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With the continued increase of demand on Texas highways, the consumption rate of our roads will accelerate due to the constrained funding for maintenance. Our highways represent a multi-billion dollar investment in our transportation system. Given the extent of the Texas highway network, ports, and the border it shares with Mexico, the state of our roads can affect the nation's economy if they are not properly maintained. Yet various studies have indicated that insufficient revenue is available to pay for the maintenance and rehabilitation (M&R) work required to keep the overall condition of the state-maintained highway system at the current target condition level. TxDOT must develop new and innovative ways to ensure that our highways fulfill their role in helping Texas maintain its economic competiveness with a safe, reliable, and economical highway transportation system. To address these funding issues, this report proposes an integrated approach based on a tiered system of roadways in which the finance, maintenance, and operation of the system are considered simultaneously.</td></tr>
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"Gentlemen, we are out of money. We shall have to think."

—Address to Parliament by Winston Churchill

1 Introduction

The budget shortfall in Texas for 2011 was as high as $27 billion. The funding for the Texas Department of Transportation (TxDOT) comes primarily from the revenues generated by the motor fuel tax. This tax has not been increased since the early 1990s. Therefore, the purchasing power has significantly eroded over the last two decades. Furthermore, the state has experienced a 57 percent increase in population, while the road capacity has increased by only 8 percent [About Toll Roads, 2012]. The population increase has not translated into additional revenue for TxDOT due to the increased use of more fuel-efficient vehicles. Over the next 25 years, population growth in Texas is expected to reach 64 percent. If the current funding trend continues, road capacity will increase by only 6 percent, according to the Texas Comptroller of Public Accounts. In other words, the trend will continue in which we have more cars on the road but they are contributing less money towards the maintenance of our highways each year.

With the continued increase of demand on Texas highways, the consumption rate of our roads will accelerate because of the constrained funding for maintenance. Our highways represent a multi-billion dollar investment in our transportation system. Given the extent of the Texas highway network, ports, and the border it shares with Mexico, the state of our roads can affect the nation's economy if they are not properly maintained [Combs, 2008]. By failing to maintain roadways, not only do we risk losing a significant amount of our highways' serviceability and mobility, we are also putting Texans' lives at greater risk. TxDOT must develop new and innovative ways to ensure that our highways fulfill their role in helping Texas maintain its economic competiveness with a safe, reliable, and economical highway transportation system.

The entire TxDOT road network requires ongoing infrastructure preservation. TxDOT maintains approximately 192,000 lane miles of paved roadway, including more than 50,000 bridges. For such a geographically extensive network, the preservation activities create significant financial needs. With growing needs and limited resources, TxDOT needs to rethink the way it conducts business to optimize its pavement and bridge infrastructure needs.

The goal set by the Texas Transportation Commission (TTC) was to preserve the asset value of all pavements by maintaining a "good" or better pavement condition score on 90 percent of Texas roads. A recent study carried out to evaluate Texas pavement maintenance needs by the year 2030 estimated that achieving and maintaining this goal would require about $3.5 billion per year on average [2030 Committee, 2009].

With the current funding allocations, pavement condition scores are projected to drop below 50 percent by 2018.

Figure 1 illustrates the funds needed for pavement preservation to attain and maintain a 90 percent "good" or better condition between 2009 and 2030. Based on the funding projection conducted by TxDOT, the available funding in the next 20 years is clearly insufficient to achieve and maintain the 90 percent "good" or better pavement condition goal [Zhang et al., 2011].

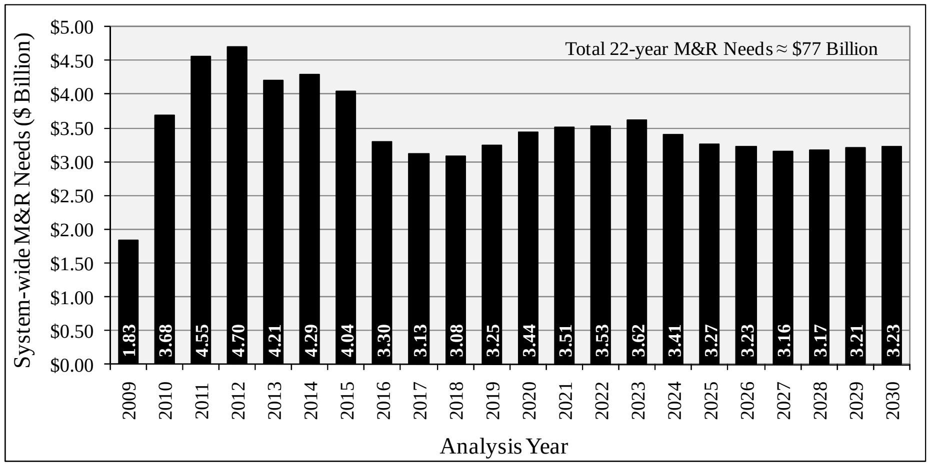


Figure 1. Annual Maintenance and Rehabilitation Needs to Attain and Maintain 90% "Good" or Better Condition [Zhang et al., 2011]

More specifically, with the current funding allocations and projections, the "good" or better pavement score will drop below 80 percent by FY 2012; by FY 2018, the score will drop below 50 percent. The "good" or better pavement condition scores are projected at 65.43, 33.72, 20.65, 13.56, and 6.94 percent for FY 2015, FY 2020, FY 2025, FY 2030, and FY 2035, respectively, as shown in Figure 2.

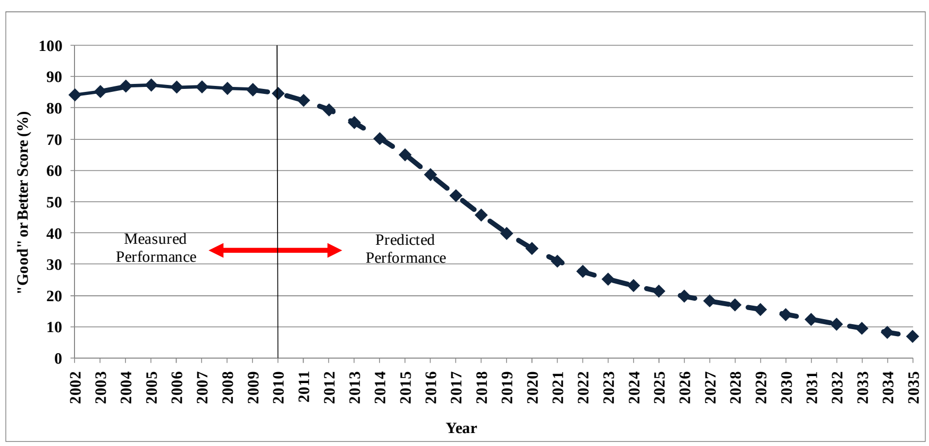


Figure 2. Predicted Pavement Performance Trend for FY 2010 to FY 2035 Based on TxDOT Funding Projections [Zhang et al., 2011]

Based on the details presented, it is clear that insufficient revenue is available to pay for the maintenance and rehabilitation (M&R) work required to keep the overall condition of the state-maintained highway system at the current target condition level. This situation necessitates a review of the state's highway infrastructure needs, classifying the transportation facility and service needs by interest and use.

To address these funding issues, this report proposes an integrated approach based on a tiered system of roadways in which the finance, maintenance, and operation of the system are considered simultaneously. This system is detailed in later sections of this report.

1.1 Problem Statement

The efficiency of the Texas transportation system, particularly its highways, is critical to the state's economic health. As Texas becomes the nation's second largest economy, businesses are increasingly reliant on an efficient and reliable transportation system to move products and services [Cauchon, 2011]. However, the average gap between projected revenues and minimum investment needs is several billions per year. In this situation, finding proper finance alternatives and maintenance strategies for the state's pavements and bridges requires fresh perspectives, obtained by looking simultaneously at the problem in terms of maintenance, finance, and operations. The additional funds generated through these finance and maintenance alternatives would be reinvested into the pavements and bridges maintenance programs.

Under current funding levels, the share of state-maintained roads and highways with pavements in "good" or better condition will decrease from 86 percent in 2010 to 21 percent by 2025.

1.1.1 Increasing Travel Demand

Despite the current economic downturn, population increases and economic growth in Texas over the past two decades have resulted in increased demands on the state's major roads and highways. The Texas population reached 24.8 million in 2009, an increase of 46 percent since 1990. The state's population is expected to increase to 31.8 million by 2030 [TRIP, 2010]. Vehicle travel in Texas increased 45 percent from 1990 to 2008—from 162.2 billion vehicle miles traveled (VMT) in 1990 to 234.6 billion VMT in 2008. By 2025, vehicle travel in Texas is projected to increase by another 40 percent [TRIP, 2010]. Texas is also home to 9 of the nation's 85 urban areas. Studies show that in 2005 4.2 billion hours were spent in Texas traffic congestion, meaning that each traveler wasted approximately 38 hours [Combs, 2008].

1.1.2 Deteriorating Infrastructure

Based on current funding projections, pavement and bridge conditions are expected to deteriorate significantly in the future. A report from the national transportation research group TRIP, *Future Mobility in Texas: Meeting the State's Need for Safe and Efficient Mobility*, finds that 11 percent of state-maintained roads and highways provide motorists with a rough ride [TRIP, 2011]. The Center for Transportation Research

(CTR) at The University of Texas at Austin estimates that, at current funding levels, the share of state-maintained roads and highways with pavements in "good" or better condition will decrease from 86 percent in 2010 to 21 percent by 2025 [Zhang et al., 2011].

The TRIP report further estimates that 3 percent of Texas bridges are "structurally deficient," meaning the bridge deck, supports, or other major components show substantial deterioration. An additional 14 percent of bridges are functionally obsolete. These bridges no longer meet current highway design standards, often because of narrow lanes, vehicle configurations, inadequate clearances, or poor alignment with the approaching road.

"Texas will need $74.9 billion in order to keep its road at the 2010 condition in the next 25 years."
—Texas 2030 Committee

1.1.3 Funding Gap

According to the findings from the recent study conducted by the Texas 2030 Committee, Texas will need $74.9 billion to keep its roads at the 2010 condition in the next 25 years. The Committee also reported that as the funding gap increases, tax revenues decline, and the state population grows annually, Texas will need $270 billion between 2011 and 2035 to maintain the state's transportation system at its 2010 condition [2030 Committee, 2009].

