both XM (Sirius Traffic Service, 2008) and Sirius Satellite Radio (Dudek and Ullman, 2006) now offer services to deliver traffic information by satellite directly to compatible on-board and after-market vehicle navigation systems. Both systems use traffic information collected from departments of transportation, police and emergency services, traffic sensors and cameras, airborne reports, and GPS equipped trucks. Depending on the availability of data,

incident information and traffic speeds/flow may be provided. Both NavTraffic and Sirius Traffic are currently available in 80 major US markets. In Austin and San Antonio, only incident information is currently available through these services. Compatible navigation systems currently cost between $1000 and $2000. Monthly NavTraffic Service costs $10 independent of XM Radio, or $4 in addition to an XM plan. Sirius Traffic costs $4, and must be purchased with a radio plan.

6.2.3 Roadside Information

Dynamic Message Signs (DMS)

Dynamic message signs (DMS), sometimes referred to as variable message signs (VMS) or changeable message signs (CMS), provide users with traffic information at the roadside. These signs can be permanently mounted at a fixed location, or fixed to a vehicle or trailer for use at a temporary location. Generally, sign messages are controlled from a remotely located computer, usually in a traffic management center. The signs can be connected to a remote computer using a variety of technologies, including dial up, T1, fiber, and wireless (Brydia, et al. 2007). The signs themselves can be expensive to install and maintain. Light-emitting components tend to deteriorate in hot weather, while light reflecting components degrade from UV exposure (TxDOT Highway Conditions Reporting System Website, 2008). Estimated costs for signs and communications components are provided in Table 6.3 (News Channels Schedule, 2008).

Table 6.3: DMS System Component Costs

(Source: ITS Cost Database)

Element	Life	Capital Cost		O&M Cost	
	Years	$K, 2007		$K/year, 2007	
		Low	High	Low	High
Signs					
Fixed Message Sign	20	50.00	75.00	2.50	3.75
Variable Message Sign*	10	47.00	117.00	2.30	6.00
Variable Message Sign Tower	20	25.00	120.00		
Variable Message Sign - Portable	14	18.30	24.00	0.60	1.80
Communications					
DS0 Communication Line (56 Kbps)	20	0.5	1	0.6	1.20
DS1 Communication Line (1.544 Mbps)	20	0.5	1	4.8	9.60
DS3 Communication Line (44.736 Mbps)	20	3	5	24	72.00
ISP Service Fee				0.17	0.60
Conduit Design and Installation - Corridor	20	50/mi	75/mi	3/mi	3/mi
Twisted Pair Installation	20	11/mi	15.8/mi	2/mi	2/mi
Fiber Optic Cable Installation	20	20/mi	52/mi	1/mi	2.5/mi
900 MHz Spread Spectrum Radio	10	9/link	9/link	0.1/link	0.4/link
Terrestrial Microwave	10	5/link	19.1/link	0.5/link	1/link
Wireless Communications, Low Usage (125 Kb/mo)				0.12	0.20
Wireless Communications, Medium Usage (1,000 Kb/mo)				0.6	0.70
Wireless Communications, High Usage (3,000 Kb/mo)	20	0.5	1	1.2	1.80

* Includes communications technologies

DMS may be used to communicate a variety of information, including: alternative routes or detours, construction, lane closures, incidents, traffic management operations (such as reversible lanes), Amber alerts, event or attraction information, individual vehicle speeds, or segment travel times. As a result, a number of different types of data may be required for DMS operation. Information required to display real-time speeds and travel times may include input from loop detectors, microwave, radar, or video technologies (Brydia, et al., 2007). Message update frequency also varies according to information type. While some messages, such as construction information or event information can be pre-programmed, others such as incident and travel-time information must be updated frequently to provide value to drivers. The usefulness of a DMS to drivers can be impacted by a number of factors, including update frequency, message design, and sign placement and spacing (Traveler Information Services and Technologies Page, 2003). Research has found that drivers are more likely to respond to a "prescriptive" sign that gives direction than one simply providing description. A message design and display manual for DMS has been developed for TxDOT (Aitken, 2008).

As previously discussed, surveys and simulation studies have been performed in many cities to examine the traffic impacts of operating DMS as part of an ATIS. Although exact results vary from city to city, studies have identified improvements in delay and safety and increased

diversion from incidents and congestion as the primary benefits of DMS. Survey results indicate that, regardless of actual traffic impacts, most drivers do consider DMS to be useful. Although measured impacts vary considerably by study location and exact traffic impacts are difficult to isolate due to the fact that DMS are often introduced in addition to other information technologies, research indicates that DMS are most useful in diverting traffic when unexpected diversion (such as in the case of an accident) is required. The fact that increasing diversion is the most recognized benefit of DMS demonstrates the appropriateness of arterial application for displaying incident and congestion information. Drivers traveling on arterials likely have many more options for diverting than those traveling on limited access freeways. Location of DMS on an arterial before a freeway entrance could prevent travelers from entering a congested freeway from which they would have difficulty exiting. Some disadvantages do exist for using DMS to provide traffic information. As discussed previously, DMS have limited space, so only a single, short message can be displayed. Additionally, drivers traveling at highway speeds may have trouble reading and processing the information on the sign. If DMS are employed on arterials, however, speeds may be considerably lower than in freeway applications. Although it is relatively simple to provide travel time information to designated destinations on a freeway, providing arterial travel times would be much more difficult, as many more possible destinations exist, and additional factors, such as signal timings and intersection delay must be considered.

Graphic Route Information Panels (GRIPs)

GRIPs are a specialized variation of DMS that provide traffic information in a graphical format (Jones et al. 2005). GRIPs can be used to present more complex traffic information than a text-only DMS. GRIPs use both active and inactive components. A reflective, static sign presents the map of a single road or network, on which light-emitting diode (LED) technologies are used to show two or three color-coded congestion levels. Additional information such as travel times and hazard warnings may be displayed on integrated DMS, and incident locations may be indicated on the sign as a blinking X. GRIPs have been deployed in Melbourne, Shanghai, Beijing, Munich, Tokyo, and Amsterdam. Detailed information about the signs deployed and traffic impacts of the Melbourne, Shanghai, and Tokyo studies are provided in Table 6.4. Traffic impact results from the Munich study could not be identified, and results from the relatively recent Beijing deployment are still being examined. A simulation performed as part of the Amsterdam study found that 40 percent of drivers preferred GRIPs to text-only DMS, and that 80 percent of the drivers found GRIPs to be "useful and worthwhile to investigate in more detail."

Table 6.4: Worldwide GRIPs Applications

(Source: Aitken)

City	Real-Time Information Displayed						Number of Signs	Results
	Travel Times	LOS	Incident/ Construction	Weather Warnings	Single Route	Multi-Route		
Melbourne	X	TT			X		13	Three telephone surveys found that information was useful to 70-90 percent of drivers. Of those who altered routes based on information, 69 percent were happy with results. No significant impacts on peak flow and speed under normal conditions were identified. It was estimated that diversion from major incidents increased 30 percent. Benefits in delay time savings due to implementation were estimated to be as much as $(Aus)830,000 per year
Shanghai (Type L)	X	TT				X	1	Benefits were identified for mean vehicle speed and duration of "free flow traffic condition", however these were measured for a broader ATIS system. GRIPs were found to "positively assist" drivers in making informed traffic decisions, especially in congested or incident conditions. 87 percent of drivers noticed signs, while 50 percent of those "completely responded" to information, and 48% said GRIPs "sometimes have influence."
Shanghai (Type M)	VMS	TT		VMS	X		2	
Shanghai (Type S)		TT			X		9	
Tokyo		S	X			X	31	95 percent of drivers noticed GRIPs. 81 percent correctly understood color coding on sign. 70 percent of drivers thought GRIPs were accurate, while 27 percent thought they were "not completely understandable." 85 percent of drivers considered signs "useful."

Some concerns with GRIPS deployment have been identified. Exact costs are difficult to identify, as signs must be custom-designed. The Amsterdam simulation found that drivers had more difficulty comprehending GRIPs than text-only DMS. A sign presenting too much information may prevent users from understanding or being able to process the information in a timely manner. Additionally, drivers are simply unfamiliar with GRIPs, and would likely require an adjustment period to fully use and understand them. UT researchers are currently providing assistance to TxDOT in examining the potential for application of these signs on Austin freeways. Like traditional DMS, GRIPs deployments have primarily been on freeways; however, also like traditional VMS, some benefits might be realized by providing information to drivers traveling on arterials, who have more opportunities to divert.

6.2.4 Developing Data Collection Technologies

It is clear that already, a number of good dissemination technologies are commercially available or in use by highway operators. The primary constraint limiting the quality of information available through these modes is a lack of good data. Speed, congestion, and travel time information can only be provided for segments of roadway where sensors or cameras are located. Some applications, such as Sirius Radio, are starting to collect satellite or cellular information from individual vehicles to supplement data collected from road sources. Data collected from GPS-equipped trucks has already been employed to better measure truck flows (ITS Joint Program Office, 2007). With most drivers carrying cellular phones, which may or may not be equipped with GPS, and many vehicles equipped with GPS-based navigation systems, opportunities exist for using individual vehicles as information probes if privacy concerns can be overcome.

Studies in San Antonio and Farmer's Branch Texas have examined the use of automatic vehicle identification (AVI) transponders to collect traffic information from individual vehicles (USDOT, Federal Highway Administration, 2000). Although at the time of the San Antonio study, the limited market penetration of toll tags prevented adequate data collection, study results suggested that if high levels of market penetration could be reached, a successful system could be implemented. As toll roads continue to open in Texas, and more vehicles are equipped will toll tags, there may be a good opportunity to use this technology for traffic data collection on both freeways and arterials.

Building on the concept of vehicles as probes, the Vehicle-Infrastructure Integration (VII) Initiative is a nationwide movement to deploy wireless vehicle-to-vehicle and vehicle-to-infrastructure communications technologies to improve safety and reduce congestion on US roads (VII Deployment Coalition Website, 2008). Federal and state government entities are working closely with automobile manufacturers to design, test, and eventually deploy on-board and roadside communications technologies. The goal of VII is to develop vehicle location and monitoring technologies that exceed the accuracy of existing systems; location, speed and braking information will be shared with other vehicles to help neighboring drivers make decisions, and with the roadside to provide highway operators with detailed movement information for individual vehicles as well as information about incidents and hazards such as pavement icing. Since many types of information will be shared between many vehicles, VII systems must be developed so that information is both prioritized and secured. VII is currently in its first phase of deployment, an operational testing and demonstration stage. Phase II, which includes researching technologies, applications, and institutional issues has also begun. Concept testing is currently being conducted in Michigan, California, Virginia, Arizona, Florida, Minnesota, and New York (VII Deployment Coalition Website, 2008).

6.3 Austin Commuter Survey Results

In 2005, researchers at the University of Texas completed a comprehensive commuter survey to identify what types of traffic information users in the Austin region seek, what information sources they currently use or would prefer to use, and when and how often they seek this information (Walton et al. 2006). Results of their findings are summarized in this section. As Table 6.5 demonstrates, the vast majority of traffic information users currently seek information from radio broadcasts, and more than a third watch television traffic reports. The vast majority of commuters continue to prefer radio as a means of receiving traffic information, although a slight reduction can be observed between current and preferred use. Only about half the number of

drivers using television for traffic information would prefer to do so. In contrast, more than three times as many drivers as currently use DMS for traffic information would prefer to do so. While only a relatively small percentage of drivers currently use internet resources, slightly more would prefer to use internet.

Table 6.5: Austin Commuter Survey: Information Sources

User Type	Percent Seeking Information from Source				
	Radio	TV	Local Newspaper	DMS	Internet
Current	89	36	4	12	15
Preferred	78	19	2	37	18

These results indicate that both DMS and internet may be "under-marketed" in Austin. This may indicate that more DMS should be deployed and that existing web information needs to be improved (although it is likely that web improvements have already been implemented since 2005). Although it was not offered as a choice, a number of respondents also cited cell phones as a mode used to receive traffic updates. It is clear from these results that Austin drivers prefer en route information to pre-trip information. The survey found that 78 percent of drivers seek en route information while 49 percent seek pre-trip information. The survey also examined when traffic information is sought. Results in Table 6.6 indicate that slightly more commuters seek information in the morning than in the evening, which likely reflects added arrival time constraints in the morning. Table 6.7 describes the types of information sought by Austin commuters. The majority of drivers are likely to seek information on accident locations, road congestion, lane closures, and weather conditions. Drivers are less likely to seek estimated trip times; this may reflect the fact that they do not trust the quality or timeliness of this information, or may simply be a reflection of the lack of currently available travel time information sources. Table 6.8 provides information on which specific information types are sought during morning and evening peak hours. This table reflects the previous finding that, in general, morning commuters are more likely to seek traffic information and that incident, congestion, and construction location information are considered most valuable.

Table 6.6: Austin Commuter Survey: Time-Of-Day Information Sought

Time-of-Day	Percent Seeking Traveler Information During Commute			
	Very Often	Fairly Often	Sometimes	Never
Morning	25	20	36	19
Evening	22	21	36	21

Table 6.7: Austin Commuter Survey: Information Types Sought

Information Type	Percent Likely/Very Likely to Seek Information
Accident Location	80
Congested Roads	70
Weather Conditions	59
Lane Closure	57
Road Work	48
Road Hazard Warning	44
Estimated Trip Time	32

Table 6.8: Austin Commuter Survey: Time-of-Day When Information Types Sought

Information Type	Percent Stating Time when Information is Most Important		
	Both AM and PM Rush Hour	AM Rush Hour	PM Rush Hour
Accident Location	75	12	6
Lane Closure	68	15	7
Congested Roads	68	14	7
Road Work	64	18	7
Weather Conditions	67	11	6
Road Hazard Warning	62	14	6
Alternate Route	58	13	8
Estimated Trip Time	46	18	7

Traffic information can impact driver route choice and trip time decisions. Sixty-seven percent of Austin drivers indicated that they would change their route in response to traffic information, and 18 percent said they would change their trip time. Responses vary according to information type. Table 6.9 shows the expected route choice response of Austin commuters to different types of available traffic information. It is clear that most drivers will change routes to avoid an accident or road work. Travel time information is less likely to cause a route change, however two thirds of drivers state that they would switch a route if a recommended alternative was provided. The factor least impacting route switching is weather. This is likely a reflection of the fact that in general, weather conditions will not vary considerably between routes, other than possible specific weather related road hazards such as flooding or icing.

Table 6.9: Austin Commuter Survey: Information Use

Information Type	Likelihood of Switching Route if Information Available		
	Very Likely/Likely	Neutral	Unlikely/Very Unlikely
Accident Locations	88	6	7
Road Work	77	12	11
Lane Closure	74	15	12
Recommended Alternate Route	66	24	12
Road Hazard Warnings	62	23	14
Estimated Travel Time	55	28	15
Weather Conditions	55	26	19

Several general conclusions can be made from the Austin commuter survey. Most drivers do seek traffic information before or during their commute, with slightly more seeking information in the morning. Drivers would like to have information on accident locations, congestion, construction, lane closures, weather, alternative routes, and estimated trip times; however, they are least likely to seek the last two, possibly reflecting a lack of trust in the information provider to provide timely, accurate information and decision-making. Given accurate information, drivers state that they would respond by changing routes and travel times. Currently, the most used modes for seeking information are radio and television; however, there is a desire for greater use of advanced technologies such as VMS and the internet.

6.4 Summary and Recommendations

The following are general conclusions and recommendations resulting from this work:

6.4.1 Pre-Trip Information Sources

- Comprehensive websites offering a variety of content on traffic flow, incidents, construction, and weather that can be personalized to localized information for a specific user are most useful; San Antonio's TransGuide provides a good example, although its capabilities are limited primarily for freeway information. In Austin, much travel information is available, but it is spread across multiple websites, even within TxDOT.

- Websites must be easily navigable and provide information in understandable text and graphic formats. While TransGuide provides a lot of information, most of it is provided in text form. Integration of this information into a graphical display might provide some users, especially infrequent pass-through users, with a better understanding of existing traffic conditions.

- Although television is relatively low tech and un-personalized, many drivers still use TV traffic reports to help make trip planning decisions. Availability of TV information is still especially important to morning commuters, who may not want to take the time to turn on a computer in the morning before work to access internet sources. As mobile internet sources such as PDAs are improved and become more widespread, the importance of TV information may decline

- Continued implementation of 511 Systems should be carefully considered. 511 was initially planned as a pre-trip information tool, but with the advent of cell phones has increasingly become an en route information source. The potential safety hazards of drivers using 511 from a cell phone should be carefully considered, and the potential impact of hand-held cell phone bans on potential use should also be examined.

6.4.2 En Route Information Sources

- It is clear from both literature review and the Austin Commuter Survey that drivers prefer en-route information to pre-trip information. Currently, most drivers rely on traditional radio traffic reports.

- New traffic-only stations on satellite radio may provide an opportunity for longer traffic reports with more location specific information than existing broadcast radio reports. Although maintaining the timeliness of information will still limits length of reports, there may be some room for additional information such as arterial speeds and travel times. However, providing this information would require additional data from sensors/cameras or vehicle probe technologies.

- HAR probably has limited applications for arterials, as it is usually deployed on closed systems. However, HAR may be useful for arterial application during major construction projects.

- Radio and Satellite technologies show a lot of promise for delivery of localized information relevant to drivers; integration with in-vehicle navigation systems allows drivers to only see information relevant to where they are traveling. However, on-board technologies required for these systems are currently very expensive, and users are also required to pay a monthly service fee.

- New types of DMS, including GRIPs, that can display roadside complex traffic information should continue to be explored for both freeway and arterial applications, as commuters have indicated a desire for roadside information.

6.4.3 General Conclusions

- In general, improvements in information quality for all dissemination modes will require better data sources. In addition to cameras, loop detectors, and other monitoring sensors, toll tags, cellular and satellite technologies all provide opportunities to use individual vehicles as probes to capture better traffic information. Implementation of additional data collection technologies will be required to provide arterial traffic information. While most existing information sources do provide incident and construction information for arterials, very few provide traffic information such as travel times, speeds, or congestion.

- Available information sources must be well advertised and easy to use. In addition to a noted lack of awareness by potential users of telephone 511 systems, many traffic information websites are difficult to find and to navigate.

- Currently available traffic data limits the quality of information available, but as market penetration of new technologies continues, private companies may have added incentives to improve data. There will likely be opportunities for government, private

information providers, and drivers to cooperate to improve data sources and finance needed technology improvements. For example, when a driver signs up for a commercially available in-vehicle information service, they could sign a contract allowing their vehicle to be used as a probe to improve available data. Probe data collected by the private company and camera and sensor data collected by the road operator could be shared between both information providers to improve overall data for information dissemination and other traffic operations purposes. However, the legal requirements and financial arrangements that would be required for such a partnership remain to be seen.

Chapter 7. Methodology for Prioritizing Arterials for ITS Implementations

7.1 Introduction

When ITS deployments are constrained by limited funding resources, arterials must be carefully selected and prioritized so that the desired ITS benefits can be achieved. However, very few efforts have been found that attempt to address this issue. Given its importance, it is necessary to develop a method to assist TxDOT staff in selecting the arterials that would benefit most from the ITS implementations. The performance measures identified in Task 2, technologies evaluated and recommended in Task 3 and 4, and dissemination modes identified and recommended in Task 5 provide a basis for guidelines to identify and prioritize arterials suitable for ITS implementation. The objective of this task was to develop a guideline that TxDOT staff can use to identify and prioritize arterial roads suitable for ITS implementations. In order to achieve this objective, the CTR team defined a set of arterial selection criteria to identify, evaluate, and prioritize possible ITS technology implementations. Based on these arterial selection criteria a guideline was proposed to comprehensively balance all the factors for suitable arterial selection. Simulation-based experimental tests are introduced and recommended as a complementary approach for verifying the effectiveness of new arterial ITS implementations.

7.2 Arterial Selection Criteria

To facilitate the selection process of identifying suitable arterials for ITS implementations, a series of selection criteria are developed. These criteria sufficiently describe the urgency, feasibility, and suitability for arterial ITS deployments and are used to develop the guideline to identify and prioritize arterials suitable for ITS implementations. Table 7.1 illustrates these selection criteria and sub-criteria. The detailed explanations are provided as follows.

Table 7.1: Arterial Selection Criteria and Sub-Criteria

Arterial Selection Criteria	Sub-Criteria
Arterial traffic and geometric characteristics	➢ Traffic Characteristics ➢ Geometric Characteristics
Current level of service	➢ Travel time between intersections ➢ Control delay at intersections ➢ Average travel speed for through vehicles ➢ LOS determination
Benefits and beneficiaries	➢ Improve safety and security ➢ Improve traffic operation efficiency ➢ Provide better traveler routing decisions ➢ Reduce fuel consumption and pollutant emissions ➢ Increase economic productivity
Existing ITS infrastructure	➢ Traffic surveillance and detection systems ➢ Travel information dissemination systems ➢ Signal control system ➢ Managed lane systems ➢ Enforcement systems
ITS Implementation costs	➢ Video detection system ➢ Emergency vehicle preemption ➢ Advanced parking information systems ➢ Management information systems ➢ Automatic ramp rollover systems ➢ Truck speed warning system ➢ Electronic payment systems ➢ ITS work zone system
Funding opportunities	➢ Funding sources from public sectors ➢ Funding sources from private sectors
Potential expansibility	➢ Connections with other major arterials ➢ Connections with other major freeways

7.2.2 Arterial Traffic and Geometric Characteristics

Traffic and geometric characteristics are important in selecting the appropriate arterials for ITS implementations. Necessary traffic and geometric data includes traffic volumes, traffic speeds, percentage of trucks or other large vehicles, the number of lanes, lane widths, shoulder widths, ramp merge/diverge conditions, weaving section lengths, lateral clearances, speed limits, horizontal and vertical alignment, pavement type, and local terrain, etc. These factors are closely associated with arterial performance and play important roles for ITS implementations.

Traffic volume is an important input for determining arterial performance and what kind of ITS implementations are required on arterial facilities. Traffic volumes may be expressed in terms of average daily traffic and hourly volumes (flow rate). In this study the average daily traffic volume and hourly volumes should be used to quantify the overall traffic operations. Average daily traffic volume represents the total traffic for a year divided by 365, or the average traffic volume per day (HCM 2000). The HCM provides a definition for flow rate, which is the

total number of vehicles that pass over a given point or section of a lane or roadway divided by the elapsed time (HCM 2000). Speed is another critical measurement. To fully indicate the arterial performance, space mean speed is utilized to estimate accurate travel times in this study. Space mean speed is calculated as the length of roadway segment divided by the total time required to travel the segment (Mannering, et al. 2004). Trucks and other large vehicles demonstrate different characteristics including slow acceleration, inferior braking, and large turning radius. The percentage of truck and other large vehicles is another significant parameter that can influence arterial performance (HCM 2000). Therefore, the HCM requires adjustments to the volumes of these vehicles in arterial capacity analysis.

Arterial traffic operations are impacted by the related geometric characteristics. In this study, geometric data include the characteristics of roadway facilities and adjacent land uses. The representative data include the number of lanes, the lane widths, shoulder widths, ramp merge/diverge conditions, weaving section lengths, lateral clearances, speed limits, horizontal and vertical alignment, pavement type, and local terrain, etc. These factors will impact the arterial performance significantly. For example, according to HCM 2000, when lane widths are less than 12 ft, drivers will travel closer to one another laterally than they would normally desire (HCM 2000). Normally, on arterial roadway, vehicles in the median lane typically move faster than in the lane adjacent to the right shoulder. These geometric data should be carefully analyzed when new ITS implementation is considered to improved arterial traffic operations.

7.2.3 Current Level of Service

Arterial roadways primarily serve longer through trips. The average travel speed for through vehicles along an urban street is the determinant of the operating level of service (LOS). The travel speed along a segment or entire length of an urban street is dependent on the running speed between signalized intersections and the amount of control delay incurred at signalized intersections (HCM 2000). The control delay is the portion of the total delay for a vehicle approaching and entering a signalized intersection that is attributable to traffic signal operation. Control delay includes the delays of initial deceleration, move-up time in the queue, stops, and reacceleration. The average travel speed can be calculated using the length of the arterial roadway divided by the travel time. According to HCM 2000, arterial roadways' LOS is based on average through vehicle travel speed for the section under consideration. Based on the speed range and urban arterial class, arterial LOS criteria are listed on the Table 7.2. The arterial class is determined based on direct field measurements of the free flow speed (FFS) or on an assessment of the arterials' functional and design categories. The detailed description is provided in HCM 2000.

Table 7.2: Arterial LOS by Class

(Source: HCM 2000)

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	55 to 45 mi/h	45 to 35 mi/h	35 to 30 mi/h	35 to 25 mi/h
Typical FFS	50 mi/h	40 mi/h	35 mi/h	30 mi/h
LOS	Average Travel Speed (mi/h)			
A	> 42	> 35	> 30	> 25
B	> 34–42	> 28–35	> 24–30	> 19–25
C	> 27–34	> 22–28	> 18–24	> 13–19
D	> 21–27	> 17–22	> 14–18	> 9–13
E	> 16–21	> 13–17	> 10–14	> 7–9
F	≤ 16	≤ 13	≤ 10	≤ 7

LOS A describes primarily free-flow operations at average travel speeds, usually about 90 percent of the free flow speed (FFS) for the given arterial. Vehicles are completely unimpeded in their ability to maneuver within the traffic stream. Control delay at signalized intersections is minimal. LOS B describes reasonably unimpeded operations at average travel speeds, usually about 70 percent of the FFS for the arterial. The ability to maneuver within the traffic stream is only slightly restricted, and control delays at signalized intersections are not significant. LOS C describes stable operations; however, the ability to maneuver and change lanes in midblock locations may be more restricted than at LOS B, and longer queues, adverse signal coordination, or both may contribute to lower average travel speeds of about 50 percent of the FFS for the arterial. LOS D borders on a range in which small increases in flow may cause substantial increases in delay and decreases in travel speed. LOS D may be due to adverse signal progression, inappropriate signal timing, high volumes, or a combination of these factors. Average travel speeds are about 40 percent of FFS. LOS E is characterized by significant delays and average travel speeds of 33 percent or less of the FFS. Such operations are caused by a combination of adverse progression, high signal density, high volumes, extensive delays at critical intersections, and inappropriate signal timing. LOS F is characterized by urban street flow at extremely low speeds, typically one third to one-fourth of the FFS. Intersection congestion is likely at critical signalized locations, with high delays, high volumes, and extensive queuing (HCM 2000).

Current arterial LOS indicates quality of service provided by the roadway section, and reflects the urgency of ITS deployment for arterial operation improvements. To maximize the benefits of ITS deployment, the roadway with the LOS D or worse may received high priority. The arterial LOS should be considered with other selection criteria to identify the suitable arterials for ITS implementations.

7.2.4 The Number of Beneficiaries of New Arterial Management Systems

New ITS implementations, including the application of advanced electronic, communication, information processing, and control technologies, will improve the safety, mobility, and productivity of transportation systems. Significant benefits have been achieved by applying these technologies in major metropolitan areas, including fewer accidents, more efficient traffic flow, fewer traffic jams, faster freight deliveries, better travel information, and quick emergency responses. Specifically, these benefits include the ability to:

1) Improve safety and security: ITS deployment can effectively improve incident management by better directing traffic flow traffic flow to reduce the risk of vehicle crashes, and decrease the severity and impacts of traffic accidents. Also ITS technologies can provide better surveillance of transportation facilities and more reliable border, weight, cargo and driver checks, monitor and track public transport vehicles, and prevent unauthorized uses for commercial vehicles. Under extreme conditions, efficient evacuation planning and execution can be provided and reliable communications during disasters may be maintained.

2) Improve traffic operation efficiency: based on arterial ITS deployment, better traffic control and management can be achieved, and traffic congestion can be alleviated. For example, advanced managed lane systems, such as express toll lane, High Occupancy Toll (HOT) lane systems are in operation to realize demand-responsive road pricing control.

3) Provide better traveler routing decisions: ITS technologies provide advanced traveler information systems and driver assistance systems, such as, intelligent speed and warning information to support aging and inexperienced drivers and travelers.

4) Reduce fuel consumption and pollutant emissions: new arterial ITS implementations reduce delays and stops for vehicles, especially for trucks at intersections, and terminals and provide information to make public transportation a more attractive alternative, therefore, fuel consumption, and air pollution can be reduced.

5) Increase economic productivity: arterial ITS deployment can provide a better ability to move freight, save billions of dollars in operating and maintenance costs, better utilize existing transportation infrastructure capacity help fiancé infrastructure development through more reliable, flexible toll collection, and provide better accessibility to transportation services for all travelers.

The potential beneficiaries of arterial ITS implementations are drivers, bicyclists, pedestrians, and local residents who live close to the treated arterial streets. Also for the system perspective, regional department of transportation, transportation agencies, and public transportation authorities will be receivers of benefits. The number of beneficiaries is one of the essential factors for determining suitable arterial roadways for new ITS implementations. It reflects the appropriateness and urgency of ITS implementations, and must be carefully considered.

7.2.5 Existing ITS Infrastructure

Existing ITS infrastructure provides a basis for new arterial management systems. To maximize the benefits achieved by the new ITS deployment, in-depth analysis must be conducted to investigate how new technologies can be incorporated with an existing ITS infrastructure and accommodate technological advances.

Traffic surveillance technologies, such as sensors or cameras monitoring traffic flow and critical transportation infrastructure for security purposes, are important components of arterial management systems. Many advanced ITS implementations are enabled through traffic surveillance and information dissemination systems. Therefore, primary existing infrastructure investigations should emphasize traffic detection and communication systems, which

disseminate important information about travel conditions to travelers via technologies such as dynamic message signs (DMS) or advisory radio (RITA, 2009). Also, existing traffic signal control systems should be studied. The key components include Adaptive Signal Control, Advanced Signal Systems, Transit Signal Priority Systems, Variable Speed Limits, Bicycle and Pedestrian Detection and Control Schemes for Special Events. Other existing ITS-based arterial management systems should be researched including managed lane systems, and enforcement systems. Typical ITS applications for managed lane systems include dynamic posting of high-occupancy vehicle restrictions and the use of reversible flow lanes allowing more lanes in the peak direction of travel during peak periods. Automated enforcement systems can increase compliance with speed limits, vehicle occupancy restrictions, traffic signals, and other traffic control policies (RITA, 2009).

7.2.6 Implementation Costs and Funding Opportunities for New Arterial Management Systems

Implementation costs and available funding sources determine the feasibility of new arterial management systems. The costs of implementing new ITS technologies vary depending on existing infrastructure and design functions of the overall arterial management system. Based on the evaluation of ITS technologies deployed in major metropolitan areas, relative implementation costs for representative arterial management technologies are illustrated as follows (Persad, et al. 2008).

- Video Detection System replacing loop detectors, Colorado Springs, CO
  - 420 semi-actuated signals, replacing 10,000 loop detectors (annual failure rate of 20%)
  - Cost: $13k/section, $5.6m total, savings in maintenance

- Emergency Vehicle Preemption, British Columbia, Canada
  - The siren of an emergency vehicle is detected and initiates a green signal for the oncoming vehicle. Pedestrian crossing signals are switched to *DON'T WALK*. A visual verification system (set of blue and white lights) indicates that the intersection is controlled by an emergency vehicle preemption system and when the system has been activated.
  - Cost: $4,000 per intersection, can be less if multiple intersections are equipped

- Advanced Parking Information Center, Seattle, WA
  - Provides information and routing directions to three major parking centers via variable message signs. This information is also available via the Internet, phone, and pagers to travelers prior to leaving for an event as well as travelers en route. Detection technology is used to monitor parking availability
  - Cost: $925k

- Management Information Systems for Transportation (MIST), Rockville, MD
  - Computerized traffic signal management system that allows the City traffic engineers to monitor and control the operation the City's traffic signal network.
  - Developed by PB Farradyne Inc in Rockville, MD. Currently the system controls 400 of the city's 800 traffic signals.
  - MIST keeps these signals synchronized, monitors the equipment operation for faults, collects traffic volume data from vehicle sensors in the road and allows the

traffic engineers to monitor operations in real-time and alter signal timing, if necessary, from the City's Traffic Management Center. This override feature is a valuable tool in managing sporting events, major road closures and other special events.

- Automatic Ramp Rollover Systems, Washington D.C.
    - Employed around the Washington D.C., Capital Beltway area. The costs of this system for software, construction, calibration, commissioning, testing, and design was $166,462 for a one-lane ramp and $268,507 for a two-lane ramp.
    - On-site sensors and computers detect truck speeds, weight, and height classification, and then calculate the probability a truck would roll over as it approached. If a truck was at risk, a roadside warning sign was activated to alert drivers to slow down. Prior to deployment there were 10 truck rollover accidents at these sites between 1985 and 1990. After deployment, no accidents were recorded between 1993 and 1997.
    - Cost: $166k single lane ramp, $269k double lane

- Truck Speed Warning System, Glenwood Canyon, CO
    - If a truck is detected (via radar) exceeding the posted speed, then the truck's speed is posted on a dynamic message sign (DMS)
    - Cost: $25-30k

- Incident Management/ Emergency Management, LifeLink Project, San Antonio, TX
    - The system supports voice and video teleconferencing between University Hospital and 10 of the ambulances in the San Antonio Fire Department.
    - Cost: $3.25m

- Electronic Payment Systems, Central Puget Sound Regional Fare, Washington State
    - Smart card technology that will support and link the fare collection systems of the major transit agencies operating in the Central Puget Sound region of Washington State.
    - The cost of the Regional Fare Collection (RFC) Project will be paid out during the 2003–2007 timeframe. The cost includes all vendor contract cost components, including equipment, equipment installation, fare cards, integration, and project management as well as other RFC Project administration costs, including sales tax, contingency fund, and project management team costs
    - Cost: $42m

- ITS Work Zone System, New Mexico
    - The system included eight fixed CCTV cameras, eight modular (expandable) DMS, four arrow dynamic signs, four portable DMS, four portable traffic management systems (a single integrated platform for camera and DMS), and four HAR units. Components were linked to base station computers via wire line and wireless communications. Information on traffic conditions were provided via the HAR and DMS, and via other outlets to include website, radio, fax, and e-mail distribution lists.
    - Cost: $1.5m

Funding opportunity for is another important consideration for ITS implementations. The potential opportunities from public sectors are listed (Persad, et al., 2008).

SAFETEA-LU: The bill contains a new real-time system management information program that directs the Secretary of Transportation to establish a program to provide, in all states, the capability to monitor, in real time, the traffic and travel conditions of the major highways in the United States. Appropriations in FY 2005 designated over 100 ITS deployment projects including ATIS. SAFETEA-LU has funds to cover these projects. After that, there are no dedicated ITS deployment funds. Although the ITS integration program is no longer available, ITS' are an eligible capital expense in FTA Federal funding programs.

New/Ongoing Federal Initiatives: USDOT recently announced nine new focal areas for ITS deployment that represent new sources of ITS funding. There also continues to be federal support and interest in ITS deployments related to safety and rural applications. The Research and Innovative Technology Administration (RITA), through the Federal Highway Administration (FHWA), occasionally requests applications from metropolitan areas to result in the award of one or more cooperative agreements under the U.S. Department of Transportation's Intelligent Transportation Systems—Operational Testing to Mitigate Congestion (ITS-OTMC) Program.

North American Free Trade Agreement (NAFTA) Transportation Corridors and Related ITS Strategies: As a state that facilitates a significant amount of the nation's trade—particularly in the form of providing safe and efficient routes for commercial trucks—Texas is well positioned to bring forward plans for ITS deployment that should receive significant federal support and be the source of innovative public-private partnering projects. ATIS deployments well suit that scope.

Homeland Security/Evacuations: As a state that is home to targets at high risk of terrorist attacks, contains several of the nation's largest metropolitan urban areas, and has the second-largest coastline in the nation that is prone to hurricanes, Texas is also well positioned to receive federal support for ITS deployment that addresses any/all of these issues. Regardless of federal support, ITS deployment projects that can offer multiple benefits by addressing many of these issues simultaneously should be considered. ATIS is no-doubt such type of deployment.

Cost-Sharing of ITS Deployment with New Toll Road Construction: In areas where new toll roads will interchange with existing roadways, there will be opportunities to co-deploy new ITS technologies and thereby accomplish increased ITS deployment at a reduced cost to TxDOT. ATIS should fall into this category.

