IH-69 ACTIVE TRAFFIC MANAGEMENT SYSTEM CONCEPT OF OPERATIONS

Prepared for:

Texas Department of Transportation
Houston District

Prepared by:
BGE, Inc.

In Association With:
Alliance Transportation Group, Inc.

July 2017

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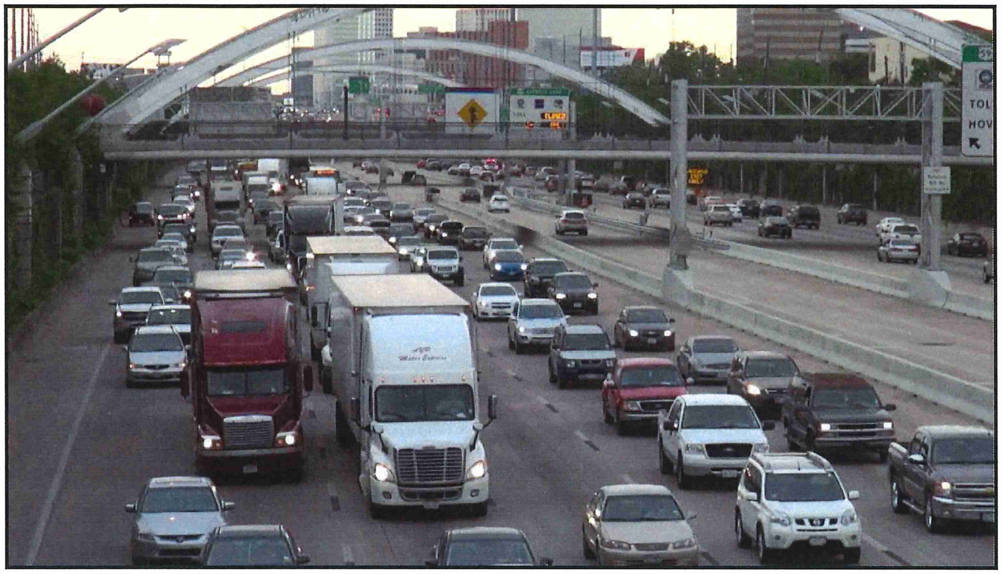

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IH 69 Active Traffic Management Systems ConOps Executive Summary

As part of a continued analysis of the *US 59/IH 69 Rider 42 Corridor Congestion Mitigation Study*, the Texas Department of Transportation (TxDOT) pursued the next step with the development of the IH 69 Active Traffic Management System (ATMS) Concept of Operations, which was a key recommendation from the Rider 42 mitigation study. The project limits for the Concept of Operations extended from Beltway 8 in southwest Houston approximately 17 miles north to IH 10 East in Downtown. The purpose of the project was to provide a high level analysis of the necessary Intelligent Transportation Systems (ITS) to develop ATMS along the project corridor. ATMS operational scenarios were developed, modeled, and analyzed to evaluate the preliminary expectations for the proposed system. Input was gathered from the Houston regional transportation agencies including TxDOT, Harris County, City of Houston, and METRO. Feedback was obtained from the first responders involved in traffic management, including the Houston Fire Department, Harris County Sheriff's Office, and Houston Police Department. The visions and expectations of the stakeholders for the system are included in the Concept of Operations.

Vision

To develop an ATMS through the use of ITS infrastructure that will improve travel mobility, safety, and reliable traffic information to the public, and use the full functionally and capacity of the roadways within the project corridor.

Goal

The goal of the ATMS is to provide reliable traffic information to the general public to improve traffic operations and safety while maximizing existing transportation infrastructure through the use of ITS.

Objectives

1. Develop agreements between the various stakeholders
2. Identify locations within the project limits for ITS infrastructure
3. Develop a plan for deploying ITS infrastructure
4. Identify preliminary costs associated with additional ITS
5. Evaluate the effective operation of ITS infrastructure

Proposed System

Currently, there are gaps in camera, Bluetooth, and radar coverage within the project limits due to line of sight interference and unfavorable infrastructure and road geometry. There have been several improvements to technology since the existing ITS equipment was deployed. The proposed ATMS will provide the necessary coverage for the project corridor with additional closed circuit television pan-tilt-zoom cameras (CCTV PTZ), CCTV fixed cameras, Bluetooth, and radar vehicle sensing devices (RVSDs). The proposed ATMS will also include existing infrastructure and equipment to ensure compatibility and efficiency.

Overhead sign bridges, spaced approximately one-half mile apart, will be used to accommodate dynamic message signs (DMS) and lane control signs (LCS). The DMS and LCS will provide real-time traffic management and information to motorists on the project corridor with data collected by CCTV cameras, Bluetooth, RVSDs, and road weather information systems (RWISs). DMS will notify drivers of incidents and travel times and will display specific messages for special events and flooding conditions. LCS will be positioned over each travel lane and shoulder, when possible, to notify drivers about lanes that are open, merging, closed, or for emergency vehicle use only. Shoulder LCS will be used when there is adequate space (minimum 10 feet). The LCS will also replace the existing queue warning system and display advisory speed limits to slow traffic and notify drivers of congestion ahead.

In advance of major interchanges along the project corridor, graphical route information panels (GRIPs) will display a portion of the Houston TranStar map showing local real-time traffic conditions. One objective of the proposed ATMS is to utilize ITS equipment such as DMS, LCS, GRIPs, and data collection devices to provide reliable traffic information so drivers can make information rerouting decisions.

The proposed ATMS will also include installation of a corridor-adaptive, system-integrated ramp metering system and wrong-way detection systems at fourteen ramp locations along the project corridor. The ramp meters will be connected to loop and RVSD detection devices and will have automated cycle time adjustments based on traffic flow. Wrong-way detection will be implemented with vehicle detectors. Algorithms can be developed to allow systems to track the order in which two installed detection devices are activated. Should wrong way vehicles be detected, an alarm will be triggered, which can notify TranStar and the police/emergency teams to assess the situation in field and activate the LCS and DMS to notify drivers of wrong-way vehicles.

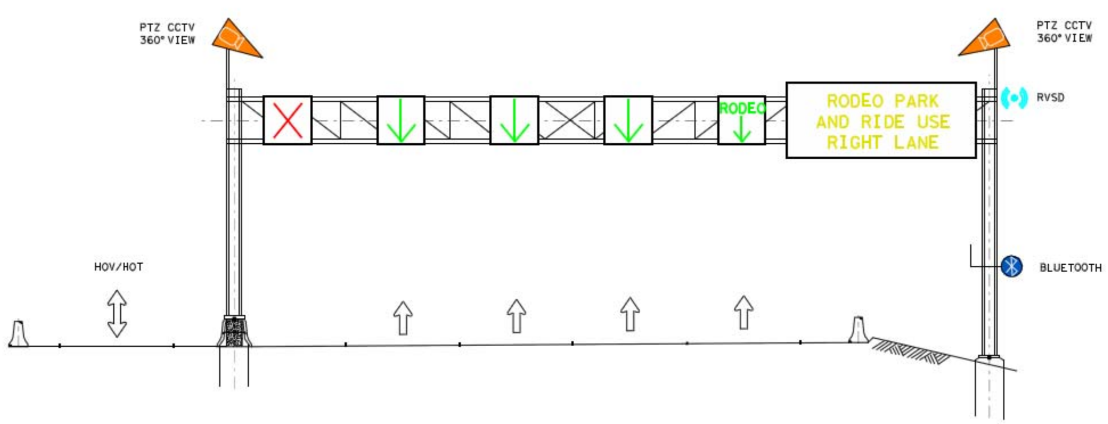


Figure ES Figure 1: Typical Overhead Sign Bridge Elevations

ES Table 1. Existing and Proposed Equipment Comparison

<table>
<tr><th>ITS Infrastructure/ Component</th><th>Existing System</th><th>Proposed System</th></tr>
<tr><td rowspan="2">Fiber</td><td rowspan="2">Strand Size Varies</td><td>144 Strand Single Mode Fiber</td></tr>
<tr><td>12 Single Mode Fiber (New Device Locations)</td></tr>
<tr><td rowspan="2">Overhead Sign Bridge</td><td>16 Structures with Guide Signs</td><td>15 Structures to be Replaced for Guide Signs</td></tr>
<tr><td>No ITS Structures</td><td>28 New Dedicated ITS Structures</td></tr>
<tr><td>Bluetooth Device</td><td>8 Devices</td><td>10 Additional Devices</td></tr>
<tr><td>Closed Circuit Television (CCTV) Pan-Tilt-Zoom (PTZ) Camera</td><td>26 Cameras</td><td>71 Additional Cameras</td></tr>
<tr><td>CCTV Fixed Camera</td><td>None</td><td>20 New Cameras for High Accident Locations</td></tr>
<tr><td rowspan="2">Advanced Detection</td><td rowspan="2">Limited</td><td>14 New Detectors at Ramp Meter Locations</td></tr>
<tr><td>Additional Detectors on Frontage Roads and at Exit Ramps near Signalized Intersections</td></tr>
<tr><td>Radar Vehicle Sensing Device (RVSD)</td><td>13 Devices</td><td>62 Additional Devices</td></tr>
<tr><td>Lane Control Sign (LCS)</td><td>None</td><td>202 New Devices</td></tr>
<tr><td>Dynamic Message Sign (DMS)</td><td>8 Signs</td><td>28 Additional Signs</td></tr>
<tr><td>Graphical Route Information Panel (GRIP)</td><td>None</td><td>6 New Signs</td></tr>
<tr><td rowspan="2">Ramp Meters and Wrong-Way Detection</td><td rowspan="2">12 Meters</td><td>12 Upgraded Corridor-adaptive and System-integrated Ramp Meters</td></tr>
<tr><td>2 New Installations</td></tr>
<tr><td>Road Weather Information System (RWIS)</td><td>2 Devices</td><td>Depressed Area of IH 610 Interchange (Pending Roadway Improvements)</td></tr>
<tr><td>Queue Warning System</td><td>3 Signs</td><td>Replaced by LCS System</td></tr>
</table>

Priority of Proposed Changes

The proposed ITS devices will be purchased, installed, and activated gradually, based on project funding and significance to the overall system. The proposed equipment was categorized into essential, desirable, and optional groups to determine priorities and approximate deployment timelines. Essential devices are crucial to operating an effective and efficient ATMS. Desirable features generate a more robust and comprehensive system. Optional devices are devices that can improve the system.

ES Table 2. Features and Devices

Essential Features	Desirable Features	Optional Features
• Required to improve mobility, reliability, and safety • System cannot function without these specific features • Supported by all project stakeholders	• Features that would improve mobility, reliability, and safety, but not required • System can function without these features • Supported by most project stakeholders	• Features that would improve mobility, reliability, and safety, but not required • Dependent on the overall cost and available technology • Supported by most project stakeholders

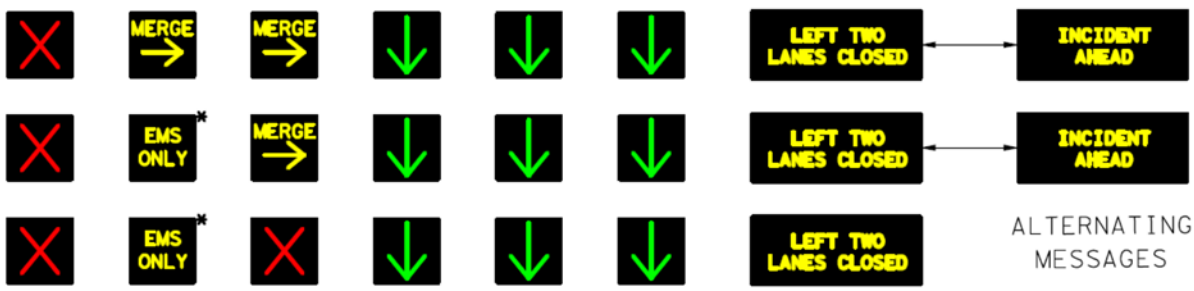
Essential Devices	Desirable Devices	Optional Devices
• CCTV • HD RVSD • LCS • DMS • Fiber upgrades • Dedicated staffing for operations and maintenance	• Additional Bluetooth sensors • CCTV with incident detection • GRIPs • Additional detours on frontage roads and at exit ramps near signalized intersections	• RWIS • Corridor-adaptive and system-integrated ramp meters • Wrong-way detection • Variable speed limits • Shoulder lanes

Overall, the proposed ITS devices and ATMS can reduce impacts from recurring and nonrecurring congestion and can improve safety with advanced traffic management techniques.

ES Figure 2. An Example of a Proposed Sign Bridge for the Corridor with DMS and LCS

Operational Scenarios

Four operational scenarios were identified for the proposed system: minor incident, major incident, daily-recurring congestion, and planned event. As part of minor and major incident operational scenarios, specific scenarios involving wrecker services were also developed to help remove inoperable vehicles off the roadway when needed. The purpose of the operational scenarios is to provide a general set of guidelines and procedures for the ATMS operators to address common traffic issues that may occur. Each operational scenario describes the roles of the ATMS, the interactions between users, and the interactions with other traffic management systems. The procedures offer conventional strategies to regional transportation agencies for ways to reduce congestion, identify incidents, manage incident progressions, and provide enhanced real-time traveler information. The process is expected to provide a proactive approach to the method, which is important for major incidents.



*Alternating with Red "X"

ES Figure 3. Minor Incident LCS and DMS Displays

Organizational Expectations

The proposed ATMS will be the first of its kind in Texas and will require special consideration and support from TxDOT, as well as local governing and participating agencies. Project support will include a dedicated group of individuals from each agency to ensure effective system communication and coordination. The highly skilled personnel for the ATMS will be required to make decisions quickly in order to meet the expectations of the proposed system. The ATMS will require 24 hours a day, 7 days a week monitoring. During peak periods, special events, and emergencies, it is recommended that up to two ATMS operators manage the ATMS and incident management system along the corridor. During off-peak periods, one operator should be able to sufficiently oversee the ATMS and incident management system.

The proposed ATMS will require frequent maintenance and equipment service to warrant a near perfect success rate. Due to the semi-automated characteristics of the system, equipment failure would have a negative impact on system operations and driver compliance.

ES Table 3. Proposed Dedicated Staff for the ATMS

Position	Responsibilities	Total Number of Personnel Required (Estimate)
ATMS Manager	Managing the ATMS subgroup personnel and operations	1
ATMS Engineer	Deploying the ATMS and LCS as well as determining incident duration estimates, alternative routes, and operations to aid emergency vehicles	2
ATMS Operator	Monitoring and operating the ATMS	3
Maintenance Technician	Maintaining and repairing the ATMS infrastructure	2
IT Specialist	Maintaining the ATMS computer systems, software, network connections, workstations, and hardware installations, configurations, and upgrades	2

Justification for ATMS

To understand the impacts of the proposed ATMS, a queuing model analysis and benefit-cost analysis were completed. In addition, a comparison of existing corridors within the United States with ATMS was performed.

Queue Modeling Analysis

A theoretical queuing model analysis was conducted to evaluate the anticipated benefits of ATMS implementation versus non-ATMS methods. A calibrated VISSIM queuing model simulation was also completed to analytically and visually understand how the proposed system would operate.

The VISSIM queuing model simulation location and time were determined to be near IH 610 on the inbound mainlanes between Hillcroft and Chimney Rock after the AM peak period. This was identified as a critical area that experiences several weaving maneuvers and a large number of incidents. The model analyzed a no build, two-lane closure, three-lane closure, and all-lane closure scenarios. The intention of the model was to provide a visual for stakeholders to understand how the system would work along the corridor.

Crash Analysis

Based on the crash data collected from January 2013 to August 2016 and the 3,968 reported crashes on the IH 69 mainlanes, 50% of the crashes were rear end and 66.7% of the individuals in the crashes were not injured. The high percentage of rear end crashes is likely caused by the high level of congestion. The high percentage of non-injury crashes reinforces the likelihood that most crashes along the corridor occur at low speeds, typical of crashes occurring during congested conditions.

Benefit-to-Cost Analysis

The benefit-to-cost ratio is anticipated to be between 5.2 and 7.3. The benefit-to-cost ratio will be lower if the ATMS devices do not induce rerouting during recurring congestion. A higher benefit-to-cost ratio is expected if the devices lead to rerouting. There are several arterials that can provide alternate routing near IH 69 during off- peak and less saturated conditions. Benefits of the proposed system include time and fuel savings as well as improved safety. Associated costs include design, construction, mobilization, software, operations, maintenance, contingencies, and dedicated ATMS employee salaries. The estimated capital cost for the ATMS is approximately $23 million. Operations and maintenance (O&M) costs for the system are expected to be approximately $2.6 million per year, which includes the following items:

- Structural inspection
- Variable message sign full matrix maintenance
- Data station maintenance
- Variable speed limit, lane control, and detour DMS maintenance
- Corridor-adaptive and system-integrated ramp metering and wrong-way detection maintenance
- Full-time staff and operation cost
- Contingency

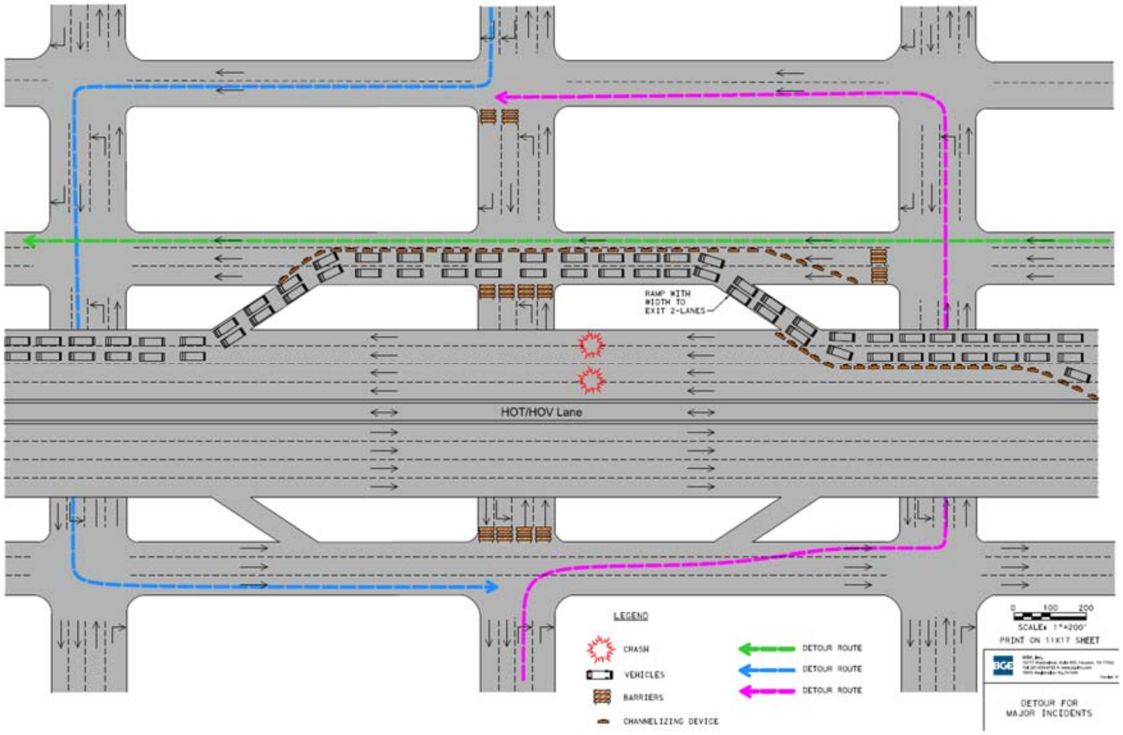
The O&M is higher than standard O&M as a result of a rigorous preventative maintenance schedule to ensure the ATMS is fully functional.

The benefit-to-cost analysis of the ATMS option is conservative, as it does not include some items that drivers would benefit from due to lack of necessary data.

ES Table 4. Items Included in Benefit-to-Cost Analysis

Item	Benefit	Cost
Included	• Time and fuel (recurring congestion and incidents) • Safety (incidents)	• Construction • Design • Mobilization • Software • Operations • Maintenance • Contingency • Salaries

Items not included are environmental savings, savings from speed harmonization (variable speeds), savings in incident identification time improvements, and incident reductions.

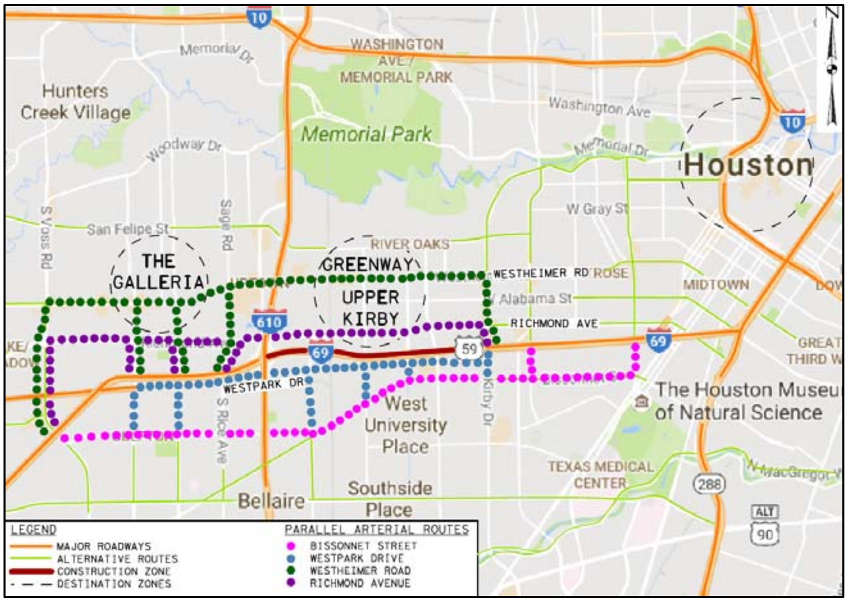


ES Figure 4. Proposed ATMS Detour Plan for a Major All-Lane Closure Incident

ES Table 5. ATMS Comparisons of Similar Proposed and Existing ATMS Corridor Projects in U.S.

Corridor	Location	ATMS Component				
		Variable Speed Limit	Queue Warning System	Adaptive Ramp Metering	Dynamic Lane Control	Dynamic Shoulder Lane
IH-5	Seattle, WA	E	E	E	E	
IH 90 & SR 520	Seattle, WA	E	E		E	
OR 217	Portland, OR	E	E	E		
IH-80	Alameda, CA	E	E	E	E	
Multiple	Los Angeles, CA		P	E	E	P
IH 15 & US 95	Las Vegas, NV	P	P		P	
Multiple	Phoenix, AZ	P		P	P	P
IH 70	Denver, CO	P	P	P	P	P
IH 35W	Minneapolis, MN	E	E	E	E	E
IH 94	Minneapolis, MN	E	E		E	
IH 270	St. Louis, MO	E				
IH 90	Chicago, IL	P	P		P	E
US 23	Michigan	P	P			P
Multiple	Boston, MA					E
Multiple	New Jersey	E	P		P	E
IH 95 & IH 76	Philadelphia, PA	P	P	P	P	P
IH 66	Virginia	E	E		E	E
IH 4	Orlando, FL	E				

E - Existing
P - Proposed



ES Figure 5. Overnight Construction Arterial Detour

Next Steps

ATMS will provide an invaluable benefit to the corridor. While the proposed overall system does not create added physical capacity, it provides a structured system using the advancements of technology to better manage the current capacity on the roadway. This system is a non-traditional approach for addressing congestion and would be the first of its kind in Texas. For areas in Houston, such as our project limits along IH 69, construction of additional lanes is not a practical solution due to limited right-of-way and high property costs, although improvements are necessary. The proactive nature of ATMS, using technology, will change the way traffic is evaluated and managed. As a result, legislation will be needed to implement new technology, such as variable speed limits.

In comparison to the cost of adding physical capacity, ATMS is a viable financial alternative. While the proposed system provides a lower cost than physical improvements such as freeway widening, there is still a cost to implement and maintain the system. Funding for the program needs to be secured with help from H-GAC, TxDOT, and other potential funding sources.

ES Table 6. ATMS vs. Conventional Improvements

Costs	ATMS	Conventional Improvements
Capital Investment	$22,620,000	$340,000,000
O&M (per year)	$2,581,250	$150,000
30-year-2016 Total Present Value	$107,415,000	$344,940,000

To achieve the highest benefit from the system, the implementation along the project corridor needs to occur quickly due to the ever-evolving nature of ITS. Since this is a technology-based system, new technology should be identified, studied, and tested as it becomes available to maintain the highest benefit from the corridor.

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Section 2.1 Project Identification, Purpose, and Need

Project Identification

The *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study* (December 2015) was conducted to identify strategies that relieve congestion, improve safety, and provide more reliable travel times on IH 69. The project provided several proposed mitigation strategies including an Active Traffic Management System (ATMS). The active traffic management system that was identified in the *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study* is being developed for implementation and operations through the IH 69 Concept of Operations. This document will be the foundation that provides detail for the successful installation of an active traffic management system along the corridor. The limits for this project are IH 69 from Beltway 8 South to IH 10 East.

The project entails evaluating the implementation and operation of an active traffic management system through the use of Intelligent Transportation Systems (ITS) to address congestion issues along the corridor. Although congestion can be reduced through the use of additional transportation infrastructure, the feasibility of constructing additional infrastructure is limited and associated costs can be an issue. For this project, the congestion along this corridor is analyzed based on improving reoccurring and incident specific traffic conditions through the use of an active traffic management system. Active traffic management for a congested freeway corridor may include ramp control through the use of ramp metering, dynamic re-routing of traffic onto intersecting freeways or arterials, temporary utilization of the capacity available on freeway shoulders and freeway frontage roads, travel information, lane change designations, and variable speed limits. To achieve a successful implementation, the existing ITS infrastructure will be analyzed as well as additional ITS infrastructure needed to provide a network that can provide travelers with travel information to make rerouting decisions will be identified.

Project Purpose

The purpose of the Concept of Operations will be to clearly convey the high-level view of the system to be developed and establish the roles and responsibilities of the operating agencies and additional stakeholders. This document will provide the overall goal for the project as well as define the objectives that are needed to achieve the goal. Through these objectives, the operations for the active traffic management system will be defined.

Project Need

According to the *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study*, the study corridor experiences an estimated total annual cost of congestion of more than $215 million. A trip that typically takes 20 minutes during the off-peak period can take over 40 minutes in the peak period. Over time, the unreliability in traffic conditions hinder the efficiency of the project corridor. Based on the travel time data provided for the *US 59/IH-69 Rider 42*

Corridor Congestion Mitigation Study, the travel time index (tti) was calculated based on the peak hour travel time compared to the free flow travel time condition. The tti for IH 69 northbound and southbound AM and PM peak periods for six segments of the study corridor were calculated and are shown in the Table 1 and Table 2.

Table 1. IH 69 Southbound Travel Time Index

Roadway Segment	AM Peak Hour Travel Time Index	PM Peak Hour Travel Time Index
IH 45 Gulf to Fannin	4.33	4.33
Fannin to Hazard	1.27	2.17
Hazard to Newcastle	1.10	3.10
Newcastle to IH 610 West Loop	1.00	2.60
IH 610 West Loop to Hillcroft	1.00	2.17
Hillcroft to Bissonnet	1.27	2.80

*Assumes base flow is 65 mph from Hillcroft to IH 45 based on 2011 TranStar data

Table 2. IH 69 Northbound Travel Time Index

Roadway Segment	AM Peak Hour Travel Time Index	PM Peak Hour Travel Time Index
Hillcroft to Bissonnet	2.59	1.03
IH 610 West Loop to Hillcroft	3.25	1.35
Newcastle to IH 610 West Loop	1.67	1.33
Hazard to Newcastle	1.71	4.33
Fannin to Hazard	1.59	6.50
IH 45 Gulf to Fannin	1.30	4.06

*Assumes base flow is 65 mph from Hillcroft to IH 45 based on 2011 TranStar data

Additional construction could be achieved along IH 69; however, significant right-of-way acquisitions would be needed. This is a significant cost constraint and can take a significant amount of time to acquire. A relief strategy is the implementation of an active traffic management system through the use of ITS. Through this system, congestion can be reduced, safety can be improved, and more reliable travel times can be provided to the public. To implement this system, the maintenance of traffic will need to be evaluated.

The management of traffic during ATMS construction will require phased traffic control. For the construction of sign bridges, there will need to be complete freeway closures as traffic cannot be active during overhead work. This will need to occur with overnight closures to minimize the impact to traffic. Traffic will be rerouted to the frontage roads and police control may be needed to maintain traffic flow along the frontage roads. Shoulder improvements may also need to be completed with evening lane closures and the use of high early strength concrete. For the ITS equipment located off of the mainlanes, one lane closures may be required.

2.1.1 Vision, Goals, and Objectives

The vision for IH 69 ATMS is using ITS infrastructure to reduce congestion along the project corridor. The statement for the vision will ultimately be based on the needs, goals, and vision of the stakeholders involved in the ATMS. The vision for the document is the following:

To develop an Active Traffic Management System through the use of Intelligent Transportation System infrastructure that will promote the improvement of travel mobility, safety, and reliable traffic information to the public to use the full functionality and capacity of the roadways within the project corridor.

The vision will be achieved through the goal and objectives that are outlined in the following subsections.

Goal

The goal of the active traffic management system is to provide reliable traffic information to the general public to improve traffic operations and safety while maximizing existing transportation infrastructure through the use of ITS.

Objectives

To support the goal, five objectives were determined based on who will be involved, how much it will cost, how it will be deployed, and how the system will operate.

Objective #1: Develop agreements between the various stakeholders

The various stakeholders will need to develop agreements to share the responsibilities and define each of the roles for managing traffic. Agreements and commitment from the agencies will be needed to share ITS infrastructure communication systems, roadway maintenance, and develop a consensus on acceptable traffic operation conditions. The three stakeholder meetings organized for this project will facilitate the initial discussions and processes for developing the agreements.

Objective #2: Identify locations within the project limits for ITS infrastructure

The existing ITS infrastructure, such as closed-circuit television cameras (CCTV), dynamic message signs (DMS), and ramp meter locations will be identified. The existing ITS infrastructure will be determined through field observations and agency identification. Once existing ITS is located, areas that need additional ITS infrastructure can be identified. Proposed ITS infrastructure will use existing infrastructure wherever possible.

Objective #3: Development of a plan for deploying ITS infrastructure

After reviewing the existing ITS infrastructure and proposing ITS infrastructure in the areas that have limited coverage, additional ITS will need to be installed. The plan for deploying the ITS infrastructure will be based on priorities. The ITS identified in Objective #2 will be evaluated based on the critical locations as well as critical ITS infrastructure. For instance, variable lane assignment signs are critical to inform drivers to use shoulders or provide advisory speeds. Ramp metering may assist in improving and monitoring the flow of traffic onto the mainlanes, but it is critical to first improve the mainlanes with lane assignment variable signs.

Objective #4: Identify preliminary costs associated with additional ITS

In addition to determining the critical infrastructure, the associated costs for the proposed ITS will need to be evaluated. The additional costs will consist of equipment costs, integration cost to interconnect the existing and proposed equipment, and the capabilities to obtain and disseminate the data to and from TranStar, the Houston regional traffic management center.

Objective #5: Evaluate how to operate ITS infrastructure

To evaluate how to operate the ITS infrastructure, reoccurring congested traffic condition scenarios will be evaluated. For each scenario, an illustration of what will need to be depicted on the lane assignment variable signs as well as DMS will be provided.

2.1.2 Project Stakeholders

Stakeholders for the IH 69 corridor were identified based on controlling agencies for the segment between Beltway 8 South and IH 10 East. The stakeholders include traffic incident responders as well as roadway maintenance crews. For the initial stages for developing the active traffic management system, the following stakeholders will be involved:

- Texas Department of Transportation - Houston District (TxDOT)
- City of Houston Department of Public Works and Engineering (HPW)
- City of Houston Police Department (HPD)
- The Metropolitan Transit Authority of Harris County (METRO)
- Harris County Sheriff's Office Motorist Assist Program (HCSO)
- Fast Tow Wrecker Service
- Harris County Toll Road Authority (HCTRA)
- Houston-Galveston Area Council (H-GAC)

Later stages of development of the active traffic management system may include:

- Harris County Judge Emmett Public Information Office (PIO)
- Texas A&M Transportation Institute (TTI)

2.1.3 Supporting Structure

Currently, there is existing ITS infrastructure installed along the project corridor. Devices include CCTV cameras, DMS, and ramp meters as shown in Figure 1 and Figure 2. The existing ITS network data is sent to TranStar for monitoring the traffic conditions. The existing equipment has been identified based on field observations and the TranStar ITS Asset Management System (TAMS) website provided by TxDOT. The aerial figures shown in **Appendix A** illustrate the approximate locations for the existing infrastructure. This provides the basis for determining what additional ITS infrastructure may be needed.

Figure 1. Dynamic Message Sign
(fhwa.com)

Figure 2. Ramp Meter
(google maps)

2.1.4 Operating Center

The Houston Regional operating center is TranStar, a Transportation Control Center, which is shown in Figure 3. TranStar houses employees from City of Houston, TxDOT, Harris County, METRO, and first responders. The purpose of TranStar is to serve as the location which the state, county, and local agencies can coordinate during incidents and emergencies as well as share resources to better monitor traffic. TranStar has provided a significant benefit to the Houston region. In 2015, the reduction in travel time for commuters decreased fuel consumption by 38 million gallons. Through the use of the traffic management system, TranStar reduced travel delays by 20.7 million hours, which has an associated cost of $460 million.

Figure 3. Houston TranStar
(http://patriotllc.us/portfolio/transtar-dot-facility/)

The proposed ITS system will be integrated into the existing TranStar system, which can provide additional coverage and improve traffic monitoring along the project corridor.

2.1.5 Geographical Boundary

The limits for the project corridor are IH 69 between Beltway 8 and IH 10 East. Although the proposed ITS network will be along the project corridor, parallel arterials will be considered to assist with alternate routing for daily congestion, major incidents, and minor incidents. The parallel arterials that are being evaluated include, but are not limited to:

- Richmond Avenue
- Beechnut Street
- Bissonnet Street
- Westheimer Road
- West Alabama Street
- Bellaire/W Holcombe Boulevard
- Almeda Road
- SH 288
- US 90 A

2.1.6 Overall System Capabilities

The overall system capabilities are expected to enhance the existing TranStar system. The purpose is to continue providing motorists with traveler information to make more informed decisions regarding their travel destination.

It is imperative that the system maintains and improves interagency communication and informs agencies within TranStar as well as the individuals that are not housed at TranStar, such as the Houston Police Department (first responders) and the City of Houston. For real-time traffic conditions to be improved, a wider range of ITS data and messages will need to be relayed through DMS. Congestion may be improved through the use of rerouting messages displayed on DMS, especially with an interconnection to major arterials that can support rerouted traffic. TranStar will be able to modify dynamic lane assignments through variable message signs for incident management and construction advisory notifications. The ability to modify the lane assignments, such as opening a shoulder for use as an additional traffic lane if an incident occurs downstream, can help traffic continue to flow. Traffic is usually stop/go during lane closures, however, the lane assignments can improve traffic volume throughput. The ability to effectively use dynamic lane assignments relies heavily on real-time enforcement. For additional safety measures, the queuing warning system can improve safety for drivers to notify them of the queues ahead. The goal for the overall system capabilities is to improve the current system with the implementation of additional advanced real-time traffic management devices.

Section 2.2 Reference Documents

Several systems were researched for the development of the IH 69 Active Traffic Management Systems Concept of Operations. The documents helped identify and clarify key concepts and procedures for traffic management and mitigation, as well as infrastructure requirements to further the IH 69 ATMS plan. The multiple sources of information utilized for the Concept of Operations are listed below.

US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study

The *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study* was conducted by H-GAC in partnership with several regional transportation agencies including TxDOT, METRO, Harris County, and the City of Houston. Active traffic management strategies were examined, as well as access modifications and managed lanes. The study was published in December 2015.

Document Summary

The purpose of the study was to analyze ways to improve congestion, safety, and travel times on the IH 69 project corridor for a minimal cost. Both long-term and short-term strategies were evaluated. The methodology of the study followed the steps listed below:

- Establish measures of performance
- Review of previous studies and existing data
- Identification of toolbox
- Identification of issues
- Public engagement and participation Meeting 1
- Refinement of issues
- Analysis of existing conditions
- Development of preferred strategies
- Public engagement and participation Meeting 2
- Finalization of strategies

Potential strategies were then modeled, researched, assessed by the public, and underwent benefit/cost analyses. Lastly, the finalized recommendations were selected and prioritized.

The existing conditions of the corridor were investigated, including the connectivity of employment centers, planned projects, traffic data, crash data, roadway characteristics, traffic operations, and transit operations. The following ITS infrastructure along the corridor was identified:

- Communications (fiber, wireless, and hardware)
- Closed-circuit television (CCTV – 22 locations)
- Automatic vehicle identification (AVI)
- Dynamic message signs (DMS – 7 locations)
- Freeway ramp meters (12 locations)
- Regional computerized traffic signal system (RCTSS)
- Roadway weather information system (RWIS)
- Automated traveler information system (ATIS)
- Regional incident management system (RIMS)
- Regional integrated traffic management system (RITMS)

The suggested mitigation strategies from the *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study* relevant to the IH 69 ATMS Concept of Operations can be found in Table 3.

Table 3. Mitigation Strategies – US 59/IH 69 ATMS

Mitigation	Strategy	Details
Traffic Management	Aggressive Incident Management	Operational system to clear incidents efficiently and safely.
	Dynamic Merge Control	Regulates or closes lanes near high-volume merge areas.
	Dynamic Rerouting	Presents drivers comparable alternative routes when normal route is severely congested.
	Queue Warning	Alerts drivers of downstream queues or slowdowns.
	Ramp Flow Control	Uses traffic signals at entrance ramps to regulate flow of vehicles entering a freeway.
	Signal Operations and Management	Monitors arterial traffic conditions and queuing at intersections to dynamically adjust signal timings based on daily conditions.
	Temporary Shoulder Use	Dynamic measure designed to adapt roadway capacity to high traffic volumes on a temporary basis.
	Traveler Information Systems	Provide real-time information and alerts to motorists via technology.
	Variable Pricing	Toll rates fluctuate based on the level of congestion.
	Variable Speed Limits/Advisory Speeds	Enacted by signs that can be changed to alert drivers when traffic congestion is imminent.
Access Modification and Added Capacity	Access Management	Techniques used to control access to highways and major arterials.
	HOV/HOT Lanes	High Occupancy Vehicle (HOV) and High Occupancy Toll (HOT) lanes that may include toll rates that fluctuate dynamically with the change in congestion on general purpose lanes.
	Intersection Improvements	Improvements to unsignalized or signalized intersections.

Fifteen tangible mitigation strategies for the IH 69 corridor were refined through an initial analysis examining traffic models, case studies, and safety measures. A benefit/cost analysis was then performed resulting in only eight recommended congestion mitigation strategies, which included active traffic management. In addition, ramp removals and reconfigurations, auxiliary lane extensions, additional HOV/HOT lane access, and variable priced HOV/HOT bi-directional lanes were also recommended strategies.

The recommended active traffic management strategy was projected to have a construction and design cost of $35,000,000 and an annual operations and maintenance cost of approximately $2,000,000. TranStar was the suggested lead agency for the strategy. The simplified active traffic management strategies for the IH 69 corridor are listed in Table 4.

Table 4. Active Traffic Management Strategies – US 59/IH 69 ATMS

Active Traffic Management Strategy	Anticipated Benefits	Potential Challenges
Dynamic Traffic Rerouting	-Reduces congestion by switching traffic to alternate routes -Maximizes efficiency & capacity of network by spreading traffic across network -Increases safety by decreasing likelihood of secondary crashes	-Extensive sensor & sign infrastructure to ensure reliable alternate route information can be generated -Available funding/cost
Dynamic Lane Assignments (Temporary Shoulder Use)	-Delays onset of congestion by increasing capacity & improving trip reliability -Increase in throughput by temporarily increasing capacity	-Available funding/cost -Not used in many places in U.S. -Legislative change (temporary shoulder use)
Adaptive Ramp Flow Control (Ramp Metering with Detection)	-Increases speed & throughput on freeway by improving flow of vehicles entering freeway -Decreases crash rates -Relatively low cost to install & maintain	-Public acceptance
Aggressive Incident Clearance	-Improves travel time reliability & decreases delay that accounts for ¼ of all congestion -Increases response time through better coordination & information management -Improves safety for emergency management personnel, those involved in incident, & other drivers	-Available funding/cost
Traveler Information Systems	-Maximizes efficiency & capacity by providing current transportation system information to drivers -Reduces impact of congestion -Increases safety by alerting drivers of upcoming hazards	-Available funding/cost
Queue Warning	-Reduces primary & secondary crashes by alerting drivers of congested conditions -Delays onset of congestion, improving smooth & efficient traffic flow & trip reliability -Provides environmental benefits through decreased emissions, noise, & fuel consumption	-Available funding/cost
Variable Speed Limit (Speed Harmonization)	-Improves safety by slowing vehicles approaching stop & go traffic -Delays onset of congestion allowing traffic to flow smoothly & efficiently & improving trip reliability -Provides environmental benefits through decreased emissions, noise, & fuel consumption	-New to U.S. (successful in Europe) -Public acceptance & understanding of system -Legislative change associated with particular strategies including temporary shoulder use & variable speed limits

Supplementary cost calculations were analyzed for the final recommendations (active traffic management, access modifications, and HOV/HOT lanes) for the IH 69 corridor. For the active traffic management strategy, a 20-year benefit of $550,000,000 was based on time savings and crash reductions. A 20-year cost of $72,000,000 was based on infrastructure improvements, maintenance, and operational staffing. The proposed active traffic management plan advocated in the *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study* included the following strategies:

- Traffic management during incidents
- Dynamic rerouting and traveler information
- Queue warning
- Variable speed limits/advisory speeds
- Temporary shoulder use during incidents
- Adaptive ramp flow control
- Signal operation and management throughout the corridor

Additionally, the 20-year cost of the plan included the following infrastructure items:

- 5 full-color matrix DMS per sign bridge
- 32 sign bridges with lane assignment DMS
- 36 detour DMS along alternative routes and arterials
- 12 adaptive ramp meters

The study anticipated the active traffic management strategy could be implemented quickly due to existing right-of-way construction. However, coordination between multiple agencies and a revised Concept of Operations would be needed before the active traffic management systems requirements and detailed design could take place.