1.2 Ideas for Generating Transportation Funds

Over the last decade, transportation agencies have seen a considerable decrease in available funds to maintain the highway infrastructure. Most states are searching for alternative sources and mechanisms to fund transportation needs. The National Surface Transportation Infrastructure Financing Commission noted in its 2008 interim report that the current levels of taxes are inadequate for funding the maintenance—let alone the improvement—of the system. It also indicated that the current funding mechanisms and levels of revenue were not closely linked to the actual usage of the transportation system, thus allowing the demand and costs to grow faster than revenue. Following are a few ideas to generate transportation funds.

1.2.1 Increasing Fuel Taxes

Although the federal gas tax has not deviated from 18.4¢ per gallon for over 15 years, at least 15 states have increased their state gas taxes [Texas Good Roads, 2012]. But further increasing the gas tax will be a challenge that requires the understanding of the general public and actions from the legislature. In addition, the buying power of the fuel tax has fallen because of inflation and reductions in fuel consumption due to fuel-efficient cars and cutbacks on driving as prices have increased. Some studies indicate that linking user payments with actual road use through tolls, congestion fees, and VMT charges are a precise and fairer way of reflecting highway usage [(TRB, 2006), (Frisman, 2012)].

Theoretically, many options might present themselves; practically, however, the choices could be very limited.

1.2.2 Raising Vehicle Registration Fees

Although registration fee adjustments are very promising both for short- and long-term revenue, actions to increase registration fees in some states have received severe opposition. For example, Idaho was forced to abandon its proposal for raising vehicle fees after a critical reception from the public and legislators. Nonetheless, some states are clearly considering vehicle registration fees and other highway user taxes a part of the revenue. Kansas, South Dakota, and Colorado have all increased registration fees to fund transportation investments in their state in 2009 [TTI 2013]. The National Surface Transportation Infrastructure Financing Commission has identified vehicle registration, heavy vehicle user taxes, sales taxes, and tire taxes as potential transportation funding mechanisms.

1.2.3 Public-Private Partnership (PPP)

A public-private partnership, commonly known as a PPP, features collaborations between the government and private companies that aim to improve public services and infrastructure by capturing the efficiencies associated with private sector involvement while maintaining the public accountability of government involvement. The Office of Innovative Program Delivery (IPD) under the Federal Highway Administration (FHWA) defines PPPs for “new build facilities” and “existing facilities.” IPD categorizes PPP for new build facilities as “Design Build,” “Design Build Operate,” and “Design Build Finance Operate” and for existing facilities as “O&M (Operate and Maintain) Concession” and “Long Term Lease.”

Over the last 15 years numerous PPPs have developed on new and existing facilities along new terms of agreement. In some cases, the purpose is to use existing assets to generate funds (asset monetization), such as with the Chicago Skyway. In other cases, PPPs are used to develop greenfield (i.e., new construction) projects (e.g., South Bay Expressway in San Diego, CA) or to rehabilitate and expand existing facilities (e.g., the Capital Beltway high-occupancy toll lanes in Northern Virginia) [FHWA 2013]. This private interest indicates that private financing is a possible solution to the funding gap faced by transportation agencies.

1.2.4 Direct User Fees

As states consider new mechanisms to close funding gaps, one option that should be considered is linking the user payments more closely to actual road use. Mark Florian, the head of investment banking at Goldman Sachs, told Congress in 2008 that the current funding mechanism is not directly linked to the use of the transportation system, allowing demands and costs for a given asset to grow faster than the revenue that funds it [Slone, 2010]. Examples of direct user fees include tolling, congestion pricing, and VMT.

(a) Tolling

In 2004, state and local governments used $6.6 billion in toll revenues for highway investments, which is 7 percent of total revenues used for highways at state and local levels [Cambridge Systematic et al., 2006]. Tolling on existing roads is challenging and is mostly prohibited on the interstate system. However, Moving Ahead for Progress in the 21st Century (MAP-21), the new transportation bill, provides more flexibility for states to toll interstate roads. Missouri, Virginia, and North Carolina are the three states that have been allowed to pursue tolling on existing interstates under the Federal Highway Administration Interstate System Reconstruction and Rehabilitation Pilot Program [Tanner, 2012]. Some grants given by state DOTs offer a considerable amount of funding in return for speedy construction, free transit usage, and the resulting traffic decongestion. In addition to this pilot program, states have been able to toll existing interstates by opening high-occupancy toll (HOT) lanes, while keeping general purpose lanes available. These projects have used congestion tolling as a means to control the average speed on the HOT lanes. AASHTO has voiced its support of tolling existing roadways in response to the declining funding provided by the state and national gas tax [AASHTO Journal, 2012]. Several other states are considering it as a policy. Florida has derived as much as 11 percent of its revenue from tolls [Cambridge Systematic et al., 2006]. Texas has already begun tolling some existing interstate lanes. For example, an 11-mile stretch on IH 10 in Houston already implements managed lanes and tolling projects have begun for IH 45, US 290, and US 59. Around 83 miles of highway will have the option of HOT lanes for motorists when the projects are completed [Samuel, 2011].

Toll Operations

Two types of toll operations are in use today. The first is the traditional tolling method: using toll stations operated by toll booth employees. This method requires the user to come to a stop and pay the toll fee. With recent technological advancements, this form of toll operation is becoming outdated as it significantly contributes to congestion and overall inefficiency of the transportation system. The more common method in practice today is open road tolling (ORT). ORT uses overhead gantries that contain radio frequency readers and video cameras to collect toll fees. This method allows the highway to flow freely with no delay. Users have the option of using a transponder, such as TxTag, or having a picture of their license plate taken to be billed later. Users without a transponder are generally charged a higher fee for passing through the gantry.

Benefits to ORT

ORT allows traffic to flow freely without delay, which reduces congestion and increases user convenience and safety by keeping motorists driving at a constant speed. Decreases in congestion and increases in efficiency allow users to reduce their travel times, resulting in a reduction of harmful gas emissions, which are a major cause of pollution. In addition, toll operating costs are decreased because this system does not require toll booth employees [North Carolina Turnpike Authority, 2011].

(b) Congestion Pricing

A funding mechanism that seeks to assess vehicles for the cost they impose on society (which may include time cost, congestion, and other variable costs such as environmental and governmental) is known as *congestion pricing*. The fees can be based either on time of day or on level of congestion. Experts believe that these pricing schemes affect congestion in several ways, such as number of trips, total miles travelled, routes taken by travelers, times of trips, and carpooling and transit usage. In addition, congestion pricing gives the operator the ability to control pricing based on the average speed. Orange County, California, provides an example of road pricing operated by a private firm. The tolls are based on time of day; revenues in excess of $44 million were received in 2006 [OCTA, 2006]. San Diego, California, has generated revenues up to $750,000 per year in operating costs with congestion pricing, which also provides $60,000 per year for enforcement [Randy Corporation et al., 2007]. Congestion pricing has also been practiced on sections of city roads. For example, London charges 8 pounds per day for city road usage. Research on this particular network found a 20–30 percent decrease in congestion during the first 3 years of implementation. In 2007, the last year of the pricing impact study, the network generated 137 million pounds in revenue. In addition to the congestion charge revenue, bus ridership increased by about 25 percent [Transport for London, 2008].

(c) Vehicle Miles Traveled (VMT) Charges

The Oregon Department of Transportation launched a pilot program in 2006 to assess the potential feasibility of replacing the gas tax with VMT charges collected at gas stations or through an online payment system. The pilot program found VMT to be a successful replacement for the current gas tax system. Ninety-one percent of participants agreed to pay VMT charges instead of gas tax. In addition, raising the VMT charge based on inflation would be much easier than increasing the gas tax. The gas tax can be changed only through legislation, while VMT charges are contingent on inflation adjustments.

The VMT system is implementable through a number of different methods [Oregon's VMT Fee Program, 2009]. One method is to install transponders in every vehicle while electronic readers set up along roadways continuously record mileage. This method allows for peak congestion management as an option, as well as charging for high-density areas and roads traveled. VMT can also be tracked on direct lane basis, known as *fine resolution*, or a zone basis, known as *coarse resolution*. Trackers installed with GPS would locate the vehicle at all times [Sorensen, 2010]. The idea of tracking drivers caused some uneasiness; however, studies show that concerns with privacy can be addressed and user privacy can be protected [Sorensen, 2010]. The VMT charge is still a highly plausible method to generate funds for roadway maintenance; usage fees would be similar to those in the tolling system.

2 Strategic Plan

This report proposes integrating the maintenance, finance, and operations components of the transportation system, as illustrated in Figure 3, to determine the proper funding strategy for and maintenance level of existing infrastructure. In this proposed solution, user fees would provide enough revenue to make the most important part of the network self-sustainable. This approach would allow the remaining part of the systems to receive more state-appropriated funding, alleviating the burden of a shrinking transportation budget. The proposed integrated approach aims to maintain the state's economic competitiveness and support sustainable economic growth.

One viable solution to manage the Texas transportation system is the implementation of integrated maintenance, finance, and operations.

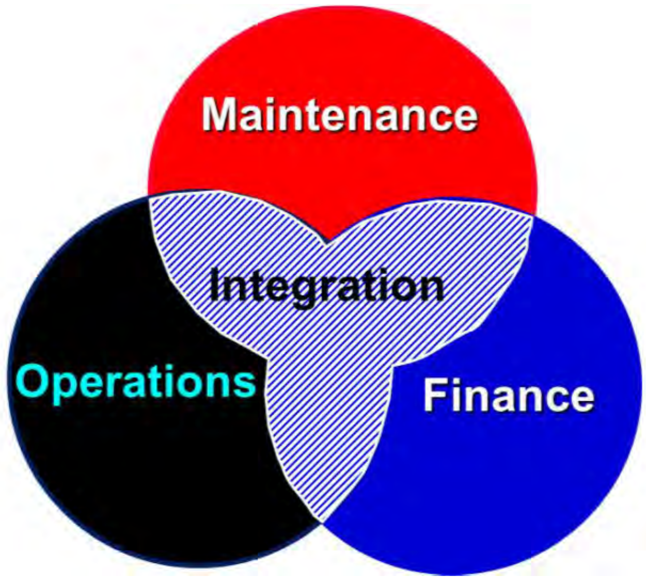


Figure 3. Concept of Integrated Maintenance, Operations, and Finance

2.1 Multi-Tier Systems

A single-tier system can work very well if the resources are sufficient to cover the entire network. However, when resources are constrained, hard decisions must be made in terms of which element of the road network should be given the priority. As performed under TxDOT research project 0-6655 (Zhang 2010), this process is usually accomplished by establishing a multi-tier system based on the relative importance of the road links in the network, where the resources are weighted more towards the road group or tier that is deemed the most important.