The potential opportunities from private sectors are very limited and generally require substantial marketing efforts. The funding opportunities from private sectors may include

Traveler Information Usage or Subscription: The commuter survey in Austin indicates that about 50% of respondents are willing to pay a fee if the information helps them save time. Therefore opportunities to create new sources of revenue for ITS funding appear to exist in several areas such as subscription services, data exchange, naming rights, sponsorships, and 511 information fees.

Multi-function, on-board units: In the toll road context, there is an opportunity to combine tolling technology with On-Board Units (OBU). As shown in TxDOT research project 0-5079, traveler information can enhance toll road revenues. Toll agencies can tap into this revenue by partnering with technology integrators to deploy toll collection systems that use multi-function and value-added on-board units.

The information regarding ITS implementation costs and potential funding opportunities will be useful for TxDOT staff to select suitable arterials and proper ITS technologies for designed arterial management systems considering funding constraints. The decision to suitable arterial ITS deployment not only simply a technical option, but also needs to consider a comparative assessment of costs, benefits, and available funding support. Therefore, this selection criterion should be integrated with others for proper arterial identification.

7.2.7 Connections with Other Major Arterials and Freeways

Connections between the selected arterials with other major arterial and freeways are important factors to indicate potential expansibility and compatibility of new arterial management systems. Care must be taken to address significant interactions between freeway and arterial management require when new ITS technologies are implemented.

In many metropolitan areas, the freeway system is functioning at or beyond the capacity for which it was designed. Many drivers are choosing to use arterial streets as an alternative. Therefore, new ITS implementation should consider the coordination between arterials and freeways. Through improving the interplay of freeway traffic management and arterial management, arterial performance, and overall system performance would be improved. For example, a study of freeway ramp metering and adaptive signal control on adjacent arterial routes in Glasgow, Scotland, found a 20% increase in vehicle throughput on the arterials and a 6% increase on freeways. Arterial traffic increased 13% after implementation of ramp metering and an additional 7% with the initiation of adaptive signal control (Diakaki, 2000). New ITS implementations should be designed to seamlessly integrate with other arterial and freeway systems, as well as existing ITS infrastructure, and maximize potential benefits of overall traffic systems.

7.3 Methodology

Based on these selection criteria, a method is developed for identifying suitable arterials for ITS implementations. This method will comprehensively consider all the impact factors and balance the urgency and feasibility to prioritize the candidate arterials. The flow chart of the proposed method is illustrated in Figure 7.1. The suitability of arterial management systems are determined by two major components, urgency, and feasibility. Analogous to cost-benefit analysis, the decision needs to be reached based on a comparative assessment of urgency and feasibility for the candidate arterials. Although it is not easy to quantify these two perspectives, the selection criteria introduced in this study will be greatly help in analyzing the urgency and feasibility of new arterial ITS deployment and further identifying suitable arterials.

7.3.1 Analysis of Urgency

The need for new arterial ITS deployment is growing steadily. Transportation authorities have to balance various factors and identify the urgency of different arterial roadways for new ITS implementations. The urgency for new arterial management systems can be analyzed on the basis of the selection criteria including traffic characteristics, geometric characteristics, current LOS, potential benefits, and the number of beneficiaries. For example, one arterial roadway currently carries a large amount of vehicles daily, and the LOS is identified as LOS E, that indicates significant delays are observed and the average travel speed is only about 33% or less of the free flow speed. Preliminary study finds after the new arterial ITS deployment, such as

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advanced traffic detection, adaptive signal control, transit signal priority, variable speed limits, and dynamic message signs, are implemented, significant benefits will be achieved through reducing arterial control delays, improving trip reliability of transit vehicles, and reducing fuel consumption and air pollutions. Also a large amount of drivers, pedestrians, bicyclists, and local residents will benefit from the new arterial management system. Therefore, this arterial roadway has high priority for new ITS implementations in terms of urgency analysis. Using the selection criteria detailed in the previous section, the urgency analysis for different arterials can be conducted. Urgency analysis will be integrated with feasibility analysis to determine suitable arterials for new ITS implementations.
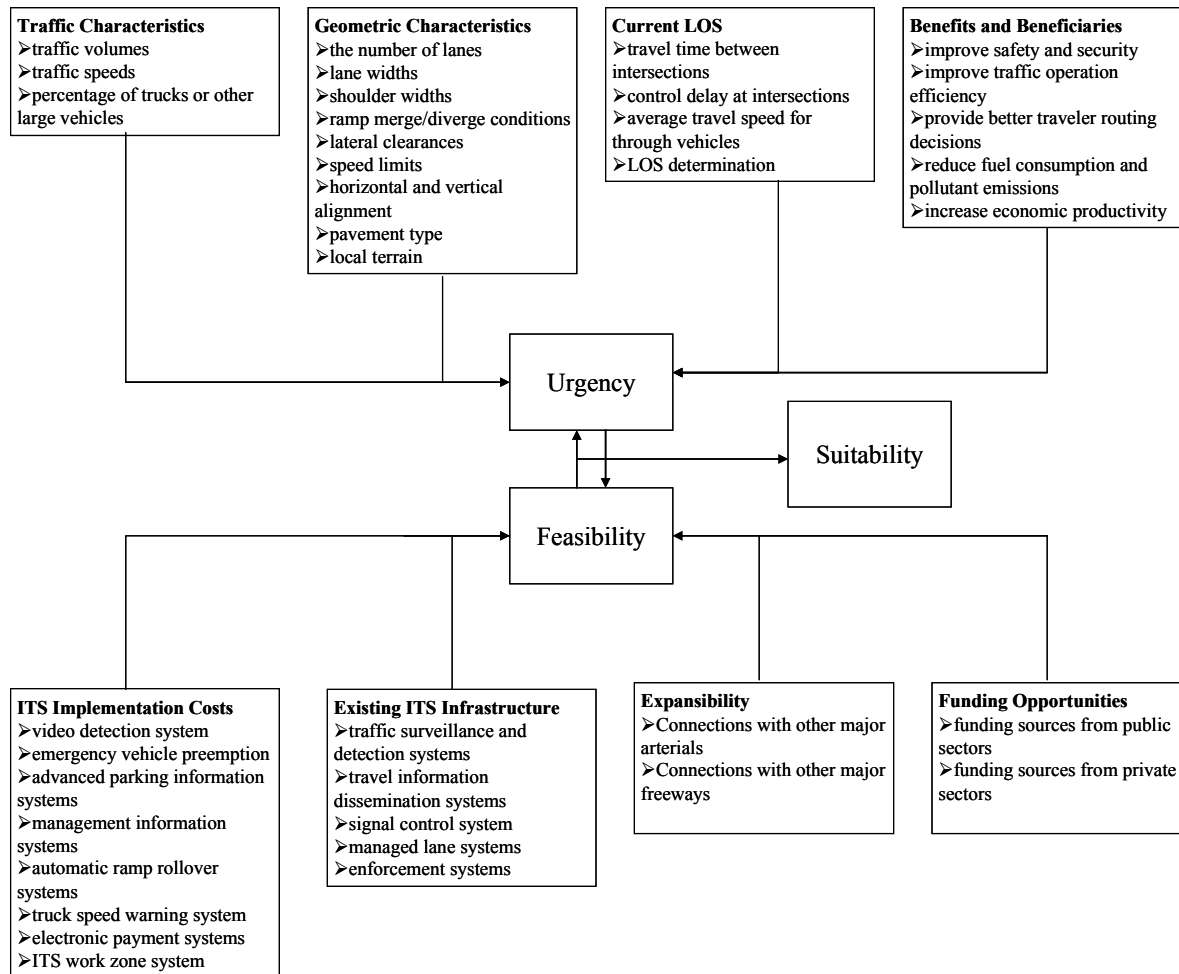
Figure 7.1: The Flow Chart of the Proposed Method

7.3.2 Analysis of Feasibility

A feasibility analysis of new ITS implementations for candidate arterials is complementary to an urgency analysis. Feasibility analyses will present a series of alternatives to evaluate the potential arterial systems and provide the likelihood of success for each arterial ITS deployment under considerations. The selection criteria for feasibility analyses include ITS implementation costs, existing ITS infrastructure, funding opportunities and connections with other major arterials and freeways. These factors indicate the potential for success of new arterial

management systems. For example, one arterial roadway has relatively complete health traffic surveillance and detection systems, and fundamental signal control devices, with an expandable roadway structure for managed lane system implementations. It provides a solid foundation for further ITS deployment with reasonable implementation costs. When the funding sources from both public and private sectors are available, the new ITS deployment becomes feasible to improve arterial traffic operation efficiency.

7.3.3 Identification of Suitability

Based on the analyses of urgency and feasibility, suitable arterials can be identified for new ITS implementations. The priority will be determined from the comparative assessment of both urgency and feasibility analyses. The arterial roadways with high levels of both urgency and feasibility should be identified as suitable arterials for new ITS implementations. Figure 7.2 illustrates different scenarios for balancing the feasibility and urgency of suitable arterial ITS deployment.

Scenario 1 indicates this arterial roadway has a relatively good LOS, and traffic is not highly congested. Also considering existing ITS infrastructure, new ITS implementation costs, inadequate funding support and limited potential benefits, the feasibility of new arterial management system become marginal. Therefore, it is not appropriate to identify this arterial for ITS deployment. Scenario 3 shows the other situation. The new management system may urgently need to consider improving highly congested roadway systems, but restricted funding support and substantive deployment costs may significantly degrade the implementation feasibility. Scenario 5 illustrates a different situation. High levels of feasibility and urgency verify its suitability for ITS deployment. The new arterial management system is highly needed to improve current traffic operation conditions and significant benefits will be achieved. Obviously, with the support of feasibility and urgency analyses, the arterial roadway under Scenario 5 will be the best candidate for ITS deployment.

The developed method for selecting suitable arterials for ITS implementations can assist TxDOT staff to compare and prioritize the candidate arterials. Complementarily, simulation-based experimental tests should be conducted before the new arterial management system is implemented in reality.
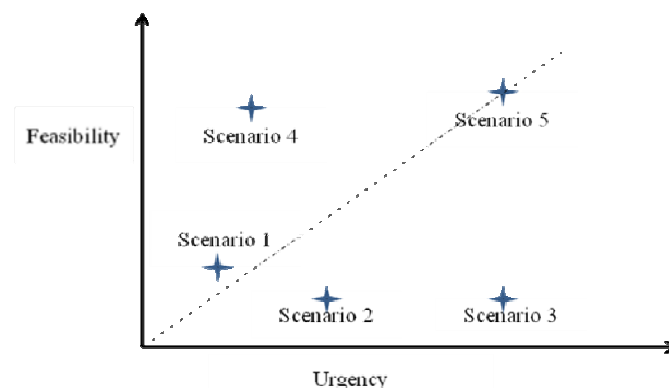

Figure 7.2: Scenarios for Balancing Feasibility and Urgency of Suitable Arterial ITS Deployment

7.4 Simulation-based Experimental Tests

To verify the system performance of the arterial roadways identified for ITS implementations, quantify their benefits, and recognize operational challenges, simulation-based experimental tests are necessary before new arterial management systems are in operation. Traffic simulation models can be applied to study arterial management system operations as a complementary, cost-effective, and risk-free approach to the theoretical analysis. Because of these major advantages, simulation has become an essential tool in traffic operational analysis. The prevalent traffic simulation tools include AIMSUN, CORSIM, and VISSIM, etc. CORSIM was developed by the Federal Highway Administration (FHWA) in the mid-1970s (FHWA, 1997). AIMSUN was developed by TSS (Transportation Simulation Systems) in Spain (TSS, 2002). Both AIMSUN and CORSIM networks are based on a link-node representation. VISSIM was developed by PTV AG, Germany (PTV, 2007). It employs links and connectors to form its network. In this study, VISSIM will be used to simulate arterial management system operations. Due to its cost-effective and risk-free features, VISSIM is widely employed by transportation researchers for exploring optimal traffic control strategies, identifying potential problems, and evaluating various alternatives for ITS implementations.

7.4.1 Introduction to VISSIM

VISSIM is a microscopic, time step and behavior-based simulation tool developed to model urban traffic and public transit operations. This software can simulate and analyze traffic operations under various scenarios. It is also very useful for evaluating various alternatives using the MOEs in transportation engineering and planning. In VISSIM the traffic model is based on the work of R. Wiedemann (1974 and 1991), which combines a perceptual model of the driver with a vehicle model. The behavioral model for the driver involves a classification of reactions in response to the perceived relative speed and distance with respect to the preceding vehicle. Four driving modes are defined: free driving, approaching, following, and braking. In each mode a driver behaves differently, reacting either to its following distance, or trying to match a prescribed target speed. Details of each mode are described as follows:

- Free driving: In this model, there are no impacts from the preceding vehicle on the following vehicle. Drivers seek to travel at a desired speed. Due to the randomness of simulation operations, the observed individual vehicle speed may oscillate around this desired value.

- Approaching: In this mode, the following driver adapts to the preceding vehicle's lower speed. When the distance between two consecutive vehicles reaches the desired safety distance, the approaching vehicle applies a deceleration or acceleration so that the relative speed can maintain zero.

- Following: In this mode, the relative distance between two adjacent vehicles maintain a safety distance, and their relative speed fluctuates around zero. The following vehicle follows the preceding vehicle without continuously accelerating or decelerating

- Braking: In this model, the relative distance between vehicles falls below a safety distance, which can result from an abrupt deceleration of the preceding vehicle, or lane changing of another vehicle. A continuous deceleration is required.

Also, drivers can decide to change lanes. This decision can be forced by a routing requirement, for example, when approaching an intersection, or made by the driver to access a faster-moving lane. In addition, traffic signals can be simulated, and are controlled in VISSIM by the Signal State Generator (SSG), which is a separate module from the traffic simulation module. Through the virtual signal controller, the user can access loop detector measurements and use such information to perform control strategies. These traffic signaling features can be used on signalized arterials to simulate signal control at intersections, and on freeway networks to simulate ramp metering control. Based on VISSIM, many modeling studies have been conducted. Gomes, May, and Horowitz (2004) developed and calibrated a VISSIM model for a congested freeway. Moen et al. (2000), Bloomberg and Dale (2000), and Tian et al. (2002) investigated the performance of VISSIM by comparing it to CORSIM, a popular traffic simulator developed by Federal Highway Administration (FHWA), and to which VISSIM compared favorably. More details can be found in (PTV 2007, Fellendorf and Vortisch 2001).

7.4.2 Simulation Model Development

For arterial management system simulation, a desirable simulation model should be capable of simulating various ITS technologies and advanced control strategies. VISSIM provides several built-in signal controllers to facilitate control logic implementation. Typical controllers include fixed-time, NEMA, and VAP controllers. Among them, the VAP controller can support complicated signal control strategies developed by users. VAP is a C-like macro language with user-configurable control and detection functions. Specific control algorithms can be implemented in VAP controller to meet user's requirements. To satisfy these requirements of arterial management systems, a VAP-based control module will be developed.

After the VISSIM simulation model is correctly configured for the arterial roadway systems identified by the proposed method, including geographic characteristics, traffic demand matrices, signal timing plans, traffic compositions, etc., virtual loop detectors can be deployed at signalized intersections as stations for data collection. The simulation model will be executed in the single-step mode (default frequency: 1 second). When traffic demand is allocated into the network by the dynamic assignment module, traffic condition information, such as flow rates, lane occupancies, intersection delays, etc., can be measured directly by the virtual sensors deployed in the network. At each single step, these traffic data will be exported and transferred to the VAP controller. These data are aggregated in an agreed interval length (could be the maximum of a representative signal control cycle length and 2 minutes) so that data from different sources have the same resolution and their random fluctuations can be offset without losing their timeliness. Based on these measurements, the ITS technologies and control strategies will be performed.

7.4.3 Simulation Model Calibration and Experimental Tests

Simulation model calibration is critical for ensuring realistic representations of simulated scenarios and achieving reliable simulation results. In this study, ground-truth traffic data, including traffic counts and speeds, will be collected from traffic sensors. The methodologies suggested by Gomes et al. (2004) and Park and Qi (2005) will be used as the base for the calibration process. After the simulation model is correctly configured, simulated vehicles are allocated to the whole network and assignment equilibrium is achieved. To check the fidelity of the simulation model, virtual sensors are placed in the simulation model according to their real-world positions in the arterial network being simulated. Traffic volume and speed data are

collected from these virtual sensors and compared to the ground-truth data. These data will be utilized to calibrate the parameters related to driving behaviors. In VISSIM, traffic flow is modeled as a discrete and stochastic process, in which each driver-vehicle-unit is treated as a single entity. The parameters, such as standstill distance, headway time, look-back distance, and minimum lane changing headway will be adjusted according to the observed field data. Based on the comparisons between the simulation results and the corresponding ground-truth data, the calibration process may be terminated or repeated. Once the difference is small enough, the model is considered reasonably calibrated and is ready for arterial traffic simulation experiments. The simulation model is built to exactly follow its arterial roadway geometric features, signal control settings, traffic demands, and operational patterns. To fully examine the performance of the arterial management system and quantify the benefit of new ITS implementations, simulation experiments will be conducted and analyzed under a broad range of test scenarios. To minimize the randomness of simulation results, multiple simulation runs will be performed, each with a different random seed. The arterial roadway system performance will be evaluated in terms of commonly used measures of effectiveness. Quantified benefits of the new ITS deployment for individual vehicles and for transportation agencies will help them make appropriate decisions regarding ITS deployment in reality.

7.5 Summary of Findings

In this task, a guideline is developed to help TxDOT staff select and prioritize arterials suitable for ITS deployment. With a comprehensive study of existing arterial ITS implementations in the United States and in other international metropolitan areas, the selection criteria are developed for quantifying various characteristics of candidate arterials. These criteria include

1) Arterial traffic and geometric characteristics;

2) Current LOS;

3) The number of beneficiaries of new arterial management systems;

4) Existing ITS infrastructure;

5) Implementation costs and funding opportunities for new arterial management systems;

6) Connections with other major arterials and freeways.

These criteria are classified into two categories to characterize the feasibility and urgency of each candidate arterial. Based on the feasibility and urgency analyses, the suitable arterials for new ITS implementations can be determined to maximize potential benefits. Simulation-based experimental tests will be performed to verify the arterial roadway system performance, quantify the benefits and recognized operational challenges. The microscopic traffic simulation tool VISSIM is recommended. Using the recommendations provided in the guideline on how to select and prioritize arterials suitable for ITS deployments, a case study will be conducted in the next section to select the appropriate arterials and to further demonstrate how to develop arterial ITS applications.

Chapter 8. Arterial ITS Application Demonstration

8.1 Introduction

Based on the technology identification, performance measurement, and arterial selection guidelines developed in the previous tasks, a case study has been conducted to demonstrate the benefits of arterial ITS implementation. The ultimate objective of this task was to assist TxDOT staff in selecting the most beneficial arterial ITS elements for technology system development. The major steps of this task include:

1. Conduct side-by-side comparisons and select the city areas with proper traffic operation conditions, data support systems, and existing ITS infrastructure

2. Identify the arterials that are appropriate for ITS implementations. Characteristics of those arterials and suitability for arterial management systems are assessed.

3. Review representative ITS strategies for arterial management enhancement. The best ITS strategies and most effective ITS technologies are identified.

4. Use traffic modeling techniques and simulate traffic arterial system operations under prevailing arterial management scenarios. The traffic simulation tool, VISSIM is used.

5. Based on the simulation test results, detailed analyses are provided to recommend potential arterial ITS implementation.

The proposed case study aims at demonstrating ITS technology implementations to enable traffic engineers to optimally respond to changes in traffic conditions. Arterial roadway traffic system performance strongly influences overall travel costs and travelers' perception of transportation in a given region, especially under heavily congested conditions. Because non-recurrent congestion is more challenging to address than recurrent congestion due to its randomness and complexity, this study focuses on non-recurrent congestion mitigation. Advanced ITS technologies, including traffic condition monitoring and data collection, dynamic vehicle routing optimization, traffic signal control coordination, and traffic information dissemination will be integrated in the simulation model.

Specifically, assuming an incident occurs on a freeway section or arterial intersection, traffic detection systems will monitor traffic condition changes and detect congestion quickly. Traffic data analysis can then be performed to identify optimal routes for traffic re-routing. Traffic information dissemination systems, for example, dynamic message signs (DMS) or radio broadcasting systems, can broadcast such information to travelers. Finally, certain proportional traffic demands are diverted to connecting local signalized arterials, and signal control strategies are coordinated to respond to traffic flow changes. The operational goal is to apply advanced ITS technologies to effectively and systematically respond to network-wide traffic condition changes, and further improve overall traffic mobility and safety.

The expected benefits of arterial ITS applications may include improved traffic safety, mobility and reliability, environmental effects, and motorist perceptions. For example, collisions that occur as a result of stop-and-go-traffic can be reduced if congestion within arterial roadway systems is effectively mitigated or the efficiency of arterial management is improved. Also when vehicles operate at a more fuel-efficient mode due to a reduction in the stop-and-go behavior

associated with congestion, the amount of vehicle pollutants released into the atmosphere generally decreases.

8.2 Case Study Design

In this report, a case study has been designed to employ the results of and demonstrate the procedures developed in the previous tasks performed for this study. The primary goals achieved in this report include:

1. Select priority arterials for ITS technology implementation (Applying results from Task 6)

2. Identify technologies for implementation (Applying results from Tasks 3-5)

3. Select performance measures for evaluation and quantification of technology benefits (Applying results from Task 2)

4. Develop a model to simulate the potential impacts of arterial ITS implementation

8.2.1 City Selection

The first step in the case study design was to determine which city to examine for ITS technology implementation. Three Texas cities were examined as candidate test locations. These included Austin, San Antonio, and Corpus Christi. A basic description of each city's primary highway transportation network is provided below:

Austin: Austin is the capital of Texas and is the fourth largest city in the state. Central Austin is bracketed by Interstate Highway (IH) 35 to the east and Loop 1 (Mopac Expressway) to the west. US Highway 183 runs from northwest to southeast, and State Highway (SH) 71 crosses the southern part of the city from east to west, completing a rough "box" around the central and north-central city. US 290 enters Austin from the east and merges into IH 35. Since 2006, three toll roads encompassing the Central Texas Turnpike System have opened in the Austin region. These include segments of Loop 1, SH 45, and SH 130. The Capital Metropolitan Transportation Authority (Capital Metro) provides public transportation to the city, primarily by bus. Capital Metro operates 72 bus routes, including 19 local service routes, 13 limited flyer routes, 5 neighborhood feeder routes, 19 special service routes (including 4 seasonal routes operated only during the academic year), and 14 shuttle routes serving The University of Texas at Austin (Capital Metro, 2009).

San Antonio: San Antonio is the second largest city in the state of Texas and is served by a number of major freeways including IH 10, IH 35, IH 37, IH 410, US 90, US 281, SH 151, and State Loop 1604. Other highways include US 87 and US 181, SH 16, and Loops 345, 368, 353 and 13. An extensive bus and streetcar system is provided by the city's metropolitan transit system, VIA Metropolitan Transit. Via operates a total of 89 bus routes.

Corpus Christi: Corpus Christi is a coastal city in the South Texas region. It is the eighth largest city in the state. Major highways serving the region include IH 37, US 77 and US 181, SH 44, 35, and 361. The public transportation system consists of 28 bus routes.

The 2007 TTI Urban Mobility Report evaluated a number of highway performance measures for the nation's 85 largest urban areas, including Austin, San Antonio, and Corpus Christi (Schrank and Lomax 2007). These measures provide quantifiable values to examine the severity of congestion on the highway system, including both freeway and arterial networks, in each of the urban areas evaluated. A higher level of severity indicates a greater need for future

operational improvements, including ITS deployment. Table 8.1 provides values for several performance measures for each of the cities evaluated.

Table 8.1: TTI Urban Mobility Report: Highway Performance Measures

System Performance Measures	Austin	San Antonio	Corpus Christi
Estimated Population of Urban Area	855,000	1,360,000	325,000
Congested Travel (% of Peak VMT)	66	61	16
Annual Delay per Peak Traveler (person-hours)	49	39	10
Annual Excess Fuel Consumed per Peak Traveler (gal)	33	27	6
Annual Congestion Cost per Peak Traveler ($)	909	706	183
Travel Time Index	1.31	1.23	1.06

In examining this table, we can see that, congestion impacts on drivers are much more severe in the larger cities, Austin and San Antonio, than in Corpus Christi. Values for congested peak travel, annual delay, excess fuel consumption, travel time index, and congestion costs are all much lower for Corpus Christi. Although Austin is a smaller city, it exceeds San Antonio in severity for each of the performance measures examined. Annual delay per traveler in Austin is more than 25 percent higher than in San Antonio, and the total annual costs of congestion for individual Austin drivers are nearly 30 percent higher. Based on these performance measures, which demonstrate the practical needs for arterial ITS deployment, and preliminary studies of each city's transportation system, which examined the system extent and diverse traffic operations in each of the potential case study cities, evaluation locations were narrowed to two cities, Austin and San Antonio. Next, meetings were held with the city traffic engineers in each of these cities to determine the extent of existing and planned ITS infrastructure in the regions. Following these meetings, field studies and investigations were conducted to fully understand their transportation systems. This section provides a description of findings for each city:

Austin: In the City of Austin, as is the case throughout the state of Texas, freeways, including Interstate, US, and State Highways, are administered by TXDOT, while city streets, including arterials, collectors, and smaller classes of streets are operated by the City of Austin. In Austin, there are two separate traffic management centers, the Combined Transportation, Emergency, and Communications Center (CTECC), which is operated by TxDOT, and the Toomey Road Traffic Management Center, which is operated by the City of Austin. CTECC operates cameras and DMS throughout the city's freeway network. City and county emergency services operate at CTECC to allow for coordinated emergency response. The City of Austin also has some operations at CTECC to allow for coordinated signal response to freeway incidents or conditions.

Most of the City's traffic monitoring is performed at the Toomey Rd. operations center. The following describes the fundamental arterial ITS-based traffic system currently operated by the city:

1) Traffic detection and data collection systems
Loop detectors are currently employed at more than 80 signals on City streets. Traffic data currently collected include directional volume and vehicle presence information. Surveillance cameras and calibrated cameras are also in operation at about 60 signals.

2) Traffic signal controller system

Coordinated signal systems are in operation. Semi-actuated control strategies are used on most arterial roadways. Different time plans are employed for different time periods of day. System-wide signal coordination is a primary issue to preserve high-quality transportation service.

3) Transit operation system

Public transportation system operations are stressed in current transportation systems. No Transit Signal Priority (TSP) systems and emergency vehicle preemption systems are in operation. However, TSP, vehicle preemption, and real-time transit vehicle location tracking systems are planned.

4) Managed lane system

Currently toll lane systems are operated by TxDOT. The existing toll lane system provides a good platform to test potential ITS technologies for further system performance improvements. No High Occupancy Vehicle (HOV) or express lanes are currently in place; however, express lanes are being considered on Loop 1.

5) Accident response system

Surveillance camera systems are used to cover the major freeway (CTECC) and arterial (Toomey Rd.) sections. Accident responses are coordinated in the traffic management center.

San Antonio: In San Antonio, like in Austin, freeways are administered by TXDOT, while city streets are operated by the City of San Antonio. The region's existing traffic management center, TransGuide, is operated by TxDOT in partnership with Via and the City of San Antonio. TransGuide operates 140 cameras, which monitor operations along a number of freeway corridors. DMS are deployed throughout the IH 10, IH 35, IH 37, IH 410, US 90, and US 281 corridors to provide incident, construction, and travel time information. The City of San Antonio primarily uses the TransGuide information for emergency response and to identify freeway conditions which may impact city street operations. The City of San Antonio is currently constructing its own traffic management center in the TransGuide building. This Center is expected to open in 2009. The following sections provide information about the city's existing and planned technology deployments on its network:

1) Traffic detection and data collection systems

Loop detectors are available on arterials; however, only vehicle presence information is collected. Vehicle volumes, lane occupancy, and vehicle speed are not directly measurable at the current stage. However, direct collection of this data is planned in the next five years. Surveillance cameras are in operation. Six CCTV cameras are currently available in the downtown area. In the next five years, 25 cameras are planned for region.

2) Traffic signal controller system

Coordinated signal systems are in operation. Signal controllers are being updated from the model 170 to the model 2070. City-wide IP-based network communication systems are used. Seventy five percent of the city's 2500 isolated intersections are under coordinated actuated control strategies. I2 systems are used for managing traffic operations. The signal control system has the potential to dynamically coordinate traffic signal systems, and integrate traffic signals with DMS and bus priority.

3) Transit operation system

Currently, no TSP systems or emergency vehicle preemption systems are in operation. However, TSP, vehicle preemption, and real-time transit vehicle location tracking systems are being considered in the next five year plan.

4) Managed lane system

No managed lane systems are currently being deployed in San Antonio, but reversible flow lanes are being considered in the next five-year plan.

5) Integrated Corridor Management (ICM) system

San Antonio proposed the ICM corridor of I-10 from I-35 in downtown San Antonio to Loop 1604. San Antonio's ICM team is working to promote mode and route shifts through improving information dissemination and optimizing traffic signal controls and signal timing plans.

Both San Antonio and Austin provide relatively compatible test environments for future arterial ITS implementation. San Antonio currently has a more extensive freeway ITS system, which would be beneficial for future system integration. However, the City of Austin currently employs more extensive technologies for data collection and system monitoring on its arterials. Because of this existing arterial infrastructure, as well as the greater severity of congestion in the region demonstrated in Table 8.1, the City of Austin was selected as the case study test location.

8.2.2 Urgency Analysis for Arterial Selection

Once the city was chosen, the next stage in case study identification was to identify the location of the arterial network. The need for new ITS deployments in the selected arterial roadway network is an essential consideration in route prioritization. Congestion in Austin has grown rapidly. One of the major components of assessing congestion is travel time and the travel time index, which is the measure of how much longer trips take during peak period travel times compared to the same trip during normal travel times. Austin's 2003 travel time index of 1.33 indicates that trips taken in 2003 during peak travel times took 33 percent longer than the same trips taken during non-peak travel times. Austin's travel time index increased from 1.08 to 1.12 over the period from 1982 to 1992 and from 1.12 to 1.33 over the period from 1992 to 2003. Austin's travel time index has been increasing at an average rate of two percent per year since 1992. Austin had the highest travel time index of any medium-size city, and a value higher than that of many larger cities, in the 2007 Urban Mobility Report. Consequently, travel delay in the Austin area has risen steadily since 1982, with substantial increases in recent years. In 1982, the average annual travel delay per person was four hours, and the average annual delay per peak period traveler was 11 hours. From 1982 to 1992, these delays grew at rates of 30 minutes per year per person and almost one hour per year per peak traveler. In 2003, Austin's annual delay per peak traveler was 51 hours, the highest of any medium-size city (TxDOT 2007).

In 1982, 28 percent of the lane miles in Austin were considered congested. That number grew at an average rate of over one percent per year until 1992 when 41 percent of the lane miles on the system were congested. From 1992 on, the percent of the lane miles congested rose at an average annual rate of over two percent until 2002 when the percentage of the lane miles affected by congestion peaked at 63 percent. In 2003 that number had fallen to 61 percent. Congestion is a catalyst for economic losses in numerous forms. Congestion directly wastes fuel and time, which indirectly raises the cost of goods and reduces real income for workers. Time is a valuable component in assessing economic losses due to congestion as travelers personal value of time

informs their daily decisions. In 2003, the average value of time for one hour was $13.75. Therefore, the average commuter who spent 15 extra minutes sitting on a congested freeway incurred an economic loss of about $3.45. In addition to lost time, the average Austin area commuter traveling during peak periods wasted 31 gallons of fuel a year merely sitting in traffic, 3 gallons more than the national average. The Austin area has been averaging a 1.2 gallon increase in wasted fuel every year for the 5 years between 1998 and 2003. In 1982, Austin's total estimated cost of congestion was $17 million ($41 per person or $96 per peak period traveler). By 1992, the total cost rose by an average of $5.3 million per year (17 percent) to $70 million ($118 per person or $253 per peak traveler). Since 1992 the annual cost of congestion has risen at a rate of $29 million per year (19 percent) to $391 million in 2003 ($457 per person and $851 per peak traveler) (TxDOT 2007).

In the Austin downtown area, there is the largest single concentration of jobs in the Central Texas area with 61,640 total employments. This total does not include the Capitol Complex and University of Texas areas, both of which are located immediately to the north. As might be expected, the highest proportion of arts, entertainment, accommodation, and food service industry jobs are located in the downtown area. Due to the large number of jobs in this area and the wide range of occupational and industrial activities present, the downtown employment center receives commuters from all over the Central Texas region. In 2000, 59,334 commuters made their way into the downtown area every day (TxDOT 2007).

As a result, an area of Central/North Central Austin was identified as the priority case study region. The total network examined was defined as the area bordered by US 183 in the north, Loop 1 in the West, Cesar Chavez St. in the south, and IH 35 in the east. The selected arterial roadway system currently carries a large amount of vehicles daily, and experiences severe traffic congestion, especially during peak hours. To improve traffic mobility and mitigate congestion, new arterial ITS applications, such as advanced traffic detection, coordinated signal control, dynamic vehicle routing and traveler information dissemination, should be deployed. The potential benefits include reducing arterial traveler delay, improving traveler speeds, improving driver routing decision-making and reducing fuel consumption and air pollution. Also a large amount of drivers, pedestrians, bicyclists, and local residents will benefit from the new arterial management system. Therefore, the selected arterial roadway network has high priority for new ITS implementations in terms of urgency analysis

8.2.3 Feasibility Analysis for ITS implementation

Feasibility analysis was conducted for ITS implementation for the selected arterial roadway network. Feasibility analysis quantifies the likelihood of success for planned arterial ITS deployments. In the selected arterial systems, many ITS components have been deployed to support further arterial ITS implementations. TxDOT currently operates detection technologies on the freeways within the defined region, and the City of Austin deploys both loop detectors and video technologies on the arterials. Loop detectors are available on major arterials, where traffic measurements, including directional volume and vehicle presence information, are collected. Surveillance cameras and calibrated cameras are also deployed for data collection and system monitoring. Coordinated Signal Systems are also in operation. Semi-actuated control strategies are used on most arterial roadways. The selected arterial roadway network has direct connections with other major arterial and freeway systems, such as W. Anderson Ln., Allandale Rd., Airport Blvd., IH 35, U.S. Highway 183, and U.S. Highway 290. These connections provide an expandable and compatible platform for further ITS deployments.

8.2.4 Suitability Analysis for ITS implementation

Based on the analyses of urgency and feasibility, suitability of the selected arterial network for new ITS applications can be verified. Statistical data indicates there are urgent needs to implement new ITS technologies and advanced control strategies to improve traffic operation efficiency and mitigate congestion in the selected arterial network. Meanwhile, the selected arterial roadway network has relatively complete health traffic surveillance and detection systems, and fundamental signal control devices, with an expandable roadway structure. It provides a solid foundation for further ITS deployment with reasonable implementation costs. When funding sources from both public and private sectors are available, the new ITS deployment becomes feasible to improve arterial traffic operation efficiency. Therefore, the selected arterial roadways demonstrate high levels of both urgency and feasibility. The suitability analysis indicates the potential for success of new ITS applications for the identified arterial networks.

8.2.5 Arterial Prioritization

The next stage of the case study was to identify priority arterials for ITS implementation and simulation. In Task 6, guidelines were developed for identification and prioritization of suitable arterials for ITS implementation. Criteria identified for evaluation included 1) current arterial traffic and geometric characteristics, 2) levels of service (determined as a function of travel time, control delay, or average traffic speed) along the arterial roadways, 3) expected benefits and the number of beneficiaries (e.g. improving safety and traffic system operation efficiency, providing better traveler routing decisions, and reducing fuel consumption and pollutant emissions), 4) existing ITS infrastructure, including traffic surveillance and detection systems, traveler information dissemination systems, signal control system, managed lane systems and enforcement systems, 5) ITS implementation costs and funding opportunities, and 6) potential expansibility (e.g. connections with other major arterial and freeway networks).

These criteria were used to evaluate existing arterials in the chosen network. In all, eight arterials were evaluated. These included Airport Blvd., Anderson Lane, Braker Lane., Burnet Rd., Congress Ave., Duval St., Guadalupe St., and N. Lamar Blvd. For each of five major criteria areas, each arterial was assigned a score ranging from one to five. No major implementation cost differences were identified between the arterials, so cost was not considered in arterial prioritization.