Houston Region ITS Architecture

The *Houston Region ITS Architecture* (RITSA) outlines how the major transportation systems of the Houston area are interrelated. Multiple transportation and emergency agencies throughout the area worked together to create a comprehensive system for transportation efficiency and safety. The process for developing the *Houston Region ITS Architecture* was based on the U.S. Department of Transportation's National ITS Architecture and closely linked with the architecture definitions of Houston TranStar. The original *Houston Region ITS Architecture* document was prepared for H-GAC in April 2003. The steering committee team included members from H-GAC, TxDOT, Harris County Traffic, METRO, City of Houston Office of Emergency Management (OEM), Harris County OEM, and TranStar. The document was revised in February 2006. Currently, there are plans to revisit the document in the summer of 2016.

Document Summary

The RITSA contains an abundant amount of information. However, for the IH 69 ATMS Concept of Operations, only items relevant to the IH 69 ATMS were evaluated and summarized in this section. For additional information, please reference the *Houston Region ITS Architecture*.

In general, the RITSA provides a framework for developing a multi-agency coordinated system that facilitates the sharing of information and resources to create a safer and more efficient transportation system. The eight counties of the RITSA include Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller. However, the majority of the planned and implemented ITS developments are in Harris County.

TranStar is responsible for the innovative Houston Advanced Traffic Management System as well as the transportation and emergency management functions of the greater Houston metropolitan area in coordination with TxDOT, METRO, City of Houston, and Harris County. TranStar is also responsible for transportation and emergency management functions for the entire southeast Texas region. It is anticipated TranStar will continue to play a major role in the development of the IH 69 ATMS.

The steps to develop a regional ITS architecture include identification of function needs by stakeholders, mapping needs to user services, grouping market packages and equipment packages, and defining the physical architecture of the system. Physical architecture includes center, roadside, vehicle, and traveler subsystems. Figure 4, the architectural illustration below, shows the Houston region's existing and planned interconnected subsystems. The three general forms of communication between the subsystems include wire-line, wide-area wireless, and short-range wireless.

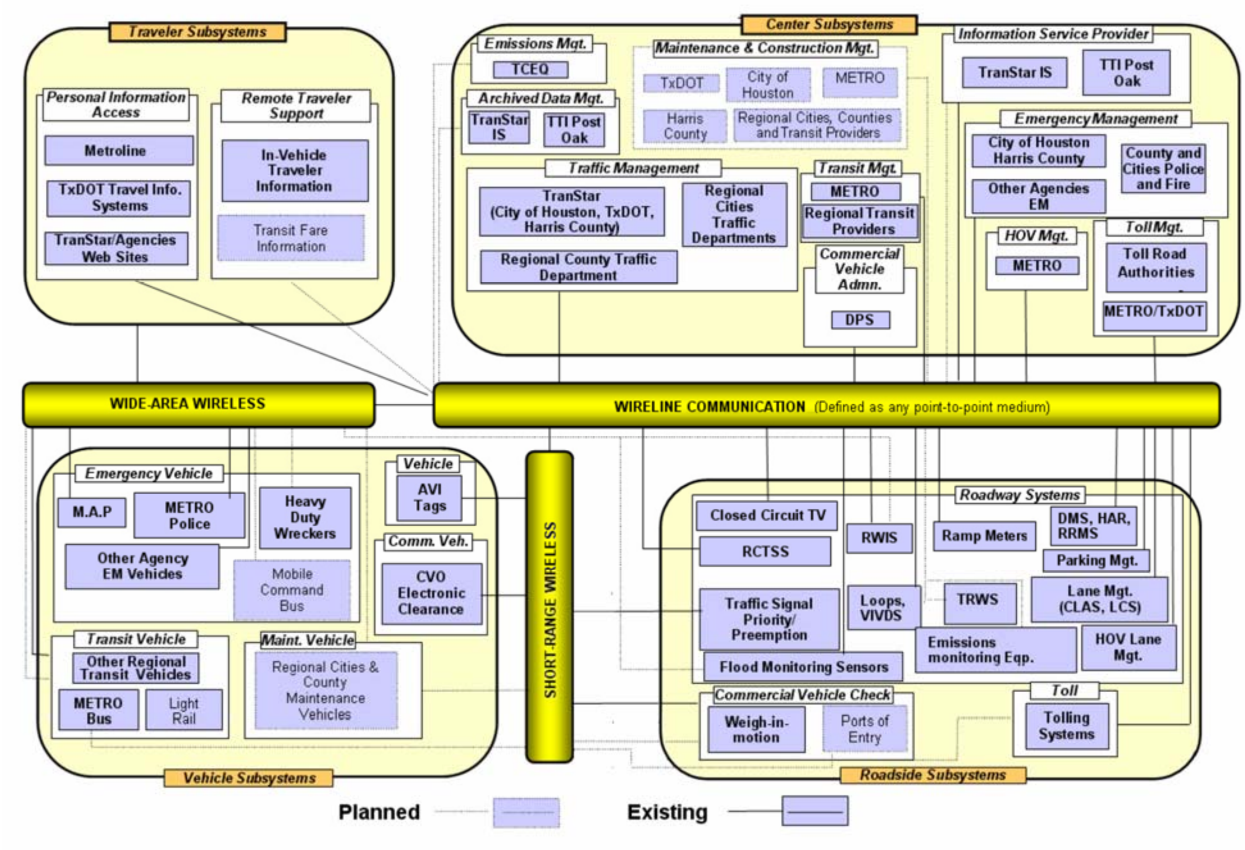


Figure 4. High-Level Physical Architecture for the Houston Region

All elements of the IH 69 ATMS are currently identified in the Roadside Subsystems (CCTV, DMS, lane management, etc.). As such, the existing legacy Roadway System and Toll System, as of April 2002, are listed in Table 5. An additional element needed for the IH 69 ATMS is an Incident Management System/Process, which will employ the existing Roadside Subsystem elements in a new type of interactive system.

Table 5. Key Subsystems in the Region – IH 69 ATMS

<table>
<tr><th colspan="4">Houston Region ITS Architecture</th></tr>
<tr><th>Subsystem</th><th>Local Program</th><th>Owning Stakeholder</th><th>Status</th></tr>
<tr><td rowspan="8">Roadway (ITS Equipment)</td><td>Freeway Closed-Circuit Televisions (CCTVs), Video Imaging Vehicle Detection Systems (VIVDS), Automatic Vehicle Identification (AVI), Lane Control Signs (LCS)</td><td>TxDOT</td><td>Current</td></tr>
<tr><td>City Arterial Signals (RCTSS)</td><td>City of Houston</td><td>Current</td></tr>
<tr><td>County Arterial Signals (RCTSS)</td><td>Harris County</td><td>Current</td></tr>
<tr><td>Reversible HOV Lanes</td><td>TxDOT, METRO</td><td>Current</td></tr>
<tr><td>Changeable Lane Assignment Signs (CLAS)</td><td>Harris County</td><td>Current</td></tr>
<tr><td>Ramp Meters</td><td>TxDOT</td><td>Current</td></tr>
<tr><td>DMS</td><td>TxDOT/METRO</td><td>Current</td></tr>
<tr><td>Road Weather Monitoring Sensors, Flood Level Sensors</td><td>Harris County, TxDOT</td><td>Current</td></tr>
<tr><td rowspan="2">Toll System</td><td rowspan="2">Tolling Booths, Equipment</td><td>HCTRA</td><td>Current</td></tr>
<tr><td>FBCTRA</td><td>Current</td></tr>
</table>

As a requisite of the National ITS Architecture, a functional needs assessment and user services identification was completed by the RITSA project team. The selected critical technical and institutional needs mapped in Table 6 depict the desires of the region's stakeholders that will likely be a factor in the development of the IH 69 ATMS. The complete mapped needs of the region can be found in Table 2-1 of the *Houston Region ITS Architecture*.

Table 6. Mapping of Critical Needs to User Services – IH 69 ATMS

	Critical Technical & Institutional Needs															
User Services	Improve Arterial Management	Manage Congestion	Improve Data Warehousing & Management	Enhance Emergency Evacuation	Improve Emergency Management	Improve Flood Monitoring	Improve Incident Management	Provide Better En-route Traveler Information	Provide Better Quality of Pre-trip Traveler Information	Provide Information on Routes & Alternatives	Implement 511	Improve Traffic Signal Coordination	Expand Incident Management to Toll Roads	Improve Traffic Management	Improve HOV Lane Management	Increase the use of Electronic Payment
Travel & Transportation Management																
1.1 Provide Pre-Trip Travel Information									X		X					
1.2 Provide En-route Information								X								
1.3 Support Route Guidance										X						
1.5 Provide Traveler Services Information								X	X		X					
1.6 Support Traffic Control	X	X										X		X		
1.7 Conduct Incident Management		X					X						X			
1.8 Support Travel Demand Management		X													X	
Electronic Payment																
3.1 Provide Electronic Payment Services															X	X
Emergency Management																
5.1 Enhance Emergency Notification & Personal Security				X	X	X										
5.2 Provide Emergency Vehicle Management				X	X											
5.3 Disaster Response & Evacuation				X	X		X	X						X		
Information Management																
7.1 Archived Data Function			X													

Within ITS architecture, market packages rationalize how the user systems will be addressed. Market packages can encompass one or more subsystems as well as one or more equipment packages (a group of functions within a subsystem that can be implemented), and each can be modified to meet the specific needs of the regional system. The regional market and equipment packages defined by the RITSA and pertinent to the IH 69 ATMS are shown mapped in Table 7. The complete mapped market packages for the region can be found in Table 3-1 of the *Houston Region ITS Architecture*.

Table 7. Mapping of User Services to Market Packages – IH 69 ATMS

Market Packages	Houston Region User Services												
	1.1 Provide Pre-trip Travel Information	1.2 Support En-route Driver Information	1.3 Support Route Guidance	1.4 Provide Ride Matching and Reservation	1.5 Provide Traveler Services Information	1.6 Support Traffic Control	1.7 Conduct Incident Management	1.8 Support Travel Demand Management	3.1 Electronic Payment Services	5.1 Enhance Emergency Notification and Personal Security	5.2 Improve Emergency Vehicle Management	5.3 Disaster Response and Evacuation	7.1 Archive Data Function
Advanced Traffic Management Systems (ATMS)													
1. Network Surveillance						X	X						
2. Probe Surveillance						X							
3. Surface Street Surveillance						X	X						
4. Freeway Control						X	X	X					
5. HOV Lane Management						X	X	X					
6. Traffic Information Dissemination		X				X	X	X					
7. Regional Traffic Control						X	X						
8. Incident Management System						X	X					X	
9. Traffic Forecast and Demand Management						X	X	X					
10. Electronic Toll Collection								X	X				
18. Reversible Lane Management						X	X	X					
Advanced Traveler Information System (ATIS)													
1. Broadcast Traveler Information	X	X	X		X								
2. Interactive Traveler Information	X	X	X	X	X		X		X				
5. ISP Based Route Guidance	X	X	X						X				
7. Yellow Pages and Reservation	X	X			X								
8. Dynamic Ridesharing			X	X					X				
Emergency Management (EM)													
1. Emergency Response										X	X		
2. Emergency Routing			X			X					X		
5. Transportation Infrastructure Protection										X			
Archived Data (AD)													
1. ITS Data Mart													X
2. ITS Data Warehouse													X

The RITSA simplified the physical architectures of major functional areas to clarify the physical interconnects and information exchanges of key ITS systems and equipment. The major functional areas appropriate for the IH 69 ATMS include traffic management, traveler information, toll management, emergency management, and archived data management. The detailed descriptions of subsystem market package diagrams can be found in Section 4.3 and Appendix A of the *Houston Region ITS Architecture*.

IH 10 Freeway Responsive System

The TxDOT *IH 10 Freeway Responsive System* study examines the responsive system along the IH 10 corridor between Mason Road and SH 6 in west Houston. The purpose of the responsive system is to mitigate freeway congestion through frontage road signalized intersections once freeway traffic is displaced. The system concept and design involves freeway condition sensors, output information to intersections, and intersection responses. Sensors are set up to monitor inbound and outbound freeway vehicular speeds, volumes, and/or occupancy. When a threshold condition is met, contact signals are sent to traffic signal cabinets through contact closure radio. Timing plans are then generated using contact inputs.

The equipment specified for the *IH 10 Freeway Responsive System* is found in Table 8. The approximate cost for the system equipment at each intersection is $11,000. The cost for an additional intersection is approximately $3,500.

Table 8. IH 10 Freeway Responsive System Equipment

Equipment	Purpose
Wavetronix HD Sensor with Criteria Signaling	Traffic monitoring
Click 513	Traffic-alert device
Intuicom 900 MHz	Radio with input/output contact closure
Econolite ASC 3	Traffic signal controller

The process of installing the system required adapting the existing freeway sensors, installing additional equipment for a responsive system, installing antennas, and installing input/output communication equipment at sensor and intersection locations. The number of lanes and direction information was part of the sensor setup. The speed, volume, and/or occupancy information was part of the closure interval criteria setup. The radios were programed for contact closure inputs and outputs at sensor and traffic signal cabinet locations, and the contact closure outputs at the intersections were connected to the designated input terminals. The radio setup allowed multiple intersections to receive multiple sensor outputs.

The HD sensors collected data at 30 second intervals and the Click 513 pulled data every five seconds. When certain criteria was met, the contact closure closed. The controller then worked through logic statements and began an action plan.

Additional uses for the system include ramp management. When an exit ramp starts experiencing long queues, a sensor can trigger a low priority preemption, a transit signal priority (TSP) input, or an alternative timing plan to clear the exit ramp. In addition, adjacent intersections can also react to new action plans with a peer-to-peer feature.

A micro-simulation using VISSIM was implemented in order to document the benefits of the system. To run the simulation, exit and entry ramp volumes, turning movement counts at intersections, timing plans, main lane volumes, and travel time data were all collected for model calibration. The developed model focused on the Barker Cypress signal, the first TxDOT maintained signal going outbound (westbound) from SH 6, during the PM peak period. The measures of effectiveness, according to the VISSIM micro-simulation, can be found in Table 9 below.

Table 9. IH 10 Freeway Responsive System – VISSIM Simulation Measures of Effectiveness PM Peak Hour (4:00 PM to 5:00 PM)

Measure		Effectiveness
Throughput	Freeway	Increased by 500 vph
	Cross street and eastbound frontage	Decreased by 115 vph
	Westbound frontage	Increased by 380 vph
Delay	Westbound freeway	Decreased by 64 veh-hrs
	Westbound frontage approach	Decreased by 130 s/veh, 86 veh-hrs
	Southbound frontage approach	Increased by 62 s/veh, 13 veh-hrs
	Total intersection	Decreased by 68 veh-hrs

The breakeven period, based on a $21.90 per hour value of time, was determined to be two days for a PM peak.

The study concluded freeway congestion can be eased by using frontage roads during unacceptable freeway levels of service. Additional study recommendations include conducting more advanced sensitivity analyses to determine when and where the system would be most beneficial, developing a guidance document, and investigating time of day triggering.

City of Houston Arterial ITS Conceptual Plan

The City of Houston plans to improve and expand its existing ITS infrastructure through the TIGER 2014 Discretionary Grant. The goals of the project include real-time management, real-time traveler information, reduced travel delay and emissions, improved capacity and reliability, optimized signal operations, and quicker equipment failure responses. The plan entails monitoring and managing arterial traffic along 150 corridors. Through the proposed advanced data collection and management system, the City of Houston ITS will be one of the most extensive arterial traffic management systems in the United States.

The system components will consist of communications equipment, central software, probe based travel times, DMS, CCTV, mid-block count stations, and enhanced signal detection. Several elements of the system are already in place or underway. Table 10 describes the components in more detail. **Appendix B** shows a map of the proposed system coverage in the Houston area.

Table 10. City of Houston ITS Components

Component	Details	
Communications	Fiber Optic Cable	150 Miles
		440 Traffic Signals
	WiMAX	60 Base Stations
		1,450 Traffic Signals
	Copper	300 Traffic Signals
Central Signal Software	*Current System:* Siemens i2	11 Communication Servers
		Database Server
		Applications Server
		Web Server
	Current Project: Install New Field & Central Software	
Probe Based Travel Times	Bluetooth Readers	
	Current System: 48 Existing Bluetooth Locations	Iteris IP Devices
	Current Project: Install Additional 602 Bluetooth Locations	
	Travel Time Arterial Map	
Dynamic Message Signs (DMS)	Travel Times on Multiple Routes	
	Incident Information	
Closed Circuit Television Cameras (CCTV)	Pan-Tilt-Zoom Digital CCTV Cameras	
	Current System: 25 Existing Cameras	Teleste Encoders
	Current Project: 113 Planned Cameras	Monitor Traffic
		Confirm Incidents
		View through Houston TranStar Website
Mid-block Count Stations	Collect Traffic Volumes, Lane Occupancy, Vehicle Classification, & Spot Speeds	
	Current System: 15 Radar Based Devices Deployed	Wavetronix Smartsensor HD
	Current Project: 144 Planned Mid-block Count Stations	
Enhanced Signal Detection	*Current System:* Sensor Pucks & Loops	Capable of Collection & Storing Data (Counts)
	Current Project: 664 Planned Locations	

Improved traffic management will also allow traffic data to be collected, archived, and analyzed. Engineers will be able to determine congestion points and travel time fluctuations, and in return, make better timing and design decisions.

More advanced incident detection will be made possible through improved travel time map and camera monitoring. Pre-planned traffic signal control arrangements will be able to alter signal timings and DMS will be able to inform travelers of incidents ahead and alternative routes. Information dissemination through DMS, the TranStar website, and news media regarding travel times and incidents will also be improved through advanced monitoring.

The breakdown of the project costs and funding sources can be found in Table 11. The total system cost is anticipated to be approximately $50 million.

Table 11. Project Costs and Funding

Components, Grant Funds, and Sources		Estimated Cost
Current Installed Components		$20 Million
Funded/On-going Components		$6 Million
TIGER Funded Components	City of Houston Funding	$14 Million
	TIGER 2014 Funding	$10 Million
Total		**$50 Million**

The funds for the program must be obligated by September 30, 2016 and all invoices/expenditures must be completed by September 30, 2021.

A summary of the ITS components are listed in Table 12.

Table 12. ITS Component Summary

Component	Existing Locations	TIGER Project Locations
Fiber Cable	150 Miles	-
WiMAX	1,450	235
Copper	300	-
Bluetooth (Travel Times)	650*	-
DMS	-	91
CCTV	25	113
Count Station	15	144
Enhanced Signal Detection	175*	489
Central Signal Software	1*	-

*Existing Locations and/or Current Transportation Improvement Program (TIP) Projects

Currently, the City of Houston is negotiating the TIGER Grant agreement with the Federal Highway Administration and analyzing options for the design and construction of the arterial ITS project. With TIP funding, the City is finalizing the deployment of 602 Bluetooth locations, preparing for field and central software replacement, and planning the deployment of fiber optic cables to connect Houston TranStar to the traffic operations maintenance facility and the WiMAX central hub.

Additional Reference Documents

The following is a list of additional documents utilized either locally, statewide, and/or nationally that identify components or systems related to ITS and active traffic management. Each document has a brief description.

Texas ITS and Active Traffic Management

- *Texas Regional ITS Architecture Home Page*

  http://www.consystec.com/texas/default.htm

  The website provides easily accessible regional architectures and deployment plans for areas across Texas. The development process began in 2002 and continued through late 2013.

  Regional Website – Statewide

- *Concept of Operations for the IH-10 Corridor in San Antonio, Texas*

  http://www.its.dot.gov/icms/pdf/14393.pdf

  The report was developed under the project titled *TransGuide Integrated Corridor Management (ICM) – Stage 1*. The document provides operational concepts, project vision, and operational scenarios for the San Antonio IH-10 corridor. The report was published in March 2008.

  Regional Document – San Antonio Area

- *System Requirement Specification for the IH-10 Integrated Corridor Management System (ICMS) in San Antonio, Texas*

  http://ntl.bts.gov/lib/30000/30400/30465/14428.pdf

  The report was also developed under the project titled *TransGuide ICM – Stage 1*. The components of the system engineering process are highlighted with respect to communication of information to stakeholders and improving system functions. The report was published in March 2008.

  Regional Document – San Antonio Area

- *Concept of Operations for the US-75 Integrated Corridor in Dallas, Texas*

  http://ntl.bts.gov/lib/30000/30400/30409/14390_files/14390.pdf

  The Concept of Operations investigates the key concepts of the ICM for the US-75 corridor in Dallas. Freeway, arterial, bus, and rail networks were examined as well as the responsibilities of stakeholders. The report was published in April 2008.

  Regional Document – Dallas Area

- *High-Level Requirements for the US-75 Integrated Corridor in Dallas, Texas*

  http://ntl.bts.gov/lib/30000/30400/30408/14426_files/14426.pdf

  The report describes the functional requirements, performance requirements, and non-functional requirements of the US-75 ICM system. The technical scope of the system, which consists of a multi-agency de-centralized operation, is defined in the report. The document was published in April 2008.

Regional Document – Dallas Area

- *Dallas Integrated Corridor Management (ICM) Demonstration Project*

  http://ntl.bts.gov/lib/56000/56700/56759/FHWA-JPO-16-234_v1.pdf

  As a continuation of the US-75 ICM, the report covers the Dallas Area Rapid Transit (DART) Demonstration Project for the region. The coordinated operations and communication of information utilizing the TxDOT Center-to-Center standards were assessed. Connections to additional stakeholders not part of the Center-to-Center network were created using SmartNET, a graphical user interface. Results from the various phases of the ICM program, lessons learned, and recommendations were also addressed in the report. The document was published in August 2015.

  Regional Document – Dallas Area

- *North Central Texas Council of Governments - Transportation*

  http://www.nctcog.org/trans/

  The website was established by the North Central Texas Council of Governments to assist local members in various regional improvements, including transportation. Several ITS and congestion mitigation resources for the Dallas and Fort Worth area can be found on the website.

  Regional Website – Dallas/Fort Worth Area

- *North Central Texas Intelligent Transportation System (ITS) Strategic Deployment Plan Draft*

  http://www.nctcog.org/trans/its/regitsarch/documents/DRAFT_ITS_SDP_Report_with_Appendices.pdf

  The plan was led by the North Central Texas Council of Governments in close coordination with regional stakeholders. The goal was to create an updated ITS Deployment Plan that supports the Regional ITS Architecture and presents an accurate outline of existing as well as future ITS deployments. The report was published in April 2016.

  Regional Document – Dallas/Fort Worth Area

- *Austin Regional ITS Architecture*

  http://austinitsarchitecture.com/

  The Austin Regional ITS Architecture website provides a central location for project documents, interactive architecture interfaces and databases, and local agency agreements. The initial Austin Regional ITS Plan was developed in 1996, and the most recent update was in 2015.

  Regional Website – Austin Area

- *Active Transportation and Demand Management Texas Test Bed*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/161408-1.pdf

  An analysis was performed on the traffic congestion along the IH-35 corridor in Central Texas. Capital Area Metropolitan Planning Organization plans were then modeled using a combination of static, time-dependent, and congestive-responsive tolling strategies. The study subsequently examined combinations of different strategies such as time-dependent pricing, reversible lanes, ramp metering, en-route diversion, and demand management to obtain the best approach to combat congested networks. The report was published in October 2014.

  Regional Document – Austin Area

- *My Interstate 35*

  http://www.my35.org/

  The website connects users to news, project updates, notifications, and road conditions along the I-35 corridor in Texas. Users also have access to live traffic camera video feeds, project reports and plans, public meeting and forum notices, and user feedback options. The award-winning approach launched by TxDOT in 2008 helped increase citizen participation in the transportation planning process.

  Regional Website – Central Texas Area

Regional ITS Architecture

- *Houston TranStar*

  http://www.houstontranstar.org/

  Houston TranStar is responsible for the Advanced Traffic Management System in the greater Houston metropolitan area. The organization is also responsible for the planning, design, and operations of transportation systems and emergency management functions throughout the southeast region of Texas in conjunction with TxDOT, METRO, The City of Houston, and Harris County. TranStar was established in 1993.

  Local Website – Houston Area

- *Warrants and Criteria for Installing and Sunsetting TxDOT ITS Equipment*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6773-1.pdf

  The purpose of the report was to develop strategies, standards, and measures to support TxDOT in decision-making specific to ITS devices and systems regarding install, repair, upgrades, and/or removal. The report was published in January 2014.

  Regional Document – Statewide

- *Research to Develop an ITS Strategic Plan for Texas*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6672-2-Vol-1.pdf

  The report discusses how ITS can support the mission of TxDOT, which is to provide safe and reliable transportation solutions. ITS can offer TxDOT the ability to maintain a safe system, address congestion, connect Texas communities, and become a best-in-class state agency. The research to develop the *ITS Strategic Plan for Texas* is documented in the report. The report was published in April 2014.

  Regional Document – Statewide

- *TxDOT ITS Strategic Plan 2013*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6672-2-Vol-2.pdf

  The plan focuses on the goals of TxDOT to create a safe system that connects communities in a seamless way with as little congestion as possible. ITS is a critical component of the TxDOT strategy and can be used to advance transportation systems throughout the state. The plan helps to promote the development, deployment, and use of ITS statewide with the help of providers, stakeholders, and agency partners. The plan was published in April 2014.

  Regional Document – Statewide

- *Communication Trends and Their Impact on TxDOT ITS Deployments*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5586-1.pdf

  The report documents the state of ATMS deployments in Texas that utilize communication infrastructures. The impacts from software interfaces, TxDOT technology architecture, industry trends, and needs of information providers are analyzed and a conceptual model for future ATMS network architecture is developed. The report was published in February 2008.

  Regional Document – Statewide

Local Agency Agreements

Additional information for local agency agreements can be found in Section 2.3.

- *Interlocal Agreement for a Regional Transportation Management Program* (the Houston TranStar master operating agreement)
- *Fifteenth Supplemental Agreement for a Houston Area Freeway Incident Management Program*
- *Multiple Use Agreement for Shared Fiber Optic Communications Cable in Support of the Regional Computerized Traffic Signal System and METRO MAN* (TxDOT and METRO)
- *Fiber Network Interconnection Agreement between Harris County and TxDOT*
- *The Houston ITS Priority Corridor Program Agreement No. 126XXF4003 and Amendment No. 7*

- *The Houston ITS Priority Corridor Program, Condition Responsive Uptown Traveler Information System Work Order Number 24*
- *Houston METRO HOT Plan and Operations Manual*
- *Transmittal of High-Occupancy Toll Lane Agreement*

Feasibility Studies

- *An Integrated Approach to Managing the Finance, Maintenance, and Operation of Transportation Systems*

  http://library.ctr.utexas.edu/ctr-publications/6-0701-1.pdf

  The document reviews the budget shortfalls in Texas for transportation in spite of an increasing population and demand on Texas roadways. The document argues TxDOT must develop new and innovative ways to ensure Texas highways fulfill their role in economic competiveness with a safe and reliable transportation system. The report was published in August 2013.

  Regional Document – Statewide

- *Guidance for Feasibility Analysis of Candidate Site: Handbook*

  http://ntl.bts.gov/lib/33000/33700/33713/0_5913_P1.pdf

  The handbook provides guidance in determining feasibility for speed harmonization and peak shoulder use. Six analysis components are described in the report including site, simulation, infrastructure improvements, public and enforcement education plan, cost benefit analysis framework, and impacts. The handbook was published in September 2009.

  Regional Document - Statewide

Operational Procedures and Additional Technical Documents

- *Texas Transportation Institute*

  http://tti.tamu.edu/

  The Texas A&M Transportation Institute provides research, training, and education to the transportation industry and transportation professionals. Engineering, planning, economics, policy, landscape architecture, environmental sciences, computer science, and social science are TTI areas of expertise. The organization was first chartered in 1950.

  National Website – Statewide Research

- *The Houston-Galveston Regional Transportation Plan 2040*

  http://www.h-gac.com/taq/plan/2040/

  The 2040 Regional Transportation Plan (RTP) offers a guide for maintaining and improving the Houston area transportation systems and identifies important transportation investments. The majority of investments are intended to increase the efficiency of current transportation facilities. The goals of the plan include improve safety, manage and mitigate congestion, ensure strong asset management and operations, strengthen regional economic competitiveness, and conserve and protect natural and cultural resources. Investment strategies include improve system management and operations, enhance state of good repair, expand the multimodal network, and coordinate development. The plan was revised March 2016.

Local Website – Houston Area

- *Traffic Operations and Safety Benefits of Active Traffic Strategies on TxDOT Freeways*

  http://www.utexas.edu/research/ctr/pdf_reports/0_6576_1.pdf

  The study created a series of interdependent models and a simulation framework to analyze traffic operations and safety benefits of active traffic management strategies. The examined strategies included variable speed limits, peak-period shoulder use, and ramp metering. ITS devices, enforcement issues, impediments, and an outline for cost-benefit analysis to determine economic viability were also discussed. The study was published in October 2011.

  Regional Document – Statewide

- *Traffic Control Strategies for Congested Freeways and Work Zones*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5326-2.pdf

  The research document evaluates ways to improve traffic operations with a primary focus on end-of-queue warning, work zone lane closures, and queue spillover at exit ramps. Various traffic control strategies were considered including queue warning systems, merge controls, and ramp metering. The document was published in October 2008.

  Regional Document – Statewide

- *Technical Memorandum #1: Literature Review & Contemporary Case Studies – Metropolitan Highway System Investment Study*

  http://metrocouncil.org/Transportation/Publications-And-Resources/MHSISAppFStateofthePractice-pdf.aspx

  The memo from the Minneapolis area discusses the results of research identifying different types of Travel Demand Management (TDM) and Intelligent Transportation Systems (ITS) applied in the United States. Active traffic management, managed lanes, shoulder use, and bus rapid transit strategies were evaluated. Literature reviews and case studies were performed in urban areas across the country that have applied the various strategies. Costs, funding, and impacts of the systems were also assessed. The memo was published in December 2009.

  National Document – Texas Research

- *An Agency Guide on Overcoming Unique Challenges to Localized Congestion Reduction Projects*

  http://ops.fhwa.dot.gov/publications/fhwahop11034/fhwahop11034.pdf

  The report describes how to overcome barriers and challenges to implementation of localized congestion relief projects. Case studies of projects that explain how to overcome challenges are also presented. The report was published in September 2011.

  National Document – Texas Research

- *Congestion Management Process: A Guidebook*

  http://www.fhwa.dot.gov/planning/congestion_management_process/cmp_guidebook/cmpguidebk.pdf

  The publication provides information for an objectives-driven and performance-based congestion management process. The importance of livability, multimodal transportation, environmental review, collaboration with partners, demand management, operations strategies, and effective documentation and visualization are also addressed. The guide was published in April 2011.

  National Document – Texas Research

Data Collection and Bluetooth Technology

- *Bluetooth-Based Travel Time/Speed Measuring Systems Development*

  http://utcm.tamu.edu/publications/final_reports/puckett_09-00-17.pdf

  The study reviews the development and testing of several prototype software and hardware platforms for measuring Bluetooth devices using the anonymous Media Access Control (MAC) address. Bluetooth is a widely used technology embedded in cell phones and in-vehicle applications for exchanging data over short distances and Bluetooth travel time measurement systems are often very cost-effective. The study was published June 2010.

  National Document – Houston Area Research

- *Transportation Operations Data Needs and Recommendations for Implementation*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5257-1.pdf

  The study summarizes research conducted to critique transportation operations data management systems. Data needs, data flows, procedures, and recommendations for optimization were analyzed. Guidelines and plans for TxDOT were also outlined in the report. The study was published in March 2007.

  Regional Document – Statewide

- *Investigation of Vehicle Detector Performance and ATMS Interface*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4750-2.pdf

  The report examines research regarding the most promising non-intrusive vehicle detectors and technology including video image vehicle detection systems (VIVDS), acoustic, magnetic, inductive loops, and microwave radar. An investigation of an interface with TxDOT ATMS contact closure inputs to Local Control Units (LCUs) was also included in the report. The study determined the microwave and magnetometers were the most promising for freeway application based on cost, accuracy, and ease of setup. The report was published in March 2007.

  Regional Document - Statewide

- *Development of Guidelines for Data Access for Texas Traffic Management Centers*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5213-1.pdf

  The document offers guidelines and recommendations for TxDOT in ways to manage traffic management center information ownership and how to address administrative concerns. Revenue opportunities, contractual agreements, and the collection and dissemination of traffic data was also discussed. The document was published in May 2007.

  Regional Document – Statewide

- *Transportation Operations Data Needs and Recommendations for Implementation*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5257-1.pdf

  The study evaluates the difficulties in managing and analyzing transportation operations data. Data needs, data flows, recommendations for production optimization, data use, and archival options were assessed. In addition, the study summarizes strategies for data management and implementation guidelines relevant to TxDOT plans and practices. The study was published in March 2007.

  Regional Document – Statewide

- *Synthesis of TxDOT Uses of Real-time Commercial Traffic Data*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6659-1.pdf

  The research project examined whether TxDOT could and should use data offerings by private sector providers. The research focused on available data, what other states are doing, utility of data sources, how the data should be managed, and recommendations for TxDOT. The study was published in January 2012.

  Regional Document – Statewide

- *Regional Transportation Data Warehouse – Phase I, II, III Technical Report*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2008-9.pdf

  The paper describes the regional mobility information system for the El Paso area. The goals were to archive ITS data, build a central repository for transportation data, monitor mobility, and create a platform to adopt new ITS technologies with data-centric architecture. The data would be used for advanced traveler information systems. The paper was published in August 2008.

  Regional Document – El Paso Region

Dynamic Lane Assignment

- *Lane Assignment Traffic Control Devices on Frontage Roads and Conventional Roads at Interchanges: Technical Report*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6106-1.pdf

  The report provides information on the importance of lane control signs at intersection approaches. Surveys and focus groups were organized to develop test signs for field deployment. Roadway widening and lane choice guide signs were evaluated. The research used to recommend implementation of non-standard signing at atypical intersections was presented. The report was published in November 2011.

  Regional Document – Statewide

- *NCHRP Synthesis 447 – Active Traffic Management for Arterials*

  http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_447.pdf

  The report covers the state of the practice associated with designing, implementing, and operating active traffic management on arterials. Management strategies, successful and unsuccessful deployments, and system and technology requirements for arterial active traffic management strategies were studied. The report was published in 2013.

  National Document – Houston Area Research

Dynamic Message Signs

- *Dynamic Message Sign Message Design and Display Manual*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4023-P3.pdf

  The manual was written for use by TxDOT personnel who have responsibility for the operation and message design of DMS. The manual contains several modules including operations and procedure guidelines. The manual was published in April 2006.

  Regional Document – Statewide

- *Effective Message Design for Dynamic Message Signs*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4023-5.pdf

  The report discusses the research on effective design and display of DMS messages. Experimental and design issues included incidents, roadwork, AMBER alerts, major catastrophes, planned special events, inclement weather, and environmental conditions. The study was published in May 2006.

  Regional Document – Statewide

- *Use of Graphics and Symbols on Dynamic Message Signs: Technical Report*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5256-1.pdf

  The study examines how graphics and symbol displays can improve or assist communication with drivers. Design elements and key benefits were identified including graphics, delivery, viewing time, and operational scenarios. The study was published in May 2009.

  Regional Document – Statewide

- *Guidelines for the Evaluation of Dynamic Message Sign Performance*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4772-1.pdf

  The research project focused on the methodology and guidelines for evaluating DMS performance. Metrics were established based on data availability, time of evaluation, and environment of application. Both qualitative and quantitative DMS benefits were discussed as well as urban and rural case studies performed. The research was published in March 2007.

  Regional Document – Statewide

- *Dynamic Traffic Assignment Based Trailblazing Guide Signing for Major Traffic Generator*

  http://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/476660-00046-1.pdf

  The study reviews the importance of placement and display of dynamic message signs regarding drivers' understanding of route networks. Experiments and models were created to measure travel times, length of routes, recognition parameters, and driver behaviors. The study concluded the developed algorithm and the assessment procedure results were imperative in guide signing, route guidance systems, and traveler information systems. The study was published in November 2009.

  Regional Document – Statewide

- *Implementing Graphic Route Information Panels (GRIPs) in the United States*

  http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=79C0319F987D210CAAF501EF4EAA2AD8?doi=10.1.1.451.24&rep=rep1&type=pdf

  The article discusses how Graphic Route Information Panels (GRIPs) can improve the traditional variable message signs by offering drivers a real-time overall view of the network with color-coded road segments of route congestion. The panels allow travelers to make informed transportation network decisions. The article was published in March 2012.

  National Document – Austin Area Research

Dynamic Traffic Re-routing and Arterials

- *Arterial Intelligent Transportation Systems – Infrastructure Elements and Traveler Information Requirements*

  https://www.utexas.edu/research/ctr/pdf_reports/0_5865_1.pdf

  Initiated by TxDOT, the study investigates arterial ITS elements, technologies, performance measures, information dissemination technologies, and financial considerations for arterial ITS deployments. The findings offer guidance to assist TxDOT to better utilize existing ITS infrastructure elements and to make intelligent investments in future applications. The study was published in August 2009.

  Regional Document – Statewide

- *Evaluation of the Overheight Vehicle Detection System (OVDS) Houston, Texas*

  The Texas Transportation Institute (TTI) report reviews the OVDS, which was deployed in 2015 by TxDOT at two locations in Houston along I-10. There are several low clearance bridges on the I-10 and I-45 corridors. Consequently, overheight vehicles are encouraged to divert their route via the I-610 loop. The goal of the OVDS is to eliminate or significantly reduce the number of bridge hits by overheight vehicles using a detection system that advises vehicles via DMS to use an alternate route. The system includes sensors, cameras, wireless communication devices, and DMS with warning beacons. The TTI study evaluated OVDS operations, effectiveness, concerns, and cost effectiveness. Overall, the system appeared to influence through trips on freeways and diverted trucks to alternate routes without adverse or unexpected consequences. TTI recommended additional long term studies to further evaluate the OVDS.

  Local Document – Houston Area

Incident Management

- *SafeClear Performance Report 2014*

  http://www.houstontx.gov/council/h/committee/20150728/2014safeclear.pdf

  The 2014 report reviews the 2008 through 2013 time period regarding the performance of the City of Houston SafeClear traffic incident management program. The SafeClear program began in 2005 and sought to mitigate problems caused by aggressive tow operators. Previous reports from 2006 and 2008 concluded the SafeClear program reduced collisions, congestion, and crash clearance times.

Local Document – Houston Area

- *Intelligent Transportation Systems for Traffic Incident Management*

  http://ntl.bts.gov/lib/jpodocs/brochure/14288_files/14288.pdf

  The document reviews the USDOT initiative to reduce incident-related congestion by improving incident response capabilities. The goal of Traffic Incident Management (TIM) is to remove traffic incidents and restore traffic capacity as safely and quickly as possible by using proper communication, technology, and ITS tools. The document reviews TIM benefits, costs, deployments, and lessons learned. The report was published in January 2007.

  National Document – San Antonio and Houston Area Research

- *Best Practices in Traffic Incident Management*

  http://ops.fhwa.dot.gov/publications/fhwahop10050/fhwahop10050.pdf

  The report offers effective strategies to combat the issues and challenges commonly encountered by TIM responders. Advanced technological information as well as simple procedural solutions are provided to maximize effectiveness of TIM efforts. The study was published in September 2010.

  National Document – Texas Research

- *A Guidebook for Effective use of Incident Data at Texas Transportation Management Centers*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5485-P2.pdf

  The guidebook provides methods for using incident data to perform evaluation/planning as well as predictive analyses. Guidelines for reporting incident characteristics, analyzing hot spots, estimating incident impacts, and calculating performance measures are described. In addition, methods for predicting incident duration using incident characteristics and predicting incident-induced congestion clearance times are also described. The guidebook was published in February 2009.

  Regional Document – Statewide

- *Evaluating and Improving Incident Management Using Historical Incident Data: Case Studies at Texas Transportation Management Centers*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5485-1.pdf

  As a companion to the guidebook, the document provides results from case studies conducted using procedures from the guidebook. Data from Houston's TranStar, Austin's CTECC, and Fort Worth's TransVISION was examined and evaluated. The research concluded historical incident data can be used to support incident management and performance evaluation processes reactively and proactively. Procedures were also automated for more efficient daily use. The paper was published in August 2009.

Regional Document – Statewide

- *Evaluation of Video Analytics for Incident Detection – Pilot Demonstration Houston, Texas*

  The Texas Transportation Institute (TTI) report evaluates the TrafficVision video analytic software for use in assisting Houston TranStar with the identification of stopped vehicles (stalls or incidents). The 12 week pilot demonstration integrated the existing pan-tilt-zoom (PTZ) functioning CCTV cameras with the video analytics software. The TTI report examines the accuracy of the software, potential for detecting incidents faster, and potential for detecting additional incidents than those identified by TranStar operators. The paper concludes video analytics software has the potential for faster detection of incidents as well as the potential to increase the number of incidents detected. However, TTI recommends additional studies to evaluate the system with fixed cameras (PTZ cameras experience drift that affects software performance) and recommends additional operator training to ensure software proficiency and proper training to address false alarms.

  Local Document – Houston Area

Managed Lanes

- *Reducing Lane and Shoulder Width to Permit an Additional Lane on a Freeway: Technical Report*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6811-1.pdf

  The study identified operational and safety implications of reduced lane and reduced shoulder widths for different freeway configurations. Speed, crash, and geometric data were analyzed. The study concluded there is a safety detriment caused by narrow lanes and narrow shoulders, despite the safety benefits of an additional lane. However, if the total paved width is increased when adding a travel lane, the crashes along the corridor will likely remain unchanged for certain lane and shoulder widths. The study was published in March 2015.

  Regional Document – Statewide

- *Katy Freeway: An Evaluation of a Second-generation Managed Lanes Project*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6688-1.pdf

  The paper is an analysis of the Katy Freeway Managed Lanes, the first operational, multi-lane managed facility in Texas. Lessons learned from the project including development, design, and operation are discussed. Through continual monitoring and adjustments to operations, the managed lanes are providing travel time savings. Adjustments in toll rates, lane configurations, and access operations ensure performance standards for the lanes are maintained. The paper was published in September 2013.

  Regional Document – Statewide

- *Operational Performance Management of Priced Facilities*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6396-1.pdf

  The report provides guidance for lane management and pricing strategies. The concept of how facility's operations change over time and ways to make operating decisions based on data collection and a formulated conceptual framework are provided. The report was published in March 2011.

  Regional Document – Statewide

- *Developing Tolled-route Demand Estimation Capabilities for Texas: Opportunities for Enhancement of Existing Models*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6754-1.pdf

  The report analyzes the travel demand models for the Transportation Planning and Programming Division (TPP) of TxDOT and acknowledges the absence of a TPP procedure to account for existing or planned toll roads. Tolled facilities in the large urban areas of Texas were reviewed and approaches to travel demand models with toll road demand estimates were provided in the report. The report was published in August 2014.

