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16. Abstract Maintaining, preserving, and enhancing the functionality of state and local roadways of our transportation system is important because it maintains capacity and efficiency, reduces potential for congestion, maintains safety, reduces the need for further (or unplanned) improvements, and protects the value of our investments in both transportation infrastructure and adjacent land development. It is important that functionality be considered and in all stages of a highway's lifecycle. This report provides guidance on how to protect, preserve, and enhance highway functionality within the areas of planning and land development, operations and capacity, right of way, infrastructure and maintenance, and safety. Each of the five areas plays a part in establishing how well or poorly a highway may function and in meeting or preserving its intended function. The project includes case studies of the IH 10 Katy Freeway in Houston, SH 289 in Frisco and Plano, and SH 105 between the cities of Conroe and Montgomery, Texas. These case studies show how functionality changes over time and identifies opportunities to preserve or restore functionality.  The report provides recommendations for how TxDOT, MPOs, local jurisdictions, and other transportation stakeholders and agencies can protect, preserve, and enhance the functionality of the state highway system in Texas. It represents report R1 of TxDOT research project 0-6208, Preserving Functionality/Asset Value of the State Highway System.					
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# **PRESERVING THE FUNCTIONALITY/ASSET VALUE OF THE STATE HIGHWAY SYSTEM: TECHNICAL REPORT**

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## **DISCLAIMER**

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The research supervisor in charge of this project was Edwin N. Hard.

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## EXECUTIVE SUMMARY

Mobility, accessibility, operational characteristics, right of way, safety, and roadway conditions define the functionality of highways. Maintaining, preserving, and enhancing the functionality of state and local roadways of our transportation system is important because it:

- maintains capacity and efficiency;
- reduces potential for congestion;
- maintains safety;
- reduces the need for further (or unplanned) improvements; and
- protects the value of investments in both transportation infrastructure and adjacent land development.

Functionality should be considered in all stages of a highway's lifecycle. Ideally, a highway should remain functional through its intended service life. However, to maintain a high level of functionality, factors that cause deterioration (e.g., increased access, more high volume at-grade intersections, land development) need to be minimized, managed, or accommodated with incremental improvements. Unless there is an active process of monitoring functionality followed by actions to restore or enhance deteriorating components, operational functionality can deteriorate to the point where a parallel or replacement facility (or reconstruction) will be needed much earlier than would otherwise be the case. That outcome can be wasteful and unnecessarily costly.

### Scope of Research

Researchers examined what losses to state highway functionality occur over time and what actions can be taken to preserve, recover, and enhance functionality over time. They reviewed practices and policies in five areas that play a part in establishing how well or poorly a highway serves its intended function. The areas included:

- planning and land development;
- traffic operations and capacity;
- right of way and utilities;
- safety; and
- infrastructure.

Within these areas, the research examined sources or causes of functional deterioration, counter-measures to address them, and how the practices, policies, or programs of TxDOT, MPOs, and local jurisdictions have or have not served to preserve, restore, or enhance highway functionality.

The study emphasized practices and policies in the areas planning and traffic operations. It reviewed where functionality is or could be addressed in statewide planning, MPO and regional planning and work programs, and local comprehensive and transportation planning efforts. Planning practices such as local street layout/connectivity, subdivision and development review, corridor/access management, and agency coordination were included in this review.

The study also assessed highway functionality in the groupings of traffic control and management, signalization coordination and optimization, and facility design and enhancements. Here, many policies and practices being used to reduce congestion, improve capacity, and reduce travel time and delays were reviewed relative to how they were or could restore, preserve, or enhance functionality. Other practices assessed relative to functionality included right of way acquisition and protection, utility accommodation, safety in geometric design, incident management and accident monitoring, highway and bridge maintenance, work zones, and construction contracting strategies.

The project included three case studies through which the research team investigated in detail the functionality and associated practices, policies, and programs of three highway sections. The highway sections were selected from a large pool candidate projects from communities of large, medium, and small sizes. The three Texas highways where detailed case studies were conducted included:

- IH 10 Katy Freeway in Houston;
- SH 289 (Preston Road) in Plano and Frisco; and
- SH 105 between the cities of Conroe and Montgomery.

## **Summary Conclusions and Recommendations**

Most of the effective practices and programs in place today that help to maintain, restore, or enhance the functionality highways are located in Transportation Management Areas (TMAs) or communities with active planning programs. In unincorporated areas of the state, the combination of a lack of local planning and proper authority to regulate access and site development combined with a business-friendly development climate are major contributors to deterioration of functionality. While TxDOT can address functionality through access management and highway design, a system-wide approach where cities, counties, and MPOs and TxDOT coordinate and work together toward common goals on functionality is needed.

The research identified many new actions, changes, or additions to current practices and policies that are needed help to protect, restore, or enhance highway functionality. In statewide and MPO planning, statewide goals, policies, and objectives to support functionality as well as a policy on adherence to functionality standards and criteria should be added to TxDOTs Statewide Transportation Plan (STP). MPOs should establish work and project priorities or strategies in their Unified Planning Work Programs (UPWPs) that enhance functionality such as access management, context

sensitive design, transit-oriented development, travel demand management, corridor management planning, and others.

In TxDOT and local planning, TxDOT should continue to implement its access guidelines through coordination in local development review and provide support to rural districts in these efforts. It should initiate corridor management planning with MPOs and local partners that include non-traversable medians, adherence to proper signal spacing thresholds, and connectivity between adjacent local streets and developments. Failing to protect or preserve right of-way early could preclude or significantly delay new facilities or expansions. Early cooperative planning efforts should ensure that adequate right of way is planned to accommodate ultimate needs.

In the area of facility design and enhancement, TxDOT should continue its practice of improving regional links in the highway system with divided sections and all new highway loops or bypasses around communities should be planned and designed as controlled access facilities. As a statewide policy, surface arterials having three or more dedicated through lanes or existing or projected traffic volumes in excess of 24,000 vehicles per day should contain raised non-traversable medians. Where possible, TxDOT should use minor geometric and operational enhancements such as restriping, auxiliary lanes, ramp metering, and braided ramp configurations as faster, lower cost options to address bottlenecks and congestion.

The development and implementation of corridor access management plans by the Houston district and the Houston Galveston Area Council of Governments (HGAC) on an annual basis is a practice that should be expanded and followed by other districts and MPOs in the state.

## **Making the Most Out of What We Have**

Preserving and enhancing functionality is about how to make the most out of what we have and effectively using our existing transportation assets such that major enhancements and the need to construct new facilities to increase capacity or improve safety can be precluded or delayed.

Texas has need for far more highways that we can afford to build. It has gotten increasingly difficult to improve even the highways we have. Hence, it is extremely important to keep Texas highways – those that we have – functioning at a high level of efficiency. That can be a challenge, given competing pressures for staff time and attention and competition for available funds.

TxDOT has two basic choices when it comes to addressing functionality of the highway system and its component highways:

1. Preserve functionality at a high level through effective planning, operational and safety management, refinement, and infrastructure maintenance.
2. Adopt a reactive and corrective approach to fix things after they deteriorate.

According to the TxDOT strategic plan, the first choice – functional preservation – is the correct choice. Much of it can be achieved through either original or ongoing

planning or regular operations and maintenance programs. It is more cost-effective and alleviates the need for as many major projects, many of which take years to get through programming and project development.

# **1. INTRODUCTION**

The operational functionality of the state highway system determines how well the system moves goods and people from where they are to where they want to go. Although that sounds simplistic, the physical assets and components of the highway system that contribute to and affect functionality are numerous.

The transportation network is the backbone of our economy and lifestyle. If goods and people cannot be transported safely and efficiently, the economy will suffer and people will not be able to conduct business and enjoy leisure time as we have become accustomed. Congestion and operational problems slow traffic, resulting in wasted fuel and time; safety problems endanger goods and people; and poor pavement can affect both travel speed and safety. To this end, it is imperative that functionality be considered in all stages of a highway's lifecycle and that it be protected, preserved, and where possible enhanced during the course of TxDOT planning, operations, and maintenance practices and functions.

## **PROJECT PURPOSE**

The purpose of this project was to examine what losses to state highway functionality occur over time, the causes of those functionality reductions, and actions that can be taken to preserve, recover, and enhance functionality over time. The key characteristic of functionality to be addressed was operational capacity and efficiency. However, the research team also examined other functional characteristics associated with planning, right of way (including boundary conditions like access), infrastructure conditions, and safety. This report is intended to help to preserve functionality, recapture or enhance functionality after partial deterioration of functionality.

This project examined experiences and results for highways within and outside Texas, both from existing information and through case studies of selected Texas highways. The research used cause and effect relationships between various policies, actions, and practices and the resulting functionality over the life cycle of highways. The project produced this research report and a guidebook of recommended practices.

## **OVERVIEW OF HIGHWAY FUNCTIONALITY**

The functionality of the state highway system depends to a large degree on how each highway functions in its role among all the roadways in the highway system. The other roadways in the system include state roads and off-system facilities, such as city and county streets and thoroughfares. In addition, an important element of the transportation system is private facilities such as access driveways and parking lots, which distribute traffic from adjacent developments to public streets and highways. To preserve and enhance the functionality of the state highway system, each of the elements of the transportation system and how they are integrated must be given careful attention.

## **Mobility versus Accessibility**

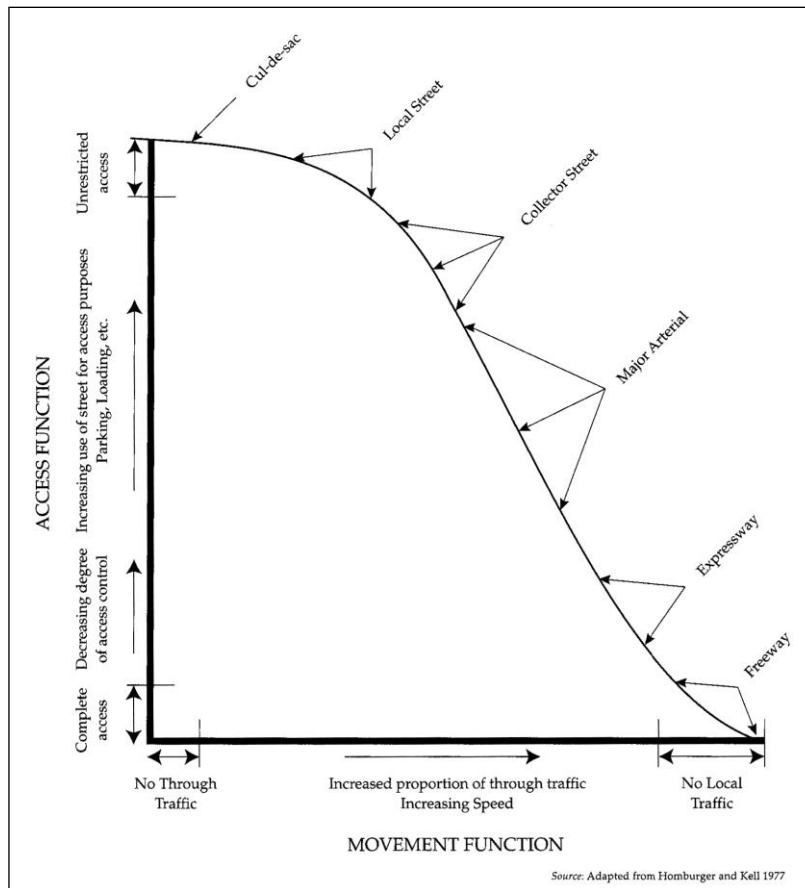
The purpose of the road network is to provide for the movement of people and goods to their destinations. To accomplish this, roads must provide an appropriate balance of mobility and accessibility in relation to their functional role in the system. Mobility (a high level thereof) refers to a continual free-flow condition of travel with no stops and little to no delay or impedance. A high level of mobility is generally associated with higher-speed, longer distance travel across communities or regions. Accessibility, on the other hand, provides an access function and relates to the ease with which travelers can gain access to and from property and development abutting the roadway system.

Different kinds of roads provide different levels of mobility and accessibility. For example, a freeway provides a high degree of mobility, because traffic can travel at high speed with minimal interruption. On other end of the spectrum, a residential street provides a high degree of accessibility because trips can start and end at any driveway along the street. However, the local residential street generally provides a low level of mobility and is not intended to do so.

A single roadway generally cannot provide high levels of both mobility and accessibility. Roads providing a high level of mobility usually provide limited accessibility (e.g., freeway or other limited access road). Roads that provide a high degree of accessibility have frequent and often poorly spaced access points, such as residential and commercial driveways and other public streets. Each of the access points, regardless of type, adds more conflicting traffic to the roadway, which slows traffic and results in a lower level of mobility.

## **Functional Classification**

In the practice of transportation planning, roads are classified according to their function. The functional classification defines the priority of mobility over accessibility and vice-versa. A widely used system of functional classification includes six hierarchical levels, which are freeway, major arterial, minor arterial, major collector, minor collector, and local street. An expressway is a lesser-used roadway category that from a functionality standpoint falls between a freeway and an arterial. [Figure 1](#) shows an illustration of the relative levels of accessibility and mobility for each functional classification.



Source: Handy, S., R. G. Paterson, and K. Butler. *Planning for Street Connectivity: Getting from Here to There*. Planning Advisory Service Report No. 515, American Planning Association, Washington, D.C., 2003.

**Figure 1. Functional Classification.**

Starting with a freeway and moving to the local street, each roadway classification has a decreasing level of mobility and an increasing level of accessibility. Each functional classification has requirements regarding elements of street design, such as street width, on-street parking, turn lanes, etc., which help to achieve the intended function of the roadway (1, 2).

It is important to emphasize that the relationships shown in Figure 1 are intended functions. If the facility's functionality is high, it will provide mobility and accessibility as shown in Figure 1. However, if functionality deteriorates due to factors to be described later, the mobility and accessibility characteristics start to move to the left and bottom of the chart. For example, this occurs in conjunction with congestion.

### Road Network Organization

In a properly designed roadway system, roads with different functional classifications are organized into a network for maximum efficiency. Under such a system, when vehicle trips begin on a local street, they next proceed to a minor collector, then to a

major collector, and so on as necessary. In this way, the trip proceeds successively through each level of the functional classification hierarchy. For the reverse side of the trip, the vehicle proceeds through the functional classifications in the reverse order, until the trip terminates on a local street (3, 4).

A well-designed transportation network is efficient because it balances mobility against accessibility for each level of the functional classification system. For example, access is limited on a major arterial so that it can serve its mobility function well. Likewise, access on a local street is unlimited so that it can serve its access function well. Collectors are an intermediate step between arterials and local streets that serve both access and mobility functions, though neither at very high levels.

### **Performance Measures**

Performance measures are used to track progress toward achieving goals and can be used to answer the question of whether investments are producing the desired results. In the context of maintaining and enhancing highway functionality, performance measures can be used to identify highway segments where functionality is deteriorating and to confirm that actions to maintain functionality are effective. Performance measures can be used to measure accessibility, mobility, economic development, quality of life, safety, and other characteristics. Commonly used performance measures quantify the quantity or quality of travel. Some of these include:

- vehicle-miles traveled,
- person-miles traveled,
- average travel time,
- average travel speed, and
- level of service (defined by the Highway Capacity Manual).

Other performance measures include:

- percent of population within a certain travel time of a certain percent of jobs,
- percent of special populations served by the transportation system,
- average trip length,
- mode split,
- time lost due to congestion,
- percent on-time transit performance,
- economic cost of congestion,
- jobs created and new housing starts as a result of transportation investment,
- tons of pollutions generated,



- fuel consumption per vehicle miles traveled, and
- number of crashes.

All agencies involved in transportation decision making can benefit from and take a role in creating and tracking performance measures, including state departments of transportation (DOTs), metropolitan planning organizations, and cities. The performance measures should explicitly reflect visions and goals that have been established through a planning process, which includes stakeholders and the public. Once performance measures are established, use of them can strongly influence the goals of the planning process, so performance measures should be chosen carefully (5, 6).

### **Components, Activities, and Practices Affecting Functionality**

The primary components and practices of the highway system that contribute to and affect functionality include:

- planning and land development,
- operations and capacity,
- right of way,
- infrastructure and maintenance, and
- safety.

While the operations/capacity and planning fields are the most apparent areas that impact highway functionality, right-of-way availability, infrastructure conditions, and safety also play a role. That being said, each of the five areas plays a part in establishing how well or poorly a highway may function and in meeting or preserving its intended function. Over the life cycle of a highway, these five components and how well they are preserved or enhanced can determine how well a highway can continue to function. Preserving the original functionality, restoring lost functionality, or enhancing existing functionality are critical to making the highway system meet transportation needs. That is especially true in this day of insufficient funding and rapid growth in travel.

Table 1 provides an overview of the assets and practices and a listing of sub-areas, components, and practices within each of the five fields. How these are created, preserved, restored, and enhanced—or permitted to deteriorate—determine how well highways will continue to function.

**Table 1. Selected Asset Components and Practices Affecting Functionality.**

<b>Capacity/Operational Efficiency</b>	<b>Right of Way</b>	<b>Infrastructure</b>	<b>Planning</b>
<ul style="list-style-type: none"> <li>• Facility function               <ul style="list-style-type: none"> <li>- Long distance/intercity</li> <li>- Local</li> </ul> </li> <li>• Signal optimization</li> <li>• Signal coordination</li> <li>• Operational assessments</li> <li>• Retrofits and enhancements</li> <li>• Minor enhancements               <ul style="list-style-type: none"> <li>- Ramps, interchanges</li> <li>- Turn lanes</li> <li>- Geometrics</li> <li>- Time managed capacity</li> </ul> </li> <li>• Network enhancements               <ul style="list-style-type: none"> <li>- Parallel facilities</li> <li>- Gap completion</li> <li>- Bottleneck improvements</li> <li>- Expansion</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• Preservation/protection</li> <li>• Acquisition</li> <li>• Protection</li> <li>• Utility location and maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Life cycle cost decision making</li> <li>• Sustainable materials, equipment, designs</li> <li>• Low maintenance infrastructure components</li> <li>• Maintenance               <ul style="list-style-type: none"> <li>- Practices (incl. preventive, corrective)</li> <li>- Scheduling</li> </ul> </li> <li>• Modern materials</li> <li>• Low maintenance equipment</li> <li>• Coordination on development planning/review</li> </ul>	<ul style="list-style-type: none"> <li>• Land use/transportation planning and decision-making</li> <li>• Plan implementation (incl. prioritization)</li> <li>• Development review/coordination               <ul style="list-style-type: none"> <li>- Subdivision</li> <li>- Zoning</li> <li>- Site plan</li> <li>- Associated road design</li> </ul> </li> <li>• Access Management</li> <li>• Corridor Management</li> <li>• Corridor Preservation</li> </ul>
	<b>Safety</b>		

Under the best of circumstances, a highway will remain highly functional through its intended service life. However, unless there is an active process of monitoring functionality followed by actions to restore or enhance deteriorating components, operational functionality can deteriorate to the point where a parallel or replacement facility (or reconstruction) will be needed much earlier than would otherwise be the case. That outcome can be wasteful and unnecessarily costly.

A transportation agency may assess the value of its assets by monitoring their functionality. For roads, functionality can be measured in terms of pavement condition, safety, operations, congestion, and other factors. By monitoring road functionality through established performance measures, a transportation agency can plan maintenance, respond to problems, and improve design standards to maximize the value of existing and future road assets. Some states monitor road functionality through traditional databases, while others, such as Michigan, use software developed specifically for this purpose.

The Federal Highway Administration (FHWA) states on its web site that transportation agencies should use well-defined performance measures to evaluate the performance of their assets as a key element of developing long- and short-range projects (7). However, even more important than a FHWA recommendation, monitoring functionality—how well TxDOT’s assets are serving their purposes—enables TxDOT to see how well the system is meeting needs and where functionality is declining and may need restoration or enhancement.

Under the Intermodal Surface Transportation Act of 1990 ISTEA, FHWA recommended that state DOTs develop several management systems. These included management systems for pavement, bridges, congestion, and safety among others. Texas had some of these even before ISTEA (8).

Access management has been evolving over the past few decades. Statewide and metropolitan transportation planning provides the equivalent of a transportation planning management system. Most urban municipalities also have programs and processes to manage urban development. All of these programs and systems have a similar impact—preservation of functionality.

In July 2002, the Michigan DOT (MDOT) established its Transportation Asset Management Council to advise the State Transportation Commission regarding asset management on a statewide basis. The 11-member council brings stakeholders from several types of agencies, including MDOT, metropolitan planning organizations, the Michigan Townships Association, and the Michigan Association of Counties. This effort recognizes the importance of including asset management issues in the transportation planning process. One of the Council's responsibilities is to develop a three-year transportation infrastructure program for all federal-aid eligible roads (9).

Some states, including California, Michigan, North Carolina, and Utah, use road functionality documentation to prioritize future road investments. These states recognize that planning decisions benefit from the use of coordinated processes that evaluate the functionality of existing and future roads (10).



## **2. PLANNING FOR HIGHWAY FUNCTIONALITY**

Though often very necessary, merely reacting after poor asset functionality occurs is not cost-effective. It is much more economical to use a preventive maintenance approach and then include appropriate restorative or enhancing measures in upcoming plans and programs. This enables a DOT to identify and stop deterioration in its early stages so the extent and cost to restore or improve functionality will be much less.

For this and other reasons, the planning process is very important in the continuing development of a state's road network. The most obvious road-planning element is determining how many lanes a new or existing road needs to carry the traffic that will use it. Many lessons can be learned from previous projects. Those lessons can contribute to a well-planned road that has a high asset value. Decisions, actions, and practices made or not made during the planning stage of the highway lifecycle arguably have the greatest impact and influence on highway functionality of any of the five major components.

Planners face several challenges, including limited financial resources, deteriorating infrastructure, political influences and pressures, public needs and desires, and legislative and environmental restrictions and demands. Balancing the responses to these challenges in a manner that yields responsible decisions requires detailed information about existing road assets. Knowledge of existing road functionality and values provides important information for which features are most cost-effective and have the greatest impact on the overall value of the road system.

The sections to follow identify current practices, processes, and policies in planning and land development that impact highway functionality. Separate sections are provided for the following areas:

- Statewide and MPO Planning Process,
- MPO Practices and Policies,
- Local Practices and Policies, and
- TxDOT Practices and Policies.

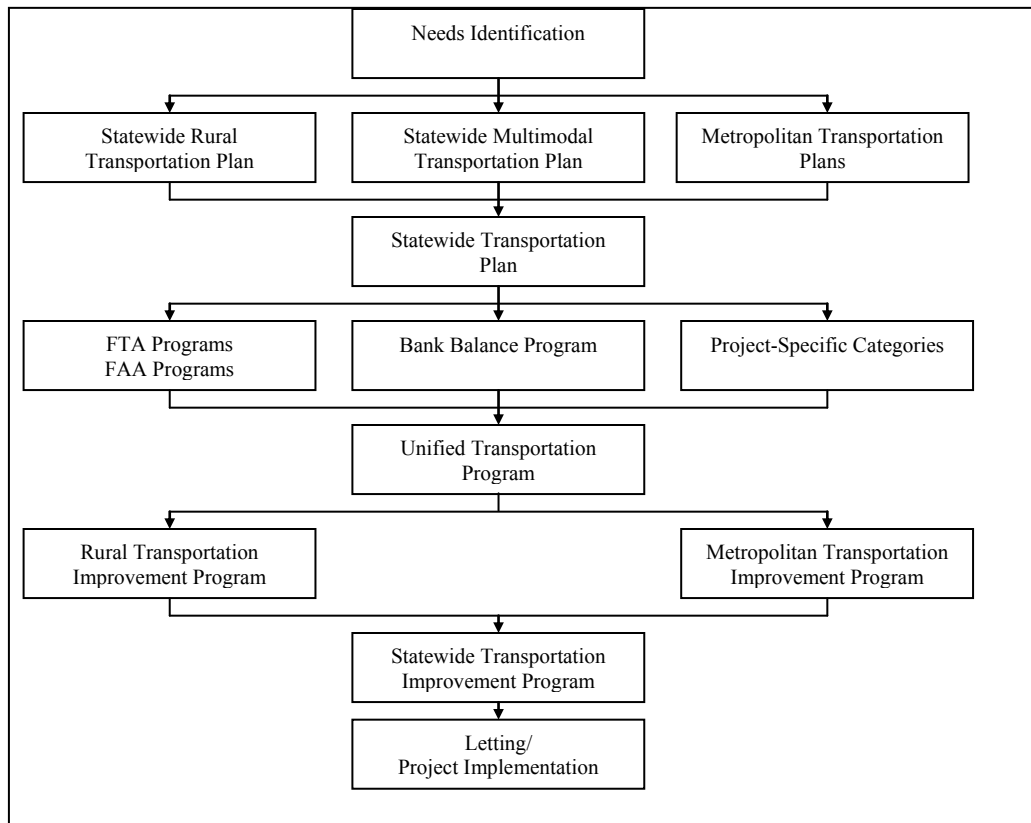
In addition to current practices and policies, sources and causes of functional deterioration related to each area will be discussed in each section.

### **STATEWIDE AND MPO PLANNING AND FUNCTIONALITY**

The statewide and metropolitan transportation planning process in Texas and other states across the USA plays an important role in shaping a state's, region's, or community's vision for its future. Maintaining and preserving highway functionality is an underlying and vital aspect of these transportation plans and programs. There are many opportunities to address highway functionality as part TxDOT's transportation planning and programming process and their coordinated activities with MPO and other transportation partners.

State legislation and federal law require preparation of the statewide transportation plan (STP). TxDOT's STP serves as the framework for long-term planning and preservation of the Texas' transportation system. The statewide plan is not a plan per se, but rather coordinated collection of approved Metropolitan Transportation Plans (MTPs) from the 25 MPOs around the state combined with the statewide rural transportation and multimodal plans. In addition to projects, the statewide plan can also include system-wide transportation goals, policies, or special initiatives to address highway functionality.

TxDOT's process of prioritizing and selecting transportation projects from the MTP for programming and development is undertaken through the Unified Transportation Program (UTP). The UTP is a ten-year planning document that guides the scheduling and development of transportation projects. Once funding has been identified and designated for a project, it is then placed on the Statewide Transportation Improvement Program (STIP). The STIP is a multiyear statewide intermodal program of transportation projects that is consistent with the STP, MTPs, and UTP. Metropolitan TIPS and rural TIPS are coordinated to provide this statewide document of programmed work. Projects, or phases of projects, can be included on the STIP only if funding can reasonably be anticipated to be available for the project within the time period contemplated. The STIP also reflects the priorities for programming and expenditure of funds (11). Figure 2 illustrates TxDOT's statewide and metropolitan plan process.



**Figure 2. TxDOT's Transportation Planning and Programming Process.**

## MPO PRACTICES AND PROGRAMS

An MPO is an area wide or regional transportation planning and policy making body made up of representatives from TxDOT districts, cities, counties, transit agencies, toll authorities, and other key agencies within the MPO's boundaries. Formation of an MPO in Texas (and in other states) is required by federal law for any urbanized area with a population greater than 50,000. Intrinsic roles and activities undertaken by MPOs that address or benefit highway functionality include:

- serving as the coordinating body for transportation plans and projects across multiple jurisdictions;
- coordinating the functionality of state roadways on local transportation plans with that on the MPO's regional plan;
- facilitating interagency coordination among transportation stakeholders and partners;
- developing existing and future inventories on socio-economic data such as population, land use, and employment for use in transportation planning and travel demand modeling; and
- educating policy and community leaders on the importance of developing and adhering to a transportation plan as well as on the symbiotic relationship between transportation and land use.

The primary functions of MPOs include carrying out the agency's Unified Planning Work Program (UPWP), preparing and maintaining a long-range Metropolitan Transportation Plan and developing a Transportation Improvement Plan (TIP) based on the MTP (5). Each of these important MPO activities either addresses or considers highway functionality as part of their process or development. MTPs must be consistent with TxDOT's statewide plan and must be updated every four to five years depending on air quality nonattainment status.

MPOs develop financially constrained TIPs at least every 4 years. TIPs include the highest priority projects taken from their MTPs. The TIP is a short-range transportation improvement program stemming from the MPO's long-range plan. The UPWP covers a 1- to 2-year period and sets forth the work tasks and planning studies to be performed by an MPO. It is within the UPWPs where MPOs can establish work priorities, programs, or strategies to directly address highway functionality. Such programs or work tasks could include projects, studies, or initiatives on any number of activities that enhance or preserve functionality such as access management, context sensitive design, transit oriented development, smart growth, travel demand management, arterial/corridor management, corridor preservation, and others. [Table 2](#) summarizes how highway functionality can be addressed in the statewide and MPO transportation planning process in Texas.

**Table 2. Functionality in the Statewide and MPO Planning Processes.**

Plan or Program	Agency	Content	Examples of Means to Address Functionality
UPWP	MPO	Planning tasks and studies to be performed	Studies on system functionality, corridor management/preservation, access management Special studies to identify and prioritize corridors needing functional enhancement or preservation treatment Education and outreach to policy boards, public, and general stakeholders on importance and benefits of highway functionality
MTP	MPO	Plan map, goals, strategies, policies, and initiatives	Development of the regional plan map illustrating existing and future thoroughfares by functional category Goals and policies related to adherence to functional criteria, access management, corridor management and preservation, and other initiatives that enhance or preserve functionality
TIP	MPO	Transportation projects to be undertaken for next 4 years	Include benefits to functionality enhancement or preservation as a factor in project selection
STP	TxDOT	Goals, policies, and approved MTPs	Development of the regional plan map illustrating existing and future thoroughfares by functional category Goals and policies related to adherence to functional criteria, access management, corridor management and preservation, and other initiatives that enhance or preserve functionality
STIP	TxDOT	Transportation projects MPO TIPs to be undertaken for next 4 years	Include benefits to functionality enhancement or preservation as a factor in project selection

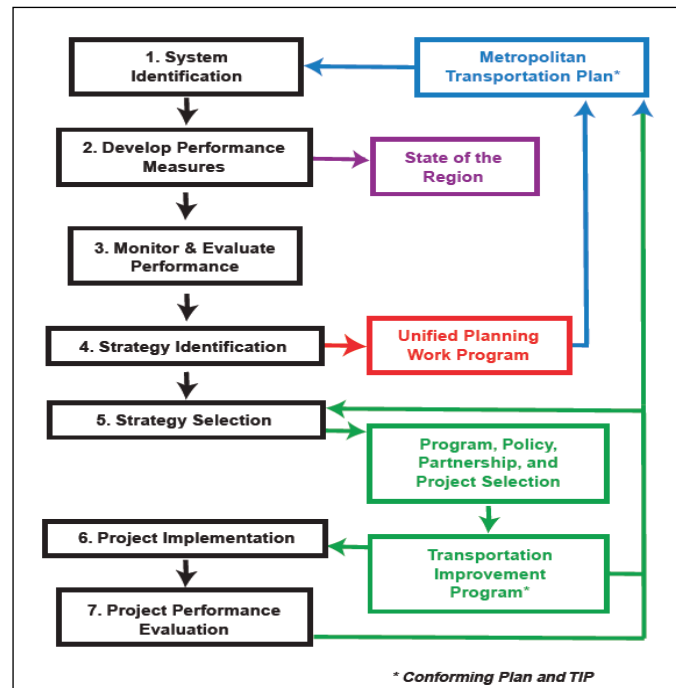
MPOs located in Transportation Management Areas (TMAs), metropolitan areas with a population of greater than 200,000, are required to undertake a congestion management process (CMP) (12). A CMP is a way MPOs, in coordination with TxDOT and local partners, can address congestion causes and reduction strategies on a system-wide basis as part of the regional planning process. The CMP is an activity that directly addresses the preservation or enhancement of functionality through measures or strategies to reduce or curtail congestion.

The CMP is intended to address congestion through a process that provides for effective management and operations, based on cooperatively developed travel demand reduction and operational management strategies (12). It addresses highway functionality by:

- identifying system-wide locations of congestion;
- determining the causes of congestion; and
- developing, implementing, and evaluating different congestion mitigation strategies.



The North Central Texas Council of Governments (NCTCOG) uses a seven-step CMP process that is integrated into their MTP, UPWP, and TIP. Their process, shown in [Figure 3](#), targets resources to operational management and travel reduction strategies and involves lower cost strategies to complement or augment major transportation improvements to address growing traffic volumes ([12](#)).



Source: NCTCOG. Regional Mobility Initiatives, Vol. XII, No.1. April

**Figure 3. Congestion Management Process Used by NCTCOG.**

According to an April 2008 NCTCOG Regional Mobility Initiatives brochure, the CMP provides for the effective management of new and existing transportation facilities through development and implementation of operational and travel demand management strategies and by providing information to decision-makers on system performance and the effectiveness of implemented strategies.

There is a large toolbox of strategies that can be used in the CMP to help alleviate congestion, which in turn, help to preserve or enhance highway functionality. The strategies can be grouped into the following three categories:

- transportation system management (TSM);
- travel demand management (TDM); and
- intelligent transportation systems (ITS).

[Table 3](#) shows a sample listing of CMP strategies by TSM, TDM, and ITS categories.

**Table 3. Sample Congestion Management Strategies by Category.**

<b>Transportation System Management (TSM)</b>	<b>Travel Demand Management (TDM)</b>	<b>Intelligent Transportation Systems (ITS)</b>
traffic signal retiming, upgrades, interconnections, demand-response	improve transportation options: car/van pooling, alternative work schedules, park and ride	public transportation tracking, fare management/policies
intersection and street improvements	incentives for alternative modes: congestion pricing, parking management	traffic surveillance, incident management, electronic tolling
bottleneck removal	sustainable development: transit oriented development, land use/density controls	commercial vehicle electronic clearance, weigh-in-motion, HAZMAT management
access management	context sensitive design, car-free planning	maintenance, construction, work zone management
special event management	TDM marketing/education	

In the Houston area, the Houston-Galveston Area Council (HGAC), in coordination with TxDOT’s Houston District, has used major access management studies, followed by implementation projects for study recommendations as one tool in their CMP process (13). Over the past six to eight years, HGAC and the Houston District have completed the following corridor access management studies:

- FM 518 Corridor Access Management Plan, September 2004;
- FM 1960 Access Management Study, October 2004;
- FM 2920 Access Management Study, November 2008;
- SH 6 Corridor Access Management Plan, November 2007; and
- Westheimer Corridor Mobility Study, April 2002.

The general purposes of the studies were to identify transportation measures that will improve public safety and traffic flow, reduce motorist delay, enhance air quality, and improve pedestrian and bicycle access. HGAC includes corridor access management studies in its annual Unified Work Planning Program and uses Congestion Mitigation and Air Quality (CMAQ) moneys to fund improvements recommended from the studies. Improvements recommended in many of the plans have been funded, implemented, and have resulted significant improvement in the traffic progression and safety of these corridors.

HGAC and TxDOT’s Houston district have identified a section of SH 105 in Montgomery County between the cities of Conroe and Montgomery as the region’s next corridor to study and develop an access management plan. The SH 105 study is scheduled to begin in the summer or fall of 2009.

**TXDOT PRACTICES AND POLICIES**

Current TxDOT practices and policies that have the most impact on urban surface highway functionality include:

- increased access management and access control in facility upgrades;
- facility design policies and practices on medians, addition of shoulders, and select turn bays on 2-lane roadways (e.g., \_super 2‘ cross-sections), frontage roads, interchanges, and ramps;
- coordination activities with local jurisdictions on local and regional transportation planning and development adjacent to state facilities; and
- traffic management in high volume urban freeway corridors.

Other activities undertaken by TxDOT that address highway functionality in planning include travel demand modeling and various traffic data collection activities.

### **Access Management at TxDOT and across U.S.**

Access management is arguably the single most important practice and concept impacting highway functionality. It is an important consideration in early planning and land use decisions, in platting and site plan development, and in project development and highway design. Since it is of primary means of protecting highway capacity, mobility, and safety, it has a direct correlation to preserving and protecting highway functionality. TxDOT practices access management through its access and roadway design manuals and applies the guidelines through access permitting and involvement in local development review, improvement and rehabilitation projects on existing facilities, and in construction of new roadways. Key TxDOT policies and regulations in place relating to access management include:

- Rule §11.50 of Title 43, Chapter 11, Part 1 of the TAC, which promotes the use of access management on the state system and intergovernmental coordination in this activity;
- TxDOT’s Access Management Manual adopted in 2003 (revised June 2004) and the general practice of most of TxDOT’s district offices of coordinating with local jurisdictions on access and in the development process;
- Incorporation of access management principles into TxDOT’s Roadway Design Manual;
- §203.002 of Texas’ Transportation Code, which emphasizes the construction of controlled access highways and planning for future highways.

Since the early 1990s, TxDOT has numerous research efforts to enhance the access management practices in Texas. In addition to the development of the TxDOT Access Management Manual in 2003, other examples include research projects 0-4429 TxDOT Involvement in the Local Development Process, 0-5606 Creating Partnerships to Manage and Preserve Corridor and 5-4221-01 (demonstrating the benefits of access management), and 0-4141 (techniques for managing access on arterials). Over the past decade TxDOT has increased its commitment to managing access more effectively to both preserve and

enhance traffic operations, but also to preserve access control to benefit future improvements.

TxDOT's Access Management Manual applies design and location criteria for access to four functional classes of state highways, including new highways or new alignments, freeway main lanes, frontage roads, and other state system highways (e.g., farm-to-market roads). Based on feedback received from TxDOT's local development workshops conducted from 2005 through 2007, TxDOT's access policy and manual has fostered partnerships with local jurisdictions by coordinating access review for development along on-system facilities (14).

The primary means through which TxDOT practices access management and pursues compliance with its access manual are (1) coordination with cities on site development plans and (2) coordination with cities and counties on plats adjacent to state roadways, and (3) application of its access policy and criteria in roadway upgrades and rehabilitation projects and in construction of new facilities. As part of a TTI research project in 2003, TxDOT districts were surveyed about their involvement with cities and counties on plats and site plans adjacent to state roadways for the purpose of access review (15). The survey found the following:

- more districts are involved in review of site plans than plats for access review;
- regarding plats, the majority of districts have some or limited input on plats and a small percent routinely review plats for access considerations, including working with locals to require access easements for driveway spacing and consolidation purposes; and
- regarding site plans, some districts routinely review sites plans for access, while what some review may depend on its size, location, and impact. How the proposed access points on local development applications are coordinated with TxDOT's access permit varies by district and locale.

Nationally, the 2003 Access Management Manual (16) serves as a general guide for access management nationwide. In addition, NCHRP initiated a variety of studies on the subject and the outcomes include the relatively recent report on *Impacts of Access Management Techniques* (17) and *A Guidebook for Including Access Management in Transportation Planning* (18). As outlined in the guidebook, access management is primarily achieved through the following methods:

- acquisition of access rights,
- access management regulations,
- policies, directives, and guidelines,
- land development regulations,

- geometric design, and
- development review and impact assessment.

In 2006, FHWA conducted a domestic access management scan tour (19), which covered three locations selected in Minnesota and Maine. The following are examples of successful practices found during the scan:

- Directly address access management in transportation plans and in development review and approval. The Dakota County in Minnesota has used this strategy to successfully accomplish effective access management. The local jurisdiction worked across functions with private property owners and other units of government to implement consistent and clearly defined access plans.
- Consider prioritized planning and preservation of mobility arterial corridors. For example, the Gateway 1 Corridor in Maine successfully gained support and cooperation from all 21 abutting towns. This is partly because Maine Department of Transportation effectively worked to preserve the historical and cultural legacy of each town when implementing access management.
- Promote traffic flow along main corridors by using alternative accesses for local business, providing shared accesses between businesses, and taking other actions to reduce congestions on local roads. This strategy resulted in successful access management in Brewer, Maine.

### **Facility Design**

Another important manner in which TxDOT improves functionality (and also practices access management) is through facility design. The primary means are:

- Non-traversable medians in arterials and to a lesser extent, frontage or backage roads along arterial sections. Over the past decade there have been many TxDOT projects around the state where upgrades and rehabilitation of urban arterials have included non-traversable medians. For example, FM 1960 and Westheimer Road (FM 1093) in Houston, US 69/Broadway Street in Tyler, and SH 6/Texas Avenue in College Station.
- TxDOT's general policy of '4-laning' major links in the state highway system with divided highway sections. For example, the conversion of numerous 2-lane undivided state highways around the state to 4-lane divided sections to improve safety and mobility.
- TxDOT's practice of modifying 2-lane state highways and farm-to-market roads by adding shoulders, turn-lanes at key intersections, or passing lanes. This low cost form of upgrade, termed a 'super 2', provides extra width to help reduce turning conflicts, improves safety, and provides added capacity to 2-lane facilities.

- Expressway designs where all abutting private access rights have been purchased and access to the facility is gained through widely spaced intersections with major thoroughfares.
- Frontage roads where properties must be provided access along freeways and some arterials.

### **Frontage Road Policies**

The current rules for frontage roads included under §203.031 of the Texas Transportation Code provide TxDOT important authority relating to preserving and enhancing functionality on the state’s highway system. Under these rules, TxDOT may:

- designate a state highway on the designated state highway system as a controlled access highway;
- deny access to or from a controlled access highway from or to adjoining public or private real property and from or to a public or private way intersecting the highway, except at specific locations designated by the commission;
- close a public or private way at or near its intersection with a controlled access highway; and
- designate locations on a controlled access highway at which access to or from the highway is permitted and determine the type and extent of access permitted at each location (20).

### **Bypass Practices**

Beginning in the early to mid 20<sup>th</sup> century and continuing on today, it has been TxDOT’s practice and the practice of most state DOTs to construct highway bypasses around the periphery of cities and towns. The most common reasons for bypasses are to divert through traffic—where there exists high volumes of through and/or truck traffic—from central business districts (CBDs) and within urban areas and to relieve congestion and improve safety in these areas. However, bypasses also provide an opportunity to replace a low speed, highly accessed surface highway with a limited or controlled access facility that provides a higher level of mobility.

A 2002 study found that from 1954 to 1992 there were 23 cities in Texas (within the population range of 2,500 and 50,000) that have had bypass routes constructed. In each of these cases, the new bypass route split from the old route at one side of the city and then rejoined the old route on the other side (21). This practice has a significant impact on the land use and development patterns and on the functionality of the state and local roadway systems. General changes in functionality include:

- an improvement in functionality in regional and statewide highway networks by improving mobility and travel times between communities and regions of the state; and

- a change in the functionality of the old state routes within CBDs and urban areas from which through traffic was diverted and re-routed to a new bypass route.

Bypasses affect the functionality of the old routes primarily due to the removal of through traffic and reduction in traffic volume from these facilities. However, there are also changes in the types and characteristics of travel and trip making on these old routes that affect their functionality such as:

- the reduction in the percentage commercial vehicles compared to non-commercial (e.g., traffic mix);
- a reduction non-local or non-resident travel; and
- a reduction in vehicle trip length.

With bypasses, changes in land use are inevitable and changes in land use also affect roadway functionality. From a land use planning perspective, bypasses create a decentralized land use pattern and decrease densities and concentration of activities. These changes, in turn, increase vehicle miles of travel (VMT) and make transit a less viable transportation option. New bypasses often stimulate commercial growth and facilitate rural and suburban residential development. These in turn generate travel demand in new areas and create the need for additional or improved streets and highways. Hence, bypass planning—especially the access management component—should be conducted very carefully in cooperation with local planning and development officials.

There are numerous examples of cities and towns in Texas that have experienced significant changes in traffic circulation and land development because of the construction of a state bypass facility. Many may associate growth and economic progress with the planning and development of a bypass, but their impacts can be viewed as both positive and negative. From a transportation planning perspective, they have positive impacts by improving statewide/regional mobility and intercity travel, but for some local officials and merchants they are often a cause for concern due to loss of business and tax revenue in core business areas.

### **TxDOT-Local Coordination in Development Review, Long-Range Planning, and Project Development**

Coordination between local jurisdictions (chiefly cities) and TxDOT districts are undertaken at the district and area office levels to protect and preserve the functionality of the state highway system. This coordination includes:

- development review;
- long-range planning; and
- project development.

These are three distinct planning practices and processes where TxDOT-local coordination is critical to highway functionality. A brief summary of each activity is provided below.

1. Development review includes TxDOT involvement in various stages of the local development process—from early conceptual plans, to zoning/rezoning applications, to subdivision plats, to site plans, and finally to development permitting. Some cities may refer to the day to day on-going activity of processing development applications and reviewing site plans and plats as “current planning.”
2. Long-range planning typically includes development and/or updates to municipal comprehensive plans or transportation plan, and to a limited extent development of county transportation plans.
3. Project development refers to local involvement in TxDOT’s 6-step process typically used in developing an improvement project for implementation. These steps include planning and programming; preliminary design; environmental; plans, specifications, and estimates; right of way; and letting. Emphasis is placed here on TxDOT including locals in the preliminary design stage where the entities can work together to develop a vision for the project followed by alternative then selected designs that consider future land use, development, and access.

As part of local development review process (current planning), the functionality of the subject highway should be considered on various aspects of master/concepts plans, site development plans, and subdivision plats at different stages in the local development process. The key reason why this state-local activity is so important is because it is a means by which transportation, land use, and site planning and decision making can be coordinated.

TxDOT-sponsored research conducted by TTI in 2003 assessed the level of coordination between TxDOT districts and areas offices with local jurisdictions on development plans and proposals impacting state roadways. Based on these findings, the majority of districts had at least some input with cities on development plans and plats adjacent to state roadways (15). It was found that some districts have a system in place where they routinely review site plans and plats, while the majority of districts perform this activity on an ad hoc basis, often dependent on the magnitude and impact of the development. It was found that the primary purpose for TxDOT’s involvement was for driveway review and right-of-way matters—two critical areas in relation to enhancing and preserving highway functionality.

The 2003 study found that much of TxDOT’s input occurs at the time of application for a driveway permit, some presumably after the site plan was already approved. The study stressed the importance of TxDOT’s involvement early in the local development process during the planning stage of a development, rather than waiting until after site plans and plats had been approved by locals (15). The study found that all of the coordination between TxDOT and local jurisdictions is informal in nature and that there are no official agency-wide policies or agreements in place to ensure that coordination in this important activity continues.



Questions related to TxDOT involvement in local comprehensive and long-range planning efforts were not included in the 2003 study, so the degree in coordination on this activity is unknown. For cities, this activity would include district involvement in development and/or updates to future land use plans, transportation plans, and possibly specialty plans such as corridor management/preservation plans.

### **Travel Demand Modeling**

TxDOT's work in travel demand modeling is another activity undertaken by the agency that addresses highway functionality in the planning process. The Transportation Planning and Programming Division (TPP) of TxDOT develops and maintains travel demand models for most of the state's 25 MPOs. The models are used to emulate existing highway networks and traffic conditions and then forecast future traffic loads on future highway networks (which may include various alternatives). The forecasts are assigned to a functionally classified highway network. Future congested areas on the network are identified when traffic loads exceed capacity thresholds that are built in for each functional class of roadway on the network. TxDOT, in cooperation with MPOs throughout the state, use travel demand models as a tool in transportation planning to assist in:

- developing and/or updating long range transportation plans;
- ranking projects in order of priority on MPO and/or local or TIPs;
- determining the proper functional classification of a new highway or that of an existing highway in the future; and
- performing various types of analyses such as the impact of a proposed new bypass facility on the existing highway system within an urban area or air quality analysis for non-attainment areas within the state.

Occasionally the travel demand models are also used to refine a project's design. Additional detail is coded into the models to test the mobility-related functionality of design alternatives. For many urban areas, TPP, MPOs, and local district offices work together to develop the model network for their regional roadway system.

Other studies performed by TPP and MPOs using models include analyses for 'no build alternatives' that look at future congestion levels on the existing highway system if no improvements are made, the impacts of tolling or congestion management options on travel demand, and the impacts of gasoline prices on the amount of travel and trip making. Estimates of future traffic levels developed by models are based on projected changes in population, employment, development patterns, and other socio-economic conditions.

### **Traffic Data Collection Activities**

In addition to travel demand modeling, TxDOT's TPP division oversees a wide range of traffic data collection activities to support planning, programming, design, and performance measurement functions of TxDOT, MPOs, and local governments. Along

with model outputs, the results of various field data collection programs play a role in addressing highway functionality through their use and consideration in development of transportation plans, corridor analyses, environmental analyses, both geometric and pavement design, and other planning activities. TPP's key data collection activities are identified and summarized in the following bullet points (11).

- **Automatic Traffic Recorder (ATR) Volume Data.** Permanent ATR equipment is in place at 160 sites around the state that continually collects traffic volume data by lane, 24 hours per day, 365 days per year. TPP retrieves the data by modem and uses it primarily to develop seasonal factors and estimates of VMT.
- **Accumulative Count Recorder (ACR) Traffic Data.** ACR data collection includes 60,000 to 80,000 counts each year. These include annual counts for HPMS and on-system facilities in combination with off-system counts conducted in 5-year cycles. Some ACR counts are conducted in-house, while some are contracted-out.
- **Highway Performance Monitoring System (HMPS) Data.** HPMS is a federally mandated program put in place to provide Congress with data on the nation's streets and highways. It includes counts for on-system and off-system roadways that are functionally classified and serves a source for allocation of federal funds to states. TxDOT district offices collect and submit the required HPMS data to TPP by December 31 of each year.
- **Five-Year Count Program.** This program consists of making ACR counts throughout the 25 urban areas in Texas for validating area travel demand models. MPOs, local TxDOT district offices, and TPP work cooperatively on identifying count locations.
- **Vehicle Classification (VC) Data.** TPP makes VC counts at 650 to 750 locations across the state each year using automated vehicle classifier (AVC) equipment or through visual classification. VC data in combination with overall volumes is used to categorize vehicles into 14 different classes that make up the 'Texas Vehicle Classification' scheme. TxDOT uses these data in support of HMPS and to develop axle load calculations in pavement design.
- **Truck Weigh-In-Motion (WIM) Data.** TxDOT uses WIM equipment to collect traffic volumes by vehicle classification and weight at up to 15 sites around the state. The data are used to calculate load factors for pavement design and to support FHWA's long-term pavement program (LTPP).
- **Vehicle Speed Data.** TPP collects vehicle speed data at 44 locations around the state on a twice-annual basis. Where possible, speed data are also collected at WIM sites and at 130 AVC sites across the state. The data are collected to monitor speeds and help measure the effectiveness of enforcement.

- **Long-Term Pavement Performance (LTPP) Data.** TPP collects LTPP data continuously at 71 sites around the state. The LTPP is a federal aid program that began as part of the Strategic Highway Research Program, which was initiated in 1987 and set to end in 2007. The data are used in pavement design, management, and sensitivity analyses that determine the affects of loading, environment and other factors on pavement performance.
- **Border Trend Traffic Data Collection.** This program includes traffic data collection by vehicle type at 25 highway sites in the areas affected by the North American Free Trade Agreement (NAFTA). The sites were selected and are continuously monitored by TxDOT district offices where the sites are located.
- **Off-System Traffic Data.** Traffic counts for off-system roadways are collected on a 5-year cycle at HPMS sites, sites identified by TxDOT districts and MPOs, and sites by functional class developed by random sample. These counts are generally conducted in conjunction with ACR contracts.

In addition to the above data collection activities, TxDOT also collects traffic data for special projects when data needed at a specific location is not available or current. To obtain special counts, TxDOT districts submit requests to TPP and, where possible, the counts are incorporated with regularly scheduled counts.

### **Corridor Preservation and Advanced Acquisition**

Corridor preservation refers to the practice of acquiring, preserving, or protecting right of way needed for a planned transportation facility. It is imperative to highway functionality because it serves to protect or preserve right of way in amounts to allow for proper functional size and design of transportation facilities needed for the future. It also benefits functionality because it necessitates coordination between DOTs, local jurisdictions, landowners, and other transportation agencies. In addition, it serves to inform the public and communities of future plans for thoroughfares such that they can be considered in land use planning and development considerations. Corridor preservation works to control use and development of the land within the right-of-way lines of existing or proposed highways. It helps highway agencies to preserve the adjacent land that has not been acquired for planned highways or future highway improvements.

Federal law and policy encourages corridor preservation. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 required states and MPOs to consider preservation of right of way for future transportation projects, including the identification of future corridors as part of the statewide planning process. As a result, some states have passed legislation to develop formal corridor preservation programs, which authorized their DOTs to engage in corridor preservation activities. However, few states have established a permanent funding mechanism to acquire or preserve right of way.

TxDOT research projects 0-1495 *Corridor Preservation: A Review of Strategies for Texas* and 0-5606 *Creating Partnerships with Local Communities to Manage and Preserve Corridors* show that TxDOT, like most state DOTs, does not have enabling legislation or a funding source to routinely practice corridor preservation. However, the

0-5606 research found that TxDOT can undertake some corridor preservation on an ad hoc basis and several districts have done so. Typical efforts include advanced acquisition practices within larger TxDOT districts or coordination with a local or private entity to preserve or acquire right of way for a planned highway project.

Advanced acquisition is the acquisition of property for a project prior to final environmental clearance. Land acquisition for right of way on a project-wide basis cannot begin until the environmental process has been completed. Techniques such as options to purchase or hardship buys have limited use in corridor preservation because they can only be used on a parcel-by-parcel basis and not applied on a project-wide or corridor-wide scale. The option to purchase has worked well for both the Houston and Dallas Districts. However, smaller TxDOT districts rarely, if ever, use options to purchase (or any other advanced method) due to their complexity and time consumption.

There are numerous examples across the state where TxDOT districts have coordinated with local jurisdictions to acquire or preserve right of way. In cases where property was on the market or there was a willing seller, the Dallas District has coordinated with local jurisdictions to purchase such property with an agreement that TxDOT would (1) either purchase it from them once they had received environmental clearance or (2) allow them to apply it toward their 10 percent local match for the project (13). The Beaumont District has also worked with landowners and local jurisdictions in acquiring and preserving right of way for existing and new alignments. On more than one project, agreements have been worked out whereby land needed for a project under development has been deeded or donated to a city or county and subsequently applied toward the local match for the project.

For more than two decades, TxDOT's Houston district has been coordinating with the Harris County Toll Road Authority (HCTRA), the Grand Parkway Association (GPA), the HGAC, the Metropolitan Transit Authority (METRO), and numerous cities and counties on the planning, right of way needs, and development of the Grand Parkway (SH 99). The Grand Parkway is a planned 182-mile limited access circumferential highway that will create a third loop around the greater Houston area. The project has been shown on governmental planning documents since the early 1960s and is currently shown on HGAC's 2025 regional plan. Due to supportive real estate interests, the GPA was able secure most of the right of way needed for the initial segment of the highway through donations. The right of way that was not acquired through donation was bought either by the GPA or by counties.

The Grand Parkway has been divided into 11 independent projects. Currently, only one 19-mile segment, located on Houston's southwest side, is open. The remaining segments are in various stages of project development with three more segments planned to be open for traffic by the end of 2015. Seven counties in the Houston area are following guidelines stipulated in Senate Bill (SB) 792 in negotiating an agreement with TxDOT to develop the Grand Parkway segments within their limits (22). SB 792, passed in 2007, gave local authorities the first option to build toll projects before these projects could be sold to private entities via comprehensive development agreements (CDAs).

Experience in Texas and across the USA reflects that in order to practice corridor preservation within the existing legal and regulatory framework, a multi-jurisdictional

approach is needed that involves a working partnership with MPOs, local governments, other transportation authorities, and perhaps even private entities or associations. Since under federal regulations project-wide right of way acquisition cannot begin until environmental clearance has been obtained, for the last many years the trend has been for state DOTs to partner with local jurisdictions to take advantage of their eminent domain and develop authorities to help acquire, preserve, or protect right of way needed for a planned highway.

In 2007 legislation was defeated that would have allowed TxDOT the ability to purchase property before the location and alignment of a highway was determined. The failed legislation, HB 2268, included language to clarify that the legal requirement that *an environmental review of a TxDOT project be conducted before the location of an alignment of the project has been determined* does not prevent the advanced acquisition of property. It also included a provision to not allow making an advance acquisition using condemnation.

TxDOT authority to purchase interests in property prior to location and alignment determination would provide it with an additional advanced acquisition tool that, compared to purchase options, would be more attractive to willing sellers. With this authority, TxDOT could acquire property early from willing sellers for known future corridors in advance of project development and environmental clearance.