Both traffic volumes and number of lanes were examined to assign a score for "Arterial Traffic and Geometric" characteristics. Major traffic data sources include the TxDOT annual traffic counts report in 2005, 2006, and 2007, and the City of Austin traffic counts report in 2006 (CAMPO, 2009). Level of service (LOS) was determined as a function of average speed for each available section. The average travel speed is computed from the running time on the arterial segments and intersection approach delay. However, the currently deployed traffic sensors (surveillance cameras and loop detectors) are incapable of collecting such data including travel time and control delay. To address this problem, the average speed values were estimated using a "floating car" as a probe sensor on the arterials under examination. Then, based on the analysis standard provided by *HCM 2000*, the LOS for each arterial was determined. Although there may be some error in the estimated value due to a lack of data availability, it provides an example of how to integrate the selection criteria, LOS, into the evaluation procedure. Scores were assigned according to the following procedure: LOS A = score 1, LOS B = score 2, LOS C = score 3, LOS D = score 4, and LOS E/F = score 5.

Assignment of a score for "Benefits" considered both the types of available benefits and the total number of potential beneficiaries (quantified by traffic volume). The score for "Existing ITS Infrastructure" was assigned based on existing detector and signal types. For video and loop detectors, each arterial received a score of 0 (no cameras or loops), 1 (less than 40% detection coverage, which is the share of intersections equipped with loops or cameras), or 2 (more than 40% detection coverage). Roads with coordinated or semi-actuated signal control were assigned an additional point. Finally, a "Potential Expansibility" score was assigned based on connectivity to freeways and other arterials. Details for each criteria and the final value assigned to the arterials are provided in Table 8.2.

Table 8.2: Comparisons of the Candidate Arterials Classified by the Selection Criteria

Arterial Roadway	Arterial traffic and geometric characteristics			Current LOS		Benefits	Existing ITS Infrastructure	Potential expansibility		Total Score
	Description	AADT	Lanes	Av. Speed	LOS			Freeway Connections	Arterial Connections	
Airport Blvd.	Major arterial connecting N Lamar Blvd. and US 183. N-S route east of Central Austin.	23550 to 31190 (Av. Section = 27228)	2 NB, 2 SB	20 to 25 mph	C	Improved operational efficiency, improved safety	Video-based detection systems deployed on major intersections. Semi-actuated control strategies implemented to coordinate signal control.	IH-35, US 290, US 183	N Lamar Blvd., E Koenig Ln., MLK Blvd.	
Score (1-5)				4	3	4	3		5	19
Anderson Ln.	Major arterial connecting Loop 1 and U.S. 290. Parallels and partially overlaps US 183. Alternative E-W route in North Austin.	23600 to 27250 (Av. Section = 24800)	2 EB, 2 WB	20 to 25 mph	C	Improved operational efficiency, improved safety	Video-based and loop-based detection systems deployed on several major intersections. Majority of signal control strategies fixed time control.	IH-35, Loop 1, US 290, US 183	N Lamar Blvd., Burnet Rd., Cameron Rd.	
Score (1-5)				4	3	4	2		5	18

Braker Ln.	Major arterial connecting Loop 1 and IH-35. Parallels US 183. Alternative E-W route in North Austin.	26640 to 37180 (Av. Section = 33280)	3 EB, 3 WB	25 to 30 mph	B	Improved operational efficiency, improved safety	Video-based and loop-based detection systems deployed on major intersections. Semi-actuated control strategies implemented to coordinate signal control.	IH-35, Loop 1	N Lamar Blvd., Burnet Rd., Dessau Rd.	
Score (1-5)				4	2	3	3		4	**16**
Burnet Rd.	Major arterial connecting Loop 1 and W 45th street. Parallels Loop 1. N-S route in North/Central Austin.	19140 to 40540 (Av. Section = 29260)	2 NB, 2 SB	15 to 20 mph	D	Improved operational efficiency, improved safety	Video-based and loop-based detection systems are deployed on major intersections. Semi-actuated control strategies implemented to coordinate signal control.	Loop 1, US 183	Braker Ln., Anderson Ln., Koenig Ln., 45th St.	
Score (1-5)				4	4	4	4		4	**20**
Congress Ave.	Major arterial in Central/South Austin. N-S route through downtown.	9160 to 27440 (Av. Section = 15880)	3 NB, 3 SB (Downtown)	15 to 20 mph	D	Improved operational efficiency, improved safety	Video-based and loop-based detection systems deployed on major intersections. Semi-actuated control strategies implemented to coordinate signal control.		MLK Blvd., 15th St., and Cesar Chaves St.	
Score (1-5)				3	4	4	3		3	**17**

	Local arterial connecting E 56th St. to San Jacinto Blvd. N-S route terminating at UT-Austin.	5610 to 13410 (Av. Section = 8502)	1 NB, 1 SB	20 to 25 mph	C	Improved operational efficiency, improved safety	No detection systems deployed. The majority of signal control strategies fixed time control.		38th St., 45th St., 51st St.	
Duval St.										
Score (1-5)			2	3		2	0		2	9
Guadalupe St.	Major arterial connecting N Lamar Blvd. to W Cesar Chaves St. Parallels Loop 1 and IH-35. Alternative N-S route in North/Central Austin (S only south of MLK Blvd.).	N-S: 17350 to 31730 (Av. Section = 23700), S Only: 8690 to 16060 (Av. Section = 12270)	2-3 NB, 2-3 SB (varies by location)	15 to 20 mph	D	Improved operational efficiency, improved safety, improved routing decisions	Video-based and loop-based detection systems deployed on major intersections. Semi-actuated control strategies implemented to coordinate signal control.		N Lamar Blvd., 45th St., 38th St. , MLK Blvd., 15th St., Cesar Chaves St.	
Score (1-5)			5	4		4	3		4	20
N Lamar Blvd.	Major arterial connecting IH-35 in North Austin to W Cesar Chaves St. downtown. Parallels IH-35. Primary N-S route in North/Central/South Austin.	11920 to 34040 (Av. Section = 22360)	2-3 NB, 2-3 SB (varies by location)	15 to 20 mph	D	Improved operational efficiency, improved safety, improved routing decisions	Video-based and loop-based detection systems deployed on major intersections. Semi-actuated control strategies implemented to coordinate signal control.	IH-35, US 183	Braker Ln., Parmer Ln., Rundberg Ln., Anderson Ln., Koenig Ln., 51st St., Guadalupe St., 45th St., 38th St. , MLK Blvd., 15th St., Cesar Chaves St.	
Score (1-5)			5	4		4	3		5	21

As the table above demonstrates, the arterials exhibiting the highest criteria score for arterial ITS implementation were N. Lamar Blvd., Guadalupe St., and Burnet Rd. As a result, these arterials were chosen for ITS implementation and simulation.

8.3 Critical ITS Technologies and Their Applications

In this case study, representative ITS technologies were used and integrated to improve arterial management. A comprehensive review of technologies was completed in Chapter 4 and 5. Five primary categories of recommended technologies for arterial ITS implementation were identified. These include:

1) Traffic Detection Systems (e.g. Loop Detectors, Video, Radar)

2) Traffic Control (e.g. Advanced Signal Control, Adaptive Signal Control, Transit Signal Priority, Emergency Vehicle Preemption, and Variable Speed Limits)

3) Lane Management/Pricing

4) Information Dissemination, (e.g. DMS, Highway Advisory Radio)

5) Speed Enforcement and Stop/Yield Enforcement

The proposed case study focuses on three of these technology groups: traffic detection, traffic control, and information dissemination. Determining elasticity of demand for arterial lane pricing would require comprehensive data collection through user preference surveys. Similarly, examination of improvements in speed and stop/yield enforcement would require additional data. Without additional data, improvements due to implementation of these technology types could not be quantified using the simulation model; as a result, these technologies were excluded from this analysis. The case study examines an integrated technology system that uses 1) traffic detection systems for monitoring traffic condition changes and detecting congestion; 2) dynamic vehicle routing strategies for optimizing vehicle routing based on real-time traffic data analysis; 3) traffic information dissemination systems for broadcasting traveler information; and 4) arterial signal control coordination strategies for adaptively optimizing signal timing to respond to non-recurrent traffic congestion in a timely manner.

8.4 Simulation Model Development and Configuration

Based on the design principles proposed in Section 2, a simulation model has been developed to measure the impacts of technology implementation. In this study, VISSIM will be used to simulate arterial management system operations. A detailed overview of the VISSIM model was provided in Chapter 7.

8.4.1 Model Description

Figure 8.1 illustrates the overview of the simulated arterial roadway network in VISSIM. As discussed in section 2, the simulation model focuses on several major arterials including N. Lamar Blvd, Burnet Rd., and Guadalupe St., and the freeway section of Loop 1 from the U.S. Highway 183 interchange to W. Cesar Chavez St. in the Austin downtown area. Figure 8.2 shows a snapshot of the simulated intersection of W. Anderson Ln. and Burnet Rd. The simulation model was configured by following the practical geographic characteristics, traffic demands, signal timing plans, traffic compositions, etc. Virtual loop detectors were applied at

signalized intersections and deployed on the freeway section as their practical deployments. The 10 major signalized intersections along the arterials were simulated using VAP-based controllers. The semi-actuated control plans were also implemented to coordinate traffic control operations along the arterials.
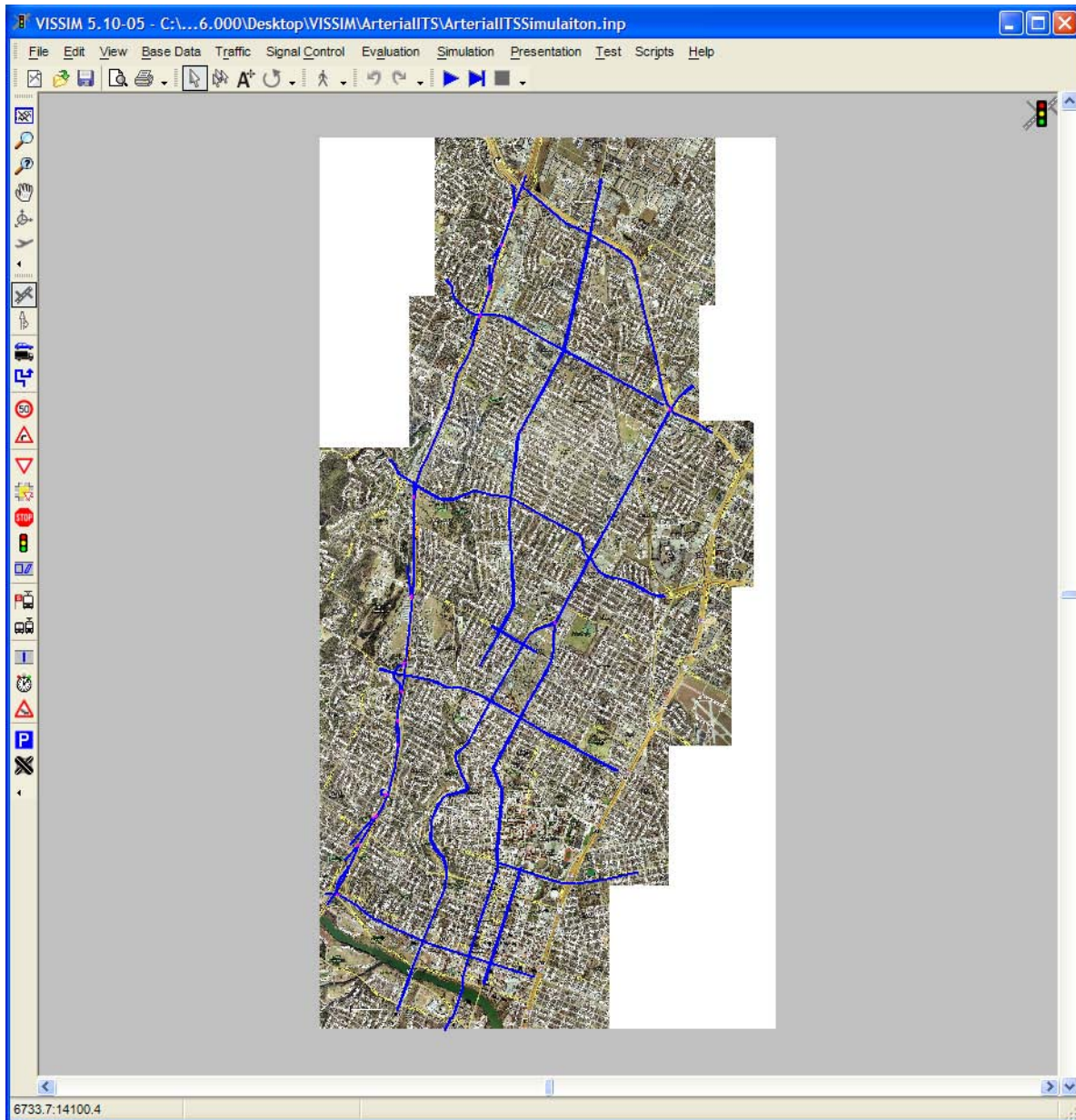
Figure 8.1: The Simulation Network Overview of Identified Arterial Roadways
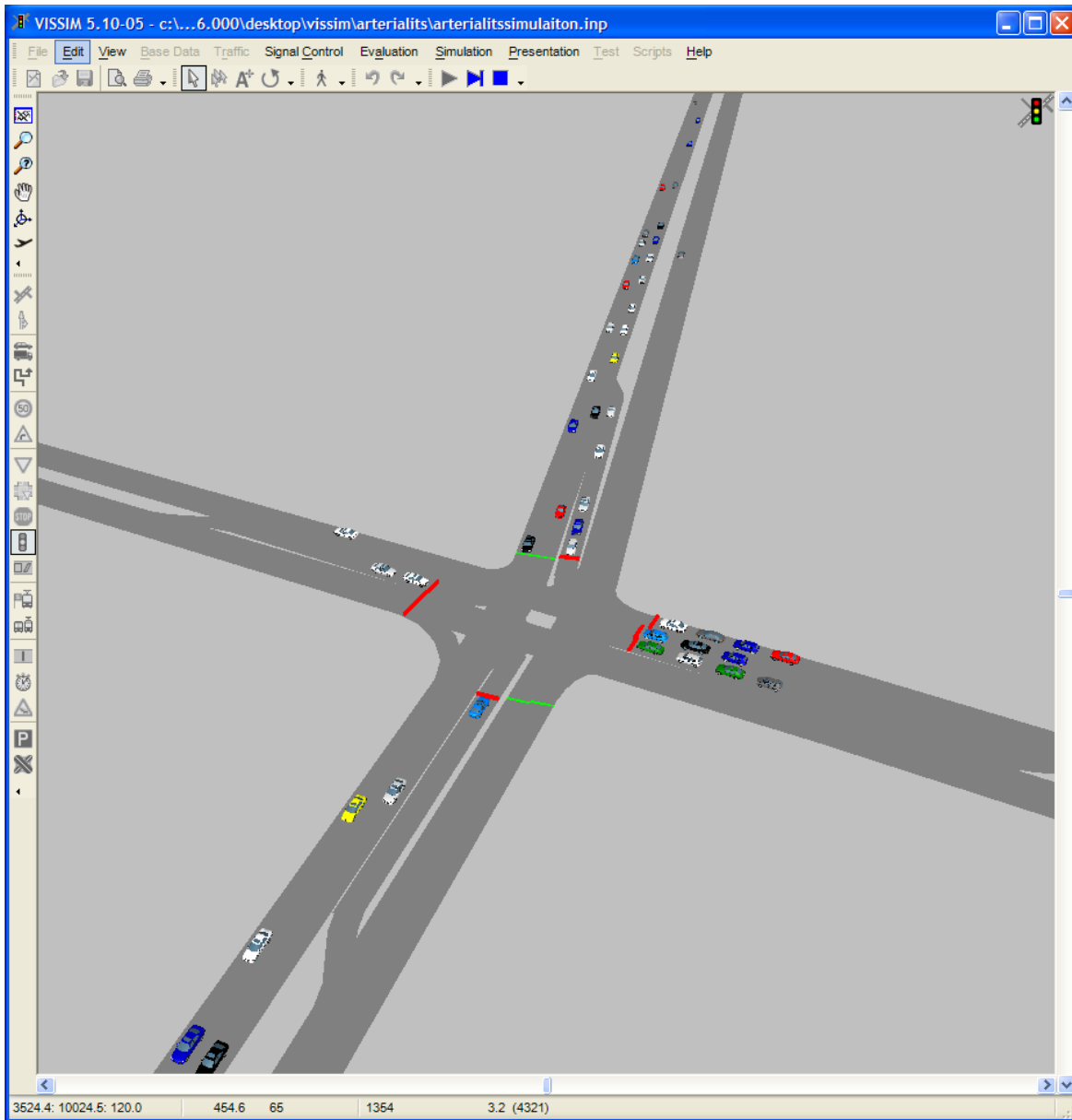
Figure 8.2: A Snapshot of the Simulated Intersection of W Anderson Ln. and Burnet Rd.

Previous work completed at the University of Texas for the Austin District IAC - Task: System-Level Analysis of Austin Arterials, sponsored by the Austin District of TxDOT, sets up a solid foundation for the simulation model development and calibration in this study. This Austin IAC project, led by Dr. Travis Waller, aims at conducting a system-wide study of Austin's arterials by employing advanced traffic modeling techniques based on the traffic simulation tool, VISTA. The entire Austin traffic network was simulated and well calibrated using the Dynamic Traffic Assignment (DTA) –based traffic modeling and simulation framework. These previous research efforts greatly facilitated simulation model development and calibration for this study. In addition to the VISTA outputs, the practical 15-min aggregated loop detector data on freeways and directional traffic volume data at signalized intersection along the arterials from 2007 were used to further calibrate and validate the simulation model. Based on the comparisons of traffic

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volumes and speeds between simulation outputs and ground-truth detector data, the model was found to be well calibrated and able to provide a realistic representation of simulated scenarios and achieve reliable simulation results.

8.5 Test Scenario Design

In order to demonstrate the potential impacts of arterial ITS technology implementation on arterial and freeway traffic operations, two test incidents will be simulated. Both incidents are non-recurrent incidents (traffic accidents) that occur at 8:00 AM on a Monday. On weekdays, the morning peak during which recurrent congestion occurs in Central Austin generally lasts from 7:30 AM to 9:30 AM; this two hour period is defined as the simulation period. In both scenarios, the simulation study will focus on southbound operations. Figure 8.3 demonstrates the locations of the traffic incidents, as well as the locations of the DMS that will be used for information dissemination.
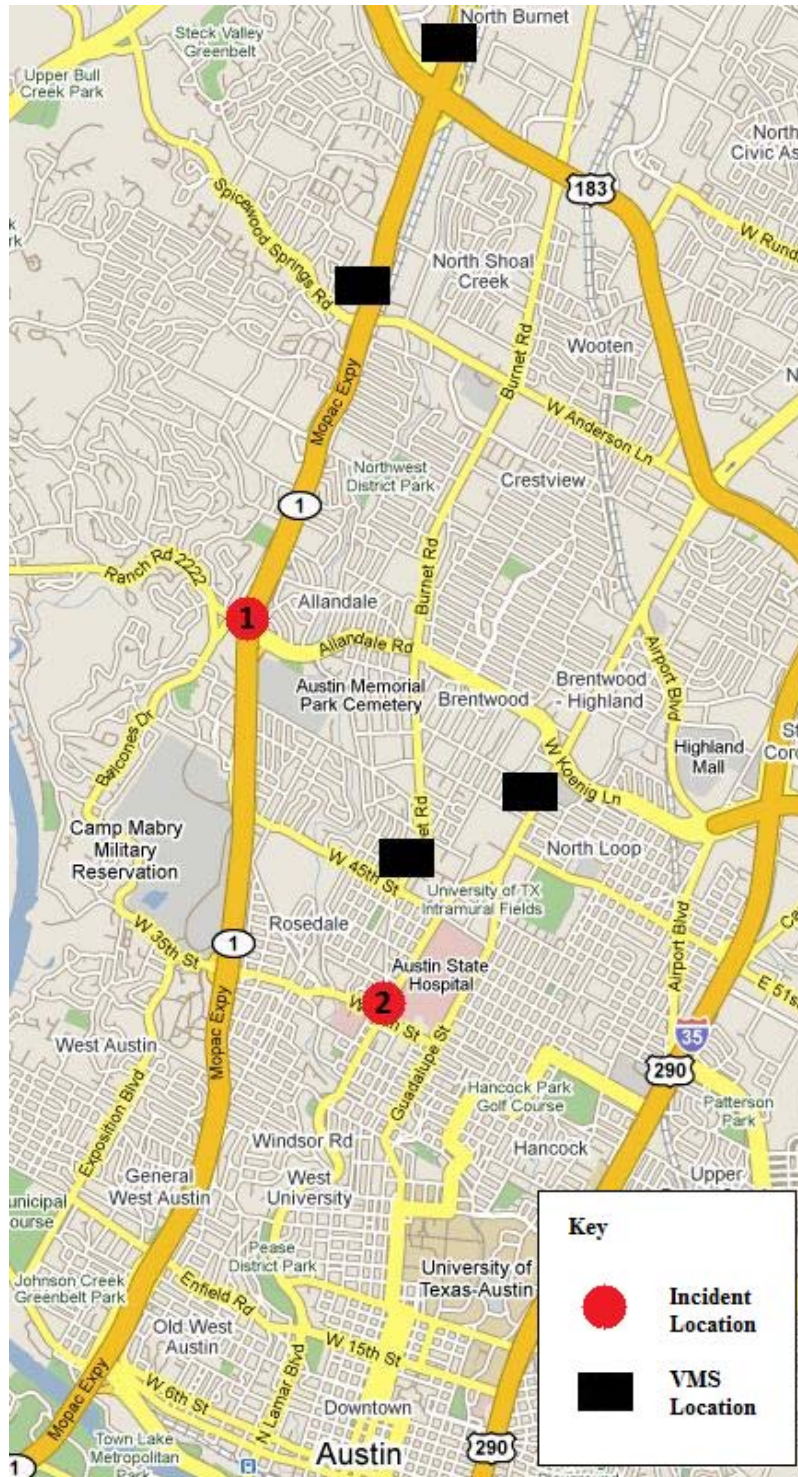
Figure 8.3: Test Scenario Locations

In incident one, an accident occurs in the southbound left lane of Loop 1 (the Mopac Expressway), a four-lane freeway, near the exit for Ranch Road 2222. This incident results in blocking of the left-most lane for a period of one hour. Closure of this lane results in a significant loss of roadway capacity and a highly congested traffic situation. In incident two, an accident

occurs in the southbound left lane of Lamar Blvd. at the intersection of 38th St. and Lamar Blvd. This incident also results in blocking of the left-through lane and increased congestion. The lane remains blocked for 30 minutes. As discussed previously, four categories of ITS technologies are used to effectively address these traffic congestion problems. First, an incident is detected using traffic condition monitoring technologies. Traffic sensors such as dual-loop detectors or surveillance cameras can be used to monitor traffic condition changes, and detect congestion and verify the incident location quickly. Once an incident has been detected, traffic signal plans can be coordinated to respond to the incident. Next, dynamic vehicle routing optimization can be employed to determine where vehicles should be routed to avoid the incident. A traffic data analysis system can be used to calculate available capabilities and optimize vehicle routing based real-time network-wide traffic conditions. Finally, traffic information dissemination systems can be used to provide guidance to travelers. Using DMS or traffic advisory radio systems, traffic congestion information and suggested alternative routes can be broadcast to travelers.

In order to evaluate the effectiveness of each class of technologies, 12 technology scenarios have been designed. Scenarios one through six will address test incident one, the accident on Loop 1, and scenarios seven through twelve will examine test incident two, the incident on Lamar Blvd. Scenarios will examine traffic impacts if 1) incidents are detected or undetected; 2) signal timings are optimized in response to the incident; and 3) information is disseminated to drivers by DMS or by radio. Table 8.3 describes the incidents and technologies examined in each scenario.

Table 8.3: Test Technology Scenarios

Scenario	Incident Location		Technology Systems			
	Loop 1	38th St. & Lamar Blvd.	Detection	Signal Control Coordination	Information Dissemination	
					Radio	DMS
1	X					
2	X		X		X	
3	X		X			X
4	X		X	X		
5	X		X	X	X	
6	X		X	X		X
7		X				
8		X	X		X	
9		X	X			X
10		X	X	X		
11		X	X	X	X	
12		X	X	X		X

In scenarios one and seven, no technologies are employed; the incidents are not detected, signals are not adjusted, and no information is provided to travelers. In scenarios two, three, eight, and nine, the incidents are detected, but no change in signalization is made. Information on the accident location and suggested route alternatives are provided to travelers. In scenarios two and eight, this information is provided by radio. In scenarios three and nine, information is disseminated using a system of four DMS. These DMS are located on southbound Loop 1

upstream of the exits for Anderson Lane and US 183, on southbound Lamar Blvd. before the intersection of North Loop and Lamar Blvd., and on southbound Burnett Rd. just before the intersection of Burnett Rd. and 45th St. These locations are shown in Figure 8.3.

In scenarios four and 10, a coordinated signal plan is employed to respond to the incident, but no information is provided to travelers. In scenarios five and 11, the coordinated signal plan is employed, and incident information is provided to travelers by radio. In scenarios six and 12, the coordinated signal plan is employed, and incident information is provided to travelers by DMS.

8.6 Simulation Experimental Tests

Simulation experiments have been conducted to evaluate the benefits of the ITS applications. A VISSIM model was developed to simulate the morning peak traffic on Loop 1, a major north-south freeway, and three parallel arterials, Burnet Rd., Lamar Blvd., and Guadalupe Street. Details of this model were provided in the previous technical memorandum. For each incident, three types of technologies have been simulated: detection, coordinated signalization, and information dissemination. Since different information dissemination technologies will lead to varying response rates, four different response rates were examined for information provided by DMS and by radio. According to the Austin Commuter Survey completed in 2005, approximately 88 percent of travelers will change their travel route to avoid an accident (Walton et. al, 2006). Since a dynamic message sign (DMS) provides information to all travelers on a road, a maximum response rate of 88 percent was tested. The Austin Commuter Survey also found that approximately 50 percent of drivers receive travel information from the radio during morning peak hours. In order to simulate an 88 percent route change by only those travelers receiving information from the radio, a 44 percent response rate was tested. However, the 88 percent route change estimated in the Austin Commuter Survey is very high, particularly for vehicles that would be required to exit the freeway. As a result, lower response rates of 60 and 30 percent were also examined for each incident. Initial traffic conditions were estimated using field data and simulation results from the VISTA model developed by Dr. S. Travis Waller at The University of Texas. In each simulation, three performance measures, space-mean speed, control delay, and travel time were evaluated for vehicles traveling on both the freeway and arterials. Complete results for each scenario and performance measure are provided in Appendix D.

8.6.1 Initial Traffic Conditions

Before the incidents were simulated, the network was evaluated to determine traffic conditions under ordinary circumstances. Estimated performance measures for this "No Incident" scenario are provided in Table D-1. Clearly, even under normal operating conditions, both Loop 1 and the arterials are already experiencing delay. The average vehicle speed on the freeway is only 30 miles per hour, and vehicles experience an average of 343 seconds of control delay. Levels of service (LOS) on the arterials can be estimated as a function of travel speed using methods described in the Highway Capacity Manual (2000). In this scenario, Burnet Rd. and Guadalupe St. are operating at about a LOS D, and Lamar Blvd. is operating at LOS D/E.

8.6.2 Incident 1

In incident one, an accident occurs in the southbound left lane of Loop 1 near the Ranch Road 2222 exit. This incident occurs during the morning peak, at 8:00 AM, and results in closure

of the left lane for one hour. In some test scenarios, traffic is diverted to the arterial network from the freeway using two exits, US 183 and Anderson Lane. The rates of diversion at each location to each arterial are provided in Table 8-4.

Table 8.4: Assumed Rates of Traffic Diversion, Scenarios One to Six

| Scenario | Percent of Loop 1 Traffic Diverting | | | | | | Total |
| | At Loop 1 @ US 183 | | | At Loop 1@ Anderson Lane | | | |
	Total	To Lamar	To Burnet	Total	To Lamar	To Burnet	
2A, 5A	22	15	7	22	7	15	44
2B, 5B	44	29	15	44	15	29	88
3A, 6A	15	10	5	15	5	10	30
3B, 6B	30	20	10	30	10	20	60

Simulation Results

Complete performance measure results for incident 1 are provided in Table D-3. Figure 8.4 shows average speed (space-mean speed) for vehicles traveling on Loop 1 and on the arterials under each technology scenario and response rate. In scenario 1, in which no technologies are employed to detect or respond to the incident, control delay on Loop 1 is close to nine minutes, and the average speed is about 23 mph, a drop of nearly 7 miles per hour from the "No Incident" Scenario. Since no traffic from the freeway is diverted to the arterial network in this scenario, arterial speeds and delays are not impacted by the incident.

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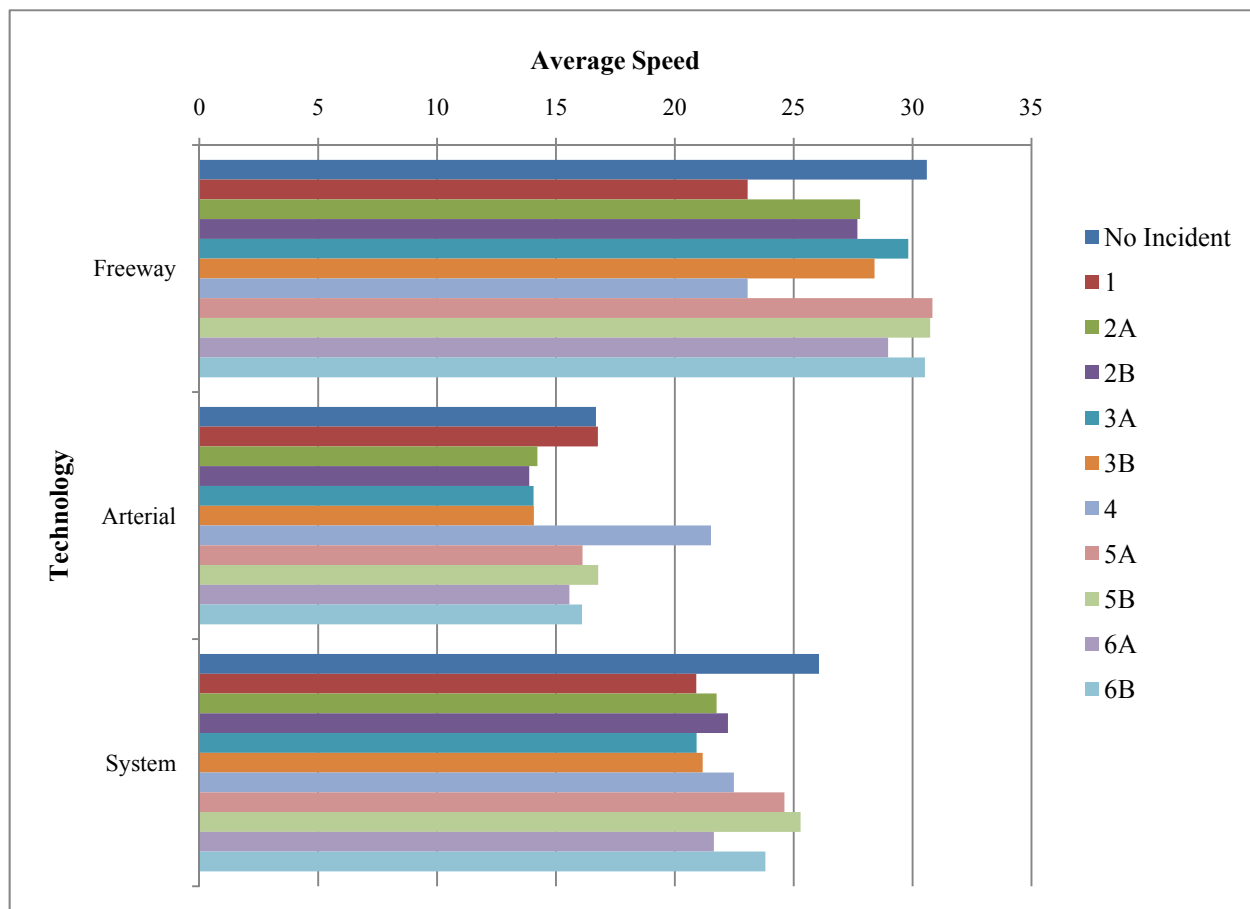
Figure 8.4: Incident 1 Technology Scenario Space-Mean Speeds
(D = Detection, S = Coordinated Signalization, ID = Information Dissemination)

If the incident is detected, and information disseminated to drivers, either by radio or DMS, freeway delays can be decreased considerably by diverting traffic to the arterial network. As can be seen in Figure 8.5, when signals are not changed and the rate of diverting vehicles increases, so does the average speed on the freeway. However, although freeway traffic improves significantly, diversion without changes in signalization result in major delays and speed decreases on the arterial network. Figure 8.5 provides the LOS estimates for each arterial under each technology scenario. In scenario 2B, it is clear that even at the lowest response rate, 30 percent, the traffic diverted from the freeway to the arterials will create gridlock. This diversion results in LOS F on both Burnet Rd. and Lamar Blvd.

Table 8.5: Incident 1 Technology Scenario Arterial LOS

Scenario	Response Rate (%)	Burnet Rd.	Lamar Blvd.	Guadalupe St.
No Incident	-	D	D/E	D
1	-	D	D/E	D
2A	44	F	F	D
2B	30	F	F	D
3A	88	F	F	D
3B	60	F	F	D
4	-	B/C	C/D	C/D
5A	44	F	D/E	C/D
5B	30	E	D/E	C/D
6A	88	F	E	C/D
6B	60	F	E	C/D

These gridlocked conditions reveal a micro-simulation modeling limitation. In extremely saturated or over-saturated conditions, the estimated speed, delay, and travel time variables are no longer random, but become a function of the length of time simulated in the model. For example, in scenario 2, the average speed estimated on Burnet Rd. decreases when less traffic is diverted from the freeway. The estimated speed for 30 percent diversion is .8 mph lower than that estimated for 44 percent diversion. This result is counterintuitive, as we would expect lower speeds and higher delays when adding traffic to the arterial. Because the model estimates speed, delay, and travel time only for the vehicles that both enter and exit the system during the analysis period, the values estimated do not consider vehicles still in the network at the end of the simulation period. When conditions are highly saturated, the model is not stable, and those vehicles experiencing higher delays toward the end of the simulation period are not considered in variable estimation. As a result, the performance measures estimated should not be employed to directly compare different gridlocked conditions.

However, when signals are coordinated to provide additional green-time to southbound traffic on the arterials, this gridlock can be alleviated, and system-wide benefits can be both achieved and measured. In Figure 8.4, it is clear that signal coordination to increase the north-south capacity on the arterials immediately reduces delay on the arterial network. Comparing the LOS for scenarios 2B and 5B, in which the same volumes are redirected to the arterials, we can see that signal coordination improves the LOS on each arterial (Table 8.5). However, if too many cars are diverted from the freeway, the available capacity on the arterials will be insufficient to handle the new demand. Figure 8.4 demonstrates that the system-wide average vehicle speed is maximized when 44 percent of freeway traffic diverts from the freeway. Examining the average speeds for Loop 1 and the arterials, we can see that for higher response rates, system-wide performance deteriorates, with both the freeway and the arterials demonstrating slower speeds and higher delays. In scenario 6, in which a DMS is deployed, response rates of 60 and 88 percent are examined. When additional green-time is allotted to north-south traffic, delay for east-west travelers will increase. In these scenarios, in addition to delays resulting from the limited capacity of the southbound arterial lanes, queuing of eastbound traffic on Anderson Lane extends to the freeway, resulting in slower freeway speeds despite higher diversion rates.

Observations

Simulation of incident 1 reveals a number of observations that should be considered in implementation of arterial ITS in responding to a freeway incident:

- Freeway conditions can be improved by diverting traffic from an incident to the arterial network.

- Coordinated signalization to adjust to growth in directional traffic flows is essential to maintain arterial performance when additional volumes are added.

- Diversions from the freeway can be counterproductive in improving system performance if the traffic diverted from the freeway exceeds the available capacity of the arterial network. In this case study scenario, response rates estimated for the DMS led to over-saturation of the arterial network, resulting in additional delays on both the arterials and the freeway.