  Regional Document – Statewide

- *Briefing Paper: Toward a Best Practice Model for Managed Lanes in Texas*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6688-P1.pdf

  The brief reviews the development and implementation of the Katy Freeway Managed Lanes (Katy Tollway) along I-10. The Katy managed lanes became operational in 2009 and the project was one of the first variably priced operations in Texas. The use of managed lanes to mitigate traffic has increased throughout the United States, and by reviewing lessons learned and adapting previous experiences to unique environments, managed lane projects can be successfully executed. The brief was published in September 2013.

  Regional Document – Statewide

Queue Warnings

- *Safety Effects of Portable End-of-queue Warning System Deployments at Texas Work Zones*

  http://docs.trb.org/prp/16-3587.pdf

  The study examines technologies to help alleviate impacts of end-of-queue warning crashes. An end-of-queue (EOQ) warning system was established along the I-35 widening project through central Texas using a portable work zone ITS. The results show the system had a positive effect in reducing crashes. The paper was published in January 2016.

  Regional Document – Statewide

- *Benefit Cost Analysis of Queue Warning System (QWS) on I-610 (West Loop)*

  The Texas Transportation Institute (TTI) memorandum presents the results of a benefit cost analysis regarding the deployed QWS along I-610 between Bellaire Blvd and the I-69 interchange. Two systems were deployed near the I-610 and I-69 interchange in 2006 by TxDOT, however, inaccurate data prevented the analysis of the northbound I-69 QWS. Based on the obtained crash data, the QWS has a positive benefit cost ratio. The crash data suggests the system is effective in warning drivers of slow speeds ahead. The likely benefits of the system include reducing the number of crashes and reducing the number of severe injury related crashes. Improvements and recommendations to the QWS by TTI include better communication, monitoring, improved radar systems with additional functionality, and DMS to replace the existing static signs to enhance and customize messages.

  Local Document – Houston Area

Ramp Metering

- *Development of Criteria and Guidelines for Installing, Operating, and Removing TxDOT Ramp Control Signals*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5294-1.pdf

  The report develops guidelines and criteria for TxDOT to determine when and where to install or remove ramp control signals. TxDOT uses ramp meters to create a uniform flow of entering freeway traffic. The process, procedures, and research used to develop the guidelines are also provided. Additional information can be found in *Operating Guidelines for TxDOT Ramp Control Signals*. The report was published in May 2009.

  Regional Document – Statewide

- *Managed Lanes Strategies Feasible for Freeway Ramp Applications*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5284-2.pdf

  The project analyzes the application of demand management strategies to main lane and managed lane ramp operations. Conditions for ramp management were assessed including target users in the corridor, congestion level, ramp spacing/density, ramp volumes, and accident history. The impacts and benefits of managed ramps were also examined, as well as guidelines for operation and enforcement. The report was published in January 2008.

  Regional Document – Statewide

- *Ramp Metering Installation and Maintenance Assessment – A Pilot Study Houston, Texas*

  The Texas Transportation Institute (TTI) document analyzes 10 ramp meter locations along I-69. TxDOT currently operates 60 ramp meters within the Houston area, and in order to assess the ramp meter program, TTI examined ramp meter warrant guidelines, operation and maintenance considerations, and overall benefits to mobility. Existing ramp meter controllers do not provide a known process for data logging and retrieval, which makes assessment difficult. However, TTI was able to review maintenance logs to identify concerns and potential solutions. Equipment knockdowns are the most common maintenance issue, in addition to communication and detection failures as well as missing equipment. TTI recommends an upgrade of controllers and a central monitoring of ramp metering operations to optimize system maintenance and ensure proper operations. TTI also states the benefit to cost ratio of ramp meters is positive and the use of ramp meters should continue.

Local Document – Houston Area

Signal Management

- *Evaluation of ACS Lite Adaptive Control using Sensys Arterial Travel Time Data*

  https://w3.usa.siemens.com/mobility/us/en/urban-mobility/road-solutions/adaptive-software/Documents/Fulton%20County%20ACS%20Lite%20Evaluation.pdf

  The paper describes the deployment of Adaptive Control Software (ACS) Lite on an arterial in Atlanta, Georgia. Evaluation of arterial travel time was aided by a Sensys Arterial Travel Time System. The paper concludes the ACS Lite system greatly reduced arterial travel times and side-street queue lengths during peak travel times.

  National Document – Houston Area Research

- *Studies to Improve Temporary Traffic Control at Urban Freeway Interchanges and Pavement Marking Material Selection in Work Zones*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5238-2.pdf

  The results of an analysis are described in the paper regarding how to improve temporary traffic control at work zones in and near urban freeway interchanges and how to select appropriate pavement marking materials in work zones. Simulators indicated guide signs no longer aligned directly over travel lanes degrade drivers' abilities to properly navigate through interchange areas. Temporary signing and/or pavement marking symbols to denote route destinations for the various lanes helped to offset degradation. The study was published in March 2008.

  Regional Report – Statewide

- *Investigation of New Vehicle Detectors for High-speed Signalized Intersections*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6828-1.pdf

  The report examines the performance of detectors designed for the stop line area and indecision zone. Infrared (IR) cameras with video imaging systems were found to improve detection for certain lighting and temperature conditions, but did not improve detection performance under all conditions. TxDOT needs for new vehicle detectors, detectors for both stop line and dilemma zone, and guidelines and recommendations for installation and use of detectors were presented in the document. The report was published in September 2015.

Regional Report – Statewide

Traveler Information

- *Implementation Issues and Strategies for Deployment of Traveler Information Systems in Texas*

  http://ctr.utexas.edu/wp-content/uploads/pubs/0_5079_P3.pdf

  The report provides an analysis of the benefits and costs associated with the deployment of Advanced Traveler Information Systems (ATIS) to toll road operations in Texas. An Austin area case study was conducted, and the results show ATIS is cost-effective. The study shows Texas transportation management centers are capable of ATIS and funding opportunities for deployment rely, in large part, on the public sector. The report was published in August 2006.

  Regional Report – Statewide

- *TTI Develops Advanced Traveler Information Map for I-35 Expansion Project*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/researcher/ttr-v50-n2.pdf

  The article reviews the updated traveler-information map for the I-35 Central Texas expansion project. The map, which was based on user feedback, improved the real-time information drivers could access before traveling the corridor. The map information was organized into tabs that include closures, alerts, signs, trip planner, weather, and camera snapshots. The article was published in 2014.

  Regional Report – Central Texas

Variable Speeds

- *Evaluation of TxDOT Variable Speed Limit Pilot Project*

  http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2015-10.pdf

  The study examines the Texas Transportation Commission rule requiring TxDOT to "study the effectiveness of temporarily lowering prima facie speed limits to address inclement weather, congestion, road construction, or any other condition that affects the safe and orderly movement of traffic on a roadway." Three sites were selected for the VSL evaluation with a focus on user perception, safety impact, overall cost, and VSL benefits. The study concludes VSL has safety benefits and recommends the operation of VSL in Texas. The report was published in June 2015.

  Regional Document – Statewide

- *Speed Harmonization and Peak-period Shoulder Use to Manage Urban Freeway Congestion*

  http://ctr.utexas.edu/wp-content/uploads/pubs/0_5913_1.pdf

  The report discusses the use of dynamic traffic management strategies in place of transportation infrastructure expansion. Speed harmonization and peak-period shoulder use approaches were analyzed to determine traffic operations and safety impacts. In addition, ITS devices, enforcement policies, possible impediments, and cost-benefit frameworks were also examined. The report was published in October 2009.

  Regional Document – Statewide

National Efforts towards Active Traffic Management Systems

There are several areas nationwide that actively practice active traffic management including Seattle, Portland, California, Minneapolis, and Virginia. However, many of the existing locations do not have an entire active traffic management system in place that is self-operating. In addition, there are several proposed active traffic management projects throughout the nation including Nevada, Colorado, and Philadelphia.

- *Guidelines for Prioritization of Future Active Traffic Management Deployment*

  http://ctr.utexas.edu/wp-content/uploads/pubs/0_5913_1.pdf

  The report addresses three objectives to the application of an active traffic management system. The report discusses the first objective of testing a procedure that uses a combination of existing data, defined performance metrics, nationally accepted algorithms, and new software tools to estimate average mobility conditions, travel reliability, collisions, and incident occurrence for a given area or project. The second objective analyzed a freeway corridor in Washington and estimated the traffic and safety characteristics of selected segments along the corridor. The third objective illustrated how the effects of potential active transportation and demand management traffic flow and safety projects can be analyzed and to document guidelines developed and lessons learned about modeling processes during the project. The project's intent was to use the I-5 corridor in Seattle, Washington and develop a procedure to then use active transportation and demand management on other corridors. The report was published in October 2014.

- *Active Traffic Management Report*

  http://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=ATM%20Report%20January%202013_4e6795ed-fd51-41f6-9e9a-9a674cfd61c5.pdf

  The purpose of the report is to track the costs associated with active traffic management systems on a corridor and report to the transportation committees of the state legislature the costs and benefits of the system. The report discusses the deployment of an active traffic management system on segments of three highways in Seattle: I-5, I-90, and SR 520. The report was published in January 2013.

- *OR217 Active Traffic Management Project*

  https://www.nascio.org/portals/0/awards/nominations2015/2015/2015OR6-Oregon-ODOT-2015%20-%20OR217%20ATM%20Project.pdf

  The report discusses the impact of an active traffic management system on the OR217 corridor. The intention of the system was to provide travel times, advisory speeds, and traveler information. When the document was written, there was an improvement in the traffic flow. However, the full benefit was not attainable due to the limited time the system was in place. The report was published in October 2014.

- *Interstate 80 Integrated Corridor Mobility Project: Concept of Operations*

  http://www.alamedactc.org/files/managed/Document/5086/I-80_ICM_Concept_of_Operations_Final.pdf

  The report provided the foundation for the development of the IH 80 Integrated Corridor Mobility (ICM) Project in California. The purpose of the document was to outline the expectation and assumptions developed for an ICM project. The report addresses potential system concepts, user-oriented operational descriptions, operational needs, system overview, operational environment, support environment, operational scenarios, and summary of impacts. The report was published in October 2010.

- *NDOT Active Traffic Management System Concept of Operations*

  http://www.alamedactc.org/files/managed/Document/5086/I-80_ICM_Concept_of_Operations_Final.pdf

  The report discusses the concept of operations for the implementation of an active traffic management system in Las Vegas, Nevada along the I-15 corridor north from 215 and along US-95. The concept of operations reviews the current conditions, NDOT active traffic management applications, concepts of the proposed system, operations scenarios and public relations. The active traffic management proposed system concepts include lane management, variable speed limits, queue warning, dynamic lane merging, dynamic ramp metering, and software interface. The report was published in December 2014.

- *Denver Metro Area Active Traffic Management Feasibility Study*

  https://www.codot.gov/projects/I25northtigeriv/References/Endnote%2023

  The report reviews active traffic management treatments that are being used throughout the US and the world. The basis for the feasibility study was to understand the benefits of the system and to evaluate the future benefits. Prioritization and implementation of active traffic management systems was analyzed in order to incorporate the needed equipment in other construction and highway projects. The report was published in June 2011.

Section 2.3 Corridor Background and Current Conditions

Corridor Background

The IH 69 study corridor is known as the Southwest Freeway. It extends from Rosenberg to Downtown Houston and is considered one of the busiest sections of freeway in the United States. According to the 2016 Texas Department of Transportation (TxDOT) ranking, segments of the IH 69 study corridor are the 3^{rd}, 4^{th}, and 31^{st} most congested roadway segments in the state. The limits of this project include the corridor between Beltway 8 east to IH 10 in Downtown Houston. The entire IH 69 system stretches from Mexico to Canada and acts as a major trade route.

The Southwest Freeway was designated a freeway in 1953 and the first section was opened in 1961. In 1975, the freeway mainlanes were completed to Sugar Land in the southwest region of the greater Houston metro area. Since the late 1970's, the Southwest Freeway has gone through several major reconstructions, expansions, and interchange modifications. In the early 1990's, the Southwest Freeway became the busiest freeway in Houston, connecting the suburbs of southwest Houston to the multiple employment centers along the corridor. Work began on the below-grade section of the freeway near Montrose, just southwest of Downtown Houston, in 1999 to address the already significant congestion. Construction was completed on this section in 2006. The project was one of the first in the country to sink an elevated freeway into a below-grade trench within the same right-of-way. In doing so, nearby historical neighborhoods were minimally impacted.

Historical Traffic Growth, Congestion, and Incidents

Non-recurring congestion, often as a result of incidents, is a major issue along the IH 69 corridor. The highest average incidents from 2013 to 2015 occurred near the Westpark Tollway and the IH 610 interchange. The highest number of incidents per mile in the AM peak period from 2013 to 2015 were within the Westpark Tollway interchange area, which is part of the large horizontal curve in the freeway. The Spur 527 area had the highest number of incidents per mile in the PM peak period from 2013 to 2015. During the same time period, the IH 610 interchange location had the highest number of incidents, the most major collisions, and also the highest rate for fatal collisions throughout the corridor. Information regarding incident data will be updated as we acquire more recent information.

Based on the TxDOT annual average daily traffic (AADT) values, the overall AADT for the study corridor from 2007 to 2014 was approximately 231,000 vehicles. The AADT in 2014 was approximately 220,200 vehicles. The averages were calculated using ten TxDOT traffic count stations along the IH 69 study corridor. The highest AADT along this project corridor was located near the IH 610 interchange, between the Westpark Tollway interchange and IH 610, with an AADT of approximately 318,700 vehicles from 2007 to 2014. The lowest AADT along this project was located near the SH 288 interchange, with an AADT of approximately 162,000 vehicles from 2007 to 2014.

Based on the TTI *2013 Mobility Investment Priorities Project*, the IH 69 corridor was divided into three segments for analysis. The IH 69 segment between Beltway 8 and IH 610 had the following characteristics, as displayed in Table 13 below. The 2014 and 2015 information was obtained from TxDOT 100 Congested Roadways lists.

Table 13. IH 69 Segment Information – Beltway 8 to IH 610

IH 69 Segment between Beltway 8 (Sam Houston Tollway) and IH 610 W (West Loop)				
Traffic Measure	**Year**			
	2013	**2014**	**2015**	**2016***
Annual Hours of Delay per Mile	310,000	358,870	288,002	292,176
Congestion Time	5 hours	-	-	-
Texas Congestion Index	1.44	1.47	1.44	1.42
Texas Ranking	24	22	31	32
District Ranking				18

*Reflects only a portion of the Year 2016 data

The 2013 study concluded the traffic along the segment follows the traditional inbound and outbound morning and evening congestion pattern, respectively. However, both inbound and outbound directions experience heavy congestion during the PM peak period.

The IH 69 segment between IH 610 and SH 288 had the following characteristics, as shown in Table 14.

Table 14. IH 69 Segment Information – IH 610 to SH 288

IH 69 Segment between IH 610 W (West Loop) and SH 288 (South Freeway)				
Traffic Measure	**Year**			
	2013	**2014**	**2015**	**2016***
Annual Hours of Delay per Mile	731,000	777,146	609,082	870,291
Congestion Time	8 hours	-	-	-
Texas Congestion Index	2.01	2.01	1.76	2.12
Texas Ranking	3	3	4	3
District Ranking				2

*Reflects only a portion of the Year 2016 data

Based on the 2013 study, the IH 610 to SH 288 segment also follows the traditional inbound and outbound congestion pattern. The northbound/eastbound direction encounters congestion during both the AM and PM peak periods. The heaviest congestion and slowdowns occur during the PM peak period for southbound/westbound traffic.

The final study segment, IH 69 between SH 288 and IH 10, had the following properties, shown in Table 15 below.

Table 15. IH 69 Segment Information –SH 288 to IH 10

IH 69 Segment between SH 288 (South Freeway) and IH 10 (East Freeway)				
Traffic Measure	**Year**			
	2013	**2014**	**2015**	**2016***
Annual Hours of Delay per Mile	743,000	666,494	810,785	514,304
Congestion Time	10 hours	-	-	-
Texas Congestion Index	2.44	2.34	2.34	2.64
Texas Ranking	2	6	3	11
District Ranking				7

*Reflects only a portion of the Year 2016 data

The TTI study concluded the northbound lanes experience average but constant congestion throughout the day and early evening periods. The southbound lanes encounter severe congestion in the morning, but during the evening, due to added congestion on nearby freeways, the congestion is less severe.

Current Operating Conditions

The IH 69 project corridor consists of several major employment centers, including Sharpstown, the Uptown/Galleria area, Greenway Plaza, Rice University, the Museum District, the Houston Medical Center, and Downtown Houston. The study corridor also includes multiple interchanges, including the Sam Houston Tollway (Beltway 8), Westpark Tollway, IH 610, SH 288, IH 45, and IH 10. The current alternative routes for the Southwest Freeway include US 90, Bissonnet Street, Bellaire Boulevard, Westpark Drive/Westpark Tollway, and Richmond Avenue.

Based on historical traffic counts along the study corridor, the average annual daily traffic (AADT) has leveled off over the past 12 years and the traffic volumes are not anticipated to have substantial growth. As it stands, the Southwest Freeway corridor is assumed to be fully developed.

Currently, the Southwest Freeway fluctuates between eight to fourteen general purpose lanes. The typical freeway section also has a single reversible HOV/HOT lane that varies in width from approximately 14 feet to 33 feet. The HOV/HOT lane operates from the south of Beltway 8 to Spur 527. The frontage roads range from two to three lanes in each direction. The agency responsible for the frontage roads, ramps, and mainlanes is TxDOT. The Metropolitan Transit Authority of Harris County (METRO) is responsible for monitoring the operation and maintenance of the HOV/HOT lane, the park and ride facilities, and the transit centers. TxDOT is responsible for the structural maintenance of the HOV/HOT lane and assists METRO with setting operational rules. The City of Houston is responsible for the maintenance and operation of arterial streets and the operation of frontage road intersection traffic signals.

The existing City of Houston traffic signal system is based on a standard signal infrastructure system with ground loops and video for detection. Most diamond intersections are running fixed-time during peak hours. Variable demand throughout the day is addressed by multiple timing plans in the signal controllers. Limited locations have WiMax communications. The City is currently working with the selected vendor, Trafficware, to replace signal controller software and the traffic signal central management system over an estimated two to three-year duration. The existing communications provide correct time-a-day for controllers to operate pre-programmed timing plans. It is anticipated that there will be full remote data access when the Trafficware implementation is complete.

The timings for the signals are based on a crossing street coordinated arterial system. No frontage road is set as a coordinated system. The cycle length varies from 90 seconds for off-peak, 120 seconds for AM and PM peaks, and various intersections operate at 130 seconds. There are certain intersections that have midday plans as well.

2.3.1 Planned Corridor Improvements

Anticipated projects along the study corridor include the reconstruction of the IH 69 and IH 610 interchange. The project involves widening direct connectors and reconstructing the IH 610 main lane bridge. In addition, drainage, weaving, and shoulder improvements are planned. The anticipated start date for construction is Fall 2017, and the completion date is estimated to be Fall 2020. The environmental reviews and consultations for the project are currently, or have been, performed by TxDOT. The March 2016 project schematic for the IH 69 and IH 610 interchange reconstruction is shown in **Appendix C**.

In addition to the IH 610 interchange, the proposed Richmond Avenue project will widen Richmond Avenue from six to eight lanes from Gessner Road to IH 610 and include multiple utility improvements. The preliminary general plan for the project was outlined in the *2006-2008 Houston-Galveston Area Council (H-GAC) Transportation Improvement Program (TIP)* and the *2025 H-GAC Regional Transportation Plan*. The projected start date for the project, according to H-GAC, is year 2020.

The planned North Houston Highway Improvement Project (NHHIP) Segment 3 will also have a major impact on the Southwest Freeway corridor near Downtown Houston. The project is anticipated to include several interchange reconfigurations at IH 69 and Spur 527, SH 288, IH 45, and IH 10. In addition, the project will incorporate the construction of entrance and exit ramps, direct connectors, freeway expansions, freeway depressions, realignments, frontage roads, and the reconstruction of several local streets along the IH 69 corridor near Downtown Houston. The estimated cost for the Segment 3 section of the project is approximately $4 billion. TxDOT began Environmental Document Preparation in 2011 and plans to complete the Final Environmental Impact Statement in 2016. A Record of Decision is scheduled for 2017. **Appendix C** also provides the April 2016 NHHIP conceptual layout for Segment 3, south of Downtown Houston to IH 10.

A recent evaluation of ten entry ramps along the IH 69 corridor with and without meters was completed by TTI in July 2016 and documented in the *Ramp Metering Installation and Maintenance Assessment – A Pilot Study*. In general, ramp meters can increase corridor travel speeds, reduce collisions, and reduce overall emissions. There is often a positive benefit cost ratio associated with ramp metering systems. Data from six existing ramp metered entry ramps and data from four ramps without ramp meters along the study corridor were collected during the months of March, May, and July 2016. Based on the data and TxDOT traffic and safety criteria, all six ramp meters were warranted. The warranted ramp meters include:

- Bissonnet Northbound Ramp
- Fountain View Northbound Ramp
- Edloe Northbound Ramp
- Kirby Southbound Ramp
- Chimney Rock Southbound Ramp
- Hillcroft Southbound Ramp

Two ramps without meters met the recommended TxDOT conditions for installing ramp meters. The warranted ramps include:

- Weslayan Southbound Ramp
- Bissonnet Southbound Ramp

Although individual meter algorithms and detection systems were not analyzed, recommendations to upgrade the metering system for proper optimization, operation, and data collection were presented in the report. At the time of the study, only two of the eight northbound ramp meters along the corridor were active. Accordingly, the report recommended the utilization of tools and procedures to monitor as well as evaluate impacts of ramp metering systems. Based on TxDOT maintenance records for ramp meters, a common problem involves signal knockdowns. The TTI study emphasized the importance of finding ways to address the significant maintenance issue. Overall, the report concludes the ramp metering system is beneficial for the corridor, but several improvements to the system are necessary.

Additional projects include upgrades to the Houston arterial ITS (TIGER 2014 Grant program) and the development of a more structured regional incident response and clearance program led by H-GAC. TTI and H-GAC anticipate providing information publicly by the summer of 2017 regarding the improved Houston Region ITS Architecture.

A list of Houston area TxDOT ITS projects was provided. The TxDOT ITS projects are approved future TIP projects from H-GAC. The Southwest Freeway projects on the TxDOT list were outside the IH 69 ATMS study corridor, as shown in **Appendix D**.

2.3.2 Major System Components and Interconnections

The major system components along the IH 69 study corridor include a variety of ITS components that are used for traffic monitoring, traveler information systems, traffic control, and control cabinets for regional ITS communication. These components are often interconnected to provide a range of capabilities, functions, and features. The following section describes the major system components on the IH 69 corridor. It should be noted that the information provided is based on available data provided by TxDOT for use in identifying the existing ITS related devices and locations along the IH 69 corridor. All of the device data, except for data on loop detection and fiber size, was verified via TAMS. Field visits would be needed to confirm actual fiber sizes and availability within the existing system.

TxDOT controls a Fiber Optic Network (FON) throughout the IH 69 corridor. The fiber optic cable connects many of the ITS devices to control hubs and allows Houston TranStar to monitor the region. The fiber network interconnection agreement between TxDOT and Harris County allows each entity to add connections to the FON. There is also an agreement in place that allows METRO to connect and add improvements to TxDOT's FON to develop and improve the Regional Computerized Traffic Signal System (RCTSS) and develop regional traffic signal communication. The fiber optic cable is continuous throughout the IH 69 corridor, but may require additional capacity and/or capabilities based on the proposed system.

Traffic Monitoring

Bluetooth

Bluetooth readers identify MAC addresses as drivers travel the corridor and the readers are able to calculate the time it takes for an individual address to travel from one reader to the next. Bluetooth readers are valuable in providing travel time information. Bluetooth devices are typically placed at a spacing that ranges from a mile-and-a-half to two miles along the IH 69 project corridor. There are currently eight Bluetooth locations, with each location typically co-located with CCTV location.

Closed Circuit Television (CCTV)

CCTV monitor freeway conditions including identifying and verifying incidents along the corridor. There are currently 23 CCTV locations along IH 69 within the project limits. A majority of the camera locations are positioned at cross streets so that both the freeway and cross street traffic may be monitored. There are currently eight CCTV locations adjacent to the IH 69 corridor. Six of the eight are located along Westpark Drive, and two are located on IH 45 just south of the IH 69 interchange area. The additional CCTVs that are not located directly on the corridor aid in monitoring direct connector traffic conditions. Due to the camera locations, overhead signs, and the geometry of the roadway, there are areas that lack roadway coverage. The existing camera coverage is shown in **Appendix E**.

Loop Detection

Loop detection is used for a multitude of reasons, including back of queue detection and signal phase detection. The project segment of IH 69 uses six variations of loop detection. There are currently loop detectors at all cross streets between Beltway 8 and Shepherd Drive providing:

- 16 loop locations at cross streets monitor traffic volumes
- 14 locations monitor both directions of the frontage road
- 8 locations monitor both directions of the mainlanes between Rice Avenue and Shepherd Drive
- 9 locations monitor traffic within the HOV lane between Bissonnet Street and Kirby Drive
- 13 locations contain a single ramp loop typically located at exit ramps between Beechnut Street and Greenbriar Drive
- 14 ramp locations contain a loop configuration for ramp meter use

Mainlane loop detectors are only located between Rice Avenue and Shepherd Drive. The HOV detectors are located between Bissonnet Street and Kirby Drive. Some ramps have loops for ramp metering, while other locations contain a single loop to monitor traffic volumes. Twelve of the fourteen locations contain equipment for a ramp meter, while the other two locations only contain the loops. Loop detection locations are tied into the existing system via loop lead-in cables.

Radar Vehicle Sensing Device (RVSD)

RVSDs are placed adjacent to the roadway and collect similar data to loop detection systems. RVSDs are less intrusive and have less maintenance costs because they are mounted on infrastructure next to the freeway. There are currently fifteen mounted RVSDs in the project limits at fourteen locations. Thirteen of the fifteen RVSDs are used specifically for ramp metering operations, and two existing RVSDs are used for general mainlane spot speed and volume data gathering. There are two devices at one location to collect data from two different traffic streams. The RVSDs are located between Beltway 8 and Kirby Drive and have a typical spacing of one-half to two miles. RVSDs are typically connected to the system using a 6-strand single mode fiber optic cable.

Traveler Information Systems

Dynamic Message Signs (DMS)

A DMS has the ability to provide the traveling public with information during their commute. There are currently seven DMS locations along the IH 69 corridor within the project limits. There are four DMS for northbound traffic and three DMS for southbound traffic. DMS are located in advance of major interchange areas and before alternative routes.

Queue Warning Systems

There are two queue warning signs with flashing beacons located near Hillcroft Street for northbound traffic. When activated, the signs warn motorists of traffic congestion ahead, which can aid in preventing secondary incidents.

Roadway Weather Information Systems (RWIS)

Two RWIS are located near the IH 45 interchange. These systems monitor weather conditions and can be used in conjunction with other traveler information systems to alert motorists of adverse conditions on the roadways.

Traffic Control

Ramp Meters

There are twelve locations between Bissonnet Street and Kirby Drive that contain a meter system. Ramp meters are located at the following entrance ramps:

- Inbound Bissonnet Street
- Inbound Beechnut Street
- Outbound Hillcroft Avenue
- Inbound Bellaire Boulevard
- Inbound Hillcroft Avenue
- Inbound Fountain View Drive
- Outbound Chimney Rock Road

- Inbound Chimney Rock Road
- Outbound Edloe Street
- Inbound Edloe Street
- Outbound Kirby Drive
- Inbound Buffalo Speedway

Ramp meters help control the flow of traffic entering a freeway, which allows for a more consistent flow of traffic on the mainlanes. Ramp meters can be ineffective during peak periods due to long queues forming on frontage roads. The ramp meters are controlled using the loop detection system, which is set up at each location to monitor volumes at the ramp meter and volumes on the approach.

Control Cabinets

There are several communications cabinets called HUBs and ITS cabinets throughout the project limits. All ITS devices report back to one of these HUBs or cabinets in order to tie into the main duct bank. The main duct bank consists of 4-3 inch conduits and runs along the northbound side of IH 69. Each HUB and cabinet is interconnected via fiber optic cable. The cables between connection points vary in size throughout the system.

2.3.3 Interfaces to External Systems and Procedures

There are several interfaces for the existing ITS along the IH 69 study corridor. These interfaces have particular standards and specifications based on State and local preferences. The existing interfaces are described below and will be utilized to connect the current process to external systems.

Center-to-Field Standards Deployed

Houston TranStar has adopted the Regional ITS Architecture that was developed and maintained by H-GAC. However, many of the TranStar field devices were deployed before most of the standard protocols were formed.

Over time, the system devices, communications, and center-to-center data flow links have been upgraded and are becoming more compliant with current national ITS standards. The National Transportation Communication ITS Protocols (NTCIP) are used for most of the field devices; however, there are some ITS systems that use proprietary protocols (namely RWIS and ramp meters). The most recent information on the system architecture can be found in the *Houston Claire-Dynasmart-Rhodes System Architecture Document*. This document includes the use case diagrams and more details on the center-to-field communications.

Center-to-Center Standards Deployed

Several center-to-center connections are currently in place including TranStar to the Harris County Emergency Center (HCEC) and the E911 Center, TranStar to the Sugar Land Operations Center (under development), and TranStar to the Montgomery County Operation Center. There is also a center-to-center link from TranStar to the HCTRA Incident Management Center. A significant amount of effort is underway to make streaming video available to other public agencies of the CCTV under TranStar control. All center-to-center activities are governed by the Regional ITS Architecture.

2.3.4 Capabilities, Functions, and Features of the Existing System

The control center for the regional ITS infrastructure on IH 69 and the entire county is Houston TranStar, the multi-agency regional transportation and emergency management center. Houston TranStar collects field data, processes the data into systems, and disseminates traveler information.

Fiber optic cables connect Houston TranStar to the various field devices. The connections allow operators at TranStar to observe traffic flow via CCTV, locate incidents, contact emergency vehicles, disseminate traveler information, and adjust ITS devices to improve traffic flow when necessary.

Houston TranStar provides speed maps, travel times, and historical traffic information at their website, www.houstontranstar.org. Speed and travel time are collected with a combination of Bluetooth and AVI data.

The ITS devices can also be used during incidents, evacuations, or special events to reduce traffic congestion. Details of the full capabilities are discussed in Modes of Operations.

2.3.5 Modes of Operations

There are multiple memorandums of understandings (MOUs), operational plans, and traffic management procedures that outline standard operations, incident scenarios, and other special event scenarios.

Standard Operation

Incidents

The Freeway Incident Management Program memorandum was created to improve traffic safety and reduce congestion on Houston area freeways. The agencies involved include TxDOT, HCSO, City of Houston, METRO, Houston Automobile Dealers Association (HADA), and Verizon Wireless.

The Freeway Incident Management Program operates from 6:00 AM to 10:00 PM and relies on the use of the Motorized Assistance Program (MAP) vehicles. MAP vehicles allow police to quickly reach incidents, safely clear the roadway, and supply the incident area with traffic control devices necessary for the safety and well-being of the public. TxDOT monitors the freeway system and MAP field operations using CCTV. TxDOT also has staff at Houston TranStar to assist in operating the Transportation Management System. The HCSO Incident Management Unit is responsible for operating and maintaining the MAP vehicles, providing patrol supervision, traffic control, and producing incident logs. HADA provides the MAP vehicles, while METRO is responsible for deputy salaries. The City of Houston provides police, fire, traffic and maintenance personnel, and equipment as needed. Verizon Wireless provides phones for staff and runs a toll free dialing code to assist with incident response.

The procedure for traffic control during a freeway incident is outlined in the Houston TranStar Incident Management Plan. The procedures outline the following:

- Directing traffic and operating traffic control
- Closing a freeway
- Clearing an incident and operating response vehicles
- Traffic control during inclement weather (ice or flooding)
- Using dynamic message signs for incidents

The priority for any incident clearance is as follows:

1. Protecting first responders
2. Caring for the injured and protecting the public
3. Clearing traffic lanes

HOV/HOT Lane

The High Occupancy Toll Lane Project Agreement allows METRO to operate the high occupancy vehicle (HOV) lanes as high occupancy toll (HOT) lanes on multiple highways, including IH 69 from Beltway 8 to Spur 527. The project included the installation of toll facilities that collect tolls from non-HOV vehicles, while allowing HOV vehicles to continue to use the lanes free of charge.

There is a single, reversible HOV/HOT lane that operates down the center of IH 69 from Beltway 8 to Spur 527. This lane is open to transit, HOV, and HOT vehicles. Access to the HOV/HOT lane is via slip ramps from the mainlanes or T-ramps from the park and ride and transit center facilities located along the corridor. There are also access points at Edloe Street, IH 610, and Smith Street. The standard hours of operation are weekdays from 5:00 AM to 11:00 AM and 1:00 PM to 8:00 PM for the inbound and outbound directions, respectively. METRO has also implemented a pilot program that extends the outbound direction hours of operation on weekdays and adds operation in the inbound direction on weekends. The toll for HOT vehicles ranges from $1.00 per vehicle at opening to $6.50 per vehicle during peak driving times.

METRO is responsible for the design, operation, management, and maintenance of the HOV/HOT facility for the project area. They are responsible for maintaining tolling equipment, enforcement equipment, traffic control devices, dynamic signs, and any other devices used along the HOV/HOT lane. TxDOT is responsible for the structural maintenance of the HOV/HOT lane and assists METRO with HOV/HOT lane procedures.

Incident/Special Event Scenarios

Houston TranStar utilizes a control room to operate the Houston area traffic effectively and adjust operation during incidents and special events. Operators at the control center observe traffic using CCTV. In addition to the standard procedures during incidents and operation, there are special incident scenarios that are outlined in the Houston TranStar Incident Management Plan that include:

- Response during a hazardous material incident
- The use of the HOV/HOT lane during emergencies
- Establishing an alternative route

There are three categories for incidents, with the duration defined as the incident time of occurrence to the time of clearance for the incident, outlined by Houston TranStar:

A. Major – expected duration of more than 2 hours
B. Intermediate – expected duration of 30 minutes to 2 hours
C. Minor – expected duration under 30 minutes

Standard procedure is typically used for intermediate and minor incidents, while major incidents often require special response. This includes use of Temporary Traffic Control (TTC) and DMS to better manage the Houston area traffic network. It could also include setting up alternative routes or using the HOV/HOT lane to provide additional capacity. As a result of the evacuations and recovery surrounding Hurricanes Rita and Ike, the transportation and emergency management agencies have coordinated control point mapping and decision support for contraflow on multiple regional facilities, including IH 69. The contraflow area on IH 69 is north of the project limits.

When a road closure is required on the IH 69 corridor, road users are diverted through lane shifts around the traffic incident and back onto the freeway downstream of the incident. Large trucks may need to follow a separate route because of bridge, weight, clearance, geometric restrictions, or hazardous material restrictions. News media is notified to alert the public of the highway closure and traveler information is dispersed via DMS.

During incidents or special events, there is capacity at existing park and ride facilities to accommodate additional vehicles.

2.3.6 Organizational Structure

The City of Houston and TxDOT provided the following organizational structures, which are housed at TranStar, for the TranStar Traffic Operations Division and the TranStar TxDOT Houston District. The organizational structures are shown in Table 16 and Table 17 below.

Table 16. City of Houston TranStar Traffic Operations Division

Traffic Signal Timing & Operations
Position
Assistant Director
Administrative Assistant
Engineer
Engineer
Graduate Engineer
Graduate Engineer
Graduate Engineer
Graduate Engineer
Electrical Estimator
Technical Hardware Analyst III
Technical Hardware Analyst III
Electrical Estimator
Electrical Estimator
TranStar Traffic Group
Position
Supervisor
Senior Project Manager
Technical Hardware Analyst I
Technical Hardware Analyst I
Technical Hardware Analyst I
Technical Hardware Analyst I
Plan Review
Position
Graduate Engineer

Table 17. TranStar TxDOT Houston District

Positions
Director of Transportation Management Systems
Assistant Director of Transportation Management Systems
TMS Records
Office
Freeway Operations Supervisor
ITS Operations Lead Tech
ITS Operations Techs
TMS Design
ITS Special Projects
TranStar IS

2.3.7 User Roles

Based on the City of Houston TranStar Traffic Operations Division organizational chart, the group is divided into three subcategories: Traffic Signal Timing and Operations, TranStar Traffic Group, and Plan Review. The Traffic Signal Timing and Operations subgroup consists of an Administrative Assistant, Electrical Estimators, Technical Hardware Analysts, Graduate Engineers, Engineers, and an Assistant Director. The TranStar Traffic Group is made up of Technical Hardware Analysts, a Senior Project Manager, and a Supervisor. The Plan Review group consists of a Graduate Engineer.

The TxDOT Houston District is led by the Director of Transportation Management Systems. The Assistant Director works under the Director and two positions lie under the Director and Assistant: TMS Records and Office. The Freeway Operations Supervisor, under the Director and Assistant Director, is over the ITS Operations Lead Tech as well as the ITS Operations Techs. The TMS Design team, ITS Special Projects team, and TranStar IS team work under the Director and Assistant Director.

2.3.8 Operational Costs

Budgets for the different IH 69 ATMS project entities are actively being pursued. It was determined that TxDOT currently compensates three contractors a combined $267,000 per month to maintain the entire ITS System. A breakdown of costs results in an average of approximately $9,630 per mile per month for the project corridor. These costs are associated with ITS upgrades, replacements, and minor pavement repairs.

TranStar

2016 Budget

The 2016 TranStar budget line items applicable to the IH 69 ATMS project are listed in Table 18 below.

Table 18. 2016 TranStar Budget Excerpt – IH 69 ATMS

Expenditure	Description	Budget
Base Salaries	Funds the annual salaries for eight of the twelve Director's Office positions	$624,250
STP Funding Program (Operations)	TxDOT's share (51.2%) of matching federal fund for various STP programs associated with specific TxDOT CSJ accounts. Total local and state contribution is $180,000 and it will yield $900,000 in program funding.	$92,160
TranStar Website	Cost for TxDOT to maintain the TranStar website	$117,564
Total		**$833,974**

The 2016 TranStar revenue distribution for the multiple entities housed at TranStar is displayed in Table 19 below.

Table 19. 2016 Revenue Distribution Summary TranStar Budget Excerpt – IH 69 ATMS

Expenditure	Revenue Distribution	Budget
Base Salaries	Harris County Traffic	$65,705
	Harris County Toll Road Authority	$32,399
	Harris County OHSEM & Port Security	$119,980
	HC Sheriff's Office w/MAP	$4,839
	City of Houston Traffic	$197,925
	City of Houston MRT	$14,619
	City of Houston Street & Drainage	$12,974
	City of Houston OEM	$5,525
	METRO	$125,866
	TxDOT	$44,419
	Total	**$624,250**
STP-Operations	TxDOT	$92,160
	Total	**$92,160**
TranStar Website	Harris County Traffic	$3,198
	Harris County Toll Road Authority	$4,122
	Harris County OHSEM & Port Security	$4,237
	HC Sheriff's Office w/MAP	$670
	City of Houston Traffic	$10,817
	Gulf Coast Rail District	$391
	City of Houston MRT	$155
	City of Houston Street & Drainage	$155
	METRO	$29,723
	TxDOT	$64,097
	Total	**$117,564**

2017 Budget

The 2017 TranStar budget line items applicable to the IH 69 ATMS project are listed in Table 20 below.

Table 20. 2017 TranStar Budget Excerpt – IH 69 ATMS

Expenditure	Description	Budget
Base Salaries	Funds the annual salaries for eight FTE's and one part-time skilled worker of the fifteen Director's Office positions	$663,354
STP Funding Program (Operations)	TxDOT's share (40.01%) of matching federal fund for various STP programs associated with specific TxDOT CSJ accounts. Total local and state contribution is $389,780 and it will yield $1,948,897 in program funding.	$155,937
TranStar Website	Cost for TxDOT to maintain the TranStar website	$117,564
Total		**$936,855**

The revenue distribution for the 2017 TranStar budget is displayed in Table 21 below.

Table 21. 2017 Revenue Distribution Summary TranStar Budget Excerpt – IH 69 ATMS

Expenditure	Revenue Distribution	Budget
Base Salaries	Harris County Traffic	$62,889
	Harris County Toll Road Authority	$35,724
	Harris County OHS&EM	$121,194
	City of Houston Traffic	$224,932
	City of Houston MRT	$14,740
	City of Houston OEM	$6,202
	METRO	$134,993
	TxDOT	$62,680
	Total	**$663,354**
STP-Operations	TxDOT	$155,937
	Total	**$155,937**
TranStar Website	Harris County Traffic	$3,205
	Harris County Toll Road Authority	$4,045
	Harris County OHS&EM	$4,283
	HCSO: MAP, IMU, & RTCC	$577
	City of Houston Traffic	$10,907
	Gulf Coast Rail District	$393
	City of Houston MRT	$155
	City of Houston OEM	$77
	METRO	$29,816
	TxDOT	$64,107
	Total	**$117,564**

METRO

2016 Budget

The 2016 METRO budget line items applicable to the IH 69 ATMS project are listed in Table 22 below. The HOV/HOT lane system is funded through Federal, State, and local resources and is managed through a collaborative effort between TxDOT and METRO.

Table 22. 2016 METRO Budget Excerpt – IH 69 ATMS

Expenditure	Budget
Union Wages	$130,344,814
Salaries and Non-Union Wages	$91,119,143
Operating Services	$42,729,310
Capital Improvement Program	$176,983,000
Total	**$441,176,267**

2.3.9 Performance Characteristics

In order to measure and assess the proposed IH 69 ATMS, existing performance characteristics of the IH 69 corridor were examined. Based on the previous *US 59/IH 69 Rider 42 Corridor Congestion Mitigation Study*, reliability, travel times, and safety were analyzed.

Reliability

Unexpected (non-recurring) congestion, as a result of incidents, special events, or evacuations, can greatly impact driver travel times. Planning Time Index (PTI) is a measure of reliability and compares the 95th percentile peak period travel time to the free-flow travel time. Congestion caused by incidents has the most impact on PTI. The PTI for various segments along the IH 69 project corridor are displayed in Table 23 below.

Table 23. IH 69 Corridor Planning Time Index

Roadway Segment	Planning Time Index
Beltway 8 to IH 610	6.69
IH 610 to SH 288	9.54
SH 288 to IH 10	10.73

In order to create a reliable corridor, variations in travel times must be reduced. One way to improve corridor reliability is to clear incidents in a timely manner. Classifying, confirming, and dispatching capabilities are very important incident clearing features. Maintaining key relationships between police, fire, emergency medical services, tow companies, traffic management, and emergency management staff is also essential. Between 2010 and 2013, there were over 1,200 incidents annually along the corridor and the average time to clear the incident was approximately 30 minutes. Several local companies provide assistance to help clear incidents and Houston TranStar maintains an area incident response manual that aims to increase safety and mobility after an accident has occurred. The City of Houston's SAFEClear program charges a $60 towing fee along major freeways within the city limits. The IH 69 project corridor consists of five SAFEClear segments.