Examples of good corridor preservation (CP) practices and initiatives from other states are provided below:

- In Utah, legislation was passed giving counties the option to impose a vehicle registration tax of up to \$10 for the purpose of funding corridor preservation activities and councils of government are allowed to establish application procedures for the disbursement of the funds. As another example, the Utah DOT administers a revolving loan program that provides funds to local entities to preserve future transportation corridors (20).
- In Florida, the DOT has emphasized involvement with locals in development review and long-range planning for CP. A 1995 statute called for the designation of corridors in local comprehensive plans. Some MPOs in Florida develop long-term corridor plans that are not financially constrained to identify locally important future corridors (23). These corridors may be designated for preservation and subsequent actions can be applied.
- The state of Nebraska is one of a handful of states that has mapping powers. Here, NDOT works with locals and the public to establish corridor priorities. Highest priority corridors are mapped and filed with permitting agencies and the state heavily relies on local jurisdictions to negotiate with developers to preserve right of way in the corridors.

- The Kansas DOT has a policy and process in place that allows corridors to be designated on local district plans. The state's Corridor Management Program requires that localities designate corridors as input for the development of plans by the state. Kansas' approach places heavy emphasis on coordination among the DOT, MPOs, and local jurisdictions. The program is funded by the state and encourages Memorandums of Understanding (MOUs) between cities, counties, and KDOT in pursuing corridor preservation (18).

Outside of the U.S., some European countries use early or advance right-of-way acquisition, or coordinating with local governments during long-term transportation planning to protect future transportation right of way from costly land use and development. These strategies help in accomplishing better decisions on future transportation needs and saving project costs and development time.

England uses protected highway designation to increase capacity of existing principal highways. Their Highways Agency may designate a major highway as protected, preventing new utility installations and sometimes expansions or replacements of existing utility facilities. Benefits of this strategy may include less right-of-way competition from utilities, better operations and capacity, and possible roadway expansion without further right-of-way acquisition.

## **LOCAL PLANNING PRACTICES AND FUNCTIONALITY**

Historically, the policies, practices, and actions of local jurisdictions in the areas of planning and land development have had a major bearing on the functionality of TxDOT roadways. Cities have authority to adopt comprehensive plans and subdivision regulations governing land use and development and the layout of local roads. Texas counties, on the other hand, have limited powers regarding land use and development, but have subdivision regulations and some transportation planning ability. Local planning, subdivision, and development authorities and practices have significant impacts on on-system facilities and can play an important role in TxDOT efforts to preserve, restore, and enhance highway functionality (20).

This section describes the policies, programs, and practices that municipalities in Texas undertake that to impact state highway functionality.

### **Comprehensive Planning**

Municipal comprehensive plans can play an important role in maintaining and preserving the functionality of TxDOT roadways. The two major components of a municipal comprehensive plan include a future land use plan and a thoroughfare plan. When properly coordinated, the future land use plan and the thoroughfare plan serve as a means to match or balance the intensity of land use with the proper functional class of both state and local roadways. Comprehensive plans may include separate plans, policies, and objectives in the areas of land use, transportation, utilities, parks, and other public facilities. Such plans impact the functionality of TxDOT roadways by setting forth

policies on direction of future growth, land use types and intensities, and key infrastructure extensions or improvements such as water and sewer.

TxDOT involvement in local comprehensive planning efforts is imperative in order to ensure that state highway functionality is considered not only in the process of developing the plan, but also in local adherence to the plan. Examples of involvement include:

- designating projected future state highway right-of-way alignments on the adopted comprehensive plan;
- creating approximate alignments for those highways so rights of way can be preserved;
- planning and managing access to future state highways as well as new access to existing state highways in a manner consistent with long range plans;
- coordinating the land use and transportation components of the comprehensive plan to ensure that access provisions do not compromise the future mobility efficiency of the highway; and
- coordination and input on transportation policies and development policies that may impact TxDOT right-of-way and facilities.

Working together, cities and TxDOT can use comprehensive plans to set the foundation for establishing practices and policies to help preserve, restore, or enhance state highway functionality.

### **Local Thoroughfare Planning**

Thoroughfare plans are prepared by cities and a limited number of Texas counties to identify and establish the layout of their existing and future transportation network by functional classification. Local transportation plans include state facilities and set forth policies and goals for the transportation system for a long-range planning horizon. For cities with zoning, a thoroughfare plan serves as one of two major components (along with the land use plan) of their comprehensive plan. Some cities in Texas do not have a zoning and a comprehensive plan, but still have an adopted thoroughfare plan. A survey of 51 Texas cities conducted in 2007 found that 90 percent of cities in Texas had an adopted thoroughfare plan (20). Local thoroughfare plans address the following:

- assign functional classifications to all thoroughfares (including state roadways) within a city's limits and typically within its extra-territorial jurisdiction;
- identify other modal elements and types of fixed facilities (if any) and depict future right-of-way needs by functional class; and
- indicate the ultimate size and function of existing and future roadways and the general alignments of planned facilities.

Local thoroughfare plans are tied back to subdivision regulations that typically include geometric design and accessibility criteria for each functional class of roadway included on the plan. Local thoroughfare plans and transportation planning activities, or the lack thereof, can impact state highway functionality in many ways. They can be used:

- to develop a supporting local street network adjacent to state roadways;
- for applying and requiring acceptable functional classification standards and criteria for local roadway layout, connectivity, and intersection spacing; and
- for protecting and preserving right of way as part of the local development process.

In addition, local plans often serve as the basis for application of local access ordinances and other development ordinances, where regulations on spacing, driveway design, and on-site components may be based on a roadway's functional class.

The purpose of most state highways is to carry longer trips at higher speeds. However, if there is no supporting local street network, the state highway will also carry many short local trips. These shorter trips add significantly to the congestion on the state highway. Supporting local streets provide an alternate route for shorter trips and relieve some of the traffic from the state highway. Supporting street networks can be required through local thoroughfare plans, subdivision regulations, and the platting process. Under functional hierarchy standards, minor streets serving local short trips should not take direct access to most TxDOT facilities, which are intended to serve longer distance, higher speed travel.

#### *Application of Functional Classification Standards and Criteria*

Standards and criteria relating to functional classifications of roadways identified on local thoroughfare plans are included in local subdivision and development regulations. The standards are used to help control the layout, spacing, connectivity, and level of access to roadways and should serve to preserve or enhance functionality. [Table 4](#) shows typical functional criteria for arterial, collector, and local (residential) roadway classes found in many local regulations (4).



**Table 4. Functional Classification Criteria.**

<b>Characteristic</b>	<b>Arterial</b>	<b>Collector</b>	<b>Local Street</b>
Street Spacing	1 mile	¼ mile	300 ft
Length	Continuous	½ mile	500 ft
Lanes	4-6	2	2
Minimum Pavement	64 ft	36 ft	32 ft
Access Spacing	1,300 ft	300 ft	60 ft
Volume	30,000 vehicles per day	5,000 vehicles per day	200 vehicles per day
Striping	Center and lanes	Center	None
Driveway Design	Curb return	Curb return	Dustpan
Parking	Prohibited	Allowed	Encouraged
Median	Yes	No	No
Turn Lane	Yes	No	No
Traffic Signals	Yes	No	No
Residential Access	Prohibited	Indirect	Direct
Maximum Grade	6%	8%	10%
Minimum Radius	1,150 ft	350 ft	170 ft
Pedestrian Crossing	Signalized Intersection	Intersection	Unrestricted
Pedestrians	Few	Many	Frequent
Speed	40 mph	30 mph	20 mph
Building Setback	Considerable	Moderate	Minimum

Source: Marks, H. *Traffic Circulation Planning for Communities*. Gruen Associates, Los Angeles, 1974.

### *Application of Subdivision and Zoning Regulations*

Local use of subdivision and zoning regulations, particularly on land immediately adjacent to TxDOT roadways, have major relevance and impacts to functionality of TxDOT roadways. Local subdivision and platting regulations are used to regulate the subdivision of land and establish requirements for infrastructure (if any), typically in accordance with a comprehensive plan or a transportation plan. Chapter 212 of the Texas Local Government Code (LGC) entitled ‘Municipal Regulation of Subdivisions and Property Development’ provides authority for municipalities to regulate subdivisions within in its incorporated limits as well as in its extraterritorial jurisdiction (ETJ).

A major cause of deterioration of highway functionality is the encroachment of development on future right of way needed for planned roadway expansion. Local jurisdictions in Texas, primarily cities, frequently use their subdivision regulations to protect or preserve TxDOT rights of way by requiring either right of way dedications or reservations on plats. Right-of-way dedications are required contributions of land (via eminent domain) for public right of way, while reservations prohibit building permanent structures on property that may be needed for future right of way. Unlike dedications, reservations do not involve a transfer of ownership.

It is through the platting process that cities and counties can get right of way dedicated or preserved (for local or TxDOT facilities) in order to adhere to the functionality of roadways identified on plans. Other important local practices in platting that benefit highway functionality include:

- the control of lot sizes and depths (often in combination with zoning);
- requirements for access easements to consolidate or minimize access points along roadways; and

- adherence to proper hierarchal street spacing or connectivity standards in subdivision layout.

One major cause of the deterioration of highway functionality is growing traffic volume that eventually exceeds the capacity of the road. The increase in traffic volumes is usually caused by land development that outpaces construction of new capacity. Zoning gives cities the ability to use and implement the land use section of their comprehensive plan. It can help to preserve highway functionality by creating a balance between intensity of land use and the intended function and capacity of roadways. Through zoning, cities can limit development intensity so that the number of trips generated does not exceed the capacity of nearby roads. Likewise, intense development can be planned and zoned in places where the transportation network has been designed to handle large traffic volumes. Key regulations stemming from zoning that cities in Texas commonly use that impact functionality on TxDOT roadways include:

- number of dwelling units per acre,
- lot size and depth,
- building size and setbacks from right of way,
- percentage of lots/parcels that can occupied, and
- corridor overlay zones.

In Texas, LGC Chapter 211 allows municipalities to adopt zoning in accordance with a comprehensive plan. This authority allows cities to coordinate land use intensity in relation to the functional class of adjacent thoroughfares, be they local or TxDOT facilities. A survey of 51 Texas cities conducted in 2007 found that 96 percent of them had zoning (20).

#### *Local Access Management Practices*

The practice of access management at the local level, or lack thereof, has a major bearing on the functionality of TxDOT roadways within communities in Texas. The primary way it is practiced is through compliance with a driveway ordinance as part of the municipal subdivision and site plan review processes. This ordinance chiefly regulates the number, location, and spacing of access points and is a tool used help implement and maintain a thoroughfare plan by helping roadways to retain their intended function. A survey of 51 cities in 2007 found that a majority of Texas cities (73 percent) had an access (or driveway) ordinance (20). TxDOT's access management manual contains guidelines for driveway spacing based on the speed limit for state highways, one-way frontage roads, and two-way frontage roads. Many municipal driveway ordinances set forth minimum driveway separation distances based on the functional class of roadways included on their thoroughfare plan.

Across the state, partnerships between TxDOT districts and cities in implementing access regulations are typical practice, with most coordination occurring as part of site plan reviews and some plat requests adjacent to state roadways. Review of proposed

driveways on site plans is often conducted in concert with TxDOT coordination for the driveway permit. A survey of 92 cities in 2003 found that 87 percent of cities coordinated with TxDOT on review of driveways as part of their site plan review process (15). The same survey found that 59 of 90 cities included TxDOT in their plat review of properties along state roadways for coordinating access points.

The authority to enforce many of the requirements set forth in municipal access ordinance stem from subdivision and/or zoning regulations. Because of this, over the past few years it has become increasingly evident through TxDOT outreach workshops that cities play an important role in assisting TxDOT at implementing its access guidelines. For example, cities commonly require access easements so that local and/or TxDOT driveway spacing requirements can be met. Other aspects of local access management practices that are not uncommon in Texas include:

- requirements on inter-parcel connectivity in site layouts;
- special requirements regarding access for corner parcels in order to minimize or prevent conflicts with turning movements at intersections;
- regulations of driveway throat length generally based on the amount of anticipated traffic generation, queuing, and/or potential for signalization;
- requirements on lot dimensions such as width and depth (through zoning) that can impact access location and design; and
- requirements or policies on the use of arterial frontage or backage roads, typically related to major commercial developments or subdivisions.

Two other ways cities practice access management is through:

1. adopted polices and/or standards for cross-sections on arterial roadways requiring non-traversable medians; and
2. adherence to proper street spacing and connectivity standards as part of street layout plans in subdivision plats.

Since many arterials in Texas cities are state roadways, local policies, or requirements for non-traversable medians in arterials provide support to TxDOT in rehabilitations and upgrades to facilities.

Access management in Texas at the local level is undertaken almost entirely by cities. Few counties in Texas practice access management since they have little authority to regulate access and development, and most do not have the ability to adopt a thoroughfare plan. However, some counties engage in access management by using their subdivision regulations to adhere to functionality standards in street layout/connectivity to TxDOT facilities as well as in the use of access easements to consolidate and/or minimize access points to TxDOT roadways. A 2003 survey found that only about 30 percent of counties have a driveway application requirement, and of those that do, only a handful of Texas counties indicated applying these to state roadways (15).

Research has clearly shown that excessive access can lead to decreases in the safety and operational capacity of a highway and causes deterioration of highway functionality.

A routine and on-going cooperative TxDOT-local practice of managing access as part of the local development process is part of the solution. The practice of access management should be comprehensive, guided by highway functionality, and address spacing between interchanges, signalized intersections, unsignalized median openings, and unsignalized access connections. Locations of future interchanges are often included on local thoroughfare plans and unsignalized access points are addressed through local access ordinances. Few local jurisdictions consider signal spacing in planning or in the consequences of their development decisions. Consideration for signals and signal spacing along TxDOT facilities is one area of planning and access managements at the local level, which should be given higher priority.

### *Corridor Management Practices*

In addition to comprehensive plans and transportation plans, cities and MPOs can develop and implement special plans to manage and preserve various aspects of transportation, land use, and development along a specially designated segment of a corridor. Over the past 10 years, there have been numerous corridor management plans and corridor access management plans developed along TxDOT roadways. This activity involves coordination and communication between TxDOT and cities on property subdivision, zoning, public utilities, access management, roadway planning and design, medians and signalization. Corridor Management (CM) and the development and adoption of corridor management plans is without question an optimal planning activity when it comes to preserving or enhancing highway functionality.

CM is a planning strategy that coordinates roadway design and function with land use and development. It includes measures or practices that are conducted in accordance with adopted land use plans, roadway improvement plans, access management, future right of way needs, and/or any specially adopted plans for a defined corridor. A 2000 National Cooperative Highway Research Report (NCHRP) synthesis on corridor management generally defines it as ‘the application of multiple strategies to achieve specific land development and transportation objectives along segments of a corridor’ (24).

In Texas, there are numerous corridor management plans on TxDOT facilities that have been developed by local jurisdictions. These special studies serve as a long-range plan for a corridor, can vary widely in type and scope, and typically address one or more of the following areas:

- roadway design and/or streetscape,
- land use, development standards, utility placement,
- access and operations, and
- local street networks.

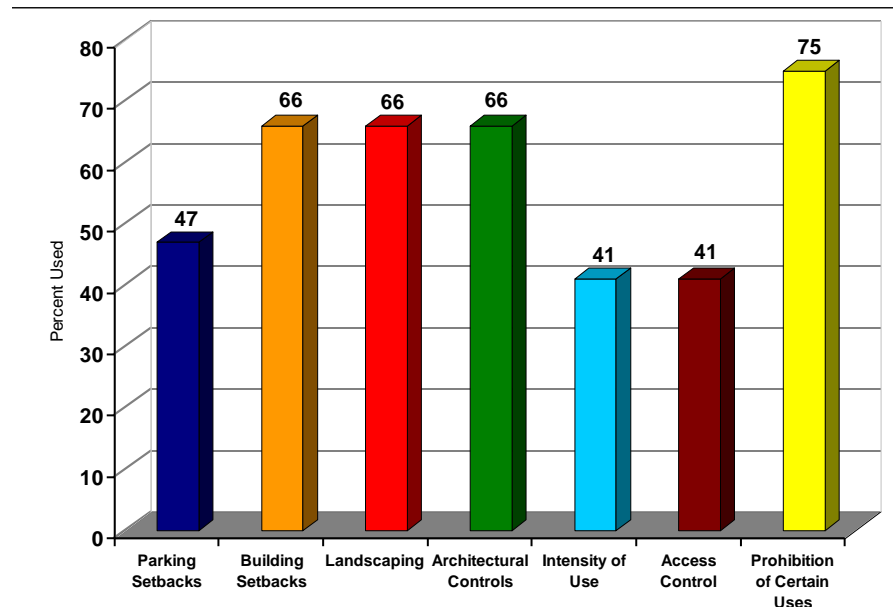
CM plans developed by cities in Texas (with zoning) typically emphasize land use and development standards, and to a lesser extent address the other components. Such plans developed in areas without land use controls will generally focus more access, operations, and roadway design elements that affect functionality.

CM plans are implemented through roadway improvement projects and/or as part of the local planning and development process through a wide variety of local and TxDOT tools, policies, and practices. [Table 5](#) provides a list of tools, techniques, and practices that can, and in most cases have been, used by local jurisdictions and TxDOT to carry out CM plans.

**Table 5. Corridor Management Tools that Benefit Functionality.**

Tool, Technique, or Practice	Local Ability		TxDOT Ability
	Zoning	Subdivision Regulations	
Driveway Spacing		✓	✓
Non-Traversable Medians		✓	✓
Signalized Intersection Spacing		✓	
Arterial Frontage and Backage Roads		✓	
Acquisition of Access Rights		✓	✓
Site Plan Review	✓	✓	
Land Use, Density Controls	✓		
Building and Parking Setbacks	✓		
Zoning Overlays	✓		
Driveway Throat Length	✓	✓	
Right of Way Exactions		✓	
Access Easements		✓	
Control of lot size, dimensions	✓	✓	

For cities, the primary tool used to implement a corridor management plan is a zoning overlay district. An overlay is a set of special requirements that are ‘overlaid’ and added to the existing requirements of the base zoning districts of parcels within defined corridor. It is an effective mechanism for cities, TxDOT, and MPOs to partner and practice CM along TxDOT roadways. A 2007 survey of 46 cities found that 61 percent of them (28 cities) had used a zoning overlay district. Figure 4 illustrates the types and percentages of special requirements that were included in zoning overlays in Texas based on this 2007 survey.



**Figure 4. Regulations Used in Zoning Overlay Districts in Texas.**

Examples of cities and segments of TxDOT facilities that have corridor zoning overlay districts include:

- SH 130 in Hutto, Texas,
- Segments of SH 289 (Preston Road) in Plano and Frisco,
- IH 20 and SH 161 in Grand Prairie,
- FM 60 (University Drive) in College Station, and
- SH 121 and Dallas North Tollway in Plano.

Cities draw on their authorities and adopted policies contained within their comprehensive plans, subdivision regulations, and zoning ordinances to support CM planning. In addition to access management, local development policies that have been used that support CM and benefit highway functionality include:

- requiring connections between neighborhoods;
- limiting unnecessary local street connections to TxDOT roadways; and
- encouraging ‘activity center’ types of development in lieu of strip development.

Local adherence to these three policies, over the long term, would have a significant benefit to the functionality of TxDOT facilities.

As discussed in the previous section on MPO practices, the Houston Galveston Area Council of Governments, has conducted large-scale corridor access management studies on several rapidly growing and congested highways in the Houston region over the past 5 to 6 years. The agency has completed studies on segments of FM 1093 (Westheimer Road), FM 518, and FM 1960, FM 2920, and SH 6. HGAC has incorporated these corridor access management studies and subsequent improvement projects into their planning process and the agency’s UPWP.

While counties in Texas generally cannot regulate land use and development, they do have abilities through their subdivision and on-site septic regulations and to take actions of benefit to CM practices. Counties can review the layout of lots and streets through the platting process and possibly address access and local street spacing along TxDOT roadways. According to a 2003 survey, 83 percent of Texas counties have adopted subdivision regulations (15). They can also assist TxDOT with its implementation of access spacing guidelines by working to include access easements in plats.

Counties can control rural development densities and therefore traffic generation through their authority to establish minimum lot size requirements for on-site septic facilities (OSSF). Texas counties have the option of enforcing the Texas Council on Environmental Quality’s (TCEQ) requirements or adopting their own regulations that may be more restrictive. The difference between TCEQ’s and county adopted regulations, typically relates to lot size requirements and the septic system design. Over

the past decade, the use of aerobic OSSF has contributed to a proliferation of residential subdivisions in suburban or rural areas containing lot sizes of 1 or more acres.

In the area of planning and land development, there are numerous activities and practices that are sources of functional deterioration to TxDOT roadways. Chief among these is the general lack of coordination and integration of transportation and land use planning and decision making. More specific and related causes include:

- unplanned and haphazard growth;
- uncoordinated and narrow subdivisions of land adjacent to TxDOT roadways;
- lack of vehicular connections between developments;
- lack of a supporting local street network and unnecessary minor street connections to TxDOT roadways;
- insufficient coordination between TxDOT and local jurisdictions;
- poor or inadequate signalized intersection location and spacing; and
- lack of ability by Texas counties to regulate land use and development and inability of most Texas counties to adopt thoroughfare plans.

Many communities in Texas have incorporated, to varying degrees, corridor management approaches into their planning and development processes that will help curtail the above sources of functional deterioration on TxDOT roadways. Through coordination with TxDOT, more measures can be added or emphasized in corridor management plans that optimize transportation and mobility aspects.

#### *Corridor Preservation by Local Governments*

A survey 307 local governments in the U.S. conducted in 2000 by the American Planning Association (APA) found that about 80 percent (with variations by population) participated in corridor preservation. By comparison, a 2007 survey of 51 Texas indicated that 63 percent were involved in corridor preservation, but only 4 percent had a funding source for land acquisition. The 2007 survey found that most Texas cities acquire land for thoroughfares primarily through plat dedication, but also through purchase, options to purchase, donations, and land trades.

According to TxDOT's right of way manual, local public agencies may purchase property for a state project prior to completion of environmental without jeopardizing state and federal participation, if certain conditions are met. *However, such practice would be at the financial risk of the locale (if environmental clearance is not obtained) and should not be undertaken without close coordination by TxDOT.*

While few, if any, cities in Texas have established corridor preservation programs, it is common for them to partner with and assist TxDOT in preserving land for a future state facility. As part of the platting and development process, cities may have opportunities to protect and/or preserve land and/or minimize conflicts for a future TxDOT corridor using:



- land use plans and zoning;
- land dedications or reservations in accordance with a transportation plan and subdivision regulations in amounts that are roughly proportional to the impact of the development; and
- outright purchase or purchase options (at their own financial risk).

There are also tools and incentives cities can use to practice corridor preservation such as interim or temporary use agreements with landowners, tax abatements, and transfers of allowable densities and development rights.

In the Dallas-Ft. Worth area, the City of Plano has partnered with TxDOT to preserve land for state corridors and interchanges. For the President George Bush Turnpike (SH 190), the city designated right of way for preservation to both preserve the corridor for eventual construction and to recognize the City responsibility for 10 percent of the right of way cost. Plano was able to obtain much of the land through dedication from landowners, who intended to or were developing along the corridor, and who recognized the value of having the highway. The City also purchased some access rights along the SH 190 as well as additional right of way that was needed for future grade separations on SH 289 (Preston Road).

The lack of authority for most Texas counties to adopt a thoroughfare plan is significant limitation on their ability to practice transportation planning and corridor preservation. Under current state law, only a small percentage of Texas' 254 counties have the authority to adopt and enforce a 'major thoroughfare plan' similar to what is done at the municipal level in Texas. In 2001, section 232.100 of the Texas LGC was amended to allow counties meeting certain population thresholds to develop and enforce a thoroughfare plan. Counties meeting these criteria include those generally in the major metropolitan as of the state as well as a few along the Texas-Mexico border.

Since 2001, several counties in Texas have developed county-wide transportation plans. Since the large majority of roadways on these plans may be TxDOT facilities, TxDOT involvement with counties on these plans to help establish future right-of-way needs and functionality is imperative. Known Texas counties that have adopted thoroughfare plans include Comal, Harris, Bexar, Chambers, and Travis (20).

The large majority of Texas counties does not meet the criteria in LGC 232 and cannot adopt thoroughfare plans. These counties lack the ability to acquire or preserve right of way in accordance with a transportation plan and thus cannot require additional right of way needed for a planned improvement to an existing highway or for a future highway as part of the subdivision process.

Legislation passed in 2007 gave counties in Texas authority help preclude development in planned corridor. Senate Bill 1857 bill amended LGC 232.0033 and added section on 'Future Transportation Corridors.' The bill gives added impetus for TxDOT and counties to coordinate and partner of corridor preservation. Under the bill, a county may refuse to approve a plat in a preserved corridor if:

- it does not state that the subdivision is located within the alignment of a transportation project as shown in the final environmental decision document; or
- all or part of the proposed subdivision is located within the area of the alignment of a transportation project as shown in the final environmental decision document.

This new legislation also requires that purchase or lease contracts for land in the subdivision must contain a conspicuous statement that the land is located within the area of the alignment of a transportation project.

Practices that have been used by Texas counties to assist in corridor preservation and advanced acquisition include:

- through coordination and consultation with TxDOT, acquire or preserve land needed with agreement that it be applied toward the local match;
- through coordination and consultation with TxDOT, serve as the recipient of deeded or donated land for a future corridor with agreement that it be applied toward the local match; and
- develop a cooperative process with TxDOT where it is notified of subdivision plats and permit requests that may impact a planned TxDOT facility.

### 3. OPERATIONS AND FUNCTIONALITY

TxDOT operates one of the largest highway systems in the country. The functionality of that system relies on the traffic operational performance of the entire network, including nodes (i.e., intersections) and links (i.e., roadway segments).

Nationwide, various manuals and guidebooks have been developed to facilitate the transportation system operations and management. The 2000 Highway Capacity Manual (HCM) (25) serves as a fundamental guidebook for designing and assessing the capacity and service quality of various types of roadways. The Manual on Uniform Traffic Control Devices (MUTCD) (26) provides standards and guidance for the design, installation, and use of traffic signs, roadway markings, signals, and many other traditional traffic control devices. The recently published Traffic Signal Timing Manual (27) assists traffic engineers with a collection of traffic signal control principles, practices, and procedures at the national level. TxDOT also has its set of manuals—discussed later in this chapter—that are used to guide operation of the state highway system. All of the resources are aimed at assisting TxDOT (and other Texas transportation agencies) to operate the street and highway system in Texas in an efficient and safe manner.

Despite the extensive efforts to improve highway functionality nationwide, roadways in many urban areas remain congested. Much of the congestion is attributable to operations and capacity deficiencies, such as ineffective or inefficient traffic control, underutilization of alternative travel modes, poorly maintained or outdated traffic signals, or facility design that does not meet current operational needs.

This section provides a brief review of the policies and practices in three areas pertaining to system operations that can help to preserve and improve highway functionality. These areas include:

- traffic control and management;
- traffic signal optimization and coordination; and
- facility design and enhancement.

#### **Operations Objectives**

Traffic operations have four primary objectives associated with improving mobility and functionality. These include:

- increasing operating capacity;
- improving operational efficiency (e.g., reduce stops and delays);
- Increasing reliability (i.e., improve travel time consistency); and
- accommodating temporary conditions (e.g., incidents, maintenance, construction).

This chapter also discusses measures to address operational deficiencies that can cause functionality loss. These measures are each usable for one or more of the

operational objectives. Finally, this chapter provides some performance measures that can be used to monitor and evaluate highway operational functionality.

## **TRAFFIC CONTROL AND MANAGEMENT**

### **Major TxDOT Policies, Regulations, and Practices**

While expanding existing highways or building new ones is often first thought of as a way to increase facility capacity, improving traffic operations and management can often produce major capacity and travel time improvements and be a cost-effective way to mitigate traffic congestion.

Traffic congestion is a major contributor for highway functionality loss. In addition to traffic delays, it can lead to vehicular crashes, energy waste, and air pollution. Bottlenecks and traffic crashes are the top two factors causing traffic congestion nationwide (28). To address network operational issues, TxDOT has implemented a variety of operational strategies over the years, with a focus on both improving existing practices and implementing research innovations. For example, TxDOT has developed the Texas MUTCD (TMUTCD) (29) and the Signs and Markings Manual (30) to better guide and regulate the use of traffic control devices on Texas highways. TxDOT also developed other manuals related to traffic operations such as the Freeway Signing Handbook (31), Standard Highway Sign Designs for Texas (SHSD) (32), and Traffic Data and Analysis Manual (33).

Effective traffic control is the key to improving traffic operations and management. As outlined in the TMUTCD, TxDOT has been using many traffic control devices and methods on Texas highways for ongoing operations. Standards and guidelines for temporary traffic control in highway work zones were also included in various related TxDOT manuals to improve safety and mitigate the functionality loss due to changes of traffic patterns.

In addition to the traditional traffic control measures, TxDOT has been using various intelligent traffic systems such as Advanced Traffic Management Systems (ATMS) (34) to enhance the traffic and incident management on Texas urban arterials. TxDOT has also initiated a number of research efforts to improve the effectiveness and reliability of traffic control measures including temporary traffic control devices and ITS applications. Some of these efforts include a comprehensive evaluation of multiple traffic control devices (35), improvements on freeway and work zone traffic control (36), and enhancements to ITS applications (37). The following is a brief summary of the general areas where ITS applications have been used (38). Many of these applications, listed below, share the same concepts and core functionalities:

- roadway management (e.g., freeway and other arterial management, crash prevention and safety, road weather management, and roadway operations and maintenance);
- transit management;

- transportation system management and operations (e.g., traffic incident management, emergency management, toll facility management, traveler information, and traffic information management);
- freight management (e.g., commercial vehicle operations and intermodal freight management); and
- intelligent vehicles (e.g., collision avoidance, driver assistance, and collision notification).

At present, ITS applications in Texas are focused primarily on freeways. Operations are monitored and conditions made available to transportation agencies and travelers. Incident management is a priority throughout highway segments that are monitored. For example, the DalTrans ITS program (39) in the north Texas region consists of approximately 200 cameras linked to the DalTrans transportation management center to collect traffic data and monitor traffic performance on major roadways in the region for real-time traffic information and quick incident response. The Houston TranStar program (40) is the counterpart for Houston area that is responsible for not only transportation management, but also emergency management in cases such as hurricanes, floods, industrial explosions, or terrorist attacks.

To more effectively use the existing highways, TxDOT has been continuously exploring other strategies, such as toll roads, high-occupancy vehicle (HOV) or toll (HOT) lanes, and public transit, to increase capacity, improve efficiency and reliability, and mitigate traffic congestion. To improve the management practices of toll facilities, TxDOT funded a number of research initiatives on related topics such as signing (41), toll collection (42), toll lane separation (43), and public outreach (44). In addition, TxDOT (and regional transit authorities) are continuously working to improve the state's public transportation. In conjunction with this effort, TxDOT also funded research projects to facilitate public transportation planning and operation (45, 46).

TxDOT has developed strategies to facilitate incident management and emergency evacuation. Many major urban areas, such as Houston, San Antonio, Fort Worth, Dallas, Austin, and El Paso, have developed freeway management systems utilizing ATMS for rapid detection and response of traffic incidents (47). Individual researchers funded by TxDOT have also explored potential improvements to these existing systems including their operations (48) and data processing techniques (49). In response to hurricanes, TxDOT has developed strategies to address the massive traffic demand during evacuations. A comprehensive hurricane evacuation system has been in use that consists of evacuation routes, designated evacuation lanes, and contraflow lanes. In addition, TxDOT initiated a series of research efforts to improve evacuation operations in various aspects such as real-time data processing, traffic control, and use of ITS (50, 51, 52).

Many other efforts in Texas also help to improve mobility and safety across the state. Texas Transportation Code has included provisions such as the driver removal requirement (53) that requires a driver to move the vehicle off the major roadway when an accident occurs on a main lane, ramp, shoulder, median, or adjacent area of a freeway in a metropolitan area. In conjunction with local agencies, TxDOT developed motorist assistance programs to better help travelers in case of incidents, such as the Motorist Assistance Program (MAP) in Houston that involved TxDOT, Harris County, and private

parties (54). The program sends vehicles equipped to handle minor automotive incidents upon requests by phone during weekdays at no cost. It provides convenience to travelers and reduces stalled vehicles that may otherwise affect mobility.

Public education is another important component of TxDOT's strategies for improving the effectiveness of traffic control and management. Public education programs may reduce aggressive or reckless driving behaviors and consequently increase traffic control compliance. Across Texas, several public education programs have been launched to improve safety, reduce congestion, and reduce traffic-related air pollution. TxDOT launched a multi-million podcast program in 2008 as a major effort to improve public information and outreach (55). It offers the public weekly podcasts on a wide range of statewide transportation topics including mobility issues and proposed solutions through the KeepTexasMoving.com web site.

## **SIGNAL COORDINATION AND OPTIMIZATION**

### **Major Policies, Regulations, and Practices at TxDOT**

Inefficient traffic signal timing accounts for an estimated 10 percent of all traffic delay on major roadways in the United States. The Institute of Transportation Engineers recommends that traffic signals be retimed every three years. However, among the approximate 330,000 traffic signals in the nation, about 75 percent are overdue to be optimized through improved timing and signal coordination (56). TxDOT maintains and operates approximately 6,200 traffic signals in Texas (57). Good practices on timing and coordinating this signal network can reduce system-wide traffic delays, increase average running speeds, and improve intersection capacities. At the national level, the FHWA Traffic Signal Timing Manual (58) serves as a key guidance for timing signals.

Signal coordination is generally achieved through two strategies, including (1) maximization of the bandwidth of the progression and (2) minimization of the overall delay and stops. TxDOT has developed the Traffic Signals Manual (59), to assist individual districts in the design and coordination of traffic signal systems on the state highway system. In addition, TxDOT has been using various software tools such as TTI PASSER<sup>TM</sup>, Transport Research Laboratory (TRL) TRANSYT, Trafficware<sup>®</sup> SYNCHRO<sup>®</sup>, and HCS to support signal design and coordination.

As described in the Texas Traffic Signals Manual, the traffic signal installation procedure in Texas involves several steps, including traffic signal installation request, installation request acknowledgement, traffic study for signal justification, installation design, traffic operations division approval, and final construction. For an intersection to be signalized, it should meet at least one of the warrants as defined in TMUTCD. However, optimal operational functionality is not achieved by merely meeting warrants or installing the signal. It needs proper phasing and timing, not only initially, but also as traffic volumes increase and traffic patterns evolve. In order to achieve proper phasing and timing, adequate spacing and separation distances are needed between signal installations and should be considered as part of the warranting and approval process.

TxDOT operates and maintains the traffic signals on the state highway system in incorporated cities of less than 50,000 population. It is responsible for authorizing traffic

signals to be installed on the state highway system at the cities' cost in incorporated cities of 50,000 or more population (59). Because it involves multiple jurisdictions and agencies, operating and maintaining the entire signal system in the state requires extensive multijurisdictional and interagency collaboration. For example, the City of Houston operates all traffic signals within its jurisdiction, including those on the frontage roads of major freeways. Cooperation in spacing and timing those signals is critical to ensure the smooth transition between on system and off system. In addition, it also helps to avoid excessive travel delays on the state highway system including the freeways in the area.

Different cities may have different practices pertaining to traffic signals in their jurisdictions depending on their staffing and funding availability. The City of San Antonio is currently undergoing a five-year traffic signal system modernization (TSSM) program that replaces existing traffic signals with more advanced signal systems (60). The city currently has more than 1,200 signals controlled by 20-year-old technology. The upcoming signal systems consist of upgraded field hardware linked with the City's traffic management center through a new communications network. The center uses state-of-the-art central control system software and hardware that allow real-time and remote signal timing adjustment and optimization. In addition to FHWA funding support, the majority of the TSSM funds come from the advanced transportation districts (ATDs) tool authorized by state law that allows the city to collect a quarter of one percent of the state sales tax for regional transportation projects. Other cities such as the City of Houston and the City of Dallas have also developed traffic signal systems with comparable features.

Over the years, TxDOT and other local research agencies have funded a large number of research projects to improve the signal design and coordination practices on the state highway system. Examples of TxDOT research efforts include the development of a Texas Traffic Signal Operations Handbook (57), guidelines for conducting traffic signal warrant analyses (61), and a traffic signal performance measurement system (TSPMS) (62). Other stakeholders in Texas also initiated research to investigate methodologies for more intelligent and efficient signal control and coordination in major intersections (63, 64).

### **Policies, Regulations, and Practices outside TxDOT**

Well-operated traffic signal systems are a key to improved transportation system performance. However, a nationwide examination on the traffic signal operation practices in 2007 indicated that the vast majority of traffic signal systems across the nation were not very well operated and most required improvements (65). According to the evaluation, many public transportation agencies and localities lacked sufficient management staffing or capabilities for traffic signal operations and suffered from poor practices on traffic monitoring and data collection. Although the evaluation showed an overall low grade for the traffic signal operation across the country and across all jurisdictional types, the review found a number of good practices on traffic signal operations and management. The following summarizes some examples of these good practices:

- **Cross-jurisdictional signal system management and coordination.** Good cross- or multi-jurisdictional signal system management and coordination help transportation agencies to improve practices from various aspects including program leadership, strategic planning, workforce development, and resource allocation, and therefore benefit traffic signal operations in a long-term basis. A previous study (66) found that a number of agencies across the nation had developed innovative approaches to successfully utilizing cross-jurisdictional traffic signal coordination. These approaches focus on better communications and cooperation achieved through methods such as inter-agency agreements and centralization of traffic control systems. For example, in the Dallas-Fort Worth area, over 1,500 signals in 11 cities and two TxDOT districts have been retimed since 2004 (67).
- **ITS applications for traffic signals (56).** Many transportation agencies have utilized ITS applications, including communications systems, adaptive control systems, traffic responsive, real-time data collection and analysis, and maintenance management systems, to enhance traffic signal system operations and management. Studies showed that incorporating them into the planning, design, and operation of traffic signal control systems could yield recognizable improvements in travel time, vehicle operating costs, and vehicle emissions—as long as they are properly maintained and periodically optimized. For example, the Los Angeles Department of Transportation’s Adaptive Traffic Control System (ATCS) was found to considerably improve the city’s traffic signal system in terms of travel time, average stops, and average delays.
- **Routine signal timing evaluation and optimization.** Case studies showed that routine, proactive signal timing evaluation and optimization helped to preserve and enhance the serviceability (and functionality) of traffic signal systems and resulted in noteworthy system-wide benefits characterized by reduced traffic delay, air pollution, and fuel consumption (65).
- **Use of traffic signal system audit (TSSA).** By incorporating TSSAs into the design and management of traffic signal and associated systems, transportation agencies can better identify on-going and new needs before signals are installed or redesigned (68). The objective of a TSSA is to assess the status of an agency’s traffic signal system design, management, operations, maintenance, and/or safety practices relative to generally recognized best practices and to recommend actions that might be taken by the agency to incorporate these practices into its existing operation.

## **FACILITY DESIGN AND ENHANCEMENT**

### **Major TxDOT Policies, Regulations, and Practices**

Good planning and design are critical for highways to serve travelers with optimal functionality throughout their design lives. The American Association of State Highway and Transportation Officials (AASHTO) publishes a policy guidebook for geometric



design of highways and streets that contains detailed requirements and guidelines for designing roadway geometrics (69). In addition, AASHTO also publishes several other guidebooks for designing roadway facilities and accessories (70, 71, 72). In addition, TxDOT uses their own Roadway Design Manual (73) complemented by the AASHTO design guide and HCM when designing transportation facilities in the state.

When operational improvements can no longer recapture or enhance the functionality of an existing roadway to meet the continuously growing demand, roadway expansion, reconstruction, or other minor or major improvements are necessary. As estimated by the Governor's Business Council, the need for highway improvement in Texas over the next 25 years would require an additional \$78 billion that need to be gathered through traditional or non-traditional methods (74). To improve system mobility and traffic capacities, TxDOT has constructed bypass or parallel facilities for many highways and freeways in the state.

TxDOT has improved or is planning to expand several strategic highways across the state to improve state-wide mobility. TxDOT has developed ambitious plans to expand the current SH 130, IH 69, and Loop 9 corridors to meet long-term transportation needs in the state. The recent reconstruction of Katy Freeway in the Houston area is another example of facility enhancement to improve mobility. The old Katy Freeway was a rural freeway originally developed in the 1960s. It had three main lanes and two frontage lanes in each direction, with a traversable transitway in the median. The freeway's functionality deteriorated significantly over the past few decades due to increasing traffic demand, resulting in severe traffic congestion, safety, and maintenance problems. The latest reconstruction between 2003 and 2008 expanded the rural freeway to a mega freeway with at least four general-purpose lanes and three frontage lanes in each direction. The new freeway also has one to two managed lanes in each direction that combine both toll and HOV concepts. Mechanisms were used during the freeway design and construction to accommodate a light rail as well for long-term traffic demand.

To provide the financial foundation for highway enhancement or construction in the state, Texas has various funding options including comprehensive development agreements, regional mobility authorities, pass-through financing, and tolling (75). TxDOT also established many funding programs for highway projects either independently or jointly with FHWA, such as Texas Mobility Fund, Statewide Transportation Enhancement Program, and Participation-Waived/Equivalent-Match Project Program. However, improvement needs far exceed available funds, so using operational improvements to optimize operational efficiency and functionality is critically important.

Instead of significantly expanding existing facilities or building new roadways, minor geometric and operational enhancements, such as re-striping, ramp modifications, interchange improvements, and intersection and other bottleneck improvements can be a cost-effective alternative for increasing highway functionality. In Texas, different districts have different policies/practices on using minor enhancements and frequently these enhancements are results of assessments for individual cases. When used properly, these measures can yield many benefits including capacity increase and safety improvement. The following is a summary of minor enhancement mechanisms used in Texas:

- **Restriping.** Restriping refers to minor lane reconfigurations such as addition of auxiliary lanes and shoulders, ramp reconfigurations, and intersection reconfigurations. For example (76), a bottleneck area on IH 35 East in Dallas was improved by replacing a little-used exit ramp with an entrance ramp, which resulted in considerable reduction of delay and crash rate. Another bottleneck area on northbound SH 360 in Arlington was improved by extending an auxiliary lane between two exiting exits by 700 ft to the next exit, which cost \$150,000 yet resulted in estimated yearly delay benefits of \$200,000 and substantial reduction of injury crashes. The lane reconfiguration at the interchange between IH 10 and US 54 in El Paso successfully decreased traffic delays in the area and the overall benefits of the improvement were estimated at \$1.3 million.
- **Access control improvements.** Improving access control along roadways may reduce crashes and improve travel speeds. TxDOT uses a large variety of measures to achieve better access control, such as use of raised medians, conversion of undivided highways to divided highways, use of grade separations at intersections, addition of frontage/backage roads, and consolidation of abutting access points. For example, compared to two-way left-turn lanes (TWLTL), raised medians restrict left turn movements and are suitable for roadways with higher speed limits and volumes. Median openings with turn bays can be used in conjunction to enable left turns at appropriate locations. Over the past decade, there have been many TxDOT projects around the state where upgrades and rehabilitation of urban arterials have included non-traversable medians, such as FM 1960 and Westheimer Road (FM 1093) in Houston, US 69/Broadway Street in Tyler, and SH 6/Texas Avenue in College Station.
- **Minor operational improvements.** Examples of minor operational improvements include use of managed lanes (e.g., HOV or HOT lanes), ramp metering, use of ITS applications, and other traffic control improvements. For instance, a transitway system was developed on several major radial freeways in Houston areas by adding a traversable HOV lane in the median of each freeway. These transitways serve a significant proportion of person volumes on these roadways during peak hours. In addition, they encourage ride sharing, mitigate traffic congestion, and yield environmental benefits in the long run.
- **Other minor improvements.** In addition to the improvements listed above, there are many other minor design and operational improvements that have been used in Texas to improve highway functionality. For example, the Houston District uses black strips to outline the traditional white strips on pavements of freeways to improve their visibility. The district also has a practice that roadway guidance is both provided on traditional overhead traffic signs and painted on pavements at major interchanges to provide better guidance. On surface highways, minor improvements include additions of left turn, right turn, and deceleration lanes, double left turn lanes, passing and climbing lanes, and improved intersection or segment geometrics.

A few examples of minor operational improvements to freeways in several Texas cities that have removed bottlenecks and expanded capacities include the following (74).

- **Interstate 35 East (IH 35E) in Dallas.** A bottleneck area on IH 35E was improved by replacing a little-used exit ramp with an entrance ramp, which resulted in considerable reduction of delay and crash rate. The estimated benefit-cost ratio for a projected 10-year life for this improvement was 9:1.
- **State Highway 360 (SH 360) in Arlington.** A bottleneck area on northbound SH 360 was improved by extending an auxiliary lane between two exiting exits by 700 ft to the next exit. The \$150,000 auxiliary lane extension resulted in estimated yearly delay benefits of \$200,000 and substantial reduction of injury crashes.
- **The interchange between Interstate 10 (IH 10) and US 54 in San Antonio.** The lane reconfiguration in the interchange area between IH 10 and US 54 successfully decreased traffic delays in the area, and the overall benefits of the improvement were estimated at \$1.3 million.

### **Policies, Regulations, and Practices outside TxDOT**

Similar to Texas, many other states follow the AASHTO geometric design policy for transportation facility design. In addition, individual states have also developed supplemental guidelines or standards for roadway geometric design. All state DOTs follow their own state highway plan and programs, consistent with federal requirements, to upgrade their highway systems. The following are some examples of minor highway improvements being made in other states to improve highway functionality (77):

- Maryland has achieved improved system performance by introducing low-cost improvements at bottleneck locations. The Maryland State Highway Administration (SHA) has a dedicated program of about \$5.0 million per year for the identification and implementation of low-cost traffic congestion improvements at intersections. In addition, the state has had successful experience of using quick projects to improve freeway ramps and merge areas.
- In Puget Sound, Washington, a new exit ramp was added from IH 405 to SH 167, which evidently reduced traffic backup and increased traffic volumes on the highway sections.
- In Florida, a free right turn lane and a signalized right turn lane were added at the interchange of IH 75 and Bruce B. Downs Boulevard, which effectively reduced traffic queuing caused by turning vehicles.
- In Atlanta, Georgia, one of the nation's worst bottlenecks on the Downtown Connector highway section was significantly improved by re-striping and adding an extended divider wall and four ramp meters.

In addition to minor highway improvements to accelerate the congestion mitigation nationwide, the U.S. Department of Transportation (USDOT) announced the National

Strategy to Reduce Congestion of America's Transportation Network (78). The initiative includes the following major activities:

- Relieve urban congestion by entering into Urban Partnership Agreements with cities in a voluntary basis to develop comprehensive and effective congestion pricing strategies.
- Unleash private sector investment resources by removing barriers to private sector investment in the construction, ownership, and operation of transportation infrastructure.
- Promote operational and technological improvements by encouraging and supporting states to advance low-cost operational and technological improvements for congestion reduction.
- Establish a "corridors of the future" competition by selecting three to five major growth corridors in need of long-term investment to encourage the development of multistate, multiuse transportation corridors.
- Target major freight bottlenecks and expand freight policy outreach by exploring and implementing solutions to freight transportation and border congestion.
- Accelerate major aviation capacity projects and provide a future funding framework by designing and deploying the Next Generation Air Transportation System and advancing reforms for better aviation management.

## **SOURCES/CAUSES OF DETERIORATION AND COUNTERMEASURES**

### **Traffic Control and Management**

Traffic control is an important component affecting how a highway system operates. Poor practices in traffic control and management can cause safety problems, capacity loss, underutilization of infrastructure and result in loss of highway functionality. The following are a sample of functionality deteriorations—within six different sub-areas—caused by poor traffic control and management:

- Traffic Control – inadequate or ineffective traffic control on highways may cause capacity losses to the existing highway network and/or traffic crashes.
- Alternative Modes – improper or insufficient use of transit management strategies such as HOV lanes can result in increased traffic demand, more traffic congestion, and decreased accessibility.
- Operational Pricing – improper or insufficient use of managed/HOT lanes can result in wasted capacity or congestion in priority lanes.
- Emergencies – poor practices for emergency evacuation and incident management may result in excessive traffic delays, transportation system breakdown, and otherwise avoidable casualties.

- Maintenance – poor handling of traffic management in conjunction with highway maintenance or construction may increase safety hazards and unnecessary traffic delays.

Poor traffic operational control and management practices can cause functionality loss during a highway’s service life. Many countermeasures may be employed in different situations to improve traffic control and management. In general, it is beneficial to improve the effectiveness of existing traffic control devices, explore more cost-effective devices, develop more effective traffic control plans, and utilize ITS for better real-time traffic control, traveler information, and incident management. In addition, it is important to continuously develop public education programs and campaigns to improve public awareness and understanding of traffic control and related safety issues. Research needs on traffic control and management should also be identified and research outcomes should be utilized in a timely manner to maximize their benefits. [Table 6](#) lists a summary of measures for improving traffic control and management.

**Table 6. Traffic Control and Management Countermeasures.**

Category	Measures
Freeways	<ul style="list-style-type: none"> <li>• Incident detection and management</li> <li>• Freeway monitoring and management system</li> <li>• Motorist information system</li> <li>• HOV lanes</li> <li>• Ramp metering</li> <li>• Time managed ramp access</li> <li>• Time managed lane use (e.g., reversible lanes)</li> <li>• Variable tolling</li> </ul>
Highways and Streets	<ul style="list-style-type: none"> <li>• Traffic signalization</li> <li>• Traffic signal retiming</li> <li>• Traffic signal systems</li> <li>• Time managed street use (incl. use restrictions)</li> <li>• Time managed lane use</li> <li>• Queue jumpers</li> <li>• Turn restrictions</li> <li>• Restriping</li> </ul>
Travel Demand Management	<ul style="list-style-type: none"> <li>• Increase transit service</li> <li>• Ridesharing</li> <li>• Transit, HOV priority</li> <li>• Alternative commute schedules, telecommuting, and other TDM</li> </ul>

### Signal Coordination and Optimization

Traffic signals are a major component of the traffic control system and deficiencies in timing and coordination directly result in degradation of highway functionality. Some examples of highway functionality loss that can be attributed to poor signal design and operation practices are:

- Improper signal timing at individual intersections can cause traffic delays and other traffic operational challenges at these intersections. Signal timing issues may include improper cycle length, improper cycle splits, inefficient phase sequences, and improper timing for pedestrians.
- Insufficient signal coordination among densely spaced intersections can cause degradation of level of service (LOS) on a large highway network.
- Poorly designed or timed signals near entrances or exits of freeway facilities can form bottlenecks and cause functionality loss to the freeway sections well beyond the immediate intersection vicinity.

To avoid functionality deterioration, traffic signals and signal systems should be actively maintained and regularly evaluated for efficiency and retimed and re-coordinated according to good practices. Generally, signal timing design and operation may be improved by:

- signal equipment modernization:
  - convert to actuated signal control,
  - upgrade detection, reliability,
  - modernize controller,
  - improve display hardware;
- signal retiming:
  - retime every three years or sooner if traffic patterns change,
  - add or change phases;
- coordinate traffic signals:
  - coordinate along route,
  - coordinate a system of signals,
  - retime and coordinate every three years or sooner if traffic patterns change;
- remove unwarranted signals; and
- preventative maintenance.

To better conduct these improvements, it is important to ensure that the business process involved in traffic signal operation and management is efficient and effective. Traffic signal operation and management frequently involve multiple agencies and jurisdictions. Improving the traffic signal program management and cross-jurisdictional coordination practices thus becomes critical. Well-developed traffic signal program management strategies in various aspects, such as program leadership, planning, and workforce development, can lead to clearly-defined goals with measurable objectives for traffic signal design and operation, which in turn result in benefits such as improved operational performance, system reliability, asset life-cycle and resource allocation. Improved cross-jurisdictional and inter-agency coordination will help to enhance the system-wide performance of traffic signal networks especially along the roadways across jurisdictional borders.

Traffic signal hardware is the foundation of traffic signal systems. Selection of appropriate hardware backed by up-to-date technologies helps in improving system performance and ease of management. Routine and sufficient maintenance of the signal hardware improves the preservation of the traffic signal investment and reduces signal failures caused by hardware deterioration. In addition, traffic demands and patterns change over time due to changes to infrastructural or operational conditions and adjacent land development. These changes will in turn require routine traffic signal evaluations to ensure that signal timing continuously meets traffic needs at the intersections. To facilitate traffic timing and retiming, improving traffic monitoring and data collection is critical. However, the data component of infrastructure is often assigned a low priority when considering the funding needs of transportation infrastructure by many transportation agencies:

- Improve traffic monitoring and data collection. Sufficient and timely traffic data are critical information for traffic signal system monitoring and improvement. However, the data component of infrastructure is often assigned a low priority when considering the funding needs of transportation infrastructure by many transportation agencies.
- Conduct routine signal timing evaluations. Over time, traffic demands and patterns change due to changes to infrastructural or operational conditions and adjacent land development. These changes will in turn require routine traffic signal evaluations to ensure that signal timing continuously meets traffic needs at the intersections.
- Appropriately select and sufficiently maintain traffic signal hardware. Traffic signal hardware is the foundation of traffic signal systems. Selection of appropriate hardware backed by up-to-date technologies helps in improving system performance and ease of management. Routine and sufficient maintenance of the signal hardware improves the preservation of the traffic signal investment and reduces signal failures caused by hardware deterioration.

### **Facility Design and Enhancement**

Facility enhancements involve improvements to existing roadways to improve their operating characteristics or to make minor capacity improvements. For the purposes of this report, construction of new highways or major widening or other large capacity improvements are not addressed here since they represent a major loss of functionality. This report is intended to help to preserve functionality or recapture or enhance functionality after partial deterioration of functionality. Hence, when design enhancements are considered here, they are limited to minor modifications or improvements. These may include:

- design modernization,
- capacity improvements,

- physical operational enhancements, and
- other minor improvements to restore or enhance operational functionality.

More specifically, minor improvements and enhancements acting as countermeasures to aid functionality may include, but are not limited to the following:

- freeways and tollways:
  - ramp or interchange redesign,
  - ramp relocation,
  - ramp closure,
  - ramp metering,
  - auxiliary or weaving lane,
  - HOV lane,
  - enhanced acceleration or merging section,
  - use of ITS; and
- highways and streets:
  - intersection improvements,
  - shoulder improvements,
  - turn lane addition,
  - passing lane,
  - grade separation,
  - unconventional intersection design,
  - addition or modification of medians to reduce turning conflicts, and
  - access point consolidation.

In many cases, developing a major highway improvement project requires several years and often a large amount of funding. Quick-fix solutions such as minor operational and infrastructural improvements can be cost-effective and typically can be implemented within a much shorter period. However, transportation problems need to be identified early in order to apply minor enhancements in a timely and efficient manner. In addition, studies frequently need to be conducted to fully analyze the potential benefits before these enhancements are carried out. When traffic problems are not achievable through minor enhancements, a major transportation enhancement needs to be developed. To overcome funding constraints, it is recommended to consider innovative traditional funding sources and non-traditional funding sources including highway pricing and private funds.