8.6.3 Incident 2

In incident 2, an accident occurs in the left lane of Lamar Blvd. just before its intersection with 38th St. This incident also occurs at 8:00 AM, resulting in lane closure for 30 minutes. In some test scenarios, upstream traffic heading to Lamar Blvd. is diverted to Guadalupe St., a parallel arterial, at the locations of the two arterial DMS. The locations, traffic splits, and rates of diversion for each scenario are provided in Table 8.6.

Table 8.6: Assumed Split of Upstream Southbound Traffic and Rates of Traffic Diversion, Scenarios 7 to 12

Scenario	Condition	At Burnet Rd. and 45th St.			At Lamar Blvd. and 51st St.	
		To Burnet	To Lamar	To Guadalupe	To Lamar	To Guadalupe
8A,11A	Initial Share	70	15	15	50	50
	Percent of Traffic Diverting	0	44	0	44	0
	Share After Diversion	70	8.4	21.6	28.0	72.0
8B,11B	Initial Share	70	15	15	50	50
	Percent of Traffic Diverting	0	30	0	30	0
	Share After Diversion	70	10.5	19.5	35.0	65.0
9A,12A	Initial Share	70	15	15	50	50
	Percent of Traffic Diverting	0	88	0	88	0
	Share After Diversion	70.0	2.8	27.2	6.0	94.0
9B,12B	Initial Share	70	15	15	50	50
	Percent of Traffic Diverting	0	60	0	60	0
	Share After Diversion	70	6.0	24.0	20.0	80.0

Simulation Results

Since this incident occurs on Lamar Blvd., the incident has an immediate impact on arterial traffic conditions, regardless of ITS implementation. Table 8.7 shows the arterial LOS resulting from the incident for each technology scenario. In scenario 7, no technologies are employed, and the lane closure on Lamar Blvd. results in a LOS F for that facility.

Table 8.7: Incident 2 Technology Scenario Arterial LOS

Scenario	Response Rate	Burnet Rd.	Lamar Blvd.	Guadalupe St.
No Incident	-	D	D/E	D
7	-	D	F	D
8A	44.0	C/D	E	D
8B	30.0	C/D	E	D
9A	88.0	C	D/E	D/E
9B	60.0	C	D/E	D
10	-	B/C	D	C/D
11A	44.0	B/C	B/C	C/D
11B	30.0	B/C	B/C	C/D
12A	88.0	B/C	B/C	C/D
12B	60.0	B/C	B/C	C/D

Scenarios 8 and 9 demonstrate the system improvements that can be achieved when an incident is detected and traffic is diverted from Lamar Blvd. via radio or DMS, with no change in signalization. As Figure 8.5 demonstrates, speed improvements are realized on both Lamar Blvd. and Burnet Rd. when traffic is diverted upstream of the accident location to open capacity on Guadalupe St. With no signal changes, as diversion increases, the speed on Lamar also increases, while the speed on Guadalupe St. decreases. Overall, the arterial and system speeds continue to improve up to the maximum tested 88 percent response rate.
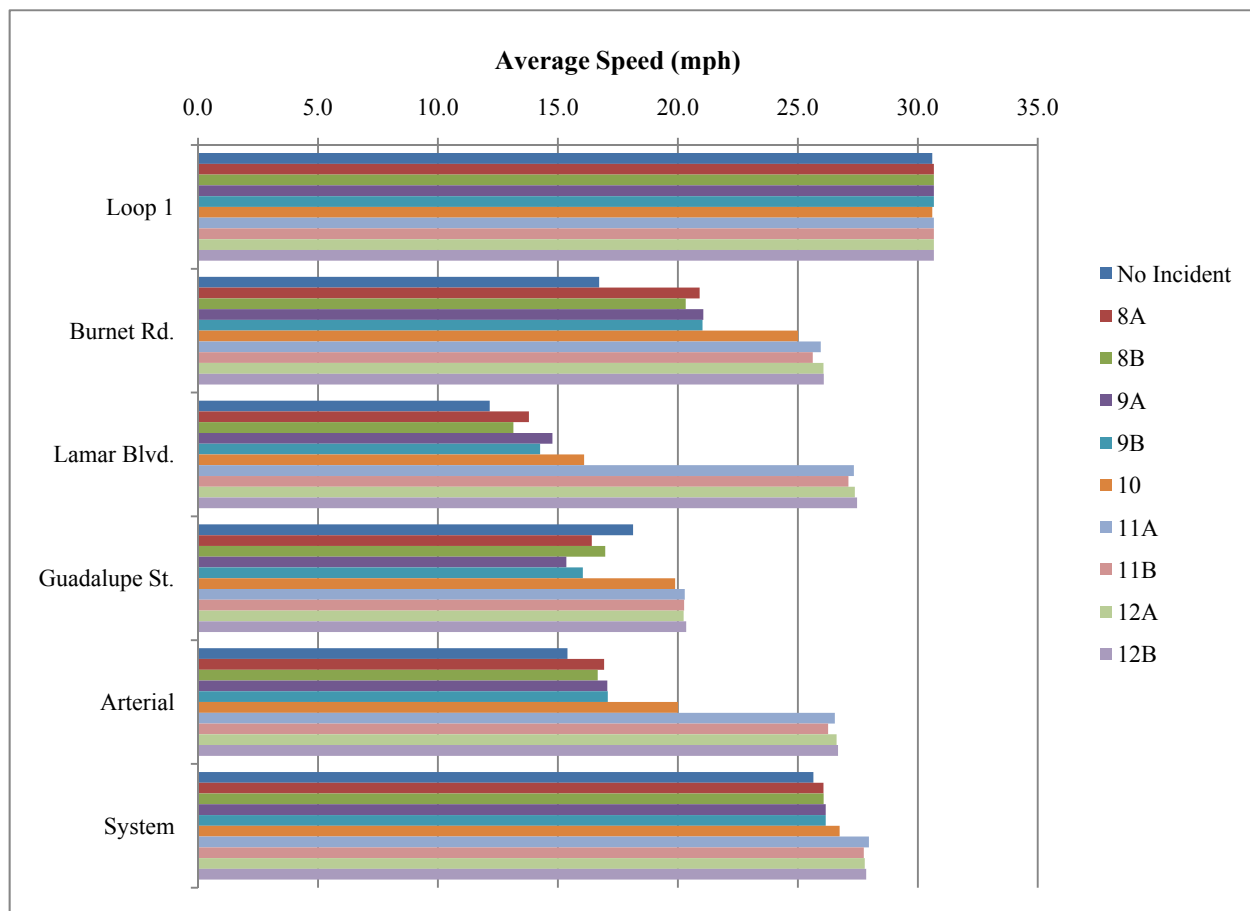
Figure 8.5: Incident 2 Technology Scenario Space-Mean Speeds
(D = Detection, S = Coordinated Signalization, ID = Information Dissemination)

In scenarios 10, 11, and 12, coordinated signalization is employed to provide additional north-south capacity. As scenario 10 demonstrates, even without the use of technologies for information dissemination and traffic diversion, the use of coordinated signalization achieves LOS improvements on all arterials (Table 8.7), and increases the average arterial speed to 20 mph. Use of all three technology systems—detection, coordinated signalization, and information dissemination—achieves even greater gains, with LOS improving to B/C on Burnet Rd. and Lamar Blvd., and C/D on Guadalupe St., and average speeds increasing to 26 to 27 mph.

Just as in incident 1, different response rates to diversion information produce different traffic impacts. However, because lower volumes are being diverted from Lamar Blvd. than were diverted from the freeway in incident 1, the traffic impacts of increased diversion rates are much smaller. As can be seen in the figures above, overall arterial speeds and delays change very little with changes in diversion rates, as improvements in speed and delay realized on Lamar Blvd. and Burnet Rd. are counteracted by degradations on Guadalupe St. Noticeable speed and delay improvements can be observed at the lowest diversion rate, 30 percent. The maximum speed improvement is achieved when 44 percent of cars divert from Lamar Blvd. However, the net differences in speed and delay achieved with this higher diversion rate are relatively small. Some very minor degradations in speed and delay occur at higher rates of diversion; however, these are also relatively small.

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Observations

Simulation of incident 2 also reveals a number of observations that should be considered in implementation of arterial ITS in responding to an arterial incident:

- If signals are not coordinated, higher rates of diversion from the incident lead to more traffic improvements, until the capacity of the parallel arterial is reached. In this model, when signals are not coordinated, the capacity of Guadalupe St., is not overwhelmed by the diverted traffic, even at the maximum rate of diversion, so no degradation is observed.

- Just as in responding to a freeway incident, coordinated signalization to adjust to growth in directional traffic flows is essential to maintain high-quality arterial performance when additional volumes are added.

- With lower volumes being redirected, and improvements on one arterial balancing degradations on a parallel route, performance measures are much less sensitive to rates of diversion when an incident occurs on the arterial network with coordinated signal timing. In the case study, noticeable traffic improvement is achieved with a 30 percent diversion rate, but relative changes for higher rates of diversion are small.

8.7 Summary and Recommendations

In general, this simulation model demonstrates that the use of a coordinated technology system to detect an incident on a freeway or arterial, coordinate arterial signals in response to an incident, and disseminate information to system users can provide network-wide traffic benefits. Use of systems that combine all three of these technologies can realize considerable time savings for travelers using both Loop 1 and its parallel arterials. However, the model also demonstrates that some components of the technology system may actually introduce new concerns while resolving initial problems.

Detection technologies are necessary to recognize an incident and deploy coordinated signalization and/or information dissemination. As a result, detection technologies are a key component to successful deployment of any arterial ITS technology system. No negative traffic impacts result from deployment of detection systems in this simulation.

Coordinated signalization also plays an important role in responding to a traffic incident, whether on an arterial or freeway. If significant volumes of traffic are redirected, signals on the new route must be adjusted to provide green time and additional capacity to the new traffic. However, in introducing new signal timings, impacts on cross-street traffic must be carefully considered. As was observed in the incident 1 simulation, if inadequate capacity is provided to some directional traffic, system-wide degradation may occur.

Information dissemination technologies are much more difficult to model. In this study, four different response rates were tested, two corresponding to assumed rates of response for users receiving information from the radio and two corresponding to assumed rates of response for users receiving information via DMS. Response rates for the DMS were estimated from the results of a survey of Austin commuters. Results of the simulations performed in this study indicate that there is no benefit to use of DMS systems during the morning peak on Austin's highly congested downtown network. In incident 1, rates of information response assumed for the DMS caused a large volume of traffic to exit the freeway, overwhelming the already

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congested arterial network. In incident 2, although changes were very minor, additional response due to use of the DMS caused slight decreases in speed and increases in delay.

Particularly for incident 1, traffic impacts are very sensitive to the assumed rates of response to traffic information. In considering deployment of advanced technologies, such as a DMS, on both the freeway and arterial networks, potential rates of response to different types of information should be carefully studied. Even when a DMS is used, it is likely that response rates to different messages will be highly variable. Detailed surveying of users of individual facilities where different technologies might be deployed would allow for more accurate estimation of response rates to different types of information. If DMS systems are going to be deployed on the arterial network, particularly during peak hours, they should be located in areas where realistic alternative routes exist. Specifically, the DMS should be located so that traffic can be easily redirected to an alternative route that under normal operating conditions has some available capacity to accommodate additional traffic volumes.

Chapter 9. Conclusions and Recommendations

9.1 Conclusions

Recent ITS technology developments have vastly improved the ability of TxDOT to monitor and manage its arterial systems. Research on arterial performance measures is of practical importance to develop optimal traffic management strategies and improve operational efficiency on urban arterial roadways. Under such a background, this study is initiated by TxDOT in September 2007 and completed by the CTR team in August 2009. The research addresses two TxDOT goals: making the current transportation system more efficient through innovative arterial ITS deployments, and maximizing the benefits of existing ITS infrastructure and new arterial ITS deployments. Specifically, six research questions have been addressed:

- What ITS strategies would be most beneficial to improve arterial management?

- What are the desired ITS technologies & solutions to improve arterial management?

- How to identify and prioritize arterials suitable for ITS deployments?

- What are the practical performance measures?

- What are the desirable traveler information and dissemination modes?

- What are the technical and financial considerations for arterial ITS deployment?

There are three main emphasis areas that this research has addressed: 1) identify the elements of arterial management systems that would benefit most from ITS technologies and related real-time information; 2) identify the available ITS technologies that would have the most immediate impact on arterial management systems; and 3) identify performance measures and traveler information dissemination modes that most clearly provide arterial performance information to the traveling public. The first area of emphasis addressed the elements of arterial management systems in terms of the potential benefits derived from real-time arterial traffic information. The elements included arterial surveillance of operations and infrastructure, traffic control (providing for transit priority, emergency vehicle preemption, adaptive signal control, etc.), lane management (HOV facilities, reversible flow lanes, emergency evacuation, etc.), parking management elements, enforcement (speeding, red-light running, failure to stop/yield), integration with transit information systems, incident management, and traveler information. The second area of emphasis addressed the ITS technologies available for arterial management in terms of their ability to provide the information needed for one or more elements of an arterial management system. The third area of emphasis addressed best-practice arterial performance measures, methods for quantifying these measures, and modes of disseminating this information to TxDOT staff, other agencies, and travelers. To accomplish the project in a comprehensive manner, the research team completed the following research tasks in a two-year schedule:

- Synthesize national and international experience in Arterial Intelligent Transportation Systems

- Define arterial performance measures and identify innovative strategies and technologies to improve arterial performance measurement

- Identify the most beneficial ITS elements for arterial management

- Identify desirable ITS technologies and solutions for arterial management

- Evaluate traveler information dissemination modes for arterial management

- Develop a guideline to identify and prioritize arterials suitable for ITS implementations

- A case study to demonstrate how to develop arterial ITS applications

Through the literature review, it was found that arterial ITS applications have the potential to reduce travel time, increase travel time reliability, increase vehicle throughput in the transportation network, and reduce fuel and environmental cost. These benefits are achieved because ITS deployments such as signal optimization and traveler information system can improve traffic operations on arterials and change driver behavior, especially route choice. As reported in different studies and in different regions, adaptive signal control systems deployed in five metropolitan areas have reduced delay 19 to 44 percent. It was also found in several studies that combining ITS technologies can result in better performance of the network system. With the rapid development of technologies, arterial ITS components are becoming more affordable and widely available. As a result, the ability of TxDOT to monitor and manage its arterial systems is technically feasible.

The findings of the critical arterial performance measure studies indicate that different agencies such as MPOs, TxDOT Districts, and RMAs in Texas had different arterial performance measures. It is important to define practical arterial performance measures and find methods to quantify these measures. In this study, eighteen different arterial performance measures were included. The top arterial performance measures were evaluated for the frequency of response in the revealed preference, stated preference, and combined preference surveys. Six arterial performance measures stood out for receiving the most positive feedback as effective tools characterize to arterial roadways, including Arterial Vehicle Miles Traveled, Level of Service, Speed/Travel Rate, Travel Time, the Volume/Capacity Ratio, and Volume. The results also indicate the top five stated preference arterial performance measures include Duration of Congestion, Total Delay, Travel Time, and in a tie for fourth, Percent of System Congested, Density, and the Roadway Congestion Index. As allocation of funding becomes more dependent on the performance of a roadway network, transportation agencies may look to these measures for evaluation of their arterial roadways.

The investigations of the most beneficial ITS elements, desirable ITS technologies and solutions for arterial management enhancement indicates that

- Traffic Control, which includes the subcategories of Transit Signal Priority, Emergency Vehicle Preemption, Adaptive Signal Control, Advanced Signal Systems, and Variable Speed Limits all have shown significant benefits to the arterial systems and are in line with TxDOT's strategic planning goals.

- Lane Management-Pricing has been an underutilized tool in managing congestion and should be investigated further to aid in relieving arterial traffic.

- Information Dissemination, primarily in the form of Dynamic Message Signs (DMS) provides drivers with information regarding traffic conditions and is effective when drivers are unfamiliar with the area. Highway Advisory Radio is beneficial when drivers are familiar with the network, but is underutilized.

- Speed Enforcement and Stop/Yield Enforcement both have shown they can enhance safety within an arterial network and the technology is mature and widely available for this purpose.

- The studies on traveler information dissemination modes found that:

- In general, improvements in information quality for all dissemination modes will require better data sources. In addition to cameras, loop detectors, and other monitoring sensors, toll tags, cellular and satellite technologies all provide opportunities to use individual vehicles as probes to capture better traffic information. Implementation of additional data collection technologies will be required to provide arterial traffic information. While most existing information sources do provide incident and construction information for arterials, very few provide traffic information such as travel times, speeds, or congestion.

- Available information sources must be well advertised and easy to use. In addition to a noted lack of awareness by potential users of telephone 511 systems, many traffic information websites are difficult to find and to navigate.

- Currently available traffic data limits the quality of information available, but as market penetration of new technologies continues, private companies may have added incentives to improve data. There will likely be opportunities for government, private information providers, and drivers to cooperate to improve data sources and finance needed technology improvements. For example, when a driver signs up for a commercially available in-vehicle information service, they could sign a contract allowing their vehicle to be used as a probe to improve available data. Probe data collected by the private company and camera and sensor data collected by the road operator could be shared between both information providers to improve overall data for information dissemination and other traffic operations purposes. However, the legal requirements and financial arrangements that would be required for such a partnership remain to be seen.

A guideline was developed to help TxDOT staff select and prioritize arterials suitable for ITS deployment. With a comprehensive study of existing arterial ITS implementations in the United States and in other international metropolitan areas, the selection criteria are developed for quantifying various characteristics of candidate arterials. These criteria include

- Arterial traffic and geometric characteristics;

- Current LOS;

- The number of beneficiaries of new arterial management systems;

- Existing ITS infrastructure;

- Implementation costs and funding opportunities for new arterial management systems;

- Connections with other major arterials and freeways.

Based on the feasibility and urgency analyses, the suitable arterials for new ITS implementations can be determined to maximize potential benefits. Based on the guideline, a case study was conducted to demonstrate how to develop ITS applications. The simulation case study indicates that

- The use of a coordinated technology system to detect an incident on a freeway or arterial, coordinate arterial signals in response to an incident, and disseminate information to system users can provide network-wide traffic benefits.

- Use of systems that combine all three of these technologies can realize considerable time savings for travelers.

- The model also demonstrates that some components of the technology system may actually introduce new concerns while resolving initial problems.

- Detection technologies are necessary to recognize an incident and deploy coordinated signalization and/or information dissemination.

- Coordinated signalization also plays an important role in responding to a traffic incident. If significant volumes of traffic are redirected, signals on the new route must be adjusted to provide green time and additional capacity to the new traffic. However, in introducing new signal timings, impacts on cross-street traffic must be carefully considered. If inadequate capacity is provided to some directional traffic, system-wide degradation may occur.

- Information dissemination technologies can significantly impact traffic congestion mitigation. However, the inappropriately overwhelming response rate may generate new congestion.

9.2 Recommendations

Based on the findings and conclusions from this study, the following recommendations are made to TxDOT.

- Detection technologies are a key component to successful deployment of any arterial ITS technology system. No negative traffic impacts result from deployment of detection systems. So it is recommend using various means of data collection technologies such as detectors, video detection, GPS detection, cell phone detection, toll tag detection, and so on to improve arterial data collection.

- Coordinated signal control plays an important role in responding to recurrent or non-recurrent congestion. Signal optimization is the most effective way to improve arterial traffic operations. The software and hardware are already mature and widely available. Therefore, it is recommended that TxDOT should consider coordinated signal control implementation to enhance arterial system performance as the first priority.

- Information dissemination technologies are essential for arterial management enhancement. Desirable characteristics of arterial traveler information systems include (a) Provide route and decision guidance (b) Be timely, accurate, available, and cost effective, and (c) Be easy to access and safe to use. It is recommended that TxDOT staff should fully consider these characteristics to maximize the benefits when implementing the information dissemination technologies.

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- Comprehensive websites offering a variety of content on traffic flow, incidents, construction, and weather that can be personalized to localized information for a specific user are most useful. Websites must be easily navigable and provide information in understandable text and graphic formats. Integration of the information into a graphical display might provide some users, especially infrequent pass-through users, with a better understanding of existing traffic conditions. These findings are recommended for TxDOT future use.

- The ideal message design should reduce driver's uncertainty regarding traffic conditions instead of overwhelming him or her with unneeded data. An auditory method is adequate and effective when drivers are familiar with the network. If DMS systems are going to be deployed on the arterial network, particularly during peak hours, they should be located in areas where realistic alternative routes exist. Specifically, the DMS should be located so that traffic can be easily redirected to an alternative route that under normal operating conditions has some available capacity to accommodate additional traffic volumes. These findings should be carefully considered for future information dissemination applications.

- Arterial management can be integrated with TxDOT's traffic management plan so that the freeway traffic operations can be enhanced through improving the interactions between arterial and freeways. Therefore, it is recommended that TxDOT should actively integrate arterial and freeway operations systematically.

- The technologies for vehicle registration/identification, toll collection, and ATIS are similar, and it is recommended that the possibilities for integration should be pursued. This integration would benefit arterial data collection as well.

References

Abdel-Aty, M. et al. Understanding the Effects of ATIS on Commuters' Route Choice Decisions. Conference Proceeding, ITS America Annual Meeting, Houston, TX, April 1996.

Austin Roads: Austin Intelligent Transportation System Website. Texas Department of Transportation, Austin, TX, 2006. http:// ausits.dot.state.tx.us. Accessed August 20, 2008.

Aitken, Ricardo. Implementation of Graphic Route Information Panels in the United States. Master's Thesis, The University of Texas at Austin, Austin, TX, May 2008.

American Signal Company. *Dynamic Stationary Signs*. 2002. http://www.amsig.com/frame_home.htm. Accessed May 9, 2009.

ACISA. Aeronaval de Construcciones e Instalaciones, S.A. 2008. http://www.acisa.es/. Accessed July 1, 2008.

AGD. Advanced Global Detection Systems. 2008. http://www.agd-systems.com/news/index.asp.Accessed July 1, 2008.

Applied Traffic Limited. Providing Customer Driven Solutions for Traffic Monitoring. 2007. www.appliedtraffic.co.uk. Accessed July 1, 2008.

ACS-Lite. Arterial management Program FHWA. 10 October 2007. http://ops.fhwa.dot.gov/acs_lite/index.htm. Accessed December 9, 2007.

ASCE Research Library. *Reversible Lane Systems: Synthesis of Practice*. 22 May 2006. http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=JTPEDI000132000012000933000001&idtype=cvips&gifs=yes. Accessed May 5, 2008.

Ballard, Andrew J. Texas Transportation Institute. *Incident Management for Managed Lanes*. 2005. http://managed-lanes.tamu.edu/products/bulletins/4160-17B.pdf. Accessed June 11, 2008.

Ballard, Andrew J. and Borchardt, Darrell W. Texas Transportation Institute. *Recommended Practice for Hurricane Evacuation Traffic Operations*. May 2006. http://tti.tamu.edu/documents/0-4962-P2.pdf. Accessed June 12, 2008.

Ballard, Andrew J. Transportation Research Record. *Traffic Operations for Hurricane Evacuation*. 2007. http://trb.metapress.com/content/d252671287703772/fulltext.pdf. Accessed June 12, 2008.

Blank, Leland and Tarquin, Anthony. McGraw-Hill Series in Industrial Engineering and Management Science. *Engineering Economy Sixth Edition*. 2005. McGraw-Hill Companies Inc. New York, NY.

Bushman, R. and A.J. Pratt. "Weigh-In-Motion Technology—Economics and Performance." Presented at the North American Travel Monitoring Exhibition and Conference, Charlotte, NC, USA, 1998.

Boriboonsomsin, Kanok and Barth, Matthew. Center for Environmental Research and Technology (CE-CERT), University of California, Riverside. *Impacts of freeway high-occupancy vehicle lane configuration on vehicle emissions*. March 2008. http://www.sciencedirect.com/science/article/B6VH8-4RV1JYG-2/2/3b0204a97b9a37e47190b75a2e1012a3. Accessed June 8, 2008.

Bloomberg, L. and J. Dale (2000). Comparison of VISSIM and CORSIM Traffic Simulation Models on a Congested Network, *Transportation Research Record 1727*, TRB, National Research Council, Washington D.C., pp. 52-60.

Bulwa, Demian. San Francisco Chronicle. *Stoplight to Punish Suburban Speeders*. April 7, 2004. http://www.sfgate.com/cgi-bin/article.cgi?file=/c/a/2004/04/07/MNG8N61MGG1.DTL. Accessed June 26, 2008.

Brydia, Robert E. et al. Communications Trends and Their Impact on TxDOT ITS Deployments. Report No. FHWA/TX-08/0-5586-1. Texas Transportation Institute, College Station, TX, November 2007.

Boarnet, M.G., E.Jae Kim, and E. Parkney. Measuring Traffic Congestion. IN Transportation Research Record 1634. Transportation Research Board, Washington, D.C., 1998, pp 93-99.

Bushman, Rob and Berthelot, Curtis. Transportation Association of Canada. Applications of ITS to Manage Traffic at a Calgary Rail Crossing. 2005.

Caven, Brent; Lee, John D.; Haake, Steven; and Brown, Timothy L. University of Iowa, Department of Industrial Engineering. Speech-based Interaction with In-vehicle Computers: The Effect of Speech-based E-mail on Drivers' Attention to the Roadway. 2001. http://www-nrd.nhtsa.dot.gov/departments/nrd-13/driver-distraction/PDF/27.PDF. Accessed June 20, 2008.

Chan, Sewell. The New York Times. *Is Manhattan Turning Against Congestion Pricing?* November 19, 2007. http://cityroom.blogs.nytimes.com/2007/11/19/is-manhattan-turning-against-congestion-pricing/. Accessed June 23, 2008.

Clark, AT; Wang, JH; Maier-Speredelozzi, V; and Collyer, CE. Transportation Research Board 87th Annual Meeting. *Assisting Elder Drivers' Comprehension of Dynamic Message Signs*. 2008. http://ntlsearch.bts.gov/tris/record/tris/01090711.html. Accessed June 20, 2008.

Coifman, Benjamin. Midwest Regional University Transportation Center. *Vehicle Classification from Single Loop Detectors*. June 2007. http://www.ceegs.ohiostate.edu/~coifman/outgoing/MRUTC070628b.pdf. Accessed June 9, 2008.

Capital Area Metropolitan Planning Organization (CAMPO), TxDOT Annual Traffic Counts, and City of Austin Traffic Counts. http://www.campotexas.org/programs_rd_traffic_counts.php, Accessed on May 20, 2009

Citilog. Paving Intelligence into Safety, Security & Mobility. 2008. www.citilog.com. Accessed July 1, 2008.

Clearview Traffic. *Moving traffic, saving lives*. August 18, 2008. http://www.clearviewtraffic.com/. Accessed July 1, 2008.

Counters & Accessories Ltd. CA Traffic Global Traffic. 2006. www.c-a.co.uk. Accessed July 1, 2008.

Capital Metro Transit Website. Capital Metropolitan Transportation Authority, Austin, TX. http://www.capmetro.org/. Accessed June 1, 2009.

Cell Phone Driving Laws. Governors Highway Safety Association Website, Governors Highway Safety Association, Washington, D.C., 2008. http://www.naghsr.org/html/stateinfo/laws/cellphone_laws.html. Accessed August 1, 2008.

Calafell, Jordi and Martin Pyne. In-vehicle Traffic Information Systems in Europe: Never Mind the (Band)Width, Feel the Quality. Journal of Navigation, Vol. 54, 2001. P. 329-335.

Carter, M. Metropolitan Model Deployment Initiative San Antonio Evaluation Report (Final Draft). May 2000. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/12883.pdf. Accessed December 1, 2007.

Chatterjee, K. et al. Driver response to variable message sign information in London. Transportation Research Part C, Vol. 10, 2002. P. 149-169.

Clauson, Jim. Deming Electronic Network. *Dr. Deming's 1950 Lecture to Japanese Top Management*. July 14, 2000. http://deming.eng.clemson.edu/pub/den/deming_1950.htm. Accessed September 29, 2008.

Committee on Urban Arterial Systems. American Society of Engineers (ASCE). *A Guide to Urban Arterial Systems*. American Society of Engineers, New York, New York, 1981.

Lomax, Tim. National Cooperative Highway Research Program. *Report 398 Quantifying Congestion Volume 1 Final Report*. 1997. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_398.pdf. Accessed September 15, 2008.

Dahlgren, Joy; Turner, Shawn; and Garcia, Reinaldo. *Collecting, Processing, Archiving and Disseminating Traffic Data to Measure and Improve Traffic Performance*. January 13, 2002. http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/TRB%20Paper%2000569.pdf. Accessed August 25, 2008.

Deployment Statistics, ITS Joint Program Office, Research and Innovative Technologies Administration, U.S. Department of Transportation, Washington, D.C., October 2007. http://www.itsdeployment.its.dot.gov/. Accessed August 1, 2008.

Decina, Lawrene E.; Thomas, Libby; Srinivasan, Raghavan; and Saplin, Loren. NHTSA. *Automated Enforcement: A Compendium of Worldwide Evaluations of Results*. July 2007. http://ntl.bts.gov/lib/26000/26600/26639/Automated_Enforcement_-_A_Compendiul_of_World_Wide_Evaluation_Results_DOT_HS810_763_July_2007.pdf. Accessed June 13, 2008.

Dudek, Conrad L. and Gerald L Ullman. Dynamic Message Sign Message Design and Display Manual. Report No. FHWA/TX-04/0-4023-P3. Texas Transportation Institute, College Station, TX, February 2006.

Diakaki, Christina, et al. "Application and Evaluation of the Integrated Traffic-Responsive Urban Corridor Control Strategy (IN-TUC) in Glasgow." Paper presented at the 79th Transportation Research Board Annual Meeting, Washington, D.C. Jan. 2000.

DMJM Harris, Inc. *Syracuse Signal Interconnect Project: Before and After Analysis Final Report*. Prepared for the New York State Department of Transportation. Syracuse, NY: Sept. 2003.

DataCollect. Where Intelligence Meets the Road. 2006. www.datacollect.com. Accessed July 1, 2008.

Diekmann, Jashua. A Modeling Approach for Evaluating Network Impacts of Operational-Level Transportation Projects. 9 May 2000. http://scholar.lib.vt.edu/theses/available/etd-05232000-14570051/unrestricted/JDThesis.PDF. Accessed December 1, 2007.

Dugas, H.P.. Pairwise Comparison Method for Evaluation of ITS Investments. 6-10 April 2003.

Dunn, Walter. U.S. Department of Transportation Federal Highway Administration. *Managing Travel for Planned Special Events Handbook: Executive Summary*. June 2007. http://www.ops.fhwa.dot.gov/program_areas/special_events_mgmt/mng_trvl_exsum/plnd_spcl_evnts.pdf. Accessed June 13, 2008.

511 Deployment Coalition Website, Implementation and Operational Guidelines for 511 Services, Version 3.0. ITS America, Washington, D.C., September 2005. http://www.deploy511.org/docs/511%20Guidelines%20Version%203.0.pdf. Accessed August 1, 2008.

European Conference of Ministers of Transport, International Transport Forum (CEMT/ITF). *Policy Responses to Congestion: Pricing*. May 2007. http://www.internationaltransportforum.org/sofia/pdf/KeyMessages/ITF200703e.pdf. Accessed June 23, 2008.

Elmore Group. Detection and Classification. Microwave Based Vehicle Detection. 29 August 2007. http://elmore.ie/content.asp?contentID=34. Accessed December 12, 2007.

Econolite. Solutions that Move the World. 2008. www.econolite.com. Accessed July 1, 2008.

EIS. Electronic Integrated Systems, Inc. 2008. http://www.eistraffic.com/hs_main.html. Accessed July 1, 2008.

Excel. Excel Technology Group. 2007. http://www.exceltech.com.au/index.htm. Accessed July 1, 2008.

Englisher, L.S. et al. User Perceptions of SmarTraveler Advanced Traveler Information System: Findings from Second-Year Evaluation. Transportation Research Record, No. 1537, 1996. P. 63-69.

Edara, Praveen; Guo, Jianhua; Smith, Brian L.; and McGhee, Catherine. Virginia Transportation Research Council. *Optimal Placement of Point Detectors on Virginia's Freeways: Case Studies of Northern Virginia and Richmond*. January 2008. http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-cr3.pdf. Accessed June 9, 2008.

European Commission Directorate General Energys and Transport, Traffic management applications on the Koge Bugt Motorway, Brussels Denmark. April 2003. http://tempo.austriatech.org/fileadmin/library/59/EEG_VK3_Traffic_Management_Koge_ Bugt_Motorway.pdf. Accessed August 1, 2008.

Fortran. Total Transportation Solutions. November 12, 2007. www.fortrantraffic.com. Accessed July 1, 2008.

Findley, Melisa D.; Durkop, Brooke R.; Wiles, Poonam B.; Carvelle, James D.; and Ullman, Gerald. Texas Transportation institute. *Practices, technologies, and Usage of Incident Management and Traveler Information Exchange and Sharing in Texas*. June 2001. http://ntl.bts.gov/lib/19000/19200/19259/PB2002105404.pdf. Accessed June 11, 2008.

Federal Highway Administration, "Traffic Software Integrated System 97 User's Guide", June 1997.

Federal Highway Administration, U.S. Department of Transportation, What Have We Learned About Intelligent Transportation Systems? Washington, D.C., December 2000.

Federal Highway Administration, *Traffic Detector Handbook*, Report No. FHWA-HRT-06-108, (Washington, DC, in press May 2006).

Federal Highway Administration, "Traffic Software Integrated System 97 User's Guide", June 1997.

FABEMA. accessories/miscellaneous. Passive Infrared Radar Traffic Detectors. 2007. http://images.google.com/imgres?imgurl=http://fabema.b9space.de/typo3temp/pics/a99386 60c5.jpg&imgrefurl=http://fabema.b9space.de/accessories.html&h=130&w=100&sz= 3&hl=en&start=71&tbnid=t5FTu6p66SKmcM:&tbnh=91&tbnw=70&prev=/images%3Fq

%3DTraffic%2BDetectors%26start%3D60%26gbv%3D2%26ndsp%3D20%26svnum%3D
10%26hl%3Den%26sa%3DN. Accessed December 12, 2007.

Fontaine, M.D., Smith, B.D.. Investigation of the Performance of Wireless Location
Technology-Based Traffic Monitoring Systems. March 2007.

Fellendorf Martin and Peter Vortisch, "Validation of the microscopic traffic flow model VISSIM
in different real-world situations," in The 80th Annual Meeting of the Transportation
Research Board, Washington, D.C., USA, Jan. 2001.

Gomes, G., A. May, and R. Horowitz (2004). Congested Freeway Micro-simulation Model
Using VISSIM, *Transportation Research Record: Journal of Transportation Research
Board*, No.1876, pp. 71-81.

GENEQ Inc. Meterology-Vehicluar Detection. 2008. http://www.geneq.com/frames.html.
Accessed July 1, 2008.

Global Traffic Technologies. 2008. www.ggt.com/. Accessed July 1, 2008.

Golden River. Traffic Management Systems. Moving traffic, saving lives. 2007.
www.goldenriver.com. Accessed July 1, 2008.

Garber, Nicholas J.; Miller, John S.; Eslambolchi, Saeed; Khandelwal, Rahul; Mattingly,
Kimberly M.; Sprinkle, Kristin M. and Wachendorf Patrick L. Virginia Transportation
Research Council. *An Evaluation of Red Light Camera (Photo-Red) Enforcement
Programs in Virginia: A Report in Response to a Request By Virginia's Secretary of
Transportation.* January 2005. http://www.thenewspaper.com/rlc/docs/05-vdot.pdf.
Accessed June 25, 2008.

Glazer, Lawrence Jessee and Cruz, Roberto. *Utah Department of Transportation. Intelligent
Transportation systems at the 2002 Salt Lake City Winter Olympic Games Event Study*.
Traffic Management and Traveler Information. April 29, 2003.
http://www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE//13850.html. Accessed June 13,
2008.

Greenough and Kelman. "ITS Technology Meeting Municipal Needs - The Toronto Experience."
Paper presented at the 6th World Congress Conference on ITS, Toronto, Canada. 1999.