Alternative routes to IH 69 include parallel frontage roads. The roadways are operated with coordination between TxDOT and the City of Houston. Currently, signal priority is given to the heavier movement on the arterial streets. The enhanced Houston arterial ITS project will likely have a positive impact on the network and improve overall reliability.

Travel Times

Congestion along the IH 69 corridor, according to historical speed charts, has increased along several segments of the freeway. The decrease in speeds from 2009 to 2013 results in longer daily commutes for drivers and passengers of transit vehicles.

Safety

A large number of incidents occur along the IH 69 project corridor. Based on the 2013 through 2015 Regional Incident Management System (RIMS) data, the most incidents along the corridor occur at the IH 610 interchange. Additional locations and interchanges with over 200 collisions include Beltway 8, Hillcroft Avenue, Westpark, Chimney Rock Road, Newcastle Drive, Weslayan Street, Spur 527, and SH 288. Based on the incident data from 2013 through 2015, the following crash data was identified for the project corridor:

- 50% of 2013-2015 crash types – rear end (attributed to congestion)
- 24% of 2013-2015 crash types – sideswipe (attributed to congestion)
- 67% of 2013-2015 crashes – no one injured
- Fatality incident clearance time is approximately 150 minutes

Table 24 lists historical crash data for the corridor and compares the crash rate to the statewide average.

Table 24. Calculated Crash Rates for the IH 69 Corridor Compared to the Statewide Average

Year	IH 69 Reported Incidents	Length (mi)	AADT	IH 69 Mainlane Crash Rate (per 100 M vehicle miles)	Urban Interstate Statewide Average Crash Rates* (per 100M vehicle miles)
2013	972	13.95	130,133	146.69	87.56
2014	1476	13.95	131,653	220.18	100.78
2015	2850	13.95	125,549	445.83	142.21

*TxDOT Reported Statewide Average as of May 11, 2016

As shown in Table 24, the crash rate exceeds the statewide average for each year. There has been an increase in the number of reported incidents between 2013 and 2015. This could either be due to an improvement in reporting incidents, or an increase in the number of crashes occurring along the corridor. The increase is likely due to a combination of these two factors. The incidents limit the efficiency of traffic flow and travel time reliability.

The number of crashes shows a deficiency in design along the IH 69 corridor. The freeway was reconstructed over 25 years ago and does not meet modern day standards. There have been some geometric updates, but the corridor still suffers from design issues.

The Houston Chronicle ranked IH 69 as the number two deadliest roadway in the state of Texas. This ranking is based on data between 2010 and 2014. A series of reports outlined the number of deaths, injuries, and accidents. Between 2010 and 2014, there were seven triple fatality accidents. (Houston Chronicle, 2014)

Specific design-related safety concerns along the corridor include freeway ramps and freeway congestion. Over half of the entrance and exit ramp weave areas along the study corridor do not meet the current minimum TxDOT standards. TxDOT recommends a spacing of 1,500 feet between the end of an entrance ramp and the start of an exit ramp with an auxiliary lane (a distance of 2,000 feet is recommended without an auxiliary lane). The majority of the crash types along the IH 69 corridor, rear end and side swipe, can be attributed to traffic congestion.

2.3.10 Operational Policies, Technical Challenges, and Constraints

Operational Policies

Freeway Incident Management Program

Purpose
To improve traffic safety and reduce traffic congestion on Houston area freeways through operation of a freeway incident management program.

Agencies
- Texas Department of Transportation (TxDOT)
- Harris County Sheriff's Office (HCSO)
- City of Houston
- Metropolitan Transit Authority of Harris County (METRO)
- Houston Automobile Dealers Association (HADA)
- Verizon Wireless

TxDOT is responsible for continued dispatch of the freeway incident management program, Monday through Friday, from 6:00 AM to 10:00 PM. TxDOT maintains staff at the Houston TranStar facility to monitor the freeway system and MAP field operations using the CCTV system. TxDOT agrees to install, maintain and operate the Computerized Transportation Management System (CTMS), TTI evaluations of MAP, participate on the Incident Management Team, and attend program review meetings as needed. TxDOT funds are used for MAP operations, dispatching, engineering support, DMS signing, maintenance of CTMS, office space at TranStar for TxDOT staff and HCSO supervisor, and monthly as well as quarterly summaries/analysis of the program by TTI.

HCSO is responsible for operating and maintaining MAP vehicles, supplementing staff costs, providing deputy patrol supervision, participating on the Incident Management Team, and attending METRO MAP program review meetings as needed. HCSO provides personnel (nine deputies per shift) for MAP vans from 6:00 AM to 10:00 PM. TranStar provides the patrol routes for MAP vehicles. MAP deputies are responsible for traffic control as required and producing incident logs. HCSO funds are used for MAP vehicle maintenance, fuel, operations, and patrol deputy supervision.

The City of Houston provides police, fire, traffic and maintenance personnel, and equipment as required under the Incident Management Team.

METRO is responsible for Harris County deputy salaries, METRO MAP officers and supervision, participation on the Incident Management Team, and conducting MAP program review meetings as needed.

HADA is responsible for providing eight MAP vehicles and printing decals for the vehicles.

Verizon provides wireless telephones for MAP vehicles and MAP program administrators along with air time and accessories for wireless phones. They also provide a toll free dialing code. Verizon funds are used for phones, accessories, and air time.

High Occupancy Toll Lane Project Agreement

Purpose
To allow METRO to operate the existing HOV lanes on IH 45, IH 69 North, IH 45 South, IH 69 South, and US 290 in Harris County, Texas as HOT lanes by installing toll facilities that would collect tolls from vehicles other than high occupancy vehicles while allowing high occupancy vehicles to continue to use HOT lanes free of charge.

Agencies
- TxDOT
- METRO

TxDOT is not responsible for the operation or maintenance of any portion of the project except that TxDOT will maintain the surface and structural components of any bridge located in the project. TxDOT will also review and approve plans and specifications, the operations manual, the project guidelines, or any other plans, rules, materials or documents in connection with the project.

METRO is solely responsible for operating the project. They are responsible for all design, operation, management, and maintenance of the HOV/HOT project. METRO is responsible for maintaining tolling equipment, enforcement equipment, traffic control devices, existing devices, and dynamic signs used in the project.

Toll revenue from the project is used first for debt service. After all debt service or investment return costs are paid, funds are used on maintenance and split between TxDOT and METRO.

Fiber Network Interconnection Agreement

Purpose
To allow the connection of the State and Harris County's respective FON by the other party. Any and all connections shall have the approval of the network's owner per the procedures set forth.

Agencies
- TxDOT
- Harris County

Each party permits and authorizes the other party to enter upon its right-of-way and to attach, install, operate, maintain, remove, reattach, reinstall, relocate, and replace such connections of the entering party's FON to the owning party's FON pursuant to the procedures outlined.

The parties exchange unmodulated, single-mode fiber optic cable strands, for transportation use only. The unit of capacity exchange is agreed upon on a case-by-case scenario.

Multiple Use Agreement for Shared Fiber Optic Communication Cable

Purpose
To allow METRO to connect and add improvements to the State's FON to aid in developing a RCTSS and develop regional traffic signal communication.

Agencies

- TxDOT
- METRO

METRO is allowed to install passive wave-division multiplex communications hardware on designated shared fibers on the State's FON, per agreed upon specifications. They may only use the fiber's 1550 nanometer optical carrier wavelength. METRO pays for project costs and 75% of annual expenses of the shared maintenance and repair costs.

MOU Shortfalls

Although there are existing MOUs in place, the implementation of an upgraded system will require addendums to the existing MOUs. There are a few shortfalls based on the existing MOUs that were identified in the December 2015 *US 59/IH-69 Rider 42 Corridor Congestion Mitigation Study*. These shortfalls include:

- Most ITS devices are operated independently by controlling agency – not in a fully integrated manner

- Traffic signal operations along arterial streets, including freeway frontage roads, are prioritized independent of traffic conditions along the freeway corridor

- Freeway incident data (RIMS) is primarily used by TxDOT, but not other agencies affected by freeway operations

Additionally, procedures for coordination on the TranStar floor should be created. There are standard practices, but no formal documentation. This would provide the opportunity to document what is being done and make any modifications for the new system.

Technical Challenges

Many of the technical challenges derive from the operational policies. For example, with the precedence in importance for safety of responders, then safety of the public, and finally traffic operations, TranStar is limited in operational capabilities and strategies at the onset of an incident. It is up to the deputy in charge at the incident to determine whether the highway must be closed. TranStar is unable to begin traffic control for rerouting until a decision is made by the deputy. An additional technical challenge is applying detours or traffic control.

With safety as the priority, it is difficult to set up detours and rerouting on the freeway. The proposed lane assignment DMS could help during detour situations and traffic control.

Another technical challenge is the ability to get the support from the public to ensure that the system improves traffic conditions. The public will need to be well informed to understand the benefits of the system and how to use the system. Various sources, such as the TranStar website and the Public Involvement Office (PIO), can assist with the educational efforts, but it will take time for drivers to adapt to the overall system.

Constraints

In terms of constraints, TranStar is unable to update the signal timings along the frontage roads to improve traffic operations without permission from the City of Houston. In addition, ramp meters must be cleared when the back of queue encroaches on an intersection. This means the ramp meter turns green (or turns off) so all vehicles can enter the highway. The clearing of the ramp essentially removes the advantages of the traffic control device.

There are a variety of geometric deficiencies and constraints throughout the IH 69 corridor as well. There are nine entrance/exit ramp pairs that do not meet the current FHWA spacing requirements. In addition, there are several constraints to roadway expansion or HOV/HOT lane expansion. The geometric constraints to capacity expansion include:

- Westpark Tollway flyover columns conflict with any expanded HOV/HOT expansion.
- Park and Ride columns near the Beltway 8 interchange conflict with HOV/HOT expansion.
- The current and proposed IH 610 interchange and column location prevent traditional widening and frontage road connectivity.
- Drainage components currently in the shoulder at various locations throughout the corridor prevent hard shoulder running.
- There are numerous retaining walls and bridges between the IH 610 interchange and SH 288/IH 45.

Roadway capacity expansion would require parallel flyover facilities to avoid the stated columns, the updated IH 610 interchange design, and reconstruction of shoulders. Due to the above geometric constraints, traditional widening would lead to high costs, extensive environmental requirements, and a long project schedule.

Section 2.4 Major System Components and Interconnections

The major system components proposed along the IH 69 project corridor include a variety of ITS components that are used for traffic monitoring, traveler information systems, traffic control, and control cabinets for regional ITS communication. After reviewing the existing system components, the limited coverage areas and technology along the project corridor were identified. Additional ITS infrastructure proposed includes:

- Overhead sign bridges
- CCTV cameras
- HD RVSD
- Bluetooth mobile devices
- RWIS
- Ramp meters
- LCS
- DMS
- Wrong-way detection

New equipment for the corridor should include graphical route information panels (GRIPs) and fixed cameras for enhanced coverage and crash analytics coverage. The components will be incorporated into an upgraded fiber optic network that will make monitoring the corridor possible at Houston TranStar. The figures in **Appendix F** show an overview of the proposed ITS equipment along the corridor. Table 25 compares the existing corridor ITS to the proposed system.

Table 25. Existing and Proposed ITS Infrastructure and Components

ITS Infrastructure/ Component	Existing System	Proposed System
Fiber	Strand Size Varies	144 Strand Single Mode Fiber
		12 Single Mode Fiber (New Device Locations)
Overhead Sign Bridge	16 Structures with Guide Signs	15 Structures to be Replaced for Guide Signs
	No ITS Structures	28 New Dedicated ITS Structures
Bluetooth Device	8 Devices	10 Additional Devices
Closed Circuit Television (CCTV) Pan-Tilt-Zoom (PTZ) Camera	26 Cameras	71 Additional Cameras
CCTV Fixed Camera	None	20 New Cameras for High Accident Locations
Advanced Detection	Limited	14 New Detectors at Ramp Meter Locations
		Additional Detectors on Frontage Roads and at Exit Ramps near Signalized Intersections
Radar Vehicle Sensing Device (RVSD)	13 Devices	62 Additional Devices
Lane Control Sign (LCS)	None	202 New Devices
Dynamic Message Sign (DMS)	8 Signs	28 Additional Signs
Graphical Route Information Panel (GRIP)	None	6 New Signs
Ramp Meters and Wrong-Way Detection	12 Meters	12 Upgraded Corridor-adaptive and System-integrated Ramp Meters
		2 New Installations
Road Weather Information System (RWIS)	2 Devices	Depressed Area of IH 610 Interchange (Pending Roadway Improvements)
Queue Warning System	3 Signs	Replaced by LCS System

Infrastructure for ITS Components

Fiber Optic Network

The proposed system is to provide a fiber based IP system. The existing trunk line connections are to be upgraded from various strands/modes to a consistent 144 strand single mode fiber, and all new device locations are to use 12 single mode fiber (unless larger is preferred by specific agencies). Existing non-fiber connections are to be converted to fiber based. Device support equipment at each device location being upgraded to fiber may need to be replaced and upgraded as necessary dependent on existing functionality and capability. All available traffic signal cabinets are to be inspected for correct connectivity to the system.

Overhead Sign Bridge

Overhead sign bridges were estimated to have approximately 2,800-foot spacing with one location having a minimum spacing of approximately 700 feet from an existing sign bridge. The locations are based on the feasible constructability, the location of existing sign bridges, sight distance, and critical decision areas. The overhead sign bridges are planned to span over one direction of travel or the entire freeway, with a total of 28 proposed locations. A major factor when identifying whether a sign bridge would span the entire freeway or only one direction was the HOV/HOT lane. The HOV/HOT lane is elevated in several places along the corridor. Due to sight distance concerns and vertical clearances needed, the sign bridges near the elevated HOV/HOT lane would not be able to span across the entire width of the corridor. Special considerations for sign bridge locations included high incident areas, location of existing overhead sign bridge near bridges that cross IH 69, depressed areas, elevated HOV/HOT lane, and existing overhead structures with static signs that would be replaced. Typical elevations were created for specific locations and conditions as well as the typical two directional overhead structure bridge span and one directional overhead structure bridge span. A typical sign bridge elevation is presented in Figure 5 and additional elevations are shown in **Appendix G**.

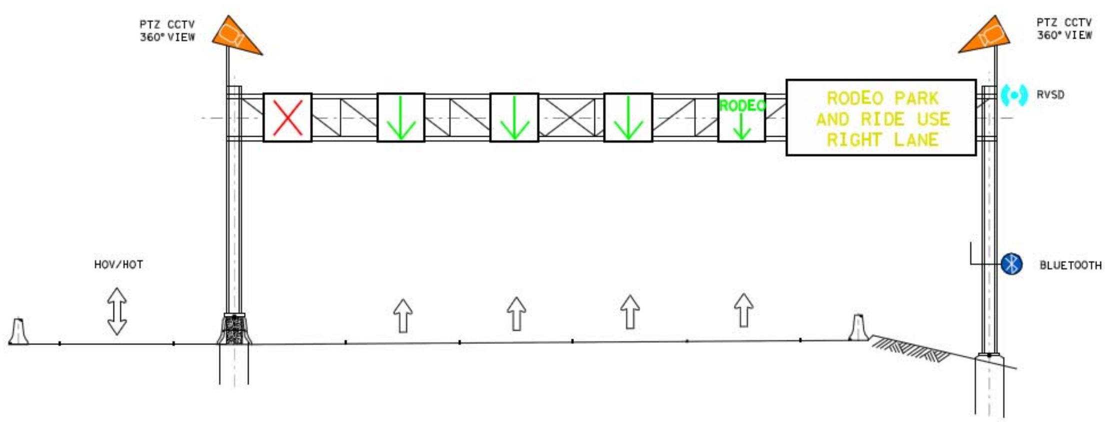


Figure 5. Typical Overhead Sign Bridge Elevation

Traffic Monitoring

Bluetooth

Bluetooth readers were added to the corridor at approximately one mile to a mile-and-a-half spacing. The locations were identified based on an ideal coverage range, including the existing equipment so that the readers would not interfere with each other. The additional Bluetooth devices are anticipated to provide additional coverage along the corridor to offer more accurate travel time readings. There are a total of ten new Bluetooth devices proposed to capture travel in both directions. The additional and existing Bluetooth devices along the project corridor will provide complete coverage.

Closed Circuit Television (CCTV)

The proposed CCTV locations were identified based on reviewing the coverage of each existing CCTV along the project corridor using the GUI system at TranStar. Each of the cameras were tested to see the limits at which it was clear to identify the travel lanes and the vehicles in each of the lanes. The areas lacking coverage identified were a result of roadway geometry, existing overhead infrastructure, and landscape. Proposed CCTV locations utilize existing infrastructure and proposed overhead sign bridges. The goal for deploying CCTV cameras is to provide complete coverage along the project corridor. There are a total of 71 CCTV devices proposed.

Fixed Camera/Crash Analytic Software

Analytic software has the potential to help identify incidents, wrong-way drivers, and congestion in an automated fashion. To fully utilize this type of software, a fixed camera network would be needed. Based on incident data provided by TTI from January 2013 to August 2016, high incident hot spots were identified. Five areas along the corridor exceeded an average of ten incidents per month and would likely benefit from a fixed cameras/crash analytic software system. The locations are as follows:

- Northbound – ¼ mile segment at Chimney Rock Road
- Northbound – ½ mile segment at IH 610 Interchange
- Southbound – ½ mile segment at IH 610 Interchange
- Northbound – ¼ mile segment at Montrose Boulevard
- Southbound – ½ mile segment between Tuam Street and Almeda Road (SH 288 Interchange)

The fixed cameras should be spaced so that the greatest amount of coverage of the high incident areas can be viewed. The optimal height to place the cameras is between 45 to 50 feet with two cameras per pole. The two cameras per pole are used to achieve complete coverage. Every camera has a blind spot, so using two cameras per pole at different angles covers the cameras blind spots. Figure 6 illustrates how two cameras on one pole can be overlapped to cover the blind spot. The typical net field of view for the first camera is 600 feet with a 10-degree field of view (FOV) (coverage begins 400 feet away from the base of the pole and ends 1,000 feet away). The second camera has a net field view of 1,500 feet with a 3.2-degree FOV (coverage begins 900 feet away from the base of the pole and ends 2,400 feet away). This spacing is not always achievable, such as in areas with interchanges where overpasses can block the view of the cameras or in areas of vertical and horizontal curves. Proposed cameras near corridor interchanges and curves were placed on either existing or proposed sign bridge structures or on existing CCTV poles to achieve the maximum coverage of the high incident areas. The fixed cameras identified for the high incident areas should be deployed first. Full corridor coverage should follow when feasible. The proposed locations for the fixed cameras can be seen on the figures in **Appendix H**.

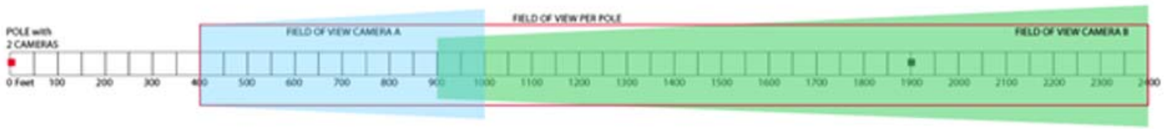


Figure 6. Fixed Camera Field of View

Loop Detection/Advance Detection

Loop detection will need to be installed at each of the ramp meter entrances and along exit ramps for congestion detection. The loop detection for ramp meters should be installed prior to the stop bar on the ramp as well as after the ramp meter stop bar. To assist with the high volume of traffic on the ramps exiting towards a signalized intersection and reduce the impact of the traffic queuing onto the mainlanes, loop detection should be installed on the exiting ramps and along the frontage road. A second loop should be installed on the exit ramps for wrong-way traffic detection. An algorithm can be developed to allow the system to track the order in which a loop is activated. If the loops are activated in reverse order, an alarm will be triggered and TranStar, emergency response teams, and police will be notified to assess the issue in the field. A total of fourteen entry and exit ramps will need advance loop detection. A typical implementation layout for the loop detection is shown in **Appendix I**.

High Definition Radar Vehicle Sensing Device (HD RVSD)

HD RVSDs should be placed at every entry and exit ramp along the project corridor to collect traffic volume data, similar to the loop detection system. HD RVSDs can also be used for congestion detection, which can trigger detour plans. Two HD RVSDs should be installed on each side of the roadway to detect mainlane, ramp, and frontage road volumes. Similar to other ITS devices, proposed HD RVSDs should be installed on existing infrastructure if feasible. There are a total of 62 proposed HD RVSDs.

Traveler Information Systems

Dynamic Message Signs (DMS)

DMS will be installed on all of the proposed overhead sign bridges. The DMS will consist of two different full graphic colored DMS signs. The small DMS, also known as lane control signs or dynamic lane control signs (LCS or DLS), will be used for lane/shoulder control, advisory speeds, etc. The larger DMS will serve to provide warnings and longer messages to drivers, such as “SLOW TRAFFIC AHEAD.” The DMS systems are intended to provide advance warnings to drivers regarding current roadway conditions and alternate routing options. The system will also operate as an advanced queue warning system. The elevations shown in **Appendix G** show how the DMS may be placed on the proposed overhead sign bridge. There are a total of 202 proposed LCS and 28 proposed large DMS to be placed on overhead sign bridges.

As part of the LCS deployment, shoulder LCS will be used when there is adequate space (minimum 10 feet) to provide a travel lane during an incident or for emergency vehicles.

Shoulder widths that are less than 10 feet often occur where there are elevated HOV lanes or interchanges. The shoulder lanes will provide temporary relief when a mainlane is blocked. Areas that do not satisfy the 10-foot minimum requirement are shown in the existing ITS infrastructure figures in **Appendix A**.

Graphical Route Information Panels (GRIPs)

GRIPs are large DMS that are able to provide route information to users with limited or no text. It is ideal to have these systems in advance of decision points on the roadway, such as interchanges. The GRIPs within the project corridor would display the Houston TranStar Map, which shows roadway congestion based on a color-coded system on the map. The map would provide more benefits to local drivers familiar with the TranStar website and the surrounding roadway network. The project corridor would benefit from a minimum of six GRIPs, with three GRIPs in each direction along IH 69. The key locations would be in advance of Beltway 8, IH 610, SH 288, and IH 10. Two of the GRIPs, one near IH 10 southbound and one near Beltway 8 northbound, should be placed outside of the project corridor. A figure showing where these proposed GRIPs should be located is shown in **Appendix J**.

At this time, there are no GRIP applications within the United States. However, GRIPs have been active in Europe, Australia, and Asia for several decades. Performance evaluations of the international GRIPs have shown positive results. The majority of drivers surveyed recognized the GRIPs, understood the system, and found it to be useful. The University of Texas researched the potential benefits of GRIPs in Texas in 2008. In order to successfully deploy the system along the IH 69 corridor, the State and FHWA would need to approve the system. Additional studies regarding sign orientation, color schemes, layout, provided information, and driver comprehension would need to be conducted.

Road Weather Information System (RWIS)

TxDOT is currently in the process of examining prospective locations for additional RWIS. Presently, the focus is on sites where fatalities have occurred. There were no reported high water fatalities along the IH 69 project corridor between January 2013 and August 2016. However, high water fatalities were reported on the Westpark Tollway exit at the IH 610 and IH 69 interchange. Reported mainlane high water accidents along the corridor include Beltway 8, Westpark Drive, IH 610, the depressed segment of IH 69 between Shepherd Drive and Spur 527, and SH 288. The Hillcroft Avenue frontage roads have also experienced high water as well as the IH 10 eastbound connector ramp. For mainlane high water monitoring, the RWIS detection devices would need to be placed in the pavement as well as in nearby inlets to evaluate the water level prior to reaching the roadway. The IH 610 interchange and Spur 527 depressed areas of the study corridor would benefit from a RWIS.

Traffic Control

Ramp Meters

All twelve of the existing ramp meters should be replaced and upgraded with current hardware and software to better evaluate ramp meter performance and allow monitoring to occur at TranStar. Based on the criteria and locations for ramp meters in the TTI document, *Ramp Metering Installation and Maintenance Assessment – A Pilot Study Houston, Texas*, two additional locations were proposed. The two locations are the southbound Bissonnet ramp and the southbound Weslayan ramp. In total, there are fourteen proposed corridor-adaptive and system-integrated ramp meters along the corridor.

Traffic Mobility

Dynamic HOV Lanes

As observed on surrounding roadways in the Houston area, HOV lanes help improve travel mobility. The ridership occupancy ratio per lane is 1.6 for a single occupancy vehicle and 2.3 for a high occupancy vehicle. It is anticipated that a proposed HOV lane along the corridor can aide in high demand traveling. For the project corridor, a peak hour HOV lane is needed. The far left general purpose lane in each direction can be converted to a "dynamic HOV lane" during peak hours only. The conversion of the left most lane in each direction could be achieved by displaying a white diamond on the lane control signs and by providing notifications through messages on DMS. The dynamic HOV lane could be designated by striping and enforced only during the peak hour traffic.

2.4.1 Interfaces to External Systems and Procedures

Existing agreements in place should be reviewed for any necessary adjustments for an actively managed traffic system. TranStar should obtain a remote connection to City of Houston signal software upgrades, for use when permitted during major incidents or special events. Figure 7 illustrates the interfaces among agencies, departments, and drivers, with Houston TranStar being the base of operation.

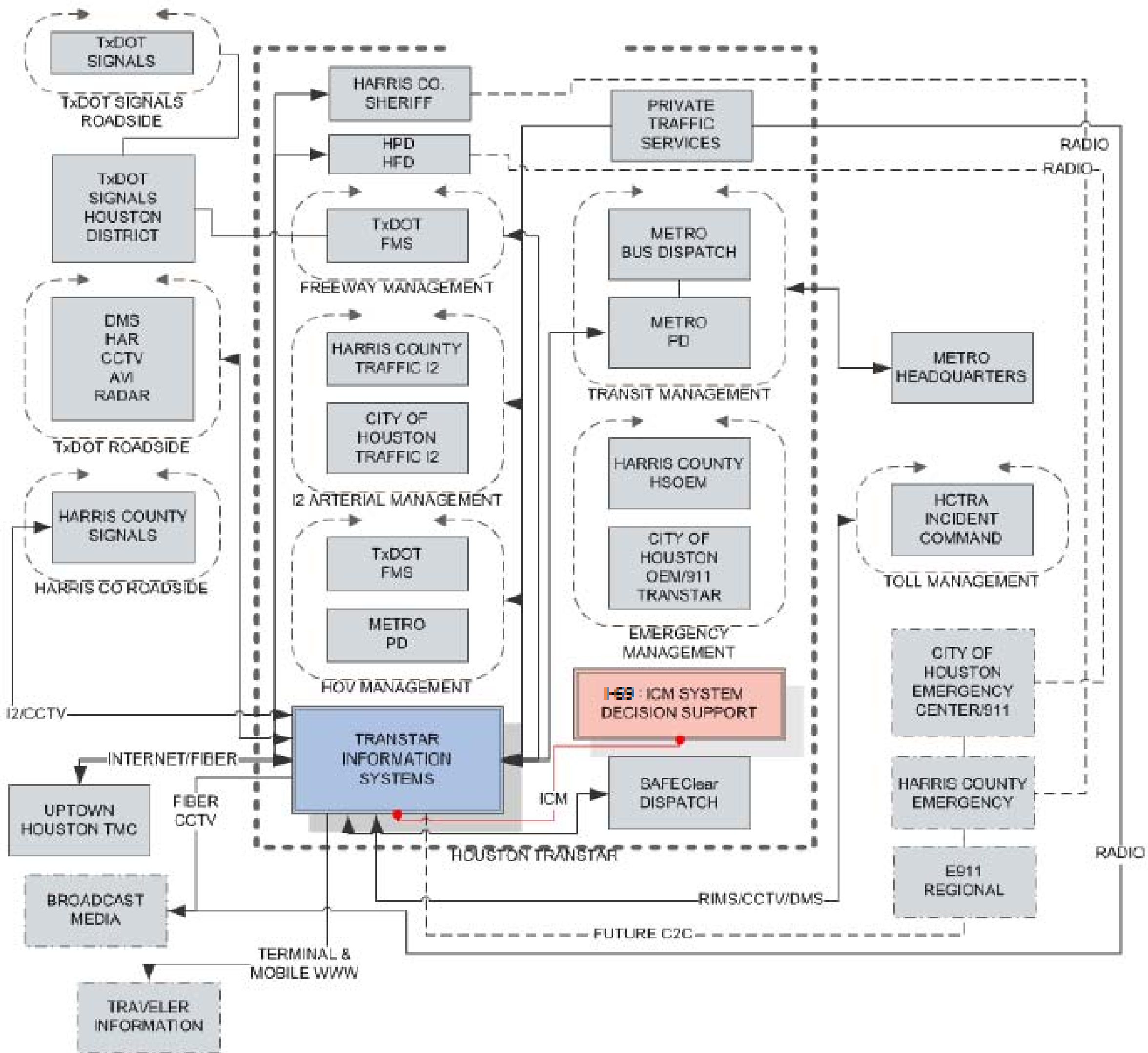


Figure 7. ICM Architecture during Normal Operations (Source: *IH 10 Concept of Operations*)

2.4.2 Capabilities, Functions, and Features of the Proposed System

As mentioned in the Existing Conditions section, the central control center for the regional ITS infrastructure on IH 69 and the entire county is Houston TranStar, the multi-agency regional transportation and emergency management center. Houston TranStar collects field data, processes the data into systems, and disseminates traveler information. The additional ITS infrastructure and devices proposed as part of the IH 69 Concept of Operations include:

- Fiber Optic Networks (FON) – Upgrades to the current fiber optic network are proposed throughout the project limits. Fiber connection will be 144 single mode fiber to accommodate the additional devices and allow capacity for future updates.

- Closed Circuit Television (CCTV) – Additional pan-tilt-zoom (PTZ) camera CCTV is proposed at various locations throughout the corridor (Beltway 8 to IH 10). The intention is to provide complete surveillance coverage. Fixed camera CCTV is proposed at locations with high incident rates (Chimney Rock, IH 610, Spur 527, and SH 288). Fixed cameras will allow traffic conditions to be monitored at TranStar with the use of an analytical software without requiring staff to maneuver the viewpoint to locate traffic incidents or special conditions.

- High Definition Radar Vehicle Sensing Devices (HD RVSD) – HD RVSDs are to be provided at each ramp location to monitor mainlane traffic flow and entering ramp traffic volume. The HD RVSDs will be linked to ramp meter signal controllers to control the flow of traffic entering the freeway based on mainlane traffic flow.

- Loop Detection – Loop detectors are to be provided at ramp meter entrance ramp locations and at exit ramps near signalized intersections. The detectors will connect to the ramp meters and intersection signals, and if the vehicle queue extends to the detector, a “flush” will be performed. A “flush” switches the ramp meter to green to allow all queued vehicles to enter the freeway, preventing backup onto frontage road intersections. The loop detectors on exit ramps and frontage roads will prevent the formation of large vehicle queues on the mainlanes. Loop detectors could also be used on ramps to provide wrong-way detection.

- Lane Control Signs (LCS) – LCS are a type of full-color matrix DMS. LCS will be placed above each travel lane and shoulder when possible. LCS are capable of displaying queue warning, merge flow functions, lane assignments, and speed limits. LCS displays will be referenced in a standard operation manual and the displays are to be stored at TranStar for quick updates during daily operation. Up to six LCS per direction will be placed on overhead sign bridges, based on the number of lanes at that location. The approximate dimensions of the LCS are 4 feet by 5 feet.

- Dynamic Message Signs (DMS) – A DMS is to be provided for each direction at LCS locations. The DMS will provide notifications, such as “INCIDENT AHEAD” or “MERGE LEFT”, disseminate traveler information, provide alternative routes, and provide queue warning.

- Ramp Meters – Corridor-adaptive and system-integrated ramp meters are proposed at all existing ramp meter locations along the corridor and two additional locations (Bissonnet and Weslayan). The ramp meters will be corridor-adaptive and system-integrated by being linked to loop and HD RVSD detection and have automated cycle time adjustments based on flow. Existing ramp meters will be retrofit to provide automated cycle time adjustments based on ramp and mainlane traffic flow.

All proposed devices and existing devices along the corridor will be connected through the upgraded FON. Devices will be operated and monitored from TranStar. Progressions for LCS will be stored at TranStar to provide easy updates during incidents or non-recurring congestion. The overhead sign bridges are spaced in 2,800-foot (minimum 700-foot) increments to aid the movement of traffic. Below is a list of standard progressions to be used during non-recurring congestion along the corridor.

- **Progression A** – Single Lane Closure (Minor) – Includes LCS progression up to six sign bridges upstream of the incident. Vehicles are directed to merge before the single-lane closure. DMS will display an advisory message “LANE CLOSED AHEAD”.

- **Progression B** – Two Lane Closure (Minor) – Includes LCS progression up to six sign bridges upstream of the incident. Vehicles are directed to merge before the two-lane closure. DMS will display an advisory message “LANES CLOSED AHEAD”.

- **Progression C** – Multiple Lane Closure (Major) – Includes LCS progression up to eight sign bridges upstream of the incident. Vehicles are directed to merge before the multiple-lane closure. DMS will display an advisory message “LANES CLOSED AHEAD”.

- **Progression D** – Queue Warning (Congestion) – Includes LCS progression up to four sign bridges upstream of the congestion. Variable speed reductions are displayed upstream of a bottleneck or slowdown in intervals of 10-15 mph. This harmonizes traffic flow and slows traffic to reduce crashes. DMS will display an advisory message “SLOW TRAFFIC AHEAD”.

- **Progression E** – All Lane Closure (Major) – Includes LCS progression up to eight sign bridges upstream of the incident and DMS notification upstream of the incident. Vehicles are diverted off of the freeway before the all-lane closure. DMS will display an advisory message “ALL LANES CLOSED AHEAD”.

- **Progression F** – Special Event Notification – Includes LCS progression up to two sign bridges upstream of the decision points that lead to the event and DMS notification upstream of the event. Road users are notified which lanes are dedicated to getting to the event.

Points of contact will be identified for each agency including TxDOT, City of Houston, Houston METRO, and Harris County. Backup points of contact will also be identified to provide redundancy and ensure efficient agency coordination. If an incident or event requires the use of alternative routes, the controlling agency will be contacted immediately. For example, a major northbound incident occurs near IH 610. Harris County is contacted to consider temporarily removing the toll along Westpark Tollway from IH 69 to Post Oak Boulevard. City of Houston is contacted to inform the agency of increased traffic at the frontage road intersections. METRO is contacted to consider removing the toll along the HOV/HOT lane, since the incident does not affect HOV/HOT operations. TxDOT is contacted to provide the necessary traffic control devices at the scene of the incident.

At the onset of an incident, routes expected to be utilized by emergency vehicles will be identified. The ramp meters that emergency vehicles are expected to use will be turned off. DMS will warn approaching emergency vehicles to aid in incident response and clearance times.

As a result of the METRO HOV Toll System extending through the project corridor, the toll system will need to be integrated into the ATMS. The integration can allow the HOV toll system to have limited coverage through the ATMS. Detection could be achieved with CCTV cameras in critical locations, in particular on the elevated HOV sections. No additional equipment was included as a part of the proposed ITS infrastructure.

The proposed ITS along the IH 69 corridor will provide a more efficient and reliable travel experience throughout the corridor. The devices will allow operators to better manage the flow of traffic during recurring and non-recurring congestion.

2.4.3 Modes of Operations

The existing standard operations and memorandums of understandings (MOUs) will remain in place with the proposed additional devices. The IH 69 corridor operation among agencies will utilize interagency agreements.

To aid in efficient operation, an IH 69 corridor team will be assigned at TranStar. Up to two qualified operators will be in control of interagency contacts, corridor surveillance, identifying incidents or traffic conditions, assigning LCS progression and device modes, identifying alternative routes, and identifying emergency vehicle routes. Initially, as other ATMS are implemented, the same staff may be able to monitor additional elements.

During normal operation, the proposed ITS, specifically the LCS, will provide variable speeds (speed harmonization) to lower the standard deviation in vehicular speeds and prevent incidents. Section 2.4.7 outlines some of the expected safety benefits that can be expected with an active traffic management system.

Specific procedure by type, location, and length of incidents/special events will be put in place with the additional proposed ITS equipment available. The primary examples of incidents and events that could occur and the response from the IH 69 corridor team are the following:

- Standard Operation
- Minor Incident Operation
- Major Incident Operation
- Special Event Operation

The standard operating procedure examples for each of the four incidents/events are described in detail in Section 2.6.1, Section 2.6.2, Section 2.6.3, and Section 2.6.4.

2.4.4 Organizational Structure

In order to ensure proper execution and supervision of the proposed active traffic management system, the agencies involved in the multifaceted process must be well organized, proficient in assigned tasks, and understand the importance of effective communication. The exchange of information is paramount due to the disposition of the traffic management discipline. Without proper communication, the effectiveness and reliability of traffic management systems is adversely affected.

The organizational structures and personnel required to manage the proposed active traffic management system should be similar to the existing TranStar arrangements. A major restructuring should not be necessary. However, the proposed system will entail several new traffic management responsibilities and tasks. Supervising and management level positions from TxDOT, the City of Houston, Harris County, and METRO must understand the impacts from the proposed ATMS, and sufficiently educate and train staff to adjust to the new system. Standard procedure documents should be made available to all TranStar personnel. Personnel fully dedicated to the proposed ATMS and incident management system may be able to aid in other TranStar operations when there is not an incident along the corridor.

The addition of an ATMS team or subgroup to the current TranStar TxDOT Houston District organization may be beneficial in regards to task, employee, and resource allocation. The TxDOT ATMS subgroup could also be a component of or extension to an existing TranStar TxDOT group. It is anticipated that ATMS teams or subgroups will not be necessary for the City of Houston, Harris County, or METRO organizations. However, it is essential that the departments inform and prepare their TranStar workforce to process and operate ATMS and incident management scenarios in conjunction with TxDOT. The development of additional MOUs and interagency agreements may be required to outline the new roles, responsibilities, training, limitations, and liabilities of dedicated ATMS employees and practices.

The ATMS subgroup will operate the corridor continuously. Multiple shifts will be required. During the peak periods, special events, and emergencies, it is recommended that up to two ATMS operators manage the ATMS and incident management system along the corridor. During the off-peak periods, one operator should be able to sufficiently oversee the ATMS and incident management system. In addition, at least one maintenance technician should be available on-call to repair ATMS infrastructure when needed.

2.4.5 User Roles

The successful operation of the IH 69 corridor ATMS will require continual 24-hour monitoring, assessment, and implementation of proper mitigation procedures. Well trained managers, engineers, and operators must understand the complexities of congestion mitigation, aggressive incident clearance, arterial detours, traveler information systems, emergency management and special event coordination, as well as daily traffic management. The departments and staff must also commit to the goals and objectives of the proposed ATMS, which is to optimize the performance of the corridor and increase safety.

Case study examples of ATMS implementation across the US were reviewed to identify their dedicated staffing and operation procedure. The IH 5 Concept of Operations Washington DOT report discussed additional staff required, including:

- Operations staff (manager and operators) to operate and monitor the ATM system
- ITS engineers to design, develop, and deploy the ITS systems
- Maintenance staff who would perform minor and major maintenance
- Software engineers who would design and maintain the software needed to operate the entire ATMS
- System administrators who would maintain system software, networks, and individual workstations

The Concept of Operations also recommend additional staffing for a 24-hour monitoring system. For the IH 80 ICM system, the Caltrans facility operates 24-hours a day, seven days a week. During normal operations, two operators and one shift leader from the Department of Operations, two operators and one shift leader from the Department of Maintenance, and two California Highway Patrol Officers operate the ICM system.

A proposed TxDOT ATMS subgroup should include engineers, operators, maintenance technicians, IT specialists, as well as an ATMS manager, who would be responsible for the overall subgroup. The majority of the positions in the subgroup could be filled by current TxDOT staff after sufficient ATMS training. For example, TxDOT engineers from the TMS Design or ITS Special Projects groups could transition to an ATMS subgroup, alleviating the need to hire from outside the organization. However, the engineers would require educational support to gain the knowledge and skills necessary to design and deploy ATMS engineering plans and programs. Similarly, current ITS Operations Techs could train to become ATMS operators. The expected responsibilities would be very similar to current operator activities. The tasks would require the following:

- Current compatible responsibilities
    - Monitor multiple PTZ cameras
    - Identify incidents and traffic conditions
    - Enter incidents into the Regional Incident Management System (RIMS) database
    - Operate DMS
    - Initiate proper mitigation procedures and responses

  - Notify proper authorities of incidents, road debris, and other hazards
  - Communicate and coordinate with the multiple TranStar departments and emergency management personnel
  - Provide the public with real-time traffic information

- Responsibilities specific to the IH 69 ATMS corridor
  - Monitor several additional PTZ and fixed cameras
  - Monitor and control several additional DMS and LCS
  - Understand and analyze data from additional ITS monitoring equipment
  - Identify alternative routes
  - Identify emergency vehicle routes
  - Operate ramp meters
  - Know how to operate and evaluate the video analytics software
    - Use as an additional incident detection tool
    - Recognize false alerts.

The ATMS manager should supervise and be responsible for the ATMS subgroup. One of the tasks should include analyzing and evaluating staff and public feedback concerning ATMS operations. The manager should also ensure communications between TranStar departments regarding ATMS is adequate and effective as well as advocate ITS and ATMS advancements throughout the TranStar organization. The ATMS manager would likely report to other TxDOT Houston District supervisors and directors.

The proposed ATMS will greatly increase the amount of ITS equipment and structures along the corridor. Therefore, it is likely additional TxDOT technicians and maintenance staff will be required to complete routine electrical, mechanical, and structural inspections and repairs. The implementation of new ATMS software and the collection and storage of additional ITS data may also necessitate extra TranStar Information Technology personnel. The City of Houston upgraded signal operation software shall be integrated into TranStar operation, only to be used under circumstances where permission allows.

A summary of the proposed staffing for the ATMS project subgroup is listed in Table 26 below.