## **OPERATIONS PERFORMANCE MEASURES**

The area of transportation operations and capacity includes several components, such as traffic control and management, signal coordination and optimization, and system enhancement. The effectiveness of the practices in most of these areas can be directly tied to the same basic operational performance measures such as LOS, travel speeds (or



times), and delays. The following are examples of general performance measures for assessing the goodness of practices in traffic operations and capacity:

- **Level-of-service.** Highway LOS is a well-established performance measure for highway serviceability. It takes into consideration factors such as volume-capacity (v/c) ratio, delays, and running speeds.
- **Travel time.** This quantifies the amount of time needed to traverse a highway segment or can be extended to apply system wide.
- **Travel time reliability.** Travel time reliability measures the travel time range travelers experience on a roadway section based on a large number of trips. It implicates the significance and frequency of the impact of reoccurring, and more importantly, non-reoccurring congestions on the roadway and its host network.
- **Travel delay.** Travel delay is a straightforward measure to the serviceability of a roadway. Excessive delays indicate low LOSs at certain points and needs for improvement on the highway functionality. In addition, the system-wide travel delays can serve as a measure to the performance of an entire transportation network in terms of mobility. Travel delays can be further classified into different types including total delays and stopped delays.
- **Average running speed.** By comparing the average running speed with the posted speed limit on a highway section, traffic analysts may understand how well a highway functions and how effective the traffic control is.
- **Capacity.** Highway capacity is determined not only by the infrastructural limits, but also by the traffic control strategies in some cases. Good traffic control plans may improve the overall capacity of a highway section or network and therefore improve highway functionality.
- **Vehicle miles of travel.** This quantifies the extent of travel of all vehicles along a corridor or throughout a system. When considering travel efficiency, it can be used to measure excess travel caused by congested highway segments and drivers diverting to alternative routes.

These and other performance measures can be used to measure the quality of operational performance—functionality—of a highway segment or a portion of a system. TxDOT uses performance measures in a number of ways. They may be used to measure functionality. The most appropriate way to do so is to determine the critical goals and functions of a facility, then adapt performance measures that describe related performance. For example, capacity and delay may be the key measures for an urban arterial. Travel time or running speed may be more important for a given freeway.

## **BEST PRACTICE RECOMMENDATIONS**

### **Traffic Control and Management**

Numerous effective and innovative good practices have been successfully used in various states. The researchers recommend the following general practices that may benefit Texas:

- Use high-visibility traffic control devices. For example, an evaluation showed that a high-visibility flashing LED stop sign was able to effectively reduce the speeds of approaching vehicles especially during nighttime (79).
- Utilize ITS applications. Explore and utilize more intelligent and advanced technologies for real-time system monitoring and fast incident response.
- Continuously develop public education programs and campaigns to improve public awareness and understanding of traffic control and related safety issues.
- Develop research projects to improve the effectiveness of existing traffic control devices, explore more cost-effective control devices, and develop more effective traffic control plans.

### **Signal Coordination and Optimization**

Based on the literature review, the researchers recommend the following best practices to be considered statewide for signal design and operation:

- Retime traffic signals at least every three years or sooner if there is a significant change in traffic flow patterns.
- Conduct routine preventative signal maintenance on a schedule. For example, the City of Austin, Texas, has established a proactive signal evaluation approach, through which the City routinely evaluate major signal systems. The practice has resulted in benefits such as reduction in delays and stops and fuel savings (65).
- Use TSSAs during signal planning and design. TSSAs can be used as a peer-review method to identify problems of a signal-timing plan or design. Qualified TSSA teams may also introduce better practices, software, hardware, and other related technologies to the design team to improve signal timing and coordination (68).
- Use ITS to enhance the design and operation of traffic signals. ITS applications for traffic signals include communication systems, adaptive control systems, real-time data collection and analysis, and maintenance management systems. A case study in Los Angeles showed that the use of an ATCS in the city evidently reduced system-wide travel delays and average stops (56).

- Establish leadership and partnership during traffic signal planning and design. This requires the development of effective communication mechanisms between different jurisdictions. Cross-jurisdictional cooperation for signal design and operation can improve system-wide signal coordination and resource/workforce allocation, and result in functionality improvement for a larger transportation network including the highways crossing jurisdictional boundaries (66).

### **Facility Design and Enhancement**

The researchers recommend the following general practices that are helpful for improving the functionality of the transportation network in the state:

- Monitor operations and identify locations or segments where level of service or other performance indicators decline significantly, then institute a corrective action program to avoid or reduce further decline.
- Consider minor geometric and operational enhancement approaches, such as re-striping, adding auxiliary lanes, access management improvements, ramp metering, and using HOV lanes as quick solutions to bottlenecks and other congestion problems. These are low cost and often can be implemented through the maintenance program.
- Consider innovative and non-traditional options for highway projects. These options may include highway pricing, unconventional operations or design (e.g., reversible lanes, time-managed ramps), or other techniques that are adaptable to special situations.



## 4. RIGHT OF WAY

Highways are built and improved on highway right of way. Effectively acquiring, preserving, and protecting the right of way is critical for maintaining the functionality of the state highway system.

Several broad topics that can be of particular concern to TxDOT and other transportation agencies include right-of-way protection/preservation, right-of-way acquisition, and right-of-way utilities. Passive practices when dealing with these aspects can and have caused noteworthy loss of highway life cycle functionality. For example, poor right-of-way protection can accelerate infrastructure deterioration by reducing improvement options or compromising design, operational, or maintenance opportunities. They can also introduce environmental issues. Ineffective practices in right-of-way protection, acquisition, and utility accommodation and relocation can cause significant increase of project costs, delays to highway construction or maintenance, and sensitive social issues. Constraints to right of way due to adjacent conditions (for example, noise tolerability, drainage, and encroachment from development) can also cause difficulties, both for current operation and for proposed highway enhancements.

Nationwide, FHWA, AASHTO and others have led several extensive efforts to synthesize domestic and international practices for right of way and utilities. In 2000, FHWA, AASHTO, and the Transportation Research Board (TRB) jointly sponsored an international scanning tour to observe right of way and utility coordination practices in four European countries (80). In 2004, the Highway Subcommittee on Right-of-Way and Utilities published a set of guidelines and best practices for the major functional work areas involved in the right of way and utilities process (81). In 2006, the National Cooperative Highway Research Program (NCHRP), through NCHRP Project 20-68, initiated a domestic scan on best practices in right-of-way acquisition and utility relocation (82). Following this scanning effort, AASHTO and FHWA sponsored another international scan on best practices of other countries on right of way and utilities (83).

This section includes an overview of right-of-way practices that affect highway functionality. Based on this review, the researchers also identified sources or causes of highway functionality loss and identified performance measures and improvement measures.

### RIGHT-OF-WAY ACQUISITION

#### TxDOT Major Policies, Regulations, and Practices

Right-of-way acquisition is a critical component in the project development process and can be very time consuming and socially sensitive. Proper practices for right-of-way acquisition allow highway projects to maintain the schedule and to be better accepted by the public. The right-of-way acquisition process typically involves several steps including appraisal, appraisal review, establishing just compensation, negotiations, administrative and legal settlements, and condemnation (84). Federally, the acquisition of right of way and related properties is primarily governed by the Code of Federal Regulations

(23CFR710 and 49CFR24) developed in response to the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (42USC61) (85). Individual states have developed more detailed regulations and guidelines to govern the right-of-way-related activities in their states. In Texas, Chapter 21, Title 43 of the TAC (83) and the TxDOT Right-of-Way Manual (86) govern the right-of-way acquisition process at TxDOT. TxDOT has also developed guidelines for local public agencies (LPAs) on real estate acquisition (87).

As outlined in the TxDOT Project Develop Process Manual (84), the right-of-way acquisition process at TxDOT generally involves the following major tasks, as listed in approximate chronological order:

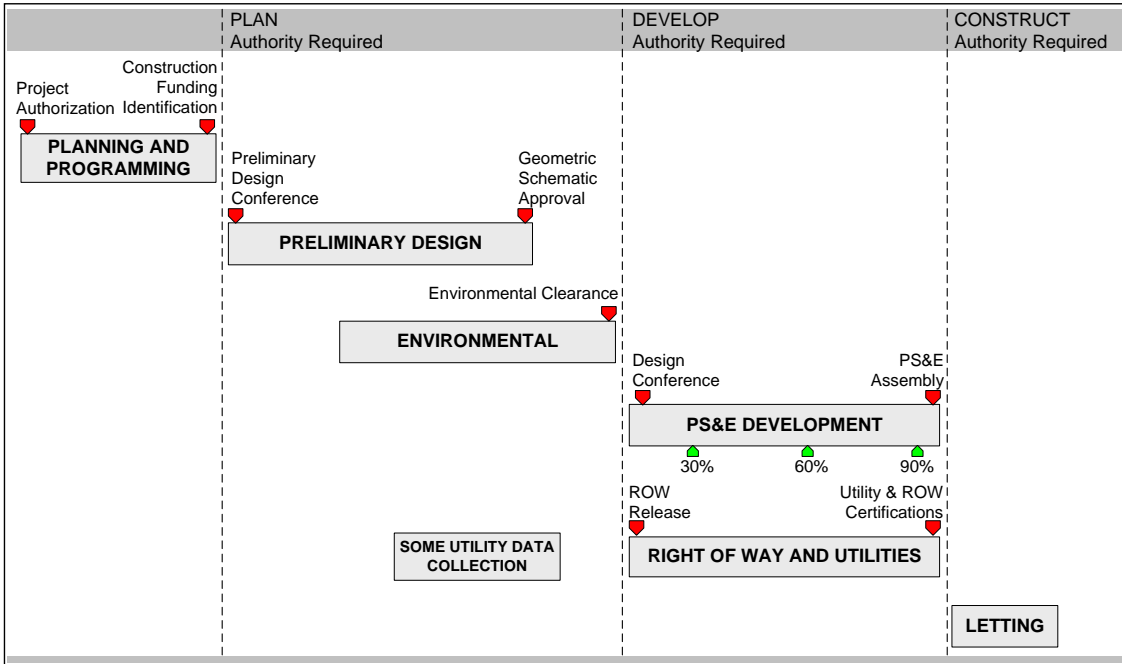
- Prepare right-of-way map and property descriptions. Accurate right-of-way maps and property descriptions are a vital part of future right-of-way-related legal instruments. It is required to prepare these documents after obtaining the project location and design acceptance.
- Obtain contractual agreements with local public agencies. When LPAs are involved in right-of-way acquisition, TxDOT and the LPAs should enter into a right-of-way agreement, which identifies each party's responsibilities.
- Perform advance acquisition for qualified parcels using the appropriate state or local authorities, as applicable and per the interagency agreement. If qualified, some parcels may be acquired on an individual at-risk basis (alignment change is possible prior to final environmental determination) prior to right-of-way project release being authorized and environmental clearance.
- Obtain authority for right-of-way project release. With the exception of eligible early acquisition, no right-of-way costs (including utility adjustments) may be incurred unless the Right of Way Division authorizes the right-of-way project.
- Review scope, cost, and staff requirements of project development. Well before the right-of-way acquisition comes into action, the project scope needs to be reviewed and project schedule, cost, and staff requirements should be developed.
- Identify impediments to parcel acquisition. Before starting parcel acquisition, the project manager, project engineers, and acquisition specialists should meet to identify impediments that might significantly affect the project schedule.
- Prepare and execute any joint- or multiple- use agreements that may be needed. Instead of purchasing, agreements need to be obtained when necessary to allow TxDOT to use the right-of-way owned by public or quasi-public entities under certain conditions.
- Appraise parcels. The district starts parcel appraisals immediately after obtaining the authority for right-of-way project release.

- Implement right-of-way acquisition process. This process involves negotiating the conditions of acquisitions, making offers based on appraised value, and using eminent domain when required.
- Implement relocation assistance program. Engineering and environmental staff members identify individuals who need relocation due to the right-of-way acquisition. District staff then provides relocation assistance information as part of the project's public involvement efforts.
- Dispose of improvements. The improvements need to be disposed after right of way is acquired and before construction begins.
- Prepare right-of-way and encroachment certifications. The certifications should be submitted along with Plans, Specifications, and Estimates (PS&E) so that a project can be advertised for construction bids.

In addition, through the research program, TxDOT has developed tools to support right-of-way acquisition. Other than the Right-of-Way Information System (ROWIS), examples include an Advance Planning Risk Analysis (APRA) tool (88), a Right-of-Way Acquisition and Utility Adjustment Duration Information (RUDI) tool (89), and a cost estimation tool for right-of-way acquisition (90). In addition, TxDOT is in the process of developing a data model for the management of the right-of-way asset (research project 0-5788 *ROW Real Property Asset Management Architecture*).

When and how TxDOT acquires right of way for projects (involving federal funds) is largely dictated by the National Environmental Policy Act of 1969 (NEPA). NEPA regulations require that the environmental clearance process be completed before state or federal funds can be used to acquire right of way on a project-wide basis. Because of this, right-of-way acquisition may not begin for many years after TxDOT's project development process has begun. Figure 5 shows a general diagram of TxDOT's Project Development process. It illustrates that right-of-way acquisition generally begins after the environmental process. The current traditional project development process used by TxDOT (and most other state DOTs) ties right-of-way funding with construction funding and delays right-of-way acquisition.

The delay to begin right-of-way acquisition may take 3-to-5 years or more and during this time as community growth and development occurs, the cost of right of way for a project may increase significantly above its initially estimated cost. Invariably, this increase in right-of-way cost reduces the amount of funds available for constructions and may make some improvements needed to preserve or enhance functionality cost prohibitive.



**Figure 5. Right-of-Way Acquisition in the Project Development Process.**

The delay in right-of-way acquisition also limits TxDOT’s ability to preserve or protect right of way for a project under development in cases where development could be eminent.

The most common method that TxDOT uses to acquire right of way for projects is through fee-simple, negotiated purchases. Using fee-simple to acquire property for right of way, TxDOT gains full title to the land and has complete control over its use. In Texas, the property conveyance is assumed to be fee-simple unless specified otherwise in the instrument of conveyance.

In acquiring right of way, if a property owner accepts TxDOT’s price offer, or if TxDOT accepts the property owner’s counter-offer, a negotiated agreement has been reached for purchase of the land. If an agreed-upon purchase price cannot be reached, condemnation proceedings are begun to acquire the needed right of way. In condemnation hearings, the legal proceedings take place in the county where the property is located.

**RIGHT-OF-WAY PROTECTION**

Right-of-way protection can involve several broad areas of concern, such as roadside management, local and advanced right-of-way acquisition methods, and coordination in local planning and land development. TxDOT has various policies, guidelines and regulations in place that can be used to help protect and preserve right of way along TxDOT facilities.



## **Protecting Right of Way through Early or Advance Acquisition**

Early or advance right-of-way acquisition refers to the acquisition of real property (right of way) in advance of NEPA environmental clearance. Just as early acquisition can be a tool used in planning and corridor preservation, it can also be used to acquire and protect right of way along an existing transportation facility that may be needed for future improvements. To do this, TxDOT must conduct an environmental review for the early or advance acquisition of property as prescribed in 23 CFR Section 710.501–710.505.

The use of an early acquisition strategy involving the full use of allowable methods could be used to acquire and protect critical parcels identified early in TxDOT’s project development process. TxDOT’s *ROW Manual* includes provisions for the three following methods of early acquisition.

- Hardship acquisition – an acquisition undertaken at the owner’s written request to alleviate the hardship of the inability to sell his/her property. This method allows TxDOT to relieve a distressed property owner when a property cannot be sold on the private market due to public knowledge of a pending highway project.
- Protective buying – an advanced method commonly used to prevent imminent development or increased cost.
- Donation – a voluntary donation of property to TxDOT (or its local partner) typically done by the owner due to some economic benefit such as an exit ramp or an overpass.

In addition to these techniques, TxDOT may also use the advance acquisition option as permitted in the Texas Transportation Code Section 202.111 through 202.114 to acquire property in advance. An advance acquisition, or options to purchase, is a contract to buy the right to purchase property. To accomplish this, TxDOT pays the property owner a fee, and the owner takes the property off the market for a specified term.

The use of these techniques is limited because they can only be used on a parcel-by-parcel basis and not applied on a project-wide or corridor-wide scale. Based on research conducted in 2006, the use of early or advanced acquisition methods, particularly options to purchase, is limited to large urban districts. Protective and hardship buys require extensive work-ups and experienced right of way staff. They can also be time consuming due to the approvals needed for their use (20).

## **Protection via Coordination in Local Planning and Development**

Transportation planning and land use planning/development are interdependent and need to be coordinated in order to bring together land use and transportation planning decision making among affected jurisdictions and agencies. TxDOT-local coordination in local planning and development, particularly through corridor management practices, facilitates better planned, more orderly development along TxDOT facilities. Planned, orderly development along TxDOT corridors helps protect TxDOT right of way in large part by the use of development setbacks that preclude development encroachments into the right of way.

The use of locally required building and parking setbacks helps to protect TxDOT right of way from development encroachments and can potentially save TxDOT money if additional right-of-way acquisition is needed. A setback is an area where permanent structures or improvements are prohibited and required to be set back from the existing right of way line. Setbacks can help reduce property damage and costs if the roadway is widened and corridor aesthetics are improved. Under normal circumstances, setbacks should only be based from the existing right of way line. However, if TxDOT has a schematic prepared that shows the location of the future right of way line and it is consistent with what is represented on an adopted local transportation plan, some local jurisdictions may have the legal comfort level to require setbacks from the future right of way line (20).

It is important to note that setbacks cannot be used arbitrarily and cannot be used for the purpose of protecting land needed for future right of way. However, when enhanced setbacks are required for other purposes, such as part of a zoning overlay district, a side effect could be keeping improvements off the property that is needed for future right of way.

Since TxDOT's authority ends at the right of way line, partnerships with local jurisdictions are important to ensure that the impact on TxDOT right of way and infrastructure are considered in local development decisions. The principal activities that TxDOT and local agencies most frequently need to coordinate are:

- the local subdivision, site review, and development processes;
- short- and long-range planning (through MPO, regional, and local planning; continually through coordination and involvement in municipal and county land use and thoroughfare planning);
- TxDOT roadway design plans and schematics (as part of project development); and
- local and MPO corridor/access management planning activities.

TxDOT should also coordinate with local jurisdictions on their major thoroughfare design standards and policies as these may be applied in the local development process as a means of acquiring or preserving right of way along a TxDOT facility. Since local thoroughfare plans commonly include state roads—cities and in some cases, counties—can require that right of way be dedicated (or reserved) for TxDOT facilities when abutting properties are platted or subdivided if:

- additional right of way is needed in order to gain compliance with an adopted municipal or county thoroughfare plan; or
- the amount of right of way dedication is roughly proportional to the impact of the development.

Right of way dedication and reservation through local platting is a good tool for protecting and acquiring right of way along existing TxDOT facilities. It is common

practice by most cities in Texas to require right of way dedication and/or reservation of right of way along state facilities as part of their platting process (15).

### **Encroachment and Outdoor Advertising**

Two roadside management activities, right-of-way encroachment control and outdoor advertisement, can have an impact on highway functionality. Summaries on these two activities are provided below:

- **Right-of-way encroachment.** Encroachment on highway right of way made by unauthorized structures or vehicles and by roadside vendors can cause damage to the infrastructure and create unsafe conditions to roadway users. TxDOT generally does not allow right-of-way encroachment, unless proper authorization is obtained (91). Encroachments within state right-of-way property lines are identified during right-of-way survey and are subject to disposition (92). TxDOT also initiated efforts to control right-of-way encroachment caused by grasses and trees that impairs sight distance and result in road deterioration (93, 94).
- **Outdoor advertisement.** Outdoor advertisement along state right of way is primarily regulated through Texas Administrative Code (TAC) (95) and the Right-of-Way Manual (86). TxDOT has developed outdoor advertisement licensing and permitting processes to manage outdoor advertisement signs. In addition, it is in the midst of a major initiative to privatize aspects of its outdoor advertising control program (96). For example, TxDOT had funded the research project 0-4609 (*Options for Outsourcing Outdoor Advertising Control in Texas*) to explore feasible strategies for outsourcing outdoor advertising. Cities in Texas can assist TxDOT in managing and controlling outdoor advertising through local ordinances that regulate in the amount, size and placement of signs and billboard along TxDOT right of way.

### **Acquisition and Protection Practices outside TxDOT**

Several comprehensive research initiatives (80, 81, 82) have synthesized both the domestic and international best practices on right of way and utilities. The following summary of practices is based on the findings of these research efforts supplemented with the survey results of this project.

- **Coordinate and communicate early and frequently with property owners as well as between staff.** For example, in Florida, district staff meets with stakeholders early in the project process to assure that owners and tenants are fully aware of planned projects and can provide their input. During negotiations with landowners, European experience showed that focusing and finding ways to compromise on issues related to just compensation helped to effectively resolve acquisition. In addition, some European countries have successfully used land consolidation strategies to pool individual and fragmented parcels into more contiguous tracts to simplify right-of-way acquisition.

- **Use available electronic technology to the greatest extent possible to expedite right-of-way acquisition.** For example, Minnesota is in process of developing a Right-of-Way Electronic Acquisition Land Management System. The anticipated benefits from this system include more efficient right-of-way data sharing and usage, and increased ability for multi-project processing. In addition, Minnesota has also used computer visualization to help landowners to better understand how their properties will be impacted by highway projects.
- **Consider advance right-of-way acquisition.** Minnesota legislature established the Right-of-Way Acquisition Loan Fund for facilitate early acquisition of right-of-way properties. Under this program, local government agencies can apply for loans to make early acquisitions of properties required for future transportation projects. The purchases are limited to hardship and protective buying on a voluntary basis.
- **Encourage the one agent concept.** Florida uses a one agent concept where the same agent handles the acquisition, relocation, property management, and clearing of the improvements for construction. This practice helps to ensure information, process, and policy consistency so that right-of-way acquisition can be conducted more effectively.
- **Acquire right-of-way for utility accommodation.** Some European countries and U.S. states acquire specific right of way for utility purposes. Acquiring sufficient right of way for utilities simplifies utility accommodation and in turn expedites project development. It may also alleviate future utility relocation costs, coordination, and delays. In certain situations, this may help property owners to avoid dealing with both highway agencies and utilities for property acquisition and therefore speed up the acquisition process.
- **Prohibit right-of-way encroachment.** As in Texas, other states also prohibit right-of-way encroachment unless authorized. Right-of-way vegetation encroachment is controlled through roadside vegetation management.
- **Manage outdoor advertising.** A domestic scan (94) showed that many states have policies or guidelines to regulate outdoor advertising in state right of way. Several states such as Arizona have been exploring outsourcing options and use of GIS for outdoor advertising control. Some states have the responsibilities centralized for more effective outdoor advertising control, while others rely on regional offices. Some states indicated that, although strict regulations had been established, a nontrivial number of non-conforming signs existed due to the seemingly weak enforcement.

## UTILITY ACCOMMODATION AND RELOCATION

### TxDOT Policies, Regulations, and Practices

Several laws regulate the utilities and their rights on TxDOT right of way. The Utility Accommodation Rules (UAR) (97) include the minimum requirements for the

accommodation, method, materials, and location for the installation, adjustment, and maintenance of public and private utilities within the right of way of the Texas state highway system. Other Texas statutes such as the Transportation Code (98), the Utilities Code (99), and the Local Government Code (100) also contain provisions pertaining to right-of-way utilities. In addition, the Right of Way Utility Manual (101) further provides specific guidelines and regulations for dealing with issues associated with the utilities on the TxDOT-owned or managed right of way.

To enable efficient accommodation of utilities and minimize delays both before letting and during the construction phase, TxDOT uses the Utility Cooperative Management Process (UCMP), a partnership between TxDOT, LPAs when applicable, and the utility industry (99). The process encourages the inclusion of the utility accommodation considerations in project planning, right of way, design, and construction functions at the district level. Through the process, TxDOT also promotes early involvement of and sufficient coordination with utility owners during the project development process.

As specified in TxDOT's Project Development Process (PDP) Manual, a preliminary gathering of utility data is required during the very first site visit of the project planning and programming. During this phase, coordination with public utilities is required to ensure that major utility relocations are identified and the projects compliment the utility stakeholders. Extensive coordination with utility owners needs to be involved in many preliminary design activities of a project. During preliminary design, roadway designers will need to identify and mark the locations of existing utilities on geometric schematics. They will also need to identify potential utility conflicts for utility owners to budget for anticipated adjustment costs. Before the project enters the construction phase, the conflicting utilities will need to be relocated so that construction can begin.

The utility coordination process frequently involves a large number of stakeholders exchanging a myriad of information in forms such as communications, agreements, contracts, permits, maps, schematics, images, and design files. The TxDOT PDP manual and the right of way manual provide high-level guidance for the coordination, while the actual procedures and methods vary more or less from district to district (102). In general, many districts devote efforts to follow the UCMP, especially for large projects. Depending on the size and complexity of a project, districts may only perform the steps and meetings of the UCMP that are determined to be necessary. In addition, districts may develop their modified versions of the process to better meet their own funding, staffing, and project conditions. Area offices have been the primary points of contact in the process and the utility coordination practices some times vary among different area offices as well.

Annual meetings have been an important channel during utility coordination for distribution of project information to utilities for the latter to assess the utility relocation needs early. Districts or area offices frequently send out project notifications to further notify involved utilities about upcoming projects. Some districts also rely heavily on consultants for utility coordination. Although varying by district, the critical steps involved in the utility adjustment process for a project typically include:

- identify all utility facilities within the project limit and their ownership;

- determine utility conflicts;
- develop utility plans;
- obtain, review, and approve agreements; and
- relocate utilities.

The importance of reducing utility conflicts has been recognized by TxDOT districts and other stakeholders as those conflicts contribute to project cost increase, project delay, and additional burden of the utility industry. To locate utility facilities early and accurately, TxDOT has been encouraging the use of subsurface utility engineering (SUE) techniques for utility data collection. At the district level, the use of SUE depends largely on project complexity and the quality and comprehensiveness of utility data provided by utility owners. However, the reliability of SUE data and funding availability for SUE services remain to be concerns limiting SUE usage. To reduce utility conflicts, some districts such as Austin stop issuing permits for utility installations in the right of way as soon as a construction project goes into planning. Occasionally, the districts may also adjust roadway designs to avoid major relocations upon early detection.

As identified during an interview with district utility specialists (102), utility coordination efforts in some districts are can be limited by staffing and fiscal resources due to the underrepresented priority. Accordingly, those districts have to allocate the limited resources to most critical utility coordination activities, causing some activities delayed or unperformed. Additional challenges affecting utility coordination activities and causing relocation delays include:

- late project notification to utility owners,
- failure of utility conflict identification,
- unresponsive or uncooperative utility owners,
- lack of expertise of utility staff, and
- lengthy process of obtaining required agreements for reimbursable utility relations compared to that for non-reimbursable relocations.

From the perspective of utility industry, smaller utility companies seem to prefer relying on their own staff for utility coordination with TxDOT, while larger companies frequently use consultants for non-reimbursable projects and most reimbursable projects. According to a survey of utility companies in Texas (102), many utility companies were reluctant to respond utility-related requests before the 60 percent meeting due to the uncertainty of the roadway designs at this stage. In addition, utility companies indicated issues on utility reimbursement processing and frequency of utility relocation requests.

In recent years, TxDOT has undertaken an ambitious program to improve the utility process at the department. For instance, TxDOT has implemented the Utility Installation Review (UIR) system to automate the utility installation permitting process (implementation project 5-2110-03). Examples of research efforts include developing procedures for better managing the utility conflict resolution and adjustment process (research project 0-5475), improving utility construction specifications and cost estimates (research project 0-4998), and better coordinating the utility conflict resolution and

environmental processes (research project 0-6065). Other examples include exploring combined transportation and utility construction strategy (research project 0-4997), and evaluating utility corridors or other utility accommodation alternatives (research project 0-4149).

### **Policies, Regulations, and Practices outside TxDOT**

It is in the public interest for utility facilities to jointly use the right of way of public roads when such use does not adversely affect highway or traffic safety, or otherwise impair the highway or its aesthetic quality and does not conflict with the provisions of Federal, State, or local laws and regulations (103). The federal government regulates utilities on the right of way of Federal-aid highways in two sections in title 23 of the U.S. Code (23 USC) (104). Section 109 (23USC109) regulates the accommodation of utilities on the right of way of Federal-aid highways and Section 123 (23USC123) specifies the regulations pertaining to relocation of right-of-way utilities on Federal-aid highways. In addition, Title 23 part 645 of the Code of Federal Regulations (23 CFR) and included FHWA regulations on right-of-way utility topics, such as utility relocations, adjustments, reimbursement, and accommodation (105). The Federal-Aid Policy Guide further includes non-regulatory supplements to the 23 CFR on right-of-way utilities (106).

Similar to Texas, other states have developed various policies and guidelines regulating utilities on state right of way. In addition, many states have implemented or been exploring innovative practices on right of way and utilities to expedite project development. Some of the good practices in these states or countries are summarized as follows (78, 79, 80, 81).

- Use available technologies to improve utility accommodation and relocation. Many states, such as Texas, Virginia, Florida, and Maryland, have been using SUE techniques to collect utility information. In addition, GIS has been used for mapping right-of-way properties in Europe. In Texas, researchers developed a utility conflict management system using GIS and tested its prototype application (107).
- Encourage early and frequent coordination and communication with public utilities on project information including long-range project plans. For example, Florida and Montana routinely provide five-year work programs or project schedules to utility companies. Nevada holds monthly meetings with local utility companies and other entities to address upcoming project needs and identify better approaches for avoiding utility relocation delays. States such as Wisconsin, Missouri, Florida, and Georgia involve utility companies in highway projects during preliminary project development and planning. Many states including Pennsylvania, Virginia, and Iowa include utility companies in the right-of-way design phase to assure that utility companies have room to relocate facilities. Some states such as North Carolina and European countries such as Netherlands and United Kingdom have developed fast communication channels with utilities including one-call notification programs to avoid underground utility damages caused by highway activities.

Wyoming recommends utilities that are affected by highway projects to attend preconstruction conference.

- Use utility corridors for utilities when necessary. Some European countries have been successfully using utility corridors for underground utilities. In the United States, several utility corridors were built utilizing existing decommissioned pipelines, tunnels and steam tunnels, or utilidors (108).
- Use standardized utility agreements such as Master Utility Agreements (MUA) in the design-build process. Standardized utility agreements save time for both state transportation agencies and utility companies, including the time necessary to consummate agreements. Many states including Pennsylvania, Missouri, Minnesota, and Montana have been using standard agreements for highway projects involving utility relocations.
- Initiate separate contracts for advance roadway work, such as clearing and grubbing, slope staking, monumentation, demolition of buildings, and advance grading, on selected projects prior to utility relocation. Examples of states that used this practice to expedite highway projects include Iowa, Florida, and Virginia.
- When relocating utilities, place them so they not only accommodate the current project being constructed, but also likely future improvements. This will reduce future conflicts and relocation expenses.
- Acquire sufficient right of way for utilities purposes. Several European countries acquire right of way for utility purposes.

## **SOURCES/CAUSES OF DETERIORATION AND COUNTERMEASURES**

### **Right-of-Way Protection**

Inadequate or non-existent policies or practices in various activities impacting right-of-way protection may result in significant loss to highway functionality. The following is a summary of the major forms of functionality loss due to inadequate practices in these areas.

- Lack of coordination and involvement with local jurisdictions in local planning, subdivision plats, and site development plans result in local decisions being made that have detrimental impacts on TxDOT right of way.
- Insufficient minimum right-of-way requirements for major local thoroughfares that prevent opportunities for right-of-way dedication or reservations along TxDOT roadways as part of the local platting process.
- The inability to begin right-of-way acquisition earlier in the project development process. This delay, perhaps several years, results in paying higher costs for right of way and reduces funds that can be used on measures to improve functionality.



- Restrictions on the use of advanced acquisition methods and the increased resources and advanced level of experience needed to undertake them.
- Poor roadside vegetation cause infrastructural deterioration and environment impact in the right of way and abutting areas. For example, improper vegetation management causes vegetation encroachment to pavements and shoulders causing increased pavement deterioration and traffic safety problems. Invasive vegetation species brought in right of way may cause significant damages to sensitive native species and change the local environment.
- Improperly installed outdoor advertising signs can reduce sight distances of motorists and cause safety concerns.
- Failure in protecting existing transportation corridors limits expansions and enhancements of highways to improve functionality and mobility. Acquiring lands with costly developments may require significant financial and enforcement efforts.
- Locations of on-right-of-way utilities can impede either safety (e.g., limit sight lines, fixed objects too close to pavement), impede improvements (require subsequent relocation or limit the configuration of the future improvement), increase improvement costs (if utility relocation has to be paid for), and increases time to complete projects (adds time for utility coordination and relocation).

Generally, ineffective practices for protecting and preserving right of way can cause functionality loss during various stages of a highway's service life. Lack of right-of-way protection hinders or potentially precludes highway re-development and upgrades and causes losses in functionality or delays enhancements for functionality improvements. Poor roadside management causes infrastructure deterioration and safety problems, which can be considered as functionality loss during the implementation, operation, and maintenance stages.

The following countermeasures may be used to prevent functionality loss due to poor right-of-way protection and preservation:

- Coordinate with local jurisdictions in the planning and development process to ensure that local subdivision regulations and development ordinances—such as building and parking setbacks and sign ordinances—are developed and enforced to prevent encroachments in right of way.
- Coordinate with cities and MPOs to practice corridor management along TxDOT roadways, develop corridor management plans, and incorporate corridor management into MPO Unified Planning Work Programs.
- Develop better roadside vegetation management practices. Highway engineers should continuously explore better practices on managing roadside vegetation. In addition, highway agencies should conduct routine inspection to avoid vegetation encroachment causing pavement damage and sight obstructions.

- Partner with local agencies to increase the potential to preserve and protect right of way along existing facilities. Work together to enable use of municipal and county powers to acquire right-of-way through plat dedications and reservations as well as through donations to locals for future use by TxDOT.
- Since TxDOT roads are included on local thoroughfare plans, coordinate on local major thoroughfare design and minimum right-of-way standards to ensure they are adequate for TxDOT needs and consider future widening.
- The amount of right of way required for state roadways via functional designations on adopted local plans should be reviewed and changed as necessary to accommodate future TxDOT cross-sections. TxDOT or mutually agreed upon right of way and/or design requirements could also be incorporated into local development regulations. Without TxDOT input, local jurisdictions may not consider TxDOT's future right of way needs when processing plats along state facilities. This can create significant and costly problems because most local development ordinances regulate on-site improvements relative to right of way location.
- Seek funds, such as they might be available for use in protective and hardship right-of-way purchases so future parcels within designated right of way can be purchased without creating either significantly higher costs or legal problems. Also seek funds for limited strategic advanced right-of-way acquisition where protective purchases cannot be used to protect future alignments.
- Address legal and resource limitations in early and advanced acquisition practices. Legal and political concerns have been one of the major hurdles to this activity in many states. The current early acquisition practices may not be considerably improved unless the legal and resource limitations are addressed. In addition, states need to develop effective policies and programs to fund and facilitate early right-of-way acquisition for protection of existing corridors and preservation of future ones.

### **Right-of-Way Acquisition**

Various forms of highway functionality loss may result from improper right-of-way acquisition, including highway project delays and inadequate right of way. Five major factors drive right-of-way acquisition duration, including:

- the processes to be followed
- total number of parcels;
- location type;
- district right-of-way staff size; and
- district annual right-of-way budget (87).

Inadequate practices or practices that do not conform to state and federal requirements can directly or indirectly contribute to some of these factors and cause acquisition delays. These delays may further lead to delays and changes to other subsequent tasks in the project development process and ultimately more significant delays to highway projects, leaving highways unimproved or not built for a longer duration. Reasons causing unnecessarily longer duration of right-of-way acquisition may include acquiring an excessive number of parcels, involvement of property condemnations, inadequate communications with property owners and tenants, and acquisition staffing issues.

Acquiring sufficient right of way for utility accommodation and future highway improvement is another important factor that helps to preserve and improve highway functionality over time. Right of way that provides sufficient space for utility accommodation may simplify utility-related tasks required for highway projects and expedite both project development, utility coordination, and total construction duration. In addition, adequate right of way may provide more flexibility for highway improvements. Major factors causing inadequate right-of-way acquisition may include long-term highway planning that is incomplete or fails to consider ultimate facility needs, problematic right-of-way design, right-of-way funding shortfalls, and lack of communication with utilities and other stakeholders.

Right-of-way acquisition issues may affect highway functionality during various stages of a highway's service life. Delays to new highway construction caused by right-of-way acquisition delays are a form of functionality loss during the project development stage. This increase in right-of-way cost due to acquisition delays reduces the amount of funds available for construction and may make some improvements needed to preserve or enhance functionality cost prohibitive. Longer durations of highway construction caused by insufficient right of way will result in functionality loss during the highway operations stage. Lack of right of way for necessary highway expansion may limit functionality characteristics during the operations stage as well.

The following countermeasures may be used to avoid right-of-way issues that cause highway functionality loss.

- Make sure adequate right of way is planned not only for the current improvement, but also to accommodate ultimate needs. Do not just rely on a 20-year traffic forecast.
- Consider ease and cost of acquiring right of way as project development progresses. Time and cost may be saved by adopting an alignment or other features that shift the right of way to parcels known to have willing sellers.
- Where possible, avoid alignments with right-of-way requirements that cause environmental impacts that will either require extensive work (and time) to pass through the environmental process or would require costly, time consuming, or difficult mitigation.

- Conduct early and frequent coordination and communication with property owners. This may include providing property owners accurate, sufficient information on acquisition, and frequent involvement of property owners and other stakeholders during the right-of-way acquisition process.
- Save time by avoiding use of the eminent domain process on an excessive number of parcels. This may be achieved by good faith negotiations with property owners, making available historical appraisal information of comparable or adjacent parcels, and conducting open meetings with multiple landowners. Note that, in certain cases, use of eminent domain process may help in terminating lengthy negotiations.
- Acquire a smaller number of parcels. This may be achieved by combining parcels during appraisal, negotiation, and acquisition.
- Acquire adequate right of way. If long-term traffic demand can be accurately predicted, adequate right of way can be acquired to meet the future improvement needs. In addition, highway agencies may also consider corridor preservations and acquiring right of way for utilities.
- Explore means of beginning some environmental work in the planning process, prior to beginning the project development process as an effort to identify fatal flaws, critical parcels, and probable alignments in order to facilitate early acquisition.
- Use a multi-jurisdictional approach to right-of-way acquisition and protection using methods that include both purchase and acquisition of property rights (e.g., options) to protect right-of-way.
- Where possible, right-of-way and other project development work could be performed concurrently, rather than in traditional TxDOT sequence. The right-of-way function could be integrated earlier into the project development process with an elevated importance.
- Work to avail lawsuits as the way to resolve disagreements with property owners or others

### **Utility Accommodation and Relocation**

Utility accommodation and relocation are two important areas of concern to highway engineers during project development. Poor utility relocation and accommodation practices result in costly complications such as incorrect or delayed utility installation or relocation and late changes to project and utility plans. These complications can cause significant delays to highway projects, leaving roadways not improved timely or occupied by work zones for longer durations. In fact, a 2002 national survey of state DOTs, highway contractors, design consultants, and others identified utility relocation as the most frequent reason for delays in highway construction (109). A previous research (87) identified that several factors, or utility adjustment characteristics, drove utility adjustment durations in Texas. These factors include highway type, project type, utility

type, reimbursable or non-reimbursable adjustments, LPA-funded or non-LPA-funded adjustments, federally-funded or non-federally-funded adjustments, location category, and quick or slow adjustments.

Highway project delays result in highway functionality loss during various stages of a highway's service life. Delays to construction of new roadways will postpone the service of these highways, which consequently extends existing congestion on adjacent roadways. Delays to highway maintenance or enhancement projects will result in prolonged existence of maintenance deficiencies and therefore undermine their functionality. Project delays during construction will leave highway work zones set up for unnecessarily longer durations, which also can cause significant sacrifice to the functionality of existing highways. In summary, poor utility accommodation, coordination, and relocation practices contribute to losses of a highway's functionality during various stages of its service life, whether it be planning, project development, operations, and maintenance.

Many mechanisms can be helpful for better dealing with utilities located in highway rights of way. When properly used, these mechanisms help engineers to expedite project development and save project costs. Generally, project delays caused by utility relocation or accommodation may be avoided using the following strategies:

- **Early, adequate involvement of public utilities.** This may include involving utilities during the project planning and programming stage, effectively and frequently coordinating with utilities throughout PDP, and establishing fast and efficient channels for utility information acquiring.
- **Avoid need for utility relocations.** The best solution for utility relocation is to not relocate the utility facility. Avoiding unnecessary utility relocations can help highway engineers to save time and project cost. Highway engineers may avoid utility relocations through minor modifications to route plans and use of advanced SUE techniques to identify underground utilities.
- **Early and accurate detection of utility conflicts.** Early and accurate detection of utility conflicts would give utility companies sufficient time to budgeting and conducting utility relocations. Various techniques may benefit utility conflict detection, such as GIS, SUE, and other sophisticated information systems.

## PERFORMANCE MEASURES

### Right-of-Way Protection

The following are examples of the criteria that can be used as performance measures for right-of-way protection and preservation:

- Extent of pavement or shoulder cracks caused by weed encroachment. Frequent pavement or shoulder cracks caused by weed encroachment are a sign of poor roadside vegetation management. Frequent roadside inspections and maintenance may help to prevent these damages and to delay roadway deterioration.

- The number outdoor advertising signs by district deemed noncompliant on an annual basis. This or a similar accounting of noncompliant outdoor advertising signs could be a performance measure for the outdoor advertising management practices.
- Percent of all plats and development proposals adjacent TxDOT facilities that are reviewed by TxDOT and coordinated with local jurisdictions on an annual or monthly basis.
- Right-of-way acquisition unit cost. If right-of-way along an existing corridor has not been well protected, acquisition may include costs of damages for improvements on developed parcels along the right of way, which may considerably increase the total acquisition costs. Therefore, right-of-way acquisition unit cost may reflect the effectiveness of corridor protection actions.

### **Right-of-Way Acquisition**

Performance measures that can be used to control right-of-way acquisition in conjunction with other factors are:

- Average right-of-way acquisition duration. The efficiency of the right-of-way acquisition process may be reflected through the average acquisition duration spent for every certain number of projects. With other factors remaining the same, a shorter duration may be a result of better acquisition practices.
- Property condemnation rate. The percent of parcels that are acquired through eminent domain process can be a measurement of the goodness of acquisition practices for a project.
- Number or percentage of right-of-way parcels acquired within a specified period of time. The number or percentage of right-of-way parcels acquired for certain highway projects within a time unit (e.g., fiscal year) may in some cases be a measurement of the efficiency of the right-of-way acquisition practices. An alternative measure may be the percentage of parcels acquired for no more than the appraised value or a specified percentage over that value.
- Length of overall rate or duration of right-of-way acquisition. By comparing the overall right-of-way acquisition durations for similar projects, highway engineers may obtain knowledge on how efficiently or cost-effectively right-of-way acquisition is executed.
- Accounting of right-of-way costs saved on an annual basis by virtue of land dedicated via plat or donation.
- Accounting of parcels acquired on an annual basis by early acquisition methods.
- Percentage of right-of-way parcels by project acquired via dedication or donation in relation to those acquired by purchase.

- Percent of highway miles with inadequate right of way (existing or for desired improvements). Over the time, highways may not provide enough capacity meeting the continuously growing traffic demand and then need to be expanded or otherwise improved. Improvement to certain highway sections may not be feasible due to the limitation of the available right of way. The proportion of these highway miles can be a measurement to the effectiveness of the initial right-of-way acquisition or preservation practices.
- Percent of right of way needed for next improvement project that is unavailable due to lawsuits or other legal obstacles

### **Utility Accommodation and Relocation**

Several measures may be used to quantify the performance of utility relocation and accommodation. Examples are:

- Number or length of utility relocations per mile or per project. Avoiding unnecessary utility relocations can help to save project time and cost. Shorter project durations can result in an earlier return to improved functionality. When other conditions remain the same, the less utility installations a project requires, the better a project design might be.
- Utility conflict points per mile. This is a measure of the extent of utility relocations that may be required for an improvement project, and reflect how long utility relocation may take.
- Percent of project budget for utility relocation. The percent of project budget spent on utility relocation may indicate the number of major utility relocations in the project for which the transportation agency is responsible. With other conditions the same, the less expenditure on utility relocation, the better a project design might be.
- Length of project duration for utility relocations. This is a direct performance measure on the quantity of utility work of a project.
- Yearly percent of utility-delayed projects. This is an approach to measure the overall performance of utility work involved in highway projects. Inefficient right-of-way utility practices may have a large proportion of its projects delayed beyond the scheduled durations by utility-related issues.

## **BEST PRACTICE AND RECOMMENDATIONS**

### **Right-of-Way Protection**

Based on this research, the researchers recommend the following best practices for right-of-way protection and preservation:

- Identify and take actions to preserve, protect, or acquire (additional) right of way needed for the ultimate configuration of the facility.

- Consider centralization or outsourcing strategies for outdoor advertising management. In addition, utilize computer technology such as GIS, database, and Internet to facilitate outdoor advertising permitting and management.
- Consider protecting certain urban arterial highways from new utility installations. When properly used, this strategy may increase the capacity of existing highways and benefit operations and management. In addition, it may also mitigate the competition from utility facilities for right of way that may be necessary for highway enhancement or expansion. Additionally, it will ultimately lead to fewer maintenance activities and fewer work zones over time, which will reduce temporary reductions of functionality.
- Identify priority transportation corridors for rehabilitation or widening during long-range transportation planning. With the critical future corridors and projects identified, transportation agencies and other stakeholders should work cooperatively to identify and implement feasible mechanisms to protect right-of-way interests within them.
- Develop a multi-disciplinary and multi-jurisdictional partnered approach that brings engineering, transportation planning, and land use decision making together to develop ultimate roadway design and right-of-way needs based on land use plans and corridor/access management plans (20).
- When designating right of way to be preserved, consider not only the next planned improvement, but also the ultimate facility needs.

### **Right-of-Way Acquisition**

The following commendable practices have been used in other states or countries and are suggested for TxDOT use:

- Make sure adequate right of way is planned not only for the current improvement, but also to accommodate ultimate needs. Do not just rely on a 20-year traffic forecast.
- Consider ease and cost of acquiring right of way as project development progresses. Time and cost may be saved by adopting an alignment or other features the shift the right of way to parcels known to have willing sellers.
- Where possible, avoid alignments with right-of-way requirements that cause environmental impacts that will either require extensive work (and time) to pass through the environmental process or would require costly, time consuming, or difficult mitigation.
- Utilize available computer technologies to expedite right-of-way acquisition. Computer technologies such as GIS, database management systems, and Internet/intranet have been widely available. These technologies may be used to develop systems that enable real-time, remote, and multi-user sharing and access of right-of-way acquisition data.



- Use the same agent throughout the acquisition process. Using the same agent throughout the right-of-way acquisition process minimizes the redundancy on various tasks during the acquisition and relocation process and therefore shortens the acquisition duration. In addition, use one agent may also help to delineate responsibility, authority, and accountability during the acquisition process.
- Use land consolidation strategies to reduce the number of parcels to be acquired. TxDOT may develop programs to consolidate parcels into larger tracts on a voluntary basis. The consolidated parcels may be acquired at once, which may save time and efforts on negotiation and documentation otherwise required for individual parcels.
- Acquire right of way for utility accommodation. Providing right of way for utility accommodation during right-of-way design and acquisition may enable more flexibility for utility accommodation and future right-of-way expansion.
- Work with local jurisdictions to get additional right of way along existing facilities dedicated and reserved as part of the platting process (when these exactions are permitted based on an adopted local plan).

### **Utility Accommodation and Relocation**

The researchers recommend the following best practices to reduce delays that affect functionality due to right-of-way utilities:

- **Early, adequate involvement of public utilities.** This may include involving utilities during the project planning and programming stage, effectively and frequently coordinating with utilities throughout PDP, and establishing fast and efficient channels for utility information acquiring.
- **Develop good working relationships with utilities.** Good working relationships with utilities help to reduce communication hurdles and improve the willingness of utilities for early and frequent involvements and in turn the efficiency and effectiveness of utility coordination.
- **Avoid need for utility relocation.** The best solution for utility relocation is to not relocate the utility facility. Avoiding unnecessary utility relocations can help highway engineers to save time and project cost. Highway engineers may avoid utility relocations through minor modifications to route plans and use of advanced SUE techniques to identify underground utilities.
- **Early and accurate detection of utility conflicts.** Early and accurate detection of utility conflicts would give utility companies sufficient time to budgeting and conducting utility relocations. Detecting utility conflicts timely and accurately is critical for keeping projects within schedule. Various techniques may benefit utility conflict detection, such as GIS, SUE, and other sophisticated information systems.

- Use advanced technologies such as GIS, Global Positioning System (GPS), and Radio Frequency Identification (RFID) for utility mapping and inventory. These technologies enable highway engineers an access to comprehensive, accurate, and readily available information on right-of-way utilities.
- **Use automated utility installation permitting process.** TxDOT has developed an automated system, the Utility Installation Review (UIR) system, for efficient submitting and processing of utility installation requests on the state-owned right of way (*110*). TxDOT has implemented UIR in several districts and is currently in the process of expanding it to all 25 districts.

## 5. SAFETY

### HIGHWAY SAFETY AND FUNCTIONALITY OVER TIME

When a highway or other transportation facility is new or reconstructed, it should be close to full functionality. It fits its design purpose. The design should be current. Operation should be optimal for the conditions at the time. Over time, conditions of use and condition can change. Pavement becomes worn. Travel patterns change. Traffic composition changes and traffic volumes increase. Access to the road is increased. Minor improvements are made, sometimes to different design criteria.

While geometric design does not itself change without construction, other conditions may change, and as a result, affect safety. Some of these include:

- pavement condition,
- sign and pavement marking condition,
- signs missing,
- sight distance changed by development, new sight obstructions,
- obstructions placed in clear zone,
- trees grow in clear zone,
- access changes operations beyond design capability to accommodate,
- weaving volumes exceed design levels,
- traffic volumes exceed capacity,
- warrants for improvement are exceeded,
- traffic signals need retiming to accommodate changed volumes or travel patterns,
- erosion changes roadside characteristics,
- more lighting needed as areas urbanize,
- inconsistency in roadway design caused by developments (such as roadway widening and extension), and
- increased pedestrian and bicycles volumes on the roadside or at the intersections.

Each of these can produce conditions that compromise safety. Some also compromise other components of functionality. Most can be addressed during the life cycle of the facility and can be maintained, rehabilitated, or improved to return full or partial additional functionality without complete reconstruction or replacement.

This review focuses on three questions regarding the preservation of the safety functionality of highways:

1. How to assess the safety functionality of a highway?
2. What factors are related to the deterioration of highway safety functionality?
3. What strategies can be used for preserving highway safety functionality?

## **ASSESSING HIGHWAY SAFETY FUNCTIONALITY**

There are several methods commonly used to evaluate the safety functionality of a highway. These are summarized in the following paragraphs.

### **Safety Performance Measures**

There are many ways to measure crash occurrence, including crash rates (often reported as number of crashes per year, crashes per million vehicle miles traveled, crashes per million vehicles entering an intersection), and crash severity (measured by number or percent of crashes involving fatalities, incapacitating injuries, and property damage). Individual crash rates/crash frequency can be derived for crashes with different levels of severities, such as fatal, serious injury, moderate injury, and property damages. Measures commonly used are crashes per million vehicle miles (for highway segments or systems) and crashes per million entering vehicles (intersection).

In addition, accident impacts related measures, such as average accident event duration and the average delay caused by accidents, can be used for evaluating the efficiency of incident management systems/programs.

TxDOT uses Mileage Death Rate (fatalities per 100M VMT) and Mileage Serious Injury Rate (serious injuries per 100M VMT) as safety performance measures in its traffic safety plan (*111*).

### **Safety Improvement Priority Indices**

Some indices are used to identify the most needed investments for safety improvements. These indices include, the number of crash hot spots, crash reduction factor (percentage), and the ratio of benefit to cost for an improvement (*112*). In its Highway Safety Improvement Program (HSIP), TxDOT uses a formula known as the Safety Improvement Index (SII) for identification which is used for the ranking and selection of eligible projects (*113*). This SII formula determines the ratio between the expected benefits in crash reduction following the proposed improvements and the costs associated with implementing the project, including operating and maintaining the project over its design life. The formula in its current form also contains terms related to exposure (i.e., traffic volume), life of the project, interest rates, crash costs, and crash reduction factors (CRFs).

### **Data Sources for Safety Performance Measures**

A good crash inventory database is needed to be able to evaluate highway safety functionality on a system wide basis. The database should contain the information about crash type, crash location, severity levels, etc. In addition, roadway databases that contain the roadway geometric and transportation assets information, such as signs, signals,

lighting, guardrails and barriers, and pavement markings and treatments, are also needed for defining roadway safety functionality. The following are some important data sources available in Texas for roadway safety performance evaluation.

- TxDOT/DPS Crash Record Information System (CRIS) – This is the official state database for traffic crashes occurring in Texas. CRIS is a joint initiative between the Department of Public Safety (DPS) and TxDOT to implement a new Crash Records Information System that will provide enhanced efficiencies to capture, manage, and deliver timely and accurate data to improve the safety of Texas roadways. The system includes web-based components, imaging, electronic forms, spatial-based accident location, data warehousing, enterprise reporting, GIS analysis and XML import and export. It went into production in 2006.
- DPS Accident History Database – This database contains information about each reported crash in Texas. The database consists of three component databases: crash database, driver/vehicle database, and casualty/occupant database. This dataset is addressed in TxDOT research project 0-4073, *Probability Generation of Frequency and Severity of Nonrecurring Congestion due to Accidents to Improve Emission Analysis*.
- TxDOT Roadway Inventory File (RI-File) – This is a roadway characteristics database developed by TxDOT. The RI-file includes information on the traffic characteristics and geometry for roadway segments for both state highways and county roads.
- Rhino, Geo-Hini, and P-Hini datasets – These are subset databases of the Texas Reference Marker System (TRM). Rhino provides segment descriptions. Geo-Hini provides information about horizontal curvature. P-Hini contains attributes about point-specific features of the roadway.

There are also regional and local databases maintained by other agencies. For example, HGAC has its Transportation Safety Data, which includes three different parts: (1) Fatality Analysis Reporting System (FARS), (2) TxDOT CRIS, and (3) Department of State Health Services Vital Statistics.

In addition, the Highway Safety Information System (HSIS) has been widely used for safety performance analysis in some other states. The HSIS is a multistate database that contains crash, roadway inventory, and traffic volume data for a select group of states. The participating States—California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, Utah, and Washington—were selected based on the quality of their data, the range of data available, and their ability to merge the data from the various files. FHWA staff, contractors, university researchers, and others use the HSIS to study current highway safety issues, direct research efforts, and evaluate the effectiveness of accident countermeasures. HSIS data system includes the following basic files (114):

- accident data,
- accident file,

- vehicle file,
- occupant file,
- roadlog file,
- reference post file,
- traffic file,
- intersection file,
- bridge (structures) file, and
- RR grade crossing file.

### **Evaluation of Highway Safety Functionality**

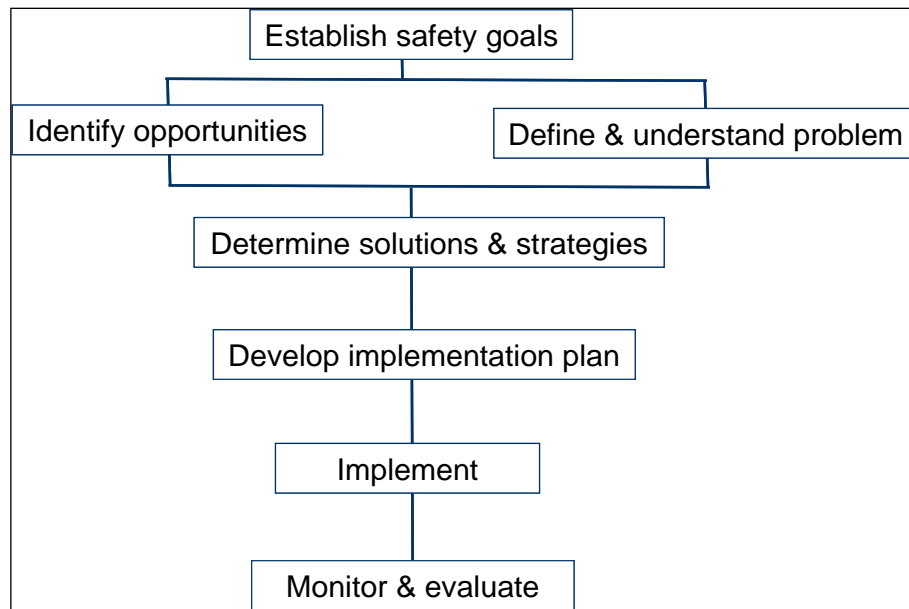
Highway safety performance can be evaluated based on the safety performance measures and safety data used. This approach is usually employed to assess the effectiveness of certain safety countermeasures. Before and after studies are usually conducted. The following are some typical examples of before and after safety evaluation studies.