Henry, Micah. Arizona Department of Transportation. *ITS Concepts for Rural Corridor
Management*. September 2007.
http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ615.pdf. Accessed
June 20, 2008.

Houston Metropolitan Transit Authority, *Emergency Response Management System Study.*
Prepared by Traffic Engineers, Inc., Houston, TX: Apr. 1991.

Hobeika, A.G., Sivanandan, R., Subramaniam, S., Ozbay, K., Zhang, Y.. Real-Time Traffic
Diversion Model: Conceptual Approach. July/August 1993.

Halkias, John and Michael Schauer. Red Light, Green Light. Public Roads Journal. U.S. DOT, November/December 2004.

Hourdakis, John; Michalopoulos, Panos G.; and Morris, Ted. Center for Transportation Studies, University of Minnesota. *Deployment of Wireless Mobile Detection and Surveillance for Data-Intensive Applications*. January 29, 2007. http://trb.metapress.com/content/01760178p282xr1r/. Accessed June 9, 2008.

Huang, Herman and Zegeer, Charles. Florida Department of Transportation. *The Effects of Pedestrian Countdown Signals in Lake Buena Vista.* November 2000. http://www.dot.state.fl.us/Safety/ped_bike/handbooks_and_research/research/CNT-REPT.pdf. Accessed June 23, 2008.

Hu, Kang and Janoyan, Verej. *LADOT's Adaptive Traffic Control System (ATCS).* January 7, 2001. http://www.signalsystems.org.vt.edu/documents/Jan2001AnnualMeeting/HangHu-LAATCS_TRB2001.pdf. Accessed June 6, 2008.

Highway Capacity Manual. TRB, National Research Council, Washington, D.C., 2000.

ITS Deployment Statistics. *2006 National Summary: Intelligent Transportation Systems*. 2006. http://www.itsdeployment.its.dot.gov/Results.asp?year=2006&rpt=M&filter=1&ID=332 Accessed May 9, 2009.

ITS Benefits. Arterial Management Systems. 2007. http://www.itsbenefits.its.dot.gov/. Accessed May 9, 2009.

ITS Cost Database. ITS Joint Program Office, Research and Innovative Technologies Administration, U.S. Department of Transportation, Washington, D.C., October 2007. http://www.itscosts.its.dot.gov/. Accessed August 1, 2008.

ITS Benefits. Arterial Management Systems. 2007. http://www.itsbenefits.its.dot.gov/its/benecost.nsf/SingleTax?OpenForm&Query=Arterial+Management+Systems. Accessed December 9, 2007.

Ivan, J.N., Schofer, J.L., Bhat, C.R., Lui, P-C., Koppleman, F.S., Rodriguez, A.. Arterial Street Incident Detection using Multiple Data Sources: Plans for ADVANCE. 25-28 July 1993.

Ivan, J.N., Chen, S.. Incident Detection Using Vehicle-Based and Fixed-Location Surveillance. May/June 1997.

Idris. Diamond Consulting Services. 2003. www.idris-technology.com. Accessed July 1, 2008.

Image Sensing Systems Inc. 2008. www.imagesensing.com. Accessed July 1, 2008.

IRD. International Road Dynamics Inc.2008. www.irdinc.com. Accessed July 1, 2008.

Iteris Vantage Video Traffic Detection Systems: Installation and User Guide. Version 2.2. Iteris, Anaheim, California, April 2000,

Iteris: Innovation for better mobility, 2008. http://www.iteris.com/. Accessed Jan, 25, 2008

ITS Decision. UC Regents. *A Gateway to Understanding and Applying Intelligent Transportation Systems*. 2005. http://www.calccit.org/itsdecision/. Accessed July 1, 2008.

ITS Lessons Learned. Arterial Management. 2007. http://www.itslessons.its.dot.gov/. Accessed December 9, 2007.

Institute of Transportation Engineers. *Automated Enforcement in Transportation*. Report No. IR-100. Washington, D.C. Dec. 1999.

Joseph Sussman, et al. What Have We Learned About ITS? Report No. FHWA-OP-01-006, Federal Highway Administration, U.S. DOT. December 2000.

Jou, Rong-Chang et al. Route switching behavior on freeways with the provision of different types of real-time traffic information. Transportation Research Part A, Vol. 39, 2005. P. 445-461.

Jones, Crystal, Daniel Murray and Jeffrey Short. Measurement of Travel Time in Freight-Significant Corridors: Phase 2. Conference Proceedings, 12th World Congress on Intelligent Transportation Systems, San Francisco, November 2005.

Jensen, M.; Cluett, Christopher; Wunderlick, Karl; Deblasio, Alan; and Sanchex, R.. U.S. Department of Transportation. Metropolitan Model Deployment Initiative Seattle Evaluation Report (Final Draft). May 2000.

Khan, A.; Armstrong, J.; Munir, A. Urban Transport XII: Urban Transport and the Environment in the 21st Century. Role of micro-simulation in evaluating intelligent transportation systems applications in urban transportation. 2006.

Knee, H.E.; Black, George; Petrolino, Joe. Society of Photo-Optical Instrumentation Engineers. Demonstration of Alternative Traffic Information Collection and Management Technologies. 2004.

Karlsson, Jan et al. European Environment Agency. *Success Stories Within the Road Transport Sector on Reducing Greenhouse Gas Emission and Producing Ancillary Benefits.* 2008. http://reports.eea.europa.eu/technical_report_2008_2/en/Success-stories-Tech_2_2008_final.pdf. Accessed June 23, 2008.

Kelly, Michael J.; Stanley, Laura M.; and Lassacher, Suzanne. Montana Department of Transportation. Driver Performance While Using a Cellular Telephone Interface to a Traveler Information System. 2005. http://ntlsearch.bts.gov/tris/search.do?b1=1&f1=0&t1=kw%3Avehicle+kw%3Asystems+kw%3Ainformation+kw%3Adissemination&r=1&d=tr&p=15&z=1&s=yr&o=1&new=n.Accessed June 20, 2008.

Kelman, Les and Kemp, Steve. Transportation Research Board. *Operation Experience with Adaptive Control Systems*. January 2001.

http://www.signalsystems.org.vt.edu/documents/Jan2001AnnualMeeting/LesKelmanSCOOT_TRB2001.pdf. Accessed June 8, 2008.

Kwon, Jaimyoung and Varaiya, Pravin. *Effectiveness of California's High Occupancy Vehicle (HOV) system*. June 18, 2007. http://www.sciencedirect.com/science/article/B6VGJ-4PMJ9T1-1/2/25de3193a15db00f1e683a0434279581. Accessed June 6, 2008.

Lee, John; Schmidt, Kristi; and Bral, Toby. University of Iowa. Driving Assessment 2001. Distraction Potential of Speech-based Driver Interfaces. August 14-17, 2001. http://ppc.uiowa.edu/driving-assessment/2001/Summaries/TechSession1/lee_john.html. Accessed June 13, 2008.

Kelly, Michael J., Laura M. Stanley, and Suzanne Lassacher. Driver Performance While Using a Cellular Telephone Interface to a Traveler Information System. Western Transportation Institute, Montana State University, July 29, 2005. http://www.wti.montana.edu/ForceDownloadHandler.ashx?name=425452_Driver_Distraction_Final.pdf. Accessed August 1, 2008.

Khattak, Asad J. Youngbin Yim, and Linda Stalker Prokopy. Willingness to pay for travel information. Transportation research Part C, Vol. 11, 2003. P. 137-159.

Klein, Lawrence; Mills, Milton; and Gibson, David. Federal Highway Administration. *Traffic Detector Handbook: Third Edition-Volume I*. October 2006. http://www.tfhrc.gov/its/pubs/06108/index.htm#toc. Accessed July 1, 2008.

Khattak, Asad J. et al. Traveler Information Delivery Mechanisms: Impacts on Consumer Behavior. Conference Proceedings, TRB 87th Annual Meeting, Washington, D.C., January 13-17, 2008.

Lake Traffic Solutions. *Pedestrian and Vehicle Safety Solutions, Roadway and Street Maintenance Products*. 2008. www.laketraffic.com. Accessed July 1, 2008.

Li, Yue; Koonce, P.; Li, M.; Zhou, K.; Li, Yuwei; Beaird, S,; Zhnag, Wei-Bin; Hegen, L.; Hu, K.; Skabardonis, A.; and Sun, Z. U.S. Department of Transportation. *Transit Signal Priority Research Tools*. May 2008. http://www.dot.ca.gov/newtech/researchreports/reports/2008/tsp_research_tools_final_report.pdfAccessed July 1, 2008.

Lockheed Martin Federal Systems, Odetics Intelligent Transportation Systems Division, 1996 . *ITS Performance and Benefit Study.* Report prepared for FHWA, USDOT, Washington, D.C.

Levinson, H.S., and T.J. Lomax. Developing a Travel Time Congestion Index. Transportation Research Record 1564. Transportation Research Board, Washington, D.C., 1996, pp 1-10.

Lomax, T., S. Turner, G. Shunk et al. Quantifying Congestion. NCHRP Report 398. National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 1997.

Lomax, Timothy and Schrank, David. Texas Transportation Institute. *Using Travel Time Measures to Estimate Mobility and Reliability in Urban Areas*. March 2002.

Lomax, T., S. Turner, and R. Margiotta. Monitoring Urban Roadways: Using Archived Operations Data For Reliability and Mobility Measurement. Texas Transportation Institute, College Station, 2001.

Litman, Todd. Victoria Transport Policy Institute. *Parking Management Strategies, Evaluation and Planning*. March 31, 2008. http://www.vtpi.org/park_man.pdf. Accessed June 13, 2008.

Lynn, Cheryl W.; Garber, Nicholas J.; Ferguson, Wayne S.; Lienau, Torsten K.; Lau, Robyne; Alcee, Janice V.; Black, Jonathan C. and Wendzel, Peter M. Virginia Transportation Research Council. *Automated Speed Enforcement Pilot Project for the Capital Beltway: Feasibility of Photo-Radar.* November 1992. http://ntl.bts.gov/DOCS/ase.html. Accessed June 25, 2008.

Medley, Sarah and Demetsky, Michael. Virginia Transportation Research Council. Development of Congestion Performance Measures Using ITS Information (Final Report). January 2003.

Mimbela, L.E.Y., Klein, L.A., Kent, P., Hamrick, J.L., Luces, K.M., Herrera, S.. Summary of Vehicle Detection and Sureillance Technologies Used in Intelligent Transportation Systems. 31 August 2007. http://www.nmsu.edu/~traffic/Publications/Trafficmonitor/vdst.pdf. Accessed 8 December 2007.

Murthy, Gummmada; Pendyala, Ram; Birenbaum, Ingrid. Internal Benchmarking of Transportation System as a Continuous Improvement Process for Dynamic Message Signs Deployment. 2003.

Martin, Peter T.; Perrin, Joseph; Chilukuri, Bhargava Rama; Jhaveri, Chantan; and Feng, Yugi. Mountain-Plains Consortium. *Adaptive Signal Control II*. January 2003. http://www.mountain-plains.org/pubs/html/mpc-03-141/disclaimer.php. Accessed June 6, 2008.

May, Adolf D.; Leiman, Lannon and Billheimer, John. California PATH Program, Institute of Transportation Studies, University of California, Berkeley. *Determining the Effectiveness of HOV Lanes.* November 2007. http://www.path.berkeley.edu/PATH/Publications/PDF/PRR/2007/PRR-2007-17.pdf. Accessed June 23, 2008.

Menendez, Monica and Daganzo, Carlos F. *Effects of HOV lanes on freeway bottlenecks*. March 7, 2007. http://www.sciencedirect.com/science/article/B6V99-4NM5S17-1/2/4ad4218e3237d1c5aa3278893767add2. Accessed June 6, 2008.

Mezghani, Mohamed and Soehnchen, Andrea. *Public Transport International. Public transport and anti-terrorism security*. March 2004. http://www.uitp-pti.com/img/cover3_2004/titres/security-en.pdf. Accessed June 8, 2008.

Monsere, Christopher M.; Breakstone, Aaron; Bertini, Robert L.; Deeter, Dean; and McGill, Galen. Transportation Research Record. *Validating Dynamic Message Sign Freeway Travel time Messages with Ground Truth Geospatial Data*. February 28, 2007. http://trb.metapress.com/content/81602707536m3580/. Accessed June 9, 2008.

Mounce, John M; Ullman, Gerald; Pesti, Geza; and Pezoldt, Valmon. Texas Transportation Institute. *Guidelines for the Evaluation of Dynamic Message Sign Performance*. December 2007. http://tti.tamu.edu/documents/0-4772-1.pdf. Accessed June 20, 2008.

Metropolitan Model Deployment Initiative: San Antonio Evaluation Report. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., May 2000. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/12883.pdf. Accessed August 1, 2008.

Mannering, F.L., W.P. Kilareski, and S.S. Washburn. (2004). *Principles of Highway Engineering and Traffic Analysis*. Third Edition. John Wiley & Sons, Inc., U.S.A.

Moen, B., J. Fitts, D. Carter, and Y. Ouyang (2000). A Comparison of the VISSIM Model to Other Widely Used Traffic Simulation and Analysis Programs, Presented at the *Institute of Transportation Engineers 2000 Annual Meeting and Exhibit*, Nashville, TN.

Medley, Sarah and Demetsky, Michael. Virginia Transportation Research Council. *Development of Congestion Performance Measures Using ITS Information (Final Report)*. January 2003.

Martin, P.; Feng, U.; and Wang, X. Mountain-Plains Consortium. *Detector Technology Evaluation*. November 2003. http://www.mountain-plains.org/pubs/html/mpc-03-154/pg1.php. Accessed July 1, 2008.

Middleton D. and R. Parker. Vehicle Detector Evaluation. *Research Report FHWA/TX-03/2119-1*, Texas Transportation Institute, The Texas A&M University System, College Station, TX, October 2002

Nee, Jennifer and Hallenbeck, Mark E. Washington State Transportation Center (TRAC). *A Motorist and Pedestrian Behavioral Analysis Relating to Pedestrian Safety Improvements*. March 2003. http://depts.washington.edu/trac/bulkdisk/pdf/560.1.pdf. Accessed June 13, 2008.

Njord, John; Peters, Joseph; Freitas, Michael; Warner, Bruce; Allred, Craig K.; Bertini, Robert; Bryant, Robert; Callan, Robert; Knopp, Martin; Knowlton, Lyle; Lopez, Carlos; and Warne, Tom. American Trade Initiatives. International Technologies Scanning Program. *Safety Applications of Intelligent Transportation Systems in Europe and Japan*. January

2006. http://www.international.fhwa.dot.gov/ipsafety/ipsafety.pdf. Accessed June 11, 2008.

News Channels Schedule. XM Radio Website, XM Satellite Radio, 2008. http://www.xmradio.com/news/index.xmc. Accessed August 20, 2008.

NavTraffic. XM Radio Website, XM Satellite Radio, 2008. http://www.xmradio.com/navtraffic/. Accessed August 20, 2008.

National Cooperative Highway Research Program. *Synthesis 311 Performance Measures of Operational Effectiveness for Highway Segments and Systems*. http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_syn_311.pdf. PBS&J. 2003. Accessed September 2007.

National Cooperative Highway Research Program. *Report 446 A Guidebook for Performance-Based Transportation Planning*. Cambridge Systematic, Inc. 2000. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_446.pdf. Accessed September 16, 2008.

Never-Fail. Loop Systems. 2001. http://www.neverfail.com/index.html. Accessed July 1, 2008.

Noptel. Specialized in Development and Manufacture of Optoelectronic Products. 2008. www.noptel.fi. Accessed July 1, 2008.

Nortech Detection. Suppliers of high-tech components used in Vehicle Detection Systems, Car parking, Traffic Control and Motorways Incident Detection. 2008. www.nortechdetection.com.au. Accessed July 1, 2008.

NOVAX. Technology that moves you. 2003. http://www.novax.com/. Accessed July 1, 2008.

OLVIA. 2007. http://www.olvia.ru/eng/index.php. Accessed July 1, 2008.

OSI. OSI LaserScan. 2007. www.osi-ls.com. Accessed July 1, 2008.

O'Brien, Amy and Jacobsen, Leslie. Freeway and Arterial Management Efforts, FAME. March-April 1991.

Office of Management and Budget. *Government Performance Results Act of 1993*. 1993. http://www.whitehouse.gov/omb/mgmt-gpra/gplaw2m.html#h3. Accessed September 18, 2008.

Quixote. Quixote Transportation Technologies Inc. *The Source for Intelligent Transportation*. 2007. www.qttinc.com. Accessed July 1, 2008.

Office of Transportation Management [OTM]. U.S. Department of Transportation, Federal Highway Administration. *Freeway Management and Operations Handbook*. September 2003.

http://www.ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/toc.htm. Accessed June 11, 2008.

Pal, Akhilesh; Riche, Michael H.; Graettinger, Andrew; Rao, Karri Veerabhadra; McFadden, John; and Turner, Daniel S. University of Alabama, Tuscaloosa. *Enhancements to Emergency Evacuation Procedures*. 2005. http://ntl.bts.gov/lib/24000/24900/24975/01105fnl.pdf. Accessed June 12, 2008.

Paniati, Jeffrey F. and Amoni, Marilena. U.S. Department of Transportation. *Traffic Signal Preemption for Emergency Vehicles A Cross-Cutting Study*. January 2006. http://www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE//14097_files/14097.pdf. Accessed June 23, 2008.

Peeta, Srinivas and Zhang, Pengcheng. Joint Transportation Research Program Purdue University. *Counting Device Selection and Reliability: Synthesis Study*. March 2002. http://rebar.ecn.purdue.edu/JTRP_Completed_Project_Documents/SPR_2486/FinalReport/spr_2486_Form1700.pdf. Accessed June 9, 2008.

Petty, Kevin R. and Mahoney, William P., III. National Center for Atmospheric Research. *Enhancing Road Weather Information Through Vehicle Infrastructure Integration*. January 9, 2008. http://trb.metapress.com/content/h13p067557tl5437/?p=a8ea5c647ba9441fa637dde3241ab41d&pi=5. Accessed June 9, 2008.

Pedestrian and Bicycle Information Center. *Right-Turn-On-Red Restrictions*. 2007. http://www.walkinginfo.org/engineering/crossings-signals.cfm. Accessed June 25, 2008.

PTV "VISSIM 5.1 User Manual", Planung Transport Verkehr AG, Germany, 2007

Persad, K., Walton, C.M., and Wang, Z. "The Vision, Goals, and Actions for Austin District's ITS Program". Center for Transportation Research, The University of Texas at Austin, August 2007.

Patriot Detection. Loops and Traffic Systems. 2008. http://www.patriotdetection.com/index.php. Accessed July 1, 2008.

PEEK. Specialists in Traffic Technology. 2008. http://www.peek-traffic.co.uk/. Accessed July 1, 2008.

Peeta, S. and Zhang, P. Indiana Department of Transportation. *Counting Device Selection and Reliability: Synthesis Study*. March 2002. http://rebar.ecn.purdue.edu/JTRP_Completed_Project_Documents/SPR_2486/FinalReport/spr_2486_Form1700.pdf. Accessed July 1, 2008.

Pickrell, S. and L. Neumann. 2000. *Linking Performance Measures With Decision Making*. In TRB, 2000.

Pearce, V. Can I Make It to Work On Time? Traffic Technology International, Oct/Nov 2001, pp 16-18.

Persad, K., Walton, C.M., and Wang, Z. "The Impact of Traveler Information on Commuters' Travel Behavior and Toll Road Choice: Findings from a Commuter Survey in Austin, Texas". Center for Transportation Research, The University of Texas at Austin, Research Product 0-5079-P1, December 2005.

Peck, C., et al. "Learning from the User: Next Steps for ITACA's Adaptive Control." *Traffic Technology International Annual Review* 1999: 155-158.

Persad, K., Walton, C.M., and Wang, Z. "Implementation Issues and Strategies for Deployment of Traveler Information Systems in Texas". Center for Transportation Research, The University of Texas at Austin, Research Product 0-5079-P3, August 2006.

Powell, James and Lipp, Louis. ITE 2004. Surface Street Performance Monitoring Using Video Detection. August 2004.

Roadtraffic-Technology: The website for the road traffic industry. *Company A-Z*. SPG Media Limited. 2008. http://www.roadtraffic-technology.com/contractors/indexAtoZ.html. Accessed July 1, 2008.

Rutherford, G. Scott, Taryn Kristoff and Mike Lowry. Assessing the Benefits of Traveler and Transportation Information Systems. Report No. TNW2005-03, Transportation Northwest, University of Washington, Seattle, March 2005.

Research and Innovation Technology Administration (RITA), Intelligent Transportation Systems Benefits Database, http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ByInfo/WhatIsAppAreas Accessed on Jan 10 2009)

Ran, Bin, Bridget Barret and Emily Johnson. Evaluation of Variable Message Signs in Wisconsin: Driver Survey. Wisconsin Department of Transportation, Madison, WI, October 2004. http://www.dot.wisconsin.gov/library/research/docs/finalreports/45-17variablemessagesigns.pdf. Accessed August 1, 2008.

Rakha, Hesham and Ahn, Kyoungho. Virginia Transportation Research Council. *Transit Signal Priority Project—Phase II: Field and Simulation Evaluation Results.* March 2006. http://www.virginiadot.org/vtrc/main/online_reports/pdf/06-cr6.pdf. Accessed June 23, 2008.

Reddy, Vivek; Abdel-Aty, Mohamed; and Pinapaka, Satya.Florida Department of Transportation. *Evaluation of Innovative Safety Treatments*. January 2008. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SF/BD500/BD500_v1_rpt.pdf. Accessed June 13, 2008.

Retting, Richard A.; Kyrychenko, Sergey Y.; and McCartt Anne T. *Insurance Institute for Highway Safety. Evaluation of Automated Speed Enforcement on Loop 101 Freeway in*

Scottsdale, Arizona. January 2008.
http://www.iihs.org/research/topics/pdf/speed_cameras_scottsdale.pdf. Accessed June 13, 2008.

Riffkin, Matt; McMurtry, Thomas; Heath, Suellen; and Saito, Misuru. InterPlan Co. *Variable Speed Limit Signs Effects on Speed and Speed Variation in Work Zones*. January 2008. http://www.udot.utah.gov/main/f?p=100:pg:1513911250646815517:::1:T,V:2020. Accessed June 6, 2008.

Siemens. Traffic Solutions: Integrated Traffic Solutions for all Requirements.2008. www.siemens.com/traffic. Accessed July 1, 2008.

SmarTek Systems. Sensing and System Integration Solutions. 2007. www.smarteksystems.com. Accessed July 1, 2008.

Smart Systems. From Science to Solutions. 2008. http://www.smart-systems.at/home_en.html. Accessed July 1, 2008.

Smith, H.; Hemily, B. and Miomir Ivanovic, Gannett Fleming, Inc. USDOT. *Transit Signal Priority (TSP): A Planning and Implementation Handbook*. May 2005. http://www.fta.dot.gov/documents/TSPHandbook10-20-05.pdf. Accessed July 1, 2008.

Schrank, David and Tim Lomax. 2007 Annual Urban Mobility Report. Texas Transportation Institute, College Station, TX, 2007.

Schrank, D., and T. Lomax. Urban Roadway Congestion 1982-1994 Annual Report. Texas Transportation Institute, College Station, 1997.

Schrank, D. and T. Lomax. Urban Roadway Congestion Annual Report: 1998. Texas Transportation Institute, College Station, 1998.

Schrank, D., and T. Lomax. The 2001 Urban Mobility Report. Texas Transportation Institute, College Station, May 2001. http://mobility.tamu.edu. Accessed December 9, 2007.

SmarTek Systems, Inc. SAS-1 Acoustic Sensor. 2007. http://www.oceanstatesignal.com/PDF/Detection/SAS1CatalogCut.pdf. Accessed December 12, 2007.

Swan, Nicole; Baker, Stephanie; Hintz, Rewa and Trimble, Tammy. Virginia Tech Transportation Institute. 511 Virginia Evaluation. January 2004.

Sirius Traffic Service. Sirius Satellite Website, Sirius Satellite Radio, 2008. http://www.sirius.com/traffic. Accessed August 20, 2008.

Siemens Automotive, USA. "SCOOT in Toronto." *Traffic Technology International*, Spring 1995.

South Dakota Department of Transportation [SDDOT}. South Dakota Department of Transportation Office of Research. *Applications of ITS in Work Zones*. July 2004. http://www.state.sd.us/Applications/HR19ResearchProjects/Projects%5CSD2003_16_Final_Report.pdf. Accessed June 11, 2008.

Shaheen, Susan A.; Rodier, Caroline J.; and Eaken, Amanda M. UC Davis. *Smart parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration*. 2005. http://www.its.ucdavis.edu/publications/2005/UCD-ITS-RR-05-02.pdf. Accessed June 13, 2008.

Soriguera, Francesc; Thorson, Leif; and Robuste, Frances. Center for Innovation in Transport, Jordi Girona. *Travel Time Measurement Using Toll Infrastructure*. January 18, 2008. http://trb.metapress.com/content/x72u553u3u318083/?p=b4203ece0d7447a598ed72a4f13bf999&pi=9. Accessed June 9, 2008.

Smith, Harriet R.; Hemly, Brendon and Ivanovic, Miomir. U.S. Department of Transportation. *Transit Signal Priority (TSP): A Planning and Implementation Handbook.* May 2005. http://www.itsa.org/itsa/files/pdf/TSPHandbook2005.pdf. Accessed June 23, 2008.

Smith, Brian L.; Park, Brian B.; Tanikella, Hema; and Zhang Guimin. *Preparing to Use Infrastructure Integration in Transportation Operations: Phase I*. October 2007. http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-cr1.pdf. Accessed June 9, 2008.

SRF Consulting Group, Inc. Minnesota Department of Transportation. *Adaptive Urban Signal Control and Integration: Evaluation Final Report*. October 2000. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13343.pdf. Accessed June 6, 2008.

Tian, Z.Z., T. Urbanik, T., R. Engelbrecht, and K. Balke (2002). Variations in Capacity and Delay Estimates from Microscopic Traffic Simulation Models, *Transportation Research Record 1802*, TRB, National Research Council, Washington D.C., pp. 23-31.

Thompson, R.D., Counts, J., Burgess, L.. Event Traffic Management Success Story: Phoenix International Raceway. 2001.

Turner, S.M. Examination of Indicators of Congestion Level. Transportation Research Record 1360. Transportation Research Board, Washington, D.C., 1992, pp 150-157.

TSS-Transportation Simulation System, "AIMSUN User Manual, Version 4.1", Barcelona, Spain, 2002

Total Traffic Network Traffic Message Channel Website, Clear Channel Broadcasting, Inc., 2008. http://www.realtimetraffic.net/. Accessed August 20, 2008.

Traffic and Weather. Sirius Satellite Website, Sirius Satellite Radio, 2008. http://www.sirius.com/trafficweather. Accessed August 20, 2008.

TxDOT Highway Conditions Reporting System Website. Texas Department of Transportation, Austin, TX, 2008. http://www.dot.state.tx.us/gis/hcrs_main/viewer.htm. Accessed August 20, 2008.

TxDOT Austin District Website. Texas Department of Transportation, Austin, TX, 2008. http://www.dot.state.tx.us/aus/. Accessed August 20, 2008.

Texas Department of Transportation. *Pocket Facts*, March, 2002.

Texas Department of Transportation Austin-Area Transportation Databook, - Austin District 2007.

Transportation Alternatives. *Congestion Pricing.* 2008. http://www.transalt.org/campaigns/congestion, http://www.transalt.org/campaigns/congestion/international. Accessed June 23, 2008.

TRB HOVworld. 2008. http://www.hovworld.com/. Accessed May 5, 2008.

Traveler Information. Services and Technologies Page, ITS Decision: A Gateway to Understanding and Applying Intelligent Transportation Systems Website. Institute of Transportation Studies, University of California at Berkeley and the California Department of Transportation, Berkeley, CA, 2003. http://www.calccit.org/itsdecision/serv_and_tech/Traveler_information/trav_info_overview.html. Accessed August 1, 2008.

Tattile. Complete Vision Solutions. 2008. www.tattile.com. Accessed July 1, 2008.

TDC. Traffic Data Collection Systems Ltd. 2008. www.tdcsystems.co.uk. Accessed July 1, 2008.

TEC Traffic Systems. Acknowledged Specialist in Traffic Technology. 2006. www.tectraffic.nl. Accessed July 1, 2008.

Telindus. Telindus Surveillance Solutions. 2008. www.telindussurveillance.com. Accessed July 1, 2008.

Traficon. Traffic Video Detection. 2008. www.traficon.com. Accessed July 1, 2008.

Tantiyanugulchai, Sutti. *Arterial Performance Measurement Using Transit Buses as Probe Vehicles*. Master thesis. Department of Civil & Environmental Engineering, Portland State University, 2003.

Traffic Technology Ltd. 2007. http://www.traffictechnology.co.uk/. Accessed July 1, 2008.

Truvelo. 2006. www.truvelo.co.za. Accessed July 1, 2008.

TSEU. TSEU Intelligent Traffic Systems: Microsense Systems and Traffic Signals UK. 2005. www.tseu.net. Accessed July 1, 2008.

Turner, Shawn; Middleton, Dan; Longmire, Ryan; Brewer, Marcus and Eurek, Ryan. Southwest Region University Transportation Center, Texas Transportation Institute, Texas A&M University. *Testing and Evaluation of Pedestrian Sensors.* September 2007. http://swutc.tamu.edu/publications/technicalreports/167762-1.pdf. Accessed June 23, 2008.

U.S. Department of Transportation Federal Highway Administration. *Managing Travel for Planned Special Events*. 2005. http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/Presentation.pdf. Accessed June 13, 2008.

US DOT JPO. Data Fusion For Delivering Advanced Traveler Information Services. May 2003. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE//13837.html. Accessed June 20, 2008.

USDOT ITS Joint Program Office. *Arterial Management Systems*. http://www.itsoverview.its.dot.gov/AM.asp. (Accessed in August 2009)

U.S. Department of Transportation (USDOT). *National ITS Architecture Version 6.0*. March 23, 2007. http://itsarch.iteris.com/itsarch/html/entity/paents.htm. Accessed July 1, 2008.

USDOT ITS Joint Program Office. *Arterial Management Systems*. 2008. http://www.itsoverview.its.dot.gov/AM.asp. Accessed March 20, 2008.

U.S. Department of Transportation: National Highway Traffic Safety Administration. Fatality Analysis Reporting System (FARS): Web Based Encyclopedia. Online. Available at http://www-fars.nhtsa.dot.gov/main.cfm. Accessed May 9, 2009.

Urbanik, T., Humphreys, D., Smith, B., Levine, S.. Coordinated Freeway and Arterial Operations Handbook. May 2006. http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/06095.pdf. Accessed 8 December 2007.

Vehicle Infrastructure Integration (VII). ITS Joint Program Office, Research and Innovative Technologies Administration, U.S. Department of Transportation, Washington, D.C., October 2007. http://www.its.dot.gov/itsnews/fact_sheets/vii.htm. Accessed August 20, 2008.

VII Deployment Coalition Website. Detailed Overview of VII. Research and Innovative Technologies Administration, U.S. Department of Transportation, Washington, D.C. http://www.vehicle-infrastructure.org/vii-overview/Detailed%20Overview%20of%20VII-1.pdf. Accessed August 20, 2008.

Walton, C. Michael, Khali Persad, and Zhong Wang. Use of Traveler Information to Improve Texas Transportation Network Operations in the Context of Toll Roads. Report No. FHWA/TX-070/0-5079-1. Center for Transportation Research, The University of Texas at Austin, Austin, TX, October 2006.

Wang, Zhong and Walton, Michael C. Center for Transportation Research. *An Investigation on the Environmental Benefits of a Variable Speed Control Strategy*. September 2006.

http://swutc.tamu.edu/publications/technicalreports/473700-00072-1.pdf. Accessed June 6, 2008.

Wang, Jyh-Hone; Hesar, Siamak G. Collyer, Charles E. Transportation Research Record. *Adding Graphics to Dynamic Message Sign Messages*. January 25, 2008. http://trb.metapress.com/content/7524034278251223/fulltext.pdf. Accessed June 20, 2008.

Wigan, Marcus and Clarke, Roger. Prometheus. *Social Impacts of Transport Surveillance*. December 4, 2006. http://www.informaworld.com/smpp/content~content=a759284027~db=all. Accessed June 9, 2008.

Wolshon, Brian and Lambert, Laurence. Transportation Research Board. *Convertible Roadways and Lanes: A Synthesis of Highway Practice.* July 2004. http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_syn_340.pdf. Accessed June 23, 2008.

Wunderlich, Karl E.; Bunch, James A.; and Larkin, James J. Federal Highway Administration. *ITS Impacts Assessment for Seattle MMDI Evaluation: Modeling Methodology and Results*. September 1999. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/11345.pdf. Accessed June 6, 2008.

Wiedemann R.. *"Simulation des Straßenverkehrsflusses"*. (In German) Schtiftenreihe des Instituts fur Verkehrswesen der Universitat Karlsruhe, Heft 8, 1974.

Wikipedia: ITS Technologies. http://en.wikipedia.org/wiki/Intelligent_transportation_system. (Accessed in August 2009)

Wiedemann R.. *"Modelling of RTI-Elements on multi-lane roads"*. Advanced Telematics in Road Transport, 1991.

Weiss-Electronic. Traffic in Motion. 2001. www.weiss-electronic.de. Accessed July 1, 2008.

WTI. Wireless Technology Inc. *Video Surveillance Products Dedicated to the Global Security and Transportation Markets*. 2008. http://www.gotowti.com/. Accessed July 1, 2008.

Wilbur, Toni. Public Roads. The ITS Metropolitan Model Deployment Initiative. November/December 1998. Vol. 62 No.3. http://www.tfhrc.gov/pubrds/novdec98/its.htm. Accessed December 7, 2007.

WSDOT Projects. Washington State Department of Transportation. US 2 Variable Speed Limit System Photos. 2007. Accessed December 12, 2007.

Xtralis. Smart Detectors for your Security and Traffic Needs. September 2007. http://www.asim-technologies.com/en/index.html. July 1, 2008.

Yannis, G. and Antoniou, C. "*Integration of Weigh-in-Motion Technologies in Road Infrastructure Management*." ITE Journal, 2005.

Yim, Youngbin and Jean-Luc Ygnace. Variable Message Signs and Link Flow Evaluation: A Case Study of the Paris Region. California PATH Program, University of California at Berkeley, Berkeley, CA, 1995. http://www.path.berkeley.edu/PATH/Publications/PDF/PWP/95/PWP-95-05.pdf. Accessed August 1, 2008.

Yim, Youngbin and Mark Miller. Evaluation of TravInfo Field Operational Test. California PATH Program, University of California at Berkeley, Berkeley, CA, April 2000. http://ntl.bts.gov/lib/7000/7600/7611/9yf01_1.pdf. Accessed August 1, 2008.

Zimmerman, Carol; Brodesky, Robert; and Karp, Jordan. U.S. Department of Transportation Federal Highway Administration. *Using Highways for No-Notice Evacuations: Routes to Effective Evacuation Planning Primer Series*. November 2007. http://www.ops.fhwa.dot.gov/publications/evac_primer_nn/primer.pdf. Accessed June 12, 2008.

Zimmerman, Carol; Bolton, Patricia; Raman, Mala; Kell, Todd; Unhoz, Stacy; and Bausher, Chris. Federal Highway Administration. *Communicating with the Public Using ATIS During Disasters: A Guide for Practitioners*. April 2007. **http://www.ops.fhwa.dot.gov/publications/atis/atis_guidance.pdf. Accessed June 20**, 2008.

Zimmerman, C.;Marks, J.; and Jenq, J.. Phoenix Metropolitan Deployment Initative Evaluation Report (Final Draft). April 2000. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/12743.pdf. Accessed December 1, 2007.

Zhou, Wei-Wu, et al. "Fuzzy Flows." ITS: *Intelligent Transportation Systems*, May/June 1997.

Appendix A. Arterial Performance Measures—Descriptions and Calculations

An important distinction needs to be made between congestions measurements versus congestion indicators. A ***measurement*** is equipped with a measurement unit i.e. congestion could be an additional travel time per mile. An ***indicator*** is a ratio between a basic situation and the situation observed (Robitaille, 2003). Arterial performance measures consisting of both measurements and indicators were selected and their descriptions and formulations where applicable will be given below:

1. Arterial VMT: This measure is a summation of the vehicle miles traveled on arterial roadways.

2. Volume: Can be expressed in a variety of different units and can be expressed in vehicles or persons. Several common volumes that are useful include annual average daily traffic, peak hour traffic, and peak-period traffic.