In conducting a multi-tier analysis, the first step is to define the tiers, using criteria such as highway functional class, average daily traffic (ADT), truck ADT, etc. A proposed three-tier system was initially selected for conducting the preliminary analysis. The three tiers—Backbone, Backup, and Connection—are shown in Table 1, along with the level of service and performance measures.

If TxDOT is going to manage the Texas transportation system as an asset, users should pay for usage at different levels of service, just as any provider charges for a service.

Table 1. Systems and Level of Service

System	Function Class	Goal Area			
		Safety	Mobility	Dependability	Confortability
Backbone	Premier				
Backup	Standard				
Connection	Basic				

Level of importance

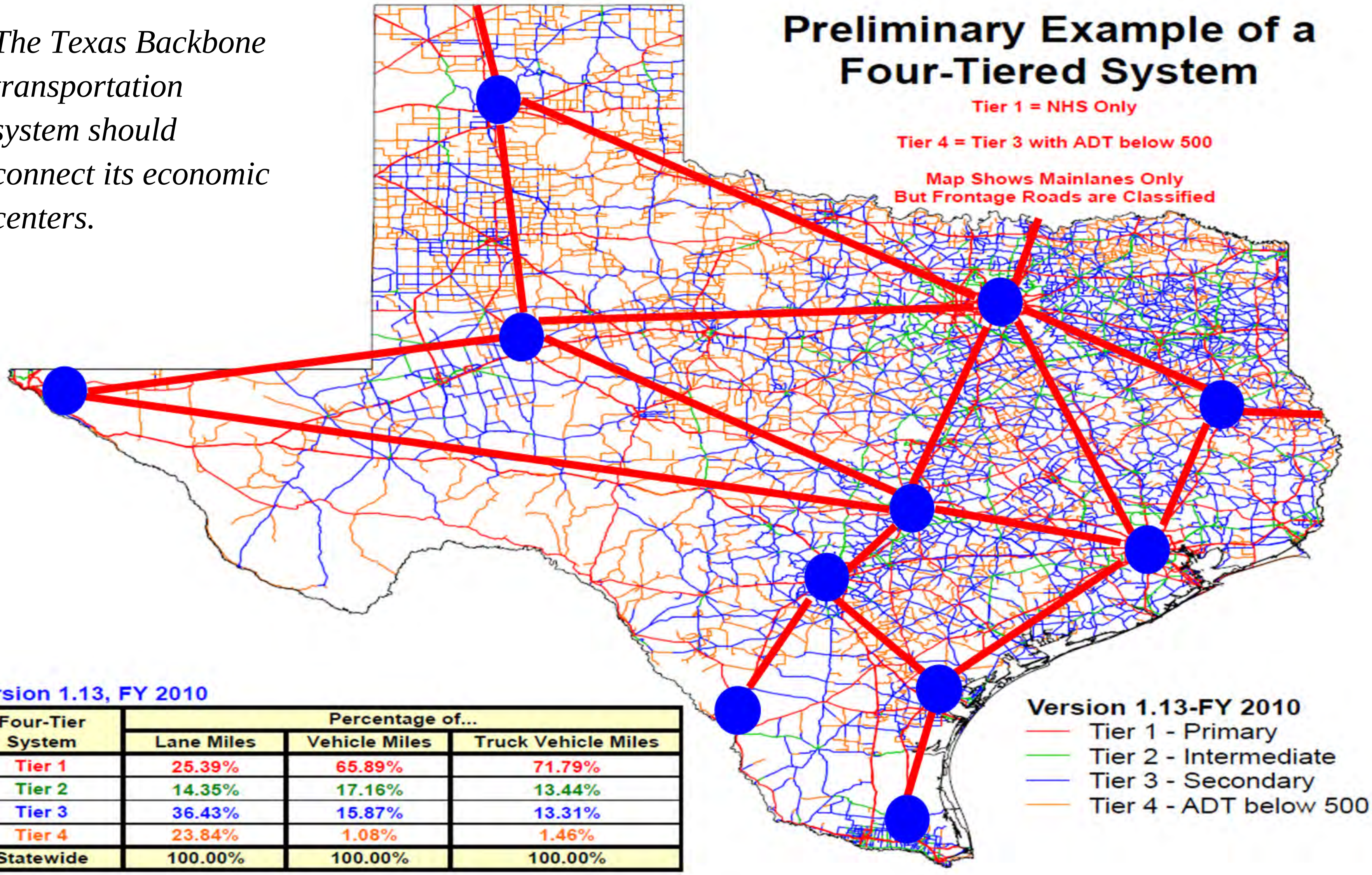
= High

= Medium

= Low

As illustrated in Figure 4, the *Backbone* system is defined as corridors that are essential to the economy of Texas. For example, this system would include Interstate 10 through the southern part of the state, Interstate 20 from east of the Dallas-Fort Worth (DFW) to Interstate 10 near Midland, along an extended Interstate 27 through western Texas, and a new terrain corridor along the northern Texas border paralleling sections of US 287 from Fort Worth to Amarillo. The level of service for the Backbone system would be defined as *Premier*, meaning that all measures (safety, mobility, dependability, and comfort) should be fully satisfied. The *Backup* and *Connection* road systems are defined as supplements to the Backbone system. The required levels of service for those two systems are not as strict as that of the Backbone system, as Table 1 indicates.

The Texas Backbone transportation system should connect its economic centers.



Version 1.13, FY 2010

Four-Tier System	Percentage of...		
	Lane Miles	Vehicle Miles	Truck Vehicle Miles
Tier 1	25.39%	65.89%	71.79%
Tier 2	14.35%	17.16%	13.44%
Tier 3	36.43%	15.87%	13.31%
Tier 4	23.84%	1.08%	1.46%
Statewide	100.00%	100.00%	100.00%

Figure 4. Illustration of the Backbone System

2.2 Levels of Service and Performance Measures

Performance measurement is a process for evidence-based decision-making and forecasting, as well as monitoring progress towards long-term goals and objectives. Performance measures should be identified in response to goals and objectives, rather than the other way around. This sequence helps to ensure that an agency is measuring the right parameters and that success on the measures will in fact lead to success in terms of goals and objectives.

The performance measures used in this report encompass a broad set of transportation goals, including safety, mobility, dependability, and comfort, as shown in Table 2. One way to support a performance-based level-of-service approach to infrastructure maintenance management is to establish a few overarching goals and identify supportive performance measures within each goal area. TxDOT could incorporate these goals and measures into its transportation planning process.

Performance should be measured with clearly defined criteria.

Table 2. Performance Measures

Goal Area	Criteria	Performance Measure
Safety	Accident reduction and health risks	Fatalities and injuries/vehicle-mile
Mobility	Efficiency in speed	Overall average speed (including delays)
Dependability	Consistency	Pavement or bridge condition rating, useful life of assets
Comfort	Roadway conditions and aesthetics	Roughness

As Table 2 shows, for safety we use fatalities and injuries per 100 million VMT. This performance measure has the ability to relate the safety of each highway to its usage. For mobility, we chose to use overall average speed. This measure shows the efficiency of highways and relates to the overall average delay. Dependability and comfort both are expressed through the condition of the pavement and bridges related to their life.

2.3 User Fees

This report suggests that user fees and user-fee backed public finance be considered potential solutions for TxDOT, as they could ensure a dedicated revenue source for transportation infrastructure and provide congestion relief through demand-based pricing. Specifically, direct user fees, or tolls, on the usage of the Backbone system could help

Texas meet the challenges of insufficient transportation funding and congestion. Tolling offers a dedicated revenue source that would be usage based, more reliable and, if appropriately structured, less susceptible to political intervention. With a dedicated revenue source in place, financing the state's roadways through the issuance of revenue bonds would become much easier.

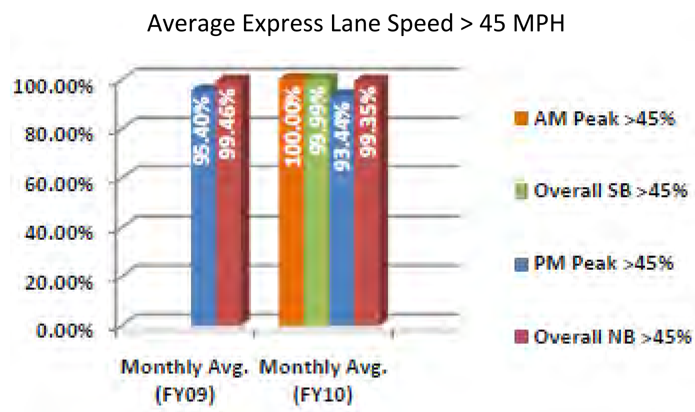
An important collateral benefit to rationing highway space with direct user fees is the potential to relieve congestion, keep the transportation system operating at higher speeds and efficiencies, and achieve environmental benefits through dynamic, demand-based pricing. Tolls would be set to rise and fall dynamically throughout the day, varying with fluctuations in user demand. For example, at midnight, when the road is not heavily used, potentially all lanes could be free. Then at 8:00 a.m., when traffic is at its worst, the toll may rise to $5 or higher. At 3:00 p.m., when traffic is relatively light, the toll might fall to $2.

All public transit could be exempt from direct user fees, resulting in less congestion, higher revenues for the Texas public transit system, and economic improvement. Drivers would have the option of traveling by bus, which reduces the volume of cars and pollution on the highways.

Case studies show that this approach has proven to be successful in other states.

2.3.1 IH 95 Express Lane Installment: Case Study 1

In Florida, the Florida DOT (FDOT) has completed Phase 1 of their congestion management program. Interstate 95, which runs along the east coast of the country, now has a 12-mile segment with managed lanes. The incentive for these toll lanes was to increase safety and reliability of mobility, and to meet the growing demands of traffic volume. Research on this newly implemented toll showed immediate signs of positive results. Tolls on IH 95 express lanes ranged from $0.25 to $6.00 in 2011. Additionally, that same year the revenue exceeded expectations by 15 percent. The express lanes were expected to maintain a speed of 45 miles per hour (MPH) or greater 90 percent of the time. The lanes ended up holding speeds above 45 MPH about 96 percent of the time. Figure 5 shows the results from the IH 95 express lanes. Note that during AM Peak rush hours the average MPH was above 45 100 percent of the time [FDOT, 2011].