- *Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on freeways* – This study employed a before/after approach to assess the safety effects of Continuous Shoulder Rumble Strips (CSRS) on single-vehicle run-off-the-road crashes. HSIS data from Illinois and California were used. The data include two parts: one are the accident data before installing the CSRS and another are the crash data after installing the CSRS. The results of conducting before/after analysis showed that there are significant decreases in crashes after installing the CSRS. For Illinois, after installing the CSRS, the single-vehicle run-off-the-road crashes were reduced by 18.3 percent. For California, after installing the CSRS, the single-vehicle run-off-the-road crashes declined by 7.3 percent (115).
- *Safety Evaluation of STOPAHEAD Pavement Markings (2008)* – Safety effectiveness of STOP AHEAD pavement marking was evaluated based on some quantifiable performance measures. To quantify the safety effectiveness of STOP AHEAD pavement marking, crash data before and after installing the STOP AHEAD pavement marking were collected at 178 unsignalized intersections, and an Empirical Bayes before-after analysis was conducted. Data analysis results indicated that there was a statistically significant reduction in total crashes after installing the STOP AHEAD pavement marking. A reduction in total crashes of at least 15 percent can be expected (116).
- *An Analysis of the Safety Effectiveness of Pavement Marking Retroreflectivity (2008)* – Before-and-after studies were conducted to analyze the relationship between of the pavement marking retroreflectivity and crash rates under different traffic volume conditions. This study developed a spatial-temporal database, which includes the information about the deterioration of pavement

markings over time. These data are tied to a statewide crash database. However, the results of model based on one set of test data suggest that pavement marking retroreflectivity does not have a statistically significant effect on crash rates (117).

## Safety Management Systems

A safety management system is a coordinated approach to the above techniques for assessing safety across the highway system. Figure 6 below shows the basic steps in the systematic approach (118).



**Figure 6. Safety Management System.**

The first step is to establish goals for the safety program to be conducted under the safety management system. This often involves not only the state DOT, but may also include other state and other organizations (e.g., DPS, Governor’s Highway Safety Council, American Automobile Association, etc.). After that is completed, the problem is defined. That may be the high crash or fatality locations, overall crash rate, certain types of crashes, drunk driving, types of safety-deficient conditions (e.g., narrow bridges with unprotected bridge ends), etc. The problem(s) to be attacked are established at this stage.

If one was to establish as the problem the deterioration of safety functionality of the highway system, the management system would be aimed at monitoring and preserving safety as it is affected by functional efficiency of the highway system. Data would be assembled from TxDOT and other sources that could be used to identify safety conditions and evolving problems.

A parallel step is to identify corrective and preventative measures for preserving or recapturing safe conditions. This may involve statewide programs (e.g., seat belt use

program) or localized applications (high crash location improvements). The program may be focused or broad, depending on goals and problems.

Consideration of the problems to be attacked and effective measures and programs leads to the development of a program strategy and solutions to be pursued. Options are considered. Cost, staffing, and other resources are considered. Once the strategies and solutions are selected, an implementation program is developed and then implemented. It is critical to the success of the safety management system that the results and system conditions be monitored and evaluated. Effectiveness can only be verified and increased if the results are analyzed.

Keys to success of a safety management system include addressing all major crash concerns including not just the highway, but also the driver, vehicles and education. A definite goal (e.g., crash rate or other target) is normally set and is usually adopted by the participating agencies so they are all committed.

### *Texas Safety Management Systems*

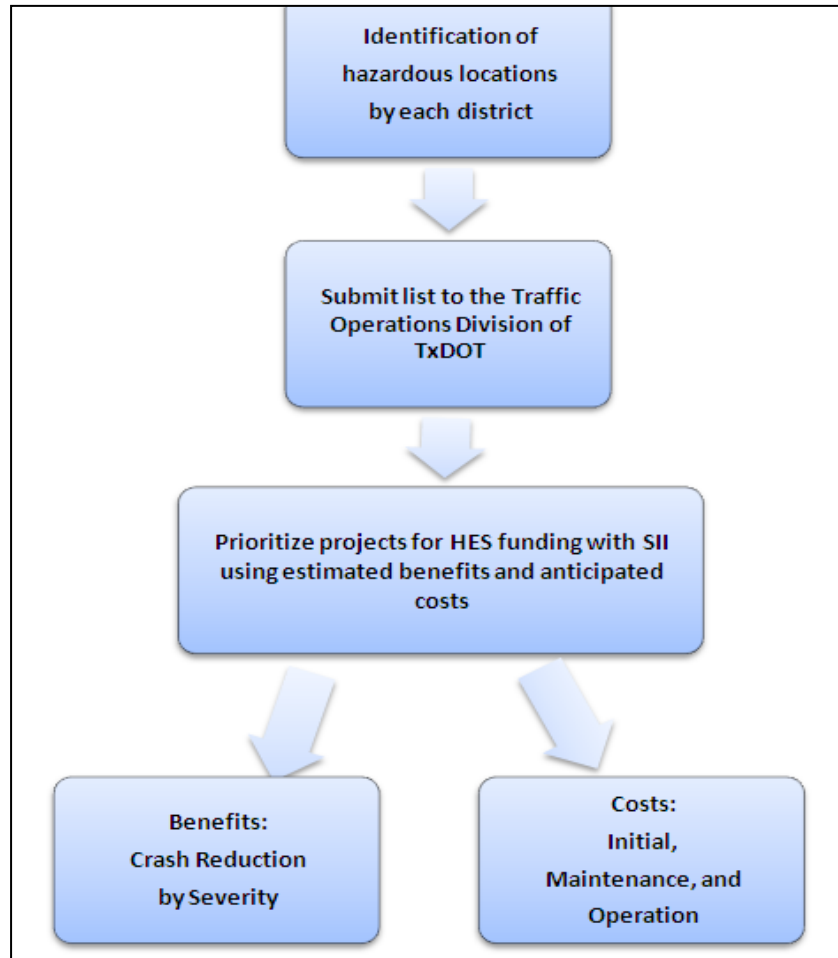
The Hazard Elimination Program is one of two safety construction programs under the Highway Safety Improvement Program (HSIP) (113). It focuses on construction and operational improvements for locations both on and off the state highway system (excluding interstate highways). The basic objective of the HES Program is to reduce the number and severity of crashes. The program objectives are accomplished through —highway safety projects,” which may accomplish any of the following:

- correct or improve high-hazard locations;
- eliminate roadside obstacles;
- treat roadside obstacles;
- improve highway signing and pavement marking; or
- install traffic control or warning devices at locations with a high number of crashes.

These projects may range from spot-safety improvements and upgrading of existing conditions to new roadway construction (such as grade separations).

To begin each round of this program, the Traffic Operations Division (TOD) distributes a statewide program call to the districts. Then, the districts work with the local governments to identify potential highway safety projects using historical crash data and other data. After that, the districts submit the request for proposed highway safety projects, and the TOD analyzes the proposed project and conducts a benefit/cost analysis using the Safety Improvement Index (SII) to prioritize the proposed project. Based on the results of priority, projects are selected for funding in the Hazard Elimination System (HES) program and are implemented by the selected districts. [Figure 7](#) presents the overall procedure of the HES program.





**Figure 7. Overview of HES Program in Texas.**

## **FACTORS RELATED TO THE DETERIORATION OF HIGHWAY SAFETY FUNCTIONALITY**

The FHWA has published a series of reports that summarize the results of research dealing with safety effectiveness of highway design features. These reports investigate the safety impacts of the geometric design factors, including: (1) access control, (2) alignment, (3) cross sections, etc.

### **Access Control**

Highway safety is affected by the location and design of access points. Each access point on a highway introduces turning movements and speed changes that may be in conflict with other vehicles in the normal traffic stream of the highway. When multiple access points are located within close proximity to each other, their overlapping traffic patterns substantially increase the range and complexity of potential conflicts (119).

As a result, the location and design of access points are very important in the design of highways. The following includes some of the most important aspects of the design.

- First, all access points should be required meet certain location and spacing requirements to guard against adverse effects on highway safety.
- The range of movements available at each access point should be limited to those that are safe and necessary for property access.
- Each access point should have adequate sight distance.
- Standard entrance designs, coupled with curb and gutter along the road, will help to preserve safety by promoting predictable traffic patterns and controlling unauthorized or unsafe movements.
- Speed transition lanes (deceleration/acceleration lanes) are often used to separate slower turning vehicles from faster through-moving vehicles, thereby reducing the potential for rear-end and right-angle collisions and improving safety.

### **Horizontal and Vertical Curves**

Crashes rates for horizontal curves are higher than for tangent sections, with rates ranging between 1.5 and 4 times greater than on straight sections. The factors influence the safety performance of curves include: (1) the geometric features of curve, (2) the stopping sight distance, and (3) the tangent distances between adjacent curves and between curves and the nearest intersection or bridge.

Increasing the degree of curvature tends to increase crash frequency. Sometimes topography can obstruct the sight line along the curve, making stopping sight distance too short.

Safety in curves results from operating speed being less than design speed. For horizontal curves, design speed is based on curvature, pavement friction, and superelevation.

Crashes result when operating speed exceeds design speed. This can occur when speed limits are increased without considering geometric features as well as when drivers exceed the speed limit.

However, a mismatch between design and operating speeds can occur in other ways. For example, as a result of seal coating or resurfacing, the pavement friction can change. If that occurs and the friction is reduced below design levels (or this happens as a result of lack of maintenance), operating speeds may exceed the effective design speed and result in increased crashes. Studies have shown that the crash rate in curves is 1.5 to 4 times higher than in tangents (i.e., straight sections) (*120*). The severity of accidents in curves is high—about 25 to 30 percent of all fatal accidents occur in curves (*121, 122*).

For vertical curves, crash frequency increases at crests and sags. Increasing the length of a vertical curve excessively, especially on a two-lane road, may extend the passing distance so much as to introduce a hazard. On crest curves, the available sight distance may not be sufficient for safe overtaking. It is important that vertical curve length be

sufficient to accommodate passing at anticipated or existing passing operating speeds. The effects of grade on speed need to be considered, especially where trucks are involved. On sag curves, critical parameters include the range of vehicle lights, the presence of bridges or other features that limit sight distance. Other elements to be considered are water accumulation and accelerated erosion of shoulders due to water runoff.

A study on vertical curves has shown higher crash rates for sag curves than for crest curves. Moreover, according to a study (*123*), crash rates are higher when entering the curve than when leaving the curve, for both crest and sag curves. To prevent crashes associated with vertical curves, it is important to provide drivers with adequate stopping sight distance (SSD). That is, enough sight distance must exist to permit drivers to see an obstacle soon enough to stop for it under some set of reasonable worst-case conditions. The parameters that determine sight distance on crest vertical curves include the change of grade, the length of the curve, the height above the ground of the driver's eye, and the height of the obstacle to be seen.

### **Cross Sections**

One of the most important roadway features affecting safety is the highway cross section. The highway cross section includes travel lanes, shoulders, side slopes, clear zones, and ditches. All these can affect the highway safety functionality. For example, in general, if the lanes or shoulders are not wide enough, there will be more crashes.

### **Other Design Features**

Depending on specific facilities and their use, other design factors contribute to the safety of a highway or street. These include:

- clear zone,
- sight distances,
- merge and weave sections and spacing between interchanges,
- structures and obstructions in clear zones (such as trees and utility poles),
- drainage,
- pedestrian and bicycle facilities,
- intersection design,
- grades,
- lighting,
- roadway delineation,
- traffic control, and
- design consistency.

This last design component deserves additional emphasis. If a highway is designed and maintained with consistent design speeds, cross-sections, treatments, signing, etc., it will provide a consistent driving look and feel.

However, over time, maintenance and minor improvements can result in introductions of inconsistencies. Examples are variations in pavement surface and friction, shoulder width, deceleration lane lengths, signing, ramp merges, and weaving sections. Consistency makes the road predictable and easier to drive safely. Inconsistencies can introduce uncertainties, surprises, and crash potential. Why is this important? Up to 95 percent of all roadway crashes involve driver error and 30 percent involve road environment factors. According to a NCHRP study (*124*), inconsistency design will result in accident rate increasing by 5 percent or more where speed changes by 5 km/h (3 mph) or more, or where lane position changes by more than 0.3 m (1 ft).

## **COUNTER MEASURES TO GEOMETRIC DESIGN RELATED CRASHES**

NCHRP 500 series reports (*125*) provides guides to assist state and local agencies in reducing injuries and fatalities in targeted emphasis areas. Each guide pertains to specific types of highway crashes and includes a brief introduction, a general description of the problem, the strategies/countermeasures to address the problem. Among these reports, volumes 3–4, 6–8, and 10 address crash types that are closely related to highway design. The following are the list of the major countermeasures recommended by these reports:

- NCHRP 500 Volume 3: Collisions with Trees – recommended countermeasure: a) Planting Guidelines and b) removal of trees in hazardous locations;
- NCHRP 500 Volume 4: Head-on Collisions – recommended countermeasure: a) alternating passing lanes or four-lane sections at key locations, and b) median barriers for narrow medians;
- NCHRP 500 Volume 6: Run-Off Road Collisions – recommended countermeasure: a) shoulder rumble strips, b) enhanced delineation of sharp curves, and c) shoulder treatments;
- NCHRP 500 Volume 7: Crashes on Horizontal Curves – recommended countermeasure: a) provide warning of changes in horizontal alignment, b) adequate sight distance, and c) pavement grooving;
- NCHRP 500 Volume 8: Utility Pole Collisions – recommended countermeasure: a) remove poles in high-crash locations, b) use frangible pole mounts, and c) shield drivers from poles; and
- NCHRP 500 Volume 10: Collisions Involving Pedestrians – recommended countermeasure: a) sidewalks/walkways, b) refuge islands, and c) lighting at crosswalks.

In sum, geometric design is critical for the roadway safety functionality. Poor design will likely result in significant more crashes and more risks to the travelers. The

geometric design factor is very important to the planning and project development stage of the highway life cycle.

## **STRATEGIES FOR PRESERVING HIGHWAY SAFETY FUNCTIONALITY**

Four strategies for preserving Texas highway safety functionality are proposed:

1. Strengthen the roles and responsibilities of traffic safety organizations/agencies;
2. Improve decision making process and information systems;
3. Improve geometric design; and
4. Strengthen asset management.

Each of the above four strategies is discussed in the following subsections.

### **Strengthening Roles and Responsibilities of Traffic Safety Agencies**

Examples of strengthening the roles and responsibilities of traffic safety agencies include:

- deployment of a transportation safety legal, institutional, and policy mechanism;
- strengthen the functionalities of highway accident appraisal organizations; and
- activate and support traffic law enforcement organizations.

One of the traffic law enforcement organizations that has the greatest impacts on the highway safety functionality is the highway safety service patrol (SSP). SSPs respond to and work to clear incidents that can further affect safety. The following are examples of the benefits of SSPs in different states as evaluated by different studies.

- *Evaluation of the Freeway Service Patrol (FSP) in Los Angeles (126)* – Freeway service patrols (FSP) work a 7.8 mile section of IH 10 freeway (Beat 8) in Los Angeles. Field data used to assess the FSP effectiveness were collected using seven specially instrumented probe vehicles traveling along Beat 8 at an average of 5.7-minute headways, six hours per day, for 32 days. These 192-hour data include detailed descriptions for 1,560 incidents, probe vehicle travel time traces for 3,619 runs (at 5.7 minute headways), and data from 240 loop detectors. Among the 1,560 incidents, 1,035 incidents were assisted by the FSP. The evaluation results showed that FSP-aided incidents were about 15 minutes shorter. The daily reductions in air pollutant emissions include a total of 60 kg of hydrocarbons, 462 kg of carbon monoxide and 122 kg of oxides of nitrogen. In addition, the estimated benefit/cost ratio of FSP is greater than 5:1. These results indicate that FSP is a successful, cost-effective operational program for the safety improvements of Los Angeles.
- *Assessing Return on Investment of Freeway Safety Service Patrol Programs in Virginia (127)* – This project developed a methodology to evaluate and quantify the benefits of Safety Service Patrol (SSP) programs. The methodology includes two steps. First, the incident durations with and without

SSPs were estimated. After that, based on the results of estimated incidents durations, benefits are estimated for reductions in motorist delay, fuel consumption, and emissions due to SSP program. The developed methodology was applied to the Hampton Roads, Virginia SSP. The results showed that incident duration reductions due to SSP operations in this area resulted in benefit–cost ratios of 5.4:1. Thus, this can indicate that SSP is a cost-effective program.

- *Cost-Effectiveness Evaluation of Hoosier Helper Freeway Service Patrol in Indiana (128)* – Hoosier Helper is an Indiana Department of Transportation sponsored freeway service patrol. It provided free assistance to motorists on part of IH 80-94 and IH 65 in Northwest Indiana. An evaluation was made of the benefit of the Hoosier Helper Freeway Service Patrol. The evaluation includes two scenarios. One is daytime patrol; the other is 24-hour patrol. The benefits of Hoosier Helper included congestion delay reduction savings, secondary crash reduction, and vehicle operating cost savings. The results of this study showed that benefit-cost ratios for the daytime program operation and 24-hour program operation are 4.71:1 and 13.28:1, respectively. Since there was a significant increase in benefit-cost ratio for 24-hour operation, the 24-hour operation strategy was recommended.

These three examples illustrate the value of SSPs in reducing the durations of crash-related incidents, which in turn can result in reducing further crash experience.

### **Improve Decision Making Process and Information Systems**

Making optimal use of safety information is a critical challenge facing state and local transportation safety professionals. Knowing how, when, where and why traffic crashes have occurred is the foundation of a comprehensive traffic safety analysis system. Crash, traffic, citations, medical, judiciary, and driver records must be available, so that proper decisions can be made and effective safety policies and projects can be developed and implemented. The following are some detail strategies that can be used for improving decision-making process and accident information systems (129).

- Improve timeliness, thoroughness, and accuracy of data collection, analysis processes, and systems including the linkage of crash, roadway, driver, medical, Crash Outcome Data Evaluation System (CODES), enforcement, conviction, homeland security data, etc.
- Improve and expand the warehousing and accessibility of safety data. Expansion will include additional data from local roads, which is at this time limited.
- Establish a Traffic Records Coordination Committee to include representation from all stakeholders with a need for traffic safety information.
- Expand the local agencies' roles and resources to improve safety.

- Provide training on data analysis, updating, definitions, importance, and uses to State and local personnel.
- Provide web access to the media and public on key data and analyses.
- Improve the exchange of information with the media.
- Independently verify the validity of the data.
- Integrate GIS-based crash database.
- Implement Road Safety Audit (RSA) Reviews as a means of identifying areas for safety improvements.

Select examples of above proposed strategies are provided in the following paragraphs.

- *Integrate GIS-based crash databases.* A number of states are now in the process of upgrading road safety and infrastructure databases to better integrated GIS-based data management systems. GIS is seen as the key linking technology because of its ability to employ a variety of integration methods to pull the various datasets together. It is important that all road crashes can be easily geo-coded on a base map. This mapping functionality can provide the basis for crash data analysis. The Oregon Department of Transportation (ODOT) has a good GIS-integrated data management system. Through the implementation of its TransGIS, ODOT has consolidated all state databases into one GIS-based program. It will provide a multitude of data to anyone who is on the system. For example, researchers can easily use the crash data to evaluate the location of highway with safety problems. The engineers, planners and policy makers can use the asset condition data and crash data to make better decisions about how to conduct asset management, where to spend the their limited resources for safety improvement and what changes are needed in the design, operations, and maintenance of the roadway safety functionality (130).
- *Conduct Road Safety Audits during Project Development, Design, and Before Opening.* A road safety audit (RSA) is a formal review of a road project (at several stages of project development, design, or implementation) to examine the project's potential crash and safety performance. When used thoroughly, the RSA may be done at any or all of the following stages, depending on the nature of the project (131):
  - project feasibility; initial schematic design,
  - preliminary design,
  - final design, and
  - pre-opening.

RSAs are proactive efforts to prevent crashes before they happen. They are usually conducted by personnel specifically trained in RSAs and crash prevention. They are

always independent of the project development, design, or construction management teams for the particular project.

Detailed checklists are extensive and vary by project type. However, a generalized checklist might include:

- design criteria and application,
- design speed,
- design traffic volumes and vehicle and mode types,
- alignment and continuity,
- cross-sections,
- intersections, interchanges,
- sight distances,
- shoulders and edge treatments,
- access management,
- environmental constraints,
- lighting,
- traffic control devices,
- drainage,
- landscaping,
- construction staging, and
- traffic operation and incident management capability.

A few examples of what may be found in a RSA include:

- insufficient merge or weave section length,
- transition problems,
- missing traffic control devices,
- sight line obstructions resulting from proposed improvements,
- potential for wrong way turns,
- drainage headwall obstructions in clear zone (not removed or introduced by project),
- guardrail without approach or departure treatments,
- insufficient traffic signal phases for pedestrian crossings,
- lack of sufficient shoulder on bridge to accommodate bicycles,



- insufficient sight distance to accommodate slow moving trucks entering traffic,
- insufficient night visibility, lighting needed at additional locations,
- temporary pavement markings still showing at pre-opening, and
- improper sign sizes installed.

Correcting the above items early costs almost nothing. Correcting at final design is usually low cost. Correcting after construction is more costly, but not nearly as costly as even a single fatal crash. That is why RSAs are used.

Conducting road safety audits on existing roads is important for improving transportation safety on existing roads. It serves to bring an improved understanding of crash causes and countermeasures to bear in a proactive manner. RSAs have been widely used to examine crash causes and countermeasures. An example of the application of an RSA is a rural freeway safety evaluation (132). After conducting the road safety audit, the geometric features of roadway, (e.g., sharp curve) which can result in safety problems are identified and the corresponding countermeasures (e.g., guardrail pretention) are provided. Figure 8 shows the pictures of a roadway section before and after conducting the road safety audit.



Before



After

**Figure 8. The Pictures of the Highway before and after Conducting the Road Safety Audits.**

Road safety audits can be used in any phase of project development from planning and preliminary engineering through design and construction. RSAs can also be used on any sized project from minor intersection and roadway retrofits to mega-projects.

### **Improve Geometric Design**

The improvement of safety in highway geometric design can be focused on the following areas.

1. Improve access control design of highway, such as:
  - a. Remove access points from through traffic;
  - b. Provide side road access for business driveways;
  - c. Use special turning lanes to separate through vehicles from those vehicles using the access point; and
  - d. Increase access spacing to crossroad near the freeway ramp.
2. Improve geometric features of curves:
  - a. Widen lanes and shoulders on curves;
  - b. Reconstruct the curve to make it less sharp; and
  - c. Increase sight distance through curve.
3. Increase the roadside recovery distance.

The following are examples of studies that were conducted to assess the impacts of geometric design on highway safety.

- *Access Control Design on Highway Interchange (133)* – The access spacing to crossroads near freeway ramps is one important factor affecting the highway safety. This project developed a model to evaluate the safety impact of different access points spacing standards. The relationship between crash rate and different access points spacing are investigated. The analysis results showed that the crash rate decreases as the access points spacing increases. There was an eight-fold decrease in the crash rate when the access road spacing increased from 0 to 300 m (1,000 ft). Additionally, there was a 50 percent reduction in the crash rate when the access road spacing increased from 90 m (300 ft) to 180 m (600 ft). In addition, the project developed a lookup table that quantifies the impact of access point spacing on the expected number of crashes per unit distance. This table is useful for policy makers to make plans for highway safety improvement. They can balance the cost of crashes and the benefit of increasing the access road spacing and make the plans that maximize the benefits.
- *Safety Aspects of Freeway Weaving Sections (134)* – One source of vehicle conflicts is the freeway weaving section, where a merge and diverge in close proximity require either merging or diverging vehicles to execute one or more lane changes. In this paper, the author divided the weaving sections into three types: (a) where every merging or diverging vehicle must execute one lane change, (b) where either merging or diverging can be done without changing lanes, and (c) where one maneuver requires at least two lane changes. The project used data for 55 weaving sections in Southern California to analyze the relationship between crash rate and weaving type. The results showed that there are significant differences between the weaving type and the severity of crashes as well as the location of crash. Based on the results, some strategies, which can used to improve the safety, were recommended. These were:

- Type A weaving section crashes are the least severe. They are more prevalent at off-peak periods, especially at night, and on wet roads. It was recommended that the sign in front of all type A Weaving Sections should be evaluated to determine if drivers are being given sufficient warning for change lanes in order to exit or enter the freeway.
- For type B sections, it was recommended that the special speed restrictions may be warranted, or more effective enforcement of posted speed limits.
- For type C weaving sections, the crashes usually occur in the left lane during weekday rush hours. It was recommended that changeable message signs warning of potential hazards should be used for alerting drivers to potential hazards during periods of heavy traffic flow.

Various tools have been developed for improving high geometric design for better safety performance. One representative tool is the *Interactive Highway Safety Design Model* (IHSDM), which is a product of the Federal Highway Administration's Safety Research. This model can be used as an analysis tool to facilitate the highway design process and evaluate safety and operational effects of geometric design decisions.

IHSDM is intended for use throughout the highway design process from preliminary planning and engineering through detailed design to final review. It may be used both for projects to improve existing roadways and projects to construct new roadways. IHSDM focuses on two-lane rural highways and has five evaluation modules: (1) policy review, (2) crash prediction, (3) design consistency, (4) intersection review, and (5) traffic analysis. Additional capabilities including a driver/vehicle module to provide measures of vehicle dynamics and evaluations of multilane rural highways are planned for future releases (135).



## 6. INFRASTRUCTURE (PAVEMENTS AND BRIDGES)

The objective of this chapter is to identify the effect of infrastructure (pavements and bridges) condition and construction activities (maintenance, rehabilitation, new construction/reconstruction) on the state highway system's functional performance.

### **POLICIES, PROGRAMS, AND STRATEGIES TO PRESERVE OPERATIONAL FUNCTIONALITY OF HIGHWAYS**

#### **Pavements and Bridges/Work Zones**

Pavements and bridges built long ago are at an age where their conditions typically require more maintenance or even reconstruction. Those actions result in work zones, some of which can decrease facility functionality. Where there is increasing traffic and congestion, the introduction of work zones may add to the problem. As a result, work zone delays and safety have become a major concern. This has led to the identification of work zone traffic management techniques to reduce the motorist delays and improve the work zone safety. FHWA's Office of Program Quality Coordination (OPQD) has identified work zone traffic management as one of the list of key ingredients essential to any Transportation Management Plan (TMP) to be effective in addressing the work zone issues.

According to OPQD's review team, this technique is a proactive approach that uses performance modeling to predict traffic and crash impacts. Commonly used performance measures for assessment of these impacts include delay, volume, travel time, number of incidents and incident response time, user costs, and queue lengths. These performance measures help in deciding which cost-effective mitigative approaches could be implemented. Reducing the exposure between motorists and highway workers can result in significant reduction in crash rates and motorist delays.

Some of the practices followed in reducing the exposure are:

- reducing the volume of traffic going through the work zone (e.g., using detours or schedule work during lower volume periods),
- reducing the length of time work zones are in place, and
- reducing the frequency that work zones are established to perform construction and maintenance operations.

The reduction in the construction time helps road users save time and fuel. This is referred to as the Road User Cost (RUC), which is the estimated daily cost to the travelling public from construction work being performed (136). To minimize the inconvenience to the motorists and reduce road user cost, TxDOT offers contractors incentives when they finish the work early and charges them liquidated damages for late completion.

TxDOT's Construction Division has guidelines set out to aid in making decisions on when to incorporate road user cost into construction contracts. Eligible projects include:

- projects that add capacity (may include grade separation),

- projects where construction activities are expected to have an economic impact on local communities and businesses, or
- rehabilitation projects in very high traffic volume areas.

Feeling the need to minimize construction time, TxDOT has started incorporating RUC into construction contracts. Projects administered through A+B contracts or lane rentals and have built-in fee component to address the road user delays. This fee motivates the contractor to minimize construction time to avoid additional cost. The following are the types of contracting strategies that TxDOT uses to administer the concept of RUC.

1. Shorten construction schedules – many construction contracts are scheduled with enough extra time so just about any kind of contractor or supplier delay can be accommodated. This provides contractors more scheduling flexibility and permits them to bid lower prices. That is advantageous to transportation agencies. However, where conditions will be congested or potentially hazardous during construction (i.e., reduced functionality), it may be cost-effective and beneficial to the community to shorten the construction schedule to reduce the duration of impeded traffic flow. This has been done on numerous urban freeway projects. In some cases, certain phase can be compressed rather than the entire project.
2. A+B bidding – This contracting strategy is also known as the cost-plus-time bidding. It involves time along with an associated cost for determining the low bid. The bid award includes the road user cost associated with the total duration of project. For projects with potential for high road user delays, A+B bidding can reduce the construction time significantly (137).
3. Lane rental – In this concept, the contractor is charged a fee for occupying the lanes to do work. If the contractor finishes the project within the planned duration, the rental fee is not charged. If the contractor requires additional days, then the rental fee is applied (137). For example, the Parmer Lane/Loop 1 project in Austin used the lane rental strategy to motivate the contractor to finish the work on time or earlier. The project is divided into three milestones with each milestone having an associated bonus/penalty amount per day defined in the contract.
4. Contractor incentives – To shorten the duration of construction, the contractor is offered an incentive to finish the work more quickly. The contractor is paid a bonus calculated on a daily basis; a penalty is levied for late completion. The contractor may also be given latitude to modify construction techniques and even materials as part of the program to accelerate the project. The reconstruction of the IH 635/US 75 interchange in Dallas used both approaches to significantly reduce the originally expected construction duration.

While it is beyond the scope of this project to cover work zone traffic management, there are many actions that can be taken to reduce the loss of functionality during maintenance and construction. Some of these include:

- use narrower rather than fewer lanes where possible;
- perform work at night or in off peak periods;

- use normal design criteria for temporary road conditions where possible (e.g., curves, tapers, merge sections, etc.); and
- increase the amount and helpfulness of motorist information.

## SOURCES AND CAUSES OF DETERIORATION OF PAVEMENTS AND BRIDGES

The primary cause for the deterioration of pavements and bridges is the structural distresses. Distresses can cause functional failure or affect the functionality associated with ride quality (operational) and safety. These conditions have a direct bearing on the functional performance; both are measurable using performance measures. Some of the common physical distresses leading to pavement deterioration are:

- *Asphalt* – bleeding, corrugation, depression, heave, lane shoulder separation, patch deterioration, polished aggregate, potholes, pumping and water bleeding, raveling and weathering, rutting, and swell.
- *Concrete* – blowup, corner break, depression, heave, joint separation, patch deterioration, pop outs, pumping and water bleeding, spalling (transverse and longitudinal cracks), spalling at corner, swell, and localized distress.

Traffic and climatic conditions are the primary sources for causing the deterioration of pavements and bridges. [Table 7](#) outlines common deteriorating mechanisms and causes for them, as given by Assaf et al. (1997) ([138](#)). [Table 7](#) presents examples that link some of the pavement conditions with their sources.

**Table 7. Deteriorating Mechanisms in Pavements.**

Deteriorating Mechanism	Agents	Examples
Structural Deficiency	Traffic	Alligator cracks, patch deterioration, polished aggregate, potholes, rutting, depression, cracks in concrete, patch deterioration
Material Deterioration	Water	Raveling and weathering, Pumping and water bleeding
Freeze thaw	Water, Temperature	Swell, 'D' cracking in concrete, pop outs
Temperature Shrinkage & Creeping	Temperature	Blowup, Longitudinal Cracks
Mix Problems	Bitumen, aggregate	Depression, Patch deterioration, Polished aggregate, construction joint deterioration

The *Distress Identification Manual for Long-Term Pavement Performance Program*, by the Federal Highway Administration, identifies different distresses along with their mechanisms, levels of severity and measurement criteria. The severity levels help to define the condition of pavements ([139](#)).

Within TxDOT, each district measure these distresses using equipment like the inertial profiler, rutbar, falling weight deflectometer, dynamic cone penetrator, and ground penetrating radar. These measurements are then used to define the structural condition of pavements through the performance indicators explained in the next section.

As noted in a 2005 article in the *Journal of Transportation Engineering*, the following are some of the measurement data stored in TxDOT's pavement management system (140).

- type of underlying pavement,
- percent deep and shallow rutting,
- patching percent,
- base failure percent,
- block cracking percent,
- alligator cracking percent,
- longitudinal cracking length per station,
- transverse cracking number per station,
- raveling score,
- flushing score,
- average 18 kip wheel loads, and
- average annual maintenance cost.

From the above measurements, a distress score, ride score, skid number, roughness index, and pavement condition score are calculated to define pavement's condition.

## **FACTORS/CAUSES AFFECTING BRIDGE PERFORMANCE**

A 2003 article in the American Society of Civil Engineer's ASCE, *Journal of Performance of Constructed Facilities*, identified the possible causes for deterioration of bridges by analyzing the frequent causes of bridge failure. The most frequent cause was due to flood and scour—those contributed to 53 percent of bridge failures. This is followed by bridge overload, lateral impact forces from trucks, barges/ships and trains constituting 20 percent of total bridge failures. The remaining principal causes were design, detailing, construction, material, and maintenance (141).

TxDOT maintains bridge inspection manual, which provides guidance for bridge inspectors and ensures consistency in inspection and rating. Unlike pavements, the bridges' structural rating is entirely up to inspector. Field inspectors rate the bridges in the following four areas and provide a suitable rating.

1. Condition Rating – This is a measure of the deterioration or damage and is not a measure of design deficiency. This also helps to identify bridges for repairs and modifications. Rating is based on evaluating six components listed in the TxDOT Form 1085, Bridge Inspection Record.



2. Appraisal Rating – This considers the field conditions, waterway adequacy, geometric and safety configurations, structural evaluation, and safe load capacity of the bridge. These are then evaluated for their effect of safety and serviceability of the bridge and its approaches.
3. Load Rating – This measures the live load carrying capacity of bridges.
4. Legal Loads and load posting.

The data collected above helps the districts to identify bridges needing repairs or modifications. TxDOT's *Bridge Inspection Manual* provides more information.

## PERFORMANCE MEASURES AND INDICATORS

Performance is defined as the execution of required function. Performance measure represents the extent to which a specific function is performed, both qualitatively and quantitatively (142). The properties of suitable performance measures should include the following (143):

- Appropriateness – A single measure should represent one goal or objective of transportation system action.
- Measureability – It should be possible and easy to measure performance within acceptable level of accuracy and reliability.
- Dimensionality – The performance measure should be comparable across time and geographic regions.
- Realistic – It should be possible to collect, generate, or extract reliable performance data.
- Defensible – A performance measure should be clear and simple in its definition and method of computing.
- Forecastable – It should be practical to use existing forecasting tools to reliably estimate performance.

All factors described in this discussion affect the performance of pavement and bridges. All can affect operations throughout the highway life cycle.

In order to monitor and study the impact of changes in asset condition, it is essential to define the condition indicators used for pavements and bridges. Common performance measures include:

- Pavements:
  - Pavement Present Serviceability Index (PSI) or Rideability Index,
  - Pavement Condition Index/Quality Index,
  - Remaining Service Life,
  - Percentage of highway mainline pavements rated good or better,
  - Percentage of highway mainline pavements rated poor, and

- International Roughness Index (IRI);
- Bridges:
  - Average Health Index (AHI) (0 – 100 Scale),
  - Percent structurally deficient (SD),
  - Percent with sufficiency rating less than 50,
  - Number of steel bridges with section loss in a member, and
  - Percent of bridges with deck, superstructure, substructure National Bridge Inventory (NBI) rating (0 - 4 Scale).

TxDOT utilizes the pavement performance measures like the IRI in its Pavement Management Information Systems (PMIS). PMIS is an automated decision support system used for storing, retrieving, analyzing, and reporting information to help in pavement related decision-making processes. PMIS uses pavement condition data stored on TxDOT’s Pavement Evaluation System (PES) to support decision makers at the division, district, area, and maintenance office. PMIS uses analytical models to predict the development of pavement distress with time. Based on the results from the prediction, the system prioritizes pavements requiring rehabilitation and also predicts their future needs.

Though TxDOT maintains a robust system for pavement management, it lacks a similar system for its bridges. TxDOT currently uses several different systems that are not interconnected to store different information of these bridges. The project to build a comprehensive Bridge Management Information System (BMIS) is underway.

## **ACTIONS TO PRESERVE, RESTORE, OR ENHANCE FUNCTIONALITY**

The main objective of maintenance and construction activities to restore the condition of the pavements and bridges is to protect them from further deterioration, and thereby have a positive impact on the capacity, safety, and operational efficiency. [Table 8](#) shows common construction activities related to restoring the functionality of the existing system, extending its service life, and increasing the capacity and strength ([144](#)).

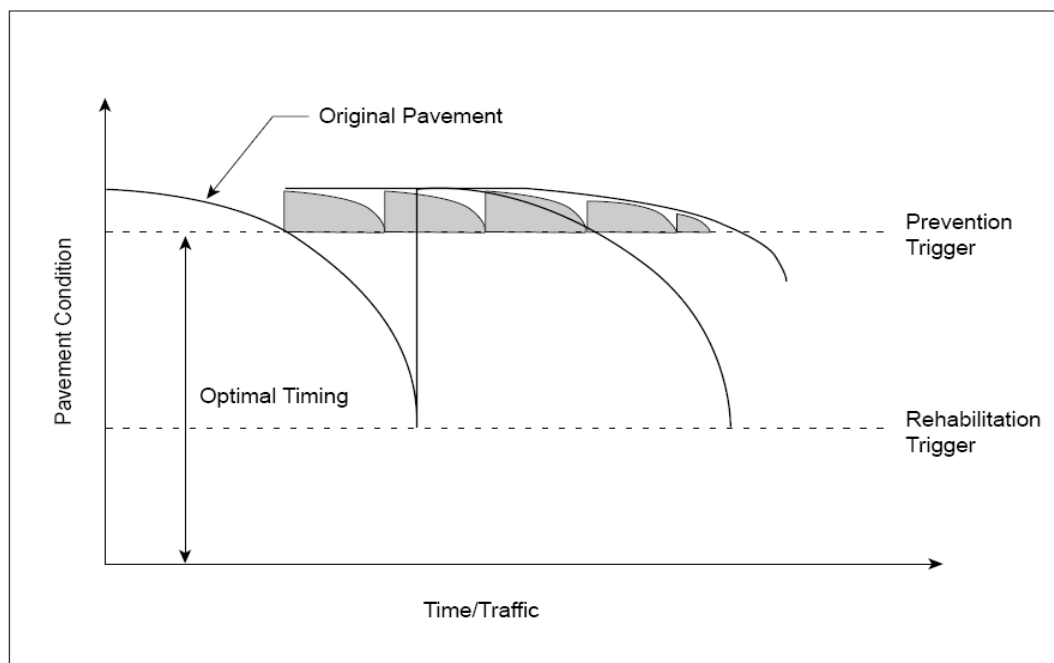
**Table 8. Construction Activities.**

Type of activity	Purpose			
	Increase Capacity	Increase Strength	Reduce Aging	Restore Serviceability
New Construction	X	X	X	X
Major Rehabilitation		X	X	X
Minor Rehabilitation			X	X
Preventive Maintenance			X	X
Routine Maintenance				X
Corrective maintenance				X

New construction is building a new facility or an infrastructure asset. This is mostly done to increase the capacity of the system. The remaining activities can be classified under the pavement preservation techniques.

## Pavement Preservation

Pavement preservation is the sum of all activities undertaken to provide and maintain serviceable roadways. Pavement preservation does not include construction/reconstruction activities that can significantly increase the structural capacity of existing system. An effective pavement preservation program encompasses a range of preventive maintenance techniques and strategies and will address pavements in good condition before the onset of structural damage. Figure 9 shows the general concept behind pavement preservation. It also illustrates the benefit of a regularly scheduled preventive maintenance program—less deterioration (both physical and functional) and less work to restore.



**Figure 9. Optimal Timing for Application of Pavement Treatments.**

## Pavement Rehabilitation

Traditional rehabilitation includes structural or non-structural enhancements to extend the service life of an existing pavement and/or improve its load carrying capacity. However, waiting until rehabilitation is needed is reactive, that is, the pavements are allowed to deteriorate to a fair or poor condition in terms of ride quality and structural condition.

The objective of the rehabilitation is to repair this damage and restore the pavement to its original condition. The rehabilitation treatments for pavements include concrete pavement restoration (PSR) and structural overlays. For bridges, rehabilitation treatments can be included in six general categories (145):

- increasing the live load capacity by strengthening critical members, removing dead load on the bridge, and adding supplemental members to carry live loads;
- improve geometrics by increasing vertical clearance, widening usable roadway, and improving horizontal approach and vertical alignment,
- correct mechanical deficiencies by repairing the bridge bearings, expansion joints, hangers, etc.;
- correct drainage problem;
- improve rideability by replacement of bridge decks and deck joints; and
- miscellaneous repairs.

The rehabilitation process/treatments described above are generally costly and time consuming processes.

### **Preventive Maintenance**

Focus is now shifting to a preservative and proactive approach that includes application of series of low-cost, preventive maintenance treatments that last for a few years. These treatments are intended to preserve the structural capacity of pavements, rather than improving them. The important consideration to be made is when the treatment needs to be applied rather than type of treatment. Since the same type of treatment can be applied for preventive, routine, and corrective maintenance, there is no clear boundary between when a treatment is preventive, corrective, and routine (146).

As defined by the 1997 *AASHTO Standing Committee on Highways*, preventive maintenance is “a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity).” Preventive maintenance is a major component of pavement preservation. It is a strategy to extend service life by applying cost-effective treatments on structurally sound pavements. Since pavements with reasonably good structural condition are candidates for preventive maintenance, not all pavement distresses can be treated with this mechanism. Distresses like fatigue cracking, patch deterioration, potholes, and shoving cannot be treated using preventive maintenance (146).

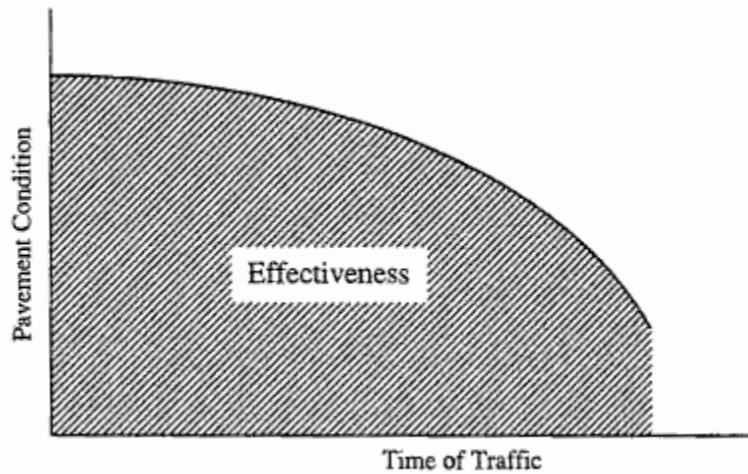
### **Routine Maintenance**

Routine maintenance consists of work that is planned and performed on a routine basis to preserve the existing condition of highway. Examples of routine maintenance include clearing of roadside ditches and structures, maintenance of pavement markings and crack filling, pothole patching, and isolated overlays.

### **Corrective Maintenance**

Corrective maintenance is more reactive and performed to restore an acceptable level of service due to unforeseen conditions. Effectiveness of all these pavement treatment strategies is based on the condition of pavements discussed in the prior section on sources and causes of deterioration. One of the measurements of effectiveness is the area under the pavement condition

category versus time as shown in Figure 10. It generally shows that the larger the area under the curve, the greater the effectiveness of the treatment.



**Figure 10. Pavement Effectiveness.**

Figures 9 and 10 show that the pavement condition deteriorates over time/traffic and it is necessary to define an optimal time needed for pavement treatment. However, the real challenge is in selecting the optimal time for treatment. Time is the element, which defines the cost-effectiveness of any preventive treatments (147).

Effectiveness is also measured in terms of disruption to traffic and safety, which in turn translates into user costs. Research shows that preventive maintenance can result in significant increase in the life of a highway leading to reduced cost and disruption to road users. Clearly then, preventive maintenance increases long-term highway operation functionality.

## **MEASURES TO ASSESS FUNCTIONAL PERFORMANCE OF PAVEMENTS AND BRIDGES**

For pavement and bridge functionality, performance measures help the agency monitor facility performance, identify and undertake requisite remedial measures, and plan for future investment. Currently most agencies have performance measures derived from agency goals that are tied to strategic objectives focusing on quality and customer service.

The focus of this study involves assessing the performance of infrastructure assets with respect to capacity, operational efficiency, and safety. The following are three categories of performance measures with a list of common performance measures that will be used in analysis.

### **Capacity**

Examples of performance measures in this category that may be related to pavement and bridge asset condition include:

- number of hours of road or lane closure;
- number of hours of on-road work zones;
- bulk material loading rate; and
- percent downtime of arterials and/or intersections under closed loop control.

### **Operational Efficiency**

Examples of performance measures in this category that may be related to pavement and bridge deterioration or maintenance work include:

- average travel time;
- average speed;
- AADT (annual average daily traffic);
- average fuel consumption per trip;
- average trip length;
- VMT by congestion level;
- number and percent of lane-miles congested;
- percent on-time performance;
- congestion severity index (hours of delay per million VMT); and
- average delay per peak period.
- 
- Since these measures may also apply to other road and bridge characteristics, any measure selected for pavement and bridge functionality should reflect the performance characteristic that is to be measured. For example, if poor pavement condition is slowing traffic, be sure that is the only cause of lower speeds. Otherwise performance due to pavement condition will not be isolated

### **Safety**

Examples of performance measure in this category that may be related to pavement and bridge deterioration or maintenance work include:

- percent of vehicle collisions on highway system where work zone related conditions are listed as contributing factor;
- roadway segments not meeting safety standards;
- vehicle collisions related to bridge characteristics;
- collision rate in work zones (fatality, injury, PDO) per million VMT;
- number of crashes in work zones;

- number of work zone locations with high crash rates or hazard indexes; and
- number of work zones not meeting the safety standards.

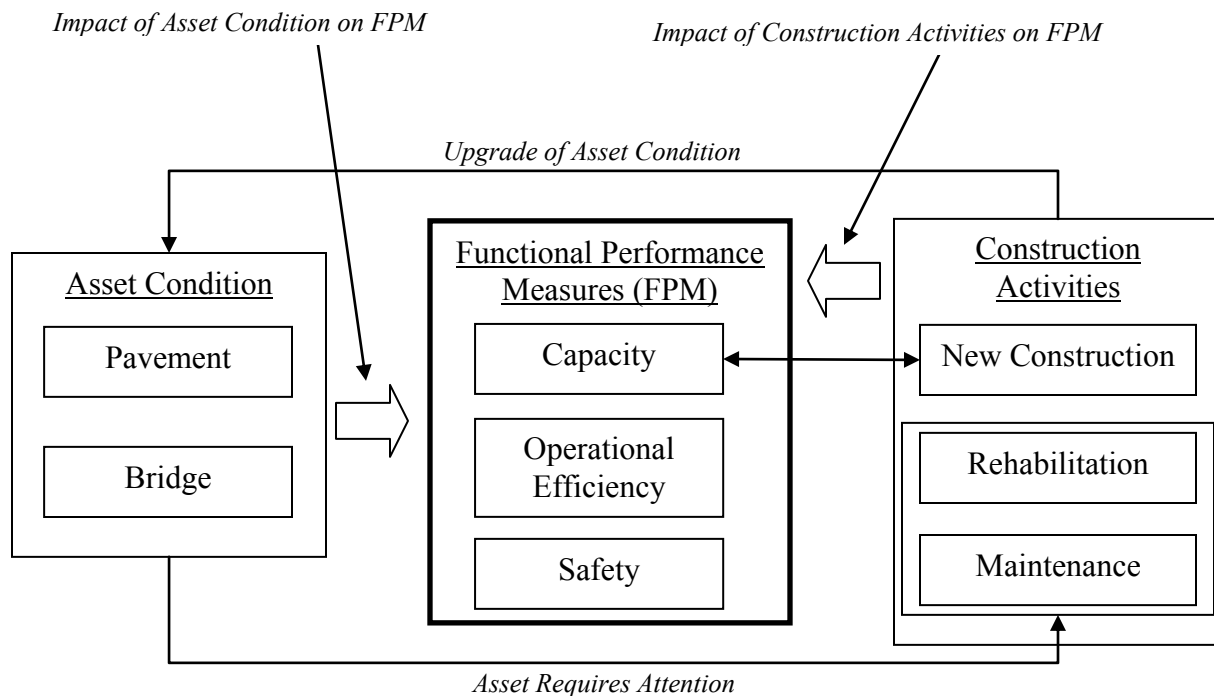
### Impact of Asset Condition on Functional Performance Measures

The changes in the physical conditions of pavements and bridges affect the performance of infrastructure system. For example, pavement with cracks and potholes affects the functional (operational) performance of the pavement by reducing the average speed, hence increasing the average trip length. This also leads to safety issues, with pavement not meeting the required safety standard.

### Impact of Construction Activity on Functional Performance Measures

The influence of the construction activities on functional performance measures is twofold: short-term negative and long-term positive. For example, in order to improve the condition of the pavement, activities like overlays or pothole patching would be conducted. As a result, the roadway would have to be temporarily closed to traffic in order to carry out the maintenance work. This affects the performance by increasing the travel time due to a detours or delay time due to congestion, hence increasing the average trip time until the maintenance activity is completed.

Figure 11 illustrates the influence of pavements and bridges on performance due to changes in the physical condition of these assets and because of the construction activities performed on these assets to improve their condition.



**Figure 11. Factors Influencing Functional Performance Measure.**

There are instances when the performance of roadway system initially decreases, but later increases. For example, when adding an extra lane to existing system, during the construction there might be a decrease in performance of the highway due to congestion and lane closure. But once the construction is completed, the performance improves, as the capacity increases, congestion decreases, the average trip time improves.

### **Infrastructure and Functionality Summary**

Infrastructure assets such as the pavements and bridges reach a stage when repairs and rehabilitation action are needed to keep the functional requirements of the traveling public and business, as well as meet increased traffic volumes. In fact, the deterioration caused by the wear and tear of these assets affects their overall efficiency since distresses have a direct impact on the ride quality and safety. FHWA's manual on distress identification outlines different severity levels to define the pavement conditions. Many agencies, including TxDOT, measure these distresses to identify the structural condition of pavements and bridges. Through sophisticated information management systems (PMIS of TxDOT), these measures can be used to prioritize the infrastructure assets that require rehabilitation or repair. The purpose of rehabilitation is to stop further deterioration and have a positive impact on capacity, safety, and efficiency. This approach is primarily a reactive approach where the pavements are repaired only after failure of functional and structural requirements. However, the focus is now shifting from a reactive approach to a proactive approach for restoring the pavements and bridges. Such proactive approach is also integrated in high-level analysis where link and network functional performance is considered.

Although asset renewal and maintenance leads to increase in the efficiency of the infrastructure assets, there is momentary drop in the efficiency due to the creation of work zones. This leads to increase in the amount of time and fuel spent by the road users in the construction zone. With additional pressure on agencies to reduce the road user costs, agencies have started emphasizing work zone traffic management techniques to address these delays and safety issues. The inclusion of the Road User Cost into construction contracts is looked as one of the effective ways to reduce construction time thereby helping road users save time and fuel. By having RUC in the contracts, the contractors are motivated to perform efficiently and avoid any additional charges.

While agencies are well equipped with sophisticated information systems and sufficient performance measures to make informed decisions on identifying infrastructure assets requiring rehabilitation, there is a lack of methods that look into minimizing the impact of construction activities on the road users. As a result, the functional performance measures like the capacity, safety, and efficiency are impacted. The solutions need to look at planned preventive maintenance rather than a reactive approach as this would cause a significant increase in the life of pavements and bridges at reduced cost and disruption to road users. By bringing in a proactive approach to maintain these assets and implementing innovative contracting strategy, agencies could address the above concerns effectively.



## 7. CASE STUDIES

This chapter includes the write-ups of case studies that were conducted to investigate the functionality and associated practices, policies, and programs of three highway sections in Texas. The case studies were selected from a large pool of candidates from large, medium, and small communities:

- **IH 10, Katy Freeway in Houston.** For the large community category, this section of IH 10 was studied because it includes a myriad of examples and lessons learned of practices and measures (in all areas—ROW, operations, design, TSM, etc.) that have or are being used that contribute to its high degree of functionality. With its latest expansion and use of managed lanes, it is considered one of the nation’s premier multi-faceted freeways.
- **SH 105 from Loop 336 in Conroe to FM 149 in Montgomery, Texas.** For the small category, SH 105 was studied because it represents the challenges of access control and functional deterioration in rapidly growing unincorporated areas of the state (e.g., counties) without planning and land use controls.
- **SH 289 in Frisco and Plano from SH 190 to US 380.** For the medium size category, SH 289 was selected because it illustrates the affects that locally adopted corridor plans, land use controls, and related ordinances can have on the functionality of TxDOT roadways.

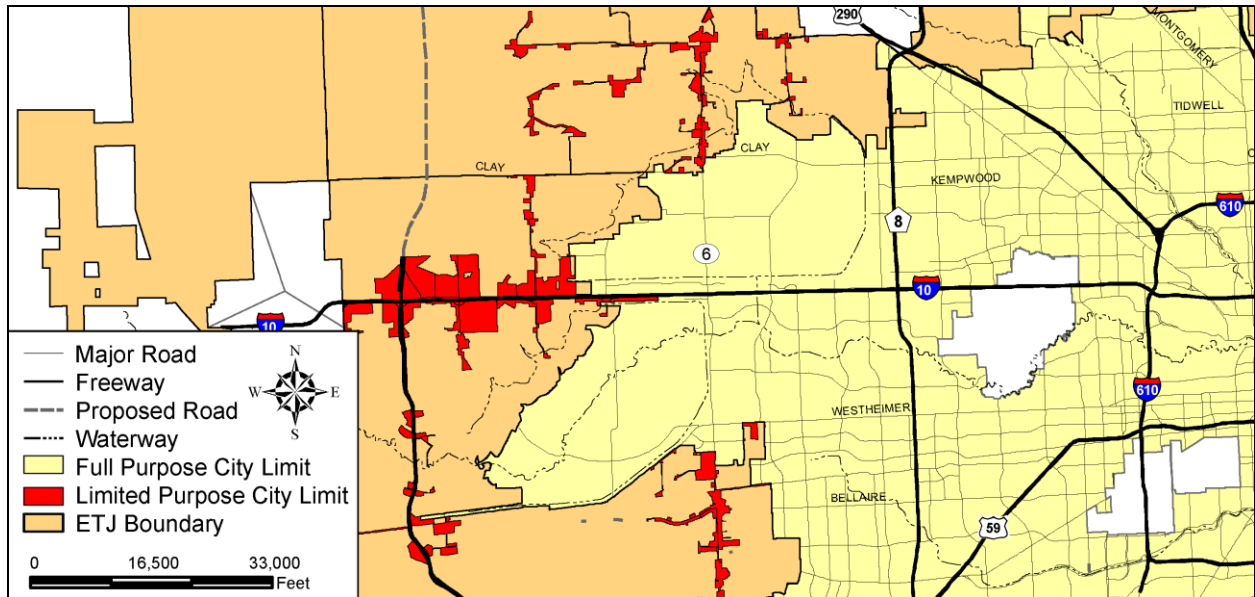
The case studies document and review how the functionality of each highway has changed and evolved over time. General areas and topics addressed in each the case studies include:

- processes, measures, programs, and practices used;
- evolving conditions encountered that led to facility functional deterioration;
- extent and causes of deterioration over a time period;
- actions taken (or not taken) to preserve, restore, and enhance facility functionality;
- results achieved through actions; and
- opportunities and lessons learned.

Detailed write-ups and discussion for each of the three case studies are provided in the following sections.