Table 26. Proposed Staffing

Position	Responsibilities	Total Number of Personnel Required (Estimate)
ATMS Manager	Managing the ATMS subgroup personnel and operations	1
ATMS Engineer	Designing, developing, and deploying the ATMS and LCS as well as determining incident duration estimates, alternative routes, and operations to aid emergency vehicles	2
ATMS Operator	Monitoring and operating the ATMS	3
Maintenance Technician	Maintaining and repairing the ATMS infrastructure	2
IT Specialist	Maintaining the ATMS computer systems, software, network connections, workstations, and hardware installations, configurations, and upgrades	2
Total Personnel Required		**10**

The responsibilities and job requirements of the positions should allow for a normal eight-hour workday. The ATMS engineer will provide a secondary task of assisting with ATMS Operator tasks when needed. Two ATMS engineers and two IT specialists would ensure flexibility if an individual ATMS employee was not available. ATMS operators and maintenance technicians should work in shifts to ensure the corridor is monitored and maintained continuously. It is anticipated that during the AM peak and PM peak periods, at least two ATMS operators would monitor the corridor. One staff member would be responsible for emergency response coordination, updates to lane closure coordination, and agency coordination during incidents. The other staff member would be responsible for updating DMS, LCS, and ramp meter controls as specified by the head of traffic operations. During extreme events, up to three operators may be necessary. During the AM peak and PM peak, it is also assumed at least one maintenance technician would be available for emergency repairs. During the off-peak periods, one ATMS operator and one maintenance technician are also advised. It is expected there will be lower traffic volumes during the evening, which could warrant a lesser staff.

2.4.6 Operational Costs

Proposed ITS Equipment

Costs associated with the proposed system may include capital costs for proposed equipment, maintenance costs, and operational costs. Maintenance costs can be assumed as a percentage of the total capital costs at this time. In actuality, maintenance costs should be low at the beginning of a device life cycle and increase as the device ages. Operational costs will be dependent on staffing requirements and software upgrades for the proposed system (see Section 2.4.5 for the proposed staffing). The operational costs will be vary depending on which ITS devices are deployed. It is anticipated that the costs of the project will be split over a three year time period. The critical devices deployed first would be the overhead sign bridge with DMS and LCS. The second phase would include CCTV, HD RVSD, and fiber-upgrade. The last phase would consist of the additional Bluetooth readers, corridor-adaptive and system-integrated ramp meters, GRIPs, and weather stations. The total project is estimated to cost approximately $23 million in construction costs and approximately $3 million in annual operations and maintenance cost due to the rigorous recommended maintenance schedule. The phased cost was broken down based on the first segment from Beltway 8 to Spur 527 and Spur 527 to IH 10 due to current construction plans for future projects. Table 27 provides a cost breakdown based on phase and divided by the two segments.

Table 27. Phase Cost per Segment

Phase	Beltway 8 to Spur 527	Spur 527 to IH 10
1	$8,931,953.74	$3,392,214.37
2	$4,432,735	$1,526,802.20
3	$3,477,093.21	$858,101.62
Total	**$16,841,781.94**	**$5,777,118.20**

The complete detailed proposed cost for the ATMS is shown in **Appendix K**.

2.4.7 Performance Characteristics

Improvements of Proposed ITS System

The proposed ITS system has full CCTV coverage along the IH 69 corridor from Beltway 8 to IH 10. CCTV coverage and updates will aid the IH 69 corridor team at TranStar in identifying incident locations, alternative routes, queue and bottleneck locations, and emergency vehicle routes.

In addition, the improvements include enhanced detection of traffic flow through the use of HD RVSDs and loop detection. The enhanced detection will aid in providing adaptive flow control in conjunction with ramp meters, adaptive signal control during incidents, and queue warning.

Expected Benefit

The expected benefits of the ITS devices and operation of proposed devices comes in the form of reduced delay, improved incident management, and improved safety. As part of a previous project, high-level benefit was estimated using DynusT software. Active traffic management benefit analysis utilized specific areas of benefit: 2-lane accidents, all-lane accidents, and crash reduction.

The benefit during 2-lane and all-lane accidents was determined based on travel time savings in DynusT model runs for these accident types. The duration of the travel time savings was set at 3 hours and the CRIS data was used to determine the number of accidents matching each incident type during the average year.

The safety benefit from crash reductions was determined based on case studies. A FHWA 2007 report, *Active Traffic Management: The Next Step in Congestion Management*, identifies a 15% reduction in injury crashes and a 30% reduction in property-damage only (PDO) crashes. The 30% reduction was adjusted to 20% as a means to make a conservative estimate on PDO crash reduction. Using the average number of crashes per year, by type, and economic cost of crashes based on a National Safety Council 2012 report, an annual cost savings was determined. Table 28 summarizes the expected benefit of the IH 69 Active Traffic Management corridor operations.

Table 28. Benefit Estimate for Proposed ITS

Strategy	Model	Annual Benefit (2011 $) (M/yr)
Active Traffic Management - Safety[1]	N/A	5 - 9 M
Active Traffic Management - 2-Lane Incident[2]	DynusT	4 - 7 M
Active Traffic Management - All-Lane Incident[3]	DynusT	0.5 - 1.5 M

[1] Based on FHWA 2007 *Active Traffic Management: The Next Step in Congestion Management* and National Safety Council 2012 Report
[2] 428 2-lane accidents per year (based on 2010-2013 RIMS data)
[3] 27 all-lane accidents per year (based on 2010-2013 RIMS data)

In addition to expected benefit based on DynusT results, there are several active traffic management strategies that are being implemented in the United States. Table 29 describes similar corridor projects in the United States.

Table 29. Active Traffic Management Case Studies

Active Traffic Management		
Location	**Description**	**Source**
US 75 Corridor in Dallas	Integrated corridor management study as part of integrated corridor management initiative. It consisted of freeway, arterial, bus, and rail alternatives. About 25 miles in total length and included 15 miles of HOV, 34 miles of tollways, and areas surrounding freeway.	RITA (ITS, gov), and 2008 Concept of Operations (USDOT)
I-15 Corridor in San Diego	ICM strategies on 21-mile segment of I-15 corridor, including an 8-mile Managed Lane facility. Currently two reversible lanes for HOV.	AMS for I-15 Corridor (Cambridge/USDOT)
IH 80 Corridor in Alameda, CA	ICM project in Alameda and Contra Costa Counties, 20.5-mile segment of IH 80, which includes incident management by use of DMS, Lane Control Signs, and Information Display Boards. Adaptive ramp metering and arterial improvements are also included.	IH 80 ICM Operations and Management Plan (DKS Associates)

A benefit-to-cost analysis was conducted for the proposed system developed utilizing the total estimate cost of the system: $23 million in construction costs and $3 million for annual operations and maintenance costs. The benefit-to-cost analysis assumes a 10-year life cycle for equipment, which is in line with typical CCTV and DMS cycle lengths of approximately 7 to 10 years. This analysis utilized results from the *US 59/ IH-69 Congestion Mitigation Study*, with updated costs to reflect the latest TxDOT bid items and proposed devices. If the ATMS were used during recurring congestion and saw an increase in alternative route use, the benefit-to-cost ratio would increase significantly along the corridor. Table 30 shows the expected range of benefit-to-cost.

Table 30: Proposed ATMS Benefit/Cost Range

Operational Strategy	Expected Benefit/Cost Ratio
ATMS	5.2-7.3

There is a large range in the benefit-to-cost ratio based on how the ATM devices will be operated. If the devices do not lead to some rerouting during recurring congestion, a benefit-to-cost ratio closer to 5.2 is expected. If rerouting occurs with the additional traveler information during recurring congestion, a benefit-to-cost ratio up to 7.3 could occur. The desirable and optional system components would aid in achieving alternative route use by offering adaptive detection, GRIPs, and corridor-adaptive and system-integrated ramp metering.

2.4.8 Operational Policies, Technical Challenges, and Constraints

For the active traffic management system to be implemented, it is necessary for the operational policies to focus on communication between agencies. Through the system, there will be technical challenges as well as constraints that would need to be addressed for the system to function in a way to improve traffic flow along the project corridor.

Operational Policies

Operational policies will need to be put in place for the active traffic management system to be implemented. As described in Section 2.3, there are currently existing MOUs for various traffic operations. However, the ATMS will result in certain policies that will need to be more thorough in outlining the staff (as described in Section 2.3.4 and 2.3.5) that will be managing and operating the system. The critical component for the system and for the operational policies is communication between the agencies.

The operational policies will include the needs for communication based on how the overall system will function, communication based on incidents, and communication for arterial detours for off-peak conditions. During off-peak conditions, an arterial detour route was evaluated for planned complete freeway closures since the arterials are already saturated during peak conditions.

Communication Needs

Overall System

Since this is an active traffic management system, the ability for the system to operate and be successful is through communication. Active traffic management requires full multi-agency cooperation. Cooperation is achieved through signed and complied MOUs between the agencies. Although this document will not have MOUs outlined, there are a few requirements needed for MOUs to be developed:

<u>System Requirements</u>:

- System interconnections between TxDOT and City of Houston's frontage road signals for arterial detours
- Integrate the analytic software into the existing CCTV GUI system for incident detection

Arterial and Frontage Road Detour

Overnight Construction Arterial Detour

During off-peak hour construction along the IH 69 corridor, road users may be diverted into parallel arterial routes around the construction zone to minimize congestion and delay. In order to improve traffic operations, safety, and delay in and around work zones, agencies should have parallel arterial routes that road users can take in order to avoid a construction zone.

There are several arterial routes and multiple interchanges along the IH 69 corridor. In case of a full road closure along the project corridor (during off-peak hours), the following parallel arterials may be taken into consideration as detour routes:

- South of the corridor
    - Bissonnet Street
    - Braeswood Boulevard
    - Beechnut Street
    - Bellaire Boulevard
    - West Belfort Avenue
    - Westpark Drive

- North of the corridor
    - Richmond Avenue
    - Westheimer Road
    - San Felipe Street

Figure 8 shows four possible parallel detour routes for the case of IH 69 being closed due to overnight construction. The parallel routes depicted were based on the location of the construction zone and the three major destination zones. It is expected that Richmond Avenue and Westpark Drive would carry most of the diverted traffic due to their close proximity to the construction zone. In addition, Westheimer Road and Bissonnet Street can be utilized as alternative routes to alleviate traffic congestion on Richmond Avenue and Westpark Drive.

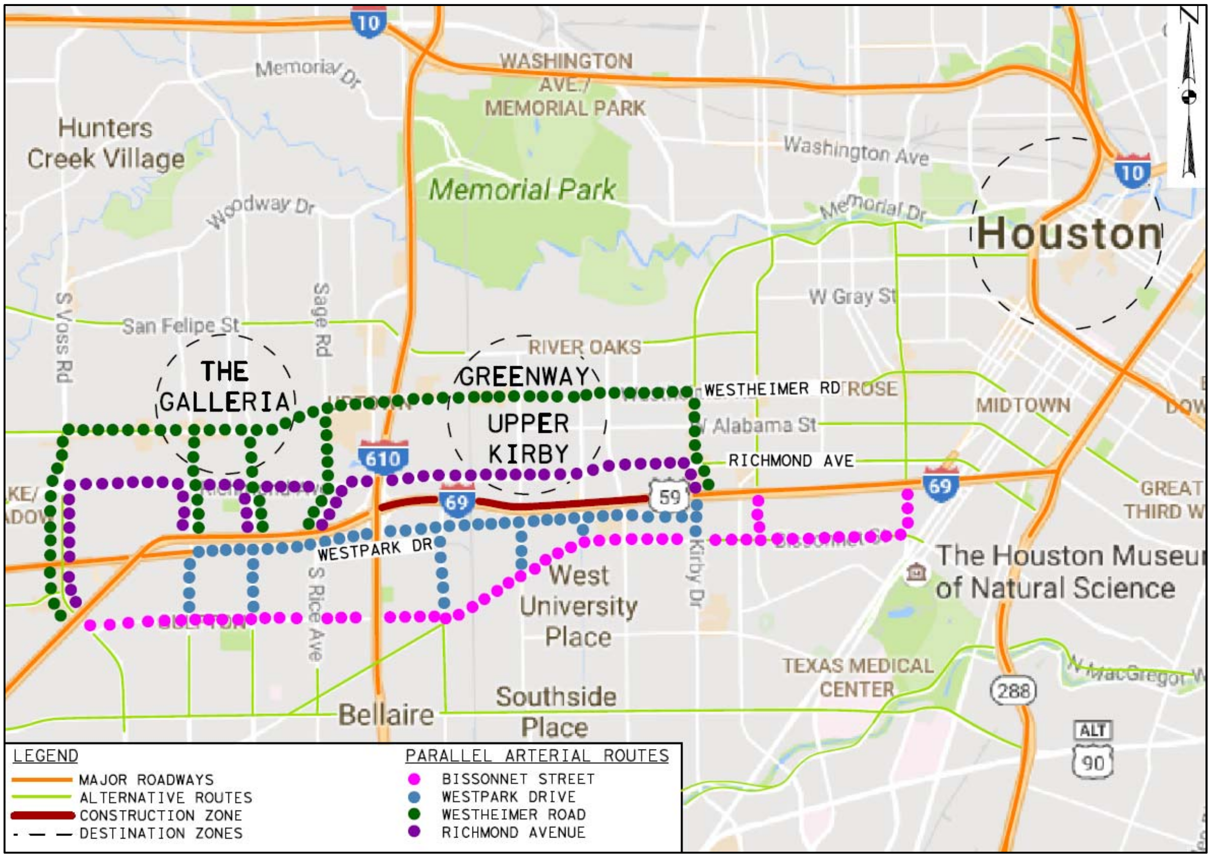


Figure 8. Overnight Work Detour

Road Detour

For complete freeway closures during the peak periods, frontage road detours will be necessary. The full roadway closures will require diverting traffic to a ramp located upstream of the closure, then move traffic from the mainlanes onto the frontage road, and finally back to the mainlanes once the accident is cleared with the use of channelizing devices as shown in **Appendix L**. In order to avoid delays and long queues, channelizing devices would need to be in place on the frontage road to keep the traffic from the mainlanes separate from the through traffic on the frontage road. Due to the increase in traffic on the frontage road from the mainlanes, channelizing devices and barricades will be placed to restrict traffic from entering the frontage road, however, access will be available for traffic that will travel from the frontage road onto the arterials. Traffic from the mainlanes will be diverted back onto the mainlanes at a downstream ramp from the full roadway closure. The frontage road between the two ramps is expected to provide free flow conditions to get the traffic around the incident quickly.

TxDOT would need to coordinate with other agencies that would be affected by any closures and they would need to work together in order to increase mobility and improve safety during full road closures. The necessary communications to improve traffic flow with multiple agencies are the following:

- Coordination between TxDOT, City of Houston, and the Houston Police Department/Harris County Sheriff's Office
- Coordination between TxDOT and City of Houston
- Notifications on proposed DMS to be deployed prior to roadway closure
- To expedite TCP devices, a multi-agency agreement should be in place to ensure sufficient equipment is deployed to improve safety and traffic flow
- Coordination between agencies and the police officers/first responders to monitor traffic at major intersections
- Agreements in place to have agency notification of closures

City of Houston ITS Efforts

The existing City of Houston traffic signal system aims to improve traffic flow of the saturated roadway conditions, especially within the vicinity of the project limits. The traffic signal system will not be updated to an adaptive system in consideration to its lack of effectiveness under saturated conditions; however, the use of TIGER grant funds will improve technology along major City corridors improving overall traffic flow conditions throughout the network. The upgraded system is not intended to directly address the frontage roadway congestion, but to provide traveler information for the internal network of the COH system which will minimize any demand increase towards the frontage roads during active incent times.

Additional Improvements with ATMS

There are two additional improvements that were evaluated with the installation of ATMS, reversible lane and dynamic HOV lane. The reversible lane was evaluated on Westpark Drive. The City of Houston will not be considering the installation of a reversible lane as they are working to remove the existing reversible lane on West Alabama for safety concerns. Although it is a viable option, the City of Houston will not proceed with it. The dynamic HOV lane was evaluated on the corridor since it is currently planned to be done on US 290 with TxDOT and METRO. For US 290, there will be a diamond lane being used in the off-peak direction during the peak period. The difficulty with dynamic HOV lanes is the enforcement requirement along the corridor. In-pavement lights are expensive and require significant maintenance, which is an additional expense for the system. Based on a conversation with METRO, the existing METRO HOV facility does not collect tolls during major incidents. Dynamic HOV lanes will not be recommended for the corridor.

Technical Challenges

There are a series of technical challenges with the application of the IH 69 Concept of Operations related to the additional ITS devices, staffing, agency coordination, operation, and maintenance. The technical challenges include:

- <u>Interagency use of ITS equipment</u> – TxDOT will own and maintain the ITS devices, while TranStar will operate the proposed devices. The active displays should be made available to each agency to aid in adjacent corridor operation.

- Coordination during incidents and special events – Radio and dispatch should be used for agency coordination. The challenge is to provide efficient traffic operation adjustments based on incident type, location, and duration.

- Operations and maintenance requirements – The proposed ITS devices require regular operation and maintenance. The IH 69 ATMS subgroup will operate the devices continuously. The overhead sign bridges for LCS will require traffic control during maintenance. If a portion of the system fails, it may impede the entire semi-automated system.

- Spacing of LCS and DMS – Ideally, the LCS would be spaced in half-mile intervals to actively improve traffic flow. However, spacing is limited and it is essential that drivers are not overwhelmed by information.

- Compatibility in software – TranStar will require multiple software capabilities to operate adaptive flow control between several devices.

- Corridor ROW – Overhead sign bridges may require ROW at various locations.

- Background projects along the corridor – IH 610 and the North Houston Highway Improvement Project (NHHIP) – The IH 610 at IH 69 interchange is proposed to be reconstructed to improve the direct connectors. The proposed ITS equipment will need to be integrated in future design work. In addition, the section of the corridor from Spur 527 to IH 10 is proposed to undergo major ramp and mainlane reconfigurations. The proposed ITS equipment will need to be incorporated in the future design.

An additional technical challenge includes the future implementation of future technology, such as dedicated short-range communication (DSRC). Sources that provide insight in this technology include FHWA, USDOT, National Highway Traffic Safety Administration (NHTSA), and reports documented through the New York Times (Quain, 2017).

The present outlook of the future of ITS suggests a proliferation of vehicle-to-vehicle (V2V) technology, in which vehicles send information to each other, and vehicle-to-infrastructure (V2I) technology, in which vehicles communicate with the built environment, such as traffic signals and electronic tolling systems. While the development of these technologies is only beginning, the benefits of its utilization are clear. V2V and V2I implementation can provide drivers forward collision warnings, approaching emergency vehicle warnings, and sudden break ahead warnings. The technology also has the potential to benefit regional transportation office by aiding in crash prevention, incident management, and congestion management (USDOT). For example, a roadside device can present drivers with an in-vehicle message about an upstream lane closure and prompt them to change lanes early, or even suggest changing their route entirely.

Certain measures can be taken to accommodate the near-future technology of vehicular communication. Dedicated short-range communication (DSRC) is an emerging technology which facilitates the passage of information between vehicles and infrastructure with a range of approximately 1000 feet. DSRC is a wireless technology which the FCC has designated 75 MHz of bandwidth of the 5.9 GHz band solely for transportation applications. DSRC has the advantage of not having the data costs of cellular, Wi-Fi, and satellite data. The only cost associated with the rollout of DSRC is the installation of antennae along the roadway (NHTSA, 2014). These DSRC antennae are typically installed about 15 feet above the roadway (FHWA, 2015). DSRC could potentially be installed on each overhead sign unit proposed in this IH 69 Concept of Operations. Vehicles driving along the IH 69 corridor that have DSRC antennae would be able to receive and transmit information with the roadway infrastructure to better facilitate active traffic management techniques.

The proposed 144-FON throughout the project corridor can also aid in the installation of vehicle-to-infrastructure devices. If new technology requires connection to fiber, the corridor FON has additional capacity for use.

It should be noted that emerging 5G cellular networks (which are still in the testing phase with a significant transition from 4G planned in 2023) may provide an alternative to DSRC in V2V and V2I communication. Cellular networks can transmit signals over a longer distance than DSRC and may provide faster speeds as well. However, cellular networks would have an increased data cost and may be unreliable in environments which do not have a high density of cell towers (Quain, 2017). Relevant agencies should closely follow the development of 5G technology as final specifications are released and evaluate its potential in providing a networking infrastructure for ITS applications.

Constraints

There are certain limitations to the function of the IH 69 ATMS. The constraints related to operation, signage, and function include:

A. Standard procedure for incidents – The ability to actively manage traffic with the proposed ITS equipment will be limited by the emergency first respondents. TranStar does not have control over how many lanes are closed, but will need to react to any changes in traffic operation during an incident.

B. Advisory vs. regulatory variable speed limits – The Harris County Sherriff's Department and the Houston Police Department do not currently have the ability to enforce/ticket advisory speeds. It is recommended that the LCS signs display regulatory variable speed limits, however, state legislation would have to update the current law governing variable speed limits. LCS would have to display advisory speed limits until the law is updated.

C. Funding – Equipment and Operations and Maintenance – Ongoing operation and maintenance funds are essential to effectively manage the IH 69 corridor. Staff personnel will need to be provided at TranStar and TxDOT will be required to maintain additional ITS hardware.

D. Automated Enforcement – There is a current prohibition of automated enforcement in Texas. The ATMS would likely function more effectively and efficiently with the ability of automated enforcement. The modification for the legislature to make automated enforcement legal is not currently expected in Texas.

E. Achieve Maximum Benefit – The entire system has to be implemented to achieve maximum benefit. Implementing certain aspects of the system will achieve a benefit, but the full potential will require the entire system with the rigorous maintenance schedule and dedicated staff. The importance of each of the components being in place was further emphasized with the understanding of other agency practices, such as MnDOT, which is outlined in **Appendix M**.

Section 2.5 Deficiencies and Limitations of the Existing System

The roadway capacity and design deficiencies along the IH 69 corridor are the primary limitations to the existing ITS. The freeway was designed before modern day roadway design standards. Table 31 outlines the number of areas in which the ramp spacing does not meet current FHWA requirements. FHWA requires an auxiliary lane between entrance and exit ramps when the ramp spacing is less than 2,000 feet. They also require entrance and exit ramp spacing to be at least 1,500 feet.

Table 31. IH 69 Corridor Merge/Weave Design Deficiencies

Segment	Number of Entrance/Exit Ramp Pairs That Do Not Meet FHWA Requirements
Beltway 8 to IH 610	2
IH 610 to SH 288	6
SH 288 to IH 45	1

There is a vertical and horizontal curve where IH 69 passes over the Westpark Tollway. The length and slope of this curve could have a significant impact on vehicles speed, especially heavy vehicle speeds. Increased speed differentials often lead to increased crash rates. This same location also has an issue with sun glare for the northbound lanes as the roadway shifts to an east-west alignment.

In the area east of Kirby Drive, the roadway is below grade. The drainage for this area is may not be sufficient and the lack of frontage roads and additional right-of-way means there is no staging area for tow trucks.

Current Traffic Operations

IH 69 suffers from daily congestion problems during the AM and PM peak periods. Table 32 through Table 35 highlight the segments (by shading) which have peak hour speeds fall at or below 40 miles per hour. These travel times and speeds were collected using historical TranStar data.

Table 32. Southbound AM Peak Speed and Travel Time

Roadway Segment	Distance (mi)	Speed (mph)	Travel Time (min)
IH 45 Gulf to Fannin	1.80	14	7.61
Fannin to Hazard	1.80	48	2.24
Hazard to Newcastle	2.50	63	2.38
Newcastle to IH 610 West Loop	1.35	64	1.27
IH 610 West Loop to Hillcroft	1.60	65	1.47
Hillcroft to Bissonnet	5.10	66	4.67
Bissonnet to Wilcrest	1.61	68	1.43
Full Corridor	**15.76**	**45**	**21.07**

Table 33. Northbound AM Peak Speed and Travel Time

Roadway Segment	Distance (mi)	Speed (mph)	Travel Time (min)
Wilcrest to Bissonnet	1.61	33	2.93
Bissonnet to Hillcroft	5.10	30	10.08
Hillcroft to IH 610 West Loop	1.60	21	4.50
IH 610 West Loop to Newcastle	1.35	40	2.01
Newcastle to Hazard	2.50	34	4.35
Hazard to Fannin	1.80	41	2.62
Fannin to IH 45 Gulf	1.80	49	2.22
Full Corridor	**15.76**	**33**	**28.71**

Table 34. Southbound PM Peak Speed and Travel Time

Roadway Segment	Distance (mi)	Speed (mph)	Travel Time (min)
IH 45 Gulf to Fannin	1.80	17	6.35
Fannin to Hazard	1.80	30	3.58
Hazard to Newcastle	2.50	20	7.38
Newcastle to IH 610 West Loop	1.35	26	3.06
IH 610 West Loop to Hillcroft	1.60	29	3.34
Hillcroft to Bissonnet	5.10	27	11.29
Bissonnet to Wilcrest	1.61	45	2.17
Full Corridor	**15.76**	**25**	**37.17**

Table 35. Northbound PM Peak Speed and Travel Time

Roadway Segment	Distance (mi)	Speed (mph)	Travel Time (min)
Wilcrest to Bissonnet	1.61	63	1.54
Bissonnet to Hillcroft	5.10	69	4.45
Hillcroft to IH 610 West Loop	1.60	48	1.99
IH 610 West Loop to Newcastle	1.35	49	1.64
Newcastle to Hazard	2.50	14	11.02
Hazard to Fannin	1.80	9	11.48
Fannin to IH 45 Gulf	1.80	15	6.99
Full Corridor	**15.76**	**24**	**39.11**

Figure 9 below show the 2015 TranStar speeds for the entire corridor. The AM and PM average speeds reported for each segment are plotted by direction. The peak hour is clearly indicated by the troughs in each plot. The HOV lanes, when present, generally have higher speeds than the general mainlanes during peak times, but are affected by the congestion. The HOV lanes currently operate with demand between 1200 to 1700 vehicles during peak periods and are projected to be at capacity in the future. About 80% of the traffic is composed of HOV, 19% single-occupancy vehicle (SOV), and 1% buses. The HOV lane operates very close to capacity.

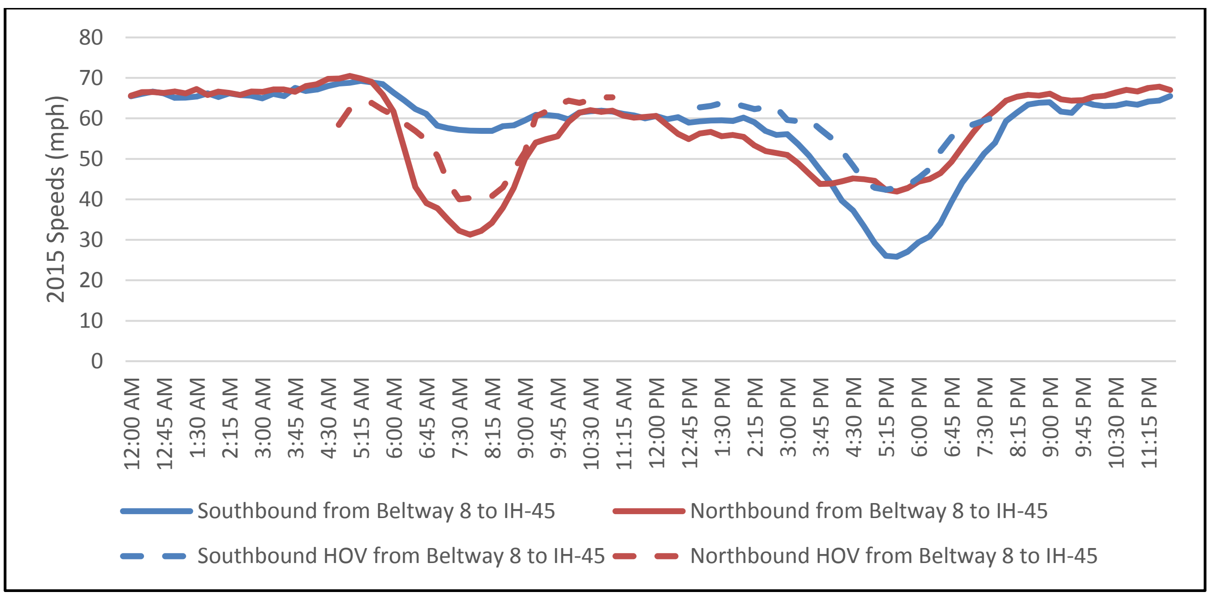


Figure 9. IH 69Corridor Speeds (Weighted Average)

The IH 69 corridor (between IH 610 and SH 288) currently ranks as the third most congested roadway in Texas (*Source: TTI, 100 Most Congested Texas Road Sections, 2016*). The 2015 TranStar speeds and travel time show this high level of congestion. In addition, travel times have been steadily increasing between 2013 and 2015. The level of congestion shows the deficiency of the corridor and limited ability of ITS to perform regular functions. The current

ITS is mainly used for incident verification, incident clearance, and special event planning. Incident clearance is aided with the use of CCTV along the corridor, while special event planning utilizes existing DMS to disseminate traveler information.

Current Crash Rates

The IH 69 corridor currently exhibits high crash rate levels. This is likely due to inadequate ramp spacing, high levels of congestion, large demand, and dated design standards. As previously discussed in Section 2.3, the crash rate exceeds the statewide average. There has been a large increase in number of reported incidents between 2013 and 2015. The number of crashes illustrate the level of geometric deficiencies, constraints, and overall congestion throughout the corridor.

Figure 10 shows the locations of 2015 major and fatal incidents along the corridor.

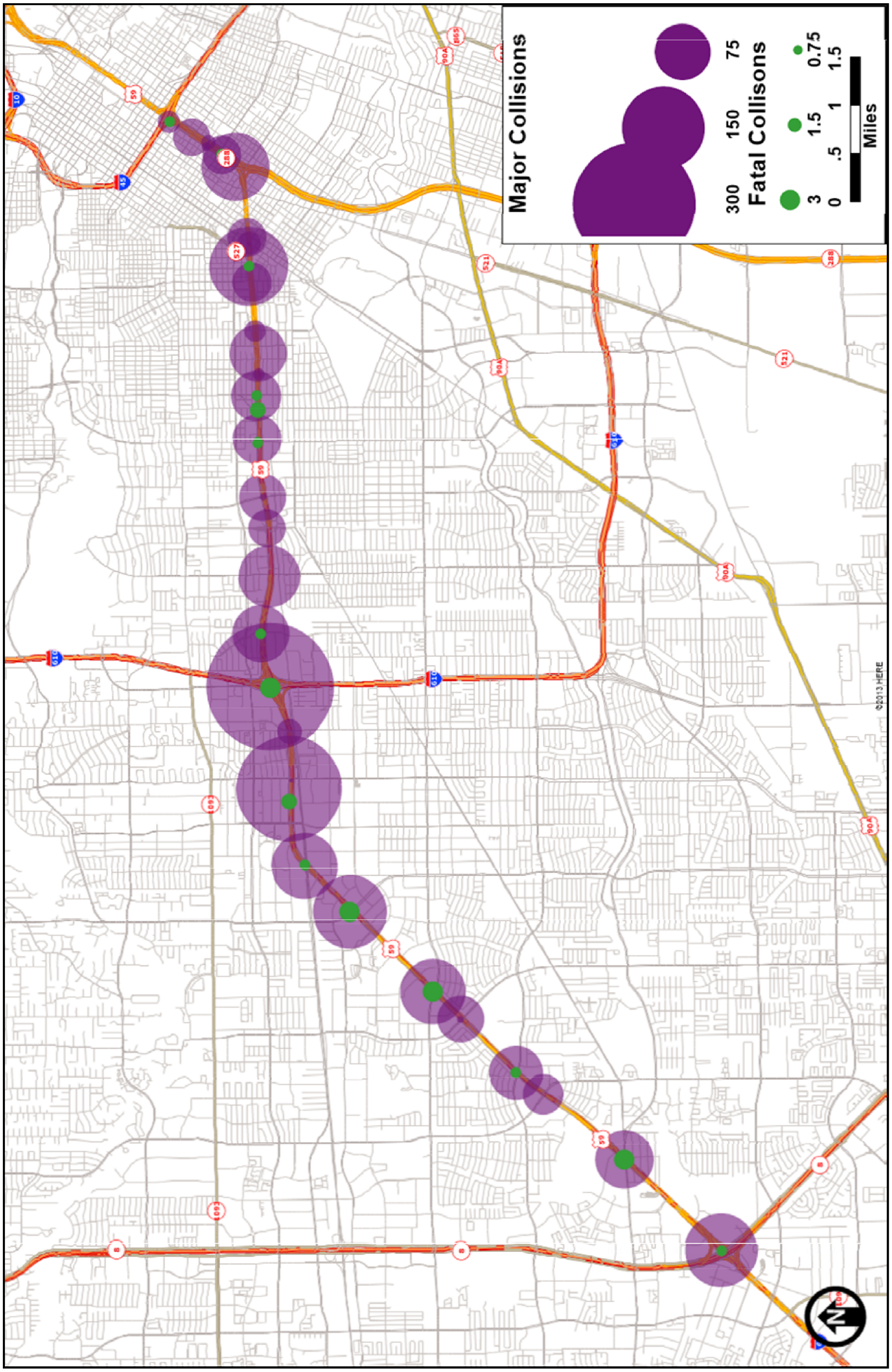


Figure 10. IH 69 2015 Major and Fatal Collision Locations

The largest number of incidents occur near larger interchanges along the corridor, such as IH 610, SH 288, Westpark Tollway, and Spur 527 (Main Street). The IH 610 interchange shows the largest number of crashes. This is likely due to the high volume of weave conditions and the ongoing construction on the IH 610 interchange.

Utilizing TxDOT's CRIS Database, the type of crashes and injuries were classified for the 3,968 reported crashes from January 2013 – August 2016 in Figure 11 and Figure 12**,** respectively.

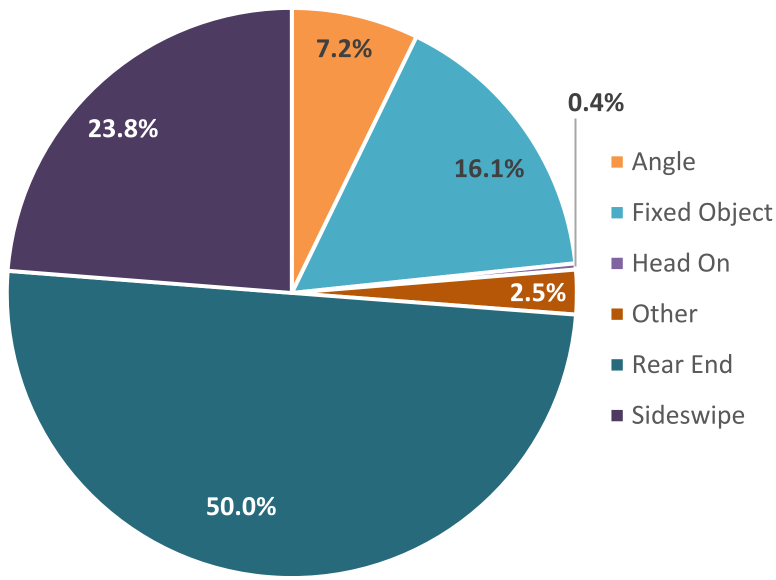


Figure 11. Crashes by Type

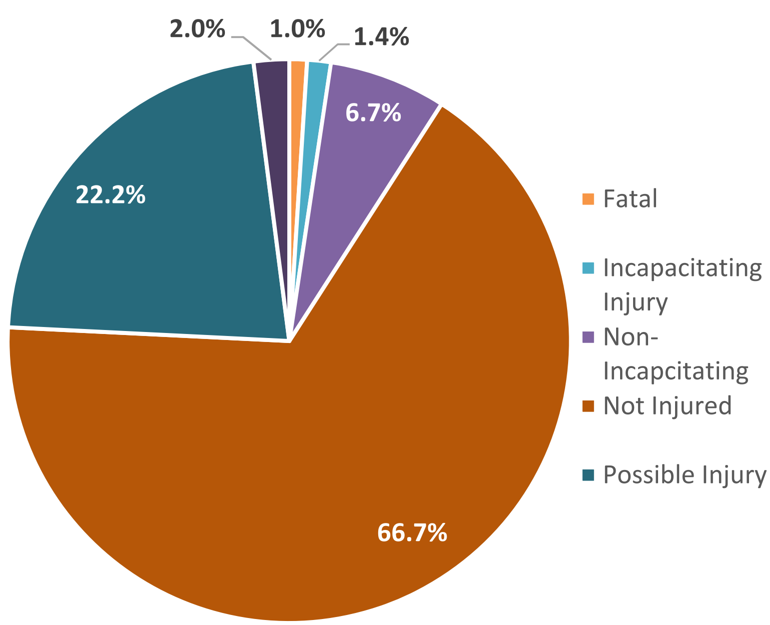


Figure 12. Injury by Type

The high percentage of rear end crashes, shown in Figure 11, are likely caused by the high level of congestion and number of secondary crashes along the corridor. The large percentage shows a need to improve queue warning, alerting drivers of slower or stopped traffic ahead. Active traffic management accomplishes this warning system through traveler information, queue warning, and speed harmonization.

The high percentage of non-injury crashes, shown in Figure 12, reinforces the likelihood that most crashes along the corridor occur at low speeds typical of crashes that occur during congested conditions. Active traffic management aims to reduce low speed crashes and reduce congestion along the freeway.

The proposed IH 80 Smart Corridor project in California is focused on improving safety with the implementation of ATMS. The study has designated an expected 25% reduction in crashes after implementation. The IH 69 corridor expects to see a 15-30% reduction in crashes based on FHWA reports, which is similar to the IH 80 Smart Corridor.

These incidents limit the mobility, reliability, and safety for travelers. The proposed ITS improvements aim to reduce the number of crashes, reduce congestion with real-time reliable traveler information, and improve operations when incidents do occur along the major freeway.

ITS Deficiencies and Limitations

There are a few key deficiencies in the existing ITS system that prevent the corridor from functioning at its full capability. These deficiencies and limitations are mainly related to the operational capabilities and current ITS devices available.

- **Interagency Coordination** – Despite existing coverage and a large number of devices along the corridor, TranStar is often limited in its ability to respond to events that occur along the corridor. TxDOT, City of Houston, Houston METRO, and Harris County each have ITS devices and responsibilities along the corridor. Interagency coordination could benefit by the use and enforcing of standard operating procedure.
- **Lack of Active Traffic Management Devices** – There are very few devices that allow the flow of traffic to be actively managed based on prevailing conditions. Ramp meters exist along the corridor, however they are not dynamic, only site-specific adaptive, meaning they do not operate based on mainlane flow of traffic. In addition, ramp meters are often "flushed", which involves the ramp meter turning green until there is no queue. This occurs when vehicles back up to a point near the frontage road intersections. There are also limited DMS to reroute traffic during recurring and non-recurring congestion.
- **New Technology** –Many of the existing devices do not have the capabilities of newer devices. The fiber network is often retrofitted based on spot location needs and available funds. The system would benefit from a complete update to the current devices and fiber network.

2.5.1. Reasons for Proposed Changes

Capabilities

The inclusion of an active traffic management system will add a multitude of devices to the corridor to provide added features and benefits. By increasing the amount of corridor coverage both from a visual perspective and by data collection, the ATMS is able to perform more effective operations along the corridor. Additional CCTV and data collection devices allow for the ATMS to operate as intended with the information necessary to use the proper operating procedure during congestion or an incident. The installation of overhead LCS and DMS allow for more effective information dissemination to motorists as they travel the network. This information transfer to the motorists can result in actions that reduce incidents and congestion. Ramp meters should be modified and upgraded to be corridor-adaptive and system-integrated, with modern equipment and interconnections. The following equipment is to provide additional capabilities to the ITS network.

- Additional PTZ CCTV locations will provide a more robust coverage of the corridor ensuring all incidents and congestion is identified and managed. It will also allow monitoring of existing and proposed DMS, as well as LCS from the TranStar control center.
    - Fixed CCTV placed in high incident areas can provide automated incident detection capabilities. With automated incident detection, TranStar will be able to efficiently take the appropriate response. Incident clearance time should improve with the improvement in incident detection time.
- Additional HD RVSD locations will aid in identifying congestion locations as well as in managing congestion by actively monitoring traffic conditions.
- Additional Bluetooth sensor locations will provide more reliable and accurate travel time information that can be provided to motorists. The information will assist in rerouting to less congested roadways. By providing better coverage, more data points will be collected to provide the higher accuracy and reliability.
- Additional RWIS locations will provide additional roadway weather condition information allowing TranStar to be proactive in informing motorists to roadway conditions. The additional information should help improve safety and significantly reduce the probability of any underwater facilities caused by flooding in the IH 69 area.
- Additional and upgraded dynamic ramp meter locations will aid in reducing congestion at merge and weave locations. Corridor-adaptive and system-integrated ramp meters accomplish this by identifying the flow rate on the mainlane facility and actively update the ramp meter green time to control the vehicles rate of entering the facility. The adaptive vehicle rate will allow more vehicles to enter when there are less mainlane vehicles to interact with, while slowing the rate of vehicles entering the mainlane when there are more vehicles occupying the mainlane facility.
- Addition of GRIPs locations allow for active re-routing and provide traveling motorists with current traffic conditions for route decision making. The proposed

display of the Houston TranStar map will allow motorists to make more accurate route choices based on current traffic conditions. It can reduce delay by communicating traffic information before travelers enter the congested corridor.

- Addition of active traffic management LCS and DMS locations provide traveling motorists corridor specific conditions and provide information to mitigate secondary incidents and reduce congestion. The LCS and DMS are strategically located to reroute traffic near high-incident locations to use frontage roads or arterial streets, while being spaced approximately at half-mile increments.

System Processing

Information collected by the field equipment will be processed at TranStar where dedicated IH 69 ATMS staff can review the data and determine if action is necessary. Once TranStar staff has verified an incident from the proposed ITS devices, the concept of operations procedures should be followed based on the incident level. Section 2.6 outlines the operational scenarios and procedures for the ITS devices. The additional field equipment can be used to determine the incident level, actively monitor the incident, monitor for secondary incidents, and deploy rerouting plans. This information is processed through and disseminated by TranStar staff to traveling motorists or other relevant agencies.

Interface

It is proposed that all devices be interconnected via an Internet Protocol (IP) fiber based network. The fiber based system provides a more reliable network connection. All devices are expected to report back to HUBs and ITS cabinets located through the corridor. Each of these HUBs and cabinet locations are interconnected via fiber, and this fiber trunk line returns to TranStar. The proposed system will include an interagency interface to display information and real-time operations to various affected agencies. It will require actions from the TranStar staff to adjust certain system components based on congestion response. LCS and DMS will need modification of full-color displays and incident management operating procedure to achieve active traffic management. Some systems such as travel time displays can be processed through an automated system.

Personnel

The addition of an ATMS will require multiagency personnel to take a more active and exclusively dedicated role during congestion. Congestion and/or incident levels will determine the appropriate response by ATMS personnel. As discussed in Section 2.4.5 User Roles, it is estimated up to ten dedicated personnel would be required. The ATMS group will need to be multiagency to coordinate efficient response. The number of personnel assumes 24-hour operation with the use of an ATMS manager, multiple ATMS engineers, maintenance technicians, and IT specialists.