Note: SB = Southbound; NB = Northbound

Figure 5. Reliability of Managed Lines [FDOT, 2011]

FDOT expects to see an increase in users but decrease in vehicle volume due to the tax exemption option for express lane users. High occupancy vehicles (HOV), registered public transportation vehicles, and motorcyclists receive a "zero toll" benefit. Studies on Florida's IH 95 express lanes show that public transit usage has already increased by 145 percent. In the long run, FDOT expects to see a decrease in harmful gas emissions because of this decrease in vehicle volume [FDOT, 2011].

2.3.2 IH 10 Katy Freeway Managed Lanes: Case Study 2

Katy Freeway is a 12-mile roadway section of managed lanes. This section primarily serves mass transit (METRO buses) and HOV needs during peak hours. Additionally, any unused lane capacity is made available to single drivers for a dynamic toll, keeping the traffic moving at target speeds. The Katy Managed Lanes toll rates vary by time of day, and follow a schedule that reflects traffic volumes. The toll for the entire section ranges from $1 to $5. Figure 6 shows a diagram of the project.

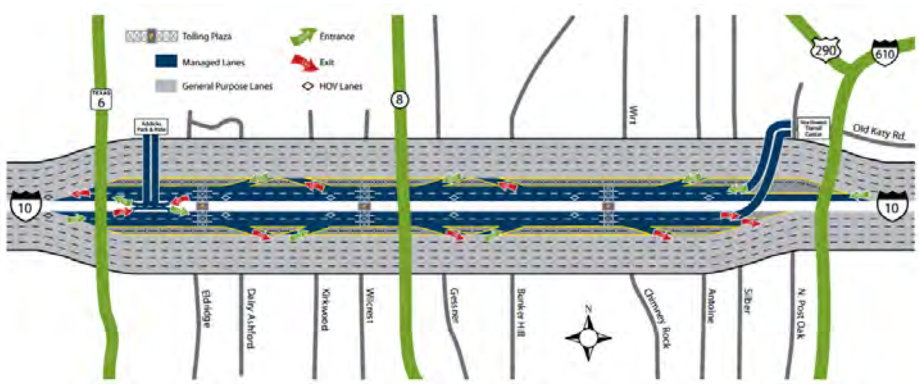


Figure 6. IH 10 Katy Freeway Managed Lines

3 Multi-Tier Network and Usage Fee Analysis

In order to implement a sound funding and maintenance strategy, the integrated approach outlined previously was analyzed. This analysis follows.

3.1 Multi-Tier Networks Defined

3.1.1 Economic Centers in Texas

Since the objective of the program is to support the state's economic growth, defining the networks should begin with identifying economic centers across the state. These major centers form the primary nodes of the Backbone network. Table 3 lists the economic indicators used to define economic centers in Texas.

Texas has clearly defined economic centers in the form of metro areas.

Table 3. Economic Indicators

Economic Indicators for Metro Areas			
Cities	**Max Truck Flow**	**Max AADT**	**GDP (millions of $ in 2010)**
Houston	17,500	108,000	384,600
DFW	20,600	40,000	374,100
Austin	21,100	126,000	86,000
San Antonio	19,000	121,000	82,000
El Paso	12,100	N/A	27,000
Corpus Christi	6,700	26,000	16,600
McAllen	16,500	N/A	13,900
Amarillo	14,600	25,000	9,700
Laredo	10,200	9,900	6,000
Abilene	10,000	20,000	5,400
Lufkin	6,400	45,000	-

Three primary criteria are used to define the economic centers of Texas. First, the gross domestic product (GDP) of each city is evaluated using the Bureau of Economic Analysis data provided by the U.S. Department of Commerce. This data provides a way to measure the economic impact of cities across the state. Next, we must take into account the annual average daily traffic (AADT) and the truck flow in each of these cities. This step helps us define the metro areas with the largest flow of vehicles passing in and out. Finally, we must consider geographic location. The network must include and connect all major areas of Texas. In addition to these three economic indicators, military installation locations need to be considered; these installations must be connected to the Backbone network of corridors with the Premier level of service.

3.1.2 Corridors Connecting Economic Centers

Once the nodes are clearly identified, the corridors can be defined by examining the existing travel routes. Table 4 shows the major roads connecting the metro areas previously selected, with their respective mileage. The Premier level of service on the Backbone network emphasizes efficiency and comfort. Therefore, the corridors must provide the most efficient means of travel, while also being the most comfortable way to travel. The interstate highways in Texas provide the best example of roadways with the Premier level of service.

Table 4. Highway Corridors

Major Roads	Mileage	Connecting Metro Areas
IH 35	370	Laredo, San Antonio, Austin, DFW
IH 20	500	El Paso, Abilene, DFW
IH 10	740	El Paso, San Antonio, Houston
IH 45	240	Houston, DFW
IH 27	120	Amarillo, Abilene
IH 37	140	Corpus Christi, San Antonio
US 281	70	McAllen, Corpus Christi
US 77	40	McAllen, Corpus Christi
US 83	180	McAllen, Laredo
US 287	250	Amarillo, DFW
US 84	110	Amarillo, Abilene
US 59	110	Lufkin, Houston
US 69	60	Dallas, Lufkin
US 175	40	Dallas, Lufkin

Figure 7 maps the travel routes connecting the most important metro areas in the state, where the size of the blue circular areas centered in each metro area is proportional to the GDP of the area. In addition, currently 11 areas have military installations in Texas. Of the 11, eight are connected in the proposed network corridors. Military bases, in some regions, provide the highest employment and funds for their metro area and thus represents an important influence on the location of the corridors. Finally, the size of the GDP in each network city is also shown in the map. Dallas and Houston have the largest GDP, while cities such as Lufkin have much smaller GDP.

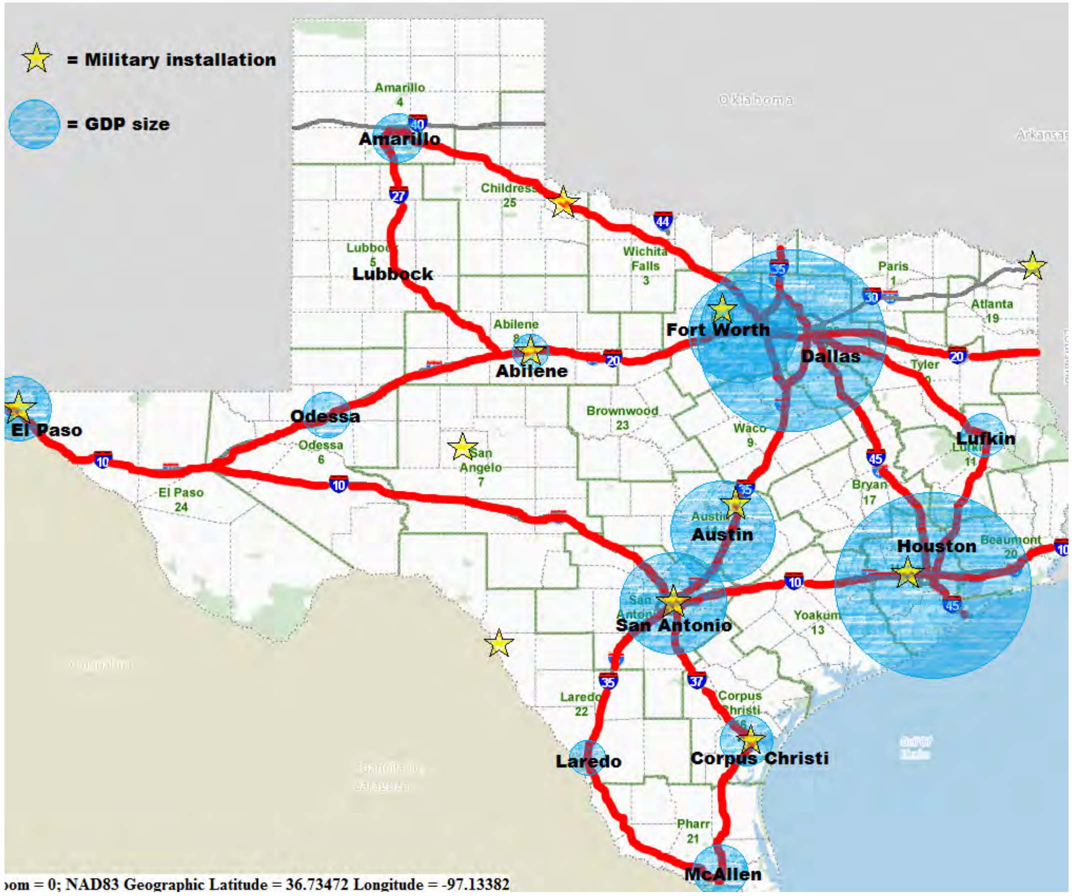


Figure 7. Backbone Network and Military Installations

3.1.3 Identifying the Tiers in the Highway Network

As part of the proposed approach, different levels of service have to be set for different tiers. Therefore, it is necessary to classify the networks into tiers. The primary tier (the Backbone network) will be maintained at the highest standard with the Premier level of service, as defined in Table 1. The second tier, composed of the frontage roads and other backup roads and so termed the Backup network, would provide connections parallel to the first tier. The third tier (the Connection network) is composed of small roads such as the Farm-to-Market (FM) and Ranch Roads (RR), providing basic level of services of connection. A basic level of service does not place an emphasis on efficiency or comfort.

3.2 Level-of-Service and Performance Measures

The strategic plan should include goals, levels of service, performance measures, and performance management, as illustrated in Figure 8. By establishing the goals, the transportation agencies recognize the need to improve areas at a global level. In this case four goals were defined:

safety, mobility, dependability, and comfort. In order to work towards the goals, the agency must define the levels of service that would be controlled by the performance measures. Then the performance management will assess how the decision-making process is working towards the goals. This process will assure that future planning and resource allocation will follow a performance-based process, which will enhance the agency's quality of performance management.

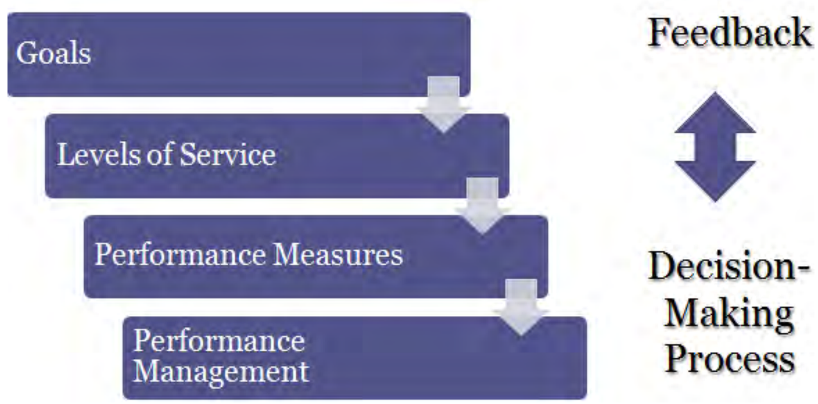


Figure 8. Strategic Plan Components

3.3 Determination of Usage Fees

If a portion of the network is maintained better than the other parts (such as the Backbone system), it will attract a larger portion of travelers, ultimately leading to congestion. Usage fees provide a mechanism to control usage on the primary tier and distribute the demand in the other tiers.