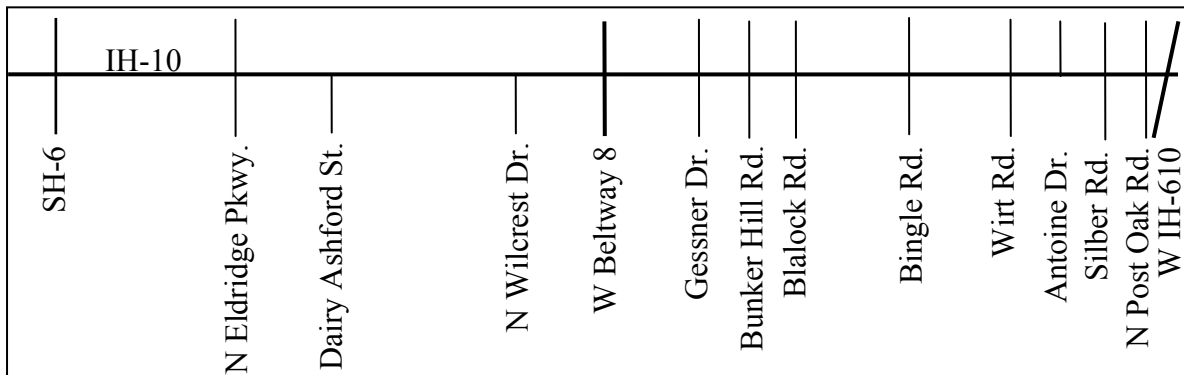
### **IH 10 WEST – HOUSTON**

The IH 10 Katy Freeway was the last of the 1960s era major radial freeways in Houston to undergo a comprehensive expansion and rehabilitation. With its latest expansion completed in late 2008, it is now one of the nation’s premier super-freeways with at least four general-purpose lanes, two managed lanes, and three frontage road lanes in each direction. This case study examines the complex evolution and development of Houston’s Katy Freeway to identify how its functionality developed, deteriorated, and enhanced overtime from various aspects including planning, operations, and right of way. To ensure depth, the study was limited to the 11.5-mile Katy Freeway section from west IH 610 west to SH 6. As shown in [Figure 12](#), the entire study section is within the Houston city limits. [Figure 13](#) shows the major roadways crossing the study freeway section.



Source: Modified from (148)

**Figure 12. Katy Freeway from State Highway 6 to Loop 610 West.**



**Figure 13. Major Roadways across the Study Freeway Section.**

During the case study, the researchers first conducted a thorough review on the history of this highway section and identified the milestone improvements it has undergone. Focused on these improvements, the case study discusses how planning and development in an area with few land use controls have affected functionality along this corridor; how aspects of main lane, frontage, and interchange design have affected functionality; and how right of way and right-of-way constraints have affected facility design and functionality throughout its history and life cycle. It also addresses how state-of-the-practice programs and measures in travel demand management involving HOV lanes, mass transit, and tolling have played/will play a role in maintaining functionality on this mega-freeway.

### Historical Review

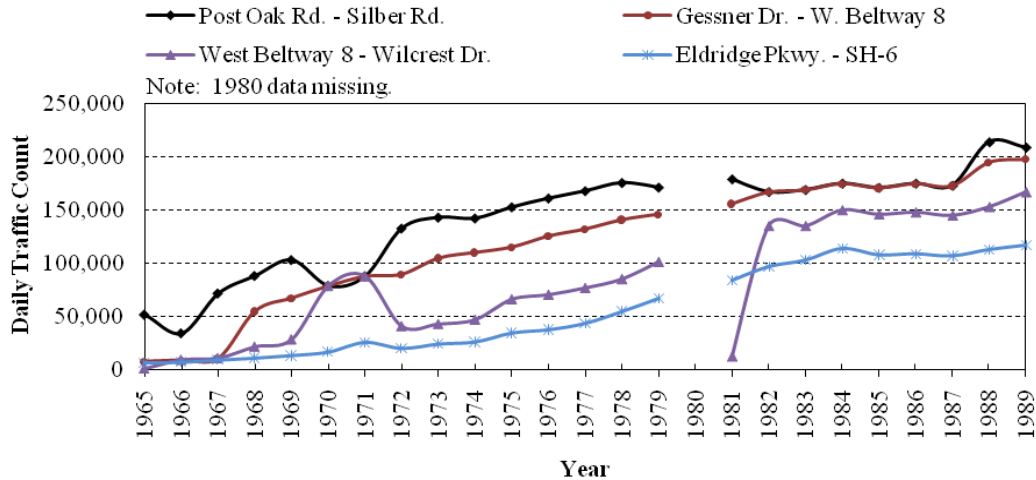
The beginnings of the modern Katy Freeway can be traced back to the original SH 73 in the 1930s that was generally located along the route of today's IH 10 (149). In 1941, the west Houston portion of the SH 73 was designated as US 90. The section between the current location

of Loop 610 and Katy was later authorized as a full freeway by the Texas Transportation Commission in 1953 and then officially designated as IH 10 in 1959. The corresponding upgrade of the highway section began in 1954 by constructing several interchanges and grade separations at intersecting local roads. In 1968, the IH 10 section between Loop 610 and the City of Katy was fully upgraded to a freeway.

In the early days of planning the Katy Freeway, there were different highway engineers in charge of planning and design for the sections inside and outside of Loop 610 and the two engineers vastly disagreed on what the ultimate right-of-way width of the freeway corridor should be (149). Outside of Loop 610 west, IH 10 was planned and constructed as a 6-lane freeway with 2-lane frontage roads in order that the facility could fit, where possible, within the available 175-ft right-of-way of US 90. However, IH 10 from inside the Loop to downtown was planned and developed as a significantly larger section with 10 freeway lanes and frontage roads within 300 ft of right of way. While the inner loop section was well designed in the early days to handle traffic far into the future, the outer loop section (the section included in this case study) was under-designed in a narrow right-of-way section that created a major constraint and source of delay for future freeway expansion.

The original US 90 was a four-lane divided section with two lanes in each direction. It was then gradually expanded to six main lanes with a two-lane frontage road on each side during the IH 10 freeway upgrade. As part of the 1960's upgrade, the 175-ft right of way was widened along most of the corridor, but a narrow 175-ft width remained in one key section of the corridor. This remaining narrow section of right of way proved to be a major constraint to expanding the Katy freeway west of Loop 610 in the 1980's and 1990's. (149). Freeway improvements to accommodate the growing traffic demand were delayed for many years due to much more costly and difficult acquisition of new right of way because of adjacent development.

As the traffic demand increased across the Houston area, many surrounding highways were expanded and improved, including the West Beltway 8/Sam Houston Tollway that was constructed in 1980s. Meanwhile, developments along the Katy Freeway corridor never stopped. Starting from the 1970s with the early Houston's energy boom, the area between SH 6 and Beltway 8 along Katy Freeway quickly developed to the well-known energy corridor housing a large number of major national and international energy-related companies (150). Along with the adjacent local residential developments, the corridor generated a significant traffic demand on the Katy Freeway. As shown in Figure 14, the daily traffic on the highway section dramatically increased from less than 50,000 in the mid-1960s to more than 200,000 in the late 1980s at several locations between Beltway 8 and IH 610, while Katy Freeway remained most of its original lane configuration without substantial improvements. It became one of the most congested highways in Houston.



**Figure 14. Daily Traffic Counts on Katy Freeway (1965–1989).**

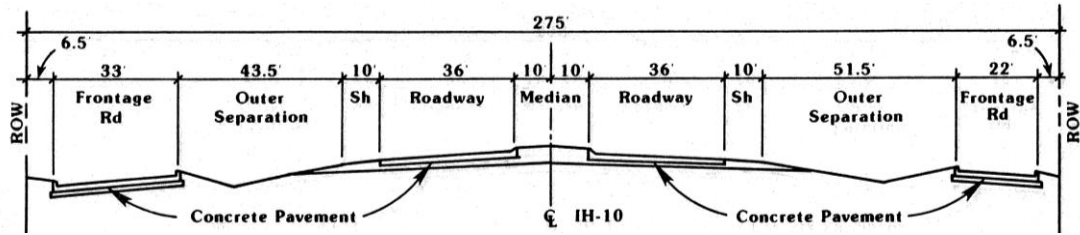
The only brief relief for Katy Freeway since then was the conversion of the median to a reversible transitway in 1980s (151). The continuously worsening traffic congestion on main lanes of the freeway called for efforts of TxDOT (SDHPT or Texas State Department of Highways and Public Transportation prior to 1991) and other stakeholders for substantially expanding the freeway. The initial planning to expand Katy Freeway to its current configuration began in the late 1990s (152). By October 2008, Katy Freeway was expanded to one of the nation’s multi-faceted super-freeways (153). The following sections look into the details of these two major improvements of Katy Freeway.

### Katy Freeway Transitway Improvement

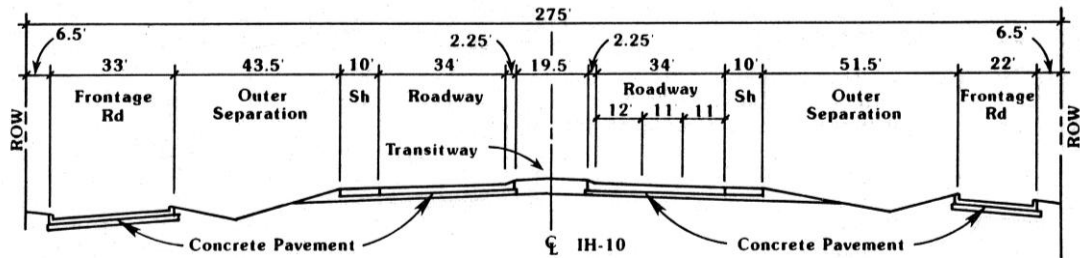
To improve mobility in Houston area, TxDOT, Harris County, and the Metropolitan Transit Authority (METRO) jointly started the development of a transitway network on five radial freeways in the region, including Katy Freeway, north IH 45, south IH 45, US 290, and south US 59, and later added a sixth corridor (US 59 North) (154). The transitways were separated and access-controlled traffic lanes constructed within the existing median of the freeways, with sufficient width to pass immobile vehicles. The transitways were used by buses and other authorized HOVs traveling inbound toward downtown in the morning and outbound in the afternoon.

The Katy Freeway Transitway was built and operated in several phases (151, 155). Phase 1 added a 4.75-mile transitway on the freeway between IH 610 and Gessner Road, which opened to traffic October 29, 1984. Phases 2 and 3 extended the transitway further west to Beltway 8 (opened to traffic May 2, 1985) then to SH 6 (opened to traffic June 29, 1987), respectively, resulting in a total of about 11.5-mile HOV facility. A later phase extended the transitway eastbound by 1.5 miles from North Post Oak Road to east of IH 610. A number of park-and-ride lots were built at strategic locations to facilitate the transitway users. The total cost for the 11.5-mile transitway constructed during the first three phases was approximately \$32 million and the annual operations and enforcement cost was about \$300,000 at that time (155).

Figure 15 shows the typical cross section of Katy Freeway before and after the transitway was added. As shown in the figure, the transitway was typically 19.5 ft wide. The width of the original main lanes was reduced to 11 ft.



a. Typical Cross Section before Transitway



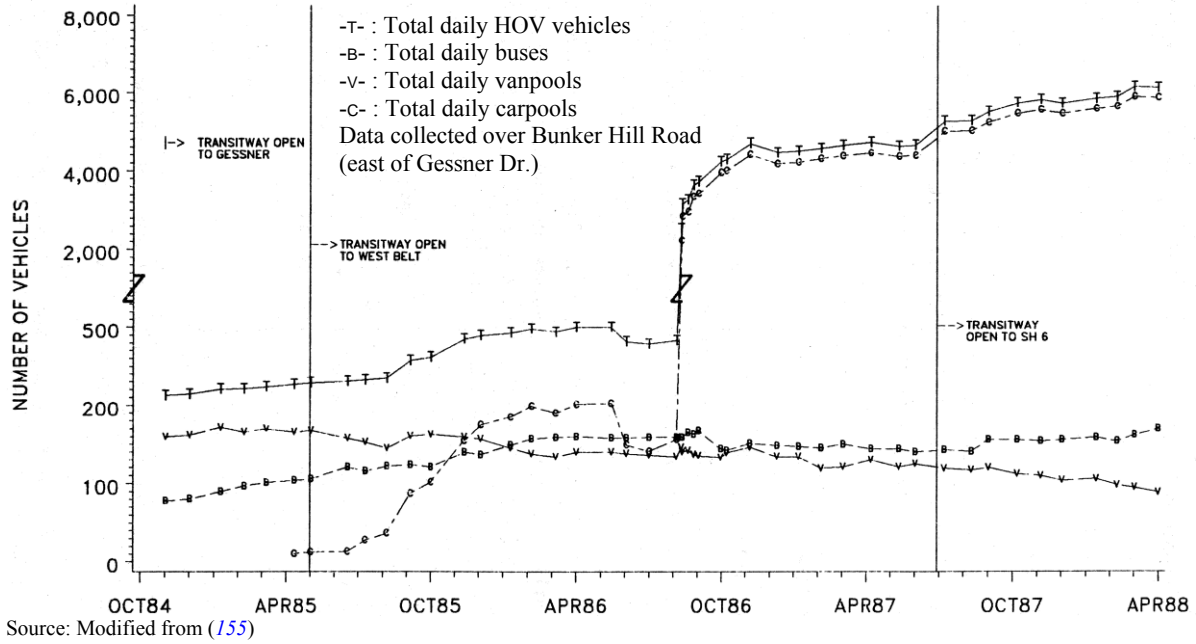
b. Typical Cross Section after Transitway

Source: Modified from (151)

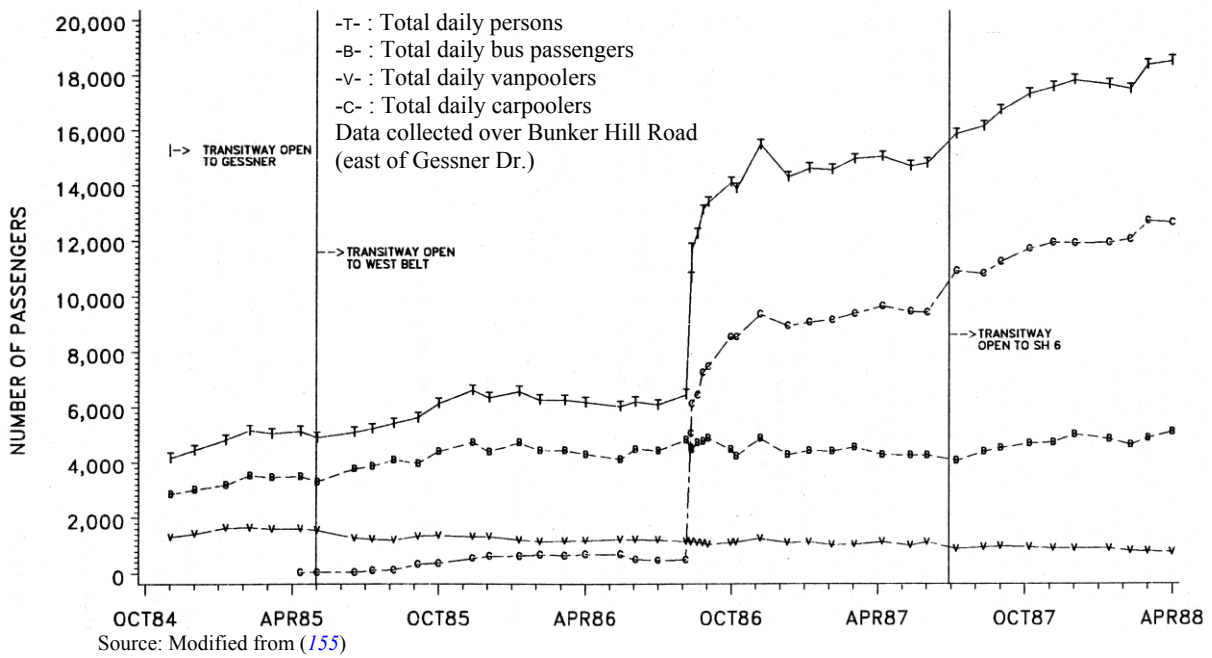
**Figure 15. Katy Freeway Cross Sections before and after Transitway.**

The transitway initially opened in October 1984 to only buses and authorized vanpools (at least eight persons registered and six riders present). This restriction resulted in only a limited number of vehicles using the facility every day. Figure 16 and Figure 17 illustrate the daily person data and vehicle data utilizing the transitway, respectively, from October 1984 to April 1988. When the phase one transitway first opened, a net travel time saving of 5 to 9 minutes per trip was observed during the peak hours on this 4.75-mile section compared with the adjacent main lanes. However, while serving approximately the same number of passengers, the peak-hour vehicle volume on the transit way was just about 5 percent of that on an adjacent main lane.

To better utilize the facility, METRO and TxDOT later opened the transitway to authorized carpools with at least four registered passengers starting April 1, 1985, and then to authorized carpools with three registered passengers beginning September 1985. Regardless of these restriction relaxations, the total number of vehicles on the facility remained low and the perception that the transitway was underutilized continued (156, 157). On August 11, 1986, the restriction was further relaxed to all passenger vehicles with two or more occupants, which resulted in a sharp increase in both the total numbers of vehicles and persons using the transitway (Figure 16 and Figure 17). Table 9 summarizes the major events associated with the Katy Freeway transitway in a chronological order (155).



**Figure 16. Katy Freeway Transitway Daily Vehicle Utilization.**

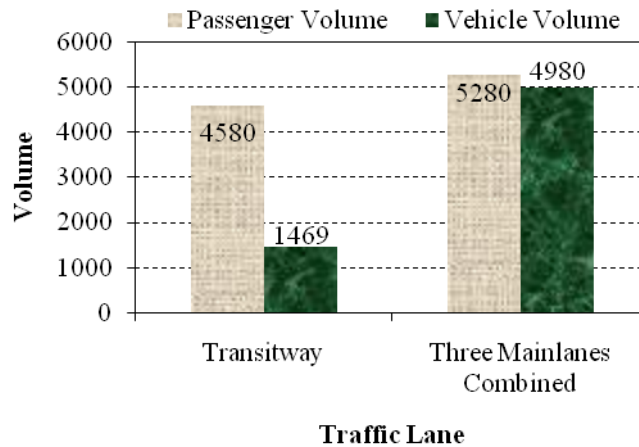


**Figure 17. Katy Freeway Transitway Daily Person Utilization**

**Table 9. Major Events Associated with Katy Freeway Transitway.**

Date	Major Event
October 29, 1984	Transitway opened from Post Oak to Gessner Drive (4.75 miles). Buses, authorized vanpools with at least eight persons registered and six riders present were allowed
April 1, 1985	Authorized carpools with at least four persons registered allowed
May 2, 1985	Transitway extended to West Beltway 8 (total length increased to 6.4 miles)
July 29, 1985	Authorized carpools with at least four persons registered and three riders present allowed
September 1985	Some authorized carpools with at least three persons registered allowed
November 4, 1985	All authorized carpools with at least three persons registered officially allowed
August 11, 1986	Passenger vehicles with at least two occupants (except large trucks and motorcycles) allowed
June 29, 1987	Transitway extended to SH 6 (total length increased to 11.5 miles)

Data collected between July and September 1987 showed that the average speed during peak hours was above 45 mph at most data collection locations on the transitway (158). A trip from SH 6 to IH 610 on the transitway took less than 15 minutes in average, while a bus trip from SH 6 to downtown Houston in 1983 would have taken 45 minutes over a distance of approximately 17 miles (151). As shown in Figure 18, the single-lane facility served just 23 percent of the vehicle volume but over 46 percent of the total passenger volume on the roadway during the morning peak hour (7:00 a.m. – 8:00 a.m.) (8). In addition, it considerably increased the use of transit and ridesharing and therefore the average vehicle occupancy and total person throughput. Studies also found that the addition of the transitway did not result in evident degradation of safety or level of service on the freeway main lanes. Although concerns existed on operation enforcement and facility underutilization during off-peak hours, a majority of the motorists considered the transitway a good transportation improvement (155, 159).



Note: Volumes counted at Bunker Hill Road for 7:00– 8:00 a.m., December 1987.

**Figure 18. Passenger and Vehicle Volumes on Katy Freeway (Morning Peak Hour).**

Because transitway volume increased dramatically after the passenger vehicles with at least two occupants joined the transitway, concerns rose about the serviceability that the transitway could maintain during peak hours (158, 160, 161). As the peak volume approached the estimated capacity of 1,500 vehicles per hour, most sections of the transitway reached a LOS of C, D, and E were recorded for certain segments. The lowest speeds at some locations dropped below 36 mph during morning peak hours and stopped delays were observed. Recognizing the situation, METRO slightly tightened the restriction to require three occupants per vehicle on the transitway between 6:45 a.m. and 8:15 a.m. starting October 17, 1988.

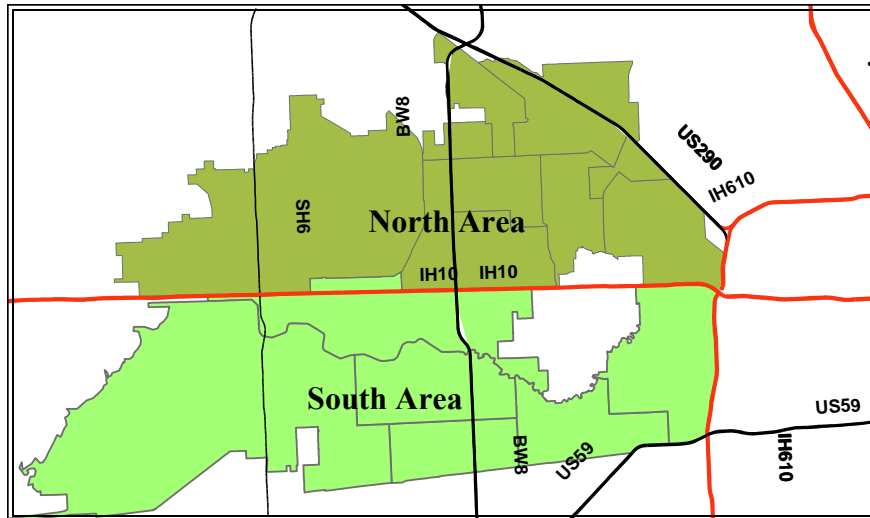
### **The Latest Katy Freeway Expansion**

The Katy Freeway transitway resulted in a slight relief to the busy highway section. However, a majority of the vehicles had to stay on the crowded main lanes and frontage roads. During the 1990s, the corridor continued developing and as the major gateway to downtown Houston on the city's west side, Katy Freeway became severely congested. As a result, the freeway finally went through a substantial expansion in the 2000s. This next section discusses this latest expansion in detail.

#### *Latest Development along the Corridor*

During the 1990s, Houston had the third largest population growth in the country with a growth rate as high as 19.7 percent, behind only Phoenix and San Antonio. Much of the growth occurred on the west side of the city, characterized by the strong development activity along the Katy Freeway corridor. In addition, according to HGAC forecasts, between 1990 and 2020, the population and employment in the west Houston area would grow by 42 percent and 44 percent, respectively, with some portions of the corridor projected to have a population growth of 130 percent (162). Figure 19 shows the two super neighborhood clusters along the Katy Freeway corridor as identified by the City of Houston Planning Department. During the last decade, the north side of the freeway had a population growth of 21.9 percent while the south side of the freeway had a growth of 19.2 percent. According to the City of Houston data as shown in Table 10 (163), several major land use types increased dramatically in both areas between 1990 and 2000, including parks/open space, commercial, office, public/institutional, industrial, and multi-family. In 2002, the energy corridor between SH 6 and Beltway 8 alone hosted about 60,000 employees in 12 million square ft of office space (164).





**Figure 19. Super Neighborhoods along the Katy Freeway Corridor.**

**Table 10. Major Land Use Changes along the Katy Freeway Corridor.**

Land Use	North Area			South Area			City of Houston Change
	1990 (acre)	2000 (acre)	Change	1990 (acre)	2000 (acre)	Change	
Single-Family	5,046.3	5,039.7	-0.1%	7,460.8	8,236.8	10.4%	5.6%
Multi-Family	1,005.2	1,254.9	24.8%	2,833.5	3,721.6	31.3%	19.5%
Commercial	719.8	1,194.1	65.9%	1,399.7	2,439.1	74.3%	25.3%
Office	250.3	377.8	50.9%	1,047.8	1,347.6	28.6%	19.4%
Industrial	3,471.7	4,409.2	27.0%	847.3	952.4	12.4%	20.6%
Public/Institutional	1,347.7	1,951.7	44.8%	644.9	1,071.2	66.1%	50.4%
Transportation/Utilities	335.5	405.6	20.9%	150.3	352.3	134.4%	223.9%
Parks/Open Space	6.8	8,604.5	125925.6%	259.8	11,336.7	4262.8%	2097.6%
Undeveloped	16,317.3	8,729.4	-46.5%	14,800.1	6,958.1	-53.0%	-24.3%
Agricultural	35.5	30.5	-14.1%	10.5	0.2	-98.3%	74.2%

As a strategic highway connecting both coasts and the only major gateway entering the city from west, the freeway carried traffic generated from several radial highways, major employment centers, and the Ports of Houston, Galveston, and Freeport (Figure 20). In addition, the freeway remained to be the most heavily traveled truck arteries in the state carrying about 16,000 heavy-duty trucks daily. With the continuously increasing traffic (Figure 21), the maintenance costs on the freeway reached nearly \$8 million a year or \$197,500 per mile per year, almost four times the normal maintenance cost, not to mention the routine flooding problem during heavy rainfall. According to 1994 crash data, freeway had a crash rate 33 percent higher than the statewide average for similar roadways (164, 165). However, until 2003, the typical cross section of Katy Freeway remained three general-purpose lanes and a two-lane frontage road in each direction (Figure 22). A detailed analysis of the corridor in 1995 confirmed that the Katy Freeway was not constructed to then current TxDOT design standards of the study year and had insufficient capacity to accommodate existing or projected traffic demand (166). In addition, the existing one-lane reversible transitway was unable to serve the increasing two-way HOV travel.





Source (149): IH 10 at Gessner Drive looking east. Photo taken September 2002.

**Figure 22. The Congested Katy Freeway**

### *Preliminary Studies for Possible Expansion*

The first studies to develop a feasible Katy Freeway expansion plan started in the mid-1980s (149). In 1986, TxDOT launched a study to evaluate three proposed options for expanding the Katy Freeway. The first alternative proposed to widen the freeway at ground level to 10 general-purpose lanes and six express lanes, which had an estimated construction cost of \$500 million (1986 dollars) excluding right-of-way acquisition costs. Both the second and third alternatives were to add six elevated express lanes in slightly different configurations, which would cost approximately \$1.1 to 1.3 billion (1986 dollars). However, the later acquisition of the railroad tracks from Union Pacific Railroad (the former Missouri–Kansas–Texas [MKT] rail line) along with the 100-ft right of way on the north side of the Katy Freeway made the expensive plans for elevated lanes unfavorable.

While the Katy Freeway expansion planning was underway, Congress passed the Intermodal Surface Transportation Efficiency Act of 1991, which required a major investment study for major roadway projects involving Federal funds (167, 168). TxDOT launched the IH 10 Katy Freeway Corridor Major Investment Study that included a series of public meetings to analyze the IH 10 corridor from downtown Houston westward to the Brazos River (approximately 40 miles) in 1995 (166). By comparing several expansion alternatives that involved operational improvements, additional special use lanes, a fixed guideway, and additional general-purpose lanes, the study recommended a cost-effective plan that proposed a significant increase in the HOV/special use lane capacity and a modest increase in the mainlane capacity.

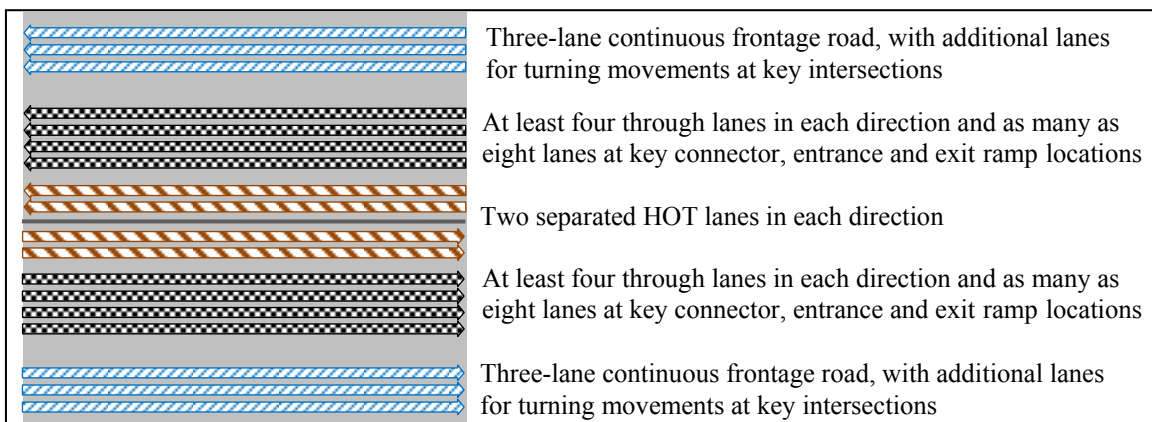
The selected alternative (166) was to include two special use lanes and four general purpose lanes in each direction between IH 610 and SH 6, with auxiliary lanes to provide lane balance at major interchanges. The proposed new capacity would meet the regional traffic demand until at least 2020. The estimated net cost for implementing the selected plan was about \$975 million (1995 dollars) over 25 years of operation while the estimated savings resulting from travel time reductions during the same period was \$3 billion. In addition to the already acquired railroad right of way, the plan required right of way for a few sections along the corridor. The plan was

quickly adopted by HGAC into the Regional Transportation Improvement Plan (TIP) on October 10, 1997, and preliminary design, environmental documentation, and final design were underway. The first stages of construction were scheduled to begin in 2003.

As TxDOT worked to accommodate public and stakeholder input, the design continued to evolve. To provide better access to the HOV lanes, an HOV lane in each direction was added to the freeway section between SH 6 and SH 99 where HOV lanes were originally not planned. With some additional changes, the design was finished in 2001, and the project received the Record of Decision (ROD) from FHWA in January 2002 (169). Later, with the participation of the Harris County Toll Road Authority (HCTRA), the four separated special-use lanes were converted to an HOT facility, or more frequently referred as the managed lanes. On March 14, 2003, FHWA, TxDOT, and HCTRA signed an agreement finalizing the proposal of the managed lanes, including their operational arrangements and financing specifics. On August 30, 2002, FHWA reissued the ROD indicating a final approval: the Katy Freeway was ready to be reconstructed.

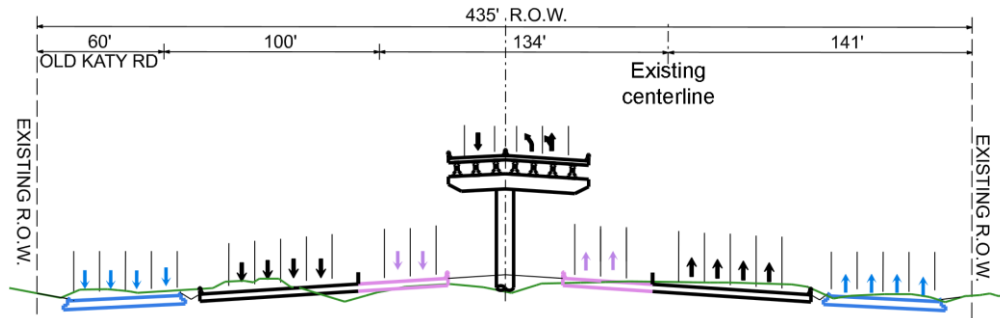
### Final Design

The final design of the study section (Figure 23) included four nominal general purpose lanes, two managed lanes, and a frontage road with three mandated through lanes in each direction. However, most sections on the Katy Freeway between SH 6 and IH 610 had additional auxiliary lanes for entering and exiting the freeway, seldom leaving only four general-purpose lanes. The continuous frontage road in each direction was also designed with auxiliary lanes for turning movements so that their impact on traffic of the three through lanes was minimized. At key connector, entrance and exit ramp locations, the freeway had as many as eight general-purpose lanes in each direction. In addition, TxDOT used stronger pavement and bridges and corrosion protection mechanisms for the managed lanes to allow timely and cost-efficient transition to a light rail in the future (169). All general purpose lanes were designed to be 12-ft wide, complemented by a 12-ft shoulder in each direction to ensure a 70 mph design speed. The concrete pavement was designed to have a service life of 30 years without major maintenance (165).

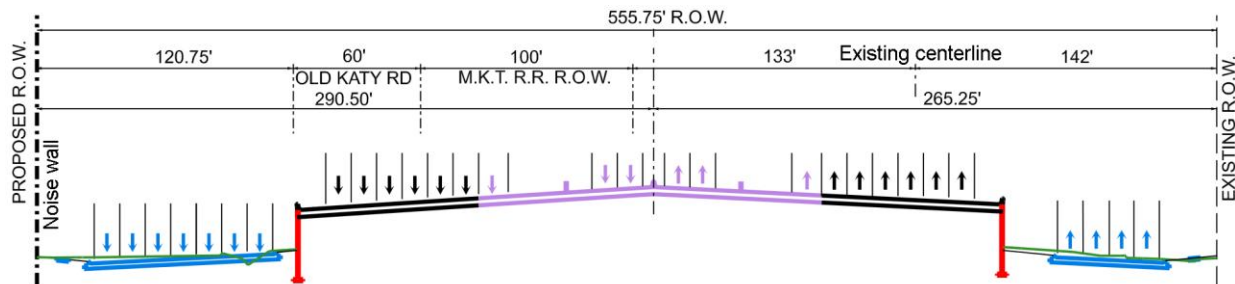


**Figure 23. Typical Katy Freeway Cross Section Lane Configuration (SH 6 to Loop 610).**

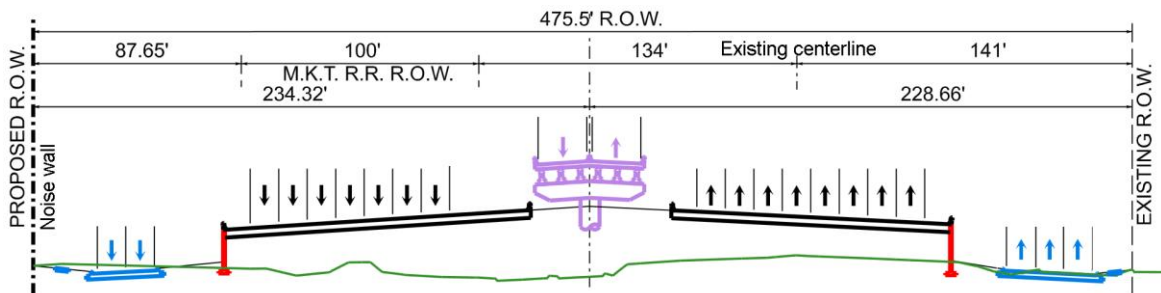
Figure 24 – Figure 26 show the cross sections (looking east) at east of SH 6, east of Bunker Hill Road, and east of Silber Road, respectively, as part of the final Katy Freeway design schematics. As seen from these cross section schematics, the freeway was designed to have four general-purpose lanes at SH 6 within a 435-ft right of way, including the original 100-ft railroad right of way and the 60-ft Old Katy Road right of way. The right of way reached its widest point of about 556 ft at Bunker Hill Road to accommodate the auxiliary lanes on both the main freeway and frontage roads. The number of general-purpose lanes on the freeway later reached to eight when it approached IH 610. From these cross section drawings, it is also clear that the freeway was expanded northward and most of the newly acquired right of way was on the north side of the previous alignment.



**Figure 24. Katy Freeway Cross Section at East of SH 6.**



**Figure 25. Katy Freeway Cross Section at East of Bunker Hill Road.**



**Figure 26. Katy Freeway Cross Section East of Silber Road .**

### *Environmental Issues and Right of Way*

The environmental impact of the Katy Freeway project was first assessed during the major investment study in 1995 (166). TxDOT Houston District Office completed the final environmental impact statement (FEIS) in November 2001 (162). Following the ROD approval, TxDOT conducted a reevaluation of the FEIS to further identify and assess the refinements in design, proposed operations, and any environmental consequences of those refinements (169). Because the new Katy freeway would generally lay out along the existing freeway corridor, with proper countermeasures, the project would not impose significant additional environment impact.

As the environmental impact studies (162, 169) suggested, the proposed Katy Freeway project would not result in considerable degradation on the existing noise and air quality. In terms of land use, much of the IH 10 Corridor had long been developed to a mix of residential, commercial, industrial, and public land uses, which would be only reinforced but not altered by the proposed project. With proper countermeasures, the impact of the project on drainage, water resources, cultural resources, wetlands, and hazardous materials were expected to be minimal. TxDOT also implemented a new Corridor Aesthetic and Landscape master plan, known as the Green Ribbon Project, along the corridor to improve the aesthetics of the new freeway (170).

TxDOT started the right-of-way acquisition effort well before the Katy Freeway project was finalized. In 1992, TxDOT purchased the 28-mile railroad line including the 100-ft railroad right of way from Union Pacific Railroad along the Katy Freeway corridor for \$103 million (1992 dollars) (149). The right of way was adjacent to the north edge of the freeway right of way. According to the agreement, the railroad was allowed to operate the track for five more years, although the operation actually lasted until 1998. This acquisition, together with the 60-ft Old Katy Road right of way that was parallel to the railroad on the north, alleviated TxDOT's concern on excessive right-of-way acquisition. The acquisition process of this project included the use of early right-of-way acquisition techniques including hardship acquisitions and protective buying.

The utility relocation was one of the major efforts involved in the Katy Freeway reconstruction (165, 169). The original four utility corridors, including one along Old Katy Road, one along the previous railroad, and one along the frontage road in each direction, had to be consolidated to fit into a single corridor that is 15-ft wide for half of the freeway. In addition, a City of Houston main water trunk line between Eldridge Road and Beltway 8 on the north side had to be relocated off the Katy Freeway right of way. The utility relocation process involved frequent communication and coordination with utility owners as well as other stakeholders. The process provided valuable experience and lessons for TxDOT that can be used for other large-scale projects in the state.

### *Project Construction*

The entire Katy Freeway reconstruction project was constructed through nine separate contracts, six of which were on the study section, as listed in Table 11 (171). The reconstruction was designed to start from the northern right of way and old lanes were closed only after new

lanes were in place, leaving no fewer lanes in service than the original freeway through the entire reconstruction period. TxDOT used a number of measures to ensure the timely completion of the reconstruction. Within each contract, hard completion dates were pre-set for important construction milestones. When a contractor reached such a milestone prior to the scheduled date, an early completion incentive would be awarded based on the number of earlier days and a pre-set daily dollar value. If a milestone was not met on time, an equal amount of disincentive would be applicable to the contractor as well. TxDOT also created a no-fault date of July 31, 2008, for several contracts enforcing the completion of major construction regardless of unexpected factors such as hurricane and evacuation events, right-of-way acquisition, and project change orders. In addition, hourly lane rental fees were utilized as well during the reconstruction, which were charged from the contractors that occupied an applicable traffic lane beyond the number of hours allowed everyday during peak periods. These contracting methods were used to try to minimize the duration of construction and its impact on freeway functionality.

**Table 11. Katy Freeway Reconstruction Contract Packages on the Study Section.**

Contract Section	Length	Start Date
East of Eldridge to West of SH 6	2.27 miles	May 2005
East of Kirkwood to East of Eldridge	1.8 miles	April 2005
East of Beltway 8 to East of Kirkwood	1.99 miles	August 2004
East of Campbell to east of Beltway 8	2.65 miles	March 2005
East of Silber to East of Campbell	2.46 miles	April 2005
IH 10/IH 610 Interchange and IH 610 from South of Post Oak Blvd. to North of Old Katy Road	1.08 miles along IH 10 and 2.55 miles along IH 610	October 2003

### The Current Katy Freeway

TxDOT celebrated the grand opening of the new Katy Freeway on October 28, 2008 (172). As a modern freeway, Katy Freeway main lanes are separated from all intersecting streets using overpasses, with turning movements handled through interchanges at crossing freeways and frontage roads at other streets. Dedicated U-turn lanes at each overpass were provided to reduce turning traffic on the intersecting streets. Both frontage roads of the freeway have three mandated through lanes to ensure reasonable capacity and mobility for shorter trips. Additional lanes of a reasonably sufficient length are provided on the frontage roads at freeway entrances and exits to store traffic exiting and entering the freeway and to reduce merging movements. Auxiliary lanes are also provided for turning movements at intersections to minimize their impact on through traffic. In many cases, these dedicated turning lanes extend for a long distance and multiple lanes are provided for certain turning movements at busy locations. In addition, elevated frontage lanes are used for Beltway 8 at the IH 10 interchange to provide additional capacity while reducing right-of-way requirement.

The flooding problem once common in some locations along the old Katy Freeway was addressed by elevating the freeway at key locations and adding 16 detention ponds along the corridor, with in-line underground storm water storage at locations where detention ponds are not sufficient. Additional drainage pumping stations were also added to minimize surface flooding along the corridor (165, 169). In addition, cameras and variable message signs that are connected to an underground fiber-optic system linking the regional traffic management center are installed along the freeway to facilitate traffic and incident management. The traffic information of the

freeway is displayed on the Houston TranStar website in a real-time basis for travelers to learn about traffic condition and plan trips accordingly.

As shown in [Figure 27](#), the previous rural two-level Katy Freeway-SH 6 interchange was reconstructed to a three-level interchange where SH 6 main lanes extend over Katy Freeway while the main lanes of the freeway pass over the frontage roads of SH 6. In addition, [Figure 28](#) shows that at Beltway 8, Katy Freeway was significantly widened by adding several additional lanes. Notice that, the figures showing after-construction conditions in [Figure 27](#) and [Figure 28](#) are computer visualizations and may be slightly different from the actual conditions. [Figure 29](#) is a photo taken on the freeway when approaching the Silber overpass from the west before the reconstruction was completed. The eastbound of the freeway was expanded to eight general purpose lanes when approaching IH 610. It is noteworthy in [Figure 29](#) that, as many other major highways in Houston area, the white lane strips on the pavement are outlined by black paint to increase their visibility. In addition to the overhead guide signs, guidance is also painted on the pavement to better facilitate travelers.



Source: (173)

**Figure 27. IH 10 at IH 6 before and after Reconstruction (Looking East).**





Source: (174)

**Figure 28. IH 10 at Beltway 8 before and after Reconstruction (Looking East).**



Source: (175)

**Figure 29. IH 10 Approaching the Silber Overpass.**

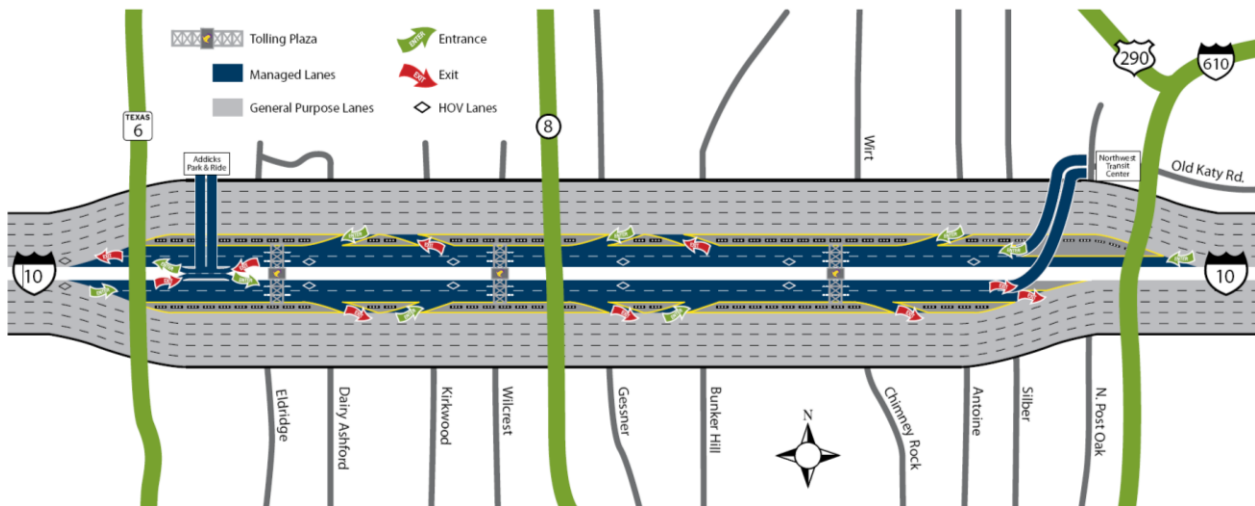
## Managed Lanes

The managed lanes were officially opened to commuters on April 18, 2009 (176). These facilities combine several transportation options including HOV lanes, transit, and toll roads and are first of their kind in Texas. METRO buses and school buses can use the lanes free of charge any time. HOV vehicles use the lanes free of charge during HOV hours but pay a toll at other times. Other vehicles can only use the facility by paying a toll at all times. The facility provides a faster option for Katy Freeway users and a funding source for highway maintenance in Harris County. More importantly, they promote ride sharing and the use of transit and therefore mitigate congestion in a long run.

HCTRA uses a dynamic tolling method to manage the tolled vehicles on the facility (177). The toll rate changes dynamically according to variables including traffic volume and time of day to leverage the traffic volume on the lanes for reasonable speed. HCTRA initially follows a predetermined rate schedule that changes at designated times during peak periods. A more sophisticated system that can determine the appropriate toll rate at a real-time basis has been explored. The four managed lanes between SH 6 and IH 610 are separated by concrete barriers and delineators with multiple access points to major freeway exits.

Figure 30 shows the access configuration and major toll-collection locations along the managed lanes. According to the Houston TranStar traffic information system (177), the

managed lanes currently provide a free flow speed higher than 60 mph at all times except at certain on/off ramps.



Source: (178)

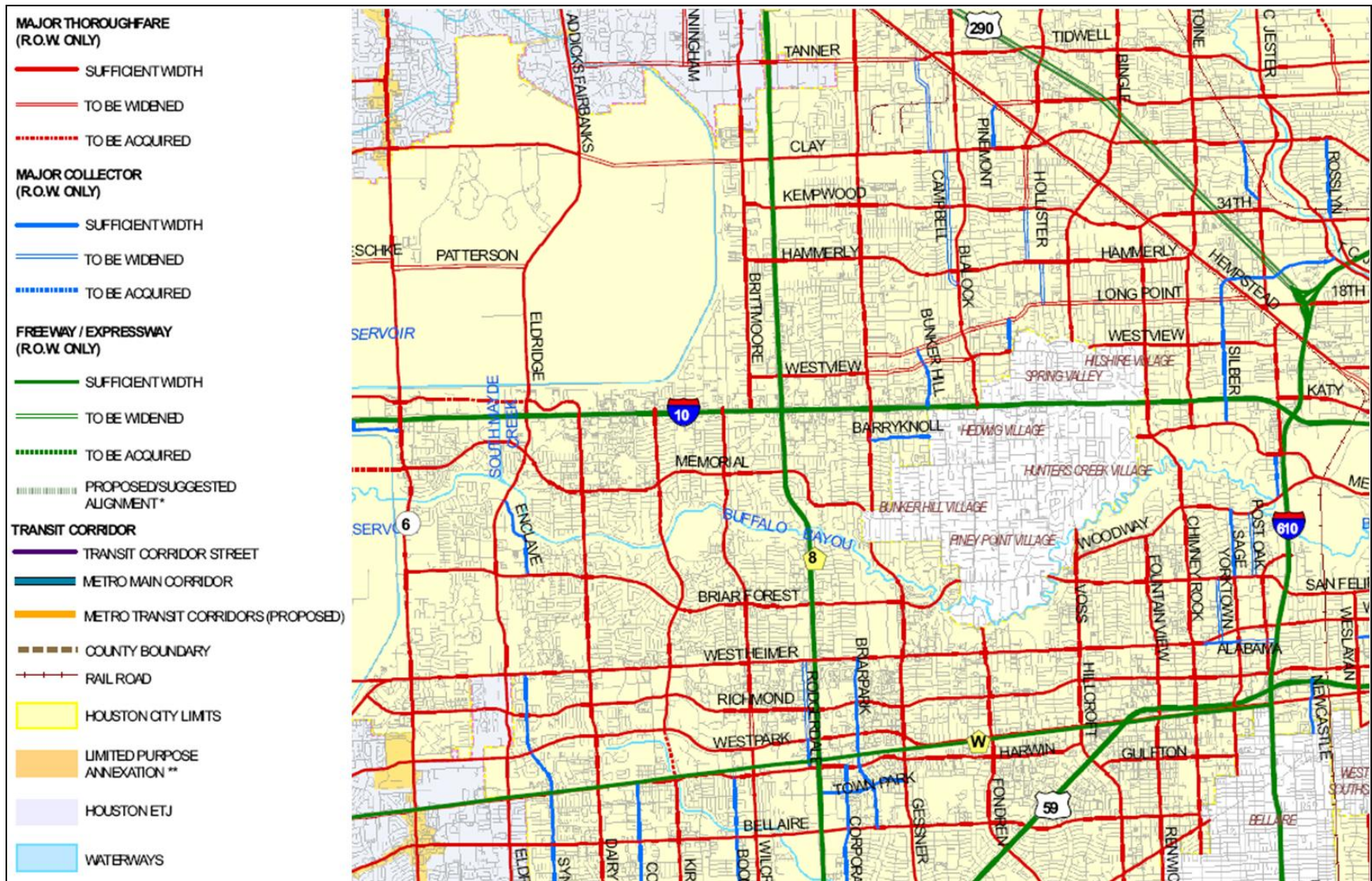
**Figure 30. Map of Katy Freeway Managed Lanes.**

### *Local Planning Effort*

In addition to managing the traffic signals along the Katy Freeway frontage roads, the City of Houston has been supporting the functionality enhancement of the corridor by increasing local arterials in the vicinity to improve system-wide connectivity and mobility. As shown in the 2008 Houston Major Thoroughfare and Freeway Plan (Figure 31), a grid of major thoroughfares has been developed along Katy Freeway. In addition to serve local traffic, these well connected roadways provide reasonable mobility and thus further draw local travelers off the freeway and its frontage roads to ultimately improve functionality of the freeway.

As stated in the Houston Major Thoroughfare and Freeway Plan (MTFP) Policy Statement (179), the city uses MTFP as a guideline to develop a general one-mile thoroughfare grid system in addition to radial and circumferential highways to enable system-wide mobility. Major thoroughfares generally require a 100-ft right of way to accommodate dual two to three lane roadways. The local development ordinance specifies the geometric standards for these thoroughfares consistent with national design guidelines for roadways with design speeds between 35–50 mph and daily traffic volumes between 20,000–50,000 vehicles. Dense intersections along major thoroughfares are discouraged to increase mobility and safety.

Since the adoption of MTFP in 1942 (179), the plan has facilitated the planning and development of the local highway system that helped to relieve the traffic burden on congested freeways. To maintain the original integrity of the plan and to ensure its implementation, the city requires that all proposals of major changes to the plan to be only approved through the public hearing process held once per year. In addition, the city planning department also discourages property owners to dedicate major thoroughfare right of way through their property by separate instrument (in lieu of dedication by plat) inconsistent with approved subdivision plans.

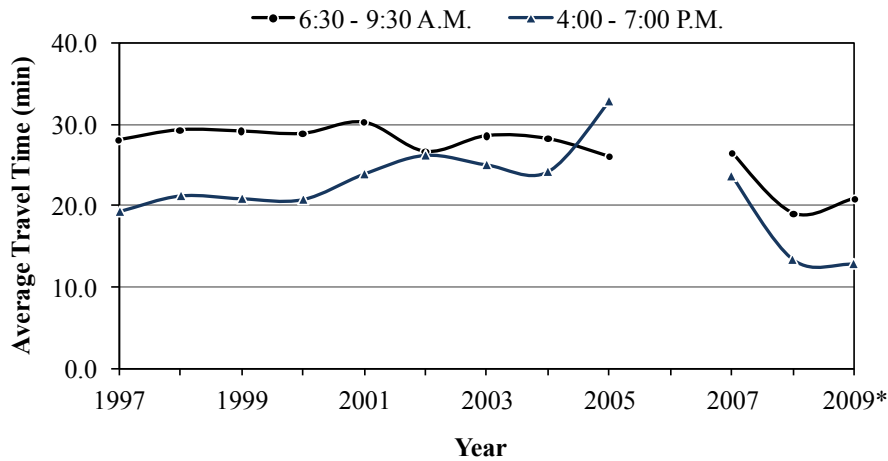


Source: Modified from (180)

Figure 31. City of Houston 2008 Major Thoroughfare and Freeway Plan.

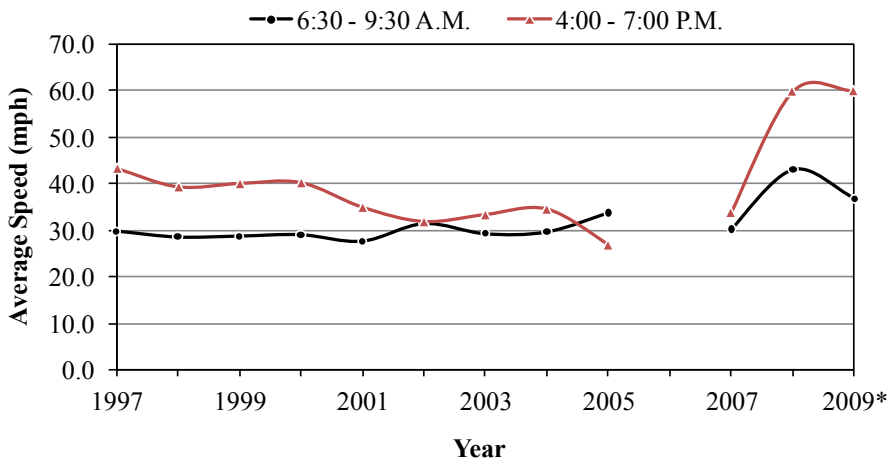
*Current Traffic Conditions*

As the new Katy Freeway went into service, users of the once congested roadway are now experiencing a mega freeway with considerably enhanced functionality. Based on an ongoing Katy Freeway traffic study and the Houston TranStar Information system (181), the average travel speeds on the study highway section are notably improved after the latest reconstruction. Figure 32 through Figure 35 illustrate the changes in average travel speed and time on the Katy Freeway general-purpose lanes between Barker Cypress Road (2.5 mile east of SH 6) and IH 610 West, a 14-mile section, during the last 13 years. As seen from these figures, the average travel speeds and times on both eastbound and westbound improved in 2008 after the new freeway went into service. Note that, during morning peak hours on eastbound and afternoon peak hours on westbound the average speeds and times improved significantly.