Environment and Support

The ATMS personnel will need to take a more active role in managing congestion, which is different from TranStar personnel daily routines. Currently TranStar responds to congestion in a reactive manner to address immediate needs and regional situations. ATMS personnel will respond proactively to developing congestion and anticipated demand through dynamic message signs, dynamic ramp control, variable speed limits, queue warning, incident identification, and incident diversion. The way motorists perceive and react to information provided on the ATMS will also change. Currently, motorists are not accustomed to an actively managed corridor in which information will be constantly provided to them. It will take time for motorists to build trust in the information. TranStar will also need to maintain this trust by providing the most up to date information. If false information is displayed on the system, motorists will become less likely to follow warnings.

Agency support of the ATMS is essential in providing the most effective application and operation. Multiple agencies will be involved in operations and maintenance of the ATMS. Most of this coordination can be accomplished through TranStar, but agency support is critical to implementing incident management techniques and maintaining the proposed ITS devices.

A critical challenge facing the deployment of ATMS on this corridor is the current prohibition of automated speed enforcement in Texas. The ATMS system would likely function more effectively and produce greater benefit with automated speed enforcement. In Texas, automated speed enforcement is illegal per the Sec. 542.2035 of the Texas Transportation Code. The Arizona DOT installed speed cameras in Scottsdale and research indicated that the savings were between $16 and $17 million per year. When implemented correctly, automated enforcement can benefit traffic operation and lead to cost savings.

Operational

Additional interagency agreements between TxDOT, Harris County, and City of Houston are recommended in order for TranStar to use the adaptive detection and signal control feature. Additional procedures for congestion and incident management will be outlined in Section 2.6, Operational Scenarios. As mentioned previously, the additional ITS devices will require staff to take a more active role in not only identifying and verifying an incident, but also in managing the congestion caused by the incident.

Section 2.4 outlined the potential operational benefits of an ATMS. The system can significantly reduce delay, especially during incidents, by applying active traffic management techniques, such as speed harmonization, traveler information, and lane control.

ATMS has proven to reduce the number of incidents, which is a key deficiency along the IH 69 corridor. There has been no ATMS evaluation in Texas, however, A 2014 study by Washington Department of Transportation (*WSDOT 2014 Corridor Capacity Report*, 2014), outlined a reduction in incidents over a six-year period of 4% along the IH 5 active traffic management corridor, while similar facilities in the state, without ATM, saw a 4% increase. FHWA points to higher expected reductions in crashes in a 2007 report, *Active Traffic Management: The Next Step in Congestion Management*, at 15% to 30% reduction in crashes.

2.5.2. Priority of Proposed Changes

A criteria was set up to categorize proposed improvements by essential, desirable, and optional. Table 36 shows the general criteria for each type of improvement. These factors were based on agency feedback and goals of the proposed system.

Table 36. Criteria for Priority of Proposed Changes

Essential Features	Desirable Features	Optional Features
• Required to improve mobility, reliability, and safety • System cannot function without these specific features • Supported by all project stakeholders	• Features that would improve mobility, reliability, and safety, but not required • System can function without these features • Supported by most project stakeholders	• Features that would improve mobility, reliability, and safety, but not required • Dependent on the overall cost and available technology • Supported by most project stakeholders

Essential Features

The essential devices for operating an effective and efficient active traffic management system include:

- Closed Circuit Television (CCTV) - Additional PTZ CCTV locations are necessary to have nearly 100% coverage of the corridor for proper identification and verification of incidents and congestion. Fixed cameras are important for video-analytics and allow the opportunity to implement automated incident detection. The CCTV will also verify that all LCS and DMS are operating correctly.
- High Definition Radar Vehicle Sensing Device (HD RVSD) - Additional high-definition RVSDs will be needed to monitor roadway congestion and to identify the magnitude of congestion. Data stored from RVSDs can also be used for future planning and analyzing peak congestion times. This information can aid in future automation of the ATMS.
- Lane Control Signs (LCS) - As part of the ATMS roadway system, full matrix DMS both for lane control use and for traveler information are included along the corridor. As a system with each location working together, this allows for essential congestion control by minimizing secondary incidents and the magnitude of congestion.
- Dynamic Message Signs (DMS) - A small DMS is to be provided at each LCS location to disseminate traveler information. They will provide useful information in identifying downstream incidents, special events, or alternative routes.
- Fiber Upgrades - The proposed system should use an Internet Protocol (IP) fiber based network for device infrastructure. Using an IP fiber based network provides reliable communications of the ATMS.

- Dedicated Staffing for Operation and Maintenance (O&M) - An ATMS team dedicated to actively operating the IH 69 corridor is critical to the success of the proposed ATMS. The individuals must be proactively adjusting the ITS features to manage demand, disseminate traveler information, and adjust vehicle flow.

Desirable Features

Desirable features that aid in making the ATMS a more robust and comprehensive system include Bluetooth sensors, GRIPs, fixed CCTV, and actively controlled traffic signals.

- Additional Bluetooth Sensors - Additional Bluetooth sensors can be used to improve travel time detection and at DMS locations as part of the ATMS. Travel time information can be used for active rerouting by displaying travel times on strategic DMS that allow traffic rerouting.
- Fixed CCTV with Incident Detection - Automatic incident detection through the use of Traffic Analytics Software can reduce the time for incident verification and sending necessary emergency notifications. By increasing the speed of detection, this could potentially reduce the incident clearance time.
- Adaptive Detection - Adaptive detection at cross-street intersections is desired, but not essential, due to possible interagency operating conflicts. By actively detecting frontage road conditions during congestion or incidents, modifications can occur to help clear queues. Traffic signal timings can also be coordinated when active re-routing is necessary due to a major incident that requires a mainlane closure or significant reduction in mainlane capacity.
- Graphical Route Information Panels (GRIPs) - GRIPs are a key feature for graphically representing alternative routes to motorists while on the network. GRIPS have been successful in other Districts and countries by reducing the volume on congested networks by acting as part of the active re-routing process.

Optional Features

Additional Roadway Weather Information Systems are considered an optional feature. These are considered optional as this information can be partially obtained through third party vendors.

- Roadway Weather Information Systems (RWIS) - Additional RWIS can help determine roadway weather conditions along the corridor. Knowing what the roadway conditions are, using the RWIS, allows for TranStar to be proactive in informing the motorist of unfavorable conditions. This may lead to reduced incidents and congestion.
- Corridor-adaptive and System-integrated Ramp Meters - Adaptive ramp meters help control the flow of traffic onto the mainlanes to reduce congestion at merge/weave locations. The corridor has several existing ramp meters that can be upgraded to work in conjunction with the ATMS. Two additional ramp meter locations are

recommended to achieve full demand and flow management throughout the corridor system.

Benefit and Cost of Features

The previously discussed benefit and cost analysis, Section 2.4, analyzed the ATMS as a complete system. Table 37 shows the ATMS benefit.

Table 37. Expected ATMS Benefit (Source: *US 59/IH 69 Rider 42 Corridor Congestion Mitigation Study*)

Strategy	Model	Annual Benefit (2011 $) (M/yr)
Active Traffic Management - Safety[1]	N/A	5 - 9 M
Active Traffic Management - 2-Lane Incident[2]	DynusT	4 - 7 M
Active Traffic Management - All-Lane Incident[3]	DynusT	0.5 - 1.5 M

[1]Based on FHWA 2007 *Active Traffic Management: The Next Step in Congestion Management* and National Safety Council 2012 Report
[2]428 2-lane accidents per year (based on 2010-2013 RIMS data)
[3]27 all-lane accidents per year (based on 2010-2013 RIMS data)

The features provided in the DynusT analysis from the *US 59/IH 69 Rider 42 Corridor Congestion Mitigation Study* included:

- En-Route Traveler Information – Drivers are presented with the location of an incident and redefine their route based on the information. The percentage of drivers receiving this information increases with ATMS.
- Dynamic Message Sign – Additional DMS were placed at strategic locations along the IH 69 corridor to simulate the additional DMS as part of the ATMS. The DMS are categorized as three types.
    - Speed Advisory – These DMS define an advisory speed and a threshold for variance among vehicles along a link. For congested areas of the networks, advisory speeds were specified.
    - Mandatory Detour – In the case of the all-lane incident, a mandatory detour was placed to force vehicles who had not already diverted to exit the corridor.
    - Congestion Warning – These DMS warn drivers of upcoming congestion and offers the possibility of an alternative route. A certain percentage of users will choose the alternative route over the congested route.
- Ramp Closure – In the case of the all-lane incident, an upstream entrance ramp was closed to prevent vehicles from entering the freeway.

The ATMS strategies were implemented as a complete set of devices in the DynusT model runs. The percent diversion assumptions are based on research that includes a full set of active traffic management techniques. The maximum benefit of an ATMS occurs when a complete and consistent set of techniques are implemented and operated.

The construction costs, including design, mobilization, and contingency, associated with the active traffic management devices are summarized in Table 38 below.

Table 38. ATMS Construction Cost by Feature

Features	Cost	% of Total Cost
Essential	$19,555,000	86.4%
Desirable	$2,555,000	11.3%
Optional	$510,000	2.3%
Total	**$22,620,000**	-

As shown in Table 38, most of the cost associated with implementing the ATMS falls into the essential feature category. The majority of the cost in the essential system is composed of the Lane Control Signs (LCS). The majority of the cost in the desirable system comes from the GRIPs. The main cost in the optional system is the ramp meters.

The operations and maintenance cost of the proposed system is crucial in ensuring that devices are working properly and adequately operated to achieve the intended benefit. Section 2.3 outlines the User Roles and responsibilities. The maintenance includes monthly minor preventative maintenance and annual major preventative maintenance for DMS signs, data stations, and corridor-adaptive and system-integrated ramp metering locations. Table 39 shows the expected O&M cost.

Table 39. ATMS Operations and Maintenance Cost

Activity	Expected Cost
Operations	$1,036,000
Maintenance (Inspection, Preventive, Repair, Etc.)	$1,029,000
Contingency	$516,000
Total	**$2,581,000**

Using the total construction and O&M cost of the system in conjunction with the overall corridor benefit, a benefit-to-cost analysis was conducted. The benefit-to-cost analysis assumed a 10-year life cycle for the equipment. This analysis utilized results from the *US 59/IH-69 Congestion Mitigation Study*, with updated cost to reflect the latest TxDOT bid items and proposed devices. If the ATMS were used during recurring congestion and saw an increase in alternative route use, the benefit-to-cost ratio would increase significantly along the corridor. Table 40 shows the expected range of benefit-to-cost ratios.

Table 40. Proposed ATMS Benefit/Cost Range

Operational Strategy	Expected Benefit/Cost Ratio
ATMS	5.2-7.3

As stated previously in Section 2.4, there is a large range in the benefit-to-cost based on how the ATM devices are operated. The desirable and optional system components would aid in achieving alternative route use by offering adaptive detection, GRIPs, and corridor-adaptive and system-integrated ramp metering.

The benefit is expected to be achieved over a three year period when the equipment is completely deployed. The equipment is anticipated to be deployed in three phases with the critical equipment, such as DMS and LCS deployed first and the other devices, such as CCTV, RVSD, and GRIPs to follow.

Implementation Strategies

Based on the benefit and cost of the ATMS features, an implementation strategy should be created. This strategy will be largely built upon the available funding and agency support for various features. It is recommended that the ATMS be constructed at one time, as a complete system, however, if available funding and agency support prevent this, the phased construction could be implemented separately. Table 41 breaks down the benefit and cost for each of the phases of the ATMS.

Table 41. Benefit and Cost for Implementation Stages

Phase	Devices	Benefit	Cost
1	DMS LCS	Notify motorists of traffic conditions Queue warning, speed harmonization, traveler information, dynamic rerouting, and dynamic merge control	$12,324,168
2	CCTV RVSD Fiber	Adaptive signal adjustments based on queues Improved surveillance of corridor Speed detection along mainlane and frontage roads Improved dynamic rerouting Complete Fiber system connectivity with full power capability	$5,959,537
3	Bluetooth CCTV Fixed GRIPs Ramp Meter RWIS	Automated incident detection Improved weather data Adaptive and integrated flow control at ramp junctions	$4,335,195

2.5.3. Benefit/Cost Analysis Methodology

As part of the previous *US 59/IH-69 Congestion Mitigation Study*, a comprehensive benefit-to-cost analysis was performed to capture the impact of active traffic management along the corridor. This methodology uses the previous report content. The study used 2011 as the base year because of the availability in traffic data. The applicable components of the analysis were applied to the IH 69/US 59 Concept of Operations. The Concept of Operations analysis was updated with more recent data on crash statistics and changes to the proposed ATMS network. Table 42 outlines some of the key assumptions for the benefit-to-cost analysis.

Table 42. IH 69 Benefit/Cost Assumptions

Assumption	Value
Value of Time (2011$/veh-hr)	26.46
Annualization Factor (days/yr)	260
Growth Rate (%)	0.79
Inflation Rate (%)	2.52
Discount Rate (%)	3.0
B/C Timeline (yrs)	20
Duration of Congestion, DynusT	3-Hour Analysis, for AM and PM

The value of time is based on the TTI 2011 rate and the percentage of trucks using the IH 69 corridor during the peak periods. 2011 savings were adjusted by year based on a 0.79% growth rate, 2.52% inflation rate, and 3% discount rate. The 2.52% inflation rate is based on Congestion Price Index (CPI) data from 1991 to 2011. The growth rate was determined using historical traffic counts. Figure 13 shows that the growth has flattened over the last several years.

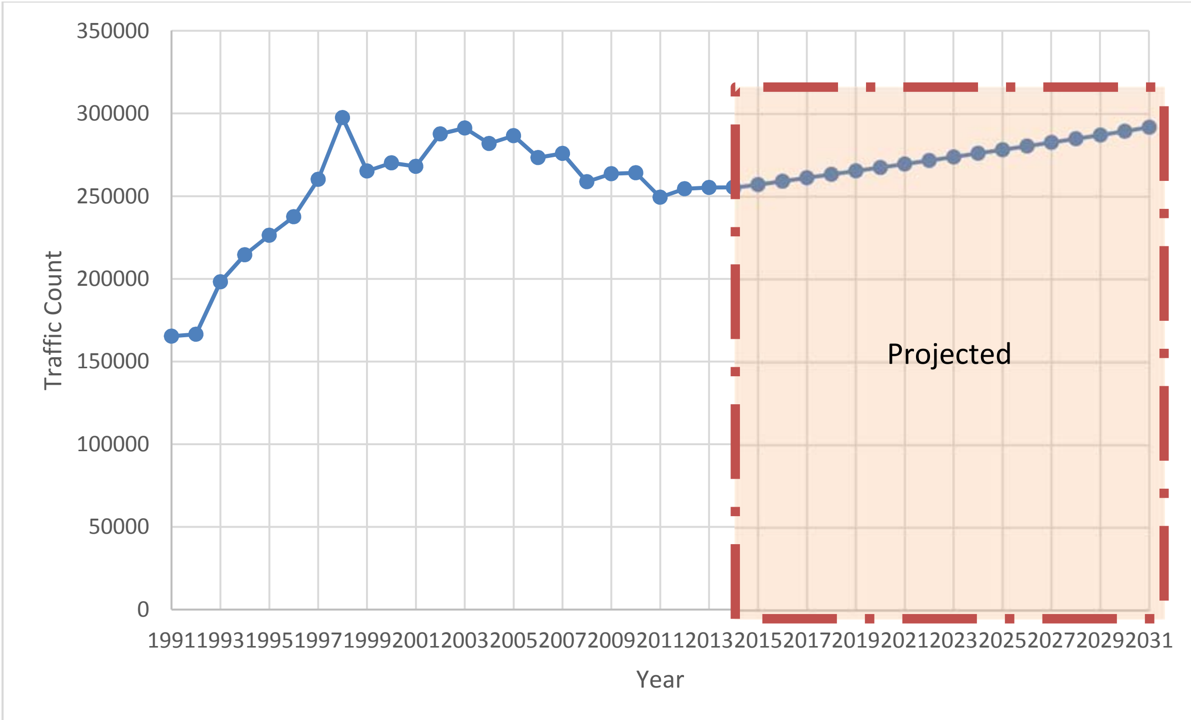


Figure 13. IH 69 Historical and Projected Traffic Counts

Active Traffic Management

Benefit

Active traffic management benefit analysis utilized four areas of benefit: recurring congestion, two-lane accidents, all-lane accidents, and crash reduction.

Recurring congestion benefit analysis utilized active traffic management during the AM inbound traffic. Diversion rate for recurring congestion was set at 10%. The travel time savings in DynusT were calculated and used to determine 2011 annual benefit for AM inbound traffic. An annualization factor of 260 days was applied to determine the annual benefit. The PM outbound benefit was assumed to be equal to the AM inbound benefit. This is a conservative assumption, considering the PM outbound traffic has lower speeds and a longer duration of congestion than AM inbound traffic. Figure 14 shows the 2011 TranStar historical speeds along the IH 69 corridor.

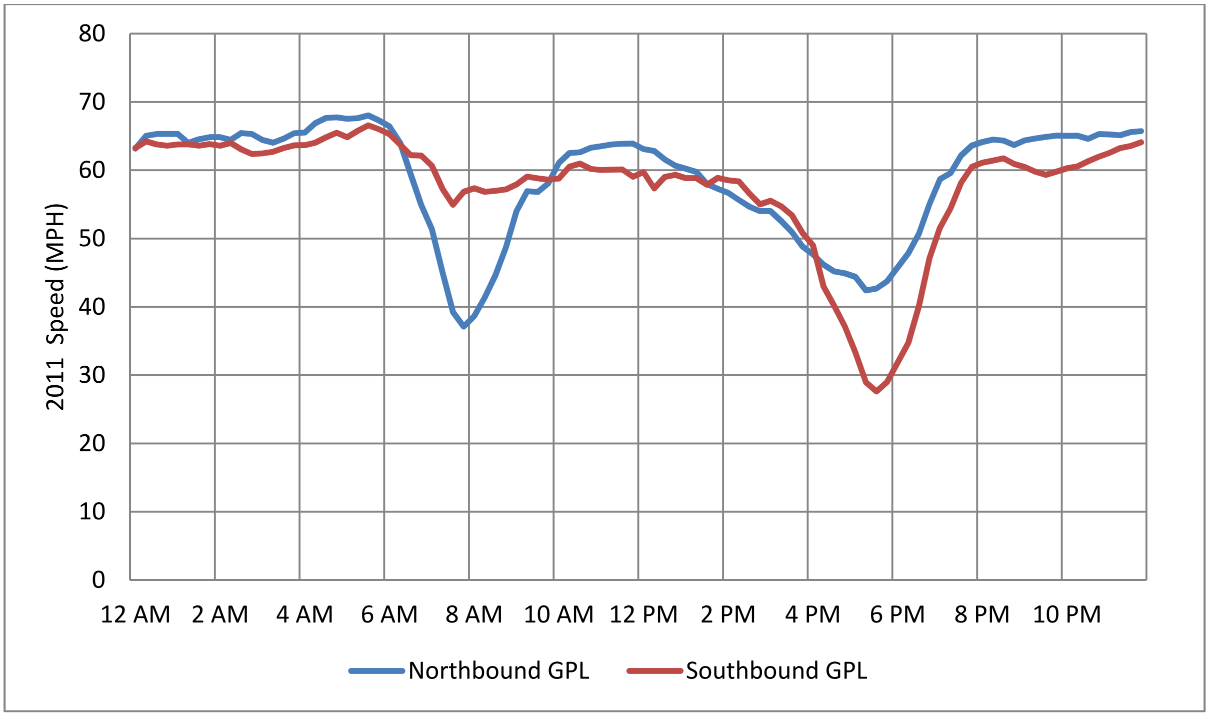


Figure 14. 2011 TranStar Historical Speed Profile along IH 69

The benefit during two-lane and all-lane accidents was determined based on travel time savings in DynusT model runs for these accident types. The two-lane and all lane accidents assumed diversion rates of 20% and 40%, respectively. In the case of the all-lane accident, the diversion rate refers to vehicles exiting prior to their required exit. The duration of the travel time savings was set at three hours and the CRIS data was used to determine the number of accidents matching each incident type during the average year.

The safety benefit from crash reductions was determined based on the combination of historical crash data and case studies. A FHWA 2007 report, *Active Traffic Management: The Next Step in Congestion Management*, identifies a 15% reduction in injury crashes, and a 30% reduction in property-damage only (PDO) crashes. The 30% reduction was adjusted to 20% as a means to make a conservative estimate on PDO crash reduction. Using the average number of crashes per year, by type, and economic cost of crashes based on a National Safety Council 2012 report, an annual cost savings was determined.

The benefit over 20 years was calculated for 2020-2040, based on the expected project completion date. The benefit was determined using a 0.79% growth rate, 2.52% inflation rate, and 3% discount rate. The yearly values were then converted back to 2016 dollars, for use in a benefit-to-cost ratio.

Cost

The construction, schematic, PS&E, and O&M costs for active traffic management were determined based on a combination of sources. Washington DOT and Caltran reports for IH 5 and IH 80, respectively, were used to help determine the costs associated with active traffic management operation and maintenance along a freeway corridor. The operation utilizes the user roles outlined in Section 2.4. 2016 TxDOT bid tabs were used for the construction items.

The operation and maintenance costs were calculated for years 2020-2040 using inflation rate of 2.52% and discount rate of 3%, then returned to 2016 present value for the benefit-to-cost ratio.

Comparison of ATMS to Conventional Improvements

The cost of ATMS implementation was compared to conventional improvements to aid in the decision making process. The conventional improvement used as a basis of comparison is an additional lane of capacity, in each direction, for the length of the project (17 miles). The cost of the additional lane is assumed to be $10 million per lane-mile, based on the range provided by TTI in *Adding New Roads or Lanes*. This document provides a range of anywhere from $2 million to $10 million dollars for adding a lane of capacity to an existing freeway. The high point of the range was used due to the urban environment that surrounds IH 69 and the bridge structures that would likely require modification. In addition, the operations and maintenance (O&M) cost for conventional improvements is based on a TxDOT study, *The Highway Construction Equity Gap* (2008), with an identified cost per lane-mile and annual growth. Table 43 summarizes the costs associated with each type of improvement over varying life-cycle lengths.

Table 43. ATMS vs. Conventional Improvement Cost

Life Cycle	Costs	ATMS	Conventional Improvements
	Capital Investment	$22,620,000	$340,000,000
	O&M (per year)	$2,581,000	$150,000
10-Year	2016 Total Present Value	$51,460,000	$341,585,000
20-Year	2016 Total Present Value	$77,315,000	$343,230,000
30-Year	2016 Total Present Value	$107,415,000	$344,940,000

As shown in Table 43, ATMS provides a relatively lower cost solution than conventional freeway expansion along this corridor. It is also worth noting that freeway expansion would likely have little impact on the congestion problem along the corridor. The IH 69 corridor suffers from inadequate ramp spacing, which leads to heavy lane change movements in several areas. Congestion often occurs due to the number of lane changes drivers must make. Capacity is also an issue, but the primary source of congestion is bottlenecks where there is high demand at various ramp locations. ATMS would mitigate congestion by providing traveler information, queue warning, and lane control guidance.

Summary

The benefit-to-cost analysis of the ATMS option is conservative, as it does not include some items that drivers would benefit from due to lack of necessary data. Table 44 provides a summary of what was or was not included in the previous study's ATMS benefit-to-cost analysis.

Table 44. Summary of Items in ATMS Benefit-Cost Analysis

Item	Benefit	Cost
Included	Time and Fuel (Recurring Congestion and Incidents) Safety (Incidents)	Construction Design Mobilization Software Operations Maintenance Contingency
Not Included	Environment Savings Savings from Speed Harmonization (Variable Speeds) Savings in Incident Identification Time Improvements	

Section 2.6 Proposed Operational Scenarios

Purpose

General guidelines for the four operational scenarios were developed using the proposed ITS infrastructure and anticipated ATMS operator capabilities. The four operational scenarios identified include minor incident, major incident, daily-recurring congestion, and planned event. Each scenario describes an operational sequence that depicts the roles of the system, interaction between users, and interaction with other systems. The scenarios were used to provide a comprehensive understanding of the operational aspects of the proposed ATMS. The operational scenarios will offer TxDOT and other agencies of TranStar various strategies to reduce congestion, identify incidents, manage incident progressions, and provide enhanced real-time traveler information.

General Functionality

The efficiency of executing an operational scenario will rely heavily on the proposed ITS infrastructure. The proposed ITS equipment will be used to monitor the corridor, alert operators of potential incidents, provide traffic control, and support traveler information systems. Bluetooth and HD RVSD along the corridor will gather and transmit data to TranStar regarding vehicle speeds, travel times, and traffic volumes. The information will allow ATMS operators to detect congestion and alert travelers of roadway conditions. Utilizing both existing and proposed equipment, a total of 18 Bluetooth devices and 75 RVSD will monitor the corridor. ATMS operators will oversee 97 existing and proposed CCTV PTZ cameras, which will provide complete coverage of the project corridor. The CCTV will assist in improving incident detection and monitoring. The proposed automatic fixed camera analytic software system will assist ATMS operators in identifying incidents. The 20 proposed fixed cameras will be stationed at high incident locations. The operational scenarios will also involve 14 existing and proposed corridor-adaptive and system-integrated ramp meters, which will automatically detect congestion, queues, and traffic flow, then alter ramp meter timings accordingly. LCS and DMS will provide extensive traveler information and will be managed by ATMS operators based on the prevailing operational scenario.

LCS will be positioned above every mainlane and shoulder (where applicable) at each of the 28 proposed sign bridge locations. The full-color matrix signs are approximately 4 feet by 5 feet, and there will be 202 total devices along the corridor. The LCS will display lane assignments, merge flow functions, speed limits, and queue warnings. Alternating messages will also be shown on the LCS to alert motorists and provide additional traveler information. The displays will be determined based on roadway conditions and executed by the TranStar ATMS manager. Table 45 below shows the different LCS messages and definitions.

Table 45. Proposed Lane Control Sign Symbols

Lane Control Sign (LCS) Symbol	Definition
	Open Lane
	Open Shoulder
	Closed Lane
	Closed Shoulder
	Merge Right
	Exit Freeway
	Posted Speed Limit
	Advisory Speed (Queue Warning)
	Advisory Speed Warning (Queue Warning)
	Interchange Direct Connector Lane Assignment
	EMS (Emergency Management System) Vehicles Only

The DMS at designated sign bridge locations will display notifications and messages regarding current traffic conditions. A total of 28 proposed full graphic colored DMS will be positioned throughout the corridor. The system will provide advanced warnings to motorists regarding roadway conditions as well as alternate routing options. Examples of DMS messages include travel times, queue warnings, merge notifications, incident warnings, lane closures, and special event notices.

Congestion is a result of excessive freeway usage, and can be described as recurring or non-recurring. Characteristics of congestion include slower speeds, longer travel times, and increased queuing. For non-recurring congestion, preprogramed LCS and DMS progressions will be utilized to aid ATMS operators and first responders in reestablishing default traffic conditions and flow. The progressions for non-recurring congestion are designed to inform as well as prepare motorists for downstream conflicts. The number of sign bridges employed for each scenario largely depends on the severity of the conflict. A summary of the proposed sign bridge procedures are displayed below in Table 46.

Table 46. Proposed Number of Sign Bridges for Operational Scenarios

Operational Scenario	Number of Sign Bridges for Scenario
Minor Incident (less than two hours to clear)	Up to six sign bridges upstream from incident, depending on the number of lanes closed
Major Incident (greater than two hours to clear)	Up to eight sign bridges upstream from incident
Daily-Recurring Congestion (Queue Warnings)	Up to four sign bridges upstream from congestion
Special or Planned Event	Up to two sign bridges upstream from event decision points

The progressions on the sign bridges will display different LCS symbols and DMS messages to direct drivers to slow down, merge, exit, or continue in the same lane.

As part of IH 69 ATMS, wrecker services will be necessary to address each of the four operational scenarios. It is recommended that tow trucks be staged along the project corridor to allow for quick response and achieve the required six minute response time. There would be limited tow trucks staged during off-peak periods with additional tow trucks staged during the peak periods for ease of access and response. Typical locations along the highway for tow truckers to park during peak periods are at gas stations, restaurant parking lots, and underpasses (where feasible).

Standard Operating Procedure for Default Conditions

During default operations, or free flow, the LCS over each mainlane will display a green down arrow, the posted speed limit, or the lane assignment. The symbols may alternate in order to improve driver alertness and awareness. The DMS will display travel times and additional traveler information. Travel times are an essential element of traveler information systems. The data is used by motorists to make informed decisions and to alert the traveling public of potential problems along the corridor. The corridor will be monitored at TranStar by one to two ATMS operators at all times, including during free flow conditions. In general, ATMS operators will observe several CCTV PTZ cameras and fixed cameras, update and verify LCS and DMS, and will review ITS data for vehicular speeds, travel times, and traffic volume information. Travel times will be updated at predetermined intervals during default operations.

ATMS operators will monitor the corridor closely and will be prepared for non-recurring events, including incidents, road debris, and other hazards. Coordination and communication with other TranStar agencies and first responders will be minor during default operating conditions. When a non-recurring event is detected by an operator, automated system, or traveler, the ATMS operators will communicate the information to all necessary agencies and parties involved. Standard operations will be suspended as the appropriate progression for non-recurring congestion is implemented. The proposed traveler information and posted speed limits will be displayed on the LCS and DMS as shown in Figure 15.

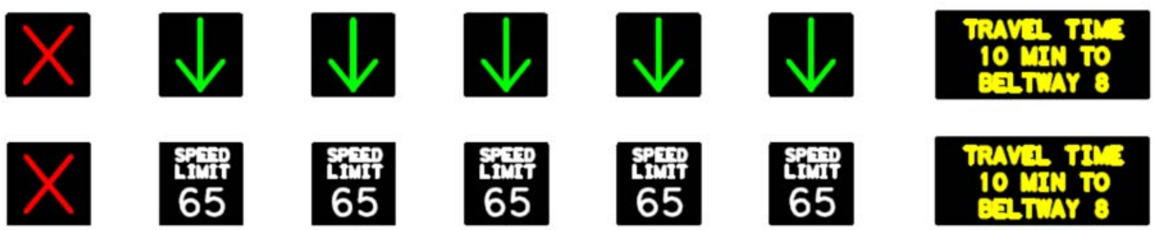


Figure 15. Default Condition Messages

Example DMS Messages for Default Conditions

- “TRAVEL TIME XXX MIN TO XXX”
- “REPORT INCIDENTS TO 281-584-7500”
- “DRIVE NOW TEXT LATER”

It is anticipated that some sign bridges will have alternating DMS messages.

2.6.1 Minor Traffic Incident

A minor traffic incident is defined as an incident that takes less than two hours to clear. The standard ATMS operating procedure for a minor incident will include ITS equipment, ATMS operators, and multi-agency coordination and communication. The minor incident process will entail detection, verification, notification, observation, clearing, and reestablishing default operations.

Incident Detection and Verification

Quick detection of minor incidents will be essential in order to promptly restore default traffic flow to the affected area. Incident detection will be initiated by a TranStar operator (monitoring PTZ cameras), call-in road user, or the proposed fixed-camera analytic software system. If the minor incident is detected by a call-in road user or the analytic software system, the ATMS operator will be responsible for confirming the incident and the exact location. False alerts will be filtered and excluded from further action. After the incident is confirmed, the operators will alert the proper emergency management dispatch authorities, and the crash will be entered into the RIMS.

When 911 is notified of the incident, the nearest HFD station will be immediately dispatched to the scene and are often the first to arrive. If the HCSO or the HPD first detects or becomes knowledgeable of an incident along the corridor, the agencies will alert the TxDOT ATMS operators. Communication between the departments at TranStar regarding incidents is crucial in order to efficiently operate and maintain the ATMS. After the initial assessment, the ATMS operators will anticipate the number of lane closures required and the amount of time it will take for the incident to clear and enact a minor or major incident operation plan. Once the on-site first responder evaluation is completed, the ATMS operators and TranStar ATMS manager will update the LCS and DMS messages, if necessary.

Minor Incident Progressions

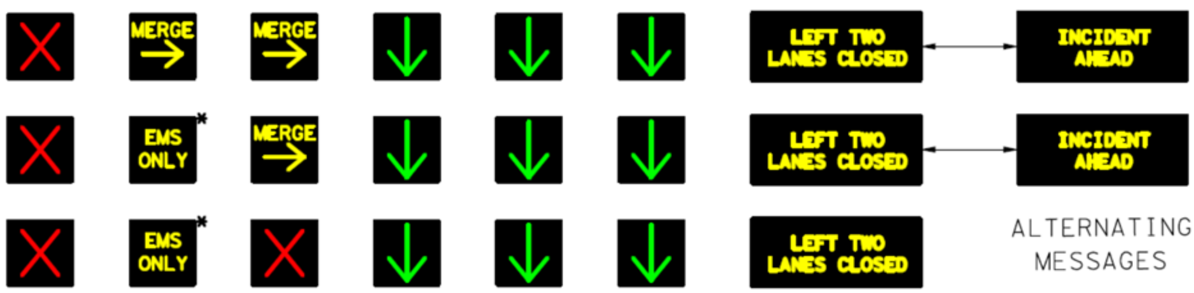
During minor incidents, it is anticipated that up to two ATMS operators will coordinate to affirm suitable traffic management procedures. After incident identification, the ATMS operators will activate incident notifications on DMS. The LCS will be customized by an ATMS operator to direct vehicles to lower speeds, merge, and remain alert for a closed lane or lanes ahead. The standard Progression A – Single Lane Closure (Minor) or Progression B – Two Lane Closure (Minor) for non-recurring congestion will dictate how, when, and where to administer the correct LCS progression. The number of sign bridges affected will depend on the anticipated number of lane closures. Below are descriptions of the standard progressions to be used during a minor incident.

- **Progression A** – Single Lane Closure (Minor) – Includes LCS progression up to six sign bridges upstream of the incident. Vehicles are directed to merge before the single-lane closure. DMS will display advisory messages similar to the following:
  - "INCIDENT AHEAD"
  - "LEFT LANE CLOSED AHEAD"

- "RIGHT LANE CLOSED AHEAD"
- "CENTER LANE CLOSED AHEAD"

- **Progression B** – Two Lane Closure (Minor) – Includes LCS progression up to six sign bridges upstream of the incident. Vehicles are directed to merge before the two-lane closure. DMS will display advisory messages similar to the following:
    - "INCIDENT AHEAD"
    - "XXX LEFT LANES CLOSED AHEAD"
    - "XXX RIGHT LANES CLOSED AHEAD"
    - "XXX CENTER LANES CLOSED AHEAD"

Based on the ATMS operators' judgement and progression, the sign bridges will begin to merge traffic into the non-closed lanes with yellow horizontal merge arrows. Green down arrows will signify lanes that will remain open. The sign bridge nearest to the incident location will display red "X"'s over the closed lane or lanes with the option of an alternating message "EMS ONLY". It is anticipated that drivers will follow the merge arrow directions, and will avoid the closed lane or lanes. By displaying information regarding an incident downstream, drivers will know what to anticipate and will be better prepared for the non-recurring congestion event. Figure 16 shows proposed LCS and DMS messages for minor incident operations.



*Alternating with Red "X"

Figure 16. Minor Incident Messages

Where possible, the IH 69 shoulder will be utilized as a through lane to aid in traffic flow during non-recurring congestion. The LCS over the shoulder will change from a red "X" to a green down arrow to alert drivers that the alternate lane is open. This will likely occur when a middle or right lane or lanes close due to a minor incident. The decision will be made by the TranStar ATMS manager and the ATMS operators will then notify emergency responders. After the incident is cleared, the LCS over the shoulder will revert back to a red "X".

Example DMS Messages for Minor Incidents

- "INCIDENT AHEAD"
- "INCIDENT AT XXX"
- "MERGE AHEAD"
- "LEFT LANE CLOSED AHEAD"
- "RIGHT LANE CLOSED AHEAD"
- "CENTER LANE CLOSED AHEAD"

- "XXX LEFT LANES CLOSED AHEAD"
- "XXX RIGHT LANES CLOSED AHEAD"
- "XXX CENTER LANES CLOSED AHEAD"
- "PREPARE FOR PASSING EMERGENCY VEHICLES"
- "LEFT SHOULDER LANE OPEN"
- "LEFT SHOULDER LANE CLOSED"
- "SLOW TRAFFIC AHEAD"
- "USE CAUTION"

It is anticipated that some sign bridges will have alternating DMS messages.

Minor Incident Clearance

Ramp meters will adapt to traffic conditions to regulate the flow of vehicles entering the freeway. However, emergency vehicles and wrecker service vehicles will have precedence at the entrance and exit ramp locations. The ATMS operators will work with emergency management departments and wrecker services to find and secure the quickest routes to the site of the incident. When needed, mainlanes could also be closed for emergency vehicle and wrecker service vehicle use only.

As the incident clearing process progresses, ATMS operators will continue monitoring the event, will update DMS and LCS, as well as identify alternative routes upstream of the incident if prolonged congestion is anticipated. Communication and coordination between the responding agencies will be essential throughout the minor incident progression. As incident details emerge, additional decisions by first responders, which includes HCSO, HPD, and HFD, will be conveyed to the ATMS operators and appropriate actions and changes to the ATMS will occur. The updates will reflect field changes and necessary incident progression and clearance adjustments.

After the minor incident is cleared and the inoperable vehicles and debris are removed from the freeway, the ATMS operators will continue to monitor the area via PTZ cameras to confirm the slow traffic is dissipating. The DMS will indicate the lanes are operating under default conditions and the DMS will provide travel time information. The upstream ramp meters will continue to operate in a modified sequence, until the mainlanes are fully recovered. The ATMS operators will verify the LCS, DMS, and ramp meters are performing correctly in order to accelerate mainlane improvements.

The LCS, DMS, and ramp meters will be returned to standard operations after the congestion from the incident is cleared. The ATMS operators will monitor the corridor and affirm the ITS equipment is functioning properly.

Standard Operating Procedure for Minor Incident

The minor incident standard operating procedure will follow the example described below.

<u>Incident Occurs</u>

- The incident is identified on the IH 69 corridor by Incident Management Team Operator, traffic analytic software, or call-in road user to HFD, HCSO, or HPD.
  - Incident Management Team Operator #1 confirms and locates the incident via CCTV and contacts HFD with the exact location of the incident.
  - HCSO or HPD Dispatch enters the crash into the CAD system which is linked to the Regional Incident Management System (RIMS).
- Incident Management Team Operator #1 notifies Incident Management Team Operator #2 to activate "ACCIDENT AHEAD" notifications on the DMS up to six sign bridges upstream of the incident.
- Incident Management Team Operator #2 sets LCS to Progression A or Progression B (1 to 2 lanes closed) upstream of the accident to encourage vehicles to merge left and have a progression of lower speeds upstream of the incident.
- Ramp meters will activate to regulate the flow of vehicles entering the freeway (except for emergency vehicles entering the ramp).

<u>Incident Progression</u>

- Based on the on-scene evaluation by HFD, Incident Management Team Operator #2 updates the DMS and identifies alternative routes upstream of the incident.
- Incident Management Team Operator #1 is contacted by HFD if an additional lane must be closed to aid wrecker services to remove vehicles.
  - Incident Management Team Operator #2 updates the LCS to another progression.
- HCSO or HPD contacts Incident Management Team Operator #1 to observe the field changes by CCTV when HFD has assessed the site and left the scene.

<u>Incident Cleared</u>

- Incident Management Team Operator #1 continues to monitor the incident via CCTV to make sure slow traffic is clearing.
- HCSO or HPD Deputy clears the inoperable vehicles from the freeway.
- Incident Management Team Operator #2 updates the LCS after the incident is cleared and reverts to variable speed (speed harmonization) mode. This provides caution to vehicles as the congestion is removed.
- Ramp meters upstream of the incident continue to operate to improve the recovery in mainlane operations.

<u>After Incident</u>

- Incident Management Team Operator #1 monitors traffic flow via CCTV.
- Incident Management Team Operator #2 reverts LCS to typical operations once the flow is deemed to be default operations.
- Ramp meters are returned to default operations.

2.6.2 Major Traffic Incident

A major traffic incident occurs when the clearance duration is over two hours. A major incident is expected to use up to eight sign bridges and DMS notifications upstream of the incident. The major incident standard operating procedure is similar to the minor and will include detection, verification, notification, observation, clearing, and reestablishing default operations.

The incident detection and verification process for a major incident is comparable to a minor incident.

Major Incident Progressions

During major incidents, it is anticipated that two ATMS operators will coordinate to affirm suitable traffic management procedures and contact the appropriate agencies for incident clearance. After incident identification and HFD field evaluation, the ATMS operators will activate major incident notifications on DMS. The LCS will be customized by an ATMS operator to encourage vehicles to lower speeds, merge, and exit the freeway for a full freeway road closure. The standard Progression C – Multiple Lane Closure (Major) or Progression E – All Lane Closure (Major) for non-recurring congestion will dictate how, when, and where to administer the correct LCS progression. Below are descriptions of the standard progressions to be used during a major incident.

- **Progression C** – Multiple Lane Closure (Major) – Includes LCS progression up to eight sign bridges upstream of the incident. Vehicles are directed to merge before the multiple-lane closure. DMS will display advisory messages similar to the following:
  - "MAJOR INCIDENT AHEAD"
  - "XXX LANES CLOSED AHEAD"

- **Progression E** – All Lane Closure (Major) – Includes LCS progression up to eight sign bridges upstream of the incident and DMS advisory notifications upstream of incident. Vehicles are diverted off of the freeway before the all-lane closure. At the designated exit for an all-lane closure, the DMS will display a message to notify drivers to form two lanes on the exit ramp. DMS will display advisory messages similar to the following:
  - "MAJOR INCIDENT AHEAD"
  - "ALL LANES CLOSED AHEAD"
  - "USE ALTERNATE ROUTE"
  - "EXIT 2 LANES WIDE"

Figure 17 shows proposed LCS and DMS messages for major incident operations.