3.3.1 Proposed Usage Fees for General Usage

The registration fee would be used to fund the entire three-tiered system. The Backbone tier could charge a flat usage fee for general use and additional fees for usage during rush hours, as illustrated in Table 5. Depending on the AADT and stretch of the highway, anywhere between 5 and 20¢ per mile would be a valid charge for a general usage fee. This range of values is common in the United States. The longer the stretch of tolled highway, the lower the fee per mile should be. To determine the user fee, the cost of maintaining the Backbone network at 90 percent "good" or better on a 5-year horizon was analyzed.

Table 5. Proposed Usage Fees

System	Backbone	Backup	Connection
Level of Service	Premier	Standard	Basic
Normal Registration Fee	√	√	√
Fee for Usage (5–20¢ per mile)	√		
Fee at Rush Hour (0–30¢ per mile)	√		

3.3.2 Maintenance Cost Analysis

The cost to maintain both the Backbone network and the entire Texas road network at a 90 percent "good" or better grade was analyzed over a 5-year time frame (2013–2017). A multi-year approach was used to capture the long-term relationship between maintenance costs and performance of the whole road system. This analysis was performed using the Pavement Needs Estimation System Tool, or PaveNEST, a roadway maintenance needs analysis system developed at CTR. Figure 9 shows the costs to maintain both the Backbone network and the entire Texas roadway network. The cost to maintain the Backbone network at a 90 percent "good" or better grade over the 5-year period is estimated to be, on average, $500 million per year, or about 12 percent of the total network cost. Table 6 shows the average maintenance costs for different networks over a 5-year horizon.

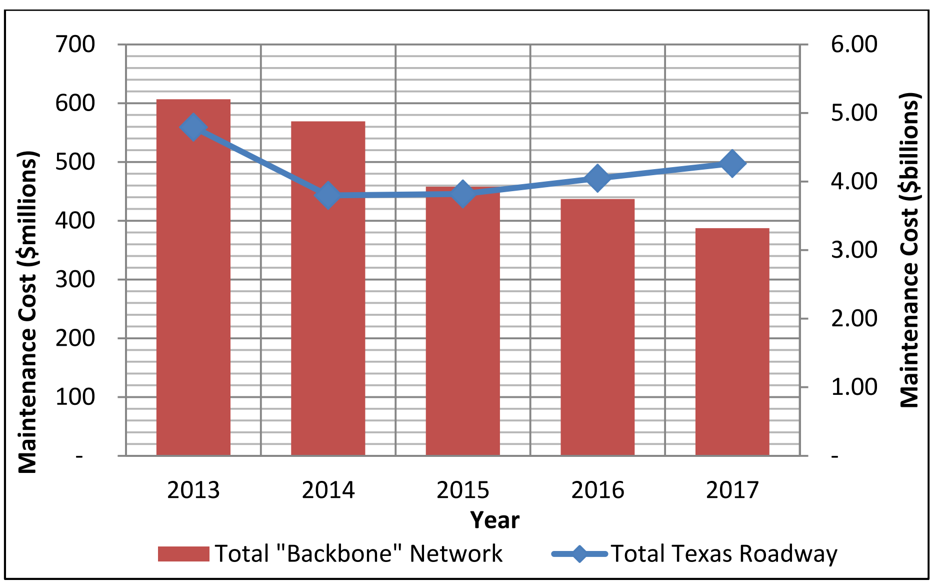


Figure 9. Cost to Maintain the Backbone and Texas Networks at a 90 Percent "Good" or Better Condition over 5-year Horizon

The cost to maintain the Backbone network at a 90 percent "good" or better grade in the 5-year period is an average estimate of $500 million per year.

Table 6. Maintenance Cost for Texas Roadways 2013–2017

Backbone Network	Cost ($ millions)	% (Total Texas Roadway Cost)
Interstates Included	401	**10**
US Routes Included	91	**2**
Backbone Network	492	**12**
Entire Texas Road Network	4,144	**100**

Note that the maintenance cost was computed *for each roadway*, not for the Backbone network. The Backbone network encompasses certain parts of the interstate and US route networks, comprising 12 percent of the total Texas roadway system. The remaining 88 percent comprises the Backup and Connection networks.

Tables 7 and 8 break down the M&R costs for all the Interstate and US Route sections of the Backbone network to maintain 90 percent "good" or better condition.

For segments of roadway in which only part of the highway was used in the network, the fraction of the cost related to the miles of roadway in the network was used. For example, US 59 has 612.2 miles of roadway in the state of Texas, but only 113 miles of the road were used for the proposed Backbone network. Therefore, we multiplied the US 59 maintenance cost ($83,293,000) by the Backbone network mileage (113 miles), divided by the total road mileage (612.2), to obtain a fractional cost ($15,374,000).

Table 7. Backbone Network (Interstates Breakdown Costs)

ID	Total length (miles)	M&R Cost ($)	Total Backbone Network (miles)	M&R Cost ($)
IH0010	**881**	105,094,000	**881**	105,094,000
IH0020	**636**	86,921,000	**636**	86,921,000
IH0027	**124**	12,162,000	**124**	12,162,000
IH0035	**505**	120,463,000	**505**	120,463,000
IH0037	**143**	21,891,000	**143**	21,891,000
IH0045	**285**	54,358,000	**285**	54,358,000
Total	**2574**	**400,889,000**	**2574**	**400,889,000**

Table 8. Backbone Network (US Routes Breakdown Costs)

ID	Total length (miles)	M&R Cost ($)	Total Backbone Network (miles)	M&R Cost ($)
US0059	**612**	83,293,000	**113**	15,374,000
US0069	**531**	29,189,000	**55**	3,023,000
US0077	**471**	52,418,000	**38**	4,226,000
US0083	**784**	61,412,000	**181**	14,187,000
US0084	**300**	48,526,000	**108**	17,469,000
US0175	**111**	15,195,000	**36**	4,928,000
US0281	**571**	54,461,000	**73**	6,962,000
US0287	**503**	49,629,000	**249**	24,573,000
Total	**3883**	**281,641,000**	**685**	**90,742,000**

3.4 Backbone Network Usage Fees Analysis

After the maintenance costs for the Backbone network were defined, different usage fees scenarios were analyzed. The main objective for this analysis was to determine the minimum level of fees that can make the Backbone network self-sustainable.

3.4.1 Usage Fees for the Entire Backbone System

Various scenarios were run using different levels of AADT and percentage tolling of the network to generate the annual funding needed to maintain the Backbone network at a 90 percent “good” or better condition: $492 million. Figure 10 shows the results for the different scenarios.

It is important to note that the revenue estimations are based on current AADT values. Actual implementation of tolling on certain roadways may result in a reduction of AADT values and, consequently, a reduction in revenue. The amount of potential reduction in AADT can vary widely based on available alternative routes, amount of the tolling, and public opinion. However, the drop in AADT from disincentives may be offset by the rising AADT values by year. For example, if a highway has a current AADT of 100,000 and it wishes to implement tolling, the facility may experience a 5–10% drop in users from disincentives, but a 5–10% increase in users on that route by the time the tolling is implemented.

The potential reduction in AADT is difficult to quantify because it would vary by location as well. The current AADT values were used as a guideline for estimation because the amount of AADT reduction or even possibly addition by the time of implementation cannot be assumed. It is already a rough estimate. In the case where a certain

AADT percentage is captured, a range of possibilities is covered to account for this variable.

Two tolling scenarios were used: a 10 percent tolling (343 miles of the 3,427 mile network) and a 50 percent tolling (1,714 miles of the 3,427 mile). The entire Backbone network could not feasibly be tolled based on public opinion, policy making, and execution; however, the scenario was still considered. The AADT was used as an average value for the entire Backbone network. For example, an AADT of 40,000 yielded a user fee per mile of 1, 2, and 10¢ for 100, 50, and 10 percent tolling, respectively. Selecting roadway segments with high AADT values to toll would be the most cost-effective. This approach would result in the lowest required user fee per mile and the least amount of roadway miles to be tolled.

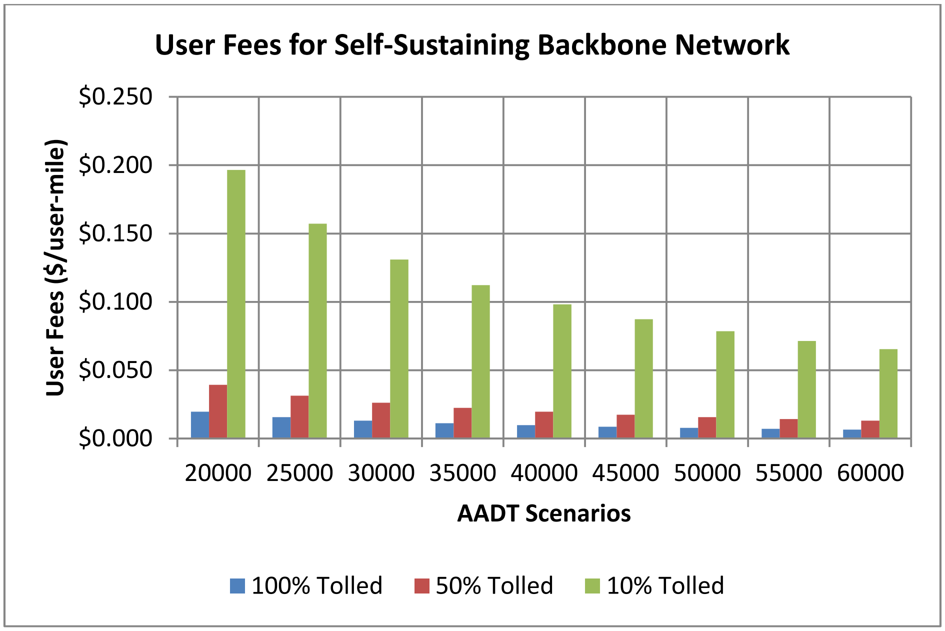


Figure 10. User Fees for a Self-Sustaining Backbone Network

3.4.2 Usage Fees over the Texas Triangle

As mentioned previously, it is not feasible to assume that the entire Backbone network would be tolled at the same time in the near future. For this reason, we proceed to analyze one of the most trafficked regions in the state, the Texas Triangle, as a case to demonstrate the viability of the proposed idea. The Texas Triangle corridor is composed of segments of IH 45 (Dallas–Houston), IH 35 (San Antonio–Dallas), and IH 10 (San Antonio–Houston). Potential revenues for each segment as well as for the entire corridor are shown in the following sections.