3. (Average) Speed/Travel Rate: This measurement can be used to calculate travel rate or travel times (Lomax, 2002).

$$Speed = Miles/Hour$$

4. Duration of Congestion: Period of congestion (in a time unit)

5. Travel Time (in minutes): This measurement is the time required to traverse a segment or complete a trip (Lomax, March 2002). Travel times can be gathered in a variety of ways using field studies or can be estimated with empirical relationships with traffic volume and roadway characteristics, computer networks models or the intended effects of improvements.

6. Percentage of System Congested: Percent of miles congested.

7. Level of service (LOS): LOS differs by facility type and is defined by characteristics such as vehicle density and volume to capacity ratio. Congested conditions often fall into a LOS F range, where demand exceeds capacity of the roadway. Volume to capacity ratios could be compared to LOS to reach conclusions about congested conditions; however, there is no distinction between different levels of congestion once congested conditions are reached (Medley, January 2003).

8. Total Delay (person-hours): This is performance measure gives the sum of time lost due to congestion of a transit or roadway segment. It can be compared in relation to free flow travel or to acceptable or target conditions of travel. This value is useful in economic or benefit/cost analyses that use information about the magnitude of the improvements for cost-effectiveness decisions (Lomax, March 2002).

$$TotalDelay = [ActualTT - AccptTT] * PV * [hours / 60 \min] * DR * SL$$

Total Delay (person-hours)
ActualTT = Actual Travel Time (minutes)
AccptTT = Acceptable Travel Time (minutes)
PV = Person Volume (persons)
DR = Delay Rate
SL = Segment Length

Another variation of Total Delay can be presented in the units of vehicle minutes (Meadly, January 2003). The calculation is shown below.

$$TotalDelay = [ActualTT - AccptTT] * V$$

Total Delay (vehicle-minutes)
ActualTT = Actual Travel Time (minutes)
AccptTT = Acceptable Travel Time (minutes)
V = Volume (vehicles)

9. Density: A common, straight forward indicator that most are familiar with.

$$Density = \left(\frac{\frac{PassVeh}{Hour}}{Lane(s)} \right)$$

PassVeh = Passenger Vehicles
Hour = Time (hours)
Lanes = Number of Lanes in System

10. Volume/Capacity Ratio (V/C Ratio): This indicator of performance is the volume of the traffic on the facility relative to capacity. The V/C ratio is an indicator of supply and demand for a facility and can be expressed in vehicles, persons, or goods moved. Furthermore the V/C ratio can have a variety of time aggregations including peak-hour, peak-period, off-peak, 12-h, 8-hr, and daily V/C (Shaw, 2003).

$$V\!/\!_C\,Ratio = \frac{V}{C}$$

V = Volume
C = Capacity

11. Buffer Index (Buffer Time Index—BTI): This calculation uses the percentage measure and the travel rate to address the average trip concerns. It can be calculated using real-time traffic monitoring data, using average speed readings and the length of a route (Meadley, January 2003). This information can provide the driver with an average of the segment-by-segment variation for a corridor, sub-area, or area of interested weighted by the amount of travel in each segment (Lomax, March 2002). The measurement is also helpful to the transportation professional because from the calculation they can determine the impact of congestion on one vehicle traveling on a segment of roadway during a specific time period (Medley, January 2003). The measure can be determined by using either roadway links combined into corridors or just the individual links. It would be explained to travelers as "you should allow an extra BTI percent travel time due to the variations in the amount of congestion delay on that that trip (Lomax, March 2002)."

$$BufferIndex(\%) = \left[\frac{(95thPertTR - TR)}{TR}\right] * 100\%$$

$95thPertTR$ = 95th Percentile Travel Rate
TR = Average Travel Rate

Note: Where all rates are in minutes per mile

12. Control Delay: The delay model from the HCM 2000 includes the uniform delay model, a version of Akcelik's overflow delay model, and a term covering delay from an existing or residual queue at the beginning of the analysis period (Roess, 2004). Control delay is the difference between the travel time that would have occurred in the absence of the intersection control, and the travel time that resulted because of the presence of the intersection control.

$$d = d_1 PF + d_2 + d_3$$

$$d_1 = \left(\frac{C}{2}\right) * \left\{ \frac{\left(1 - \frac{g}{c}\right)^2}{1 - \left[\min(1, X) * \frac{g}{c}\right]} \right\}$$

$$d_2 = 900T \left[(X - 1) + \sqrt{(X - 1)^2 + \left(\frac{8klX}{cT}\right)} \right]$$

d = control delay, s/veh
d_1 = uniform delay component, s/veh
PF = progression adjustment factor
d_2 = overflow delay component, s/veh
d_3 = delay due to pre-existing queue, s/veh
g = effective green time, s
T = analysis period, h
X = v/c ratio
C = cycle length, s
k = incremental delay factor for actuated controller settings; 0.5 for all pre-timed controllers.
I = upstream filtering/metering adjustment factor; 1.00 for all individual intersection analyses
c = capacity, veh/h

13. Total Intersection Delay: Average of the control delay for all lane groups.

14. Corridor Mobility Index: This indicator measures the mobility level provided by transportation facilities in a corridor compared to a recognized operating standard. The measure combines the attributes of speed or travel and the number of people being moved. Primarily the indicator provides a value that can compare alterative transportation improvements (Lomax, March 2002).

$$CorridorMo\,bilityIndex = \frac{(PerVolume * Speed)}{Normalizin\,gValue}$$

PerVolume = Person Volume (persons)
Speed = Average Travel Speed (mph)
NormalizingValue = Normalizing Value e.g., 25,000 for streets or 125,000 for
   freeways

15. Delay Rate (minutes per mile): This is the rate of time loss for vehicles traveling during congested conditions for a segment or whole duration of the trip (Lomax, March 2002). It can be calculated in two ways both shown below.

$$DelayRate = ActualTR - AccptTR$$

Delay Rate (minutes/mile)
ActualTR = Actual Travel Rate (minutes/mile)
AccptTR = Acceptable Travel Rate (minutes/mile)

Or,

$$DelayRate = \frac{[ActualTR - AccptTR]}{SL}$$

Delay Rate (minutes/mile)
AcutalTR = Actual Travel Rate (minutes)
AccptTR = Acceptable Travel Rate (minutes)
SL = Trip or Segment Length (miles)

16. Road Congestion Index (RCI): This indicator is based on the number of hours of the day that might be affected by congested condition on the roadway (Robitaille, 2003).

$$RoadwayCon\,gestionIndex = \frac{Volume}{Demand}$$

Volume = Daily Traffic Volume
Demand = Roadway Demand (with regard to traffic handling capacity)

17. Travel Rate Index (TRI): This indicator can be beneficial to both agencies and travelers. The TRI reflects the travelers' perceptions of travel time on the roadway, transit facility or other transportation network element. This comparison can be based on the travel time increase from either free flow conditions or to the target (or acceptable) conditions (Lomax, March 2002)." Travel rate then is needed to perform the calculation for this indicator and ultimately the TRI compares measured travel rates to free flow conditions and can be related to the public as an indicator of the length of extra time spent in the transportation system.

$$TravelRateIndex = \frac{\left[\left(\frac{FreewayTR}{FreewayFFR}\right)*FreewayPPVMT\right]+\left[\left(\frac{ArtStTR}{ArtStFFR}\right)*ArtStPPVMT\right]}{FreewayPPVMT+ArtStPPVMT}$$

FreewayTR = Freeway Travel Rate
FreewayFFR = Freeway Free Flow Rate
FreewayPPVMT = Freeway Peak-Period VMT
ArtStTR = Principal Arterial Street Travel Rate
ArtStFFR = Principal Arterial Street Free Flow Rate
ArtPPVMT = Principal Arterial Street Peak-Period VMT

18. Travel Time Index: This indicator requires use of arterial traffic data and requires separation of recurring and incident delay. Its main disadvantage is that it can be difficult for the public to understand (Meadley, January 2003). This index is similar to TRI, except that it includes both recurring and incident congestions (Robitaille, 2003).

$$TravelTimeIndex = \frac{AdTime}{FFTime}$$

AdTime = Additional Time Required to Make a Trip in Congested Conditions
(Both Recurring and Incident Congestion)
FFTime = Time Required in Free Flow Traffic

Appendix B: Reported Impacts of Arterial ITS Elements

Note: In Appendix B the bullets with dates and no author information came from the reference [USDOT ITS JPO Arterial Management Systems, 2008]. More information about the specific authors and articles can be found at the ITS JPO website.

Surveillance—Traffic

Positive Impacts on Traffic Operations

- An automated work zone information system deployed on a California interstate greatly reduced traffic demand through the work zone resulting in a maximum average peak delay that was 50% lower than expected (22-26 January 2006).

- Modeling showed that an advanced transportation management and traveler information system serving northern Kentucky and Cincinnati reduced delay by 0.2 minutes per trip during AM peak periods and by 0.6 minutes during PM peak periods (4-7 June 2001).

- Modeling found emissions reductions of 3.7 to 4.6% due to an advanced transportation management and traveler information system servicing northern Kentucky and Cincinnati (4-7 June 2001).

- A model indicated that an advanced transportation management and traveler information system serving northern Kentucky and Cincinnati reduced crash fatalities by 3.2% during peak periods (4-7 June 2001).

- Simulation results indicated that vehicle emissions could be reduced by 2% if arterial traffic flow data were included in the traveler information system in Seattle, Washington (30 May 2000).

- Modeling indicated that coordinating fixed signal timing plans along congested arterial corridors leading into Seattle, Washington, and incorporating arterial traffic flow data into the traveler information system would reduce vehicle delay by 7% and 1.8% respectively (30 May 2000).

- Users of the Advanced Traveler information System in Seattle, Washington were satisfied with the information on freeway and transit conditions provided via web sites and Traffic TV service (30 May 2000).

- A model determined that incorporating arterial traffic flow data into the traveler information system in Seattle, Washington could decrease the number of stops by 5.6% (30 May 2000).

- More than 99 percent of the surveyed users said they benefited from information provided by an advanced transportation management system and traveler information system serving northern Kentucky and Cincinnati (June 1999).

- Travel time on highways can be estimated with the use of the existing toll highway infrastructure. Algorithms exist to estimate the single-section travel time (Soriguera, 2008).

Negative Impacts on Traffic Operations

- For the purpose of determining travel time from point detector data, little guidance exists on how to place detectors for effective sampling on a freeway corridor (Edara, 2008).

- Challenge with single loop detector based on length based classification comes from accurately estimating speed and thus, length. Vehicle classification data are important inputs for pavement maintenance, traffic modeling and emissions evaluation (Coifman, 2007).

- Digital video is superior to analog because it can be compressed at the source to a small fraction of its original size. This reduces transmission cost while preserving speed and quality. Video digitization and compression are relatively new technologies that are evolving rapidly (Hourdakis, 2007).

- During installation, inductive loops can deteriorate pavement. They can also perform poorly under bad pavement conditions, disturb traffic, require multiple detectors for a location and water penetration will affect performance (Peeta, 2002).

- Passive Magnetic Detectors require extensive effort for installation, some models need pavement cutting, and the detectors cannot detect stopped vehicles (Peeta, 2002).

- Microwave detectors have restriction of antenna beam bandwidth and the Doppler sensors cannot detect stopped vehicles (Peeta, 2002).

- Infrared detectors may be affective by fog or snow and the detector's sensitivity to vehicles reduces in rain and fog for passive detectors (Peeta, 2002).

- Ultrasonic detector performance can be affected by temperature change and extreme air turbulence. The detectors also have problems on freeways when vehicles travel at moderate to high speeds (Peeta, 2002).

- Acoustic detection is affected by cold temperatures and some models have poor performance for slow traffic (Peeta, 2002).

- Video Image Processor detection is affected by inclement weather, shadows, vehicle projection, and time of day (Peeta, 2002).

- Trust is crucial to public acceptance of intrusive measures, but the absence of justification for surveillance, and of controls over abuses, is likely to see the rapid dissipation of trust, firstly in the assertion of national security and law enforcement agencies, and secondly in the politicians who have been rubber-stamping their demands (Wigan, 2006).

Surveillance—Infrastructure

Positive Impacts on Traffic Operations

- Dynamic message signs are able to communicate important messages to travelers, including weather conditions, incidents, construction, and homeland security and AMBER alerts. Recent FHWA policy encourages states to use their DMS infrastructure more effectively by displaying reliable travel-time information along freeway corridors (Monsere, 2007).

- Video-surveillance systems can be used to monitor public transit infrastructure. Dummy cameras can be installed to increase the perceived risk for criminal action (Mezghani, 2004).

- The potential deployment of vehicle infrastructure integration (VII) holds considerable promise to improve transportation system operations (Smith, 2007).

- Vehicle infrastructure integration (VII) represents a concept with the potential to aid in the reduction of weather-related accidents on U.S. roadways while increasing surface transportation mobility and efficiency (Petty, 2008).

- Vehicle infrastructure integration (VII) would enable vehicle-to-vehicle and vehicle-to-infrastructure communications through dedicated short-range communications (wireless radio communication at 5.9 GHz) (Petty, 2008).

Negative Impacts on Traffic Operations

- Travel times on a majority of links in Portland, Oregon were reasonably accurate under most traffic conditions, but were affected by the presence of an incident or by poor detector placement (Monsere, 2007).

- Trust is crucial to public acceptance of intrusive measures, but the absence of justification for surveillance, and of controls over abuses, is likely to see the rapid dissipation of trust, firstly in the assertion of national security and law enforcement agencies, and secondly in the politicians who have been rubber-stamping their demands (Wigan, 2006).

Traffic Control—Transit Signal Priority

Positive Impacts on Traffic Control

- In the central area of Chicago, a feasibility study indicated that driver assistance technologies and transit signal priority for bus rapid transit would be cost-effective (19 August 2004).

- When transit signal priority was not used in Portland, Oregon; bus travel times increased up to 4.2% during peak periods and up to 1.5% in non-peak periods (19-22 May 2003).

- In Dallas, Texas, simulation found that transit signal priority reduced bus travel time up to 11% during peak periods, reduced car travel times up to 16%, vehicle delay up to 4% and personal delay up to 6% (14-17 October 2002).

- In Helsinki, Finland a transit signal priority system improved on-time arrival by 22 to 68% and real-time passenger information displayed were regarded as useful by 66 to 95% of passengers (13-17 January 2002).

- A transit signal priority system in Helsinki, Finland reduced delay by 44 to 48%, decreased travel time by 1 to 11%, and reduced travel time by 35,800 to 67,500 passenger-hours per year (13-17 January 2002).

- Simulation of a transit signal priority system in Helsinki, Finland indicated that fuel consumption decreased by 3.6%, Nitrogen oxides were reduced by 4.9%, Carbon monoxide decreased by 1.8%, hydrocarbons declined by 1.2%, and particulate matter decreased by 1% (13-17 January 2002).

- During the AM peak period, transit signal priority on an arterial route in Arlington, Virginia could increase carbon monoxide emissions by 5.6% and decreased nitrogen emissions by 1.7% (13-17 January 2002).

- During AM peak period, transit signal priority on an arterial route in Arlington, Virginia could reduce bus travel time by 4.0 to 9.1%, decrease person delay of a bus passenger by 6.0 to 14.2%, and reduce transit vehicle stops by 1.5 to 2.9% (13-17 January 2002).

- Evaluation of several transit signal priority systems found decreased bus travel time variability by 35%, lowered bus travel times by 6 to 27%, reduced AM peak intersection delay by 13%, and decreased signal-related bus stop by 50 % (January 2002).

- A before-and-after study found that transit patrons experience a smoother and more comfortable ride when a transit signal priority system was implementing in Seattle, Washington (January 2002).

- In Tucson, Arizona, models indicated adaptive signal control in conjunction with transit signal priority can decrease delay for travelers on main streets by 18.5% while decreasing delay for travelers on cross-streets by 28.4% (7-13 January 2001).

- A transit priority system along an urban arterial in Vancouver, Canada reduced travel time variability by 29 and 59% during AM and PM peak periods (6-10 August 2000).

- Implementing traffic signal priority for a light-rail transit line in Toronto, Canada allowed system operators to remove one vehicle from service and maintain the same level of service to passengers (6-10 August 2000).

- At an intersection in Eindhoven, The Netherlands a transit signal priority system reduced bus schedule deviation by 17 seconds (1-4 May 2000).

- When conditional priority was deployed in Eindhoven, the Netherlands; buses experienced 27 seconds of delay without priority and no significant change in delay under conditional priority (9-13 January 2000).

- In Toronto, Canada adaptive signal control reduced ramp queues by 14%, decreased delay up to 42%, and reduced travel time by 6 to 11%; and transit signal priority reduced transit delay by 30 to 40% and travel time by 2 to 6% (8-12 November 1999).

- When bus priority was used with an adaptive signal control system in London, England average bus delay was reduced by 7 to 13% and average bus delay variability decreased by 10 to 12% (6-12 November 1999).

- A transit signal priority system in Eastleigh, England reduced bus fuel consumption by 19% and reduced bus emissions by 15 to 30%, and increased fuel consumption for other vehicles by 5% and increased the emissions of other vehicles up to 11% (1999).

- A transit signal priority system in Eastleigh, England reduced bus delay by 9 seconds/vehicle/intersection and increased delay for other traffic by 2.2 seconds/vehicle/intersection (1999).

- A transit signal priority system in Southampton, England reduced bus fuel consumption by 13%, lowered bus emissions by 13 to 25%, increased fuel consumption for other vehicles by 6%, and increased the emissions of other vehicles up to 9% (1999).

- A transit signal priority system in Southampton, England reduced bus delay by 9.5 seconds/vehicle/intersection and increased delay for other traffic by 3.8 seconds/vehicle/intersection (1999).

- There were 32 accidents along a transit way at the University of Minnesota before transit priority lights were installed, while no accidents were reported after installation of the lights (2 February 1998).

- Transit priority system in England and France have reduced transit vehicle travel times by 6 to 42%, while increasing passenger vehicle travel time by 0.3 to 2.5% (December 1995).

- A bus priority system on a major arterial in Portland, Oregon reduced bus travel times by 5 to 8% (July 1994).

- Three evaluation projects conducted in Europe found that transit signal priority reduced travel time for transit vehicle by 5 to 15% (1994-1998).

- A bus priority system in Sapporo City, Japan reduced bus travel times by 6%, decreased the number of stops by 7%, and reduced the stopped time of buses by 21% (Undated).

- In Tacoma, WA the combination of TSP and signal optimization reduced transit signal delay about 40% in two corridors (Smith, 2005)

- TriMet (Portland, OR) was able to avoid adding one more bus by using TSP and experienced a 10% improvement in travel time and up to a 19% reduction in travel time variability. Due to increased reliability, TriMet has been able to reduce scheduled recovery time (Smith, 2005).

- In Chicago PACE buses realized an average of 15% reduction (3 minutes) in running time. Actual running time reductions varied from 7 to 20% depending on the time of day (Smith, 2005).

- With the implementation of TSP and through more efficient run cutting, Pace (Chicago) was able to realize a savings of one weekday bus while maintaining the same frequency of service (Smith, 2005).

- Los Angeles experienced up to 25% reduction in bus travel times with TSP [Smith, 2005]

- It was uniformly reported that the impact to the non-priority street flow was extremely small or imperceptible. The number of seconds taken from non-priority street green is so small, it is rarely noticed (Smith, 2005).

- Reduced variability in operations or schedule adherence for buses (Smith, 2005).

- Reduced recovery time at end of run (Smith, 2005).

- Los Angeles, CA—Ridership Metro Rapid lines up 4-40% depending on the line. One-third are new transit riders (Smith, 2005).

- Vancouver, B.C.—98 B-Line reduced travel time in the corridor from 100 to 84 minutes. Resulted in a 23% modal shift from auto to transit in the corridor. Net benefit of the BRT line: CD $2.9M (US $2.4M). Main TSP benefit: significant reduction (40-50%) in travel time variability (Smith, 2005).

Negative Impacts on Traffic Control

- Typically one second delay per vehicle per cycle on non-TSP roads (Smith, 2005).

- TSP operations at *near-side bus stops* (within the detection zone) resulted in increased delays in the range of 2.85%, while TSP operations at mid-block and far-side bus stops resulted in network-wide savings in delay in the range of 1.62%. Consequently, we recommend not implementing TSP in the vicinity of near-side stops that are located within the TSP detection zone (Rakha, 2006).

Traffic Control—Emergency Vehicle Preemption

Positive Impacts on Traffic Operations

- Modeling indicated that emergency vehicle signal preemption at three intersections on a Virginia arterial route increased average travel time by 2.4% when priority was requested (July 1999).

- An emergency vehicle signal preemptions system in Houston, Texas reduced emergency vehicle travel time by 16 to 23% (April 1999).

- In Denver, Colorado emergency vehicle signal preemption reduced response time by 14 to 23% (5 October 1978)

- The emergency vehicle crash rate fell by 71% after deployment of emergency vehicle signal preemption system in St. Paul, Minnesota (19 August 1977).

- Emergency vehicle preemption has allowed Fairfax County, Virginia to reduce its response times. The system permits emergency vehicles along U.S. 1 to pass through

high volume intersections more quickly with fewer conflicts, saving 30 to 45 seconds per intersection (Paniati, 2006).

- Emergency vehicle preemption in the City of Plano, Texas has dramatically reduced the number of emergency vehicle crashes—from an average of 2.3 intersection crashes per year to less than one intersection crash every five years (Paniati, 2006).

- In addition, due to reduced delays at signalized intersections, the City of Plano can achieve the same response times with fewer fire/rescue and EMS stations than would normally be required, providing significant cost savings. The city has maintained a response time goal achievement rate of over 90 percent, contributing to its Insurance Services Office Class 1 Fire Suppression Rating—the highest possible rating on a scale from 1 to 10 (Paniati, 2006).

- Can benefit many stakeholders, including police, fire/rescue, EMS, and transit operators (if transit signal priority is also provided) (Paniati, 2006).

- Improved response times can lead to an improvement in the insurance industry ratings of a community's fire suppression service, with a corresponding reduction in fire insurance rates for residential and commercial property owners (Paniati, 2006).

- As EVP systems have the potential to improve response times and safety, this trend can translate into cost savings for the community… ITS solutions, such as EVP, can lead to improved EV response times increasing the effective service radius of a single station (Paniati, 2006).

- A study conducted by the City of Plano Risk Management Office indicated that there were 22 EV crashes from 1981 to 1983…seven occurred at signalized intersections…Over the 20 years since the installation of EVP, there have been only four crashes involving emergency vehicles at intersections. In three of these crashes, the cause of the crash was failure of the private vehicle involved to stop for the red signal display correctly generated by the EVP system. The fourth was caused by EV driver error (Paniati, 2006).

- As the city [Plano] grew, the response time benefit of EVP has been incorporated into the geographical information systems (GIS)-based planning models the city uses to evaluate fire/rescue and emergency medical service expansion needs. As a result, the city is now serving 7.5 square miles per station instead of the anticipated 5.6 square miles. The benefit to the city is that it is currently operating 10 stations compared with the 13 that had been forecast resulting in a capital cost savings for the city of approximately $9 million and an annual operating cost savings of approximately $7.5 million (Paniati, 2006).

- Increase chance of survival for the cardiac arrest or trauma patient (Paniati, 2006).

- Cost-effective alternative to building new stations by increasing the effective service radius of current facilities (Paniati, 2006).

- Provide the foundation for transit signal priority when deployed on key transit corridors (Paniati, 2006).

Negative Impacts on Traffic Operations

- Signals near emergency facilities (i.e., hospitals, trauma centers, and fire/rescue and EMS stations) will be preempted more often than others and drivers may experience delays if multiple preemption events occur during a short period of time. Each of the sites indicated that the public accepted these delays and that a public awareness campaign highlighting the public safety benefits of preemption was a key factor in reducing preemption-related complaints (Paniati, 2006).

- In Plano, some signals near hospitals often experience multiple preemption calls resulting in queues that take several cycles to clear. During peak periods, it can take 10 to 20 minutes for the traffic flow to return to normal (Paniati, 2006).

Traffic Control—Adaptive Signal Control

Positive Impacts on Traffic Operations

- Evaluation data show that adaptive signal control strategies can improve travel times in comparison to optimized signal timing plans (2 February 2005).

- A simulation study found that adaptive signal control reduced delay by 18 to 20% when compared to fixed-time signal control (13-17 January 2002).

- In Los Angeles, adaptive signal control system improved travel time by 13%, decreased stops by 31%, and reduced delay by 21% (July 2001).

- In Tucson, Arizona, models indicated adaptive signal control in conjunction with transit signal priority can decrease delay for travelers on main streets by 18.5% while decreasing delay for travelers on cross-streets by 28.4% (7-13 January 2001).

- Optimized signal timing plans, coordinated traffic signal control, and adaptive signal control reduced fuel use by 7.8% in California (11 January 2001).

- The estimated benefit-to-cost ratio for optimizing signal timing plans, coordinating traffic signal control; and implementing adaptive signal control in California was 17:1 (7-11 January 2001).

- Optimizing signal timing plans, coordinating traffic signal control, and implementing adaptive signal control in California reduced travel time by 7.4 to 11.4%, decreased delay by 16.5 to 24.9%, and reduced stops by 17 to 27% (7-11 January 2001).

- Adaptive signal control systems in Los Angeles, Broward County, and Oakland County reduced vehicles stops by 28 to 41% (December 2000).

- Adaptive signal control may lower operations and maintenance costs associated with traffic signal retiming; in Minnesota DOT signal technicians indicated that adaptive signal control systems were easy to operate and required minimal maintenance (December 2000).

- Adaptive signal control systems deployed in five metropolitan areas have reduced delay 19 to 44% (December 2000).

- Adaptive traffic signal control systems in Los Angeles, Broward County, and Newark decreased travel times by 13 to 25% (December 2000).

- Simulation revealed that in Fargo, North Dakota, a freeway management system display incident warning on DMS and integrated with adaptive signal control could decreased traveler times by 18% and increase speeds by 21% (6-10 August 2000).

- Adaptive signal control integrated with freeway ramp meters in Glasgow, Scotland improved network travel times by 10% (January 2000).

- Adaptive signal control integrated with freeway ramps in Glasgow, Scotland increased vehicle throughput 20% on arterials and 6% on freeways (January 2000).

- An adaptive signal control system in Toronto, Canada reduced vehicle emissions by 3 to 6% and lowered fuel consumption by 4 to 7% (8-12 November 1999).

- The payback period for expansion of an adaptive signal control system in Toronto, Canada was estimated at less than two years (8-12 November 1999).

- In Toronto, Canada adaptive signal control reduced ramp queues by 14%, decreased delay up to 42%, and reduced travel time by 6 to 11%; and transit signal priority reduced transit delay by 30 to 40% and travel time by 2 to 6% (8-12 November 1999).

- An adaptive signal control system in Toronto, Canada increased traffic flow speeds by 3 to 16% (8-12 November 1999).

- A simulation study of five intersections in Oakland, Michigan indicated that adaptive signal control resulted in lower travel times than optimized fixed-time signal control (8-12 November 1999).

- When bus priority was used with an adaptive signal control system in London, England average bus delay was reduced by 7 to 13% and average bus delay variability decreased by 10 to 12% (6-12 November 1999).

- Implementation of an adaptive signal control system in Anaheim, California resulted in travel time changes ranging from a 10% decrease to a 15% increase (July 1999).

- Adaptive signal control deployed in Madrid, Spain, decreased travel time by 5%, and reduced delay by 19% and the number of stops by 10% (1999).

- Adaptive signal control in Sao Paulo, Brazil, increased speed by 25% and reduced delay by 14% (1999).

- An adaptive signal control system in Oakland County, Michigan reduced travel time by 7.0 to 8.6% during peak periods (4-6 May 1998).

- Simulation of a network based on the Detroit Commercial Business District indicted that adaptive signal control for detours around an incident could reduce delay by 60 to 70% and that travel times can be reduce by 25 to 41% under non-incident conditions (June 1997).

- An adaptive signal control system in British Columbia, Canada reduced delay by 15% during peak periods (May 1997).

- A survey of drivers in Oakland County, Michigan revealed that 72% believed that they are better off after deployment of adaptive signal control (May 1997).

- The Institute of Transportation Engineers (ITE) estimates that traffic signal improvements can reduce travel time by 8 to 25% (1997).

- Simulations performed for the national ITS Architecture Program indicted that delay can be reduced by more than 20% when adaptive signal control is implemented (June 1996).

- In Toronto, Canada, an adaptive signal control system reduced travel time by 8%, decreased delay by 17%, and reduced vehicle stops by 22% (Spring 1995).

- Fuel consumption fell by 5.7%, hydrocarbons declined by 3.7%, and carbon monoxide emissions were reduce by 5.0% when an adaptive signal control system was implemented in Toronto, Canada (Spring 1995).

- A computerized signal control system in Los Angeles, California increased average speed by 16%, reduced travel time by 18%, decreased vehicle stops by 41%, and reduced delay by 44% (June 1994).

- Fuel consumption fell by 13% and vehicle emissions were reduced by 14% due to a computerized signal control system in Los Angeles, California (June 1994).

- Crash frequency declined when an advanced traffic management system and an advanced traveler information system were integrated in Oakland County, Michigan (1994).

- Integrating an advanced traffic management system and advanced traveler information system in Oakland County, Michigan increased average speed and reduced the number of stops by 33% (1994).

Negative Impacts on Traffic Operations

- Neutral/no impacts on traffic [SRF Consulting Group, 2000]

- Boundary effects (worsened travel time); The impacts from routes within the study area were mixed: travel times improve on some routes, worsen on others. Overall, results from routes within the study area reveal no significant differences in travel times between the SCOOT [adaptive] and T2000C [existing] systems…Travel time along routes that traverse the study boundary are approximately 15 percent longer with SCOOT in control (SRF Consulting Group, 2000).

- Review of each video sensor image to verify proper aiming and performance….is a relatively time-consuming task; the City plans to do it annually when interns are available [SRF Consulting Group, 2000]

- Peak period travel times within the study area show no significant change under SCOOT…some route travel times improve under SCOOT, while some worsen (SRF Consulting Group, 2000).

- Detector demanding. Adaptive control systems need real-time detector data. The decision to implement adaptive control has to be matched by a commitment to maintain the expanded detector system. Much like an actuated signal control, if detectors fail, then the benefits of adaptive control are eliminated as they revert to a fixed-time effectiveness (Martin, 2003).

- SCOOT's performance can degrade significantly when detection fails (Kelman, 2001).

- Traffic Engineers may notice an improvement. Individual drivers, not so likely (Kelman, 2001).

Traffic Control—Advanced Signal Systems

Positive Impacts on Traffic Control

- The Texas Traffic Light Synchronization Program reduced delay by 23% by updating traffic signal control equipment and optimizing signal timing on a previously coordinated arterial (October 2005).

- Across the nation, traffic signal retiming programs have resulted in travel time and delay reductions of 5 to 20%, and fuel savings of 10 to 15% (November/December 2004).

- In Oakland County, Michigan a two-phase project to retime 640 traffic signals resulted in a benefit-cost ratio of 175:1 for the first phase and 55:1 for the second (November/December 2004).

- In Oakland County, Michigan retiming 640 traffic signals during a two-phase project resulted in Carbon monoxide reductions of 1.7 and 2.5%, Nitrogen oxide reduction of 1.9 and 3.5%, and hydrocarbon reductions of 2.7 and 4.2% (November/December 2004).

- Signal retiming projects in several U.S. and Canadian cities reduced fuel consumption by 2 to 9% (April 2004).

- Signal retiming projects in several U.S. and Canadian cities decreased delay by 13 to 94%, and improved travel times by 7 to 25% (April 2004).

- Signal retiming projects in several U.S. and Canadian cities contributes to a reduction in crash frequency (April 2004).

- By implementing coordinated signal timing on the arterial network in Syracuse, New York total fuel consumption was reduce by 9 to 13%, average fuel consumption declined by 7 to 14%, average vehicle emissions decreased by 9 to 13% (September 2003).

- Coordinated signal timing on the arterial network in Syracuse, New York reduced vehicular delay by 14 to 19%, decreased total stops by 11 to 16%, and increased average speed by 7 to 17% (September 2003).

- Simulations indicated that using a decision support tool to select alternative traffic control plans during non-recurring congestion in the Disney Land area of Anaheim,

California could reduce travel time by 2 to 29% and decrease stop time by 15 to 56% (December 2001).

- Optimizing signal timing plans, coordinating traffic signal control, and implementing adaptive signal control in California reduced travel time by 7.4 to 11.4%, decreased delay by 16.5 to 24.9%, and reduced stops by 17 to 27% (7-11 January 2001).

- The estimated benefit-to-cost ratio for optimizing signal timing plans, coordinating traffic signal control, and implementing adaptive signal control in California was 17:1 (7-11 January 2001).

- Optimized signal timing plans, coordinated traffic signal control, and adaptive signal control reduced fuel use by 7.8% in California (7-11 January 2001).

- A preemptive signal control system used to minimize truck stops in Sullivan City, Texas has resulted in cost savings due to reduced fuel consumption and emissions, less pavement wear, and reduced tire and break wear (September 2000).

- In Sullivan City, Texas, a signal control system that gives priority to trucks has reduced truck stops by 100 for a weekly volume of 2,500 trucks and has reduced truck delay (September 2000).

- Modeling indicated that coordinating fixed signal timing plans along congested arterial corridors leading into Seattle, Washington, and incorporating arterial traffic flow data into the traveler information system would reduce vehicle delay by 7% and 1.8%, respectively (30 May 2000).

- A model found that coordinating fixed signal timing plans along congested arterial corridors leading into Seattle, Washington would help reduce the number of expected crashes by 2.5% and the frequency of fatal crashes by 1.1% (30 May 2000).

- Evaluation indicted that integrating DMS and incident management systems could reduce crashes by 2.8%, and that integrating DMS and arterial traffic control systems could decrease crashes by 2%, in San Antonio, Texas (May 2000).

- Modeling performed as part of an evaluation of nine ITS implementation projects in San Antonio, Texas indicated that integrating DMS, incident management, and arterial traffic control system could reduce delay by 5.9% (May 2000).

- In Arizona, traffic signal coordination among two jurisdictions contributed to a 1.6% reduction in fuel consumption and a 1.2% increase in carbon monoxide emissions.

- Evaluation of ITS implementation projects in San Antonio, Texas, demonstrated that integrating freeway DMS with incident management systems could reduce fuel consumption by 1.2%, and that integrating the DMS with arterial traffic control systems could save 1.4% (May 2000).

- Traffic signal coordination among two jurisdictions in Arizona resulted in a 6.2% increase in vehicle speeds; optimization of the coordinated timing plans was predicted to reduce AM peak period delay by 21% (April 2000).

- Crash risk along a corridor in Arizona was reduced by 6.7% due to traffic signal coordination among two jurisdictions (April 2000)

- Optimizing signal timing at 700 intersections in the Tysons Corner area of Northern Virginia lead to a 9% reduction in fuel consumption and a 134,600 kilogram decrease in annual emissions (March 2000).

- By optimizing signal timing at 700 intersections in the Tysons Corner area of Northern Virginia, delay was reduced by approximately 22% and stops were reduced by roughly 6% (March 2000).

- A simulation study indicated that integrating traveler information with traffic and incident management systems in Seattle, Washington could diminish delay by 1 to 7%, reduce stops by about 5%, lower travel time variability by 2.5%, and improve trip time reliability by 1.2% (September 1999).

- Weather-related traffic signal timing along a Minneapolis/St. Paul corridor reduced vehicle delay nearly 8% and vehicle stops by over 5% (1999).

- In Japan, upgrading traffic signals improved travel times by 17 to 21% and increased average speed by 19 to 21% (March 1998).

- Installing new traffic signals in Japan reduced crash frequency 75 to 78% and upgrading existing traffic signals reduced accidents up to 65% (March 1998).

- In the St. Paul, Minnesota region ramp metering has increased throughput by 30% and increased peak period speeds by 60% (November 1997).

- Simulation of a network based on the Detroit Commercial Business District indicted that adaptive signal control for detours around an incident could reduce delay by 60 to70% and that travel times can be reduced by 25 to 41% under non-incident conditions (June 1997).