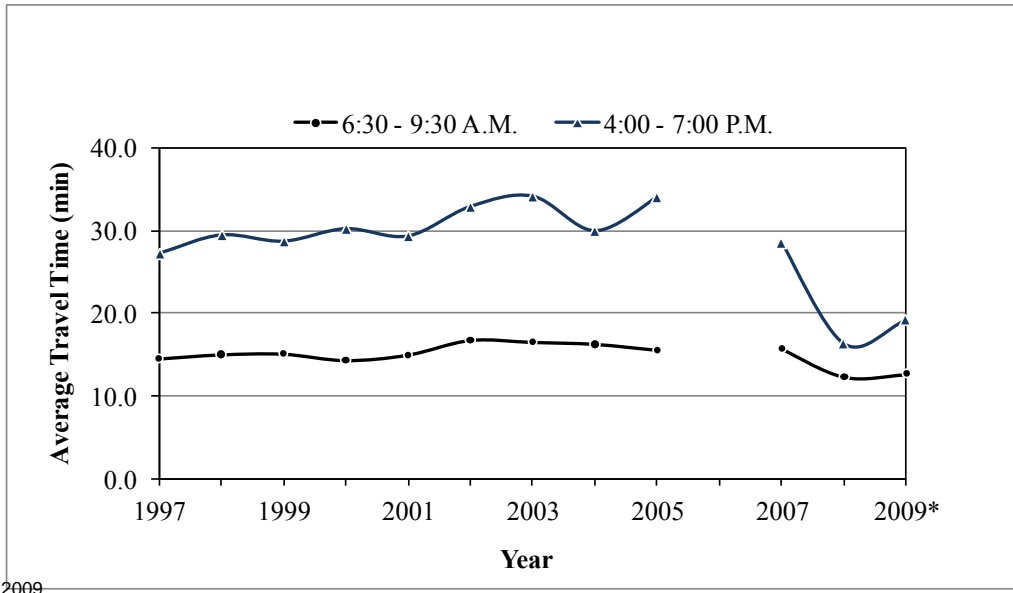
\* Jan-Mar 2009

**Figure**



\* Jan-Mar 2009

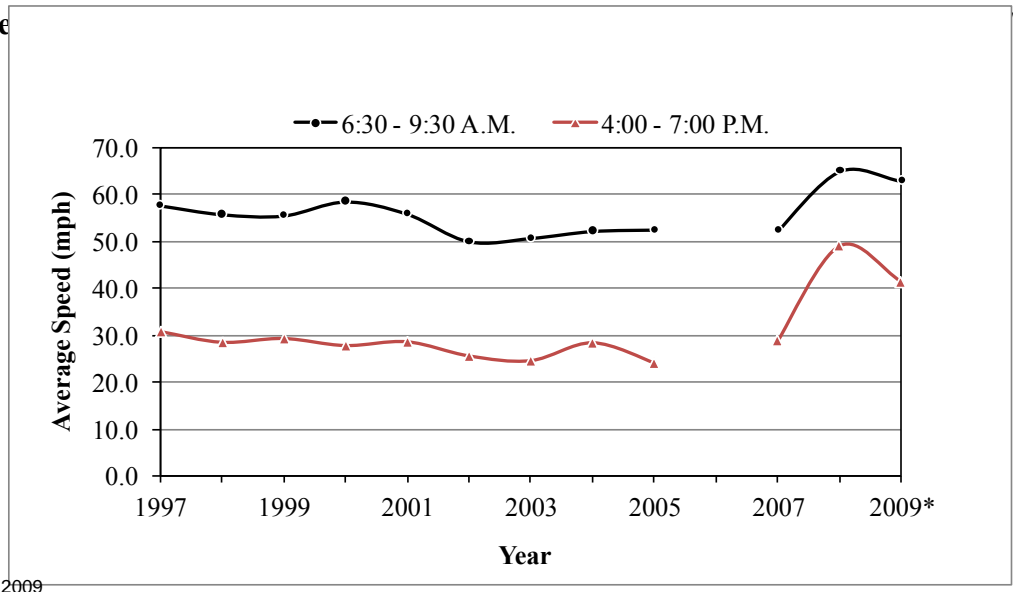
**Figure 33. Average Peak Hour Speed (Barker Cypress Road to IH 610 West, Eastbound).**



\* Jan-Mar 2009

Figure

est,



\* Jan-Mar 2009

**Figure 35. Average Peak Hour Speed (Barker Cypress Road to IH 610 West, Westbound).**

**Conclusions**

In this case study, the researchers examined the functionality evolution of Katy Freeway in the latest few decades. The study was focused on the 11.5-mile section from west IH 610 west to SH 6 within the Houston city limit. The freeway section was the last of Houston’s 1960s era major freeways to undergo a comprehensive expansion and rehabilitation. With its latest expansion completed in late 2008, it is now one of the nation’s top-ranked freeways with at least four general-purpose lanes, two managed lanes, and three frontage lanes in each direction. During the case study, the researchers first conducted a thorough review on the history of this highway section and identified the milestone improvements it has undertaken. Focused on these improvements, the case

study highlights the contributions and impact of various decisions on the functionality of the freeway from aspects such as planning, design, operations, and right of way.

As identified during the case study, the Katy Freeway underwent three major improvements after its freeway designation in 1953. Along these improvements is a complex course of functionality evolution, including deterioration, restoration, and enhancement. The first major improvement was the freeway upgrade between 1954 and 1968. The outcome of this upgrade was a conservative six-lane rural freeway that quickly became outdated for the rapid growing traffic demand in west Houston. With little right of way preserved, a reversible transitway was developed in the median of the freeway to partly alleviate its traffic congestion in the 1980s. This improvement partly restored the functionality of the freeway and particularly benefited the travelers via buses and HOVs. To further enhance the functionality, a substantial expansion was later carried out between 2003 and 2008. The current freeway has a much larger number of traffic lanes and the structural support for a potential light rail. It is expected to well serve the region within the foreseeable future. Through this functionality evolution and during the latest reconstruction, there were several factors that played an important role in functionality.

**Interagency Collaboration.** Interagency collaboration played a significant role in preserving and enhancing the freeway functionality during the two latest major improvements of the freeway. The Katy Freeway Transitway in the 1980s was a collaborative improvement by TxDOT and METRO, which benefited almost half of the person volume on the freeway. The latest Katy Freeway expansion project was another example of interagency collaboration involving FHWA, TxDOT, HCTRA, and METRO. The funds due to HCTRA's participation reduced the construction schedule from 10 years to six while releasing resources for use on other Texas roadways. Recognizing the partnership success, the National Partnership for Highway Quality (NPHQ), a collaboration of federal and state highway officials and highway industry leaders, awarded the project a silver —"Making a Difference" prize for partnering (182). Currently, HCTRA operates, maintains, and provides enforcement on the managed lanes; TxDOT operates and maintains the general purpose and frontage lanes; and METRO continues to operate the buses on the Katy Freeway Managed Lanes. HGAC is also involved in the freeway by overseeing long-term transportation planning along the corridor.

**Right-of-Way Preservation.** Right-of-way preservation can play a critical role in supporting highway functionality especially in areas with rapid development. Due to limited right of way and the lack of corridor preservation strategies historically, the latest Katy Freeway expansion was delayed for many years, resulting in extensive travel delays, maintenance costs, and safety problems. The Katy Freeway upgrade in the 1960s was an opportunity for constructing a more ambitious facility to better respond to the rapid urbanization in west Houston area. However, instead of preserving sufficient right of way along the much less developed corridor, the upgrade was conducted in a narrow strip with little right-of-way expansion. At the same time, the Katy Freeway section within the IH 610 loop was constructed to a modern freeway with five lanes in each direction, which has well met traffic demand and lasted to today. Other major freeways in west Houston area, such as Beltway 8 that intersects with the study freeway, were expanded much earlier partly due to their well preserved right of way.

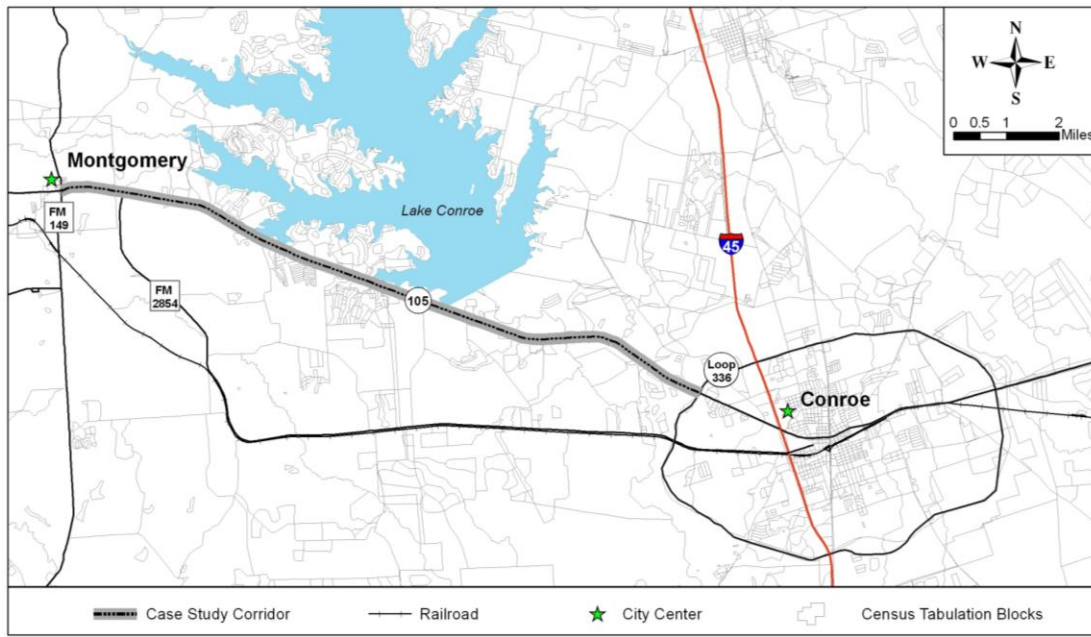
**Use of Minor Improvements.** The importance of minor improvements when major improvements are not available has been well recognized. Minor improvements demand less funding resources and implementation efforts and can be quick relieves for many congestion problems. In the case of Katy Freeway, the reversible transitway in the 1980s was implemented promptly without changing the highway cross section significantly. Although it shared a relatively small proportion of the traffic, it was able to provide approximately half of the person volume on the freeway with much improved travel speeds while having minimum impact on capacity of the other lanes. The improvement encouraged the use of mass transit and HOVs and therefore partly alleviated the traffic burden on the general-purpose lanes of the freeway as well.

**Managed Lanes.** A noteworthy feature of Katy Freeway after the latest improvement is the four managed lanes that innovatively combine the concepts of toll, HOV, and transit. These managed lanes reduce travel delays for METRO buses and HOVs and provide an option for regular travelers to drive at a higher speed at a cost. As the traffic continuously increases over time, it is foreseeable that these facilities will play a more important role in the near future in relieving traffic congestion on the freeway.

**Local Planning Support.** A well-established local highway network can support the functionality of major freeways by providing system-wide accessibility, connectivity, and mobility. Such a network attracts shorter trips and share traffic burden from the major freeways. An example is the thoroughfare system planned and developed by the City of Houston to support the major freeways in the area. Since the adoption of the first MTFP in 1942, the city has been well implementing the plan to develop a 1-mile grid of arterials with relatively high capacities and design speeds.

## **SH 105 CASE STUDY**

This case study addresses the functionality of SH 105 from FM 149 in Montgomery to Loop 336 in Conroe and how it has evolved and changed since the development of Lake Conroe in late 1960s and early 1970s. The section of SH 105 included in the study, shown in [Figure 36](#), is located in Montgomery County and is 12.9 miles in length.



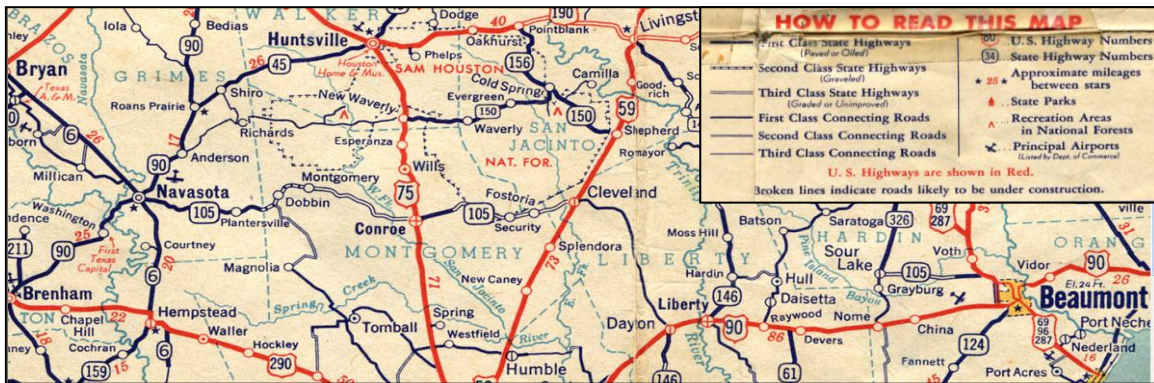
**Figure 36. Limits of SH 105 Case Study.**

Prior to development of the lake, this section of SH 105 functioned as a low volume 2-lane rural state highway. It is now a bustling high-speed multi-lane arterial with a center two-way left turn lane (TWLTL) in a non-urban design section with shoulders and open ditches. The case study describes how three decades of rapid growth in an unincorporated area without an adopted plan, land use controls, or municipal development regulations has impacted the functionality of not only SH 105, but also the adjacent land uses. The case study examines lessons learned, where this facility lies within its life cycle, and its potential future changes in its functionality that may be needed in light of continued high levels of development, crash frequency, and increasing traffic volumes as this area continues to grow and urbanize.

### **Early History of SH 105**

State Highway 105 is a regional east-west highway in southeast Texas that extends from Brenham to the east side of Beaumont. Between these two endpoints, SH 105's route passes through the cities of Navasota, Conroe, and Cleveland as well as many other smaller Texas towns and unincorporated communities. According to TxDOT records, the highway was proposed in 1939 from Navasota through Conroe and Cleveland to a point on US 69 near Beaumont. From Cleveland the route generally followed an existing county road known as the Cleveland-Nevilles Ferry road to SH 146 near Moss Hill (183). Figure 37 shows a depiction of SH 105 from Navasota to Cleveland from a 1942 road map of Texas. It also shows a small section SH 105 in place east of Beaumont. According to the map's legend, about a third of SH 105 in place at the time was a first class state highway that was paved and oiled. The remaining two-thirds is depicted as a gravel second class highway or a graded or unimproved third class highway. The section between Conroe and Beaumont was not completed until the 1960s. In 1973, SH 105 was extended southwest into Brenham, replacing SH 90.





Map Source: [http://www.oscarmail.net/dfwfreeways/images/oldRoadMaps/1942\\_humble\\_se\\_texas\\_med.jpg](http://www.oscarmail.net/dfwfreeways/images/oldRoadMaps/1942_humble_se_texas_med.jpg)

**Figure 37. Depiction of SH 105 on 1942 Highway Map.**

Since the early 1970s, the greatest changes in SH 105 have occurred generally within about a 10-mile section that passes by the south side Lake Conroe between the cities of Montgomery and Conroe. Located on the west fork of the San Jacinto River, Lake Conroe was built as a joint project of the City of Houston, the Texas Water Development Board, and the San Jacinto River Authority in 1973 as an alternate water source for the City of Houston (184).

Since the completion of the lake in early 1970s, traffic volumes on the SH 105 corridor between Conroe and Montgomery have increased more than 10-fold due to high amounts of residential and commercial development and the lake’s role as regional tourism and recreational destination, particularly from the greater Houston area.

### **Lake Conroe Development and the SH 105 Corridor**

The development of Lake Conroe spawned economic development. Beginning in the early 1970s the rural agriculturally dominated land use patterns began to give way to major single family residential subdivisions and commercial development. Over the past few decades, sizeable amounts of woodland and farmland acreage have been subdivided and developed. Growth in the cities of Conroe and Montgomery, along with the general the northern expansion of the city of Houston—including The Woodlands and Oak Ridge areas—contributed to this growth. Employment in the area shifted from farming and ranching to professional services, real estate development, construction, and retail trade (185).

Lake Conroe’s recreational attributes and proximity to the Houston area made it a desirable location for single family housing developments. Three of the largest subdivisions along the SH 105 corridor, Walden, April Sound and Cape Conroe, were begun in 1972. When developed in 1972, April Sound reserved 120 ft along the highway for the purpose of future highway expansion, greenspace, and as a buffer for homesites. However, in 1972 it was not anticipated that more than 120 ft would be needed for the highway (186). Table 12 provides a general overview of residential development along the SH 105 corridor over the past several decades.

**Table 12. Residential Development within the SH 105 Study Corridor.**

Subdivision	Year Subdivision Established	Yearly Number of Dwelling Units	Median Year Built	Median Lot Size
Walden	1972	3,250	2000	7692
April Sound	1972	1674	1993	9756
Cape Conroe	1972	693	1997	7944
Lake Conroe Forest	1959	618	1983	46392
Grand Harbor	1999	400	2004	26550
Del Lago	1981	199	1997	7260
Diamond Head	1972	93	1990	9637
Sunrise Ranch	2001	89	2005	5500
West Fork	2002	75	na	na
Mia Lago	2008	66	2008	na
Highland Hollow	1976	62	1980	13584
Harborside	2000	62	2004	43908
Lake Forest Lodge	1957	56	1978	40000
Del Lago Estates	1983	52	1996	26919
Blue Heron Bay	1997	40	2004	17391
Lake Lorraine	1964	36	1996	26888
Lake Conroe Village	1988	29	1996	2244

Sources: Houston Association of Realtors (<http://www.har.com/neighborhoods/>) and Montgomery County Engineers Office

Most of the single-family residential developments in the SH 105 corridor contain little, if any actual frontage along SH 105, but are connected to the highway by a local residential street. Development along SH 105 is primarily commercial or retail uses due to its high value. Today, commercial development along the SH 105 corridor is characterized by strip retail, fast food chain restaurants, convenient stores with gas pumps, real estate offices, storage facilities, auto repairs, motels, industrial uses, and other businesses. One big box retail store, a super Wal-Mart, is located on SH 105 at Walden Road.

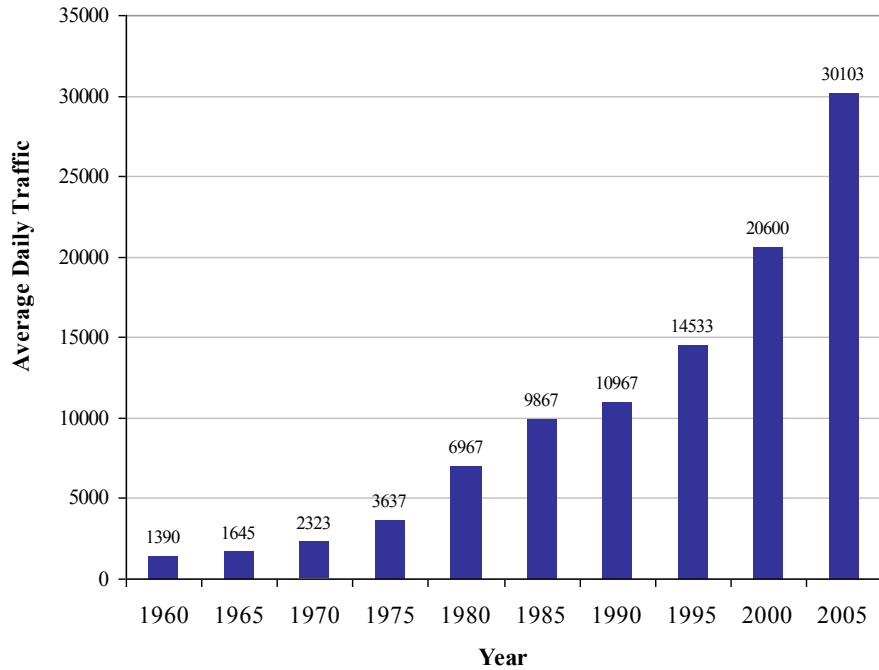
### **Historic Traffic Volumes on SH 105**

Since 1960 TxDOT has conducted traffic counts on an annual basis at three separate locations within the 12.9-mile SH 105 study section. Traffic counts have been taken each year on SH 105 (with a few exceptions) at points on SH 105 approximately mid-way between the following roadways:

- La Salle Drive and Sapp Road, located on the east side of the study limits about midway between the Lake Conroe dam and Loop 336;
- Tejas and Marina Drives near the middle of the 12.9-mile SH 105 study section; and,
- FM 2854 and FM 149 near the western terminus of the study area and the city of Montgomery.

As residents and businesses continually increased, so too did the traffic volumes along the SH 105 corridor. In the 1960s, average daily traffic volumes on SH 105 between Conroe and Montgomery were below 2,000 vehicles per day. With the

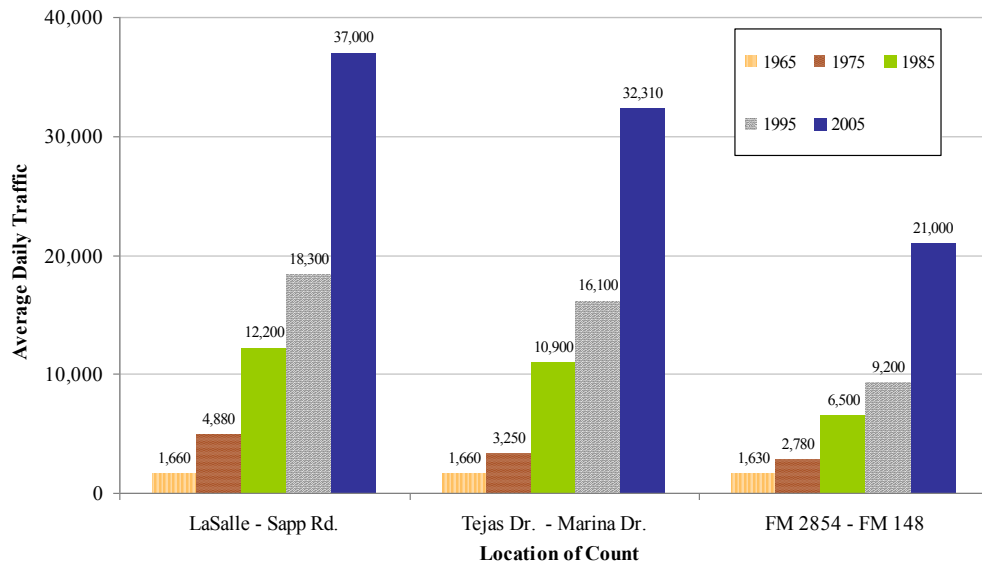
development of the lake, traffic volumes on this section of highway doubled by the mid-1970s. From 1975 to 2005, average daily traffic counts on SH 105 increased from about 3,600 to 30,000 vehicles per day. Figure 38 illustrates the increases in traffic volumes within the SH 105 study area from 1960 to 2005. The counts shown for each five-year increment are the average of the traffic counts from TxDOT's three count sites in the SH 105 study section.



**Figure 38. Traffic Volumes on SH 105 by Lake Conroe since 1960.**

Traffic volumes at each of the three count sites along SH 105 within the study area are shown in Figure 39. It shows the average traffic daily volumes at each count location in 10-year increments, beginning in 1965 and ending in 2005. Since the lake was completed, growth has occurred most heavily toward the east end of the study section. This is as would be expected with the City of Conroe and I-45 proving the highest levels of services and regional access.

Chapter 5, Transportation, of the City of Conroe's Comprehensive Plan shows a 2006 traffic volume of 41,400 vehicles per day (vpd) on SH 105 between Walden and Old River Roads and a count of 40,800 vpd on SH 105 between Carter Moore and Loop 336 west.



**Figure 39. Historic Traffic Volumes by Count Site on SH 105.**

### Needs for Improvements Planned in 1970s and 1980s

Prior to its improvements in the 1990s, SH 105 between Conroe and Montgomery was a two-lane undivided rural highway with 8 to 12 ft unpaved outside shoulders and open ditches contained within a 120 ft right of way. With high levels of persistent growth in the corridor in the 1970s and projections for it to continue and increase, the need for added capacity on this section of highway rose quickly. TxDOT consideration for major improvements to the highway began in the mid-1970s and by early 1983 they received authorization to begin preparation of plans for widening and capacity improvements.

By January of 1984, TxDOT had completed a design concept to improve SH 105 from two to four lanes with a center two way left turn lane (TWLTL). In March of 1988, the schematic was submitted to the FHWA. The agency reviewed the design concept and based on future traffic projections, directed TxDOT to revise the schematic to include a 6-lane section from just east of FM 2854 to Loop 336. The highway design was subsequently revised and FHWA approved the the schematic later that year (meeting with Jim Heacock, Houston District, July 1, 2009).

The project’s environmental assessment stated that land use in the project area was expected to continue toward increased development and urbanization, thus creating the need for the additional capacity. It also concluded that noise abatement barriers were warranted in some places, but they were not recommended due to the numerous access points along the facility (183).

Figure 40 shows an example of what SH 105 generally looked as a 2-lane rural roadway prior to the development of Lake Conroe. The depiction is not totally accurate as the shoulders were not paved on SH 105 in the 1960s and 1970s.



**Figure 40. Example Depiction on SH 105 Prior to Development of Lake Conroe.**

In early 1989, TxDOT held a public hearing on the project at Conroe High School. During the public hearing, TxDOT relayed that the purposes of a state highway were not only to address local traffic needs, but also to improve and accommodate regional mobility for the broader travelling public. Most concerns and comments relayed by participants stemmed from right-of-way acquisition, but there were also concerns expressed about the effect that the widened roadway would have on the ecology, the natural beauty, and country atmosphere along the corridor.

Local officials and community leaders were much in favor of the project and submitted resolutions to TxDOT in support of the project. The primary reasons for their support included economic development benefits, enhanced mobility, improved safety, and a broadening of the tax base (186). In July 1989, TxDOT received final environmental clearance from FHWA that allowed for the expenditure of federal funds to begin acquiring right of way for the project.

### **Early 1990s Widening and Current Roadway Cross-Sections**

According to the TxDOT Conroe Area Engineer's office, the widening and upgrade of SH 105 between Conroe and Montgomery to its current configuration was undertaken via two separate construction projects having different contractors. The first project began in May of 1992 and ended in May of 1994 and went from Loop 336 in Conroe west to McCaleb Road. The second project began in July of 1992 and was completed in May of 1995. This project picked up where the first one left off at McCaleb Road and went to the intersection of FM 149 in Montgomery. The combined length of both projects was 12.8 miles.

The widening projects completed in 1994 and 1995 included the addition of one or two travel lanes in each direction, improved signing and pavement markings, and a center TWLTL. More specifically, the improvements included:

- an upgrade to four 12-ft lanes with a 16-ft flush center median, 10-ft shoulders and open ditches from 0.3 miles east of FM 149 to 0.2 miles east Old River Road, and
- an upgrade to six 12-ft lanes with a 16-ft flush center median, 10-ft shoulders and either curb and gutter or open ditches from 0.2 miles east of Old River Road to to Loop 336.

Figure 41 shows a picture the 5-lane section as it currently exists from near Old River Road west to FM 149 in Montgomery. It also clearly shows the 10-ft shoulders and open ditches.



**Figure 41. Existing 5-Lane Section of SH 105 on West Side of Corridor Study Area.**

Figure 42 shows a picture the 7-lane section as it currently exists from near Old River east to Loop 336 in Conroe. According to the TxDOT Conroe Area Engineer's office, there was little, if any consideration given to the installation of raised medians in the project, in lieu of the center TWLTL.



**Figure 42. Existing 7-Lane Section of SH 105 on East Side of Corridor Study Area.**

Based on the project's Environmental Assessment, right-of-way widths for the improved cross-sections varied from about 120 to 350 ft. As such, the project required acquisition of approximately 166 acres of right of way and included 30 displacements (185). Montgomery County hired a right-of-way agent to help purchase the right of way and help speed up the acquisition process. The county issued certificates of obligation to help finance their share of the right-of-way costs. Right-of-way displacements included 14 residences, two small metal buildings, five building lots, some business parking spaces, and three miscellaneous structures (e.g., gas pumps). The total cost of the project was \$53.3 million.

A separate project widened SH 105 through the town of Montgomery to a 4-lane divided highways from 0.3 miles east of FM 149 west to Old Plantersville Road. This project did not require any additional right of way (186).

### **Current Conditions along the Corridor**

There have been no major improvements to SH 105 since the mid-1990s and within the 12.9 mile study area the highway remains 4-lanes with a center TWLTL east of Old River Road (shown in Figure 41) and 6-lanes with a center TWLTL west of Old River Road (shown in Figure 42). The posted speed limit within the corridor is predominantly 60 miles per hour, but there are a few small sections of roadway with a lower posted speed.

### *Traffic Signals and Signal Spacing*

There are currently 12 signalized intersections on SH 105 between FM 149 in Montgomery to Loop 336 in Conroe. All signalized intersections, illustrated in Figure 43

and listed in Table 13, are operated and maintained by TxDOT. They operate independently and are not interconnected.

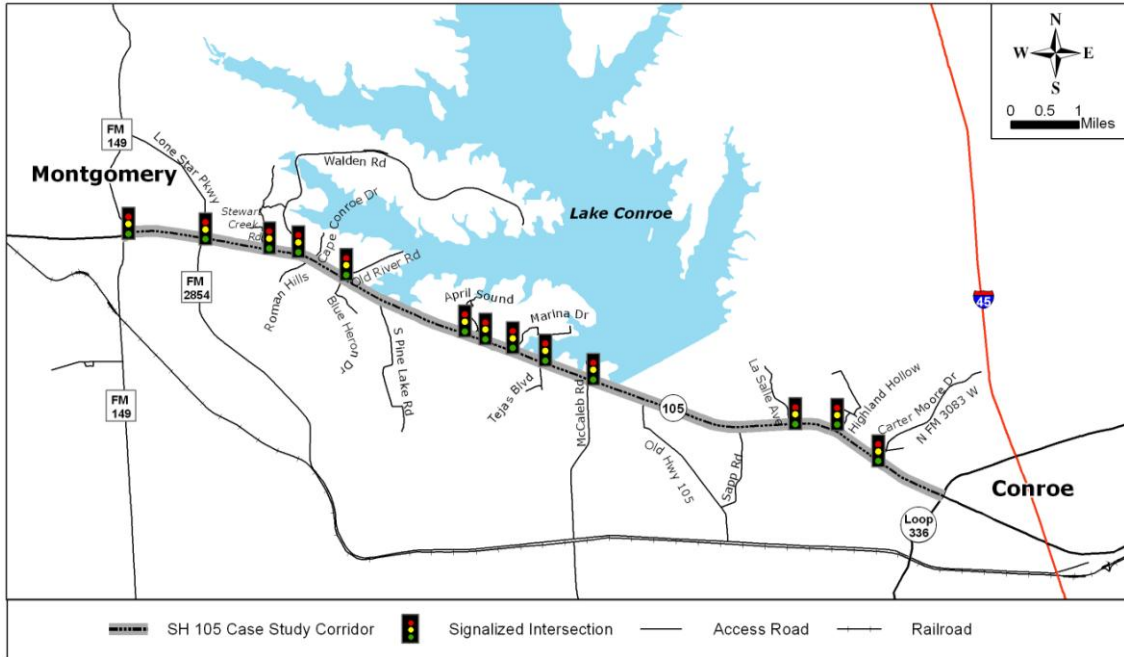


Figure 43. Traffic Signal Locations.

Table 13. Traffic Signal Locations.

Signalized Streets/Access Points on SH 105 in Study Area	Intersection Type	Number of Through Lanes (excluding TWLTL)	Signal Head Mounting Type	Warning Beacon in Advance of Signal
FM 149	Full	4	span wire	No
FM 2854/Lone Star Pkwy.	Full	4	span wire	No
Steward Creek Rd./Private Dr.	Full	4	span wire	No
Walden Rd.	T	4	span wire	No
Old River Rd./Blue Heron Dr.	Full	6	span wire	Yes
April Sound Dr. (West)	Full	6	span wire	Yes
April Sound Dr. (East)	T	6	span wire	Yes
Marina Dr.	T	6	span wire	Yes
Tejas Road	Full	6	span wire	Yes
McCaleb Rd.	Full	6	span wire	Yes
La Salle Dr.	T	6	span wire	Yes
Highland Hollow Dr./Private Dr.	Full	6	span wire	Yes
Carter Moore Dr./West Fork Blvd.	Full	6	mast arms	Yes
Loop 336	Full	4	span wire	No



As shown in [Table 13](#), eight signal installations are at full intersections, while four are at ‘T’ intersections (3-legged). Most of the signals are installed using span wire in lieu of mast arms. Advanced signal warning beacons are in place along SH 105 on the approaches to 9 of the 12 signals in the corridor. Typical reasons for the use of advanced beacons are high speeds and a high frequency of crashes.

The wide roadway cross-section created by the flush TWLTL and the 10-ft shoulders contributes to the need for the advanced signal warning flashers. The wider cross-section is conducive to higher speeds that require a greater time and distance needed to react to a traffic signal. Some sort of visual break or separation between the travel lanes, such as that created by a raised or divided median, would help improve signal detection and awareness, and lessen the need for advance signal warning beacons. Such a division in the roadway separates on-coming vehicles and reduces head-on crashes.

A long and uniform spacing of signals is needed to establish optimal timings for efficient traffic movement and progression. The overall spacing of the existing signals along SH 105 is not uniform, and several are located too close together. For the regional highway function of SH 105 where it serves non-local traffic travelling through the Conroe/Montgomery area, signals should be located no closer than 1 mile apart. The average spacing distance of all signals within the 12.9-mile corridor is about 5,700 ft apart, but 8 of the 12 signals are located less than 1 mile apart. The distance between traffic signals on SH 105 is the same as the segment length provided in [Table 14](#) of the next section. Normally to achieve signal progression, signals need to be spaced no more than ½ mile apart if they are interconnected. To have independent signals (not interconnected or coordinated) work well, they need to be at least a mile apart.

### *Unsignalized Access and Connectivity*

The design and project development for the 1992-95 widening of SH 105 occurred well before TxDOT’s Access Management Policy (adopted in 2004) was in place. In light of this, there was little if any consolidation of driveway access included in project design or construction. There are currently over 300 unsignalized access points along the 12.9-mile study section of SH 105. Approximately 14 percent of these are minor local streets, and the remaining 86 percent are private driveways providing access to businesses and other uses.

For access inventory purposes, the SH 105 study area was broken down into highway segments between traffic signal installations. [Table 14](#) shows the number of existing access points located within each segment. This table also shows the access density for each segment. The non-signalized access density for the full 12.9 study section is estimated at about 25 access points per mile. Three segments were found to have an access density of 39 access points per mile.

Few access connections are in place between developed properties and businesses adjacent to SH 105. Also, little, if any consolidation of access is in place along the corridor where a single driveway is shared between two or more businesses. Many parcels have multiple driveways. [Figure 44](#) shows an example of a section of SH 105 in the area of McCaleb Road that has a high access density and little on-site connectivity between adjacent developments.

**Table 14. Access Density by Highway Segment.**

<b>Highway Segment (between signalized intersections)</b>	<b>Segment Length (ft/miles)</b>	<b>Total Access Points (unsignalized)</b>	<b>Access Density (points/mile)</b>
FM 149 to FM 2854/Lone Star Pkwy	6500/1.23	25	20.3
FM 2854/Lone Star Pkwy to Stewart Creek Rd	1950/.37	0	0
Stewart Creek Rd. to Walden Rd	5600/1.06	30	28.3
Walden Rd. to Old River Rd./Blue Heron Dr	3900/.74	29	39.3
Old River Rd./Blue Heron Dr. to April Sound Dr. (West)	11,150/2.11	28	13.3
April Sound Dr. (West) to April Sound Dr. (East)	400/.076	0	0
April Sound Dr. (East) to Marina Dr.	3200/.61	15	24.8
Marina Dr. to Tejas Road	1950/.37	4	10.8
Tejas Road to McCaleb Rd.	4000/.76	30	39.6
McCaleb Rd. to La Salle Dr	16,300/3.09	89	28.8
La Salle Ave. to Highland Hollow Dr	4000/.67	30	39.6
Highland Hollow Dr to Carter Moore Dr./West Fork Blvd.	4050/.77	21	27.4
Carter Moore Dr./West Fork Blvd. to Loop 336	5400/1.02	18	17.6
Totals	68,400/12.95	319	24.6



**Figure 44. High Access Density on SH 105 Near McCaleb Road.**

The proliferation of access points, lack of inter-parcel connectivity, and access consolidation between developments adds conflicts points along the highway that result in decreasing speed, an increase in vehicle conflicts and the crash rate, and has a detrimental impact on highway functionality.

*Crash History*

Table 15 shows the crash history of reported crashes on SH 105 from FM 149 in Montgomery to Loop 336 west in Conroe from 2003 through July 13, 2009. The source of this data is the Motor Vehicle Traffic Crash Data records maintained by TxDOT. It represents reportable data collected from Texas Peace Officer’s Crash reports (CR-3) received and processed by TxDOT.

**Table 15. Crash History on SH 105 from FM 149 to Loop 336.**

Year	Total Crashes	Injury or Possible Crashes	Non-Injury Crashes	Fatal Crashes	Number of Fatalities
2003	101	45	53	0	0
2004	100	45	52	2	3
2005	115	48	63	3	4
2006	99	45	53	1	1
2007	101	43	55	2	2
2008	109	46	60	3	4
1/1/2009-7/13/2009	54	26	24	2	2
Totals	679	298	360	13	16

The data show that the total number of crashes on SH 105 within the corridor study area have remained about the same since 2003. Not included in the Table 15 are two fatal crashes involving three fatalities that occurred earlier in July of 2009. Figure 45 shows local emergency services at the scene of a crash on July 10, 2009 that involved two fatalities.



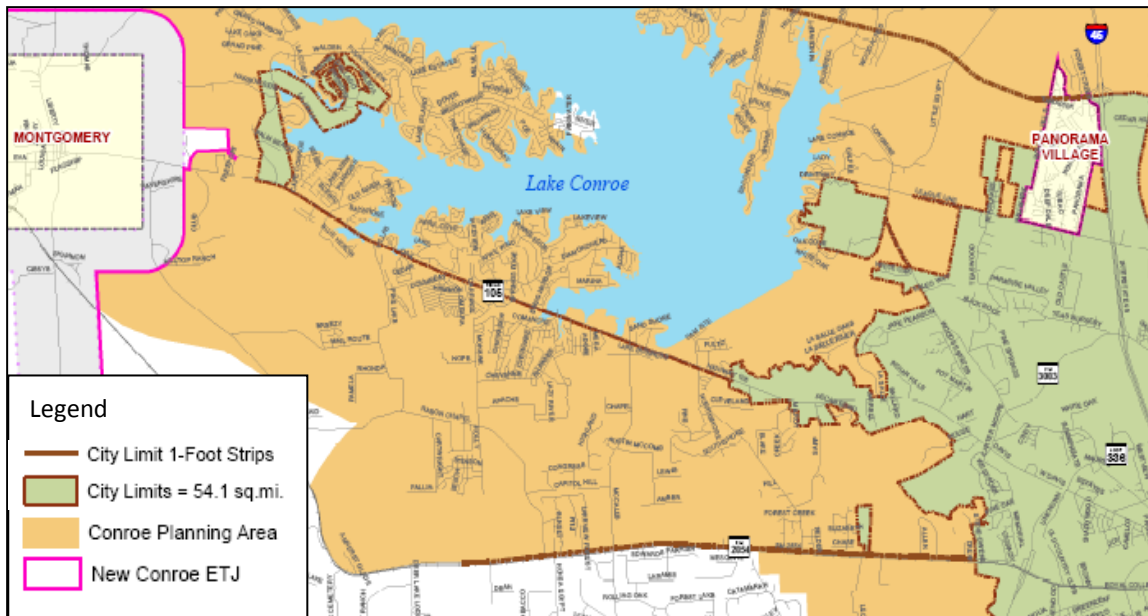
**Figure 45. Accident on SH 105, July 10, 2009.**

More detailed review of crashes, beyond the scope of this study, is needed to help identify crash ‘hotspots’ and the types and causes of crashes along the corridor.

## Jurisdictional Boundaries

Figure 46 shows the current city limits of Conroe and Montgomery and their extraterritorial jurisdictions in relation to the SH 105 corridor in the area of Lake Conroe. For the 12.9-mile section of SH 105 between FM 149 and Loop 336, Figure 45 indicates that:

- about one-third of the 12.9 study corridor is in the Conroe city limits;
- over one-half is within Conroe’s ETJ, and
- the remainder is within the city of Montgomery or its ETJ.



Source: 2008 Extraterritorial Jurisdiction & Joint Planning Area Map, City of Conroe, Community Development.

**Figure 46. Local Jurisdictional Boundaries in the SH 105 Study Area.**

In the late 1960s, the city of Conroe annexed a 1-ft strip along SH 105 from its city limit line west to about Walden Road. This action extended the city’s ETJ and served to prevent this area from being annexed by any other city. Beginning in the mid-1980s, the city of Conroe began to annex property along SH 105 west of Loop 336 in the direction of Lake Conroe. Based on the city’s Annexation Map dated December 2008, four separate annexations occurred from 1987 to 2000, which extended the Conroe city limits to take in about 4 miles of SH 105 to a point near Beach Road.

Today, the large majority of SH 105 and the surrounding area is located within Conroe’s ETJ and its joint planning area, an area within Conroe’s ETJ identified as having the potential to be annexed in the next 10 years. The joint planning area was established through a joint agreement between the city of Conroe and Montgomery county.

**Development Processes, Practices, and Regulations**

Historically and still today, the subdivision regulations of Montgomery County have been and are the primary, if not sole, source of regulations imposed on most development in the SH 105 corridor study area. Because this area was not located within a city with an adopted comprehensive plan and related development ordinances, it has developed without land use controls and minimal regulations on development.

Under their subdivision regulations, Montgomery County can regulate the layout of streets, lots, utility infrastructure, and drainage. Other areas regulated by the county as part of land development included the FEMA 100-year floodplain and septic systems. Developments adjacent to or impacting the lake may also be subject to requirements and regulations of the San Jacinto River Authority and the Army Corp of Engineers. Like other Texas counties, Montgomery County has no authority to regulate land use and little or no authority to regulate aspects of site development such as access locations, internal circulation, setbacks, signs, parking, landscaping, buffering, building materials or architecture, lighting, and noise.

Currently, how proposed subdivision plats and site development plans are processed along the corridor varies depending on if the area is in:

- the Conroe city limits,
- the Conroe planning area, and
- or the city of Montgomery’s jurisdiction.

Today, the large majority of the corridor is located the city-county joint planning area. In this area, the city reviews plats and site plans and approves residential building permits, but commercial building permits are approved by the county. Developments in the planning area are required to meet city detention and right-of-way requirements and install street lights, but roadways are still built to county standard. Table 16 shows the responsibility for development review by jurisdiction within the SH 105 corridor as indicated on Planning page (<http://www.cityofconroe.org/content/view/154/499/>) of the City of Conroe’s website.

**Table 16. Development Review Responsibility.**

Jurisdiction within Corridor	Engineering Division		Building Permits	
	Subdivision Plats	Site Plans	Residential	Commercial
Conroe City Limits	City	City	City	City
Conroe Planning Area	City	City	City	County
Conroe ETJ	County	County	County	County

All plats, site plans, and building permits in the SH 105 corridor located in the City of Conroe are handled by the city. Though allowed by state statute, it has opted not review any plats in its ETJ (187). The city does not have zoning, access, or sign ordinances. Key items that it regulates include on-site parking amounts and building setbacks. The city does not require a parking setback but does have a landscape ordinance.

As indicated in a meeting with staff of the TxDOT's Conroe Area office on July 10, 2009, there is currently little or no coordination between the local jurisdictions and TxDOT in plat and site development review along the corridor for the purpose of helping to implement TxDOT's access spacing guidelines. It has also been the practice of the City of Conroe and Montgomery County to not require access easements in platting to help consolidate driveways or require internal connections between developments. [Figure 47](#) shows the lack of shared or cross access between the corner development and surrounding shopping center at the corner of SH 105 and Loop 336 in Conroe. If the city of Conroe had an access ordinance, it could also be applied in the ETJ to help TxDOT manage access along the corridor.



**Figure 47. Lack of Shared or Cross Access between Developments at SH 105 and Loop 336.**

The cumulative affect of the lack of access related regulations along the corridor has resulted in a proliferation of conflict points along the highway that has impacted safety and mobility. The lack of land use controls and other regulations such as sign ordinances, parking screening may also have impacted property values, aesthetic quality, and the types and levels of investments along the corridor.

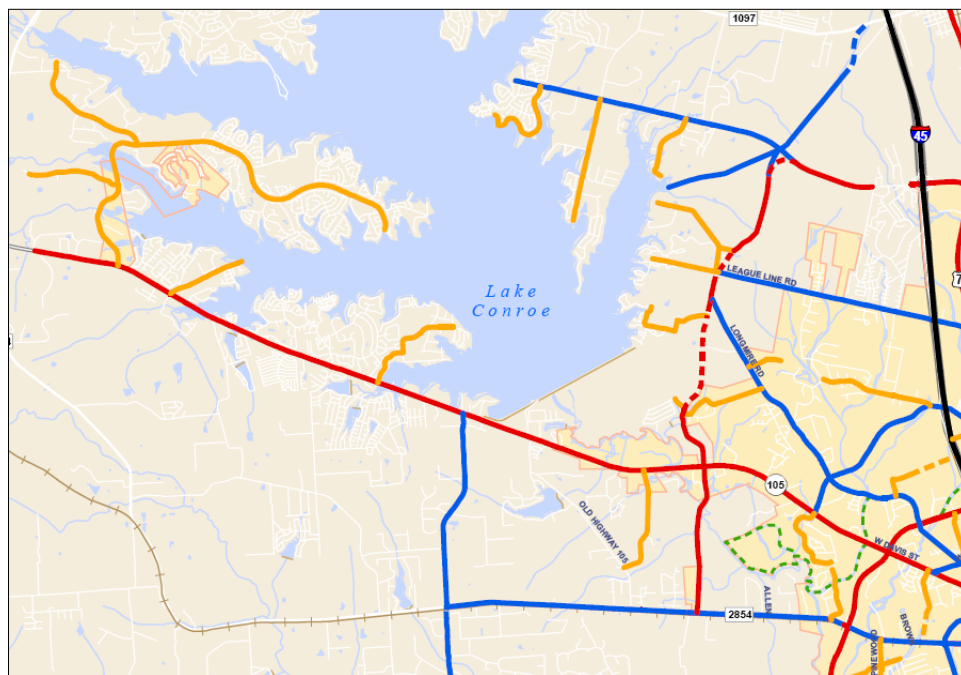
### **Local and Regional Transportation Planning**

In the 1960s, 70s, and 80s, when many of the major residential subdivisions were being planned near Lake Conroe, there was no local transportation plan in place to help

guide and create a coordinated and connected layout of the local street network adjacent to SH 105. A key benefit of such a plan would have been to prevent minor residential streets from connecting to SH 105 and establishing a proper spacing of collector and arterial street intersections along the corridor.

A portion of the city of Conroe's current Thoroughfare Plan, shown in [Figure 48](#), shows SH 105 functionally classified as a principal arterial, which calls for mobility to be its primary function and access its secondary function. The plan, adopted in 2006, shows Walden Drive, Old River Road, Marina Road, and Sapp Road extending from the north side of SH 105 as collector streets. McCaleb Road is shown as a minor arterial and extends south past FM 2854 to FM 1488. This proposed extension is known as the Fish Creek thoroughfare. With the exception of Sapp Road, the thoroughfare plan shows no collector streets on the south side of SH 105.

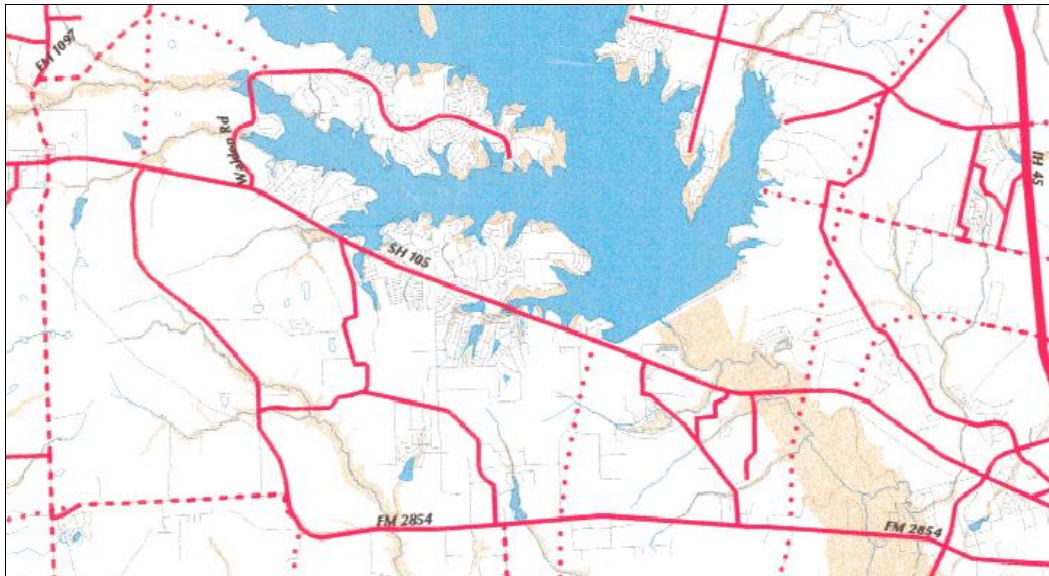
The current thoroughfare plan lacks a sufficient level of detail to be used as a guide in the platting process to coordinate subdivision connectivity. Connectivity between neighborhoods and commercial developments adjacent to SH 105 is important for the development of a local street and circulation network to support SH 105. The City of Conroe's planning area and Thoroughfare Plan needs to be expanded to cover the south side of SH 105 to at least FM 2854. In addition to the current collector street, a minor (or residential) collector street classification could be added to the plan to show more detail, and where feasible, connections in the local street system adjacent to SH 105.



**Figure 48. SH 105 in the City of Conroe Thoroughfare Plan.**

A portion of the Houston-Galveston Area Council's 2025 Regional Transportation Plan (RTP), shown in [Figure 49](#), shows SH 105 as an existing thoroughfare with

sufficient right of way. The regional transportation plan is not intended to include all collector streets since those are normally included in the city throughfare plan.



**Figure 49. SH 105 in HGAC's Regional Transportation Plan.**

HGAC's RTP is a coordinated transportation plan for the entire Houston region. It is maintained by HGAC, but is developed with the participation of cities, counties, and TxDOT. The RTP includes the widening of SH 105 west of Snug Harbor to a 6-lane divided highway on its list of existing and proposed projects. It also includes a project to connect Walden Road with FM 149 and the aforementioned Fish Creek thoroughfare.

In recent years, Montgomery County has been following the RTP plan with the development of Lone Star Parkway aligned opposite FM 2854 on the north side of SH 105. The county is also actively working on developing McCaleb Road on the south side of SH 105 as the Fish Creek thoroughfare. This facility will provide a direct connection between the densely populated Woodlands and south Montgomery County area to SH 105 and Lake Conroe area.

### **Summary Conclusions and Future Opportunities**

The case study revealed how three decades of rapid growth in an unincorporated area without an adopted local plan, land use controls, and only minimal development regulations can impact the functionality of a state highway. Up until the mid to late 1970s, SH 105 was a rural country highway that primarily served longer distance travel between small southeast Texas communities. The completion of Lake Conroe in the early 1970s spawned high levels of persistent growth within the corridor and the need for added capacity rose quickly. The development of large single-family subdivisions combined with commercial development along the corridor shifted the vehicle mix on SH 105 from predominantly longer distance non-local travel to shorter distance trip making of the new residents and visitors in the area. In the 1980s, TxDOT prepared plans to



widen the highway and in the early 1990s let construction projects to widen the highway to its current configuration of a multilane arterial with a center TWLTL from Loop 336 in Conroe to FM 149 in Montgomery. The design and construction took place prior to TxDOT adoption of its Access Management Guidelines and the mid-1990s upgrade did not consider raised non-traversable medians or consolidation of access.

Today, SH 105 serves competing dual functions of a regional arterial highway designed to carry longer distance higher speed traffic and a local urban arterial serving local traffic at lesser speeds. Traffic volumes on SH 105 have risen from a few thousand vehicles per day in the 1970s to in excess of 40,000 today. The city of Conroe's 2006 Comprehensive Plan shows that conditions on SH 105 in the area of Lake are at LOS E and F. These figures indicate poor operational conditions and reflect that traffic volumes are exceeding the capacity of the roadway (in some areas). The capacity and ability to efficiently and safely move traffic on SH 105 has been significantly reduced since its reconstruction as a multi-lane arterial in the mid-1990s.

Key conditions that have contributed to the accident frequency and the loss of highway functionality on SH 105 are identified and addressed in the following bullet points.

- **Frequent and closely spaced non-signalized access points.** The access density of the 12.9 miles SH 105 corridor was found to about 25 access points per mile, with some sections reaching about 40 access points per mile. Research shows that crash rates more than double when access density increases from 10 to 40 points per mile. In 2003, TxDOT adopted an Access Management Manual. The city of Conroe and Montgomery County can now assist TxDOT in regulating the location and spacing of access through the local platting process. In addition, the City of Conroe could develop a municipal access ordinance, as many other cities have done, to help TxDOT manage access along SH 105 as part of new development and redevelopment. State statutes allow a city to apply such an ordinance in its ETJ as part of its subdivision regulations.
- **Lack of vehicular connections between sites.** Many cities require inter-connectivity between developments through zoning or related development policies or ordinances. Along SH 105 inter-connectivity between businesses and developed parcels could be accomplished through requirements for cross-access easements in platting or through a policy in a municipal (Conroe) access ordinance.
- **Continuous two-way left turn lanes.** The benefits of increased capacity and reduced delay offered by TWLTL's, are negated by reduced safety and increased collisions when traffic volumes begin to approach about 20,000 vpd. The traffic volumes on SH 105 have now increased to a point such that the TWLTLs may no longer be safe, especially considering the 60 mph speed limits. Research indicates that TWLTLs on multi-lane arterials are not appropriate when traffic volumes exceed 24,000 vpd. Such facilities, particularly those with high crash rates, should include non-traversable medians to limit or remove left turns to improve safety. In addition, SH 105's

TWLTLs have accommodated strip development and fostered excessive access points and the lack of internal connections between developments.

- **Lack of a supporting local street network, neighborhood connectivity, and unnecessary minor street connections.** A supporting local street network is needed to keep local short trips off major highways to help preserve functionality. The development of a detailed transportation plan identifying connections between residential collector streets and collector or arterial roadways that should take access to SH 105 could help achieve this objective. City and county planners and engineers can work with developers in the platting process to make connections between local streets and preclude minor street access to SH 105.
- **Signal location, spacing, and operations.** There are currently 12 signal installations within the SH 105 study corridor. The disruption to traffic flow due to too many and poorly or closely spacing traffic signals causes a significant loss to capacity, progression, and highway functionality. Signals on regional arterial highways should be located from 1 mile to several miles apart. Adherence to signalization standards should be considered in local street planning, access permitting, and median design.

As noted in [Chapter 2](#), the HGAC in coordination with the TxDOT's Houston District has selected the section of SH 105 between Conroe and Montgomery as its 2009 location to study and develop a comprehensive corridor access management plan. The study is an opportunity for the affected business and property owners, community leaders, the general public, and all stakeholders to partner with TxDOT and HGAC to identify both short-term and long-range measures to improve traffic safety, traffic flow, and corridor aesthetics. Much to the benefit of the local area, there is follow-up by the Houston District with construction projects to implement study recommendations.

HGAC's and the Houston District's selection of SH 105 for a corridor management plan represents an opportunity to (1) make major safety, operational, and aesthetic enhancements to the corridor and (2) potentially receive funds to make to make major transportation improvements to the corridor that would otherwise not be available.

The planned widening of the section of SH 105 from about Old River Road to Walden Road from four lanes to six lanes is an opportunity to improve the safety, functionality, and aesthetics of this section of SH 105 through measures such as access consolidation, raised non-traversable medians, or other measures. The conversion of TWLTLs to raised medians due to increased traffic levels and accident rates is becoming increasingly common in TxDOT districts across the state. Tyler's Loop 323, shown in [Figure 50](#), is an example of high speed, multi-lane arterial where the TWLTL was replaced with a raised median.