(a) Dallas to Houston (IH 45)

For this analysis, the average AADT from Dallas to Houston was found to be, on average, 89,100 veh/day over a 241-mile stretch. To obtain this figure, we determined the AADT values on IH 45 by county and then calculated the average [TxDOT, 2010].As shown in Table 9, potential revenue was calculated for various user fee amounts.

Table 9. Dallas–Houston (IH 45)

Length (miles)	241	
Annual Maintenance Cost ($)	$54,358,000	
AADT	89,100	
Traffic Station Counts	34	
Fee per mile (self-sustainable)	**$0.006**	
Other Funding Options (Annually)	**Fee/mile**	**Generated Funds**
	0.02	$156,785,000
	0.04	$313,569,000
	0.06	$470,354,000
	0.08	$627,139,000
	0.10	$783,923,000
	0.15	$1,175,885,000

These user fees would be attributed to each lane over this 241-mile stretch of highway. Charging only 0.6¢ per mile would be enough for the segment to be self-sustainable. Additionally, if TxDOT were to charge 15¢ per mile, annual revenue of over $1 billion could potentially be obtained. However, this revenue does not factor in toll operation or implementation cost.

(b) Dallas to San Antonio (IH 35)

We determined that the average AADT from Dallas to San Antonio was 104,926 veh/day over a 278-mile stretch. To obtain this figure, we determined the AADT numbers on IH 35 by county, then averaged the values [TxDOT, 2010]. Of the three segments of the Texas Triangle, this segment’s average AADT was the largest. It is important to point out that IH 35 passes through Austin, increasing the AADT over the segment under analysis. As IH 35 approaches Dallas, it splits into IH 35W and IH 35E. AADT values were taken from IH 35E since it passes through downtown Dallas. As shown in Table 10, if TxDOT were to charge only 0.6¢ per mile, the segment would be self-sustainable. Also, if TxDOT were to charge 10¢, over $1 billion in annual revenue could potentially result.

Table 10. San Antonio–Dallas (IH 35)

Length (miles)	277	
Annual Maintenance Cost ($)	$66,075,100	
AADT	104,900	
Traffic Station Counts	54	
Fee per mile (self-sustain)	**$0.006**	
Other Funding Options (Annually)	**Fee/mile**	**Generated Funds**
	0.02	$212,171,000
	0.04	$424,341,000
	0.06	$636,512,000
	0.08	$848,683,000
	0.10	$1,060,854,000
	0.15	$1,591,280,000

(c) San Antonio to Houston (IH 10)

This analysis used an average AADT from San Antonio to Houston of 75,800 veh/day over a 194-mile stretch. As with the other two segments of the Triangle, we determined the AADT on IH 10 by county, then averaged the values [TxDOT, 2010]. Table 11 shows the features for the San Antonio–Houston stretch. The potential revenue generated from this analysis is the lowest of the Texas Triangle interstate highways; however, the usage fee of 0.4¢ per mile is also the lowest when compared to the other segments. Additionally, San Antonio–Houston is the shortest stretch of the three segments of the Triangle. Even so, TxDOT could generate a potential half a billion dollars in revenue by charging 10¢ per mile.

By charging 2¢/mile on the Texas Triangle, the potential revenue would be 97% of the costs needed to maintain the Backbone network.

Table 11. San Antonio–Dallas (IH 35)

Length (miles)	197	
Annual Maintenance Cost ($)	$23,500,000	
AADT	75,800	
Traffic Station Counts	40	
Fee per mile (self-sustain)	**$0.004**	
Other Funding Options (Annually)	**Fee/mile**	**Generated Funds**
	0.02	$109,008,000
	0.04	$218,016,000
	0.06	$327,024,000
	0.08	$436,032,000
	0.1	$545,040,000
	0.15	$817,560,000

(d) Texas Triangle corridor potential revenue

After analyzing the three segments, the total revenue for the entire Texas Triangle corridor was computed by combining all three segments at the same usage fee. An average AADT of about 91,500 and a total length of 751 miles were used to determine the Triangle's potential revenue. We determined that the total cost for M&R for the Texas Triangle interstates was approximately $136 million per year, which can be covered with a fee lower than the 0.5¢ per mile. Table 12 shows the potential revenues for various levels of usage fees.

Table 12. Potential Generated Funds for Various Usage Fees Scenarios

Total Generated Funds		
	Fee/mile	Generated Funds
Usage Fee Scenarios	0.02	$477,963,000
	0.03	$716,945,000
	0.04	$955,927,000
	0.06	$1,433,890,000
	0.08	$1,911,854,000
	0.10	$2,389,817,000
	0.15	$3,584,725,000

As Table 12 indicates, a 2¢ per-mile charge over the length of the entire Triangle would be almost enough to make the entire Backbone network self-sustainable. Moreover, a 15¢ per-mile charge would create revenue exceeding $3.5 billion, almost enough to fund the M&R needs of the entire state-maintained road network in Texas.

Charging 15¢/mile would create revenue exceeding $3.5 billion, almost enough to fund M&R of the entire Texas highway network.

3.4.3 Truck/Car User Fee Split on the Texas Triangle Corridor

Agencies have different philosophies when it comes to tolling trucks. On the one hand, trucks provide the valuable service of transporting goods, which helps the economy. On the other hand, trucks make a far greater impact on pavement deterioration than passenger cars. The amount required for network self-sustainment is fixed, but their tolling charge fluctuates based on the percentage of the network that is funded by the cars or trucks.

One approach is to charge trucks less at tolling facilities in order to stimulate economic productivity. If attempting to create a self-sustaining Backbone network, this would result in an increase in tolling prices for cars to account for that loss in potential funding. Another approach is to charge trucks more at tolling facilities to account for their severe impact on pavement deterioration. Again, in a self-sustaining network, this would conversely result in a decrease in tolling prices for cars, as trucks carry more of the funding burden.

The analysis in Section 3.4.2 did not include a series of usage fees that differentiate by the vehicle type. Due to the heavy loads and axle configurations, trucks in general cause more damage to the roadway compared to passenger cars. Trucks also take up more space on the roadway, causing more air pollution, and contribute to congestion at a higher rate than cars. In other words, trucks consume more roadway than cars do in terms of both structures and capacity. That being said, the truck industry is essential in the success of the Texas economy. Different fee split scenarios were analyzed on the Texas Triangle network to develop various scenarios of charges for self-sustainment. The percentage of trucks obtained from traffic data on the Texas Triangle corridor was about 17 percent [TxDOT, 2010]. Table 13 and Table 14 show the results for the usage fee split for trucks and cars. The series of percentage combinations account for the different tolling scenarios that would sustain the Texas Triangle. For example, a 40/60 split would mean that trucks would generate 40 percent of the funds for sustaining the Texas Triangle, despite accounting for 17 percent of the AADT. The remaining 60 percent will be covered by the passenger cars.

Table 13. Truck/Cars Split Texas Triangle for Texas Triangle Self-Sustainment

Self-Sustainment	$136,000,000	
Segment Miles	715	
AADT	91,600	
Truck AADT	15,300	
Car AADT	76,300	
Truck/Car Fee Split (%/%)	Fee/mile for Self-Sustainment	
	Truck	Car
0/100	$0.000	$0.007
20/80	$0.007	$0.005
40/60	$0.014	$0.004
60/40	$0.020	$0.003
80/20	$0.027	$0.001
100/0	$0.034	$0.000

Table 14. Truck/Cars Split Texas Triangle for Backbone Network Self-Sustainment

Self-Sustainment	$492,000,000	
Segment Miles	715	
AADT	91,600	
Truck AADT	15,300	
Car AADT	76,300	
Truck/Car Fee Split (%/%)	Fee/mile for Self-Sustainment	
	Truck	Car
0/100	$0.000	$0.025
20/80	$0.025	$0.020
40/60	$0.049	$0.015
60/40	$0.074	$0.010
80/20	$0.099	$0.005
100/0	$0.123	$0.000

The entire triangle network was analyzed in an attempt to keep the fees lower. In order to fund the entire Backbone network on a 40/60 truck-to-car fee split, a 2¢ per mile user fee for cars and 6¢ per mile fee for trucks would have to be applied. This amounts to a $4–5 charge for cars on each leg of the Triangle, and a $12–15 charge for trucks on each leg of the Triangle.

If TxDOT were to implement congestion charging in Houston, DFW, & San Antonio in sections with AADT more than 100,000, there is potential revenue of approximately $2.4 billion.

3.4.4 Additional Fees for Rush Hour Usage

In order to control congestion during rush hours, a dynamic usage fee should be considered for the Backbone system. Congestion tolling can be based off a set MPH goal that will maintain a steady capacity. The IH 95 express lanes charge motorists with the intent of speeds never dropping below 45 MPH [FDOT, 2011]. Considering capacity and the speed norm in Texas, dynamic usage fees should range from 0 to 30¢ per mile.

(a) Analysis of Congestion Charge for Interstates

For this analysis, segments of interstate highways were chosen based on AADT values, as shown in Figure 11. Each stretch of highway has AADT values exceeding 100,000 at all measured points. An average congestion charge of 15¢ per mile was used for analysis. The results are shown in Table 15. The congestion charge would vary depending on the time of day. During non-peak hours the charge would be 5–10¢ per mile, while during peak hours it would be 25–35¢ per mile. The average congestion charge value is based on the IH 95 Express average congestion fee for its 12-mile stretch in Miami [FDOT, 2011]. As shown in Table 14, IH 45 in Houston has the highest AADT over the longest stretch of highway. If TxDOT were to implement congestion charging in the sections shown in Figure 11, there is the potential for over $2.3 billion in revenue. Every possible congestion fee for interstates generates a significant amount of revenue, even when it is over a short stretch of highway.