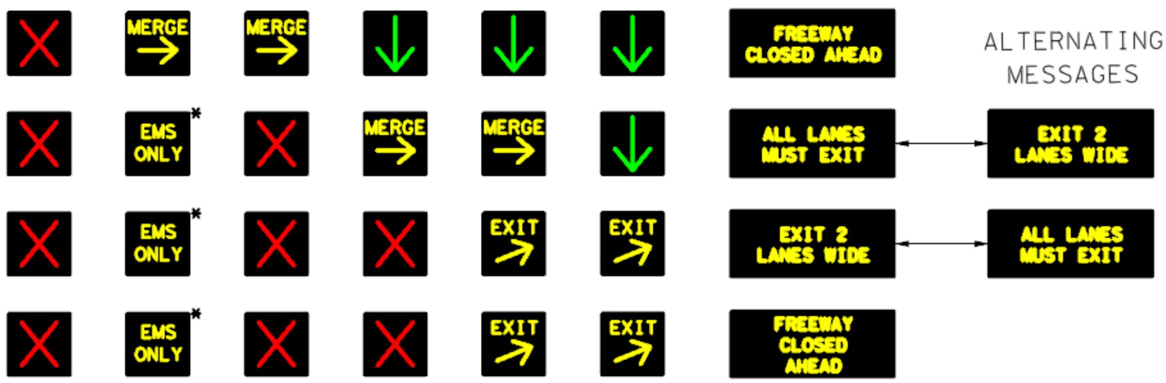


Figure 17. Major Incident Messages

Example DMS Messages for Major Incidents

- “MAJOR INCIDENT AHEAD”
- “XXX LANES CLOSED AHEAD”
- “FREEWAY CLOSED AHEAD”
- “FREEWAY CLOSED AT XXX”
- “ALL LANES CLOSED AHEAD”
- “USE ALTERNATE ROUTE”
- “ALL TRAFFIC MUST MERGE”
- “ALL LANES MUST EXIT”
- “EXIT 2 LANES WIDE”
- “FREEWAY CLOSED”
- “SLOW TRAFFIC AHEAD”
- “USE CAUTION”

It is anticipated that some sign bridges will have alternating DMS messages. Sufficient traveler information regarding closed lanes will allow drivers to make an informed decision about exiting the freeway prior to the dedicated two-lane exit ramp and take an alternative route.

Major Incident Clearance

Due to the duration of a major incident, traffic control devices can be deployed in addition to the LCS and DMS to ensure traffic merges to the designated two-lane exit ramp of the freeway. The on-site response team will be contacted by ATMS operators to deploy traffic control devices at the scene of the incident. If additional traffic control equipment is needed, the City of Houston Mobility Response Team (MRT) can be coordinated with to provide supplementary equipment and assistance as needed.

The ATMS operators will work with emergency management departments, on-site incident management teams, and wrecker services to find and secure the quickest routes to the site of the incident. If possible, the closed mainlanes will be assigned for emergency vehicle and wrecker service vehicle use only. Possible upstream alternative routes for freeway traffic will also be identified by ATMS operators and directed by the TranStar ATMS manager to help reduce corridor delays. As incident details emerge, additional decisions by first responders will be conveyed to the ATMS operators, which will disseminate all information to the necessary entities.

Communication and coordination between the responding agencies as well as METRO and City of Houston will be essential throughout the major incident progression. METRO has the ability to remove the HOV/HOT lane tolls and allow traffic to freely use the HOV/HOT lanes to bypass the incident and clear traffic. Tolling will restart after the incident is cleared and/or when the traffic can access the mainlanes. When there is a complete freeway closure and traffic is diverted to the frontage road, the City of Houston will be notified to coordinate the signal timing at the signal or signals between the exit ramp and the entrance ramp. Traffic will be directed to exit and enter the freeway in two lanes.

For the project limits of the corridor, there are locations that may require two cross streets to be closed due to the location of the on-ramp when traffic is diverting off of the mainlanes. There would be in an increase in traffic rerouted from the cross streets and additional barricades and enforcement officers required to move traffic through multiple intersections. Signal timings should be coordinated for the impacted intersections during the major incident to allow free flow traffic along the frontage road to the on ramp.

The standard operating procedures for a major incident regarding incident clearance and traffic revitalization are similar to the minor incident methods.

Standard Operating Procedure for Major Incident

The major incident standard operating procedure will follow the example described below.

<u>Incident Occurs</u>

- Incident is identified on IH 69 corridor by Incident Management Team Operator, traffic analytic software, or call-in road user.
    - If the analytic software or call-in road user identifies the incident, then Incident Management Team Operator #1 confirms and locates incident on CCTV and contacts HFD with the exact location of the incident.
    - The incident is reported to HCSO or HPD to be entered into their CAD system.
    - Incident Management Team Operator #1 will notify media outlets of all lane closure.
- Incident Management Team Operator #1 notifies Incident Management Team Operator #2 that an incident occurred and which CCTV cameras need to be viewed.
    - Camera view is shown on the floor of TranStar to allow all the operators to monitor the incident.
    - TranStar ATMS manager monitors the CCTV feed to determine the appropriate response for the incident.

- Based on the TranStar ATMS manager's assessment of the incident, the HCSO, HPD, HFD, EMS, and/or Medical Examiner's Office are notified.
  - If a fatality occurs:
    - The first responder to arrive at the scene, often HFD, will call the Medical Examiner's Office to notify them of a fatality.
    - HPD will provide the official call to the Medical Examiner's Office.
- Incident Management Team Operator #1 inputs the incident information in the RIMS.

<u>Incident Progression</u>

- Incident Management Team Operator #2 activates LCS to Progression E up to eight sign bridges upstream of the incident, identifies alternative routes upstream, and follows the progression of the incident. The on-site responders will keep the Incident Management Team Operator #2 updated with real-time information to make sure the LCS are functioning and up-to-date.
- On-site Incident Management Team is contacted by Incident Management Team Operator #1 to deploy traffic control devices at the scene of the accident.
  - Progression E (all lanes closed) will direct vehicles to exit the freeway and take the most immediate alternative route. Traffic is rerouted on the frontage road prior to the incident and diverted back onto the freeway on the first ramp downstream from the incident. Traffic is monitored by Incident Management Team Operator #1 and continued updates are provided to the TranStar ATMS manager to ensure interagency communication.

<u>Incident Cleared</u>

- Incident Management Team Operator #1 continues to monitor the incident via CCTV to make sure slow traffic is clearing.
- Incident Management Team Operator #2 updates the LCS after the incident is cleared and reverts to variable speed (speed harmonization) mode. This provides caution to vehicles as the slow traffic recovers.
- The On-site Incident Management Team clears the control devices along the frontage road and mainlanes.
- Ramp meters upstream of the incident continue to operate to improve the recovery of mainlane operations.

<u>After Incident</u>

- Incident Management Team Operator #1 monitors traffic flow via CCTV.
- Incident Management Team Operator #2 reverts LCS to default operations once the flow is deemed to be recovered.
- Ramp meters are returned to default operations.

2.6.3 Daily Operations – Recurring Congestion

Recurring congestion is defined as the expected reduction of traffic flow speeds and increased travel times due to daily excessive freeway usage. The standard ATMS operating procedure for recurring congestion will include ITS equipment and ATMS operators. The recurring congestion process will require detection and notifications to drivers of posted speed limits, advisory speeds, and slow traffic. Advisory speeds are expected to slow traffic as well as create a more uniform and homogenous flow. The slower traffic can reduce stop-and-go movements and allow drivers to reach their destinations more quickly. In addition, incidents are less likely to occur due to a lower standard of deviation in vehicular speeds. The operational procedure, Progression D – Queue Warning (Congestion), for recurring congestion will also upgrade and replace the existing queue warning system along the corridor. Below is the description of the standard progression to be used during a recurring congestion.

- **Progression D** – Queue Warning (Congestion) – Includes LCS progression up to four sign bridges upstream of the congestion. Advisory speeds are displayed upstream of a bottleneck or slowdown. This harmonizes traffic flow and slows traffic to reduce crashes. DMS will display advisory messages similar to the following:
  - "SLOW TRAFFIC AHEAD"
  - "BE PREPARED TO STOP"
  - "MAINTAIN SLOW SPEEDS"

Monitoring Recurring Congestion

ATMS operators will be familiar with the ITS infrastructure needed to monitor recurring congestion. The ITS equipment will include PTZ and fixed cameras, Bluetooth, HD RVSD, LCS, DMS, and ramp meters. PTZ and fixed cameras will be used to detect the recurring congestion, and the Bluetooth and HD RVSD will be used to monitor vehicular speeds and volumes for up-to-date travel times and traffic flow. The data output from the ITS equipment will be used by the TranStar ATMS manager to determine appropriate advisory speeds. The advisory speeds will be displayed on the LCS and additional traveler information will be presented on DMS, as shown in Figure 18.

Figure 18. Advisory Speed Messages

During standard operations for recurring congestion, DMS will show travel times and queue warnings. Queue warnings, or warnings of slow traffic ahead, will alert drivers to changing speeds, slower traffic, congestion, and queues. Informed travelers will be more prepared to decrease speeds or come to a complete stop, which may reduce traffic incidents.

The proposed corridor-adaptive and system-integrated ramp meter system will automatically detect increasing and decreasing congestion along the mainlanes and adjust accordingly to ease the inflow of traffic from the frontage roads to the mainlanes. The ramp meters will deactivate when the mainlanes are at full capacity (fully saturated).

The corridor and ITS equipment will be monitored at TranStar by the ATMS operators during recurring congestion. The LCS, DMS, advisory speeds, travel times, and additional queue warnings will be updated by the ATMS operators as directed by the TranStar ATMS manager and will be administered up to four sign bridges upstream of the congestion. Travel times will be updated at predetermined intervals, but the duration may require adjustments during periods of intense congestion. During recurring congestion, coordination and communication with other TranStar agencies will be minor, but the ATMS operators should be prepared for non-recurring events to occur including incidents, road debris, and other hazards.

Example DMS Messages for Recurring Congestion

- “BE PREPARED TO STOP”
- “SLOW TRAFFIC AHEAD”
- “REDUCED SPEED”
- “XX MPH”
- “ADVISORY SPEEDS DISPLAYED”
- “MAINTAIN SLOW SPEEDS”
- “USE CAUTION”
- “KEEP 2 CAR LENGTHS BETWEEN VEHICLES”

It is anticipated that some sign bridges will have alternating DMS messages.

2.6.4 Planned Event

A planned event is defined as an occurrence that has been evaluated in detail to determine expected traffic conditions and event program. Typical planned events in the Houston area include the Houston Rodeo, sports events, conferences, conventions, concerts, shows, and festivals. The ATMS progression for special or planned events is Progression F – Special Event Notification. Based on the location of the event decision points (entrance ramps, exit ramps, and interchanges), up to two sign bridges will be used to notify motorists of impending event directions and instructions. Below is the description for the standard progression to be used during a planned event.

- **Progression F** – Special Event Notification – Includes LCS progression up to two sign bridges upstream of the decision points that lead to the event and DMS notification upstream of the event. Road users are notified which lanes are dedicated to getting to the event.

Monitoring Planned Event

A planned event will require the approval and coordination of several agencies, including TxDOT. The ATMS operators and other TranStar agency staff will have prior knowledge of the special event, and LCS and DMS messages will be predetermined for specific locations and times along the corridor. The LCS will dictate a lane or lanes for the planned event traffic flow. An arrow with the event name will be displayed over the event lanes, while the other mainlanes continue to show the standard green down arrow. Additional lane assignment possibilities for the LCS include interstate or state highway shields, as shown in Figure 19. The DMS on the sign bridges will display information regarding the planned event, and as the special event motorists approach the event ramp or interchange, the DMS will provide specific instructions.

Figure 19. Planned Event Messages

It is anticipated that at least two ATMS operators will monitor the corridor during a planned event. One ATMS operator will monitor the freeway for incidents, while the other ATMS operator will maintain the LCS and ATMS for the planned event. If an incident occurs during Progression F, the ATMS operators will determine if any special event decision points conflict with the incident messages. If conflicts arise, the incident messages will take precedence over the planned event notices. The event messages will then be shown upstream of the incident messages in order to provide motorists with planned event as well as incident traveler information.

Standard Operating Procedure for Planned Event

Due to the extensive planning involved with special events, the ATMS operators and other TranStar agency staff will anticipate and be prepared for event traffic, event congestion, and possible event related traffic conflicts.

The planned event standard operating procedure will follow the Houston Rodeo example described below.

Event Traffic based on Event Coordinator is Determined

- Incident Management Team Operator #1 monitors the IH 69 corridor segment for incidents, while Incident Management Team Operator #2 controls the LCS and DMS for the planned event.
- In the case of the Houston Rodeo, Incident Management Team Operator #2 will be changing the LCS on the sign bridges prior to Beechnut Street, IH 610, Kirby Drive, and SH 288.
- For special events, Progression F will be implemented to inform drivers which lanes lead to the event and have non-event traffic merge to the lanes that will not be traveling to the event.

Event Traffic with Incident

- Incident Management Team Operator #1 coordinates with Incident Management Team Operator #2 to identify where the decision points for the incident are located.
    - If the decision point conflicts with a message that is being displayed for the special event, then the incident message takes precedence.
    - In the event that the special event message is replaced with an incident message, then the event message will be shown on the message upstream from the incident message to provide drivers notification of where to access the special event.

Example DMS Messages for Planned Events

- "EVENT TRAFFIC USE RIGHT LANES"
- "EVENT TRAFFIC USE LEFT LANES"
- "EVENT TRAFFIC USE XXX NORTH"
- "EVENT TRAFFIC USE XXX SOUTH"
- "EVENT TRAFFIC USE XXX EAST"
- "EVENT TRAFFIC USE XXX WEST"
- "EVENT EXIT"

It is anticipated that some sign bridges will have alternating DMS messages.

2.6.5 Planview for the Operational Scenarios

For four operational scenarios: minor incident, major incident, daily operations - recurring congestion, and planned event, planview exhibits were developed to provide an example of the scenarios along the IH 69 corridor within the project limits. The planview exhibits were developed based on the progressions outlined in Section 2.4 and described above. The exhibits are shown in **Appendix N**.

Minor Incident

A minor incident that occurs on IH 69 Southbound between Spur 527 and Weslayan Street is shown in **Appendix N**. The minor incident shows a two-lane closure of the left lanes, which is activated by Progression B. For a two-lane closure, drivers are notified of the incident on up to six sign bridges upstream of the incident. Vehicles are directed to merge before the two-lane closure. LCS and DMS will display which lanes are closed and the location of the incident. Based on **Appendix N**, examples of alternating DMS messages displayed to warn drivers of the incident include the following:

- "INCIDENT AHEAD"
- "LEFT TWO LANES CLOSED"

The lane merging display on the LCS will have the word "MERGE" and an arrow pointing in the appropriate direction and the lane closure display will have a red "X" over the closed lanes. However, LANE 1, as shown in **Appendix N**, will have an alternating message "EMS ONLY" (emergency vehicles only) in addition to the red "X". The lane closures will be reinforced with the use of emergency vehicles blocking the appropriate lanes. For a single lane closure, which is activated by Progression A, the drivers will be notified up to four sign bridges upstream of the incident. Vehicles will be directed to merge before the single-lane closure and similar to the two-lane closure, emergency vehicles will be used to block the appropriate lane. The sign bridge downstream of the incident will show default traffic operations and the DMS will provide travel times.

Major Incident

The major incident shown in **Appendix N** is in the same area along the corridor as the minor incident. According to the Operational Scenario section in Section 2.4, Progression E will be activated for a major incident with an all lane closure. Progression E notifies drivers of a major incident up to eight sign bridges and DMS notifications upstream of the incident. Vehicles are diverted off the freeway during an all-lane closure. According to **Appendix N**, examples of the displayed alternating messages to notify drivers that the roadway is closed and there is a dual exit ramp include the following:

- "MAJOR INCIDENT AHEAD"
- "FREEWAY CLOSED AHEAD"
- "ALL LANES MUST EXIT"
- "EXIT 2 LANES WIDE"

- "FREEWAY CLOSED"

The closed lanes can be used for emergency vehicles in order to arrive at the scene quickly. The mainlanes will be closed using traffic control devices and emergency vehicles and the traffic will be diverted to the frontage road. The cross streets to the frontage road will be rerouted to parallel streets to allow traffic from the exit ramp flow freely to the next entrance ramp downstream from the incident. The frontage road traffic will be controlled by police to get the traffic back onto the mainlanes. The sign bridge downstream of the incident will show default traffic operations and the DMS will provide travel times.

Daily Operations - Recurring Congestion

For the daily operations with recurring congestion, Progression D for non-recurring congestion described in the Operation Scenario section in Section 2.4 will be activated. Up to four sign bridges upstream of the congestion will display advisory speed reductions in intervals of 10 to 15 mph. According to **Appendix N**, the DMS will display the following example advisory messages to drivers:

- "SLOW TRAFFIC AHEAD"
- "USE CAUTION"
- "BE PREPARED TO STOP"

For the exhibit shown in **Appendix N**, the sign bridges of the inbound direction towards Downtown between Weslayan Street and Dunlavy Street show the advisory speeds due to slow traffic. Under recurring congestion, drivers will be notified of the slow traffic ahead and advisory speeds. The slow traffic ahead warnings and advisory speeds are intended to replace the existing queuing system and improve traffic congestion through the corridor using a lower speed. The ultimate goal for daily operations with recurring congestion is to provide variable speeds that can be enforced through video detection to ensure system compliance and improvement.

Planned Events

For a planned event such as the Houston Rodeo, as shown in **Appendix N**, Progression F from the Operational Scenario section in Section 2.4 will be activated. The drivers will be notified on two sign bridges upstream of the decision points that lead to the event and DMS notifications upstream of the event. Road users will be notified which lanes are dedicated to getting to the event. For the Houston Rodeo example, the dedicated lanes are IH 610 South. The overhead sign bridges at Fountain View Drive and Chimney Rock Road will provide notifications for the northbound traffic and the overhead sign bridges prior to Weslayan Street and Edloe Street will provides notifications for the southbound traffic. For planned events, caution regarding lane configurations will need to be taken near interchanges that have direct connectors.

2.6.6 Operational Integration

Roles of the System

The purpose of the proposed ITS infrastructure is to not replace the existing system, but rather upgrade and integrate existing equipment with the proposed system to provide real-time information. The current capabilities of the system that are to continue include:

- Use of PTZ cameras to view incidents and overall traffic conditions
- DMS to provide travel time information and any change in roadway conditions
- Notifying proper authorities of incidents, road debris, and other hazards
- Communicate and coordinate with multiple TranStar departments and emergency management personnel

The ATMS will require the upgrade of all fiber within the project limits to 144 single mode fiber. The fiber currently in place varies along the corridor, but will need to be upgraded to accommodate the equipment and allow for the information to be transmitted back to TranStar to provide real-time traffic information using Bluetooth and HD RVSD technologies.

The new ITS equipment will provide video detection for full coverage of the corridor with a fixed camera system and additional PTZ cameras. Initially, the fixed cameras will be located in high incident areas and will assist ATMS operators in identifying incidents more quickly using an automated system with a traffic analytics software. The additional PTZ cameras addresses the areas lacking overage of the existing cameras. The ATMS operators will be able to monitor and verify LCS and DMS messages that are directed by the TranStar ATMS manager.

The LCS and DMS will be located on the proposed 28 overhead sign bridges. The messages will be updated based on minor incidents, major incidents, daily recurring congestion, and planned events. The LCS will display green arrows, the posted speed limit, or lane assignments for default conditions, when the other operational scenarios are not occurring. The TranStar ATMS manger will determine which messages are displayed based on camera coverage and/or on-scene personnel. The LCS messages will notify drivers which lanes can be utilized and lane merging during non-recurring traffic conditions. The DMS will be used to provide reliable travel time information to drivers as well as caution drivers of approaching traffic conditions, such as being prepared to stop during congested conditions.

The upgraded and new ramp meters will be part of a corridor-adaptive and interconnected system. The adaptive component will allow the ramp meters to adjust to traffic flow conditions. The interconnected component will connect all the ramp meters to operate as a closed system. The corridor-adaptive interconnected system will improve the effectiveness of the ramp meters. The designated ATMS personnel for the ramp meters will ensure the meters are operating correctly.

Ultimately, the proposed system is expected to develop into a semi-automated system that can improve traffic flow during recurring and non-recurring traffic conditions. The system is not intended to remove personnel, but to improve efficiency between the system and the ATMS staff.

Interaction between Users

For ATMS, it is critical to have full cooperation between the different agencies. Currently, TranStar provides the necessary facility to enable communication between the different agencies by housing the small groups of personnel at the same facility. It is expected that a separate ATMS group at TranStar will be created to focus on the proposed system within the limits of the project corridor. For each agency, there will need to be a point person that is the main contact for the ATMS team. It is essential that there is clear and quick communication to make sure the system is operating efficiently. This requires detailed and organized information regarding staffing schedules to know which individuals need to be contacted. In addition, the ATMS maintenance crews will need to perform frequent preventative maintenance on the system to ensure proper ATMS operations.

The coordination between various agencies will occur during a minor incident, major incident, and a planned event. A minor incident primarily involves the coordination of the HPD and HFD. For a major incident, coordination between the HPD, HFD, City of Houston, TxDOT, and METRO may be required under certain circumstances. The ATMS TranStar manager will need to be the principal coordinator to ensure that all information is being disseminated accurately and timely.

Interaction with Other Systems

Currently, many of the agencies' systems are connected to TranStar. The upgrade to ATMS along the project corridor will require changes to how the systems communicate, since it is expected to be a semi-automated system and requires quick responses. The existing frontage road traffic signals, operated by the City of Houston, will need to be integrated into the new system. According to the City of Houston, the new signal system will provide integration into TranStar for signal coordination. During a major incident full lane closure, the signal timings are expected to immediately operate as fully actuated until a police officer arrives at the impacted intersection(s) between the incident vicinity exit and entrance ramps to operate the signal(s) as free flow.

In addition, communication between METRO and the ATMS will need to be coordinated in the event of an incident near the HOV lane. For major incidents only, METRO can allow the HOV lane to operate "free" to clear traffic and begin tolling after the incident area. Though several agency systems are currently integrated at TranStar, the coordination and communication between departments should be improved.

2.6.7 Operational Expectations

The operational expectation for the implementation of ATMS can be evaluated using a preliminary queuing evaluation. The expected roadway performance can be impacted by design as well as traffic operations, and can also be measured and quantified in multiple ways. Traffic flow, vehicle speeds, number of lanes, and traffic control devices are a sample of the elements that can impact operations. Traffic queues also influence performance, and can be modeled and analyzed using traffic flow theory in order to predict queuing formation, dissipation, and additional queuing-related characteristics. Congestion and vehicle delays as a result of traffic queues can greatly reduce corridor performance. If a system to reduce traffic queues was established, such as an ATMS, the operations of a corridor could be improved.

Queueing behavior can be modeled using several different theories with varying arrival and departure patterns. Deterministic approach and departure models are the most simplistic, and assume vehicles are uniformly spaced and use equal time intervals. In addition, queueing models for traffic often assume one available departure channel (highway lane) and a first-in, first-out (FIFO) discipline, meaning the first vehicle to arrive is the first vehicle to depart. As a result, the queuing model (assumes deterministic arrivals and departures with one departure channel) is frequently used as an intuitive and graphical way to represent traffic congestion.

Major Traffic Incident Example

To illustrate the benefits of ATMS, a queueing model for a major traffic incident with an all-lane closure was developed to compare the vehicle delays for a non-ATMS corridor and an ATMS corridor. The assumed time of the incident was 9:00 AM, after the morning peak hour, in order to avoid congested and saturated traffic conditions.

Queueing models for incidents take into account the temporary nature of the situation as well as changes to highway capacity over time. As motorists choose other routes and/or departure times due to traveler information, adjustments can be made to the traffic flow and incident queuing models.

The following assumptions in Table 47 were made regarding the characteristics of the example corridor:

Table 47: Major Traffic Incident Example Corridor Characteristics

Characteristic	Value	Units
Total Freeway Capacity (μ)	10,000	vehicles/hour
Number of Lanes	5	lanes
Time for All-Lane Closure	0.5	hours
Number of Lanes Opened after Closure	2	lanes
Partial Capacity (μ_r)	4,000	vehicles/hour
Total Incident Duration	2	hours

The assumptions were based on the approximate existing IH 69 conditions and used to create both plots. However, the non-ATMS and ATMS plots use different constant traffic flows, which are displayed in Table 48.

Table 48: Major Traffic Incident Example Constant Traffic Flows

Corridor System	Characteristic	Value	Units
Non-ATMS	Constant Traffic Flow (λ)	6,000	vehicles/hour
ATMS	Constant Traffic Flow (λ_{ATMS})	4,500	vehicles/hour

The constant traffic flow for the ATMS assumed a decrease of 1,500 vehicles per hour, or 25% of the total non-ATMS constant traffic flow, due to upstream vehicle diversion. The decrease of 25% was based on the approximate weighted average of the diversion percentages. The major traffic incident progression and warning system for the ATMS (using DMS and LCS) should notify and advise approaching vehicles of an all-lane closure ahead, and instruct motorists to exit the freeway and find alternative routes. The all-lane closure ATMS procedure should also inform vehicles immediately upstream of the major incident to create two lanes to exit the freeway. Details for the major traffic incident ATMS progression can be found previously in this section. Consequently, the following assumptions were made regarding the ATMS queuing model:

- Two upstream exit ramps diverting a total of 1,500 vehicles per hour
    - One distant upstream exit ramp diverting 500 vehicles per hour
    - One immediate upstream exit ramp diverting two lanes of vehicles for a total of 1,000 vehicles per hour

Based on the information above, queuing diagrams for a non-ATMS scenario as well as an ATMS scenario were created and are presented below in Figure 20 and Figure 21.

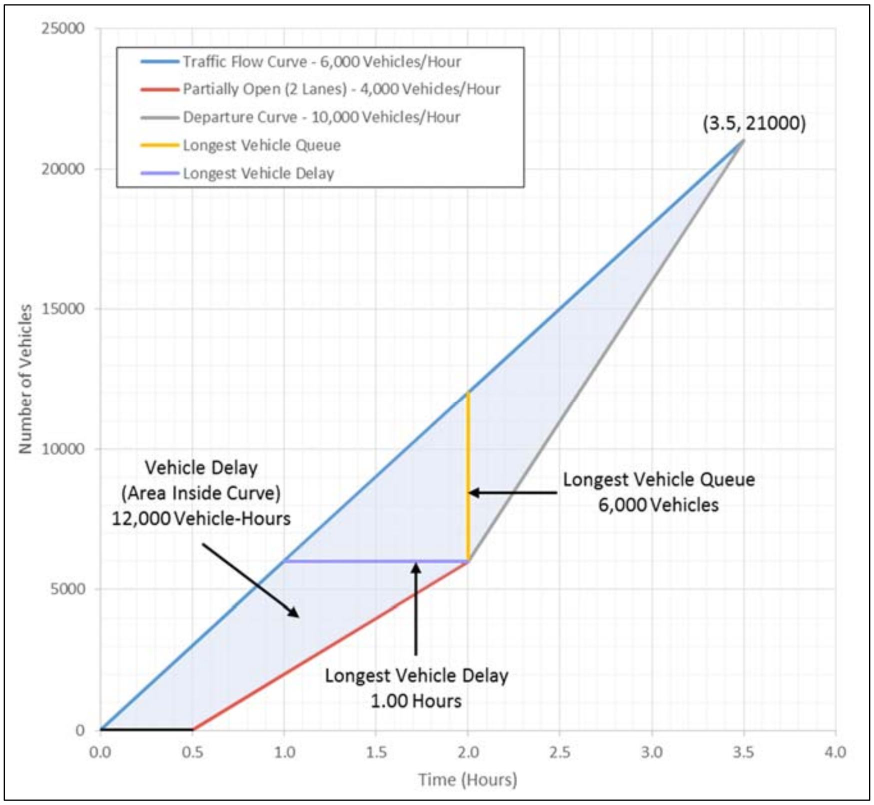


Figure 20. Major Traffic Incident Example Non-ATMS Queuing Diagram

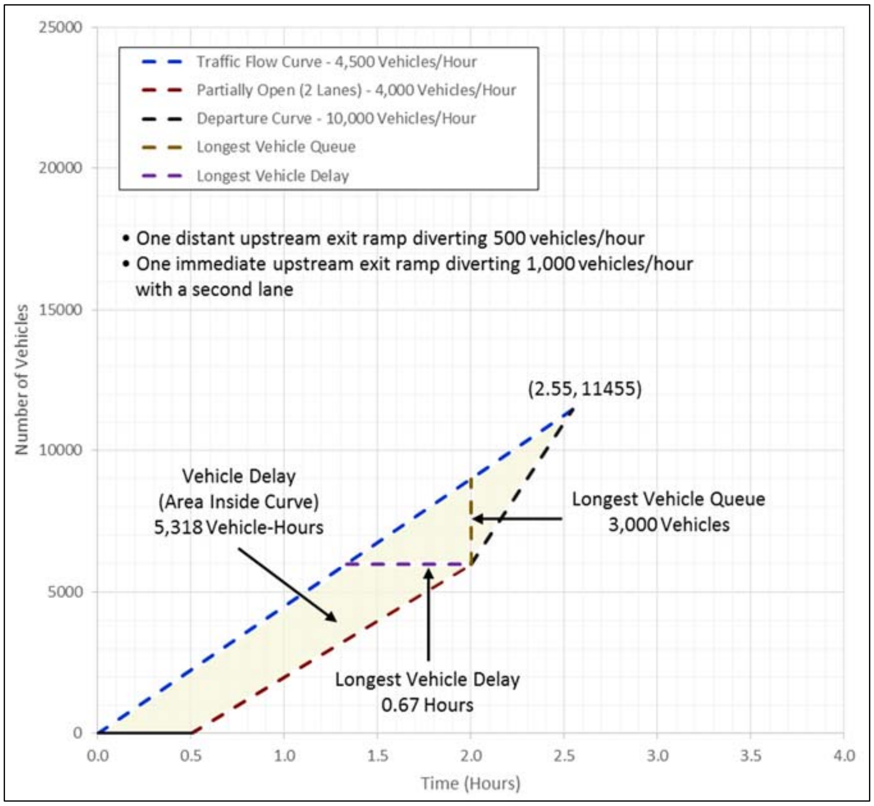


Figure 21. Major Traffic Incident Example ATMS Queuing Diagram

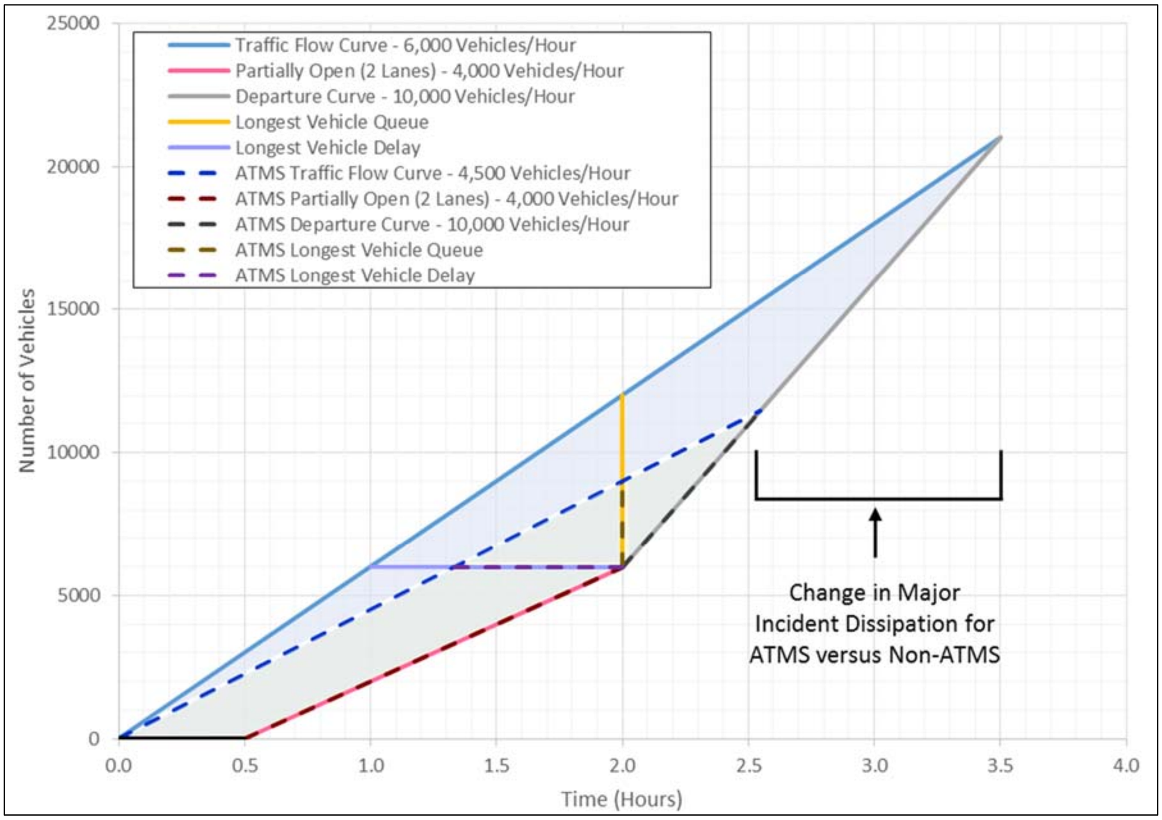


Figure 22. Major Traffic Incident Example Queuing Diagram Comparison

Figure 22 compares the two plots by placing the ATMS diagram on top of the non-ATMS diagram. As can be seen, the time for the all-lane closure is the same (0.5 hours) for both plots as well as the partial capacity slope and duration (4,000 vehicles per hour). The slope for the departure curve (10,000 vehicles per hour) is also the same for both plots, but the length of time to reach free flow conditions (highest point of the quadrilateral shape) is different. Based on the non-ATMS queuing model, it is expected to take approximately 3.50 hours to completely clear congestion as a result of a major incident and resume free flow traffic conditions. Based on the ATMS queueing model, it is expected that the roadway will resume free flow traffic conditions in approximately 2.55 hours as a result of prior notifications. The ATMS is expected to improve the corridor system by achieving free flow conditions approximately one hour quicker than a non-ATMS.

Additional comparisons showing differences in queue lengths and delays for the two diagrams are shown in Table 49.

Table 49. Major Traffic Incident Example Corridor Characteristics Comparison

Characteristic	Non-ATMS Value	ATMS Value	Difference	Units
Total Freeway Capacity (μ)	10,000	10,000	-	vehicles/hour
Number of Lanes	5	5	-	lanes
Time for All-Lane Closure	0.5	0.5	-	hours
Number of Lanes Opened after Closure	2	2	-	lanes
Partial Capacity (μ_r)	4,000	4,000	-	vehicles/hour
Total Incident Duration	2	2	-	hours
Constant Traffic Flow (λ)	6,000	4,500	1,500	vehicles/hour
Dissipation Duration (t)	3.50	2.55	0.95	hours
Departing Vehicles (λt)	21,000	11,455	9,545	vehicles
Maximum Vehicle Queue	6,000	3,000	3,000	vehicles
Maximum Vehicles per Lane Queue (5 Lanes)	1,200	600	600	vehicles/lane
Maximum Queue Length	6.82	3.41	3.41	miles
Vehicle-hour Delay	12,000	5,318	6,682	vehicle-hours
Average Delay Per Vehicle	0.57	0.46	0.11	hours
Longest Vehicle Delay	1.00	0.67	0.33	hours

The total vehicle delay (vehicle-hour delay) is determined by calculating the area inside the curves of the plot. Based on the queuing models, an ATMS corridor would provide an approximate savings in delay of 6,682 vehicle-hours during a major traffic incident with all-lane closure.

Additional queuing models with alternative assumptions regarding exit ramp diversion capacity and incident duration were also analyzed. The following alternatives to the example in Section 2.6.7 assess changes to exit ramp capacity as well as an increase to the duration of an all-lane closure. As can be seen, the altered variables affect the overall dissipation and delay benefits of an ATMS.

Alternative 1: Capacity Reduction on Ramps

For this example, the traffic diversion to the exit ramps was reduced to 250 vehicles per hour compared to 500 vehicles per hour. All other values remained the same. The corridor characteristics and constant traffic flows for Alternative 1 are shown in Table 50 and Table 51.

Table 50. Major Traffic Incident Example Corridor Characteristics (Alternative 1)

Characteristic	Value	Units
Total Freeway Capacity (μ)	10,000	vehicles/hour
Number of Lanes	5	lanes
Time for All-Lane Closure	0.5	hours
Number of Lanes Opened after Closure	2	lanes
Partial Capacity (μ_r)	4,000	vehicles/hour
Total Incident Duration	2	hours

Table 51. Major Traffic Incident Example Constant Traffic Flows (Alternative 1)

Corridor System	Characteristic	Value	Units
Non-ATMS	Constant Traffic Flow (λ)	6,000	vehicles/hour
ATMS	Constant Traffic Flow (λ_{ATMS})	5,250	vehicles/hour

Based on the information above, queuing diagrams for a non-ATMS scenario as well as an ATMS scenario were created and are presented below in Figure 23 and Figure 24**,** with a comparison of the two scenarios in Figure 25.

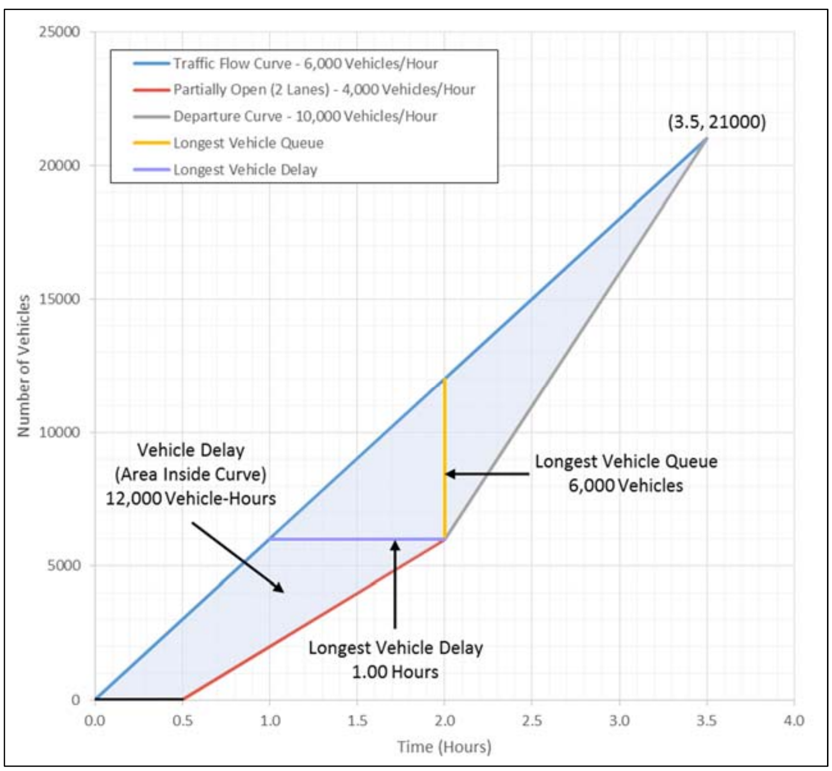


Figure 23. Major Traffic Incident Example Non-ATMS Queuing Diagram (Alternative 1)

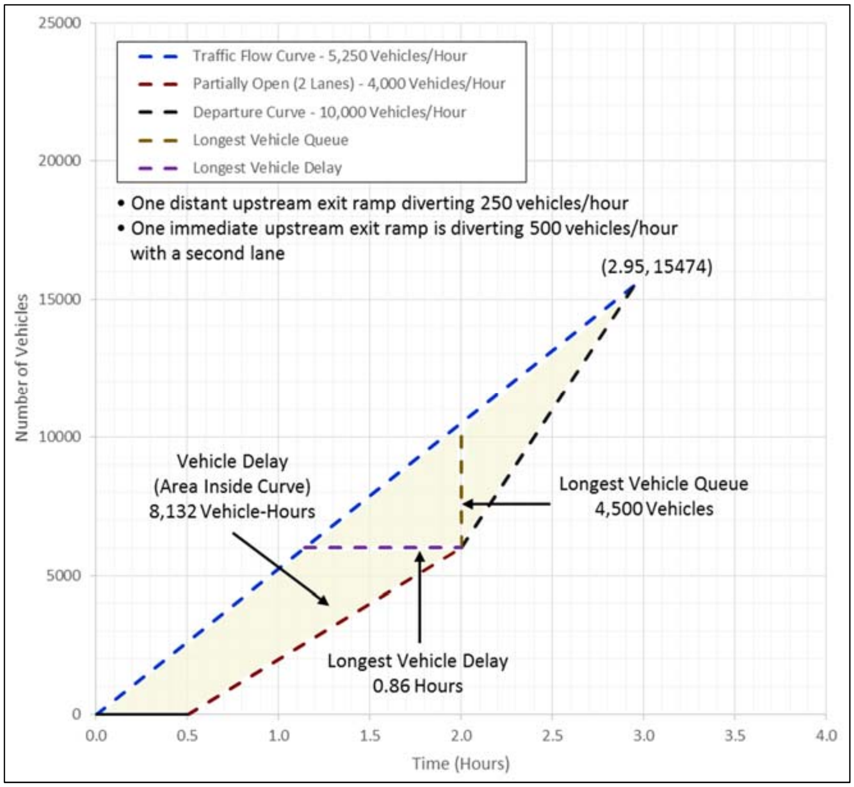


Figure 24. Major Traffic Incident Example ATMS Queuing Diagram (Alternative 1)

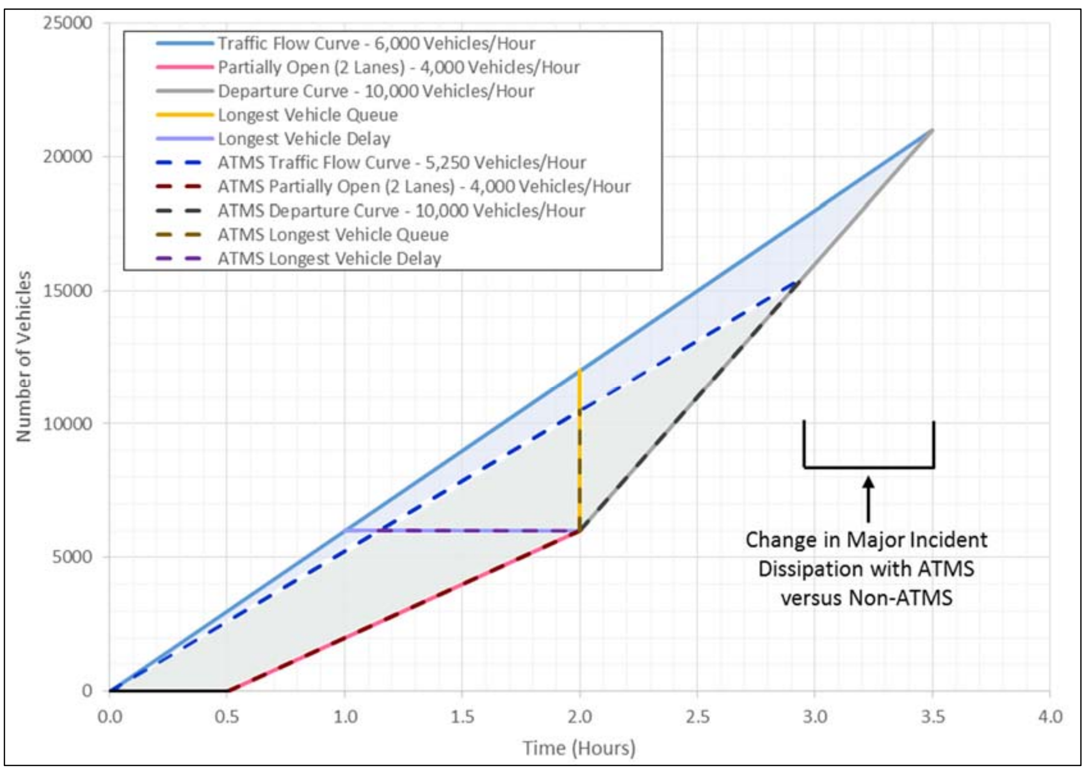


Figure 25. Major Traffic Incident Example Queuing Diagram Comparison (Alternative 1)

Table 52. Major Traffic Incident Example Corridor Comparison (Alternative 1)

Characteristic	Non-ATMS Value	ATMS Value	Difference	Units
Total Freeway Capacity (μ)	10,000	10,000	-	vehicles/hour
Number of Lanes	5	5	-	lanes
Time for All-Lane Closure	0.5	0.5	-	hours
Number of Lanes Opened after Closure	2	2	-	lanes
Partial Capacity (μ_r)	4,000	4,000	-	vehicles/hour
Total Incident Duration	2	2	-	hours
Constant Traffic Flow (λ)	6,000	5,250	750	vehicles/hour
Dissipation Duration (t)	3.50	2.95	0.55	hours
Departing Vehicles (λt)	21,000	15,474	5,526	vehicles
Maximum Vehicle Queue	6,000	4,500	1,500	vehicles
Maximum Vehicles per Lane Queue (5 Lanes)	1,200	900	300	vehicles/lane
Maximum Queue Length	6.82	5.11	1.70	miles
Vehicle-hour Delay	12,000	8,132	3,868	vehicle-hours
Average Delay Per Vehicle	0.57	0.53	0.05	hours
Longest Vehicle Delay	1.00	0.86	0.14	hours

The results, shown in Table 52, indicate that there will still be a time savings benefit as a result of the reduced capacity on the exit ramps, however, the time savings will be approximately a half hour (0.55 hours) versus a savings of nearly an hour (0.95 hours). This reduced capacity (750 vehicles per hour) provides a basis for an incident that occurs with only one exit ramp prior to the incident, which will be the case if an incident occurs when approaching the IH 69 ATMS project corridor. Without a fully operational ATMS traveler information system, it is assumed the number of vehicles that will exit the freeway prior to the major traffic incident will be minimal due to a lack of adequate information and instruction. The reduced exiting vehicle capacity reduces the benefits of an ATMS. Alternatively, if more traffic can be diverted, the benefits will increase.