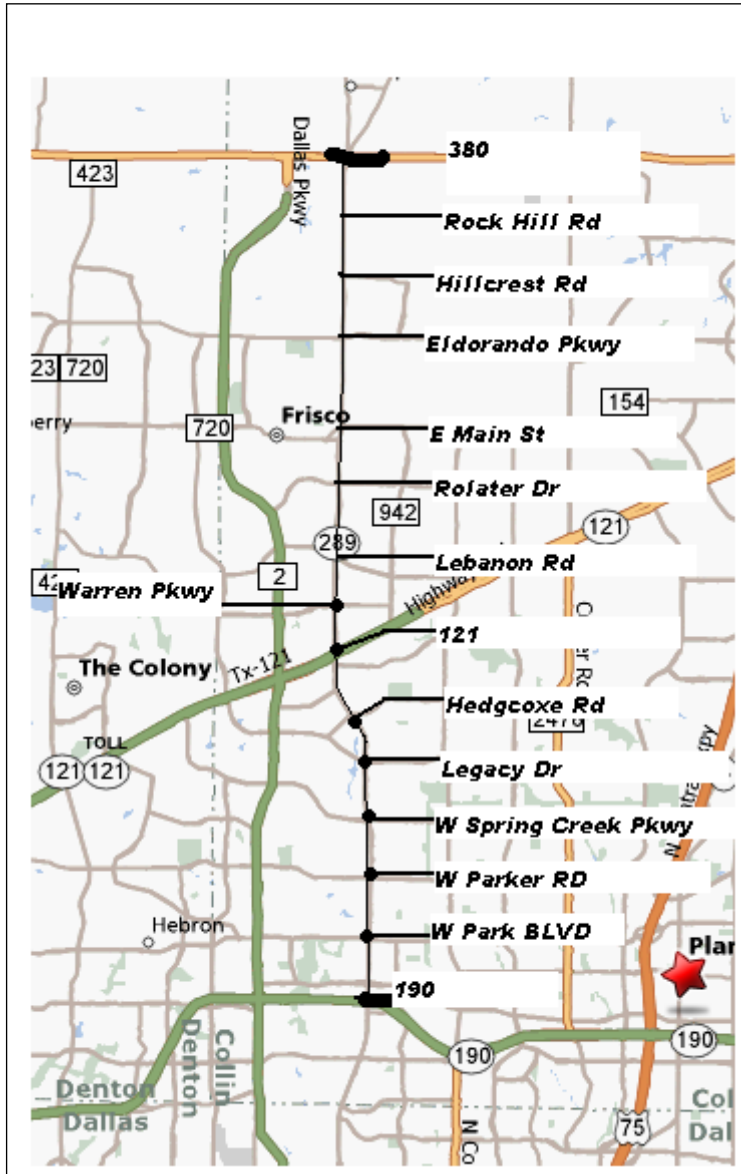
**Figure 50. Loop 323 in Tyler: Example of High Speed, Multi-lane Arterial with Raised Median.**

SH 105's evolution over the past few decades, is not unlike many other state highway corridors located in unincorporated areas where there is rapid growth, a lack of planning, a lack of proper county authority to regulate site development and access, and a politically influenced, business friendly development climate. Across the state, the combination of these conditions is a major contributor to the deterioration on highway functionality. In response to this, now more than ever TxDOT is partnering with local jurisdictions in the development review process for access management and right-of-way preservation purposes. In addition, some districts are now installing medians as part of facility upgrades ahead of development.

## **SH 289 – PRESTON ROAD CASE STUDY**

### **Corridor Location and History**

This is a case study of SH 289, known locally as Preston Road, from SH 190 (President George Bush Turnpike) in Plano on the south to US 380 in Frisco on the north. The southern portion of approximately 6.0 miles lies within the Plano city limits, while the northern portion of approximately 8.4 miles is within the Frisco city limits. These two cities share a border at SH 121.



**Figure 51. Map of SH 289 (Preston Road) Corridor.**

Preston Road is a historic corridor, following the same path as the Preston Trail, which was used for cattle drives beginning in the late 1800s. As the area evolved into metropolitan cities, Preston Road was built in segments northward from Dallas. Today, Preston Road extends from Central Dallas to beyond US 380. It is one of the longest continuous streets in the metropolitan area. Preston Road has been in existence for many decades; a history of improvements, provided by TxDOT, shows that in 1948 the two existing 9-ft lanes between FM 3537 and US 380 were widened to 11-ft lanes.

The Plano portion of Preston Road is on relatively level terrain, with very little relief throughout the corridor. In general, vertical relief causes little to no issues with sight distance or uphill acceleration. The southern half of the Frisco portion of Preston Road is also on relatively level terrain, while the northern half lies on rolling terrain. There are

some portions of the northern-most part of Preston Road where sight distance and uphill acceleration may possibly be issues as that land develops with access points.

### Facility Development

Preston Road has been widened in segments through Plano and Frisco beginning in the 1980's. The first lane expansion on the case study segment occurred in 1986 when the two lanes between SH 190 and Legacy Drive were replaced with six lanes and raised medians. Similar expansions were constructed in 1991 between Legacy Drive and SH 121 and in 1997 between SH 121 and FM 3537 in Frisco. A final reconstruction to a six-lane cross-section, with raised medians, is scheduled to be let in late 2009. According to TxDOT, a 30-year service life is expected for these road segments, indicating that the southern-most segment (between SH 190 and Legacy Drive) would meet its expected service life in 2016.

### Traffic Volumes

Traffic volumes on Preston Road, shown in [Table 17](#), have steadily increased as development has continued north along the corridor.

**Table 17 . Historic Traffic Volumes on SH 289.**

Year	SH 190 – Spring Creek	Spring Creek – Hedgecoxe	Hedgecoxe – SH 121	SH 121 – Lebanon	Lebanon – Main	Main – Hillcrest	Hillcrest – US 380
1960	1,680	1,940	1,940	1,670	1,880	1,880	1,570
1965	2,200	2,090	2,040	1,970	2,330	2,330	2,330
1970	3,890	3,990	3,620	3,260	3,320	3,320	2,400
1975	9,350	5,520	4,560	4,560	4,610	3,340	3,020
1980	12,300	9,000	5,100	5,100	5,200	4,300	3,300
1985	18,500	14,000	9,300	9,300	8,700	7,200	5,700
1990	30,000	25,000	10,300	10,300	12,400	7,800	5,700
1995	44,000	41,000	16,000	16,900	14,900	10,500	6,900
2000	53,000	40,000	35,000	30,000	16,400	14,800	10,400

Source: Texas Department of Transportation.

### Land Development

Retail commercial development dominates the abutting land in Plano and in the southern portion of the Frisco part of the case study area. [Figure 52](#) shows mid-rise office buildings that exist at the southern end of the case study around the Park Road and Plano Parkway intersections. There are a few multi-family residential complexes directly adjacent in Plano. In the northern-most part of the Plano segments, there are some plots dedicated to agricultural uses. [Figure 53](#) shows corporations that have developed campus-style office complexes along Preston Road near Legacy Drive in Plano.



**Figure 52. Sidewalk Feature and Mid-rise Office Land Use near Park Road.**



**Figure 53. Agricultural and Office Campus Land Uses near Legacy Drive.**

Figure 54 shows commercial land uses along Preston Road between SH 121 and Main Street in Frisco. The land uses north of Main Street, shown in Figure 55, are primarily agricultural and related activities.



**Figure 54. Commercial Land Uses in Southern Portion of Frisco.**



**Figure 55. Agricultural Land Uses in Northern Portion of Frisco.**

### **Regulatory Jurisdictions**

The entire SH 289 case study lies within the Frisco and Plano city limits. Each city has control over land use regulations in their respective portions of the road. The City of Plano also has an agreement with TxDOT to process access requests along Preston Road within its city limits. After TxDOT implemented its access management program in 2004, it began to establish agreements with cities that requested the authority to issue access permits along state-maintained highways within their city limits. These agreements are based on the requesting city having an access management program or policy with access spacing guidance equal to or more restrictive than TxDOT's.

The City of Plano requested this authority because of the inefficiencies involved in the previous multi-jurisdictional permit review process. City of Plano staff reported that the process has greatly improved since the access review authority was transferred.

The Cities of Plano and Frisco each have a zoning overlay district pertaining to SH 289. These overlay districts contain several elements that affect mobility, safety, and aesthetics along the corridor.

### **SH 289 Zoning Overlay District in Plano**

The Preston Road Overlay District includes all properties within 300 ft of the existing centerline of Preston Road and all properties within 300 ft of the centerlines of intersecting major thoroughfares, except SH 190 and 121. The district extends along those major thoroughfares to the centerlines of Ohio Drive, Ventura Drive, Bay Water Drive, and Silver Creek Drive. In other cases, the district extends 1,000 ft east and west along lesser thoroughfares, as measured from the centerline of Preston Road.

Two sections in this zoning overlay district provide requirements regarding roadway aesthetics—“Landscape Edge” and “Electric Utility Lines.”

### *Landscape Edge*

Several aspects of these requirements pertain directly to right of way and roadway functionality, including driveway openings and current and future roadway improvements. As part of the zoning overlay district, a minimum 30-ft wide landscape edge must be provided along the roadway. However, the 30-ft requirement is not intended to prohibit the placement of driveway openings as specified in the City of Plano's thoroughfare standards, rules and regulations.

The landscape edge may be reduced by as much as 15 ft if the combined width of the unpaved right of way and the landscape edge is at least 40 ft. This condition is to accommodate variations in unpaved rights-of-way along the roadways due to grade-separated interchanges, turning lanes, transit stops, drainage improvements, underground utilities, or related facilities. The 40-ft distance is measured from the back of the permanent curb of the roadway, including those existing or planned acceleration and deceleration lanes, loop roads, and ramps at grade-separated interchanges.

### *Electrical Utility Lines*

The overlay district also addresses the placement of electrical utility lines. For new development or redevelopment, the ordinance requires electrical and communications utility lines to be installed underground.

## **SH 289 Zoning Overlay District in Frisco**

The City of Frisco's zoning overlay district contains more requirements than the Plano overlay district relative to preserving roadway functionality. The Preston Road Overlay District in Frisco includes all property within 750 ft of the centerline of SH 289 through the city. The overlay subdivides the roadway into five separate districts with variations in requirements to better reflect the intensity of land use in each district. The five sub-districts of the roadway are:

- US 380 Gateway;
- Rural Corridor;
- Main Street;
- Retail Corridor; and
- SH 121 Gateway.

The following sections are organized by roadway characteristic and include discussions for each of the sub-districts.

### *Setbacks*

In the US 380 Gateway and Rural Corridor sub-districts, the minimum front setback is 50 ft and includes a 50-ft landscape easement. The SH 121 Gateway sub-district requires a minimum front yard of 50 ft with a 30-ft landscape easement.



Slip roads are required adjacent to Preston Road with buildings placed accordingly in the Main Street and Retail Corridor sub-districts. The slip roads are akin to an on-site frontage road or driving aisle that parallels Preston Road. If development constraints prevent the use of slip roads in the Retail Corridor sub-district, the minimum front yard is 50 ft and with a 30-ft landscape easement. The Main Street sub-district requires a minimum front setback of 30 ft and with a 30-ft landscape easement if a slip road is not feasible. Parking or drive aisles are not permitted in the landscape easements of any sub-district.

Another setback option is possible in the Retail Corridor and SH 121 Gateway sub-districts. The minimum front yard may be reduced to 30 ft, but the building must be constructed on the 30-ft building line and no parking or drive aisles are allowed between the building and adjacent street.

In the Retail Corridor, Main Street, and SH 121 Gateway sub-districts, buildings containing a non-residential use may be located 5 ft from the street right of way on non-major thoroughfare roads intersecting Preston Road. Seventy five percent of the building must be constructed on the 5-ft building line, with the additional 25 percent setback a maximum of 10 ft.

#### *Sidewalks*

In the US 380 Gateway, Retail Corridor, Rural Corridor, and SH 121 Gateway sub-districts, meandering sidewalks with a width of 4 ft are required to be constructed in accordance with city standards along the right of way along the entire length of the street frontage. Where the sidewalk is constructed on private property, a sidewalk easement shall be dedicated for sidewalk and maintenance activities.

In the Main Street sub-district, sidewalks with a width of 6 ft are required to be constructed in accordance with city standards within the right of way along the entire length of the street frontage.

#### *Conditional Development Standards*

Several land uses within Frisco's overlay district on SH 289 are permitted subject to compliance with conditional development standards. The land uses include service stations, landscape, and parking requirements.

Service stations and convenience stores with gas pumps are the only type of business with specific conditions in Frisco's overlay district. These businesses are only allowed to be constructed at the intersection of major thoroughfares. No mid-block stations are allowed.

#### *Off-Street Parking*

All driveways aligned with a median opening and serving parking fields with over 200 parking spaces must provide a median-divided driveway at the entry. There must also be internal stacking areas with a minimum of 150 ft at entries/exits, with no intersecting driveways except for slip roads. This element recognizes that driveways with higher traffic volumes function differently than those with lower volumes.

In terms of slip roads, the first row of parking on a slip road is located 8 ft from the property line. Slip road parking can be screened from Preston Road with a low row of shrubs. With the exception of the Rural Corridor sub-district, the area between the slip road and the property line may be improved with enhanced paving, rather than landscaping. Finally, slip roads can be interrupted by building placement or other means prior to intersection with a street that intersects with Preston Road. Roadway access is one of the criteria in considering the location and placement of buildings on individual sites.

## Existing Conditions

### *Road Configuration/Cross Section*

The portion of Preston Road in Plano, shown in [Figure 56](#), has a cross-section of three lanes in each direction with raised medians and left-turn lanes in the center of the road. Right-turn and auxiliary lanes are common through Plano at high-volume driveways and street intersections. The only grade separations are at SH 190 (the southern terminus of the case study) and SH 121, which is the Plano-Frisco city limit border. However, right of way has been preserved for possible future grade separations at Plano Parkway, Park Boulevard, and Legacy Drive.



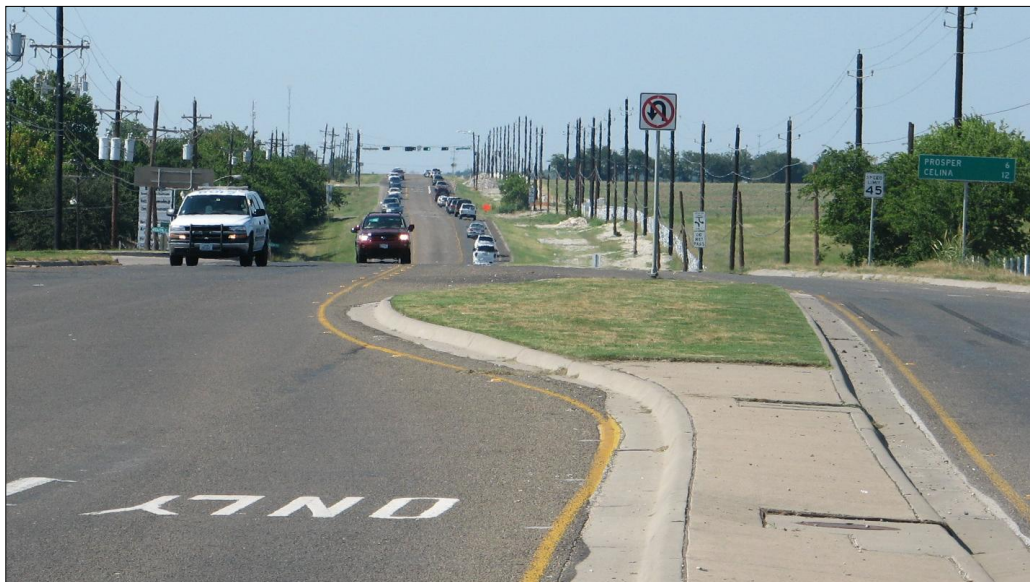
**Figure 56. Typical Cross-Section in Plano.**

Some of the median openings along Preston Road are designed for directional left-turns only. [Figure 57](#) shows one of these locations, often referred to as hooded left-turn design, where left turns out of driveways are not physically possible. This design removes conflict points from the roadway and reduces the numbers of crashes at these types of limited median openings.



**Figure 57. Hooded Left-Turn Design on Preston Road.**

From SH 121 to Main Street in Frisco, Preston Road has three lanes in each direction, with raised medians and left-turn lanes in the center of the road. Right-turn lanes were observed less frequently in the Frisco segments than in Plano. [Figure 58](#) shows Preston Road immediately north of Main Street where the cross-section narrows to one lane in each direction, with a center TWLTL for part of the distance and no TWLTL for the northernmost part.



**Figure 58. Cross-Section Transition North of Main Street in Frisco.**

### *Parallel Network Facilities*

West of Preston Road in Plano, the Dallas North Tollway runs parallel to Preston and one to two miles to the west (approximately 2 miles at the southern end of the corridor and approximately 1 mile at the northern edge of Plano). The tollway has been extended incrementally north from IH-635 starting in the 1980s and recently reaching US 380. This controlled-access facility handles commuter traffic between the Plano-Frisco area and downtown Dallas, including points and highway interchanges in between. North-south streets provide intermittent interconnectivity through and among single-family residential neighborhoods between Preston Road and the Dallas North Tollway. There is no north-south street between these two facilities that connects the southern and northern termini of the case study corridor.

Coit Road is a north-south arterial street that lies approximately two miles east of Preston Road. Coit Road connects SH 190 and McDermott Road, just south of SH 121. There is a similar pattern of streets connecting residential and other land uses between Preston Road and Coit Road as there is between Preston Road and the Dallas North Tollway.

### *Traffic Volumes*

As development activity occurred in the 1980s through the 2000s, traffic volumes increased accordingly. Plano experienced significant growth in the 1980s and 1990s resulting in commercial and office development along Preston Road.

The peak traffic volume recorded by TxDOT on Preston Road within the limits of case study was 53,000 in 2000, between SH 190 and Spring Creek Parkway in Plano. Volumes along that segment decreased until 2003 when it reached a volume of 46,000. Between 2003 and 2006, volumes on that segment fluctuated between 46,000 and 48,000. As one would likely assume, volumes along each segment going north decrease as there is less development adjacent to and near Preston Road.

In 2006, volumes for the segments between SH 190 in Plano and Main Street in Frisco were in the mid-40,000 range. Volumes between Main Street and Hillcrest Road were 29,000 and were 18,000 between Hillcrest Road and US 380.

### **Access**

Access is an issue that has one of the greatest impacts on roadway functionality, in terms of mobility. The number of access points, depending on the volumes at each one, affects traffic flow on the road. If right-turn lanes are present, the impacts are less than if right-turn lanes are not present. The right-turn lanes allow turning vehicles to exit the through-lanes as they decelerate and make the right-turn. Removing these vehicles from the through-lanes decreases the amount of deceleration of through-traffic. Therefore, there are a few issues that affect the impact of access point density on the traffic flow.

### *Driveway Density*

[Table 18](#) provides the density of access points, including streets and driveways, for the study section of Preston Road broken down by eleven segments. The overall access

density, including driveways and all public streets, for the 14.4-mile study section of the corridor is 19.2 access points per mile. The research team analyzed segments by land use type, between and not including roads at major intersections. This analysis found that the access density ranges from a low of 9.3 where there are campus-style office parks and vacant land (a 1.4-mile segment) to a high of 35.0 on a segment dominated by retail development (a 0.8-mile segment). This corridor has a relatively low overall access density, as well as in the segments that are dominated by retail land uses. The vast majority of the access points are private driveways (217), while there are only 47 public street intersections. [Table 18](#) shows the individual segments, total access points, numbers of driveways and street intersections, as well as access, driveway, and street intersection densities.

**Table 18. Preston Road Access Densities by Segment.**

Segment	Total Access Points	Driveways	Streets	Segment Length (miles)	Total Access Density	Driveway Density	Street Density
US 380 to Main St.	48	35	13	4.5	10.7	7.8	2.9
Main St. to Rolater Dr.	24	19	5	1.0	24.0	19.0	5.0
Rolater Dr. to Lebanon Rd.	38	36	2	1.3	30.4	28.8	1.6
Lebanon Rd. to Warren Pkwy.	28	24	4	0.8	35.0	30.0	5.0
Warren Pkwy to SH 121	16	15	1	0.8	20.0	18.8	1.3
SH 121 to Headquarters Dr.	7	5	2	0.6	11.7	8.3	3.3
Headquarters Dr. to Legacy Dr.	13	9	4	1.4	9.3	6.4	2.9
Legacy Dr. to Spring Creek Pkwy.	19	16	3	1.0	19.0	16.0	3.0
Spring Creek Pkwy to Parker Rd.	21	16	5	1.0	21.0	16.0	5.0
Parker Rd. to Park Blvd.	16	13	3	1.0	16.0	13.0	3.0
Park Blvd. to SH 190	34	29	5	1.0	34.0	29.0	5.0
TOTALS*	264	217	47	14.4	18.4	15.1	3.3

Notes: \* Represents the number of streets between the 12 major intersections

[Table 19](#) shows that the access densities in the Plano and Frisco portions of the corridor are very similar. The greatest concentrations of retail development have the highest access density in each city. It is worth noting that the northern half of the Frisco portion is agricultural or vacant. As that land develops, it is very likely that the access density will increase in Frisco.

**Table 19. Preston Road Access Densities by City.**

City	Total Access	Driveways	Streets	Length (miles)	Access Density	Driveway Density	Street Density
Frisco	154	129	25	8.35	18.4	15.4	3.0
Plano	110	88	22	6.0	18.3	14.7	3.7

### *Access Types*

Access points vary from full movements (left and right-turns in and out of driveways) to partial movements (right-in/right-out only and left-in only) along the corridor. All public street intersections have full median openings except those within the SH 12 interchange on and off-ramps. Most driveways, including major, high-volume driveways do not have full median openings.

### *Driveways per Site and Access Sharing*

Most of the retail development throughout the corridor are large-scale, multi-tenant buildings with out-parcels. These developments typically have two to three access points shared by all buildings. There are a few instances in which single businesses are located on individual lots, having one or two of their own driveways. These situations are rare along the overall corridor and are more common in Frisco. Office building and campuses typically have no more than one driveway directly onto Preston Road and none in some cases.

The City of Plano currently has no cross-access requirements, but staff stated that they do commonly ask developers and businesses to provide it.

### *Connectivity between Development (Cross Access)*

The larger developments along Preston Road commonly have very good internal circulation and cross access among businesses. This feature allows vehicles to move among parking areas for specific building without having to re-enter and exit the road. With fewer vehicles entering and exiting the road, functionality, in terms of mobility, is improved. Safety can also be improved with fewer opportunities for crashes between entering/exiting and through-traffic. There are some examples where adjacent individually developed businesses have provided cross-access. However, there remains the ubiquitous challenge of getting adjacent businesses on individual lots to share access points and provide cross access between them.

## **Signalized Intersections**

At signalized intersections with arterial streets, Preston Road typically has dual left-turn lanes and channelized right-turn lanes. At signalized intersections with roads of lower hierarchy, single left-turn lanes are more common and there are not typically channelized right-turn lanes.

The City of Plano continually strives to time the traffic signals along Preston Road to provide coordination through the corridor between SH 190 and SH 121. City staff stated that there have been discussions with the City of Dallas (adjacent to Plano on the south) and the City of Frisco to coordinate traffic signals along Preston Road through all three cities, but there have been too many obstacles to date to make it happen.

The City of Frisco also works to provide coordination of traffic signals along Preston Road between SH 121 and Main Street. There is only one traffic signal between Main Street and US 380, located at Eldorado Parkway.

## **Congestion Points**

The signalized intersections at the southern end of the corridor experience the greatest levels of congestion, typically at peak morning and evening commute periods. Researchers also observed congestion during the peak commute period at some intersections in the northern part of Frisco, where Preston Road is two lanes wide.

City of Plano staff stated that congestion occurs occasionally on Preston Road in Frisco, and sometimes into Plano, due to events and stadiums or a large specialty retail store. In some cases police officers are used at signalized intersections in Frisco to provide specific traffic control at those locations. During some of those events, the City of Plano sends technicians to signalized intersections to manually control them according to specific situations as they vary through the events.

## **Grade Separation and Median Left-Turn Proposals**

In the 1990s, the City of Plano developed a plan to have grade separations at 10 arterial street to arterial street intersections. This concept was a plan to efficiently handle traffic at what were anticipated to be the highest volume intersections in the city. By 2004, the City, working through the metropolitan planning organization, secured funding for all 10 grade separations. Prior to letting the projects, the City conducting public participation activities due to the time that had passed since the previous public involvement. As a result of the public participation, the City decided to not follow through with the plan. This decision was based largely on citizens not wanting the overpasses near residential areas. The right of way for the grade separations still exists and the at-grade intersections have been built to accommodate the grade separations.

The latest plan for these intersections is to install what the City of Plano refers to as “median left-turns.” At these intersections, traffic on the street that would have been at the ground level of the grade separation will not be permitted to make a traditional left-turn at the intersection with the other street. Instead, traffic that desires to turn left will make a right-turn (heading in the direction of arrow 1 in [Figure 59](#)), proceed down the intersecting street, then make a U-turn through the median (heading in the direction of arrow 2 in [Figure 59](#)), then proceed in the desired direction (heading in the direction of arrow 3 in [Figure 59](#)). This alternative left-turn concept originated in Michigan and is commonly used in that state where median widths allow.



**Figure 59. Proposed “Median Left-Turn” Concept.**

**Transit**

Dallas Area Rapid Transit (DART) provides scheduled bus service along Preston Road in Plano. According to City of Plano staff, buses stop in the far right travel lanes, as there are no pull-outs at bus stop locations. Staff added that there are few interruptions to traffic because ridership along Preston Road is relatively low. There is no public transportation in Frisco; therefore, there are no concerns relative to buses and bus stops.

**Coordination in Development Review**

The preliminary plat stage of development review is crucial in Plano. City staff reviews and provides the applicant with details of what they will need to dedicate in



terms of right of way for necessary improvements. The City requires developers to provide right of way for any turn lanes, sidewalks, etc.

The Cities of Plano and Frisco communicate with TxDOT during the review process. Both cities have been granted access permit review authority by TxDOT along this state-maintained route. When large developments have occurred, such as a regional mall and very large furniture store, the Cities of Plano and Frisco have worked with each other to address impacts on Preston Road in both cities.

### **Pavement Conditions**

Field observations identified a road that is in very good to excellent condition with regard to pavement. No major structure failures were found.

TxDOT staff indicated that there is a life-cycle expectancy of approximately 30 years for thoroughfares such as Preston Road. Given that scenario and based upon the dates of the lane expansions, there are four segments of Preston Road through Plano and Frisco with individual life-cycle stages. Those four segments are as follows:

- SH 190 to Legacy Road – 23 years into life-cycle (completed in 1986);
- Legacy Road to SH 121 – 18 years into life-cycle (completed in 1991);
- SH 121 to FM 3357 – 12 years into life-cycle (completed in 1997); and
- FM 3357 to US 380 – will begin a new life-cycle once the lane expansion (planned to be let in 2009) is completed.

### **Lessons Learned**

There are several examples, discussed below, that have had positive effects on the functionality of Preston Road.

#### *Right-of-Way Preservation*

The efforts to obtain appropriate amounts of right of way for six lanes and raised medians as Preston Road was widened through Plano have proven very effective. In general, right of way was obtained as the road was expanded from two to six lanes throughout the corridor. In addition, the right of way obtained and preserved at intersections where grade separations had been previously proposed and will now have —median left-turns” will be very useful as these features are installed.

#### *Corridor Plans and Zoning Overlay Ordinances*

The Cities of Plano and Frisco each conducted corridor studies for the section of Preston Road within their cities. The studies included both land use and transportation components and established the vision for how the cities desired Preston Road to look, develop and function in the future.

The zoning overlay districts serve as the key mechanism by which Plano and Frisco are implementing their adopted strategic plans for the roadway. In addition to land use/density controls, the overlay zones include numerous tools that help to preserve or

enhance functionality of the roadway such as the use slip roads, medians in driveways, and enhanced driveway throat lengths. The enhanced building and parking setbacks also helped by improving sight distance and creating longer driveway throat lengths to sites. The setbacks in combination with the enhanced landscape requirements help to corridor aesthetics.

### *Raised Medians*

To help improve its function (and perhaps visual appeal), the corridor studies conducted by the Cities of Plano and Frisco plans called for the use of raised non-traversable medians in Preston Road.

Raised medians and associated turn lanes provide specific points at which vehicles may turn left. The raised medians prevent the problems that frequently occur when two-way-left-turn lanes are used on high-volume, six-lane thoroughfares, such as Preston Road. Hooded left-turn bays provide opportunities for left-turns into driveways only, thus preventing left-turns out and reducing the opportunities for related side-impact crashes.

### *Access Regulation*

Preston Road serves as an example of where there has been proactive enforcement of TxDOT's access guidelines as well as enforcement of a local access ordinance that is at least as restrictive as TxDOT's guidelines. Good access control practices in combination with good TxDOT-local coordination on access to site development has helped to preserve or enhance Preston Road's function as a major arterial in this area.

### *Right-Turn Lanes*

Right-turn lanes allow turning vehicles to move out of the through-lanes, reducing rear-end crashes related to speed differentials between turning vehicles and through-traffic. City staff stated that rear-end crashes are much less common at driveways where right-turn lanes are present.

### *Signal Coordination*

The Cities of Plano and Frisco each continue to monitor and adjust signal coordination as appropriate. Signal coordination has been successful in maintaining traffic flow (mobility functionality) along Preston Road.

### *Supporting Street Network*

The presence of parallel roads in Plano provides opportunities for traffic to stay off Preston Road for long trips (such as when using the Dallas North Tollway for commuting) and for shorter trips (such as when using the shorter collector and minor arterial streets that connect adjacent residential and commercial developments).

### *What Could Be Improved?*

Increased raised median widths that would consistently provide enough space for a vehicle turning left out of a driveway to wait in the center of the road until traffic approaching from the right is clear.

The median left-turns that will be installed in the rights of way of the previous planned grade separations should benefit functionality. The goal is to simplify the traffic signal phasing at these intersections by preventing left-turns from one of the streets. This technique has proven effective when used in other locations, such as Michigan, where the idea was originally conceived and implemented.

### **Opportunities for Future Preservation/Improvement**

#### *Additional Right-Turn Lanes*

Preston Road has been built to a cross-section of six lanes with a raised median. It is very unlikely that additional through-lanes would be added. The most likely potential opportunities for improvement related to cross-section would be installing right-turn lanes at higher-volume driveways where rear-end crashes occur more frequently.

#### *Signal Coordination among Adjacent Cities*

As opportunities arise and technology improves, the three cities (Dallas, Plano, and Frisco) along and adjacent to this case study segment should continue to pursue signal coordination for as great a distance along Preston Road as possible.




## 8. SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

Highway functionality determines how well highway facilities serve Texas and its many highway corridors. With Texas' population and economy spreading everywhere across the state, our state highways are the lifeblood of Texas. Achieving a high level of functionality across the Texas highway system is important to the state's residents and businesses for many reasons:

- Mobility and accessibility are major factors in making Texas economically competitive and successful as well as delivering a desirable quality of life;
- Highway safety is greater when highways function efficiently, and safety is important to the health and welfare of all Texans;
- Efficiently functioning state highways make for cost-effective use of investments made with Texas tax dollars;
- Preserving efficient operations and good physical condition of state highways protects the value of existing state highway assets;
- Preserving highway functionality and condition helps to avoid the need for undue or premature major highway improvements or replacements, which is especially important with highway funding already short of current needs.

Functionality is not a constant. It consistently evolves as many factors affecting highway functionality change over time. [Table 17](#) lists some of the changes that occur in this functionality cycle, along with indicators that can quantify or otherwise show changes as they occur.

**Table 20. Functionality Cycle – Stages and Indicators.**



Normal Cycle	Functionality Indicator	Infrastructure Deterioration Indicators
New/improved facility	High level-of-service; no problems	None
Increased accessibility	More driveways	Driveway density
More development	Changes in land use	Driveway density or developed frontage on right of way
More traffic, safety concerns	More signals, driveways, turn conflicts, crash potential	Increasing maintenance
More development		
Congestion, crash increase	More signals, driveways, turn conflicts, crash potential	Increasing challenges to maintain traffic flow during maintenance if not planned
Continuing development		
Need for improvement	Operational and/or safety breakdown	Higher level of improvement needed
(Eventual right-of-way limitations)	Conflicts between utilities in right of way	Utility relocations
Need for additional facility	Potential to improvement functionality of existing facility	Can no longer improve functionality of existing facility to meet demands

Under the best circumstances, a highway will remain functional through its intended service life. However, to maintain a high level of functionality, factors that cause deterioration (e.g., increased access, more high volume at-grade intersections, frequent overweight trucks) need to be minimized, managed, or accommodated with incremental improvements. Unless there is an active process of monitoring functionality followed by actions to restore or enhance deteriorating components, operational functionality can deteriorate to the point where a parallel or replacement facility (or reconstruction) will be needed much earlier than would otherwise be the case. That outcome can be wasteful and unnecessarily costly.

The primary components and practices of the highway system that contribute to and affect functionality include:

- Planning and Land Development,
- Operations and Capacity,
- Right of Way,
- Infrastructure and Maintenance, and
- Safety.

While the operations/capacity and the planning components are the most apparent areas that impact highway functionality, right-of-way availability, infrastructure conditions, and safety also play a role. That being said, each of the five areas plays a part in establishing how well or poorly a highway may function and in meeting or preserving its intended function.

The purpose of this project was to examine what losses to state highway functionality occur over time and what actions can be taken to preserve, recover, and enhance functionality over time. The key characteristic of functionality addressed was operational capacity and efficiency. However, the research team also examined other functional characteristics associated with planning, right of way (including boundary conditions like access), infrastructure conditions, and safety, both from existing information and through case studies of selected Texas highways. The research used cause and effect relationships between various policies, actions, and practices and the resulting functionality over the life cycle of highways.

This project included three cases studies through which the research team investigated in detail the functionality and associated practices, policies, and programs of three highway sections. These highway sections were selected from a large pool of candidates of large, medium, and small sizes. The three Texas highways selected for detailed case studies include:

- **IH 10, Katy Freeway in Houston.** Of all case study freeways, this section of IH 10 provided a myriad of examples and lessons learned of practices and measures (in all areas—ROW, operations, design, TSM, etc.) that have or are being used that contribute to its high degree of functionality. With its latest expansion and use of managed lanes, it is considered one of the nation's premier super freeways.

- **SH 289 in Frisco and Plano from SH 190 to US 380.** For the medium size category, SH 289 was selected because it involves integrated transportation and land use planning using locally adopted corridor plans being implemented through zoning overlay districts.
- **SH 105 from Loop 336 in Conroe to FM 149 in Montgomery, Texas.** For the small category, SH 105 was studied because it represents the challenges of access control and functional deterioration in rapidly growing unincorporated areas (e.g., counties) without planning and land use controls.

Focusing on one or more functionality areas, the case studies assessed the effectiveness of various practices and measures to preserve, restore, and/or enhance Texas highway functional preservation and addressed the following key areas:

- processes, measures, programs, and practices used;
- evolving conditions encountered that led to facility functional deterioration;
- extent and causes of deterioration over a time period;
- actions taken to preserve, restore, and enhance facility functionality;
- results achieved through actions; and
- lessons learned.

The products of this comprehensive research include this research report and a guidebook of recommended practices. This report is intended to help to preserve functionality or recapture or enhance functionality after partial deterioration of functionality. The following sections summarize the research findings relating to practices, programs, and policies that affect highway functionality in Texas.

## **PLANNING AND LAND DEVELOPMENT**

The planning and land development process is very important to highway functionality. It is during this time that TxDOT and its local partners can consider and address functionality at an early stage. Decisions, actions, and practices made during the planning process arguably have the greatest impact and influence on highway functionality of all other areas.

### **MPO and Statewide Efforts**

Preparation of STP is required by state legislation and federal law. TxDOT's STP serves as the framework for long-term planning and preservation of the Texas' transportation system. The statewide plan is not a plan per se but rather a coordinated collection of approved MTPs from the 25 MPOs around the state combined with the statewide rural transportation and multimodal plans. In addition to projects, the statewide plan can also include system-wide transportation goals, policies, or special initiatives to address highway functionality.

MPOs have many intrinsic roles and activities that address or benefit highway functionality such as serving as a coordinating body for transportation plans and projects across many jurisdictions and agencies. The primary functions of MPOs include carrying out the agency's UPWP, preparing and maintaining a long-range MTP, and developing a

TIP based on the MTP. Each of these important MPO activities either address or consider highway functionality as part of their process or development. Based on the comprehensive review of practices and in-depth case studies, a number of actions are recommended as part of MPO and statewide planning efforts for addressing highway functionality.

- **TxDOT Statewide Transportation Plan.** The STP coordinates MTPs of all MPOs and could establish statewide goals and policies on transportation planning and functionality. The following actions relating to the STP are recommended to address highway functionality statewide:
  - develop statewide transportation plan map and functional categories for state roadways;
  - develop statewide goals, policies, and initiatives to support functionality;
  - develop district plan maps illustrating existing and planned highways by functional category; and
  - establish policies for adherence to functional criteria.
- **MTPs and Regional Transportation Planning.** MTPs consider and coordinate the functionality and connectivity of all local transportation plans within the MPOs study area. They should coordinate functionality of state roads on local plans with MPO plans. MTP-related recommendations that lead to improved highway functionality include:
  - develop MTP maps illustrating existing and future thoroughfares by functional category;
  - include goals and policies related to adherence to functional criteria, access management, corridor management and preservation, and other initiatives that enhance or preserve functionality; and
  - develop a corridor preservation strategy that involves working with cities, counties, MPOs, RMAs, and other transportation authorities or stakeholders as appropriate to preserve or protect future transportation corridors prior to environmental clearance. Such corridors should be identified and prioritized through the MPO process.
- **Unified Planning Work Programs.** UPWPs can serve as a mechanism to ensure that functionality is included and addressed in MPO planning and projects. MPOs should:
  - establish work and project priorities or strategies in UPWPs that enhance functionality such as access management, context sensitive design, transit oriented development, smart growth, travel demand management, and arterial/corridor management, corridor preservation, and others.
- **MPO practices.** To improve the functionality of a highway network, MPOs should serve as a coordinating body that considers the functionality of the roadway network at a regional level. The following actions need to be considered:
  - facilitate interagency coordination;



- provide education and outreach to policy boards, public, and general stakeholders on importance and benefits of highway functionality in planning and project prioritization; and
- assist TxDOT in finding funding sources such as Congestion Mitigation and Air Quality monies to fund studies on TSM, TDM, or ITS strategies as well as for implementing recommended improvements.
- **Transportation Improvement Plan.** Statewide TIPs identify transportation projects to be undertaken for next 4 years in the state and can play a noteworthy role in highway functionality improvement. The researchers recommend TIPs to:
  - include benefits to functionality enhancement or preservation as a factor in project selection.
- **Congestion management process.** The congestion management process at MPOs in TMAs improves functionality by identifying and addressing congestion locations and facilitating partnerships between stakeholders to continue benefiting from and to improve the process, MPOs should:
  - develop travel demand reduction strategies and operational management strategies as part of regional planning process;
  - provide information to decision-makers on system performance and effectiveness of implemented TDM, TSM, and ITS strategies in coordination with TxDOT and other transportation authorities; and
  - implement safety and congestion mitigation strategies using corridor/access management studies.
- **Travel demand modeling.** Travel demand modeling is an important activity for estimating future roadway capacity needs in order to plan the proper functional class of roadways. TxDOT representatives on MPO technical and policy boards, particularly in non-metropolitan areas of the states, should:
  - advocate the use and importance of up-to-date travel demand models in long range transportation planning, alternatives analyses, and TDM strategies; and
  - advocate the importance of developing and training MPO technical staff on maintaining and utilizing TxDOT supported models.

### **TxDOT and Local Practices and Recommendations**

Current TxDOT practices and policies that have the most impact on urban surface highway functionality include access management, facility design, coordination and involvement in local planning and development, and traffic and travel demand management on urban freeway corridors.

Policies, practices and actions at the local level in the areas of planning and land development have a major bearing on the functionality of TxDOT roadways. Cities have authority to adopt comprehensive plans and subdivision regulations governing land use and development and the layout of local roads. Texas counties have limited powers regarding land use and development, but have subdivision regulations and some transportation planning ability. Local planning, subdivision, and development authorities

and practices have significant impacts on on-system facilities and can play an important role in TxDOT efforts to preserve, restore, and enhance highway functionality.

Recommendations in TxDOT and local planning practices to address highway functionality are provided below by activity.

- **Access management.** Access management is arguably the single most important practice and concept impacting highway functionality. TxDOT access guidelines and most local access ordinances regulate the spacing and design of driveway access by functional class of roadway. To maximize the benefits of access management for functionality, TxDOT should:
  - continue to pursue compliance with its access manual through coordination on site development plans and plats, and in roadway upgrades, rehabilitation projects and new facilities;
  - continue to foster partnerships to use local ordinances or regulations for increased driveway throat length, internal access for outparcels, and connectivity between adjacent developments along state routes;
  - provide outside support to rural or non-urban districts to implement and uphold TxDOT's access management guidelines; and
  - involve senior level local staff in development of preliminary design schematics to consider future land use, development, and access.
- **Local comprehensive planning.** Comprehensive plans impact the direction of growth and infrastructure that can have major impacts to the functionality of state routes. In addition, land use plans can be used to help coordinate land use intensity with roadway function and design. Districts should be involved in development or updates to local comprehensive plans to:
  - promote policies and practices that preserve, restore, or enhance roadway functionality;
  - coordinate land use intensity with roadway design and function;
  - have input on the development of transportation and land use goals, policies, and objectives such as direction of future growth, utility extensions; and
  - promote activity-based instead of strip-type development along corridors.
- **Corridor management planning.** Corridor management is a planning strategy that coordinates transportation, land use, and development components of a corridor using a comprehensive, in lieu of a piecemeal approach. Adopted corridor management plans can be used so that local development decisions can be based on the ultimate design and function of the highway. The following actions are recommended relative to of corridor management planning:
  - initiate and coordinate corridor management planning along TxDOT roadways with MPOs and local jurisdictions;
  - develop corridor management plans on TxDOT roadways that include non-traversable medians, minimum spacing requirements for traffic signals, and connectivity between developments;

- advocate adoption of corridor management plans as part of local comprehensive plans and incorporate related implementation projects into MPO UPWPs; and
  - work with locals on development of zoning overlays to help to implement corridor plans.
- **Local thoroughfare plans and planning.** Access spacing for state roadways can be based on the functional classes of roadways on local thoroughfare plans. They can serve as the basis for utilizing local development regulations and can be of great importance in cooperative, multijurisdictional corridor preservation efforts. Listed below are actions for improving local thoroughfare planning:
    - promote layouts of local street plans that follow the functional hierarchy where minor street connections to major roadways are limited or avoided and subdivisions are connected by local streets;
    - since TxDOT roads are included on local thoroughfare plans (city and county), coordinate on local thoroughfare design and minimum right-of-way standards to ensure they are adequate for TxDOT needs and consider future state widening; and
    - include a representative from TxDOT districts and/or area offices on technical advisory panels utilized in the development or updates to local comprehensive or thoroughfare plans.
  - **TxDOT involvement in local development review.** The number and location of access points are typically determined or established in early conceptual site plans or plats. Therefore, it is important that TxDOT is involved in local development review early and sufficiently. The researchers recommend for TxDOT to:
    - be involved in the earliest stages of development review to provide input during the conceptual or planning stages of developments;
    - routinely review subdivision plats and site plans that impact TxDOT facilities to help implement TxDOT access guidelines and to acquire or protect needed right of way where possible; and
    - review plats adjacent to TxDOT roads to help prevent creation of lots that cannot meet access spacing guidelines.

## **OPERATIONS AND CAPACITY**

TxDOT operates one of the largest highway systems in the country. The functionality of this system relies on the traffic operational performance of roadway segments and intersections. Despite the extensive efforts to improve highway functionality, roadways in many areas experience extended periods of congestion. Much of the congestion is attributable to operations and capacity deficiencies, such as ineffective or inefficient traffic control, underutilization of alternative travel modes, poorly maintained or outdated traffic signals, or facility design that does not meet current operational needs.

The researchers examined policies, programs, and practices in three major areas of operations and capacity that have impact on highway functionality. These three areas include:

- traffic control and management,
- traffic signal optimization and coordination, and
- facility design and enhancement.

The following sections summarize major practices pertaining to these areas and recommended actions to enhance highway functionality.

### **Traffic Control and Management**

Numerous areas pertaining to traffic control and management can cause or contribute to functionality loss. In particular, inadequate practices in areas such as traffic control measures, utilization of alternative modes, operational pricing, incident management, emergency evacuation, and work zone traffic management are among the major sources to functionality deterioration. The functionality loss can be in various forms such as increased congestion, capacity loss, traffic delays, and safety problems.

To address network operational issues, TxDOT has implemented a variety of operational strategies over the years, with a focus on both improving existing practices and implementing research innovations. Examples of countermeasures TxDOT has used to maintain and improve highway functionality in the area of traffic control and management include:

- ITS applications such as Advanced Traffic Management Systems (ATMS) in major urban areas to enhance the traffic and incident management;
- measures to encourage ride sharing and public transit, such as HOV/HOT lanes;
- highway pricing measures including toll roads and HOT lanes;
- measures to facilitate hurricane evacuations, including designating evacuation lanes and routes, and development of operational plans during evaluation;
- motorist assistance programs developed in conjunction with local agencies; and
- policies and regulations pertaining to traffic control and management.

Many good practices have been or can be adopted by TxDOT to increase capacity, improve efficiency and reliability, and mitigate traffic congestion. Based on the research findings, the researchers recommend the following general actions:

- use high-visibility traffic control devices with high retro-reflectivity or improved with high-visibility LEDs;
- utilize ITS applications for real-time system monitoring and fast incident response;
- continue developing public education programs and campaigns to improve public awareness and understanding of traffic control and related safety issues;
- consider unconventional operations or design (e.g., reversible lanes, time-managed ramps), or other innovative techniques that are adaptable to special situations;
- use traffic control strategies that encourage transit or ride sharing such as HOV/HOT lanes; and

- develop research projects to improve the effectiveness of existing traffic control devices, explore more cost-effective control devices, and develop more effective traffic control plans.

## Signal Coordination and Optimization

TxDOT maintains and operates approximately 6,200 traffic signals in Texas and is responsible for authorizing traffic signals to be installed on the state highway system in incorporated cities of 50,000 or more population. Because it involves multiple jurisdictions and agencies, operating and maintaining the signal system in the state requires extensive multijurisdictional and interagency collaboration. Good practices on timing and coordinating this signal network can reduce system-wide traffic delays, increase average running speeds, and improve intersection capacities.

Highway functionality loss due to improper or insufficient traffic signal timing and coordination can come in various forms. Improper signal timing at individual intersections can cause traffic delays and other traffic operational challenges at these intersections. Insufficient signal coordination among densely spaced intersections can increase travel delays and capacity loss throughout the network. In addition, poorly designed or timed signals near entrances or exits of freeway facilities can cause traffic queues on ramps that lead to bottlenecks on the freeway. Their impact frequently extends to roadways well beyond the immediate intersection vicinity, causing operational glitches system-wide.

TxDOT has developed various manuals and guidelines to facilitate the design, installation, and maintenance of traffic signals including both hardware and software. Different cities also developed various procedures and practices in operating and managing the signal systems within their jurisdictions. In order to achieve proper phasing and timing, adequate spacing and separation distances are needed between signal installations and should be considered as part of the warranting and approval process. In addition, proper signal phasing and timing is needed not only initially but also as traffic volumes increase and traffic patterns evolve.

Summarized below are examples of best practices and actions for signal coordination and optimization that improve highway functionality.

- **Maintenance and operation of signals.** Traffic patterns change over time due to changes in adjacent land developments as well as other factors such as work zones. It is recommended that TxDOT and their local partners:
  - conduct routine signal timing evaluations and retime traffic signals at least every three years and do so following any significant change in traffic flow patterns.
- **Signal design and coordination.** Good timing and coordination of signals and signal networks can reduce system-wide traffic delays, increase average running speeds, and improve intersection capacities. Listed below are actions recommended to improve signal design and coordination:
  - use a TSSA program during signal planning and design to improve signal timing and coordination;

- use ITS to enhance the design and operation of traffic signals;
  - improve traffic monitoring and data collection to support traffic signal design, operation, and improvement; and
  - establish leadership and partnership during traffic signal planning and design, which is critical for the improvement of system-wide signal coordination and resource/workforce allocation.
- **Signal spacing on state roads.** A long uniform spacing of traffic signals on arterials and principal highways is crucial to maintaining good traffic progression and preserving the roadways primary function of regional mobility over local access. To ensure proper spacing of traffic signals:
    - minimum separation distances between signals should established and applied in warranting and new signal installations;
    - districts should partner on corridor management plans that establish minimum signal spacing and/or future signal locations; and
    - where possible, consider raised medians or a limited access raised center median in lieu of a signal installation if conditions permit.
  - **Signal hardware and software.** Well-designed and maintained signal hardware and software help to ensure signals work properly and in turn improve operations and safety. Actions recommended that pertain to signal hardware and software include:
    - select appropriate traffic signal hardware with up-to-date technologies that lasts long, produces minimum malfunctions, and requires minimum maintenance;
    - conduct routine signal hardware inspection and maintenance to minimize malfunctions and hardware failures;
    - use advanced signal communication and operation software/technology to improve traffic signal operations and management; and
    - update signal hardware and software periodically in consistency with the latest operational and technological trends for better traffic signal operations and management and cross-jurisdictional signal coordination.

## **Facility Design and Enhancement**

When operational improvements can no longer recapture or enhance the functionality of an existing roadway to meet the continuously growing demand, roadway expansion, reconstruction, or other minor or major improvements are necessary. TxDOT has used various approaches to improve system mobility and traffic capacities, including constructing bypass or parallel facilities, reconstructing existing facilities, and improving existing facilities through minor geometric and operation enhancements.

Improvement needs far exceed available funds, so using minor operation improvements to optimize operational efficiency and functionality is critically important. Instead of significantly expanding facilities or building new roadways, minor geometric operational enhancements such as restriping, ramp modifications, interchange improvements, and intersection and bottleneck improvements can be cost-effective alternatives for improving functionality.

In the area of facility design and enhancement, the researchers recommend the following general practices or actions for improving functionality.

- **Expansion of strategic highways.** Conversion of regional highway links from undivided to divided sections improves safety, mobility, and capacity, and enhances functionality. It is recommended that TxDOT:
  - continue the practice of ‘four-laning’ major links in the state highway system with divided highway sections.
- **Arterial rehabilitation and upgrades.** Access management measures should be included during rehabilitation and upgrades of arterials to preserve or enhance roadway functionality. A statewide policy on the use of non-traversable medians in TxDOT roadways should be established as follows:
  - all designs that include three or more dedicated through lanes in each direction should contain a center non-traversable median;
  - all designs should include a center non-traversable median when the existing or projected average weekday traffic volume is greater than 24,000; and
  - TxDOT design of rehabilitation projects should include consolidation of access points as needed for compliance with TxDOT access guidelines, which may require local subdivision and development ordinances to achieve compliance.
- **Minor geometric and operational enhancements.** Researchers recommend the following actions relative to minor enhancements:
  - consider minor geometric and operational enhancement approaches, such as re-striping, adding auxiliary lanes, ramp metering, and using HOV lanes as quick solutions to bottlenecks and other congestion problems; and
  - for new and upgraded urban frontage roads, utilize ramp braiding (the ‘X’ ramp configuration) where exit ramps are located on the downstream side of interchanges and entrance ramps are located on the upstream side.
- **Expressway and super arterial designs.** Expressway designs ensure a high level of long-term functionality since access is gained only through widely spaced intersections and abutting access rights have been purchased. Researchers recommend that TxDOT:
  - increase the use of expressway designs to achieve a high degree of functionality where all abutting private access rights have been purchased and access to the facility is gained through widely spaced intersections with major thoroughfares.
- **Roadway improvement funding.** Limited funding availability from traditional sources is frequently a major factor delaying roadway improvements and causing foreseeable or existing functionality losses not prevented or restored. The researchers recommend that TxDOT:
  - utilize innovative and non-traditional options such as highway pricing and other innovative funding sources, unconventional operations or design (e.g.,

reversible lanes, time-managed ramps), or other techniques that are adaptable to special situations.

- **Design of community loops and bypasses.** Loops and bypasses divert through traffic, namely heavy commercial vehicles, from populated communities and provide operational and safety benefits, which consequently improves system-wide functionality. The researchers recommend that:
  - new highway loops around communities should be planned and designed as controlled access facilities with a minimum of 1-mile spacing for grade separated interchanges;
  - if new loops are to be surface arterials, they should be designed with center non-traversable medians with a minimum of 1-mile spacing for signalized cross streets; and
  - TxDOT should no longer allow or fund upgrades to surface arterial loops around communities that do not include non-traversable medians or that are not conversions to a controlled access facility.

## **RIGHT OF WAY AND UTILITIES**

Highways are built and improved on highway right of way. Effectively acquiring, preserving and protecting the right of way is critical for maintaining the functionality of the state highway system. Several broad topics that can be of particular concern to TxDOT and other transportation agencies include right-of-way acquisition, right-of-way protection/preservation, and right-of-way utilities.

Passive practices when dealing with these aspects can and have caused noteworthy loss of highway functionality. For example, poor right-of-way protection can accelerate infrastructure deterioration by reducing improvement options or compromising design, operational, or maintenance opportunities. They can also introduce environmental issues. Ineffective practices in right-of-way protection, acquisition, and utility accommodation and relocation can cause significant increase of project costs, delays to highway construction or maintenance, and sensitive social issues. Constraints to right of way due to adjacent conditions (for example, noise tolerability, drainage, and encroachment from development) can also cause difficulties, both for current operation and for proposed highway enhancements.

This section summarizes major right-or-way-related practices and actions that can be used to improve highway functionality.

### **Right-of-Way Acquisition**

Right-of-way acquisition is a critical component in TxDOT's project development process. It can be time consuming and socially sensitive, and be the source to increased project costs and delay. Proactive practices for right-of-way acquisition allow highway projects to maintain the schedule and to be better accepted by the public.

Various forms of highway functionality loss may result from improper right-of-way acquisition. Delays during right-of-way acquisition process lead to delays to subsequent



project tasks, leaving highways unimproved or not built for a longer duration. Work zones staying set up for longer durations also result in highway functionality loss. The increase in right-of-way cost due to acquisition delays reduces the amount of funds available for construction and may make other improvements needed to preserve or enhance functionality cost prohibitive. Lack of right of way for necessary highway expansion limits the functionality of those highways as well.

Reasons causing unnecessarily longer durations when acquiring right of way may include acquiring an excessive number of parcels, involvement of property condemnations, inadequate communications with property owners and tenants, and acquisition staffing issues. To improve right-of-way practices and thereby reduce impact on highway functionality, recommended actions by sub-areas are provided in bullet points below.

- **Early project planning/project development activities.** Acquiring right of way for the ultimate roadway cross section will prevent right of way from being a constraint to subsequent improvements and functionality. The following actions during early project planning and development help for sufficient right-of-way acquisition:
  - make sure adequate right of way is planned not only for the current improvement, but also to accommodate ultimate needs, and do not just rely on a 20-year traffic forecast; and
  - develop a multi-disciplinary and multi-jurisdictional partnered approach that brings engineering, transportation planning, and land use decision-making together to develop ultimate roadway design and right-of-way needs.
- **Evaluation of alternative alignments.** Project delays and increased costs due to right-of-way acquisition delays can impact roadway function by impacting project design and extending the duration of unimproved congested conditions. During the project development process, an alignment should be selected taking into consideration the ease and cost of associated right-of-way acquisition. When possible, the researchers recommend TxDOT to:
  - consider adopting an alignment or other features that shift the right of way to parcels known to have willing sellers; and
  - avoid alignments with right-of-way requirements that cause environmental impacts that will require costly and time consuming efforts to pass through the environmental process.
- **Methods and analysis for acquisition.** Right-of-way acquisition may be expedited through consolidating parcels and use of the efficient and advanced database, geospatial, and Internet resources. In particular, the researchers recommend the following actions:
  - use land consolidation strategies to reduce the number of parcels to be acquired and develop programs to consolidate parcels into larger tracts on a voluntary basis;
  - where possible, dedicate or reserve right of way as part of the local platting process;

- utilize available computer technologies, such as GIS, database management systems, and internet/intranet, to expedite right-of-way acquisition; and
- use the same agent throughout the acquisition process to ensure consistency, efficiency, and accountability during the acquisition process.

### **Right-of-Way Protection**

Right-of-way protection can involve several broad areas of concern such as local and advanced right-of-way acquisition methods, coordination in local planning and land development, and roadside management. Inadequate or non-existent policies or practices in various activities impacting right-of-way protection may result in significant loss of highway functionality. Potential causes for functionality loss due to inadequate right-of-way protection may stem from the following:

- lack of coordination and involvement with local jurisdictions in local planning, subdivision plats, and site development plans;
- insufficient minimum right-of-way requirements for state roadways shown in local thoroughfares plans;
- delay in beginning right-of-way acquisition until later in the project development process;
- restrictions on the use of advance acquisition methods and the increased resources and advanced level of experience needed to undertake them;
- poor roadside vegetation management;
- improperly installed outdoor advertising signs;
- failure in protecting existing transportation corridors; and
- improper locations of on right-of-way utilities.