Table 15. Congestion Charging for Interstates ($.15/mile)

Highway	Length (miles)	AADT	Generated Funds($/yr)
IH 10 Houston	31	196,600	$333,651,000
IH 45 Houston	71	215,400	$837,378,000
IH 20 DFW	46.5	149,800	$381,404,000
IH 35E Dallas	49	155,900	$418,174,000
IH 10 San Antonio	14	158,000	$121,107,000
IH 35 San Antonio	38	147,700	$307,347,000
Total Potential Revenue			**$2,399,061,000**

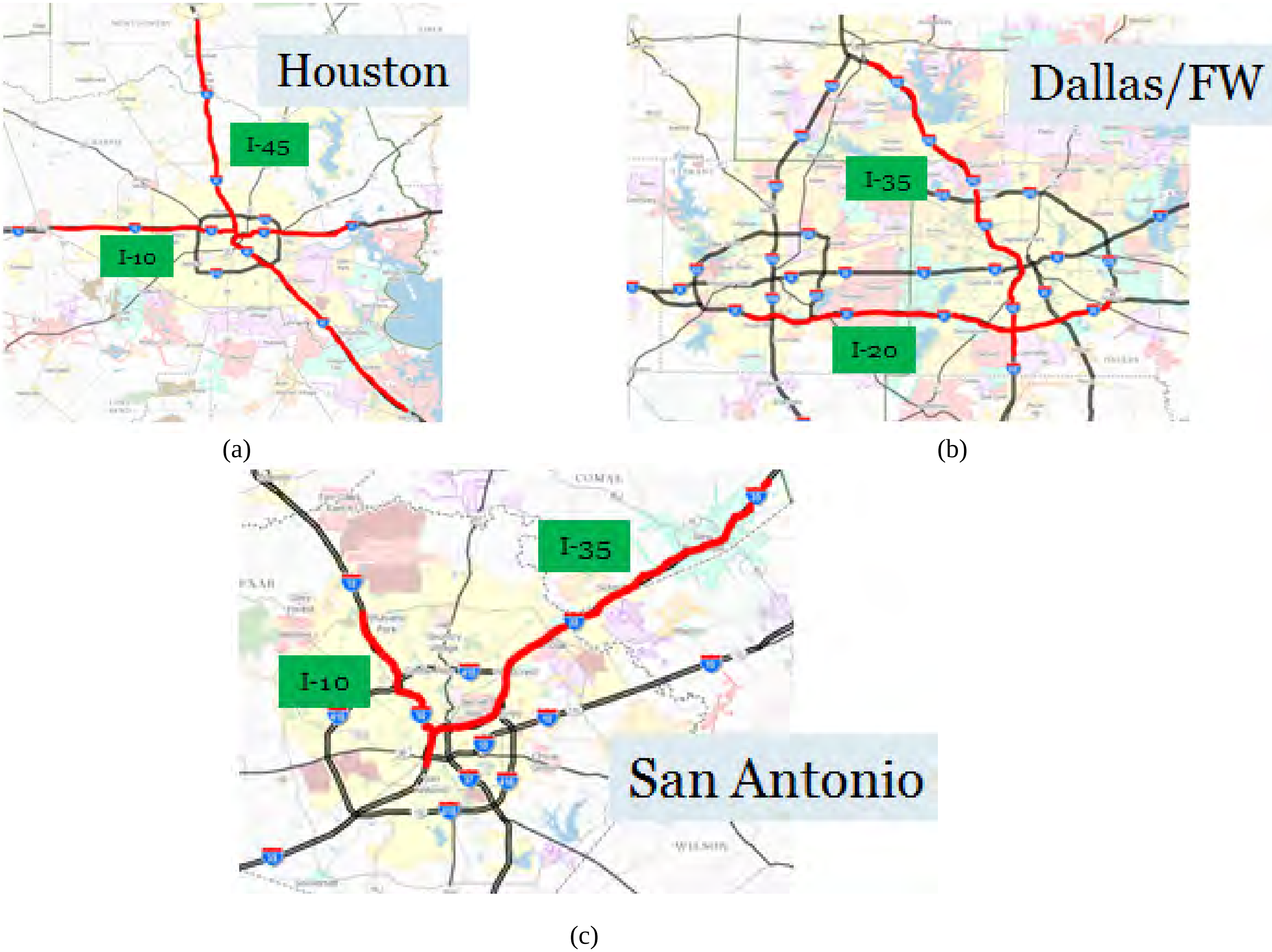


Figure 11. Segments with AADT Greater than 100,000: (a) Houston, (b) DFW, and (c) San Antonio

With managed lanes at the suggested interstate segments, capturing 20 percent AADT would generate enough funds to cover the maintenance costs of the Backbone network.

(b) Congestion Charge for Managed Lanes

The possibility of applying a congestion charge over a managed lane was also analyzed. For example, if the stretch of highway had four lanes in each direction, TxDOT could turn two lanes into managed lanes in an attempt to capture 30–40 percent of the AADT. An average daily usage charge of 15¢ per mile was used to run the analysis. As briefly discussed in previous sections, this charge would vary based on peak hours and the amount of congestion.

As Table 16 indicates, if managed lanes were applied at each of these interstate segments with a goal of capturing 20 percent of the AADT, it would generate enough funds to cover the maintenance cost of the entire Backbone network. Granted, the cost of construction and operation of managed lanes is higher than converting them into entire toll sections, but the public is more receptive to this approach. Further studies should be carried out to determine the feasibility of managed lanes in Texas.

Table 16. Managed Lanes Scenario Results

Highway	Length (miles)	AADT	% AADT Captured		
			20	30	40
IH 10 Houston	31	196,600	$67	$100	$133
IH 45 Houston	71	214,400	$167	$251	$335
IH 20 DFW	46.5	149,800	$76	$114	$153
IH 35E Dallas	49	155,900	$84	$125	$167
IH 10 San Antonio	14	158,000	$24	$36	$48
IH 35 San Antonio	38	147,700	$61	$92	$123
Total	**249.5**		**$480 ***	**$720***	**$960***

* Generated Funds in $ millions

4 Recommended Framework for Optimizing Funding Balance between Infrastructure Preservation and Mobility Projects

The impetus of the proposed strategic maintenance approach is that the highway network in Texas will be maintained by tiers where each tier has a different level of service in terms of safety, mobility, dependability, and comfort. This implies that the maintenance strategies or treatments will differ for different tiers. Table 17 shows the suggested maintenance strategies.

Table 17. Illustration of Maintenance Strategies

System	Service	Treatments			
		Major Repair	Minor Repair	Maintenance	Other
Backbone	Premier	X	X	X	Eliminating bottlenecks, etc
Backup	Standard	Reduced Frequency	X	X	
Connection	Basic		Reduced Frequency	X	Reduce speed limits, etc

Additionally, the research team developed a methodological framework for the optimal selection of infrastructure preservation and mobility projects under limited budget. Infrastructure preservation and mobility enhancement are arguably the two primary investments in transportation systems. Infrastructure preservation projects improve existing infrastructure conditions, whereas mobility enhancement projects look to add new links to the network, expand existing links, and so on. In the current funding allocation process, these two investments are usually considered separately.

Funding allocation for infrastructure preservation projects usually accounts for road deterioration. The objective for this problem is to maximize road condition during the planning horizon under budget constraints or to minimize the total cost incurred while satisfying a given condition goal. The funding allocation process for road mobility projects consists primarily of determining a prioritized list of candidate projects, subject to the funding constraint using the user equilibrium principle, where drivers choose a route so as to minimize his/her travel time and on the assumption that such a behavior on the individual level creates an *equilibrium* at the system (or network) level; flows on links (whose travel times are assumed to vary with flow) are said to be in equilibrium when no trip-maker can improve his/her travel time by unilaterally shifting to another route.

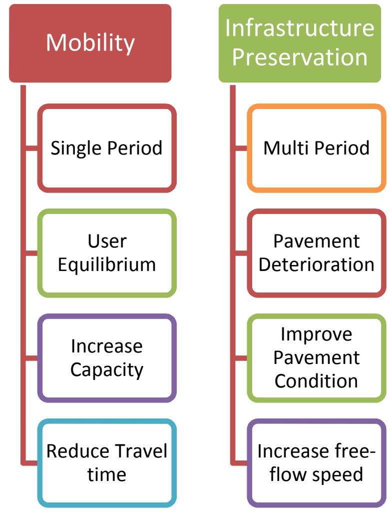


Figure 12. Mobility and Infrastructure Preservation Projects

Although the resource allocation processes for infrastructure preservation and for mobility projects are carried out separately, investment in infrastructure preservation projects can also help reduce travel time. Researchers in the pavement community discovered that road condition, especially roughness, has a significant impact on vehicle speed and vehicle operating cost. For example, Watanatada el al. reported that vehicle speed can be expressed as a function of road characteristics. Chandra in 2004 also showed the effect of road roughness on road capacity by establishing a relationship between roughness and free-flow speed. In other words, investment in infrastructure preservation projects also has an effect on the overall system performance through improved free-flow speed.

In this task, an integrated methodological framework for the selection of both infrastructure preservation and mobility improvement projects was developed. More specifically, a multi-period, mixed-integer, bi-level optimization model was developed with the objective of finding the optimal balance between mobility and pavement condition. Therefore, given a set of infrastructure preservation and mobility improvement candidate decisions from the upper-level problem, the user-equilibrium traffic flow is solved in the lower-level problem. The major difference between the approach developed in this task and a traditional mobility improvement problem is that the proposed approach considers multi-period decisions. If mobility improvement decisions are the sole consideration in each year, there is no need to formulate the problem in a multi-period setting. However, if considering infrastructure preservation scheduling, decisions in subsequent years must be examined, as road conditions deteriorate over time. This is because it is generally more cost-effective to perform preventive maintenance during earlier stages than to take more expensive rehabilitative measures in later stages.

For demonstration purpose, let us consider a road network as shown in Figure 13, where 4,000 drivers wish to travel from point Start to End. The free-flow travel time in minutes on the Start-A segment is 2 minutes, on Start-B 2.5 minutes, and on A-End and B-End 9.6 minutes. The capacities of those four links are 1,000, 3,000, 1,000, and 3,000, respectively. Moreover, the roughness of those four links is assumed to be 3, 5, 6, and 6 (mm/m).