- The delay reduction benefits of improved incident management in the Greater Houston area saved motorists approximately $8,440,000 annual (February 1997).

- The Institute of Transportation Engineers (ITE) estimates that traffic signal improvements can reduce travel time by 8 to 25% (1997).

- An advanced signal system in Richmond, Virginia reduced travel time by 9 to 14%, decreased total delay by 14 to 30%, and reduced stops by 28 to 39% (June 1996).

- An advanced signal system in Richmond, Virginia reduced fuel consumptions by 10 to 13% and decreased vehicle emissions by 5 to 22% (June 1996).

- A computerized signal control system in Los Angeles, California increased average speed by 16%, reduced travel time by 18%, decreased vehicle stops by 41%, and reduced delay by 44% (June 1994)

- Fuel consumption fell by 13% and vehicle emissions were reduced by 14% due to a computerized signal control system in Los Angeles, California (June 1994).

Negative Impacts on Traffic Control

- Overall energy consumption in the corridor is projected to increase as additional travel demand is drawn into the more efficiently operating corridor roadway system.

However, fuel economy (on a miles-per-gallon basis) within the corridor is slightly improved because of reduced stop-and-go traffic conditions. Overall emissions of pollutants (HC, CO, and NOx) are generally slightly lower, but in many cases these reductions are too small to be statistically significant (Wunderlich, 1999).

Traffic Control—Variable Speed Limit

Positive Impacts on Traffic Control

- A variable speed limit system deployed at a work zone on I-96 in Lansing, Michigan contributed to a decrease in travel times and an increase in average speeds (September 2003).

- VSL signs reduced both the average speed and the variation in speed (Riffkin, 2008).

- It can be inferred from the reduction in average speeds and deviation in speeds that the VSL signs will result in reduced work zone accidents (Riffkin, 2008).

- On "Ozone Action" days, by managing the freeway/expressway traffic speeds at appropriate levels through VSL, the major pollutants…(NOx) emissions, could be significantly reduced. A comparison of NOx emissions under the 65 mph regular speed limit and the 55 mph new speed limit shows that if the VSL is operated on an "Ozone Action Day," the variable speed limit strategy can help reduce emissions in morning off-peak hours, daytime off peak hours, and evening off-peak hours with a daily reduction of 10.8 percent (Wang, 2006).

Negative Impacts on Traffic Control

- Using variable speed limits improperly may cause confusions to drivers and consequently reduce drivers' compliance (Wang, 2006).

Traffic Control—Bicycle & Pedestrian

Positive Impacts on Traffic Control

- Automated pedestrian detection at signalized intersections tested in three U.S. cities reduced the number of pedestrians who began crossing during the steady DON'T WALK signal by 81% (August 2001).

- Vehicle-pedestrian conflicts were reduced by 89% in the first half of the crossing and 43% in the second half with automated pedestrian detection at intersections in Los Angeles, California; Rochester, New York; and Phoenix, Arizona (Spring/Summer 1999).

Negative Impact on Traffic Control

- Pedestrians may walk into the detection zone without any intent to cross the street (Turner, 2007).

- [Some sensors may have] difficulty with detecting bicyclists traveling faster than 10-15 mph (Turner, 2007).

- A motorist stopped at an intersection on a red signal phase is waiting for the green light. The driver can clearly see the device counting down and uses it as a "starting gun" to step on the accelerator as soon as the countdown displays zero seconds, even before he or she gets the green light. A pedestrian who is still in the process of crossing the street may be struck by this motorist (Huang, 2000).

- Huang and Zegeer (1999) found that those countdown signals reduced pedestrian compliance with the Walk phase. Another adverse effect was that the countdowns increased the number of people who finished crossing after the steady Don't Walk display appeared (Huang, 2000).

- Countdown signals may result in more pedestrian signal violations among some age groups. For example, teenage and young adult males (such as near high schools and universities) may try to "beat the light" after seeing that they still have several seconds to cross (Huang, 2000).

Traffic Control—Special Events

Positive Impacts on Traffic Control

- An operator at a traffic operations center may be handling other activities during a special event such as an incident not associated with the event (Dunn, 2007).

- Crash prevention through portable lighting, congestion warning signs, public information safety campaign, and enforcement (Dunn, 2007).

- Minimize quality of life impacts on represented residents and businesses (Dunn, 2007).

- The Wisconsin DOT [reported] for the opening of Miller Park in Milwaukee: "Despite the triple whammy of rush hour, an opening day crowd of 42,000 and a presidential motorcade, officials reported few problems along freeway routes leading to Miller Park Friday"[do to special events traffic planning efforts] (Dunn, 2007).

- Facilitate ongoing commercial enterprises and associated commercial deliveries (Dunn, 2007).

- Achieve predictability, ensure safety, maximize efficiency, minimize regional traffic effects from events, meet public and event patron expectations (Dunn, 2007).

- Transfer strategies to day-to-day operations (Dunn, 2007)

- Planned special events generate income through tax revenue and may also spur development. Also, showcasing a successful special event could lead to increased future tourism for the community (Dunn, 2007).

- Improve mobility; form partnerships & build trust; promote interagency coordination, resource utilization & sharing; incorporate new procedures, plans & practices into day-to-day operation of agencies (US DOT, 2005).

- CCTV emerged from this study as the "most valuable player" in the traffic-management toolbox. It was used extensively by all levels within the TOC, for surveillance, decision making, and response execution. In a new security conscious era, it also serves as a preventative public safety tool for transportation related situations (Glazer, 2003).

- CCTV deployment is expensive, but once a "critical mass" of coverage is reached, it delivers unequalled benefits for traffic management and public-safety (Glazer, 2003).

- One notable "organizational" example would be the TDM [Travel Demand Management] program, which helped avoid traffic problems by reducing travel demand (Glazer, 2003).

- The CommuterLink Website was heavily used during the [Olympic] Games for traveler information, by visitors and residents. Both the website and 511 telephone service were highly-rated by residents and visitors, although the 511 service was not as heavily used as the website. Both worked synergistically with the printed material and media coverage also used for distributing traveler information during the Games (Glazer, 2003).

- Detailed contingency planning and preparations are expensive, but they are absolutely essential and should be viewed as "event insurance." (Glazer, 2003).

Negative Impacts on Traffic Control

- Equipment failure or personnel shortages (Dunn, 2007).

Lane Management—HOV Facility

Positive Impacts on Traffic Control

- HOV lanes in Houston move 40,000 commuters in express transit buses each day, up from virtually no express transit riders in 1979.

- Los Angeles area HOV lanes move almost a million people each day, and they save an accumulated total of more than 30,000 hours of delay.

- Recent surveys in Seattle show over an 80% approval rating with their area's HOV lane system.

- In most cases on California's freeways, the introduction of HOV lanes has been followed by a gradual build-up of ridesharing and an increase in the life span of carpooling and vanpooling arrangements (May, 2007).

- California's HOV lanes offer significant time savings to ride sharers and are well utilized during the peak periods (May, 2007).

Negative Impacts on Traffic Control

- HOV lanes are under-utilized (Kwon, 2007).

- Many HOV lanes suffer degraded operations (speeds < 45mph) (Kwon, 2007).

- HOV lanes suffer a 20% capacity penalty (Kwon, 2007).

- HOV lanes offer small travel time saving; however, HOV travel times are more reliable (Kwon, 2007).

- Travel time savings do not to provide a statistically significant carpooling incentive (Kwon, 2007).

- A system with one HOV and three GP lanes carries the same number of persons per hour as a system with four GP lanes (Kwon, 2007).

- HOV lanes reduce overall congestion slightly only when the GP lanes are allowed to become congested (Kwon, 2007).

- On some projects, such as the Santa Monica Diamond Lanes and Route 237 in Santa Clara, California, accident rates have increased significantly following the introduction of HOV lanes. Yet other concurrent flow lanes have been installed with no increase in accidents (May, 2007).

- While speeds in the HOV lane were significantly greater than speeds in the non-HOV lanes, the reduced-access design saw an increase in total passenger hours, fuel consumption, and vehicle emission levels, and a decline in passenger-miles served over all combinations of carpool percentages and demand levels (May, 2007).

- A freeway with an HOV lane can store fewer vehicles, and may spread its queues more widely over the network. This is the main drawback of HOV lanes. Longer queues reduce system output if they block busy off-ramps (Menendez, 2007).

- If HOV facilities are implemented improperly, they can create bottlenecks whose damage can be enormous (Menendez, 2007).

Lane Management—Reversible Flow Lanes

Positive Impacts on Traffic Control

- Dearborn, Michigan: The comparison of travel time and travel speed also showed improvement over conventional nonreversible operations. The travel time comparison showed that, on average, the time required to traverse the reversible segment dropped an average of 16.5%, from 3 min 28 s to approximately 2 min 52 s in the morning peak and from 4 min 39 s to approximately 3 min 57 s in the afternoon peak. The comparison travel speeds showed that the average speeds recorded at the three stations within the segment increased by an average of 21.6%, from 24.2 mph to about 29.4 mph in the morning peak and from 18.1 mph to 21.3 mph during the afternoon peak period (Wolshon, 2004).

- Dearborn, Michigan: The volume comparisons showed an average total traffic volume increase of approximately 3.5% during the peak 3-h period, from about 5,415 to 5,605 vehicles; an average increase in the high 2-h traffic volume of approximately 3.4%, from about 4,029 to 4,172 vehicles; a highest 1-h traffic volume increase of

approximately 7.1%, from about 2,213 to 2,373 vehicles; and a high 15-min volume increase of approximately 5.9%, from about 627 to 665 vehicles (Wolshon, 2004).

- A project to improve operations on Memorial Drive in Atlanta, Georgia, involved the evaluation of a reversible operation. It was reported that although traffic volumes "increased modestly after the improvement," morning travel times in the major-flow direction decreased by 25% and by 5% in the minor-flow direction. During the evening peak period, travel time reductions were reduced by 24% for flows in the heavier directions and 3.5% in their lighter directions (Wolshon, 2004).

- Reversible lane operations have proven to be particularly effective at locations such as Daytona Beach, Florida, during Bike Week and at Ann Arbor, Michigan, for University of Michigan football games, where the occasional event traffic would not justify constructing additional lanes to accommodate the occasional demand. Other advantages of short-term reversible operations are that they are highly adaptable and can be deployed on an as-needed basis with little need for permanent or long-term control systems and equipment. As a result, they are far less expensive than similar permanent configurations (Wolshon, 2004).

- Enhancement of transit and high-occupancy vehicle (HOV) operations (Wolshon, 2004).

- Traffic management for planned special events (Wolshon, 2004).

Negative Impacts on Traffic Control

- Gwinnett County, Georgia: The overall conclusion was that the reversible segment had an "accident experience no higher than a 6-lane road with a two way left turn lane [TWLTL]. However, injury and fatality rates are significantly greater than [on] the TWLTL roadway." Ultimately, the general feeling was that the reversible operation was dangerous and the section of highway would be reconstructed to a divided highway (Wolshon, 2004).

- It is assumed that pedestrian problems would be limited to arterial roadways, in which people would not be aware of the direction from which traffic was approaching. The effect for pedestrians could be most significant for fully reversible roadways where traffic in the lane adjacent to the pedestrian walkway would be flowing in either direction during different times of the day (Wolshon, 2004).

- ITE stated that some of the noteworthy disadvantages of reversible operation were a reduced capacity for flow in the minor direction and operational difficulties at the termini. Unfortunately, however, neither of these phenomena has been evaluated in significant detail (Wolshon, 2004).

- Officials at the South Carolina DOT suggested a study on the issues of safety where guardrail and bridge ends are not protected in the reversed direction (Wolshon, 2004).

Lane Management—Pricing

Positive Impacts on Traffic Control

- Congestion charging in London resulted in pollutant emission reductions: 8% for oxides of nitrogen, 7% for airborne particulate matter, and 16% for carbon dioxide (July 2007).

- Congestion pricing in London decreases inner city traffic by about 20% and generates more than £97 million each year for transit improvements (January 2006).

- Survey data collected from an organization of approximately 500 businesses in London indicated that 69% of respondents felt that congestion charging had no impact on their business, 22% reported positive impacts on their business, and 9% reported an overall negative impact (January 2006).

- Congestion mitigating benefits of cordon charging in London enabled taxi drivers to cover more miles per hour, service more riders, and decrease operating costs per passenger-mile (January 2006).

- Brought about increased use and effectiveness of public transport, in particular buses. The first year saw a 37 % increase in the number of passengers entering the charging zone by bus during charging hours (Karlsson, 2008).

- Within the [London] charging zone the number of vehicles subject to the scheme charges fell by 30 % between 2002 (prior to implementation) and 2005, whereas the number of non-chargeable vehicles [taxis, buses, bicycles, powered two-wheelers] increased by 12 % (Karlsson, 2008).

- Transport for London…estimated that the changes in traffic within the zone have been responsible for between 40 and 70 fewer accidents resulting in personal injury within the zone and on the inner ring road (Karlsson, 2008).

- Stockholm: reduced noise levels (Karlsson, 2008).

- *Acceptance increases with familiarity.* The availability of alternative un-tolled routes is perhaps significant for the acceptance of charges on expressways, but success in decongesting traffic is at least as important a factor. For citywide charging systems, lack of un-tolled road alternatives increases political sensitivity but in both London and Stockholm public opinion became favorable once the systems were in operation and achieving their objectives (CEMT, 2007).

- Journey times across the centre of [London] improved (cut 14%) (CEMT, 2007).

- Current estimates, based on an $8 charge for entering Manhattan south of 86th Street, place annual revenue from the charge at roughly $400 million in the first year and up to $900 million by 2030 (TransAlt, 2008).

- Stockholm: The congestion charge resulted in a 20% reduction in traffic, while air pollutants dropped roughly 10% (TransAlt, 2008).

- Singapore: The charge has been successful in reducing the number of solo drivers and shifting trips from peak to non-peak times. Singapore's Congestion Zone has seen a

13% reduction of traffic during charging period. It has also led to a reduction of 24,700 cars driving during peak and a 22% rise of traffic speeds (TransAlt, 2008).

Negative Impacts on Traffic Control

- The scheme has been seen as controversial and has faced strong opposition from sections of the media, politicians, motorist groups, business interests, some London residents, and labor organizations (Karlsson, 2008).

- The new [Quinnipiac University] poll found that [as late as Nov 2007] 61 percent of city voters now oppose the congestion pricing plan, compared with 33 percent who favor it (NYTimes).

Lane Management—Lane Control

Positive Impacts on Traffic Control

- Overhead signs with static and changeable messages are used to manage traffic flow, reduce congestion, and communicate incidents and other information (Njord, 2006).

- Speed management and control were the focus of a number of European Union efforts to reduce crashes and their consequential injuries and fatalities. The 85-percent reduction in crashes measured in one study of a French motorway is noteworthy and reflects the possible benefits of this strategy (Njord, 2006).

- Video incident detection was demonstrated in a way that reflected significant potential value in improving safety. Critical to successful use of video detection are the algorithms used to discern between typical traffic flow and activity and the circumstances associated with an incident or crash (Njord, 2006).

- Reduce frequency of collision when motorist encounter congested conditions, work zones, or incidents (OTM, 2003).

- Improve throughput and/or reduce emissions by achieving more uniform and stable traffic flow as demand approaches capacity (OTM, 2003).

- Improve reliability of travel times for certain classes of travelers (OTM, 2003).

- Distribute total delay in a more equitable manner, preserving some capacity for downstream segments (OTM, 2003).

- Increase the efficiency of operation under reduced capacity conditions cause by incidents or maintenance operations (OTM, 2003).

- Divert some freeway traffic to alternative routes or encourage alternative departure times to better use corridor capacity. This will reduce peak-period traffic demand on the freeway (OTM, 2003).

- Extend pavement life (by restricting trucks from particular lanes) (OTM, 2003).

Negative Impacts on Traffic Control

- Drivers are inundated with information (including that provided by typical signing, advertising, and cellular services) and can become overwhelmed if the information isn't presented in an easily understood manner (Njord, 2006).

- If general purpose lanes and managed lanes aren't overseen by the same incident response team, a scenario exists for decrease in efficiency of the system. The negative potentials within these scenarios can be mitigated though multi-agency cooperation i.e. mutual aid agreements, hold-harmless agreements, quick clearance policies, abandoned vehicle policies, post-indecent briefings, shared information, etc. (Ballard, 2005).

- Some incompatibilities exist with various portable dynamic message signs that have been purchased over time. However, standards continue to be developed to facilitate interoperability and interchangeability with equipment provided by different manufactures (SDDOT, 2004).

- Information shared across jurisdictions/agencies may have different meanings which interfere with information sharing. For instance, one agency may consider "clear" to be when everyone at the incident is gone, while another agency may define "clear" as all lanes of traffic being open, but the emergency response organizations are still at the location (Findley, 2001).

Lane Management—Emergency Evacuation

Positive Impacts on Traffic Operations

- Annual contracts should be let before the hurricane season to provide the additional personnel and equipment that may be necessary if an evacuation in called and for the repair of infrastructure during the recovery (Ballard, 2007).

- A tool that can be used during evacuation is "contraflow," otherwise known as "lane reversal" and "reverse lane." This evacuation plan calls for operating four-lane divided controlled-access highways so that traffic in all four land traveling away from the coast toward inland destinations where the dangers posed by the approaching hurricane are significantly reduced (Ballard, 2007).

- Some states including North Carolina and Alabama choose to operate contraflow only during daylight hours, but not all states have ruled out nighttime operation (Ballard, 2007).

- DMS, PCMSs (portable changeable message signs), flip-down signs, highway advisory radio, Wizard CB, and 511 have all been shown as effective to communicate with evacuating and reentering motorists during an emergency evacuation (Ballard, 2007).

- Evacuees can benefit from motorist information on websites as well if the technology is available (Ballard, 2007).

- Courtesy patrols provide a department of transportation (DOT) with an excellent positive customer service image and help to facilitate traffic flow by getting a stalled

vehicle off the road or shoulder, they also contribute greatly to the image of the department (Ballard, 2006).

- The relatively new and growing 511 Traffic and Travel Information telephone system can be used to disseminate information during an evacuation (Ballard, 2006).

- Technology systems like variable message signs and highway advisory radio can be adopted in greater numbers though the region to facilitate the distribution of information to evacuees, whose stress level can be reduced if they have real time information about the threat and their best course of action (Pal, 2005).

Negative Impacts on Traffic Operations

- If preplanning is not completed prior to an emergency evacuation, the evacuation will not be as effective. In addition, preplanning must not be done only once; the process and the findings need to be updated regularly on at least an annual basis (Zimmerman, 2007).

- Contraflow lanes or shoulders can be used by motorists during evacuations, but introduce unusual features to drivers. Often times there are no or few traffic signs, entrance ramps may be used as exit ramps, motorist encounter "wrong way" messages from pavement markings, and so forth (Ballard, 2007).

- One problem that is faced with using contraflow lanes is the terminus and how to avoid congestion without overwhelming the system (Ballard, 2007).

- If center-to-center communications between the evacuating communities and refuge communities, as well as with the rural areas and pass-through communities along evacuation routes are not established confusion will ensue for the motorists (Ballard, 2007).

- Because of motorist are unfamiliar with using contraflow lanes it is recommended that vehicles towing trailers and trucks be directed to the normal lands and be restricted from the contraflow or emergency shoulder lanes (Ballard, 2006).

Parking Management—Data Collection

Positive Impacts on Traffic Operations

- In European cities, advanced parking information systems have reduced traffic volumes related to parking space search up to 25% (August 1999).

- Excessive parking requirements waste resources, both directly, by increasing the money and land devoted to parking facilities, and indirectly, by increasing automobile use and sprawl. Better parking management actually tends be more *conservative* overall (Litman, 2008).

- Parking management can help solve a variety of economic, social and environmental problems, increase economic productivity, and make consumers better off overall (Litman, 2008).

- Newer electronic systems…can accommodate various payment methods (coins, bills, credit and debit cards, and by cellular telephone or the Internet), charge only for the amount of time parked, incorporate multiple rates and discounts, automatically vary rates by day and time, and are convenient to use (Litman, 2008).

- Payment systems can be integrated with other public services such as transit, roads tolls, and telephone use. Some employ contactless technology which automatically deducts payment. Newer systems also produce printed receipts and record data for auditing, which prevents fraud and increases convenience for customers, operators, and local governments (Litman, 2008).

- Evaluations (empirical and simulation) of PGI [parking guidance information] systems suggest that they…can significantly reduce parking facility queues, and may produce relatively modest overall system-wide reductions in travel time and vehicle travel (Shaheen, 2005).

- In general, smart parking technology allows people to dynamically reserve and pay for parking. Such technology may facilitate the introduction of parking pricing policies and significantly reduce auto travel and increase transit ridership. Paying for parking at Bay Area transit stations may be more palatable to motorists, if they feel they are getting an advanced benefit from it. Furthermore, motorists may pay a premium for the luxury of knowing that they won't have to circle for parking once they arrive at their destination (Shaheen, 2005).

- Smart parking may achieve what many of its forerunners have attempted to: more efficient use of existing land dedicated to parking (Shaheen, 2005).

- The systems in Torbay and Turo were found to reduce queue lengths at full parking garages, and in Liecester a significant number of cars were diverted from parking garages that were full or almost full. Reduction in queues and a more even distribution of parking facility use have been reported in the Osaka and Tokyo, Japan, systems (Shaheen, 2005).

- The system produced "greater visitor satisfaction with trips to downtown St. Paul, Minnesota, along with decreased parking-related congestion around event sites, better use of available parking spaces in various ramps and lots, and improved patronage of St. Paul's cultural institutions, parks, businesses, hotels, and shopping complexes (Shaheen, 2005)."

- A modeling study of the Frankfurt main system found that search times were reduced…PGI systems reduced individual travel times (or avoided search times) by four percent and wait times (or time queuing) by five percent…Another study found that city center traffic in a small town in the Netherlands could be reduced by 32 percent…An optimization model found that a system in Tama New Town near Tokyo would significantly reduce queue lengths and vehicle kilometers traveled…[A] network modeling study of the Southampton (U.K.) PGI system, found "savings can be achieved for each section of the journey individually (driving, queuing, searching and walking)" but "the greatest proportionate savings are obtained in queuing time (up to 7% overall)" and thus the system "has the effect of spreading the demand more evenly across car parks." However…when the study results were evaluated at the network-

level, reductions in average travel time were minimal…with reductions in total travel time for all drivers in the [40,000 vehicle] network typically in the range of 0.1-1.0% (Shaheen, 2005).

- Smart parking management systems that improve transit access may increase transit mode share and revenues, and thus reduce vehicle travel, fuel consumption, and air pollution (Shaheen, 2005).

- *AVI (Automatic Vehicle Identification) technology tags:* High-security tags can combine a personal access card ID and vehicle ID to generate access for both driver and vehicle throughout the airport premises"…These systems can also monitor taxis and other courtesy vehicles, to identify "known vehicles as they enter and exit the premises," and help focus security efforts (Shaheen, 2005).

- In an increasingly digital and wireless age, parking managers can take advantage of available technology to reduce operation, maintenance, and enforcement costs [via smart payment methods] as well as to improve motorist ease and convenience (Shaheen, 2005).

- Potential benefits of e-parking:
  - Reduced search time;
  - Easier parking payment;
  - Certain parking at trip destination;
  - Customized information;
  - Parking information provided before and during trip;
  - Improved use and management of existing parking spaces;
  - Greater security (cashless payment, knowledge of customers, and improved antifraud measures); and
  - Increased revenues (Shaheen, 2005).

Negative Impacts on Traffic Operations

- Not reported

Parking Management—Information Dissemination

Positive Impacts on Traffic Operations

- In European cities, advanced parking information systems have reduced traffic volumes related to parking space searches up to 25% (August 1999).

- Remote parking requires providing adequate use information and incentives to encourage motorists to use more distant facilities. For example, signs and maps should indicate the location of peripheral parking facilities, and they should be significantly cheaper to use than in the core. Without such incentives, peripheral parking facilities are often underused while core parking is congested (Litman, 2008).

- Improve User Information and Marketing: Provide convenient and accurate information on parking availability and price, using maps, signs, brochures and electronic

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communication (typical reduction in amount of parking required: 5-15%) (Litman, 2008).

- Impacts generally increase over time as programs mature. A low value may be appropriate the first year, but increases to medium after two or three years, and high after five or ten years (Litman, 2008).

- Research suggests a significant relationship between transit use and transit station parking (Merriman, 1998; Ferguson, 2000). Quick, convenient auto access to park-and-ride lots can be essential to making transit competitive with the auto particularly in suburban areas (Shaheen, 2005).

- Reduce central city peak hour congestion: Parking search traffic can be a significant contributor to central city congestion during peak commute hours. In fact, many have estimated that such traffic composes between 25 to 50% of all peak period traffic (Shaheen, 2005).

- Reduce airport parking delays: A 1994 study of U.S. airport operators indicated that passengers experience significant delays accessing airport parking (Shaheen, 2005).

- Khattak and Polak (1993) evaluate a real-time parking information system in Nottingham, England, in which "real-time information was disseminated through the radio, while historical information regarding parking lots was disseminated through newspaper advertisements and leaflets." The results indicate that "drivers were more inclined to use the relatively under-utilized park-and-ride facilities instead of the city center car parks, if they received parking information from newspaper advertisements and leaflets." This study suggests the importance of pre-trip information with respect to parking choice and increased transit use (Shaheen, 2005).

- On-road survey data was collected (3,893 motorists) and evaluated to examine the effect of traffic information on driver behavior. The study found that 23.4% of respondents would not change their mode, route, or departure time and 50% were receptive to pre-trip information and as a result may alter their mode, route, or departure time (Shaheen, 2005).

- German Ministry of the Interior [opinion] surveys cited the highway park-and-ride displays in the Frottmaning system as the main reason many motorists have shifted from driving to taking the train to work. A survey about the Toyota, Japan system indicated that after six months of operation: (1) 95% of respondents were aware of the signs; (2) 71% made use of the information; (3) 87% thought the system was helpful; and (4) 32% of those who used the system lived outside the city (Shaheen, 2005).

Negative Impacts on Traffic Operations

- Not reported

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Information Dissemination—Dynamic Message Signs (DMS)

Positive Impacts on Traffic Operations

- Simulations indicated that using a decision support tool to select alternative traffic control plans during non-recurring congestion in the Disney Land area of Anaheim, California could reduce travel time by 2 to 29% and decrease stop time by 15 to 56% (December 2001).

- A model indicated that an advanced transportation management and traveler information system serving northern Kentucky and Cincinnati reduced crash fatalities by 3.2% during peak periods (4-7 June 2001).

- Modeling found emissions reductions of 3.7 to 4.6% due to an advanced transportation management and traveler information system serving northern Kentucky and Cincinnati (4-7 June 2001).

- Modeling indicated that an advanced transportation management and traveler information system serving northern Kentucky and Cincinnati reduced delay by 0.2 minutes per trip during AM peak periods and by 0.6 minutes during PM peak periods (4-7 June 2001).

- A simulation study of the road network in Seattle, Washington demonstrated that providing information on arterials as well as freeways in a traveler information system reduced vehicle-hours of delay by 3.4% and reduced the total number of stops by 5.5% (6-9 November 2000).

- A simulation study of the road network in Seattle, Washington demonstrated that providing information on arterials as well as freeways in a traveler information system increased throughput by 0.1% (6-9 November 2000).

- Reduce Travel time (Mounce, 2007)

- Increase travel speeds (Mounce, 2007)

- Decrease the number of stops (Mounce, 2007)

- Can reduce the delay and risks caused by crashes, stalls, disabled vehicles, and construction, etc. (Mounce, 2007)

- Improve safety (Mounce, 2007)

- Increase throughput (Mounce, 2007)

- Cost savings (Mounce, 2007)

- Reduced emissions (Mounce, 2007)

- Reduced fuel consumption (Mounce, 2007)

- Graphic-aided DMS messages helped improve the responses of non-native-English-speaking drivers (Wang, 2008).

Negative Impacts on Traffic Operations

- Elderly drivers responded slower and less accurately than younger drivers to Dynamic Message Signs (Clark, 2008).

- Can overload the driver with information and they no longer use or pay attention to the DMS (Mounce, 2007).

- In order for DMSs to produce appropriate driver response, the messages must be meaningful, accurate, timely, and useful. If the messages displayed on DMSs have not adhered to these guidelines, driver credibility will be lost (Mounce, 2007).

- Driver confidence in DMS signs can be lost by: displaying inaccurate or unreliable information; displaying information too late for drivers to make an appropriate response; displaying messages drivers do not understand; displaying messages that are too long for drivers to read; not informing drivers of major incidents; telling drivers something they already know; displaying information not related to environmental, roadway, or traffic conditions, or routing; and displaying garbled messages (Mounce, 2007).

Information Dissemination— In-Vehicle Systems (IVS)

Positive Impacts on Traffic Operations

- Information assists travelers in selecting their mode of travel, route, and departure times. Dynamic information comes from a variety of sources including road-based sensors, surveillance equipment, and driver information (US DOT JPO, May 2003).

- Results show a 30% (310msec) increase in reaction time when the speech-based system is present (Caven, 2001).

- With the development of laptop, palmtop, and wearable computers, together with cellular communication technology, the idea of placing computers in cars and trucks has become very attractive. These new information systems can enhance mobility and productivity, but they may also distract drivers and undermine safety (Caven, 2001).

- Speech-based interaction offers a promising alternative to the graphical user interface of desktop computers, one that seems consistent with the visual and motor demands of driving- a speech based interface allows drivers to keep their hands on the wheel and eyes on the road (Caven, 2001).

Negative Impacts on Traffic Operations

- Speech-based interaction with an in-vehicle information system has the potential to distract the driver even though they are not required to take their eyes off the road. A high amount of cognitive demand may be placed on a driver when errors occur in the interchange between the driver and the speech-based system (Lee, 2001).

- Recent studies have reported that hands-free cell phones have at least as great a risk factor as hand-held phones (Kelly, 2005).

- Results from studies have indicated that the use of cell phones while driving, whether dialing, answering, or conducting mobile telephone calls, may add a significant increment of risk to the driving tasks. Making a call during a trip may more than triple the risk of a crash (Kelly, 2005).

Information Dissemination—Highway Advisory Radio (HAR)

Positive Impacts on Traffic Operations

- A simulation study of the road network Seattle, Washington demonstrated that providing information on arterials as well as freeways in a traveler information system reduced vehicle-hours of delay by 3.4% and reduced the total number of stops by 5.5% (6-9 November 2000).

- A simulation study of the road network in Seattle, Washington demonstrated that providing information on arterials as well as freeways in a traveler information system increased throughput by 0.1% (6-9 November 2000).

- Broadcast range may vary from one to six miles depending on the power of the transmitter and the surrounding terrain (Henry, 2007).

- Nearly all HAR systems use the AM band and do not contain entertainment or commercial messages and are available to broadcast 24 hours a day (Henry, 2007).

- No additional equipment is needed to receive HAR broadcast since most vehicles and trucks have AM radios (Henry, 2007).

- Information typically relayed to motorist through HAR include: construction project information on work zone restrictions and closure durations; hazardous roadway conditions caused by inclement weather; operating restrictions such as requirements to put on snow tires or chains; warnings of hazards such as forest fires, floods, mudslides or highway closures; traffic conditions along short segments of specific routes, especially work zones; alternative recommended detour routes; directions and information for tourist attractions; parking availability; public transit alternatives; and notices of events (Henry, 2007).

Negative Impacts on Traffic Operations

- Some challenges of implementing HAR include: maintaining accurate, up-to-date messages to be relayed to motorists; designing messages so that they are comprehensive yet succinct; maintaining AM signals at a quality that is clear and enjoyable to listen to; providing reliable power for 24-hour operation; and providing adequate coverage across a limited area (Henry, 2007).

- Under some conditions, placing, installing and maintaining antennas can be costly, as well as the staffing and equipping of a central control facility to coordinate information from multiple agencies (Henry, 2007).

- Deployment in rural or suburban areas tends to be more successful than in urban areas, where structural interference is a problem. Also, HAR is licensed as a secondary user

under the guidelines established by the Federal Communications Commission (FCC), which means HAR transmission cannot interfere with primary users such as commercial broadcast stations and the FCC limits antenna height approximately fifty feet, which limits its broadcast quality (Zimmerman, 2007).

- In a case study done at the Phoenix International Raceway during the spring 2005 NASCAR races, the HARs became inoperable due to radio interference from the sheer number of communications devices operating at the same time in the area, which caused the HAR to be unsuccessful (Zimmerman, 2007).

Enforcement—Speed Enforcement

Positive Impacts on Traffic Operations

- In Brazilian cities, automated speed and red light enforcement lowered crash frequency by 14%, decreased crash injuries by 19 to 98%, and fatalities 7 to 83% (2001).

- In London, England; automated speed enforcement systems have reduced speed by 10%, decreased all crash injuries by 20%, and reduced serious and fatal crash injuries by 50% (March 1995).

- Six months after mobile speed cameras were deployed in the District of Columbia, mean vehicle speeds declined 14 percent, and the proportion of vehicles exceeding the speed limit by more than 10 mph declined 82 percent (Retting, 2008).

- In Garland, Utah, highly publicized speed camera enforcement reduced mean speeds in a 20 mph school zone from 36 to 22 mph (Retting, 2008).

- A recent evaluation of automated speed enforcement on Spain's Barcelona beltway reported a 27 percent decrease in crashes following installation of speed cameras, equivalent to preventing an estimated 364 collisions and 507 people injured during the 2-year study period (Retting, 2008).

- One factor that may have contributed to the large spillover effects well beyond the 8-mile enforcement corridor was extensive media coverage of the Loop 101 pilot program (Retting, 2008).

- The size of the effect on speeding 10 mph or more above the speed limit varied by type of study site — 70% on streets with both warning signs and speed cameras, 39% on streets with just warning signs, and 16% on residential streets in the same county with neither warning signs nor speed cameras. The finding of speed reductions beyond the specific locations where cameras were deployed during the initial enforcement period is evidence that highly visible automated enforcement can promote community-wide changes in driver behavior (Retting, 2008).

- Even if the camera is not operating during certain periods, the traveling public would likely be unaware of this fact (Decina, 2007).

- Mountain et al. (2004) indicate that fixed camera speed enforcement reduced frequencies of injury crashes by about 25% up to 500 m from camera sites and 24% on aggregate up to 1 km upstream and downstream of camera sites over an average 2.3-

year after-period. The authors therefore suggest that monitoring for longer distances can document greater overall crash savings…Cameras could have benefits beyond 1 km, but this study could not assess that outcome (Decina, 2007).

- Evidence for shifting of traffic to other routes, sufficient to contribute 5% of the overall treatment-related decrease in crashes (Decina, 2007).

- The British Columbia, Canada, ASE program apparently used no warning signs advising of the automated speed enforcement although there was general publicity of the program…A significant reduction in mean speeds at monitoring sites lacking photo radar enforcement suggests a generalized province-wide decrease in speeding following program implementation. The estimated 25% reduction in daytime, unsafe speed-related collisions province-wide and reductions in victims carried by ambulances (-11%) and in fatalities (-17%, trend) concurrent with reductions in speed indicates that the program was effective at improving safety. The study did not examine possible effects on other-injury or no-injury crashes… The evaluation covered only the first year of operation and thus, longer-term impact or sustainability, was not addressed (Decina, 2007).

Negative Impacts on Traffic Operations

- One example of a popular form of resistance to speed detection technology is the use of a radar detector. Radar detectors, which are illegal in Virginia, sound a warning to the driver when they detect the microwave signal emitted by the radar unit. Drivers have also tried using other methods to avoid being caught speeding by radar. These methods included using transmitters designed to disrupt the radar signal, putting nuts and bolts in the hubcaps, painting the fan blades with aluminum paint, and attaching hanging chains to the undercarriage of the car. There is even a 160-page book entitled *Beating the Radar Rap*. Photo-radar will no doubt encounter many, if not all, of these methods of resistance (Lynn, 1992).

- People finding ways to evade identification and prosecution: "To avoid being recognized, people would speed by the Orbis [camera] machine wearing a Halloween Mask (Lynn, 1992).

- Constitutional arguments: Because a citation for a speeding violation detected by photo-radar must pass through a development process and is issued through certified mail, there is a delay between the time of the violation and the issuance of a citation that could undercut efforts by a violator to prepare a legal defense. For this reason, a ticketed driver could assert that photo-radar use constitutes a denial of due process of law (Lynn, 1992).