Generally, ineffective practices for protecting and preserving right of way can cause functionality loss during various stages of a highway's service life. Lack of right-of-way protection hinders or potentially precludes highway re-development and upgrades and causes losses in functionality or delays enhancements for functionality improvements.

TxDOT has various policies, guidelines, and regulations in place that can be used to help protect and preserve right of way along TxDOT facilities. The following bullet points include recommendations in the area of right-of-way protection to address highway functionality.

- **Project identification and prioritization in planning to protect right of way.** Failing to protect or preserve right of way early could preclude new facilities and expansions of highways to improve mobility and functionality. Actions to improve right-of-way protection during the early stages of planning include:
  - identify priority transportation corridors for rehabilitation or widening during long-range transportation planning;

- use a multi-jurisdictional partnering approach to preserve, protect, or acquire (additional) right of way needed for the ultimate configuration of the facility; and
  - identify fatal flaws, critical parcels, and probable alignments early to facilitate advanced or early acquisition.
- **Protecting right of way using early or advance acquisition methods.** Delaying project-wide right-of-way acquisition until environmental clearance (as required by NEPA) can result in higher right-of-way costs and reduce funds that can be used on measures to improve functionality. Currently, the use of early or advance acquisitions is limited due to the restrictions on these methods and the increased resources and advanced level of experience needed to undertake them. The researchers recommend the following actions in this regard:
    - seek funds, such as what might be available for use in protective and hardship right-of-way purchases, so future parcels within designated right of way can be purchased;
    - seek funds for limited strategic advance right-of-way acquisition where protective purchases cannot be used to protect future alignments; and
    - address legal and resource limitations in advance acquisition practices.
  - **Right-of-way protection via local thoroughfare plans and authority.** Insufficient minimum right-of-way requirements for major local thoroughfares can prevent opportunities for right-of-way dedication or reservation along TxDOT roadways, impact cross-section design, increase project costs, and deteriorate functionality. To protect right of way, the researchers recommend the following actions:
    - review and change as necessary the amount of right of way required for state roadways via functional designations on adopted local plans to accommodate future TxDOT cross-sections;
    - where possible, protect needed right of way via right-of-way reservations in the local platting process as well as through donations to locals for future use by TxDOT; and
    - TxDOT or mutually agreed right of way and/or design requirements could also be incorporated into local development regulations.
  - **Roadside management.** Development and outdoor advertising activities along roadways and right-of-way encroachments affect traffic operations, safety, and asset value, and can cause functionality loss over time. Actions recommended to improve roadside management include:
    - utilize computer technology such as GIS, database, and Internet to facilitate outdoor advertising permitting and management; and
    - pursue the use and enforcement of local building and parking setbacks and sign ordinances to prevent encroachment in TxDOT right of way.

## Utility Accommodation and Relocation

Utility accommodation and relocation are two important areas of concern to highway engineers during project development. Poor utility relocation and accommodation practices result in costly complications such as incorrect or delayed utility installation and late changes to project and utility plans. These complications can cause significant delays to highway projects and result in highway functionality loss during various stages of a highway's service life. Delays to construction of new roadways will postpone the beginning of the service of these highways, which consequently move congestion to adjacent roadways. Delays to improvement projects will result in work zones staying set up longer to deteriorate the functionality of existing highways.

Several laws or regulations in Texas regulate the utilities and their rights on TxDOT right of way, such as the UAR, Transportation Code, the Utilities Code, and the Local Government Code. The Right of Way Utility Manual also provides specific guidelines and regulations for dealing with issues associated with the utilities on the TxDOT-owned or managed right of way. In addition, TxDOT uses the UCMP to ensure the inclusion of the utility accommodation considerations in project planning, right of way, design, and construction functions at the district level. Through the process, TxDOT also promotes early involvement of and sufficient coordination with utility owners during the project development process.

The utility coordination process frequently involves a large number of stakeholders exchanging a myriad of information in forms such as communications, agreements, contracts, permits, maps, schematics, images, and design files. Challenges affecting utility coordination activities and causing relocation delays can include limited staffing and fiscal resources, late project notification to utility owners, failure of utility conflict identification, unresponsive or uncooperative utility owners, and lack of expertise of utility staff. The lengthy process of obtaining required agreements for reimbursable utility relocations compared to that for non-reimbursable relocations can also be a challenge.

The following are the recommended actions to address highway functionality via practices and policies related to utility accommodation.

- **Utility coordination.** Well-established coordination with utility owners is important for supporting utility accommodation and relocation and helps to avoid utility-related project delays. To improve utility coordination, the researchers recommend the following:
  - involve public utility companies and franchises early to ensure for adequate involvement, which may include involving utilities during the project planning and programming stage, effectively and frequently coordinating with utilities throughout PDP, and establishing fast and efficient channels for utility information acquiring; and
  - develop good working relationships with utilities to reduce communication hurdles and improve the willingness of utilities for early and frequent involvements.

- **Utility conflict detection and management.** Early and accurate detection of utility conflicts would give utility companies sufficient time to budget and conduct utility relocations. In addition, effective data management practices help engineers to accurately manage the information of utility conflicts throughout the project development and construction and therefore avoid highway functionality loss caused by project delays. The researchers recommend the following actions:
  - detect utility conflicts using advanced techniques early and accurately, such as GIS, GPS, SUE, and other sophisticated information systems, to keep projects within schedule;
  - use advanced technologies such as GIS, GPS, and RFID for utility mapping and inventory; and
  - use utility conflict management systems supported with technologies such as GIS and database management systems to effectively inventory and track utility conflicts throughout projects to avoid project delays.
  
- **Utility relocation.** Relocating utilities sometimes can be time-consuming and cost prohibitive. Therefore, avoiding unnecessary utility relocations can help highway engineers to save time and project cost. To reduce negative impact of utility relocation on highway projects and further on highway functionality, the researchers recommend the following actions:
  - avoid needs for utility relocation through mechanisms such as minor modifications to highway designs; and
  - use automated utility installation permitting process such as the UIR system developed by TxDOT that has been used in several districts.
  
- **Utility accommodation restriction for roadway protection.** Restricting certain utilities in congested right of way or use of efficient strategies for utility accommodation can ease right-of-way congestion caused by utilities. In this regard, the researchers recommend that TxDOT:
  - consider protecting certain urban arterial highways from new utility installations to improve safety and operations of existing highways, mitigate the competition from utility facilities for right of way needed for highway enhancement or expansion, and reduce maintenance activities and work zones;
  - consider innovative utility accommodation practices such as utility corridors or joint trenching to consolidate underground utility facilities and ease right-of-way congestion caused by utilities; and
  - acquire dedicated right-of-way for utility accommodation to simplify the utility accommodation process and reduce utility-related interruptions to roadway construction and operations.

## **SAFETY AND FUNCTIONALITY**

Roads that have safety problems are considered to hinder the safe and efficient movement of goods and people, hence creating a detriment to the functionality of the highway. Crashes interrupt the trips of vehicles involved and delay trips of other vehicles that are detoured, slowed, and/or stopped due to the incidents. The safety function of

roads can be addressed during the design phase of a project, as well as by monitoring safety issues on existing roads.

Geometric design elements and crash occurrence are two primary areas considered when assessing the safety functionality of a road. Crash occurrences can be measured by crash rate, frequency, and severity. Primary geometric design factors that impact highway safety functionality include access density, horizontal and vertical alignment, and roadway cross-section—including travel lanes, shoulders, side slopes, clear zones, and ditches. All these can affect the highway safety functionality.

Another factor affecting highway safety is the inconsistencies that arise over time such as variations in pavement surface and friction, shoulder width, deceleration lane lengths, signing, ramp merges, and weaving sections. Consistency makes the roads predictable and easier to drive safely, and inconsistencies introduce uncertainties and surprises.

As part of its infrastructure management program, TxDOT can identify road segments that have safety problems in order to prioritize them for funding to address the problems. TxDOT district offices submit projects for safety-related projects through the HES Program. District offices identify road segments that have experienced safety problems and submit them in response to a call for projects.

The following practices and actions are recommended to mitigate safety-related functionality losses on Texas roadways.

- **Consideration of safety in geometric design.** Features of geometric design such as access control, horizontal and vertical curves, lane widths, and clear zones can create inconsistencies between design speeds and operating speeds that impact safety and functionality. The researchers recommend that TxDOT:
  - improve safety in highway geometric design focusing on access reduction and spacing, use of turn lanes to separate turning traffic, improved design of curved roadways (e.g., wider lanes and shoulders, proper design speed and function, and increased sight distances), and increased roadside recovery distances; and
  - conduct RSAs for new highway project designs to further increase the resulting safety characteristics.
  
- **Incident management.** Highway SSPs are critical for responding to and clearing on-road incidents that affect safety and mobility of other vehicles. Therefore, the researchers recommend to:
  - strengthen the roles and responsibilities of traffic safety organizations and agencies such as the highway SSPs for faster incident response and management.

- **Crash location and frequency monitoring and use of safety performance measures.** Readily available data on crash frequency and how, when, where, and why crashes have occurred is important in order for better safety policies and measures to be developed and implemented. The following actions and practices can be used by TxDOT to improve safety and therefore highway functionality:
  - improve the decision-making process and information systems by making optimal use of traffic safety information;
  - improve timeliness, thoroughness, and accuracy of data collection, analysis processes, and systems including the linkage of crash, roadway, driver, medical, CODES (crash outcome data evaluation system), enforcement, conviction, homeland security data; and
  - improve safety data warehousing and accessibility.
- Take corrective actions to address hazardous conditions on existing highways through a regular safety program that includes:
  - review system-wide crash data (frequency, rate, severity) to identify high hazard locations and segments;
  - conduct road safety review, assess field conditions, and determine causes of high crash frequency, rate, or severity so that appropriate corrective actions can be selected;
  - improve hazardous conditions with spot improvements or improvements to highway segments, which may be separate safety projects or part of highway upgrades; and
  - program safety improvements as part of the overall TxDOT program with a goal of addressing all locations and segments with high crash frequency.

There are various types of performance measures that are used for assessing highway safety. Most of these measures take into consideration factors such as crash rate, severity, or the combination of both. TxDOT uses Mileage Death Rate (fatalities per 100M VMT) and Mileage Serious Injury Rate (serious injuries per 100M VMT) as safety performance measures in its traffic safety plan.

In addition to performance measures, TxDOT also use a number of safety-related criteria to identify the most needed investments for safety improvements. These criteria include the number of crash hot spots, crash reduction factor (percentage), and benefit-cost ratio for an improvement. In its HSIP, TxDOT uses SII, an index calculated primarily based on the ratio between the expected benefits in crash reduction and the project costs, for ranking and selecting eligible projects.

## **INFRASTRUCTURE EFFECTS ON FUNCTIONALITY**

TxDOT manages a vast network of pavements and bridges and related transportation assets over wide geographical areas that are subjected to different utilization and environmental conditions. To support and preserve operational function of such an extensive network of assets, TxDOT annually invests over one billion dollars in repair and replacement of aging structures and reconstruction and maintenance of pavements. Overseeing the upkeep of these assets involves a process of integrating traditional

engineering functions and principles with sound business practices to manage them in a cost-effective manner and in ways that meets the expectation of the public.

Deteriorated infrastructure and construction activities can cause highway functionality loss in various aspects. Deteriorated pavements have impact on various operational characteristics such as travel speeds, comfort, and safety. Structurally deficient or obsolete bridges impose hazards to vehicles and can cause complete loss of functionality upon structural failures. Bridges that are functionally deficient or obsolete, form barriers to freight movement creating another form of functionality loss. In addition, work zones can cause a temporary loss of highway functionality for periods of years.

TxDOT utilizes a PMIS to store pavement condition data on TxDOT's PES to support decision makers at the division, district, area, and maintenance office levels. However, it lacks a similar system for its bridges. A preventive rather than reactive maintenance approach would cause a significant increase in the life of pavements and bridges at reduced cost and disruption to road users. Proactive preventative maintenance combined with innovative contracting strategies will help minimize infrastructures impact to highway functionality.

The following section summarizes the actions to address highway functionality via practices and policies related to the maintenance of pavements and bridges.

- **Pavements and bridges.** A proactive maintenance approach to pavements and bridges will increase the life of these assets at a lesser cost and reduced disruption to road users. In addition, effective management information systems for pavements and bridges help prioritize and allocate maintenance resources considering cost-effectiveness and physical needs and condition. Therefore, the researchers recommend the following actions to improve transportation infrastructure:
  - use pavement management systems to take a proactive in lieu of a reactive approach;
  - use pavement performance measures such as the IRI in the PMIS to aid in making proactive decisions relative to preventative, in lieu of corrective, maintenance practices;
  - complete the development of its Bridge Management Information System and practice a robust bridge management system similar to what it does for pavement management; and
  - undertake a pavement preservation program that encompasses a range of preventive maintenance techniques and that includes regularly scheduled preventative maintenance activities.
- **Work zone traffic management strategies.** Work zone traffic management techniques can be used to reduce exposure between motorists and highway workers and reduce crash rates and motorist delays in work zones. The researchers recommend the following actions:
  - reduce the volume of traffic going through the work zone (e.g., using detours or schedule work during lower volume periods);
  - reduce the length of time work zones are in place;
  - use narrower rather than fewer lanes where possible;



- perform work at night or in off-peak periods;
  - use normal design criteria for temporary road conditions where possible (e.g., curves, tapers, merge sections, etc.);
  - increase the amount and helpfulness of motorist information; and
  - reduce the frequency that work zones are established to perform construction and maintenance operations.
- **Work zone contracting mechanisms.** TxDOT should use or continue to use contracting strategies that consider road user costs to shorten work zone durations. Examples of these contracting mechanisms include:
    - shorten the construction schedule to reduce the duration of impeded traffic flow during construction;
    - utilize cost plus time (A+B) bidding;
    - charge lane rental fees for occupying lanes to do work when construction extends beyond the project's planned duration; and
    - offer incentives to finish projects early and charge liquidated damages for late completion.

## CONCLUSIONS

Texas has the need for far more highways that we can afford to build. It has become increasingly difficult to even improve the highways we have. In fact, highway maintenance, including corrective maintenance and reconstruction, now consumes most of TxDOT's capital budget. Hence, it is extremely important to keep Texas highways—those that we have—functioning at a high level of efficiency. That can be a challenge, given competing pressures for staff time and attention and competition for available funds.

The good news is that preserving and maintaining functionality does not have to cost a lot of money. In fact, as demonstrated in the previous sections, *preserving a high level of functionality is more tied to how things are done than how much money might be available.*

### Choices

TxDOT, and indeed all transportation agencies, have two basic choices when it comes to addressing functionality of the highway system and its component highways:

1. Preserve functionality at a high level through effective planning, operational and safety management, refinement, and proactive infrastructure maintenance.
2. Adopt a reactive and corrective approach to fix things after they deteriorate.

#### *Functional Preservation: The Proactive Approach*

TxDOT's motto is to "Keep Texas Moving." Goal 5 of TxDOT's current strategic plan is to preserve the asset value of transportation assets (188). The plan states that—preserving these (highway) assets and increasing their value to the public is critical for

Texas' economic health and safety." Further, the plan says that one of TxDOT's goals is to "minimize costs over time of managing and maintaining the transportation system."

Functionality preservation takes a proactive, preservative, or preventative approach to keep the highway functioning at a high level. Performance is monitored and actions are taken to keep functionality at or near the level intended at the design stage. This keeps operations efficient and safer and keeps the physical infrastructure—pavement, structures, traffic control devices, etc.—all in condition to meet or exceed specified levels.

Choice 1, functional preservation, uses the proactive approach to not let assets deteriorate to the point where they operate significantly below the intended design levels.

#### *Corrective Improvements: The Reactive Approach*

Choice 2, corrective improvements after deterioration, is much easier on a day-to-day basis but can result in higher long-term cost and effort. TxDOT's strategic plan states that "(facilities) that are allowed to deteriorate for too long must be replaced or rebuilt at a much higher cost..." While this statement in the plan is aimed at infrastructure maintenance, it is equally applicable when directed toward operations and safety. The longer a facility's operational or safety is allowed to deteriorate, the more serious the shortfall or deficiency gets and the more re-investment will usually be needed to restore the original functionality.

For example, if access is well coordinated and managed along a section of state highway, it is likely that a fair amount of development and associated access traffic can be accommodated with limited impact on operational efficiency. However, if driveways are permitted to be built anywhere requested and left turn access points are closely spaced, it is likely that conflicts will arise, operation efficiency will decline, and crashes will increase. The longer the laissez faire approach continues the more operating conditions will decline. At some point, either more lanes or even a replacement or supplemental highway may be needed. This approach is more costly in the long term.

#### **The Right Choice**

According to the TxDOT strategic plan, the first choice—functional preservation—is the correct choice. Much of it can be achieved through either original or ongoing planning or regular operations and maintenance programs. It is more cost-effective and alleviates the need for as many major projects, many of which take years to get through programming and project development.

## REFERENCES

1. Handy, S., R.G. Paterson, and K. Butler. *Planning for Street Connectivity: Getting from Here to There*. Planning Advisory Service Report No. 515, American Planning Association, Washington, D.C., 2003.
2. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington D.C., 2004.
3. Stover, V.G., M. Zubel, E. Holy, and B. Thompson. *City Street Design*. Texas Transportation Institute, The Texas A&M University System, College Station, TX, 1988.
4. Marks, H. *Traffic Circulation Planning for Communities*. Gruen Associates, Los Angeles, CA, 1974.
5. *The Transportation Planning Process Key Issues*. A Publication of the Transportation Planning Capacity Building Program, Federal Highway Administration, Washington, D.C., September 2007.
6. *Performance Measures of Operational Effectiveness for Highway Segments and Systems*. NCHRP Synthesis 311, Transportation Research Board, Washington D.C., 2003.
7. [www.fhwa.dot.gov.asset.assetmgmt\\_saftey.cfm](http://www.fhwa.dot.gov.asset.assetmgmt_saftey.cfm).
8. *States' Implementation of Traffic Management Systems*. U.S. General Accounting Office, Washington D.C., January 1997, p.11.
9. [www.michigan.gov/printerFriendly/0,1687,7-151-9260\\_11057-43609--,00.html](http://www.michigan.gov/printerFriendly/0,1687,7-151-9260_11057-43609--,00.html).
10. "Relationships Between Asset Management and Travel Demand: Findings and Recommendations from Four State DOT Site Visits." Federal Highway Administration, Washington, D.C.
11. Texas Department of Transportation. *Transportation Planning Process Manual*, September 2001.
12. North Central Texas Council of Governments. *Regional Mobility Initiatives*, Vol. XII, No.1. April 2008, p. 3.
13. Hard, E.N., B.S. Bochner. *Workshops on Corridor Management and Preservation in Texas*, Course material from workshops, Product 5-5606-01-P1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, August 2008.
14. Hard, E.N. and W.L. Eisele. *Workshops on TxDOT Involvement in Local Development Review*, Course material from workshops, Product 5-4429-01-P1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, August 2005 – August 2007.

15. Hard, E.N., W.L. Eisele, and W.E. Frawley. *Methods and Benefits of TxDOT Involvement in Local Development Review*. Technical Report 0-4429-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, October 2003.
16. *Access Management Manual*. Transportation Research Board, National Research Council, Washington D. C., 2003.
17. *Impacts of Access Management Techniques*. NCHRP Report 420, Transportation Research Board, National Research Council, Washington D. C., 1999.
18. *A Guidebook for Including Access Management in Transportation Planning*. NCHRP Report 548, Transportation Research Board, National Research Council, Washington D. C., 2005.
19. *Domestic Access Management Scan Tour Summary Report*. Federal Highway Administration, Washington, D.C., 2007.  
<http://www.accessmanagement.info/2006SCAN/index.htm>. Accessed November 10, 2008.
20. Hard, E.N., P.N. Ellis, and B.S. Bochner. *Creating Partnerships with Local Communities to Manage and Preserve Corridors*, Technical Report 0-5606-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, September 2007.
21. Srinivasan, S. and K. Kochelman. *The Impacts of Bypasses on Small- and Medium-Sized Communities: An Economic Analysis*, Journal of Transportation and Statistics, V5/N1, 2002.
22. Harris County Toll Road Authority, Construction and Engineering, Major Projects, The Grand Parkway. [https://www.hctra.org/about\\_construction/the-grand-parkway/](https://www.hctra.org/about_construction/the-grand-parkway/). Accessed January 22, 2009.
23. Williams, K.M. and R. Frey. "Corridor Preservation: Best Practices for Local Governments." In *Transportation Research Record No. 1895*, pp. 156-162. Transportation Research Board, Washington, D.C., 2004.
24. Williams, K. *Corridor Management: A Synthesis of Highway Practice*. NCHRP Synthesis 289. Transportation Research Board. Washington, D.C. 2000.
25. *Highway Capacity Manual 2000*. Transportation Research Board of the National Academies, Washington D. C., 2000.
26. *Manual on Uniform Traffic Control Devices, 2003 Edition*. Federal Highway Administration, Washington D. C., 2007.
27. *Traffic Signal Timing Manual*. Publication FHWA-HOP-08-024, Kittelson & Associates, Inc., Portland, OR, 2008.
28. *Congestion Relief*. Keptexasmoving.com, Texas Department of Transportation. [http://www.keptexasmoving.com/index.php/congestion\\_relief](http://www.keptexasmoving.com/index.php/congestion_relief). Accessed November 13, 2008.
29. *Texas MUTCD*. Texas Department of Transportation, Austin, TX, 2006.

30. *Signs and Markings Manual*. Texas Department of Transportation, Austin, TX, 2006.
31. *Freeway Signing Handbook*. Texas Department of Transportation, Austin, TX, 2008.
32. *Standard Highway Sign Designs for Texas*. 2008 Edition, Texas Department of Transportation, Austin, TX, 2008.
33. *Traffic Data and Analysis Manual*. Texas Department of Transportation, Austin, TX, 2001.
34. Brydia, R.E., L.G. Ruback, R. Rajbhandari, L.D. Johnson, and E. Brackin. *Communications Trends and their Impact on TxDOT ITS Deployments*. Publication FHWA/TX-08/0-5586-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2007.
35. Hawkins, H.G. Jr., C.L. Williams, and S. Sunkari. *Evaluation of Traffic Control Devices: Fourth Year Activities*. FHWA/TX Report 08/0-4701-4, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
36. Ullman, G.L., M.D. Finley, A.M. Pike, K.K. Knapp, P. Songchitruksa, and A.A. Williams. *Studies to Improve Temporary Traffic Control at Urban Freeway Interchanges and Pavement Marking Material Section in Work Zones*. Publication FHWA/TX-08/0-5238-2, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
37. Pesti, G., P. Wiles, R.L. Cheu, P. Songchitruksa, J. Shelton, and S. Cooner. *Traffic Control Strategies for Congested Freeways and Work Zones*. FHWA/TX Report 08/0-5326-2, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2007.
38. Maccubbin, R.P., B.L. Staples, F. Kabir, C.F. Lowrance, M.R. Mercer, B.H. Philips, and S.R. Gordon. *Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned: 2008 Update*. FHWA-JPO Report 08-032, Noblis, Washington D. C., 2008.
39. DalTrans. Texas Department of Transportation, Austin, TX. DalTr<http://www.dfwtraffic.dot.state.tx.us>. Accessed July 29, 2009.
40. HoustonTranstar.org. <http://www.houstontranstar.org>. Accessed July 26, 2009.
41. Chrysler, S.T., A.A. Williams, and K. Fitzpatrick. *Preliminary Guidelines for Signing on Toll Facilities*. FHWA/TX Report 07/0-5446-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2007.
42. Persad, K., M. Walton, and S. Hussain. *Toll Collection Technology and Best Practices*. Research Report 0-5217-P1, Center for Transportation Research, University of Texas, Austin, TX, 2007.

43. Hlavacek, I., M. Vitek, and R.B. Machemehl. *Best Practices: Separation Devices between Toll lanes and Free Lanes*. FHWA/TX Report 07/0-5426-1, Center for Transportation Research, University of Texas, Austin, TX, 2007.
44. Prozzi, J., I. Victoria, G. Torres, C.M. Walton, J. and Prozzi. *Identifying, Measuring, and Mitigating Environmental Justice Impacts of Toll Roads: Executive Summary Report*. FHWA/TX Report 07/0-5208-1, Center for Transportation Research, University of Texas, Austin, TX, 2007.
45. Overman, J.H., L.K. Cherrington, and J.C. Arndt. *Regional Public Transportation Coordination in Texas*. FHWA/TX Report 08/0-5542-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
46. Lewis, C.A., L. Higgins, J. Perkins, F.B. Zhan, and X. Chen. *Public Transportation Solutions for Regional Travel: Technical Report*. FHWA/TX Report 08/0-5345-1, Center for Transportation Training and Research, Texas Southern University, Houston, TX, 2008.
47. Brydia, R.E., J.D. Johnson, and K.N. Balke. *Improving TxDOT's Incident Detection Algorithm*. Project Summary Report 0-4770-S, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2006.  
<http://tti.tamu.edu/documents/0-4770-S.pdf>. Accessed November 14, 2008.
48. Waller, S.T., S. Boyles, D. Fajardo, A. Karoonsoontawong, and Y. Chiu. *Ramp Treatment and Dynamic Closure Strategies for Incident Traffic Management*. Project Summary Report 0-5422, Center for Transportation Research, University of Texas, Austin, TX, 2007.
49. Songchitruksa, P., K.N. Balke, K. Hamad, Y. Zhang, and G. Pesti. *A Guidebook for Effective Use of Archived Operations Data at Texas Transportation Management Centers*. FHWA/TX Report 08/0-5485-P1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
50. Ballard, A.J., B.R. Ullman, N.D. Trout, S.P. Venglar, D.W. Borchardt, A.P. Voigt, K. Obeng-Boampong, and R. Rajbhandari. *Hurricane Evacuation Traffic Operations*. FHWA/TX Report 08/0-4962-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
51. Borchardt, D. W. and D.D. Puckett. *Real-Time Data for Hurricane Evacuation in Texas*. SWUTC Report 08/167764-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
52. Ullman, B.R., N. Trout, and A.J. Ballard. *Guidelines for Hurricane Evacuation Signing and Markings*. FHWA/TX Report 08/0-4962-P1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2007.
53. Texas Transportation Code, Sec. 550.022. Accident Involving Damage to Vehicle. <http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.550.htm>. Accessed August 5, 2009.
54. HoustonTranstar.org. <http://www.houstontranstar.org>. Accessed July 26, 2009.

55. KeepTexasMoving.com. Texas Department of Transportation, Austin, TX. <http://www.keeptexasmoving.com/index.php>. Accessed July 26, 2009.
56. *Intelligent Transportation Systems for Traffic Signal Control: Deployment Benefits and Lessons Learned. Intelligent Transportation Systems*. U.S. Department of Transportation. [http://www.its.dot.gov/jpodocs/reports/14321\\_files/a1019-tsc\\_digital\\_n3.pdf](http://www.its.dot.gov/jpodocs/reports/14321_files/a1019-tsc_digital_n3.pdf). Accessed November 24, 2008.
57. Bonneson, J.A., M.P. Michael, and S. Sunkari. *Best TxDOT Practices for Signal Timing and Detection Design at Intersections*. TxDOT Project Summary Report 0-5629, 2008. <ftp://ftp.dot.state.tx.us/pub/txdot-info/rtp/psr/5629.pdf>. Accessed November 24, 2008.
58. *Traffic Signal Timing Manual*, FHWA-HOP Report 08-024, Federal Highway Administration, Washington, DC, June 2008.
59. *Traffic Signals Manual*. Texas Department of Transportation, Austin, TX, November 1999.
60. Jacobson, M.S. and L. Banda. —The City of San Antonio, TX, USA’s Traffic Signal System Modernization Program.” *ITE Journal*, May 2009.
61. Hawkins, H.G., Jr. *Traffic Signal Warrants: Guidelines for Conducting a Traffic Signal Warrant Analysis*. Second Edition, Product Number 0-4701-P2, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
62. Balke, K.N., H. Charara, and R. Parker. *Development of a Traffic Signal Performance Measurement System (TSPMS)*. FHWA/TX Report 05/0-4422-2, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2005.
63. Shenoda, M. and R. Machemehl. *Development of a Phase-by-Phase, Arrival-Based, Delay-Optimized Adaptive Traffic Signal Control Methodology with Metaheuristic Search*. SWUTC Report 06/167863-1, Center for Transportation Research, University of Texas, Austin, TX, 2006.
64. Zhang, Y., Y. Xie, and Z. Ye. *Development and Evaluation of a Multi-Agent Based Neuro-Fuzzy Arterial Traffic Signal Control System*. SWUTC Report 07/473700-00092-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2007.
65. *2007 National Traffic Signal Report Card: Technical Report*. National Traffic Operations Coalition, Washington D. C., 2007.
66. Timbrook, P., J. Trombly, and A. Gupta. *Cross-Jurisdictional Signal Coordination Case Studies*. FHWA-OP Report 02-034, Science Applications International Corporation, Oak Ridge, TN, 2002.
67. Kurfees, W. —Comprehensive Signal Retiming in the Dallas-Fort Worth Area,” *Compendium of Technical Papers*, 2009 Annual Meeting and Exhibit, Institute of Transportation Engineers, San Antonio, TX, August 2009.

68. *Traffic Signal Audit Guide*. National Transportation Operations Coalition, Washington, D. C., 2007. [http://www.ite.org/reportcard/traffic\\_audit\\_FINAL.pdf](http://www.ite.org/reportcard/traffic_audit_FINAL.pdf). Accessed November 2008.
69. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D. C., 2004.
70. *Guidelines for Geometric Design of Very Low-Volume Local Roads*. American Association of State Highway and Transportation Officials, Washington, D. C., 2001.
71. *Guide for High-Occupancy Vehicle (HOV) Facilities, 3<sup>rd</sup> Edition*. American Association of State Highway and Transportation Officials, Washington, D. C., 2004.
72. *Roadside Design Guide*. American Association of State Highway and Transportation Officials, Washington, D. C., 2002.
73. *Roadway Design Manual*. Texas Department of Transportation, Austin, TX, 2006.
74. *Texas Metropolitan Mobility Plan: Breaking the Gridlock*. Public Information Office, Texas Department of Transportation, Austin, TX, 2003. <http://www.dot.state.tx.us/btg/tmmp.pdf>. Accessed November 4, 2008.
75. "Project Funding Options." Keptexasmoving.com, Texas Department of Transportation, Austin, TX. [http://www.keptexasmoving.com/index.php/project\\_funding\\_options](http://www.keptexasmoving.com/index.php/project_funding_options). Accessed November 25, 2008.
76. Walters, C.H., S.A. Cooner, and S.E. Ranft. —"Reconsidering Freeway Bottlenecks: Case Studies of Bottleneck Removal Projects in Texas." *Transportation Research Record 1952*, Transportation Research Board of the National Academies, Washington, D. C., 2005. pp. 66-75.
77. Margiotta, R.A., N.C. Spiller, and J. Halkias. *Traffic Bottlenecks: A Primer Focus on Low-Cost Operational Improvements*. FHWA-HOP Report 07-130, Cambridge Systematics, Inc., Knoxville, TN, 2007.
78. *Innovative Finance Primer*. Federal Highway Administration, Washington, D. C., 2002. <http://www.fhwa.dot.gov/innovativefinance/ifp/index.htm>. Accessed November 25, 2008.
79. Arnold, E.D., Jr. and K.E. Lantz, Jr. *Evaluation of Best Practices in Traffic Operations and Safety: Phase I: Flashing LED Stop Sign and Optical Speed Bars*. FHWA/VTRC Report 07-R34, Virginia Transportation Research Council, Charlottesville, VA.
80. *European Right-of-Way and Utilities Best Practices*. Federal Highway Administration, American Association of State Highway and Transportation Officials, and Transportation Research Board, Washington, D.C., 2002.



81. *Right-of-Way and Utilities Guidelines and Best Practices*. Highway Subcommittee on Right-of-way and Utilities, American Association of State Highway and Transportation Officials, Washington, D.C., January 2004.
82. *U.S. Domestic Scan Program: Best Practices in Right-of-Way Acquisition and Utility Relocation*. Final Scan-Tour Report, NCHRP Project 20-68, Cambridge Systematics, Inc., Cambridge, MA, 2006.
83. Zaharewicz, J. —Advancing Innovative Utility Practices: Domestic and International Utility Scans.” Presentation for the 2008 AASHTO Subcommittee Conference, May 5, 2008. [http://cms.transportation.org/sites/rightofway/docs/2008\\_ch05s01.pdf](http://cms.transportation.org/sites/rightofway/docs/2008_ch05s01.pdf). Accessed October 20, 2008.
84. *Project Development Process Manual*. Texas Department of Transportation, Austin, TX, 2008.
85. *Code of Federal Regulations*, —Title 23 – Highways, Part 710 – Right-of-Way and Real Estate.” 2008. [http://www.access.gpo.gov/nara/cfr/waisidx\\_08/23cfr710\\_08.html](http://www.access.gpo.gov/nara/cfr/waisidx_08/23cfr710_08.html). Accessed October 28, 2008.
86. *TxDOT Right-of-Way Manual*, —Volume 2 – Right-of-Way Acquisition.” Texas Department of Transportation, Austin, TX, 2008.
87. *Real Estate Acquisition Guide for Local Public Agencies*. Texas Department of Transportation, Austin, TX, 2008.
88. Caldas, C.H., T. Le, G.E. Gibson, Jr., and M. Thole. *Identifying Right-of-Way Requirements during the Project Development Process*. FHWA/TX Report 08/0-5478-1, Center for Transportation Research, University of Texas, Austin, TX, 2007.
89. O’Connor, J.T., G.E. Gibson, S.M. Hedemann, G.R.L. Chang, and W.K. Chong. *Duration Quantification and Opportunities for Improvement in the Texas Department of Transportation’s Utility Adjustment Process*. Report 0-4617-2, Center for Transportation Research, University of Texas, Austin, TX, 2006.
90. Kockelman, K.M., J.D. Heiner, S. Hakimi, and J. Jarett. *Estimation of Right-of-Way Acquisition Costs in Texas*. Project Summary Report 0-4079-S, Center for Transportation Research, University of Texas, Austin, TX, 2004.
91. *Texas Administrative Code*, —Title 4 - Transportation, Part 1 – Texas Department of Transportation, Chapter 22 – Use of State Property.” [http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac\\_view=4&ti=43&pt=1&ch=22](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=4&ti=43&pt=1&ch=22). Accessed May 4, 2008.
92. *TxDOT Survey Manual*. Texas Department of Transportation, Austin, TX, January 2008.
93. Meyer, R.E., E.S. Motteram, S.G. Evans, and W.G. McCully. *Controlling Forest Encroachment along East Texas Roadways*. Report 902-8, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 1993.

94. Engelke, M.C., S.K. Riffell, and K.B. Marcum. *Avoiding Degradation of Road Shoulder Asphalt Due to Turfgrass Encroachment*. Report TX-95/1903-2F, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 1995.
95. *Texas Administrative Code*, —Title 3 - Transportation, Part 1 – Texas Department of Transportation, Chapter 21 – Right-of-Way.”  
[http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac\\_view=4&ti=43&pt=1&ch=21](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=4&ti=43&pt=1&ch=21). Accessed May 4, 2008.
96. Outdoor Advertising Control Domestic Scan. Federal Highway Administration.  
<http://www.fhwa.dot.gov/REALESTATE/scans/pheofreport.htm>. Accessed November 5, 2008.
97. *Texas Administrative Code*, —Title 3 - Transportation, Part 1 – Texas Department of Transportation, Chapter 21 – Right-of-Way, Subchapter C – Utility Accommodation.”  
[http://info.sos.state.tx.us/pls/pub/readtac\\$ext.ViewTAC?tac\\_view=5&ti=43&pt=1&ch=21&sch=C&rl=Y](http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=43&pt=1&ch=21&sch=C&rl=Y). Accessed May 4, 2008.
98. *Texas Statutes, Transportation Code*. <http://tlo2.tlc.state.tx.us/statutes/tn.toc.htm>. Accessed October 20, 2008.
99. *Texas Statutes, Utilities Code*. <http://tlo2.tlc.state.tx.us/statutes/ut.toc.htm>. Accessed October 20, 2008.
100. *Texas Statutes, Local Government Code*. <http://tlo2.tlc.state.tx.us/statutes/lg.toc.htm>. Accessed October 20, 2008.
101. *ROW Utility Manual*. Texas Department of Transportation, Austin, TX, 2008.
102. Kraus, E., C. Quiroga, R. Brown, C. Stevens, and N. Koncz. *Development of a Utility Conflict Management System*. FHWA/TX Report 07/0-5475-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, January 2007.
103. *Utilities - Utilities Program*. Federal Highway Administration.  
<http://www.fhwa.dot.gov/programadmin/utility.cfm>. Accessed October 20, 2008.
104. *U.S. Code*, —Title 23 – Highways, Chapter 1: Federal-Aid Highways.” 2006.  
[http://www.access.gpo.gov/uscode/title23/chapter1\\_subchapter1.html](http://www.access.gpo.gov/uscode/title23/chapter1_subchapter1.html). Accessed October 20, 2008.
105. *Code of Federal Regulations*, —Title 23 – Highways, Part 645 – Utilities.” 2004.  
[http://www.access.gpo.gov/nara/cfr/waisidx\\_04/23cfr645\\_04.html](http://www.access.gpo.gov/nara/cfr/waisidx_04/23cfr645_04.html). Accessed October 20, 2008.
106. *Federal-Aid Policy Guide*, —Title 3 – Code of Federal Regulations (and Non-regulatory Supplements), Chapter 1 – Federal Highway Administration, Department of Transportation, Part 645 – Utilities. 2008.”  
<http://www.fhwa.dot.gov/legsregs/directives/cfr23toc.htm>. Accessed October 20, 2008.

107. Kraus, E., C. Quiroga, N. Koncz, and H. Dawood. *Development of a Utility Conflict Management System*. FHWA/TX Draft report 08/0-5475-4, Texas Transportation Institute, The Texas A&M University System, College Station, TX, October 2008. Submitted for review.
108. Kuhn, B., A. Parham, D. Jasek, B. Ullman, R. Brydia, and B. Blaschke. *Utility Corridor Structures and Other Utility Accommodation Alternatives in TxDOT Right-of-Way*. FHWA/TX Report 03/4149-1, Texas Transportation Institute, The Texas A&M University System, College Station, TX, September 2002.
109. Ellis, R. and H. Thomas. —“The Root Causes of Delays in Highway Construction.” In Proceedings of the 82<sup>nd</sup> Annual Meeting of the Transportation Research Board, Transportation Research Board of the National Academies, Washington, D.C., January 11 – 16, 2003. CD-ROM.
110. Quiroga, C., Y. Li, E. Kraus, and J. Le. *Utility Installation Review System – Implementation Report*. FHWA/TX Report 08/5-2110-03-2, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 2008.
111. Texas Department of Transportation. *FY 2009 Texas Traffic Safety Goals, Strategies, Performance Measures, and Objectives*. 2009.  
<http://www.dot.state.tx.us/txdotforms/GetForm?formName=/PerformanceMeasures.pdf&preference=PDFForm&appID=/trf&fileID=1233334&status=/reportError.jsp&configFile=WFServletConfig.xml>. Accessed December 26, 2008.
112. Vermont Agency of Transportation. *Vermont’s Highway System Policy Plan*. VAOT Publication, Montpelier, VT, 2004.
113. Lopez, C.A. *Highway Safety Improvement Program Manual*, Texas Department of Transportation, Austin, TX, 2008.
114. U. S. of Transportation Federal Highway Administration. Highway Safety Information System Laboratory. <http://www.tfhrc.gov/about/hsis.htm>. Accessed October 5, 2008.
115. Griffith, M. S. —“Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed On Freeways.” *ITE Journal* Vol. 70 No. 6, 200, pp. 168–177.
116. Gross, F., R. Jagannathan, B. Persaud, C. Lyon, K. A. Eccles, N. X. Lefler, and R. Amjadi. *Safety Evaluation of STOP AHEAD Pavement Markings*. FHWA-HRT Report 08-043. FHWA, U.S. Department of Transportation, 2008.
117. Smadi, O., R.R. Souleyrette, D. Ormand, and N.R. Hawkins. —“An Analysis of the Safety Effectiveness of Pavement Marking Retroreflectivity.” 87<sup>th</sup> Annual Meeting of the Transportation Research Board, Transportation Research Board, Washington, D.C., 2008.
118. *The Traffic Safety Toolbox*. Institute of Transportation Engineers, Washington, DC, 1999, p. 3-14.

119. Maryland Department of Transportation State Highway Administration. *Managing Highway Access*. <http://www.sha.state.md.us/businesswithsha/permits/ohd/02.asp>. Accessed October 5, 2008.
120. Zegeer, C.V., J.M. Twomey, M.L. Heckman, and J.C. Hayward. *Safety Effectiveness of Highway Design Features: Volume II, Alignment*, FHWA-RD Report 91-045, Federal Highway Administration, Washington, DC, 1992.
121. Glennon, J.C. —Effect of Alignment on Highway Safety,” *State-of-the-Art Report 6*, Transportation Research Board, Washington, D.C., 1987.
122. Lamm, R., B. Psarianos, and T. Mailaender. *Highway Design and Traffic Safety Engineering, Handbook*, McGraw Hill. 1999.
123. Mullins, B.F.K. and J.F. Keese. *Freeway Traffic Accident Analysis and Safety Study*, Highway Research Board Bulletin 2915, Highway Research Board, 1961.
124. Wooldridge, M.D., K. Fitzpatrick, D.W. Harwood, I.B. Potts, L. Elefteriadou, and D.J. Torbic. *NCHRP Report 502: Geometric Design Consistency on High-Speed Rural Two-Lane Roadways*. National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2003.
125. NCHRP 500 Series, *Volume 1-21*, Transportation Research Board. <http://www.trb.org/news/blurbs/browse.asp?id=2>. Accessed December 26, 2008.
126. Skabardonis, A., K. Petty, P. Varaiya, and R. Bertini. —Evaluation of the Freeway Service Patrol (FSP) in Los Angeles.” *PATH Research Report*. UCB-ITS-PRR-98-31.
127. Dougald, L.E., and M.J. Demetsky. —Assessing Return on Investment of Freeway Safety Service Patrol Programs.” 87<sup>th</sup> Annual Meeting of the Transportation Research Board, Transportation Research Board, Washington, D.C., 2008.
128. Steven P. L., P. Raktim, C. S. Kumares. —Cost Effectiveness Evaluation of Hoosier Helper Freeway Service Patrol.” *Journal of Transportation Engineering*, Vol. 125, No. 5, September/October 1999, pp. 429-438.
129. Tennessee Strategic Highway Safety Committee. *State of Tennessee Strategic Highway Safety Plan*. Tennessee Department of Transportation. June, 2007.
130. Epstein, K., G. Corino, D. Neumann. *National Review of the Highway Safety Improvement Program*. March/April 2002. <http://www.tfhr.gov/pubrds/02mar/04.htm>. Accessed October 5, 2008.
131. *Road Safety Audit*, Austroads, Sydney, Australia, 1994.
132. U.S. Department of Transportation, Federal Highway Administration (FHWA). *Road Safety Audits*. <http://safety.fhwa.dot.gov/rsa/index.htm>. Accessed October 5, 2008.
133. Rakha, H., A.M. Flintsch, M. Arafeh, A.G. Abdel-Salam, D. Dua, and M.M. Abbas. —Access Control Design on Highway Interchange.” 87<sup>th</sup> Annual Meeting of the Transportation Research Board, Transportation Research Board, Washington D.C., 2008.

134. Golob, T.F., W.W. Recker, and V.M. Alvarez. —Safety Aspects of Freeway Weaving Sections.” *Transportation Research. Part A: Policy and Practice* Vol. 38 No. 1, 2003.
135. Federal Highway Administration (FHWA). *Interactive Highway Safety Design Model (IHSDM)*. <http://www.tfhrc.gov/safety/ihsdm/ihsdm.htm>. Accessed September 20, 2008.
136. Daniels, G., D. Ellis, and W. Stockton. *Techniques for Manually Estimating Road User Costs Associated with Construction Projects*. Texas Transportation Institute, The Texas A&M University System, College Station, TX, December 1999.
137. Anderson, S. and I. Danjanovic. *Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion*. NCHRP Synthesis 379, Transportation Research Board, Washington, D.C., October 2008.
138. Assaf, G.J., R. Haas, and C. Bergeron. *Cause Oriented Deterioration Modelling for Urban Pavement Management*. Innovations in Urban Infrastructure, NRCC, 1997.
139. Miller, J.S., and W. Bellinger. *Distress Identification Manual for the Long-Term Pavement Performance Program*. FHWA-RD Report 03-031, Federal Highway Administration, Washington, D.C., June 2003.
140. Gransberg, D. and M. Zaman. —Analysis of Emulsion and Hot Asphalt Cement Chip Seal Performance.” *Journal of Transportation Engineering*, 131(3), pp. 229-238, 2005.
141. Wardhana, K. and F. Hadipriono. —Analysis of Recent Bridges Failure in the United States.” ASCE, *Journal of Performance of Constructed Facilities*, Vol. 17, Iss. 3, pp. 144-150, August 2003.
142. Sinha, K.C. and S. Labi. *Transportation Decision Making: Principles of Project Evaluation and Programming*. 2007.
143. Turner, S.M., M.E. Best, and D.L. Shrank. *Measures of Effectiveness for Major Investment Studies*. SWUTC Report 96/467106-1, Southwest Region University Transportation Center, Texas Transportation Institute, The Texas A&M University System, College Station, TX, 1996.
144. FHWA, Office of Asset Management. —Pavement Preservation Definitions,” Memo issued by Director, September 12, 2005.
145. Berger, R.H. and S. Gordon. *Extending Service Life of Existing Bridges*. Transportation Research Board, Washington, D.C., September 1978.
146. Mamlouk, M.S. and J.B. Zaniewski. —Pavement Preventive Maintenance: Description, Effectiveness, and Treatments.” *Flexible Pavement Rehabilitation and Maintenance, ASTM STP 1348*. American Society of Testing and Materials, 1998.
147. Davies, R.M. and J. Sorenson. —Pavement Preservation: Preserving Our Investments in Highways.” *Public Roads*, January 2000.

148. City of Houston/ETJ. Planning and Development Department, City of Houston. [http://www.houston.tx.gov/planning/Annexation/etj\\_city\\_11x8.pdf](http://www.houston.tx.gov/planning/Annexation/etj_city_11x8.pdf). Accessed July 5, 2009.
149. Slotboom, E. —Chapter 4: The Spokes,” *Houston Freeways – A Historical and Visual Journey*, 2003, pp. 205 – 216. <http://houstonfreeways.com/ebook.aspx>. Accessed March 15, 2009.
150. Houston Chronicle Archives. —Energy Corridor’s Leasing Booming, with More to Come.” [http://www.chron.com/CDA/archives/archive.mpl?id=2001\\_3332732](http://www.chron.com/CDA/archives/archive.mpl?id=2001_3332732). Accessed March 23.
151. Mounce, J.M. and N.M. Kuo. —Birth of a Transitway: Katy Freeway (I-10W), Houston, TX.” *Transportation Research Record 1051*. Transportation Research Board, Washington D.C., 1986, pp. 13 – 22.
152. Turnbull, K. F. *Houston Managed Lanes Case Study: The Evolution of the Houston HOV System*. FHWA-OP Report 04-002, Texas Transportation Institute, The Texas A&M University System, College Station, TX, September 2003.
153. —I-10/Katy Freeway Grand Opening.” Texas Department of Transportation, Austin, TX. <http://www.katyfreeway.net/GrandOpening/index.asp>. Accessed March 20, 2009.
154. Mullins, J.A. III, E.J. Washington, and R.W. Stokes. —Land Use Impacts of the Houston Transitway System.” The 68th Transportation Research Board Annual Meeting, Washington, D. C., 1989.
155. Christiansen, D.L. and S.E. Ranft. *The Katy Freeway Transitway, Evaluation of Operations During 1987, the Third Year of Operation*. FHWA/TX Report 88/339-15F, Texas Transportation Institute, The Texas A&M University System, College Station, TX, June 1988.
156. Houston Chronicle Archives. —Katy Transitway saves time, but is underused by vans, car pools.” [http://www.chron.com/CDA/archives/archive.mpl?id=1985\\_21980](http://www.chron.com/CDA/archives/archive.mpl?id=1985_21980). Accessed April 2, 2009.
157. Houston Chronicle Archives. —3-person car pools get Katy OK.” October 1985. [http://www.chron.com/CDA/archives/archive.mpl?id=1985\\_224121](http://www.chron.com/CDA/archives/archive.mpl?id=1985_224121). Accessed April 2, 2009.
158. Christiansen, D.L. and W.R. McCasland. *Options for Managing Traffic Volumes and Speeds on the Katy Transitway*. FHWA/TX Report 88/484-6, Texas Transportation Institute, The Texas A&M University System, College Station, TX, April 1988.
159. Houston Chronicle Archives. —Solo transitway.” December 1988. [http://www.chron.com/CDA/archives/archive.mpl?id=1988\\_591719](http://www.chron.com/CDA/archives/archive.mpl?id=1988_591719). Accessed April 2, 2009.

160. Houston Chronicle Archives. —Metro ends Katy Transitway access for 2-person car pools.” October 1988. [http://www.chron.com/CDA/archives/archive.mpl?id=1988\\_576335](http://www.chron.com/CDA/archives/archive.mpl?id=1988_576335). Accessed April 2, 2009.
161. Houston Chronicle Archives. —Metro officials fear congestion on Katy.” November 1986. [http://www.chron.com/CDA/archives/archive.mpl?id=1986\\_423896](http://www.chron.com/CDA/archives/archive.mpl?id=1986_423896). Accessed April 2, 2009.
162. *Final Environmental Impact statement Summary*. Texas Department of Transportation, Austin, TX. [http://www.katyfreeway.org/EIS\\_Summary.pdf](http://www.katyfreeway.org/EIS_Summary.pdf). Accessed April 6, 2009.
163. *Houston Land Use and Demographic Profile 2000*. Planning and Development Department, City of Houston, TX, 2003. <http://www.houstontx.gov/planning/GIS/GIS.htm>. Accessed June 22, 2009.
164. —Interstate 10 West Construction – Historical Information.” Interstate 10 West Construction Update Center, West Houston Association. [http://www.westhouston.org/i-10\\_historical\\_info.htm](http://www.westhouston.org/i-10_historical_info.htm). Accessed July 6, 2009.
165. *Building a Legacy: the IH 10 West Katy Freeway Story*. Parsons Brinckerhoff. December 2008. [http://www.katyfreeway.org/GrandOpening/Katy\\_Video\\_Booklet.pdf](http://www.katyfreeway.org/GrandOpening/Katy_Video_Booklet.pdf). Accessed June 25, 2009.
166. *Major Investment Study (MIS)*. Texas Department of Transportation, Austin, TX. <http://www.katyfreeway.org/mis.html#alt%20developed>. Accessed April 5, 2009.
167. *Intermodal Surface Transportation Efficiency Act of 1991 – Summary*. National Transportation Library. <http://ntl.bts.gov/DOCS/ste.html>. Accessed April 5, 2009.
168. *A Guide to Metropolitan Transportation Planning Under ISTEA - How the Pieces Fit Together*. FHWA-PD Report 95-031, Federal Highway Administration, Federal Transit Administration, Washington, D. C., July 1995. <http://ntl.bts.gov/DOCS/424MTP.html>. Accessed April 5, 2009.
169. *Reevaluation of the Final Environmental Impact Statement for IH 10 West: From Taylor Street to FM 1489*. Texas Department of Transportation, Austin, TX, January 2003.
170. —Landscape: Green Ribbon Project.” Texas Department of Transportation, Austin, TX. [http://www.katyfreeway.org/green\\_ribbon.html](http://www.katyfreeway.org/green_ribbon.html). Accessed April 6, 2009.
171. —Construction Packages – Katy Freeway Reconstruction Program.” Katyfreeway.org. Last revised November 5, 2008. <http://www.katyfreeway.org/contracts.html>. Accessed June 23, 2009.
172. —I10/Katy Freeway Grand Opening.” Katyfreeway.org. <http://www.katyfreeway.org/GrandOpening/index.asp>. Accessed April 5, 2009.
173. —Contract C1 Before/after Rendering.” Katyfreeway.org. [http://www.katyfreeway.org/ContractC1\\_SH6.html](http://www.katyfreeway.org/ContractC1_SH6.html). Accessed March 20, 2009.

174. —Contract D Final Build Out.” Katyfreeway.org.  
[http://www.katyfreeway.org/ContractD\\_final.html](http://www.katyfreeway.org/ContractD_final.html). Accessed March 20, 2009.
175. —Katy Freeway Construction.” Houstonfreeways.com. July 2008.  
[http://www.houstonfreeways.com/modern/2008-07-06\\_katy\\_freeway.aspx](http://www.houstonfreeways.com/modern/2008-07-06_katy_freeway.aspx).  
 Accessed April 6, 2009.
176. —Katy Freeway Managed Lanes: Frequently Asked Questions.” Harris County Toll Road Authority. <http://www.h-gac.com/tag/managedlanes/docs/KatyLanesFAQsFINAL.PDF>. Accessed July 12, 2009.
177. —Houston TranStar Speed Charts.” Houston TranStar.  
<http://traffic.houstontranstar.org/speedcharts/>. Accessed July 13, 2009.
178. —Katy Freeway Managed Lanes: Interactive Map.” Harris County Toll Road Authority. [https://www.hctra.org/katymanagedlanes/managed\\_lanes\\_map.html](https://www.hctra.org/katymanagedlanes/managed_lanes_map.html). Accessed July 11, 2009.
179. —Major Thoroughfare and Freeway Plan Policy Statement.” Planning and Development Department, City of Houston.  
<http://www.houstontx.gov/planning/DevelopmentRegs/mobility/MTFP.htm>.  
 Accessed July 14, 2009.
180. —2008 Major Thoroughfare and Freeway Plan.” Planning and Development Department, City of Houston, 2008.  
<http://www.houstontx.gov/planning/DevelopmentRegs/MTFP.htm>. Accessed July 13, 2009.
181. Houston TranStar. <http://traffic.houstontranstar.org/layers/>. Accessed July 14, 2009.
182. Templeton, B. F. —Best of the Best? *Public Roads* 68 (6), Federal Highway Administration, May/June 2005. <http://www.tfhrc.gov/pubrds/05may/04.htm>. Accessed April 20, 2009.
183. —Highway Designation He.” Texas Department of Transportation, Transportation Planning and Programming Division.  
<http://www.dot.state.tx.us/tpp/hwy/sh/sh0105.htm>. Accessed May 29, 2009.
184. Volumetric Survey of Lake Conroe, *History and General Information of the Reservoir*. Texas Water Development Board, March 2003.  
[http://www.twdb.state.tx.us/hydro\\_survey/conroe/ConroeRPT.pdf](http://www.twdb.state.tx.us/hydro_survey/conroe/ConroeRPT.pdf). Accessed May 29, 2009.
185. *Environmental Assessment, SH 105 from FM 149 to Loop 336*. State Department of Highways and Public Transportation, November 2, 1988.
186. Public Hearing Summary, Project to Widen SH 105 from FM 149 to Loop 336 (West), Conroe High School auditorium, February 28, 1989.
187. —Community Development: Planning,” *Within the Extraterritorial Jurisdiction (ETJ) Area*. <http://www.cityofconroe.org/content/view/154/499>. Accessed May 14, 2009.



188. *Strategic Plan – 2009 Through 2013 – Texas Department of Transportation*. Texas Department of Transportation.  
[http://www.dot.state.tx.us/publications/government\\_and\\_public\\_affairs/strategic\\_plan/](http://www.dot.state.tx.us/publications/government_and_public_affairs/strategic_plan/). Accessed July 22, 2009, p. 30.