The queueing models were analyzed using linear relationships, which allows benefits to be computed directly proportionally to the model variables.

Alternative 2: All-Lane Closure for 2 Hour Duration

For this example, the all-lane closure time was increased to 2 hours compared to the 0.5 hours, and the total duration of the major traffic incident was increased to 4 hours compared to the 2 hours. The corridor characteristics and constant traffic flows for Alternative 2 are shown in Table 53 and Table 54.

Table 53. Major Traffic Incident Example Corridor Characteristics (Alternative 2)

Characteristic	Value	Units
Total Freeway Capacity (μ)	10,000	vehicles/hour
Number of Lanes	5	lanes
Time for All-Lane Closure	2	hours
Number of Lanes Opened after Closure	2	lanes
Partial Capacity (μ_r)	4,000	vehicles/hour
Total Incident Duration	4	hours

Table 54. Major Traffic Incident Example Constant Traffic Flows (Alternative 2)

Corridor System	Characteristic	Value	Units
Non-ATMS	Constant Traffic Flow (λ)	6,000	vehicles/hour
ATMS	Constant Traffic Flow (λ_{ATMS})	4,500	vehicles/hour

Based on the information above, queuing diagrams for a non-ATMS scenario as well as an ATMS scenario were created and are presented below in Figure 26 and Figure 27**,** with a comparison of the two scenarios in Figure 28.

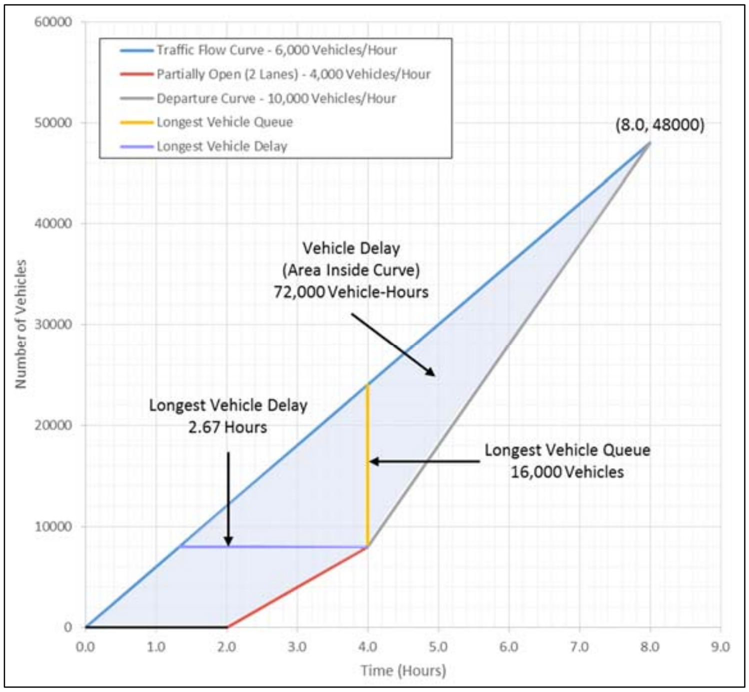


Figure 26. Major Traffic Incident Example Non-ATMS Queuing Diagram (Alternative 2)

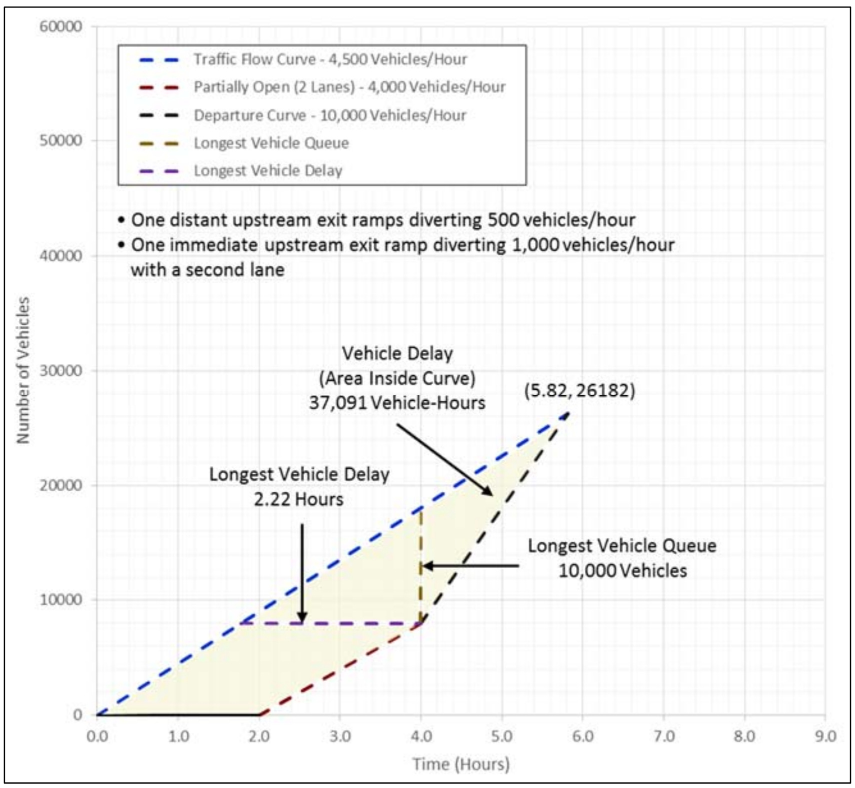


Figure 27. Major Traffic Incident Example ATMS Queuing Diagram (Alternative 2)

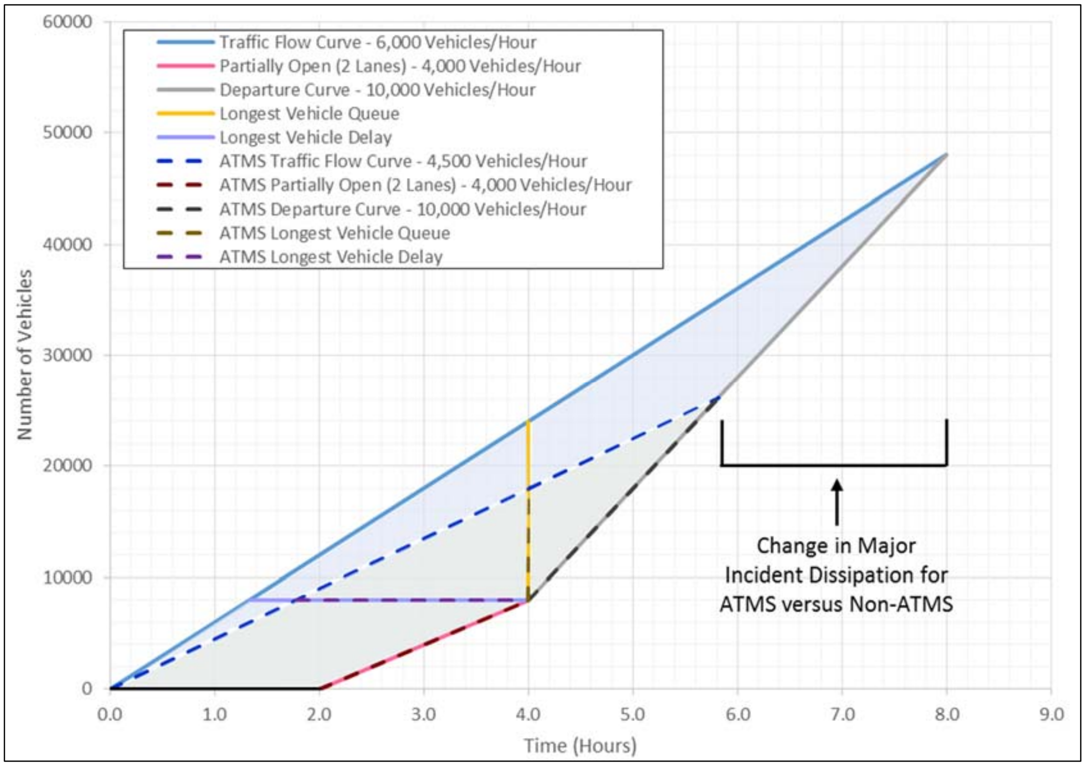


Figure 28. Major Traffic Incident Example Queuing Diagram Comparison (Alternative 2)

Table 55. Major Traffic Incident Example Corridor Comparison (Alternative 2)

Characteristic	Non-ATMS Value	ATMS Value	Difference	Units
Total Freeway Capacity (μ)	10,000	10,000	-	vehicles/hour
Number of Lanes	5	5	-	lanes
Time for All-Lane Closure	2	2	-	hours
Number of Lanes Opened after Closure	2	2	-	lanes
Partial Capacity (μ_r)	4,000	4,000	-	vehicles/hour
Total Incident Duration	4	4	-	hours
Constant Traffic Flow (λ)	6,000	4,500	1,500	vehicles/hour
Dissipation Duration (t)	8.00	5.82	2.18	hours
Departing Vehicles (λt)	48,000	26,182	21,818	vehicles
Maximum Vehicle Queue	16,000	10,000	6,000	vehicles
Maximum Vehicles per Lane Queue (5 Lanes)	3,200	2,000	1,200	vehicles/lane
Maximum Queue Length	18.18	11.36	6.82	miles
Vehicle-hour Delay	72,000	37,091	34,909	vehicle-hours
Average Delay Per Vehicle	1.50	1.42	0.08	hours
Longest Vehicle Delay	2.67	2.22	0.44	hours

The results, shown in Table 55, indicate that the major incident all-lane closure duration increased from 0.5 hours to 2 hours. The ATMS dissipation benefit was approximately an hour. With a longer closure, the ATMS dissipation benefit is over two hours of time savings. According to the queue model results, the longer the incident, the more benefits can be seen with an ATMS. The increase in benefits is based on the queue model's calculations, where delay is proportional to the closure-time variables.

VISSIM Queuing Modeling

With the understanding of the theoretical queuing model analysis, a calibrated VISSIM queuing model simulation was also completed to analytically and visually understand how the proposed system would operate.

The VISSIM queuing model simulation analyzed an area near IH 610 on the inbound mainlanes between Hillcroft and Chimney Rock immediately following the AM peak period. This was identified as a critical area that experiences several weaving maneuvers and a large number of incidents. The model analyzed a no build, two-lane closure, three-lane, and all-lane closure scenarios. The intention of the model was to provide a visual for stakeholders to understand how the system would work along the corridor. The results from the modeling are outlined in **Appendix O**.

Section 2.7 Summary of Impacts

The summary of impacts purpose is to inform affected organizations of the proposed changes and prepare them as they transition to the new system. The addition of an ATMS will impact existing operations, maintenance, support, and training of personnel. The IH 69 ATMS will offer TxDOT and other stakeholder agencies the opportunity to implement various strategies to reduce congestion, identify incidents, manage incident progression, and provide enhanced real-time traveler information. These strategies will require additional and dedicated monitoring and support from staff and agencies. The ATMS will require dedicated staffing for the IH 69 corridor, and will also require existing personnel to adapt to the proposed system and change existing traffic monitoring practices. In addition, developmental impacts will include design, implementation, and inclusion to the existing system (hardware and software).

2.7.1 Operational Impacts

Interfaces and Changes in Procedure

The ATMS will upgrade the existing ITS infrastructure and require a more active role from participating agencies. The system should be actively monitored to identify congestion or incidents and provide the appropriate response. The proposed devices will be installed by TxDOT and will require ongoing coordination and operation to achieve ATMS benefits. TranStar should complete the following to aid in operating the IH 69 ATMS corridor in the most effective manner:

- Obtain a remote connection to the City of Houston signal software system, for use when permitted during major incidents and/or special events. Coordination with the City of Houston will be needed to ensure timings are adjusted according to the traffic flow demand as impacted by incidents. Software integration and compatibility is essential in achieving optimal benefits from the ATMS software. The ATMS IT Specialists, mentioned in Section 2.6, will need to meet with City of Houston early in the design and implementation process to identify necessary software upgrades and system requirements. ITS components at various locations on City of Houston arterials are being upgraded through a TIGER Grant funded project and expected to be completed in FY 2019. Ideally, the data from the ITS system will feed into the City software and TranStar. The proposed ITS system will introduce Bluetooth travel time, a new Traffic Management System (TMS), and wireless communication. The IT specialists should coordinate with the City to seamlessly integrate the software for efficient use of the proposed devices and system.

- Expand communication and software integration with Houston METRO. This will allow the IH 69 ATMS corridor team to effectively monitor and operate traffic in an event that occurs on or adjacent to the HOV/HOT lane. This will also allow users to use the HOV/HOT lane during an all-lane incident, where feasible as agreed upon by METRO.

- Expand communication and software integration with HCTRA. In the event of an all-lane closure, the IH 69 ATMS corridor team will monitor traffic and coordinate with HCTRA to remove the tolls on Westpark Tollway, where feasible as agreed upon by HCTRA and granted through Commissioners Court action, to provide an alternative route for motorists. The DMS along HCTRA facility can be used as needed.

- Provide a sector of the TranStar operation management center for the IH 69 ATMS corridor team. This will be the base of operations and require space to accommodate the additional staff. The majority of the proposed ATMS devices will be supported by existing Lonestar software. However, LCS is a new device that will require appropriate Lonestar protocols to employ. In addition, it is expected that the upgraded corridor-adaptive and system-integrated ramp meters will continue to run through SunGuide software, which is integrated into the Lonstar system through firmware.

Additional software needs regarding ATMS should be integrated into Lonestar as required.

An ATMS IH 69 corridor team will be developed to operate the new system. This team will have points of contact for immediate response with the other agencies to operate the system effectively. The ATMS manager at TranStar will need to take an active role in approving messages for DMS display and to inform staff of the correct procedures during incidents, congestion, or special events. As on-scene events progress, the TranStar ATMS manager will adjust signage based on first responder evaluations. The TranStar ATMS manager will be the principal coordinator to ensure that all information is being disseminated accurately and timely by ATMS operators and that each respective agency is properly informed. Maintenance personnel will need to perform frequently scheduled preventative maintenance on the system to ensure proper ATMS operations and improve equipment life. For much of the equipment currently in place, responsive maintenance and minimal preventative maintenance occurs, which will not insure the operation of the system.

The proposed ATMS detour plan for a major all-lane closure incident is presented in Figure 29. The plan will require extensive communication and coordination between the TxDOT ATMS IH 69 corridor team, the City of Houston, as well as other agencies to determine appropriate operations, procedures, and possible alternative route options.

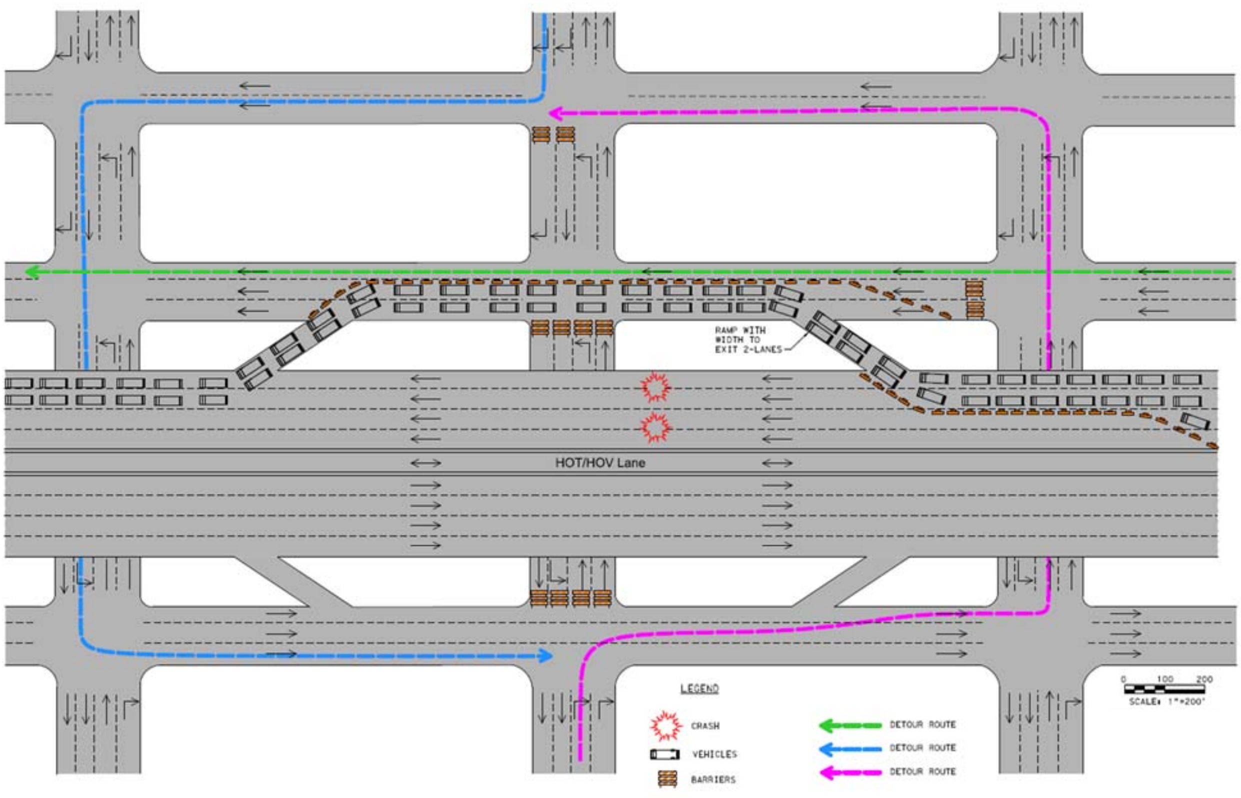


Figure 29. IH 69 Proposed ATMS Detour Plan

Data Sources

With the addition of the proposed ATMS, TranStar will receive additional data along the IH 69 corridor. TranStar will need to expand storage and processing capacity to handle the increased data flow. The data received will be in several different formats due to the variety of proposed ITS components. The majority of the proposed ITS devices will have similar data outputs compared to the existing system components, but the proposed quantities of data will increase greatly. The fixed CCTV locations and incident analytics software data will be new to TranStar, which will require additional training with the product manufacturer.

There will be three stages of data collection and storage that will require different levels of data retention.

- Before Implementation – During this stage, TranStar will collect data relative to the IH 69 corridor prior to IH 69 ATMS implementation. This will aid in performing a before and after analysis. It will also help identify IH 69 corridor patterns to aid in system testing. Recurring congestion areas can be identified during this stage.

- System Testing (During Implementation) – The application of ATMS devices along the corridor will require system testing. Devices should be tested prior to field construction and then undergo a period of testing post-construction. System testing should be conducted during off-peak/low-volume hours to ensure that the devices are operating at full capacity. Next, the system testing will involve applying the operational scenarios in select situations to identify optimal techniques for standard procedure.

- After Implementation – Data from devices should be collected and stored after implementation to aid in system validation. TranStar data consistent with what was collected before implementation should be collected to provide a direct comparison in system validation use. The post-implementation data collection and storage should allow adequate time for system testing to ensure that optimal standards are being applied prior, during, and after system validation.

Post-processing procedures will need to be put in place to determine how to process the data and add the data to the system in a timely manner. The proposed devices will allow a large amount of data to be captured, however, much of the data can likely be filtered and removed either immediately or after a designated period of time. Improvements to policies for data retention will need to be developed to assist in providing real-time travel time information to motorists.

Modes of Operation

The development of an IH 69 ATMS corridor team will change the existing mode of operation for the system. Under existing conditions, DMS messages provide limited information to motorists. The ATMS personnel will need to constantly monitor the system and be prepared to enact procedures for resolving congestion, incident, and/or special event occurrences. The ATMS personnel are expected to be highly skilled in order to make quick traffic management decisions. The implemented traffic management actions will be determined and/or approved by the TranStar ATMS manager. As the system is implemented and the incident analytics software is validated, the system may begin to develop semi-automation features. Operational characteristics are discussed in Sections 2.4 and 2.6.

An IH 69 ATMS operational manual should be created during the system testing stage of implementation. The manual will outline optimal strategies identified through research and applied to the IH 69 corridor. The manual will include standard operation procedures during congestion, incidents, and events. The manual should also discuss the specific devices installed in the field, their respective manufacturer, and any nuances in their data, maintenance, and/or operation. All staff are expected to be trained on using this manual and applying the concepts to the IH 69 ATMS corridor operation.

Operational Budget

The operations and maintenance budget for the IH 69 ATMS will need to be increased to properly operate and maintain the system. As mentioned in Section 2.5, the operations and maintenance of the IH 69 ATMS corridor is expected to require approximately $2.6 million annually in funding.

Maintenance will require a more proactive role and regularly scheduled preventative maintenance visits in order to lengthen device lifespans and reduce faulty equipment to ensure the system operates effectively. Two specially trained full-time employees are expected to maintain the ATMS and be continually performing device checks for preventative maintenance and routine repair. Additional operational staff will be part of a dedicated, 24-hour a day, IH 69 ATMS corridor team. The proposed twelve full-time highly skilled employees are expected to cover all hours and effectively serve the length of the corridor. With the addition of the numerous proposed ITS devices, there will be an increase in operational costs for the devices themselves as well as upgrades to TranStar to handle the additional information.

Table 56 compares the existing corridor ITS devices to the proposed system components.

Table 56. Existing and Proposed ITS Infrastructure and Components

ITS Infrastructure/ Component	Existing System	Proposed System
Fiber	Strand Size Varies	144 Strand Single Mode Fiber
		12 Single Mode Fiber (New Device Locations)
Overhead Sign Bridge	16 Structures with Guide Signs	15 Structures to be Replaced for Guide Signs
	No ITS Structures	28 New Dedicated ITS Structures
Bluetooth Device	8 Devices	10 Additional Devices
Closed Circuit Television (CCTV) Pan-Tilt-Zoom (PTZ) Camera	26 Cameras	71 Additional Cameras
CCTV Fixed Camera	None	20 New Cameras for High Accident Locations
Advanced Detection	Limited	14 New Detectors at Ramp Meter Locations
		Additional Detectors on Frontage Roads and at Exit Ramps near Signalized Intersections
Radar Vehicle Sensing Device (RVSD)	13 Devices	62 Additional Devices
Lane Control Sign (LCS)	None	202 New Devices
Dynamic Message Sign (DMS)	8 Signs	28 Additional Signs
Graphical Route Information Panel (GRIP)	None	6 New Signs
Ramp Meters and Wrong-Way Detection	12 Meters	12 Upgraded Corridor-adaptive and System-integrated Meters
		2 New Installations
Road Weather Information System (RWIS)	2 Devices	Depressed Area of IH 610 Interchange (Pending Roadway Improvements)
Queue Warning System	3 Signs	Replaced by LCS System
HUB	16 Locations	Tie into Existing HUB System - Additional Locations as Needed

2.7.2 Organizational Impacts

Roles and Responsibilities

As discussed in the operational impacts and throughout the scenarios in Section 2.6, the roles and responsibilities for each organization should be adjusted to provide an IH 69 ATMS. The goal is to provide quick, precise, and concise information between organizations. To provide an efficient and effective ATMS, data received should be processed quickly and provided to the proper entities as well as the driving public in a timely manner. An ATMS team is expected to be developed to operate the system within TranStar. The ATMS team may be comprised of the following staffing:

- IH 69 ATMS Manager Traffic Operations (1) – Experienced traffic engineer that makes final decisions on DMS displays, LCS progressions, incident duration estimates, alternative routes, and operations to aid emergency vehicles. They will be responsible for managing the ATMS subgroup personnel.

- IH 69 ATMS Engineer (2) – Two ATMS engineers will be required to implement, deploy, and evaluate the ATMS. The engineers will be crucial in determining the initial incident duration estimates, defining alternative routes, and aiding emergency response.

- IH 69 ATMS Operator (3) – Three ATMS operators will be responsible for monitoring and operating all ATMS devices 24-hours a day, 7 days a week. The operators should be trained with the IH 69 operation manual and be active in providing input and updates to the standard procedure. Operators will also be responsible for agency coordination and aiding emergency dispatch and routing. The ATMS operators will be responsible for coordinating with first responders to understand the status on-scene and update the LCS and the DMS accordingly.

- IH 69 ATMS Maintenance Technician (2) – Up to two ATMS maintenance technicians should be on hand to maintain and repair the proposed infrastructure. The devices will require constant preventive maintenance to extend the service life and prolong system replacement. Major maintenance projects will be coordinated with and completed by the contracted technicians.

- IH 69 ATMS IT Specialist (2) – Two ATMS IT specialists will be responsible for software coding and ensuring that the system is operating at full capacity. The IT specialists will outline the system needs for optimal agency software compatibility and network capacity.

Points of contact will be identified for each agency, including City of Houston, Houston METRO, TxDOT, Harris County, HPD, HFD, and HCSO. Backup points of contact will also be identified to provide redundancy and ensure efficient agency coordination. A list of contacts will be actively updated and maintained to guarantee a direct line of communication between the IH 69 ATMS team and each respective agency.

If an incident or event requires the use of alternative routes, the controlling agency will be contacted immediately to allow adaptive traffic control and disseminate traveler information. For example, a major northbound incident occurs near IH 610. Emergency operators are contacted immediately and referred to a designated optimal route to gain access to the affected area. HPD, HFD, and HCSO are contacted to make certain that the responsible party is aware of the incident and can access the incident by the most efficient route. Harris County is contacted to consider removing the toll along Westpark Tollway from IH 69 to Post Oak Boulevard. City of Houston is contacted to allow TranStar to extend the green time at frontage road intersections. Houston METRO is contacted to consider removing the toll along the HOV/HOT lane, since the incident does not affect HOV/HOT operations. TxDOT is contacted to provide the necessary traffic control devices at the scene of the incident. Overall, effective and prompt communication and coordination between the multiple agencies will ensure efficient ATMS procedures and operations.

Job Positions and Training Personnel

With the addition of an ATMS team to monitor the IH 69 corridor, multiple full-time positions will be added and will require dedicated annual funds. An IH 69 ATMS manager should be hired to effectively manage the ATMS and proceed in hiring preferred subgroup personnel. Since ATMS is a constantly evolving and developing concept, personnel should receive annual training, with additional training sessions as needed, for operating an ATMS. The IH 69 ATMS corridor engineers and operators should be well-versed in standard operating procedure and actively update and maintain a standard operation manual.

The operating staff should be well trained on the devices they operate so they know the constraints and can better identify maintenance issues before sending maintenance personnel on-site. Staff should be trained to know the operations of the system and know who needs to be contacted for each scenario. Efficiency in staff and communications will aid in operating an effective ATMS. It is anticipated that changes to agency ATMS personnel are immediately updated at TranStar to ensure the points of contact are accurate.

As a supplement to training, a “User Manual” should be developed to provide a framework for understanding the system. The manual should be reviewed periodically by the staff to ensure that the most up-to-date procedures are being used. A separate maintenance manual should be developed for the IT personnel.

2.7.3 Developmental Impacts

Design and Implementation Involvement

Agencies housed at TranStar as well as other participating agencies should be involved in the development process of the ATMS and should offer feedback regarding current traffic patterns, issues, and needs. Existing high incident areas, congestion areas, and areas lacking coverage in the CCTV system were identified and detailed in Section 2.3. TranStar keeps and should continue to keep detailed records of incidents and congested areas, which will be utilized by ATMS operators and engineering staff. The ATMS should be designed to address these areas and provide TranStar the ability to mitigate problems as best as possible. The system testing stage will offer an opportunity to bring the IH 69 ATMS corridor team into the TranStar sector to identify and evaluate adjustments that must be made before full system implementation. The length of system testing will be specified based on TranStar preference and allow gradual implementation.

The existing high incident locations along the IH 69 corridor are presented in Figure 30.

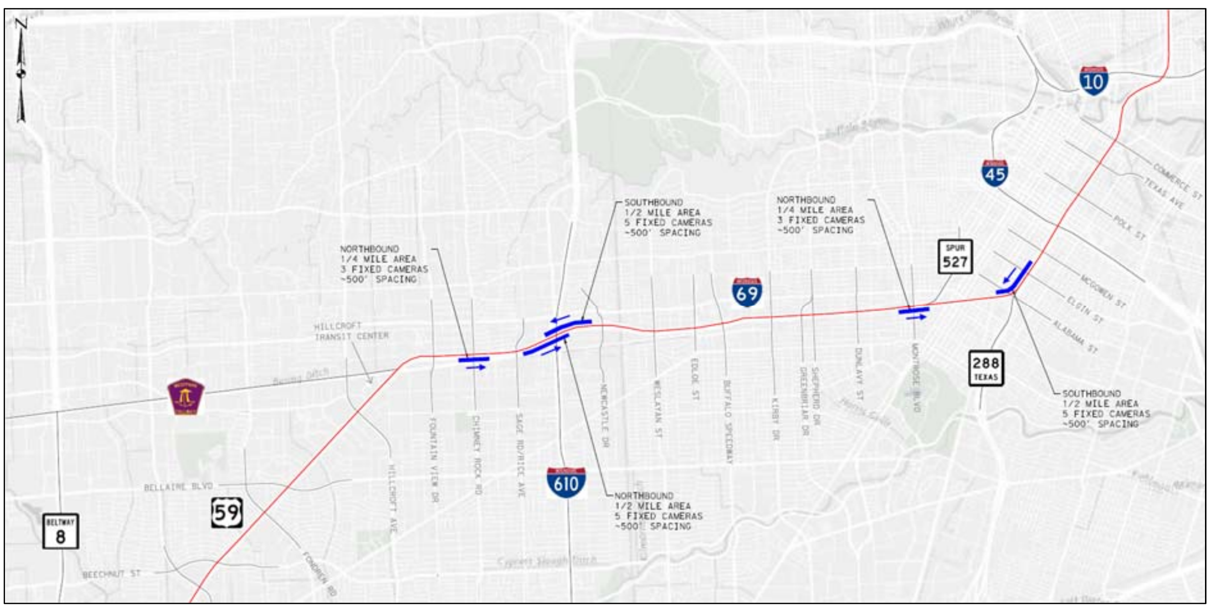


Figure 30. IH 69 High Incident Locations

Public Support Involvement

TranStar and all affected stakeholders that utilize the corridor should make every effort to inform and educate the public of how the new ATMS operates. One approach to informing the public about ATMS is through public service announcements (PSAs). PSAs will need to be developed and distributed prior to system testing. The benefits of this system should also be thoroughly expressed to help the public understand and support the ATMS. Information can be provided through the TranStar website and the Public Involvement Office can communicate with drivers to let them know how the system will be benefit them. The ATMS will require unconventional procedures and additional traveler information compared to existing conditions, including:

- Two-lane exit ramp during a major incident
- Altered frontage road signal timings during all-lane closures
- HOV/HOT lane alternative during a major incident
- Advisory speeds
- Open and closed shoulder lane
- LCS displays
    - Open lane
    - Merge
    - Closed lane
    - Emergency vehicle use only
- Special event directions and information
- GRIPs

The proposed GRIP for the IH 69 corridor is shown in Figure 31.

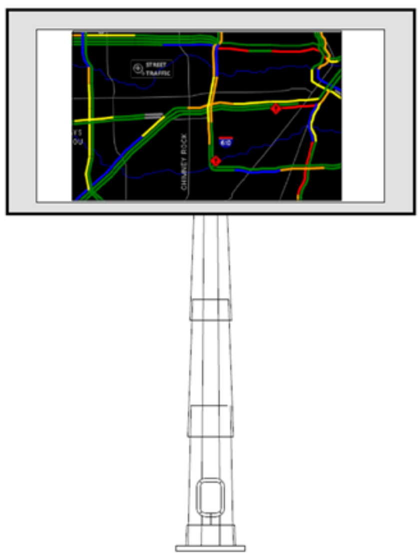


Figure 31. Proposed GRIP

Information regarding advisory speeds should be fully explained to the public in order for drivers to comprehend how and why traveling at slower speeds during recurring congestion can result in reduced travel times. Overall, the ATMS will alter the way motorists move and make decisions along the project corridor. For the ATMS to function and resolve conflicts properly, drivers must be able to identify and understand how the individual components of the system work as well as how the complete system operates.

The design and operations of the system will need to be done effectively as to not build public mistrust. The implementation should involve device testing, field installation, and system testing to allow gradual application. This will aid in educating the users of how to operate the system with the additional traveler information dissemination. The system will be designed to ease congestion and improve travel along the corridor, which can be illustrated to the public through before and after system validation statistics, public training videos, social media campaigns, and fact sheets that compare the relatively low-cost of ATMS versus reconstruction.

Inclusion of ATMS to Existing System

The inclusion of the IH 69 ATMS into the existing system will require TranStar to include capacity and compatibility for the new system devices. This may be accomplished through the addition of an ATMS team, additional storage capacity for new and updated device data, upgrades to fiber optic network connections, and budget increases for maintenance. The devices, with the exception of the LCS, may be brought online once installed. The LCS system should be brought online once the entire LCS network is complete to effectively apply ATMS principle strategies. Each LCS and sign bridge location is intended to work in conjunction with upstream and downstream locations. An example of a proposed sign bridge with DMS and LCS for the corridor is shown in Figure 32. Without the full LCS system in place, the system will provide little benefit and give a false sense of application to users. Operating the system without full functionality can also result in driver mistrust. Current maintenance staff should be trained and prepared for the inclusion of new devices to the existing system. The current TranStar agencies should also be trained and prepared for system implementation.

Figure 32. IH 69 Proposed Sign Bridge

The system testing implementation stage of the IH 69 corridor is expected to have little impact on the corridor operations, but will serve an integral function in making sure the devices work in conjunction with one another. It will also provide the IH 69 ATMS corridor team select situations to test the system. The system testing can occur during low volume hours, or during specific incident/event scenarios that provide an opportune time to apply ATMS strategies.

After the system validation stage, parallel operations can be considered. This will be dependent on before and after results and adequate implementation of the IH 69 ATMS. Based on the effectiveness of the ATMS equipment and expected benefits, devices will be deployed within the existing system in stages based on ease of implementation. The proposed ITS devices are intended to improve and enhance existing corridor systems, which are currently limited in detection and operational capabilities. It is expected that parallel facility

ATMS operations would considerably improve the overall network and the IH 69 corridor by offering well-managed alternative routes.

The ideal timeline for the construction and implementation of the proposed system is approximately 4 years. This timeline includes the design, construction, system testing, and complete implementation of the ATMS. The timeline will be extended based on additional right-of-way requirements, additional pavement needed, and/or funding for the project. The funding and the progression of the project will need to be discussed with TxDOT's Project Programming Office to evaluate when funds will be available for the IH 69 project corridor. It is the responsibility of the TxDOT PM for IH 69 ATMS to follow up with the Project Programming Office regarding future project deployment and implementation.

Automated Enforcement System

An automated enforcement system (AES), as an addition to traditional enforcement operations, has the potential to augment speed and traffic management practices as well as increase safety. For automated speed enforcement, AESs use speed cameras or photo radar devices to record vehicle speeds and take photos of vehicles exceeding a threshold limit. For lane closure enforcement, the cameras can be used to detect and record vehicles using a designated closed lane within a corridor. AES penalties are typically sent to and are the responsibility of the vehicle owner.

Automated speed enforcement can also be used to enforce regulatory variable speed limits. Regulatory variable speed limits are used to slowdown traffic due to congestion and/or queuing upstream. The purpose of variable speeds is to harmonize traffic flow and reduce incidents. However, studies suggest public compliance is minimal if the variable speeds are unenforceable. Regulatory variable speed limits are currently prohibited in Texas. However, TxDOT is currently overseeing a pilot project to study the effects of variable speed limits in regards to congestion, road construction, and inclement weather.

The effectiveness of an AES is determined through reductions in vehicular speeds, incidents, and unlawful activity. Research has found the average speed and speed variance near enforced sites decreases after an AES is installed. Studies also suggest speed cameras can greatly reduce speed related crashes and have a positive economic impact due to a decrease in incident related costs. Less impact from traditional ticketing processes can improve traffic flow and congestion. The presence of law enforcement officers can contribute to additional delay due to distracted motorists and parked vehicles along freeway shoulders.

Equipment for an AES is typically installed and maintained by private contractors for a set expense. Equipment can also be purchased or leased by a municipality. The initial purchase price for AES equipment is approximately $55,000 per camera location. The annual operation and maintenance costs for the systems, which can be in excess of $100,000 per camera, often take into consideration the required costs for management personnel, agency staff, vendor costs, and additional system equipment. For a typical proposed four lane sign bridge, the estimated annual cost for an AES is approximately $500,000. The revenue from fines is typically greater than the expenses of the system, however, this cannot always be expected. To improve public acceptance, revenue from the systems should be used to fund highway safety functions as well as maintain and update AES equipment.

Public acceptance of AESs is difficult to obtain and sustain. Opposition usually includes concerns regarding privacy and improper extensions of law enforcement, conflicts of interest, and/or the belief automated enforcement systems are primarily a method for revenue generation rather than safety.

Currently in Texas, automated enforcement systems cannot be used to enforce speed and speed cameras are prohibited. For AESs to be implemented, State laws and local ordinances must support and allow AES programs to exist, and constituents must be informed and understand the system rules and regulations as well as the system benefits. To gain public support, the program should emphasize traffic safety and transparency regarding program contracts, costs, and revenue. An example of the requirements and steps involved to enact legislative action for an automated enforcement program include the following:

- Define the problem and consider relevant information and data sources to be shared
- Get organized and identify specific venues to be used for campaign
- Develop a public information and education program and determine objectives
- Agree on supporting activities and develop an implementation plan
- Plan committee meetings and information packages
- Begin committee work and develop the campaign
- Deliver the campaign, evaluate the impacts, and provide feedback

Strong support from State and local policy makers will be essential for modifications to existing laws and ordinances. In addition, the roles and responsibilities of lawmakers, law enforcement agencies, and courts will need to be specifically communicated in order to identify the jurisdictions and agencies responsible for speed enforcement and to determine legal authority. Existing laws in Texas will require repeal in order to establish an AES and updates to the Texas Transportation Code will also be necessary.

Just as with any ATMS or ITS, AES should be thoroughly tested and analyzed to ensure proper operation. Public acceptance, confidence, and adherence largely depends on the consistency and reliability of an automated system.

2.7.4 Overall Project Implementation Impacts

Benefit-Cost Evaluation

As discussed in Section 2.5, Identification and Justification for Change, the expected benefit/cost ratio will be between 5.2 and 7.3. The benefit/cost ratio will be lower if the ATMS devices do not induce rerouting during recurring congestion. A higher benefit/cost ratio is expected if the devices lead to rerouting. Benefits of the proposed system include time and fuel savings, as well as improved safety. Associated costs include design, construction, mobilization, software, operations, maintenance, contingencies, and employee salaries. The estimated capital cost for the ATMS is approximately $23 million. Operations and maintenance (O&M) costs for the system are expected to be approximately $2.6 million, which includes a rigorous preventative maintenance schedule to ensure the ATMS is fully functional.

Next Steps

ATMS will provide an invaluable benefit to the corridor. While the proposed overall system does not create added physical capacity, it provides a structured system using the advancement of technology to better manage the current capacity on the roadway. This system is a non-traditional approach for addressing congestion and would be the first of its kind in Texas. For areas in Houston, such as our project limits along IH 69, construction of additional lanes is not a practical solution due to limited right-of-way and high property costs, although improvements are necessary. The proactive nature of ATMS, using technology, will change the way traffic is evaluated and managed. As a result, legislature will be needed to implement new technology, such as variable speed limits.

In comparison to the cost of adding physical capacity as shown in Table 57, ATMS is a viable financial alternative. While the proposed system provides a lower cost than physical improvements such as freeway widening, there is still a cost to implement and maintain. Funding for the program needs to be secured with help from H-GAC, TxDOT, and other potential funding sources.

Table 57. ATMS vs. Conventional Improvements

Costs	ATMS	Conventional Improvements
Capital Investment	$22,620,000	$340,000,000
O&M (per year)	$2,581,250	$150,000
30-year- 2016 Total Present Value	$107,415,000	$344,940,000

To achieve the highest benefit from the system, the implementation along the project corridor needs to occur quickly due to the ever-evolving nature of ITS. Since this is a technology-based system, new technology should be identified, studied, and tested to maintain the highest benefit from the corridor, as it becomes available.