- Admissibility of photographic evidence *without* a witness (such as a police officer present at the scene, which I take is unlikely for speed enforcement cameras) for the prosecution of violators (Lynn, 1992).

- The photo-radar system would be set up outdoors, and tampering with the system would be possible in un-monitored locations (Lynn, 1992).

- In some instances, more than one vehicle may be shown in the same photograph, thereby creating difficulty in determining which of the drivers was speeding (Lynn, 1992).

- "It is clear that under Maryland law the mailing of citations to the residence of the alleged offender would violate the service requirements incorporated in the Maryland Transportation Code, Section 26-203. Section 26-203 specifically requires at the time of issuance the driver's signature as acknowledgment of receipt of a traffic citation. Therefore, using photo-radar in Maryland would require either statutory revision or personal issuance of the citations by police officers (Lynn, 1992).

- Virginia feasibility study: Three manufacturers took pictures of receding traffic as part of the demonstration, with two of these also taking pictures of approaching traffic. Of these three companies, the license plate number could be determined from the photograph in 58.6%, 39.6%, and 8.5%, respectively. With the additional requirement that the speeding vehicle be identifiable in multivehicle pictures, these percentages dropped to 51.9%, 24.1%, and 7.4%, respectively (Lynn, 1992).

- Four manufacturers took pictures of oncoming traffic as part of the demonstration. In these pictures, both the license plate and the driver's face were required to be identifiable. For these four firms, 23.1%, 13.1%, 9.1%, and 8.6%, respectively, of the pictures met this requirement. When the requirement that the speeding vehicle be identifiable in a multivehicle photograph was added, the percentages for the four firms dropped to 13.3 percent, 7.5%, 8.4%, and 4.2%, respectively (Lynn, 1992).

- All equipment tested is capable of detecting and properly photographing a much higher percentage of speed violators than can the average police officer in a patrol car (Lynn, 1992).

Enforcement—Stop/Yield Enforcement

Positive Impacts on Traffic Operations

- In Great Britain, automated speed and red-light enforcement reduced the percentage of vehicles exceeding the speed limit by 58%, the number of persons killed or seriously injured by 4 to 65%, and the personal injury accident rate by 6% (11 February 2003).

- 70% of survey respondents in Great Britain thought that automated speed and red-light enforcement cameras were a useful ways to reduce accidents and save lives (11 February 2003).

- Automated enforcement at intersections in the United States reduced traffic sign violations by 20 to 87% (13 August 2001).

- In the United States, approximately 60 to 80% of survey respondents approve of automated enforcement system at traffic signals (13 August 2001).

- Automated red light enforcement at 11 intersections in Oxnard, California reduced crashes by 7%, decreased right-angle crashes by 32%, lowered injury crashes by 29%, and reduced right-angle injury crashes by 68% (7-11 January 2001).

- In Brazilian cities, automated speed and red light enforcement lowered crash frequency by 14%, decreased crash injuries by 19 to 98%, and fatalities by 7 to 83% (2001).

- A survey conducted in 10 U.S. cities indicted that 76 to 80% of drivers strongly favor automated red light enforcement systems (6-10 August 2000).

- An automated enforcement system in Charlotte, North Carolina reduced red light violations by 75% and decreased associated crashes by 9% (May/June 2000).

- Automated red light enforcement in Fairfax, Virginia has reduced the crash rate by 35% (16 March 2000).

- Automated red light enforcement system has reduced right-angle crashes by 32% in Victoria, Australia; and decreased crash frequency by 47% and red light violations by 53% in Howard County, Maryland (January/February 2000).

- Automated enforcement systems in Arizona, California, Maryland, and New York have reduced red-light violations by 20 to 60% and crashes by 22 to 51% (December 1999).

- Automated red light enforcement reduced the number of violations by 42% at 5 intersections in San Francisco, California (March 1999).

- Studies in six metropolitan areas of the United States and Australia; automated enforcement system reduced red light violations by 20 to 60%, decreased right-angle crashes by 30%, and reduced crash injuries by 10% (August 1997).

- Automated enforcement systems have reduced light violations by 50 to 60% at two intersections in Fort Mead, Florida and Jackson, Mississippi (17 March 1995).

- In London, England; automated speed enforcement system have reduced speed by 10%, decreased all crash injuries by 20%, and reduced serious and fatal crash injuries by 50% (March 1995).

- Higher motorist yielding rates were observed for both directions at the N 170th St location with marked crosswalks; motorists yielded as often as 33% of the time in comparison to 7% before the crosswalks were marked (Nee, 2003).

- Data suggest that when pedestrians pushed the button to activate the [flashing crosswalk] signs, motorists were more likely to yield…For pedestrians who pushed the button at both locations, almost 90% of the time traffic from one direction would yield, whereas when pedestrians did not push the button, traffic would yield only half the time or less. This finding suggests that the roving eyes system has positive effect on motorists' yielding action (Nee, 2003).

- When motorists did yield to pedestrians, they tended to stop at the yield bars (Nee, 2003).

- The red light violation data collected at the study intersections before and after the installation of white lights were compared. According to the data collected during the morning and evening peak periods, the total number of violations (AM and PM hours combined) across 17 study intersections was reduced from 759 to 567… it may be stated that the installation of white lights coupled with aggressive enforcement was able to significantly reduce the number of red light violations (Reddy, 2008).

- White light enforcement: The analyses showed that while the average annual crash frequency of all crashes had increased over time at the 25 study intersections, the number of red light running crashes (all approaches combined) was reduced (Reddy, 2008).

Negative Impacts on Traffic Operations

- Advance stop/yield line: If placed too far in advance of the crosswalk, motorists may ignore the line (walkinginfo.org, 2007).

- Prohibiting RTOR may cause congestion at locations with high right turn movements (walkinginfo.org, 2007).

- The presence of the cameras also seems somewhat correlated with an increase in the *number of rear-end crashes*. In Fairfax County, these increases were significant, whereas in Fairfax City and Vienna, the increases were statistically insignificant. In Falls Church, cameras were associated with an insignificant decrease in rear-end crashes (Garber, 2005).

- The cameras are correlated with an increase in total crashes of 8% to 17% (Garber, 2005).

- The cameras are correlated with an increase in total injury crashes, with the increase being between 7% and 24% (Garber, 2005).

- The cameras are correlated with an increase in rear-end crashes related to the presence of a red light; the increase ranges between 50% and 71% (Garber, 2005).

- Red light cameras: Generally, the number of violations will decrease (which will reduce revenue) while many cost components will remain fixed, such as maintenance expenses (Garber, 2005).

- In a move unprecedented in the Bay Area, the city's traffic engineers have created a traffic signal with attitude. It senses when a speeder is approaching and meters out swift punishment. It doesn't write a ticket. It immediately turns from green to yellow to red…[The city of] Thousand Oaks has discovered a few hiccups, [senior civil engineer] Mashiko said. Pedestrians, for example, must be given the green on all four crosswalks in the intersection at the same time, so they are not confused by a sudden yellow and red aimed at a speeder. In addition, red rage could become an issue as drivers can be guilty by association if a speeder is just in front of them, just behind them or moving simultaneously in the opposite direction. Pleasanton plans to address at least one of those issues: the opposite- direction speeder. The Pleasanton signal will allow a red light to shine in just one direction, letting the light stay green for the non-speeding driver in the opposite direction. In such cases, any cross traffic will continue receiving the red light (Bulwa, 2004).

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Appendix C. Implementation Requirements and Cost Matrix for Arterial ITS Elements

Acronyms
COTS – Commercial-off-the-shelf software
IDAS – ITS Deployment Analysis System
MMW – Millimeter Wave Radar

*Note all dollar values have been adjusted to the year 2006.

Table C1: Equipment Costs for Emergency Response Center (ER)

		Price in 2006 Dollars		
	Life (years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Basic Facilities, Comm for Large Area		5380	538-807	For population >750,000. Based on purchase of building rather than leasing space. Communications includes communication equipment internal to the facility such as equipment racks, multiplexers, modems, etc.
Emergency Response Hardware	10	8-10	0.15-0.20	Includes 3 workstations.
Emergency Response Software	10	68-146	0.5-3.4	Includes emergency response plans database, vehicle tracking software, and real traffic coordination.
Emergency Response Labor			73-240	Two people. Salary costs are fully loaded including salary, overtime, overhead, benefits, etc.
Emergency Management Communications Software	20	5-10	2.4-5	Shared database between 4 sites. Cost is per site; software is COTS.
Hardware, Software Upgrade for E-911 and Mayday	10	102-175	1.7-2.4	Data communications translation software, E911 interface software, processor and 3 workstations.
800 MHz 2-way Radio	5	0.7-1.6	0.08-0.11	Cost is per radio.

Table C2: Equipment Costs for Emergency Vehicle On Board (EV)

		Price in 2006 Dollars		
	Life (years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Communications Interface	10	0.3-2	0.02	Emergency vehicle communications. Cost is per vehicle.
Signal Preemptions/Priority Emitter	10	0.5-2.1		Data-encoded emitter; manually initiated. Complement to Roadside Signal Preemption/Priority (see Roadside Control subsystem).

Table C3: Equipment Costs for Parking Management (PM)

		Price in 2006 Dollars		
	Life (years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Entrance/Exit Ramp Meters	10	2-4	0.2-0.4	Ramp meters are used to detect and count vehicles entering/exiting the parking facility.
Tag Readers	10	2-4	0.2-0.4	Readers support electronic payment scheme.
Database and Software for Billing & Pricing	10	10-15	1-2	Database system contains parking pricing structure and availability.
Parking Monitoring System	10	19-41		Includes installation, detectors, and controllers.

Table C4: Equipment Costs for Roadside Control (RS-C)

		Price in 2006 Dollars		
	Life (years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Linked Signal System LAN	20	23-55	0.3-0.6	The element provides the connections to the linked signal system.
Signal Controller Upgrade or Signal Control	20	2.4-6	0.2-0.4	Local controller upgrade to provide advanced signal control.
Signal Controller and Cabinet		8-14	0.2-0.5	Includes installation of traffic signal controller per intersection.
Traffic Signal		90-180	2.2-2.7	Includes installation for one signal (four leg intersection), conduit, controller and detection device. Cost ranges from traffic signal with inductive loop detection (low) to non-intrusive detection (high).
Signal Preemption Receiver	5	2-6	0.04-0.2	Two per intersection. Complement of IDAS elements RS005 and TV004.
Signal Controller Upgrade for Signal Preemptions	10	2-4		Add-on to base capability (per intersection). Complement of IDAS elements RS004 and TV004.
Roadside Signal Preemption/Priority	10	5-6	0.2-1	Includes infrared detector, detector cable, phase selector, system software, and installation. Complement to transit (or emergency vehicle) on-board Signal Preemption/Priority Emitter.
Ramp Meter	5	24-49	1.2-2.7	Includes ramp meter assembly, signal displays, controller, cabinet, detection and optimization.
Software for Lane Control	20	24-49	3-5	Software and hardware at site. Software is off-the-shelf technology and unit price does not reflect product development.
Lane Control Gates	20	78-117	1.6-2	Per location.
Fixed Lane Signal	20	5-6	0.5-0.6	Cost per signal.
Automatic Anti-icing System—Short Span	12	22	1.8	Typical automatic anti-icing system consists of a control system, chemical storage tank, distribution lines, pump and nozzles.
Automatic Anti-icing System—Long Span	12	45-446	2.4-26.6	Typical automatic anti-icing system consists of a control system, chemical and storage tank, distribution lines, pump, and nozzles.

Table C5: Equipment Costs for Roadside Detection (RS-D)

		Price in 2006 Dollars		
	Life (years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Inductive Loop Surveillance on Corridor	5	3-8	0.4-0.6	Double set (4 loops) with controller, power, etc.
Inductive Loop Surveillance at Intersection	5	8.7-15.6	0.9-1.4	Four legs, 2 lanes/approach.
Machine Vision Sensor on Corridor	10	21.2-28	0.2-0.4	One sensor both directions of travel. Does not include installation.
Machine Vision Sensor at Intersection	10	16-25.9	0.2-1	Four-way intersection, one camera per approach. Does not include installation.
Passive Acoustic Sensor on Corridor		3.5-7.7	0.2-0.4	Cost range is for a single sensor covering up to 5 lanes. Costs do not include installation or mounting structure.
Passive Acoustic Sensor at Intersection		5-14	0.2-0.4	Four sensors, 4 leg intersection.
Remote Traffic Microwave Sensor on Corridor	10	9-13	0.1-0.59	One sensor both directions of travel. Includes sensor, transceiver, cabinet, electrical serve and pole.
Remote Traffic Microwave Sensor at Intersection	10	17	0.1	Four sensors, 4 leg intersection. Includes installation.
Infrared Sensor-Active		5.5-1		Sensor detects movement in two directions and determines vehicle speed, classification, and lane position.
Infrared Sensor-Passive		0.7-1.1		Sensor covers one lane and detects vehicle count, volume, and classification.
CCTV Video Camera	10	9-19	1-1.3	Cost includes color video camera with pan, tilt, and zoom (PTZ), cabinet, electrical series, encoder/decoder, and installation.

| | Life (years) | Price in 2006 Dollars | | Notes |
		Capital Cost ($K)	O&M Cost ($K/year)	
CCTV Video Camera Tower	20	4-13		Cost depends on tower height. Camera lowering unit additional cost.
Pedestrian Detection-Microwave		0.6		Cost is per device. Can be used for detection of pedestrians at the curbside.
Pedestrian Detection—Infrared		0.3-0.5		Cost is per device. Does not include installation. Can be used for detection of pedestrians in the crosswalk.
Environmental Sensing Station (Weather Station)	25	30-49	1.9-4	System consists of pavement temperature sensor, subsurface temperature sensor, precipitation sensor, wind sensor, air temperature and humidity sensor, visibility sensors, and remote processing unit (RPU).
Traffic Camera for Red Light Running Enforcement		71-128	57	The vendor receives compensation from fines charged to violators.
Portable Speed Monitoring System	15	4.8-14.4		Trailer mounted two-digit dynamic message sign, radar gun, computer; powered by generator or operates off of solar power; and requires minimal operations and maintenance work.
Portable Traffic Management System		78-97		This portable unit collects traffic data, communicates with a central control facility, and displays real time traffic information to travelers. Cost will vary depending on the type and number of traffic sensors installed.

Table C6: Equipment Costs for Roadside Information (RS-I)

	Life (Years)	Capital Cost ($K)	O&M Cost ($K/year)	Notes
		Price in 2006 Dollars		
Roadside Message Sign	20	39-58	2-3	Fixed message board for HOV and HOT lanes.
Wireline to Roadside Message Sign	20	5-8		Wireline to VMS (0.5 miles upstation).
Variable Message Sign	10	48-119	2.3-6	Low capital cost is for smaller VMS installed along arterial. High capital cost is for full matrix, LED, 3-line, walk-in VMS installed on freeway. Cost does not include installation.
Variable Message Sign Tower	20	26-126		Low capital cost if for a small structure for arterials. High capital cost is for a larger structure spanning 3-4 lanes. VMS tower structure requires minimal maintenance.
Variable Message Sign—Portable	14	18.6-24	0.6-1.8	Trailer mounted VMS (3-line, 8" character display): includes trailer, solar or diesel powered, and is equipped with cellular modem for remote communication and control. Operation costs are for labor and replacement parts.
Highway Advisory Radio	20	14-35	0.6-1	Capital cost for a 10-watt HAR. Includes processor, antenna, transmitters, battery back-up, cabinet, rack mounting, lighting, mounts, connectors, and cable and license fee.
Highway Advisory Radio Sign	10	5-9	0.25	Cost is for a HAR sign with flashing beacons. Includes cost of the controller.
Roadside Probe Beacon	5	5-8	0.5-0.8	Two-way device (per location).

	Life (Years)	Price in 2006 Dollars		Notes
		Capital Cost ($K)	O&M Cost ($K/year)	
LED Countdown Signal	10	0.306-0.424		Cost range from low (two 12x12-inch dual housing unit) to high (16X18-inch single housed unit). Signal indicated time remaining for pedestrian to cross, and a walk or don't walk icon. Count-down signals use low 8-watt LED bulbs, which require replacement approximately every 5-7 years.
Pedestrian Crossing Illumination System	5	26.8-41	2.6-4	The capital cost range includes cost of equipment and installation. Equipment includes fixtures—4 lamps per lane—for a three lane crosswalk, controller, pole, and push button activator. Installation is estimated at 150-200% of the total equipment cost. Capital cost would be greater if the system included automated activation of the in-pavement lighting system.
Variable Speed Display Sign		3.5-4.7		Low range is for a variable speed limit display system. High range includes static speed sign, speed detector (radar), and display system.

Table C7: Equipment Costs for Roadside Telecommunications (RS-TC)

		Price in 2006 Dollars		
	Life (years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
DS0 Communication line	20	0.5-0.9	0.6-1.2	56Kbps capacity. Leased with typical distance from terminus to terminus is 8-15 miles, but most of the cost is not distance sensitive.
DS1Communication Line	20	0.5-0.9	4.6-9.6	1.544Mbps capacity (T1 line). Leased with typical distance from terminus to terminus is 8-15 miles, but most of the cost is not distance sensitive.
DS3 Communication Line	20	2.7-4.6	22-67	44.736 Mbps capacity (T3 line). Typical cost from terminus to terminus in 8-15 miles but most of the cost is not distance sensitive.
ISP Service Fee			0.17-0.6	Monthly service fee varies for dial-up compared to DSL.
Conduit Design and Installation	20	50-75	3	Cost is per mile.
Twisted Pair Installation	20	11-15.7	1.98	Cost is per mile.
Fiber Optic Cable Installation	20	20-52	1-2.5	Cost is per mile and in-ground installation. Cost is less for an aerial installation.
900 MHz Spread Spectrum Radio	10	8.2	0.1-0.4	Cost is per link.
Terrestrial Microwave	10	5-19.1	0.5-1	Cost is per link.
Wireless Communications, High Usage	20	0.5-0.9	1.1-1.7	3.000 Kbytes/month available usage (non-continuous use).
Call Box	10	4-6.7	0.25-0.57	Includes installation.

Table C8: Equipment Costs for Transit Management Center (TR)

	Life (Years)	Capital Cost ($K)	O&M Cost ($K/year)	Notes
		Price in 2006 Dollars		
Basic Facilities, Comm for Large Area		5380	538-807	For population > 750,000. Based on purchase of building rather than leasing space. Communication includes communication equipment internal to the facility such as equipment racks, multiplexers, modems, etc.
Transit Center Hardware	10	8-10	0.15-0.20	Includes 3 work stations.
Transit Center Software, Integration	20	798-1671	6-13	Includes vehicle tracking & scheduling, database & information storage, schedule adjustment software, real time travel information software, and integration. Software is COTS.
Transit Center Labor			100-400	Labor for 1 to 3 staff @ 125K. Salary cost are fully loaded prices including base salary, overtime, overhead, benefits, etc.
Upgrade for Auto. Scheduling, Run Cutting or Fare Payment	20	19-39	0.4-0.8	Processor/software upgrade, installation and 1 yr. maintenance (for Processor). Software is COTS.
Integration for Auto. Scheduling, Run Cutting, or Fare Payment	20	219-486		Integration with other systems.
Further Software Upgrade for E-Fare Payment	20	39-58	0.8-1.2	Software upgrade. Software is COTS. Automatic passenger counter processing software cost an additional $25K to several hundred thousand dollars depending on the system.
Vehicle Location Interface	20	10-15		Vehicle location interface.
Video Monitors for Security System	5	2-5	0.05-0.11	Five per site.
Hardware for Security System	10	13-19	0.3-0.4	Includes 1 server and 3 workstations.
Integration of Security System with Existing Systems	20	243-486		Integration with other systems.

| | Life (Years) | Price in 2006 Dollars | | Notes |
		Capital Cost ($K)	O&M Cost ($K/year)	
Labor for Security System			293-359	Labor for 3 staff @ 75K each. Salary cost are fully loaded prices including base salary, overtime, overhead, benefits, etc.

Table C9: Equipment Costs for Transit Vehicle On-Board (TV)

		Price in 2006 Dollars		
	Life (Years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Driver Interface and Schedule Processor	10	0.2-0.4	0.005-0.01	On-board schedule processor and database.
Cell based Communication Equipment	10	0.14-0.23	0.00-0.011	Cell-based radio with data capacity.
GPS/DGPS for Vehicle Location	10	0.5-2	0.01-0.038	AVL GPS/DGPS. Capital cost depends of feature of unit.
Signal Preemptions Processor	10	0.2-0.5	0.005-0.008	On-board schedule processor and database. Complement to IDAS elements RS004 and RS005.
Signal Preemptions/Priority Emitter	10	0.5-2.1	0.1	Data-encoded emitter; manually initiated. Complements to Roadside Signal Preemptions/Priority (see Roadside Control subsystem).
Preemptions/Priority Emitter		0.07		Passive transponder mounted on underside of transit vehicle. Requires transit priority system at the Transit Management Center.
Trip Computer and Processor	10	0.1-0.12	0.002	On-board processor for trip reporting and data storage.
Security Package	10	3.3-6	0.16-0.2	On-board CCTV surveillance camera and hot button. The high capital cost represents a common installation of a digital event recorder system.
Electronic Farebox	10	0.6-1.2	0.03-0.06	On-board flex fare system DBX processor, on-board farebox, and smart card reader.
Automatic Passenger Counting System	10	0.98-9.8		Low cost reflects the APC system as an add-on to an existing route scheduling or tracking system. High cost reflects the APC system as a standalone installation. Cost is per vehicle and includes installation.

Table C10: Equipment Costs for Transportation Management Center (TMC)

		Price in 2006 Dollars		
	Life (Years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Basic Facilities, Comm for Large Area		4314-9860	431-1479	For population >750,000. Based on purchase of building rather than leasing space.
Hardware for Signal Control	5	18-25	7-8.2	Includes 1 server and multiple workstations.
Software, Integration for Signal Control	5	102-145	145	Software and integration for a large urban area. Cost would be lower for a few arterial intersections.
Labor for Signal Control			579-708	Costs include labor or operations, transportation engineering, update timing plans and signal maintenance technician. Salary cost are fully loaded prices including base salary, overtime, overhead, benefits, etc.
Hardware, Software for Traffic Surveillance	20	131-160	6.6-8.0	Processor and software.
Integration for Traffic Surveillance	20	219-267	10.9-13.4	Integration with other systems.
Hardware for Freeway Control	5	8-10	0.38-0.5	Includes 3 workstations.
Software, Integration for Freeway Control	5	166-203		Software and integration, installation and 1 year maintenance. Software is off-the-shelf technology and unit cost does not reflect product development.
Labor for Freeway Control			268-328	Labor for operations and maintenance technicians. Salary cost are fully loaded prices including base salary, overtime, overhead, benefits etc.
Hardware for Lane Control	5	3	0.13-0.2	Includes 1 workstation and 19" monitor.
Software, Integration for Lane Control	10	219-267	11-13	Software development and integration and software upgrade for controllers.
Labor for Lane Control			107-131	Labor for 2 operators.

	Life (Years)	Capital Cost ($K)	O&M Cost ($K/year)	Notes
		Price in 2006 Dollars		
Software, Integration for Regional Control	10	287-383		Software integration installation and 1 year maintenance. Integration with other TMC's. Software is COTS.
Real-time, Traffic Adaptive Signal Control System	10	110-137	18	The cost range is based on commercially available packages, which run on a centralized computer. The cost range is representative of 65-235 intersections; cost would be lower for a smaller number of intersections.
Labor for Regional Control			214-262	Labor for operators, transportation engineer, and maintenance contract. Salary costs are fully loaded prices including base salary, overtime, overhead, benefits, etc.
Video Monitors, Wall for Incident Detection	10	44-80	2-4	Video wall and monitors.
Hardware for Incident Detection	5	33.6-52	2-3	Includes 4 servers, 5 workstations, and 2 laser printers.
Integration for Incident Detection	20	87-107	4.4-5.3	Integration with other systems.
Software for Incident Detection	5	83-101	4.1-5	Software is COTS and includes development cost.
Labor for Incident Detection			751-917	Labor for operators and 2 maintenance technicians.
Hardware for Incident Response	5	3	0.13-0.2	Includes 1 workstation and monitor.
Integration for Incident Repose	20	175-214		Integration with other systems.
Software for Incident Response	2	13-16	0.656-0.802	Software is COTS.
Labor of Incident Response			107-131	Labor for incident management coordinator.
Automated Incident Investigation System	5	14.1		Includes workstation, tripod, monopole antenna, Auto Integration and AutoCAD software.

	Price in 2006 Dollars			
	Life (Years)	**Capital Cost ($K)**	**O&M Cost ($K/year)**	**Notes**
Hardware for Traffic Information Dissemination	5	3	0.13-0.2	Includes 1 workstation.
Software for Traffic Information Dissemination	5	17-21	0.9-1	Software is COTS.
Integration for Traffic Information Dissemination	20	83-101	4.4-5.3	Integration with other systems.
Labor for Traffic Information Dissemination			107-131	Labor for 1 operator.
Software for Dynamic Electronic Tolls	5	22-27	1.1-1.3	Includes software installation and 1 year maintenance. Software is COTS.
Integration for Dynamic Electronic Tolls	20	87-107	4.4-5.3	Integration with other systems.
Hardware for Probe Information Collection	3	3	0.13-0.2	Includes 1 workstation.
Software for Probe Information Collection	5	17-21	1.7-2.1	Includes software installation and 1 year maintenance. Software is COTS.
Integration for Probe Information Collection	20	131-160	13-16	Integration with other systems.
Labor for Probe Information Collection			54-66	Labor for 1 operator.
Software for Rail Crossing Monitor	5	17-21	1.7-2.1	Includes software installation and 1 year maintenance. Software is COTS.
Integration for Rail Crossing Monitor	20	87-107		Integration with other systems.
Labor for Rail Crossing Monitor			54-66	Labor for 1 operator.
Road Weather Information system (RWIS)	25	11	0.2-2	A RWIS consists of an environmental sensing station (ESS), CPU, workstation with RWIS software, and communications equipment.

Table C11: Equipment Costs for Vehicle On-Board (VS)

		Price in 2006 Dollars		
	Life (years)	Capital Cost ($K)	O&M Cost ($K/year)	Notes
Communication Equipment	7	0.2-0.4	0.004-0.007	Wireless data transceiver.
In-Vehicle Display	7	0.04-0.1	0.001-0.002	In-vehicle display/warning interface. Software COTS.
In-Vehicle Signing System	7	0.12-0.31	0.002-0.006	Interface to active tag reader, processor for active tag decoder, and display device for messages.
GPS/DGPS	7	0.2-0.4	0.004-0.01	Global Positioning System/Differential Global Positioning Systems.
GIS Software	7	0.2-0.3		Geographical Information System (GIS) software for performing route planning.
Route Guidance Processor	7	0.08-0.12	0.002	Limited processor for route guidance functionality.
Sensors for Lateral Control	7	0.6-0.9	0.012-0.017	Includes lane sensors in vehicle and lateral sensors MMW radar.
Electronic Toll Equipment	7	0.03-0.1		Active tag interface and debit/credit card interface.
Mayday sensor and Processor	7	0.12-0.5	0.002-0.01	Collision detector sensor and interface for Mayday processor. Software is COTS
Sensor for Longitudinal Control	7	10.2-0.4	0.005-0.01	Longitudinal sensors MMW radar.
Advanced Steering Control	7	0.4-0.5	0.008-0.01	Advanced steering control ("hands off" driving). Software is COTS.
Advanced Cruise Control	7	0.12-0.23	0.002-0.009	Software/processor for infrastructure transmitted information, interface to in-vehicle signing and audio system, software and processor to link longitudinal and lateral vehicle control modules based on input signal from vehicle intersection collision warning equipment packaged. Software is COTS.
Vision Enhancement System	7	2-2.4	0.1-0.12	In-vehicle camera, software & processor, heads-up display, and infra-red sensors (local sensor system). Software is COTS.

	Life (years)	Price in 2006 Dollars		Notes
		Capital Cost ($K)	O&M Cost ($K/year)	
Driver and Vehicle Safety Monitoring system	7	0.51-1	0.026-0.05	System includes safety collection processor and software, driver condition sensors, six vehicle conditions sensors and vehicle data storage. Software is COTS.
Pre-Crash Safety System	7	0.9-1.7	0.03-0.05	Vehicle condition sensors, vehicle performance sensors, software/processor, interface, pre-crash safety systems deployment actuators. Software is COTS.
Software, Processor for Probe Vehicle	7	0.05-0.15	0.001-0.003	Software and processor for communication to roadside infrastructure, signal generator, message generator. Software is COTS.
Toll Tag/Transponder	5	0.025		Most toll tags/transponders cost approx. $25. Some toll agencies require users to pay a refundable deposit in lieu of purchasing a tag. The user is charged the cost of the tag if the tag is lost.
In-Vehicle Navigation System	7	2.5		COTS products that includes in-vehicle display and supporting software.

Appendix D. Simulation Results

Table D1: Estimated Performance Measures, No Incident Scenario

Scenario	Roadway Section	Travel Time (sec)	Distance (ft)	Speed (mph)	Travel Delay (sec)
No Incident	Loop 1	755.0	33881.6	30.6	343.3
	Burnet Rd.	819.0	21248.1	17.7	372.2
	Lamar Blvd.	1424.7	30998.0	14.8	777.9
	Guadalupe St.	530.3	13965.0	18.0	235.3
	Arterial			16.7	486.4
	System			26.1	389.9

Table D2: Information Response Rates, Scenarios 1-12

Scenario	Response Rate (%)	
	Radio	DMS
1	-	-
2A	44	-
2B	30	-
3A	-	88
3B	-	60
4	-	-
5A	44	-
5B	30	-
6A	-	88
6B	-	60
7	-	-
8	44	-
9	-	88
10	-	-
11	44	-
12	-	88

Table D3: Estimated Performance Measures, Scenarios 1-6

Scenario	Roadway Section	Travel Time (sec)	Distance (ft)	Speed (mph)	Travel Delay (sec)
1	Loop 1	1001.7	33881.6	23.1	591.1
	Burnet Rd.	805.9	21248.1	18.0	359.1
	Lamar Blvd.	1429.0	30998.0	14.8	781.8
	Guadalupe St.	532.3	13965.0	17.9	235.8
	Arterial			16.8	480.4
	System			20.9	553.2
2A	Loop 1	831.1	33881.6	27.8	420.5
	Burnet Rd.	1228.3	21248.1	11.8	781.5
	Lamar Blvd.	1661.3	30998.0	12.7	1013.3
	Guadalupe St.	530.5	13965.0	18.0	232.7
	Arterial			14.2	701.1
	System			21.8	545.3
2B	Loop 1	834.6	33881.6	27.7	424.0
	Burnet Rd.	1317.1	21248.1	11.0	871.3
	Lamar Blvd.	1644.2	30998.0	12.9	996.3
	Guadalupe St.	531.7	13965.0	17.9	234.1
	Arterial			13.9	730.1
	System			20.3	544.6
3A	Loop 1	774.6	33881.6	29.8	364.0
	Burnet Rd.	1316.1	21248.1	11.0	870.6
	Lamar Blvd.	1692.4	30998.0	12.5	1045.6
	Guadalupe St.	516.5	13965.0	18.4	221.1
	Arterial			14.1	736.1
	System			20.9	574.3
3B	Loop 1	813.5	33881.6	28.4	402.9
	Burnet Rd.	1274.1	21248.1	11.4	828.6
	Lamar Blvd.	1707.8	30998.0	12.4	1059.6
	Guadalupe St.	518.4	13965.0	18.4	223.9
	Arterial			14.1	729.8
	System			20.6	567.8
4	Loop 1	1001.7	33881.6	23.1	591.1
	Burnet Rd.	559.9	21248.1	25.9	112.5
	Lamar Blvd.	1100.8	30998.0	19.2	452.9
	Guadalupe St.	470.0	13965.0	20.3	173.5
	Arterial			21.5	264.7
	System			22.5	467.8

Scenario	Roadway Section	Travel Time (sec)	Distance (ft)	Speed (mph)	Travel Delay (sec)
5A	Loop 1	749.1	33881.6	30.8	338.5
	Burnett	1193.3	21248.1	12.1	747.5
	Lamar	1423.5	30998.0	14.9	774.0
	Guadalupe	469.2	13965.0	20.3	173.7
	Arterial			16.1	559.6
	System			24.6	432.0
5B	Loop 1	751.5	33881.6	30.7	340.9
	Burnett	1107.3	21248.1	13.1	660.1
	Lamar	1319.9	30998.0	16.0	670.2
	Guadalupe	465.5	13965.0	20.5	170.1
	Arterial			16.8	499.1
	System			23.1	402.6
6A	Loop 1	797.3	33881.6	29.0	386.7
	Burnett	1271.4	21248.1	11.4	824.7
	Lamar	1501.0	30998.0	14.1	851.4
	Guadalupe	470.4	13965.0	20.2	175.5
	Arterial			15.6	612.0
	System			21.6	509.9
6B	Loop 1	757.0	33881.6	30.5	346.4
	Burnett	1154.2	21248.1	12.6	708.6
	Lamar	1458.9	30998.0	14.5	809.6
	Guadalupe	466.4	13965.0	20.4	171.0
	Arterial			16.1	565.2
	System			22.6	448.1

Table D4: Estimated Performance Measures, Scenarios 7-12

Scenario	Roadway Section	Travel Time (sec)	Distance (ft)	Speed (mph)	Travel Delay (sec)
7	Loop 1	755.0	33881.6	30.6	344.4
	Burnet Rd.	866.3	21248.1	16.7	419.6
	Lamar Blvd.	1738.0	30998.0	12.2	1037.1
	Guadalupe St.	525.2	13965.0	18.1	230.0
	Arterial			15.4	599.3
	System			25.7	427.4
8A	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	693.0	21248.1	20.9	245.6
	Lamar Blvd.	1533.1	30998.0	13.8	885.9
	Guadalupe St.	580.3	13965.0	16.4	284.8
	Arterial			16.9	502.5
	System			26.1	396.2
8B	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	712.7	21248.1	20.3	265.3
	Lamar Blvd.	1607.8	30998.0	13.1	961.5
	Guadalupe St.	560.9	13965.0	17.0	268.1
	Arterial			16.7	528.8
	System			26.1	403.7
9A	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	687.8	21248.1	21.1	240.4
	Lamar Blvd.	1430.9	30998.0	14.8	783.7
	Guadalupe St.	620.2	13965.0	15.4	324.7
	Arterial			17.1	471.4
	System			26.2	385.3
9B	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	688.9	21248.1	21.0	241.5
	Lamar Blvd.	1482.1	30998.0	14.3	835.8
	Guadalupe St.	593.6	13965.0	16.0	300.8
	Arterial			17.1	482.4
	System			26.2	389.0
10	Loop 1	755.0	33881.6	30.6	344.4
	Burnet Rd.	579.3	21248.1	25.0	131.3
	Lamar Blvd.	1313.4	30998.0	16.1	662.1
	Guadalupe St.	478.8	13965.0	19.9	183.4
	Arterial			20.0	348.5
	System			26.7	345.9

Scenario	Roadway Section	Travel Time (sec)	Distance (ft)	Speed (mph)	Travel Delay (sec)
11A	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	558.1	21248.1	26.0	110.8
	Lamar Blvd.	773.1	30998.0	27.3	121.3
	Guadalupe St.	469.2	13965.0	20.3	173.7
	Arterial			26.5	135.5
	System			28.4	263.2
11B	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	565.4	21248.1	25.6	117.1
	Lamar Blvd.	779.6	30998.0	27.1	127.9
	Guadalupe St.	470.0	13965.0	20.3	178.1
	Arterial			26.3	139.9
	System			27.8	267.0
12A	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	555.7	21248.1	26.1	108.1
	Lamar Blvd.	772.1	30998.0	27.4	120.8
	Guadalupe St.	470.4	13965.0	20.2	175.5
	Arterial			26.6	135.3
	System			27.8	262.0
12B	Loop 1	753.3	33881.6	30.7	342.7
	Burnet Rd.	555.4	21248.1	26.1	108.0
	Lamar Blvd.	769.5	30998.0	27.5	123.2
	Guadalupe St.	467.9	13965.0	20.3	175.1
	Arterial			26.7	134.2
	System			27.9	264.0