Suppose that options are available to decision-makers to preserve road conditions, for example, applying overlays with different thicknesses. Infrastructure preservation projects primarily improve road capacity by improving surface smoothness. Similarly, a set of options are available for mobility improvement, in this example adding additional capacity to existing links. These projects are subject to a budget constraint. In this situation, the decision-makers will have to choose how to spend the limited resource between the mobility projects and infrastructure preservation projects. Figure 14 presents the results of different funding scenarios for the network shown in Figure 13. As can be seen from Figure 14, when the resource allocated to mobility projects increases, the equilibrium travel time of Start-End will be reduced and the average road roughness will increase. By using Figure 14, decision-makers are able to find the optimal balance between mobility and preservation projects.

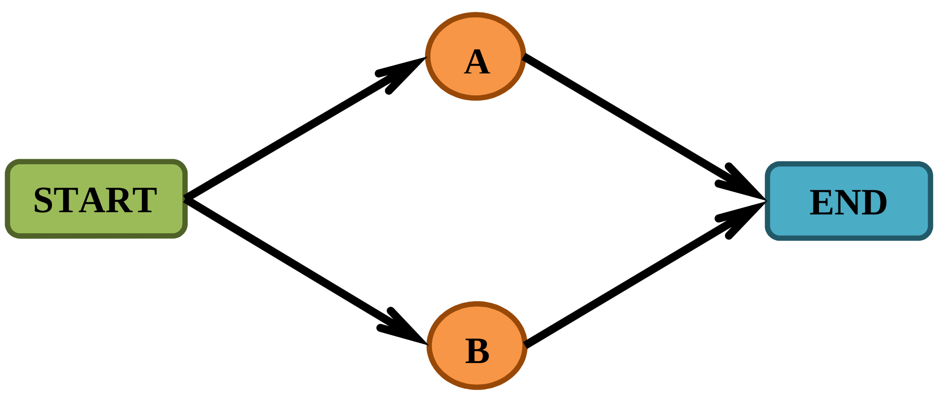


Figure 13. Demonstration Example

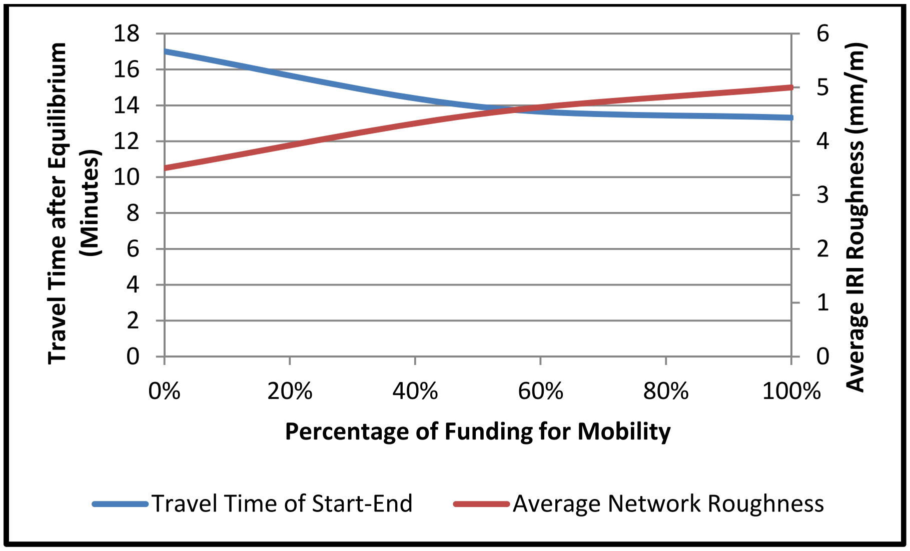


Figure 14. Different Funding Scenarios

5 Recommended Approach

In order to create an optimized overall performance for this maintenance strategy, infrastructure preservation and mobility projects are developed into an integrated solution. Normally, infrastructure preservation is viewed as a multi-period analysis, while mobility projects are done through single-period analysis. Integration of these two techniques has the potential to create an optimized funding and performance system. The goal is to make the Backbone network the most efficient, while also making it self-sustainable. We found three approaches that are most feasible for attaining this goal. One of the main targets for each approach is to find roadways that can become more efficient and maintain the AADT to generate sufficient funds.

5.1 Managed Lanes

Managed lanes provide a means to make congested interstates more efficient and generate funds for rehabilitation. As mentioned earlier, the IH 95 Express lanes in Miami, FL, have made that interstate much more efficient, while also generating revenue. A managed lane system in Texas has the potential to achieve similar results. In order to generate enough funds for the entire Backbone network, managed lanes would have to be installed on a much larger scale. The user fee analysis shows that if 30 percent of the AADT is captured on the 250 miles of congested interstate, enough funds would be generated to fund the entire Backbone network. Managed lanes also give the user the choice of paying for the increased level of service or using the general purpose lanes without an additional user fee.

Public opinion is essential in making this project work; managed lanes are the best option for a positive result. In a survey done on IH 95 Express, 55 percent of respondents "strongly favored" or "favored" the managed lanes [FDOT, 2011]. Getting a positive response to applying user fees is difficult, but managed lanes offer that opportunity.

5.2 Tolling the Texas Triangle

Another possible approach to funding the Backbone network would be to apply a toll on the Texas Triangle, tolling IH 35 from San Antonio to Dallas, IH 10 from Houston to San Antonio, and IH 45 from Dallas to Houston (715 miles of interstate highway). Applying a fee to all three legs of the Triangle would allow the user fee to be much more reasonable. The fee could be based on vehicle, charging freight trucks at a higher rate. Trucks have a larger impact on congestion and pavement maintenance, and therefore should be required to pay more based on this impact. In one possible user fee set-up, trucks would pay 6¢ per mile, while cars pay 2¢ per mile. This would amount to trucks paying $12 to $15 for traveling from one Triangle city to another, while cars would only pay $4 to $5. This approach would generate enough funds to sustain the entire Backbone network.

Tolling the Texas Triangle requires a secure and reliable backup system currently not fully available. The frontage roads would be the option drivers could use as an alternative route; however, these roads are not a reliable option as they are not available throughout the entirety of the Triangle. Research shows that the frontage road disappears mostly where bridges are located. If the Texas Triangle tolling option is seriously considered as an approach to optimize mobility and preserve infrastructure in Texas, construction will be necessary on the frontage roads. Figure 15 shows the places where frontage roads disappears; dots in red indicate the the presence of frontage roads is completely absent and yellow dots signify that the frontage road is available in only one direction. If the interstate is to be tolled, these locations need reconstruction and the addition of frontage lanes.

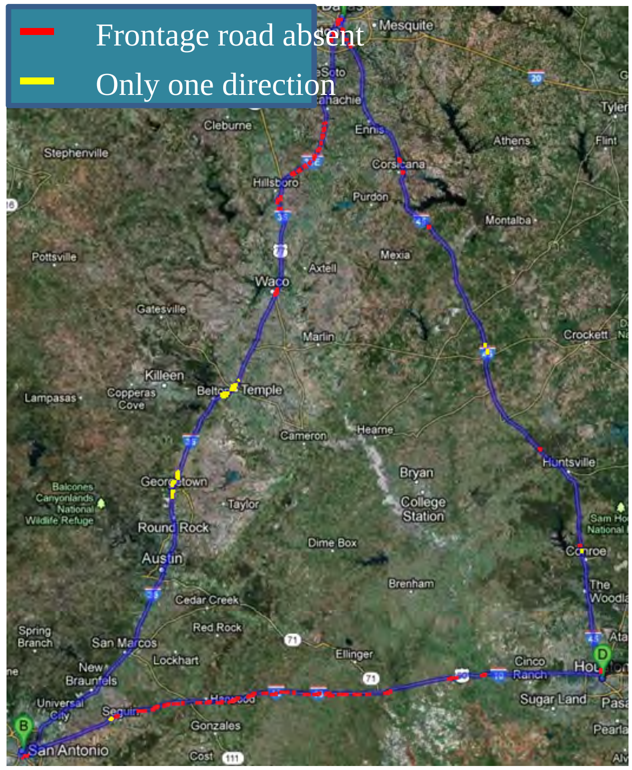


Figure 15. Texas Triangle Frontage Roads

Another difficulty in applying tolls to the Texas Triangle would be public opposition. Other routes are available for the Backup system; however, the alternative routes for travel between Texas Triangle cities require considerably longer travel time. For example, going from San Antonio to Houston on IH 10 takes 3 hours 20 minutes, while the non-interstate alternative takes about 4 hours 50 minutes. Depending on how the users value their time, they would have to choose between tolled and non-tolled routes.

The geographic location of Texas makes it a significant hub and corridor for the movement of freight throughout the United States. Studies show a projected increase in freight movement, stressing the challenges facing the state's deteriorating infrastructure and budget shortfalls [Prozzi et. al, 2011]. However, the increase of tolls can transfer travel costs to businesses and consumers. Another possible detriment to this approach would be the impact of truck fees on the Texas economy. Much of the Texas economy relies on the use of freight to transport goods, but freight trucks do negatively impact road conditions.

5.3 Congestion Charging

Congestion charging provides a means to curb congestion while taking in a user fee. In this approach, all of the lanes charge a user fee that would vary based on the time of day. At peak hours, the fee could be as high as 40¢ per mile, while travel during off hours requires no fee. This approach has the potential to alter work day hours, and by doing so, lower congestion. Applying congestion charging to 71 miles of IH 45 in Houston would generate enough funds to provide maintenance to the entire Backbone network. This approach provides the most optimal means of generating funds on the smallest amount of roadway.

Again, the difficulty in applying congestion charges would arise from public opposition. Some people argue that congestion charging favors the wealthy. If this approach were taken, an alternative route would have to be available for the general public to use without fees.

More research needs to be done on the specific areas of the interstate requiring congestion reduction. The impact of congestion charging on the Texas economy and public opinion also needs to be researched.

5.4 Suggested Implementation Strategy

The strategy for implementing managed lanes on the Backbone network has been split into three different phases, as Figure 16 illustrates. Phase 1 consists of tolling one leg of the Texas Triangle. For example, IH 35 from San Antonio to Dallas could be used as a pilot segment to implement the proposed approach—the longest leg of the Triangle, it runs through densely populated cities such as Austin and Waco and has the potential to accurately model the results of the new tolling system.

Phase 2 expands the implementation to the entire Texas Triangle. As previously explained, the Texas Triangle has much potential to generate the revenue needed to maintain the interstates. Should Phase 2 implementation prove successful, the final phase would begin.

Phase 3 is the installation of tolls on the entire Backbone network. This scenario would allow all the Backup and Connection roads in Texas to have a greater share of the state-appropriated funding, resulting in higher maintenance levels for the entire Texas road system.

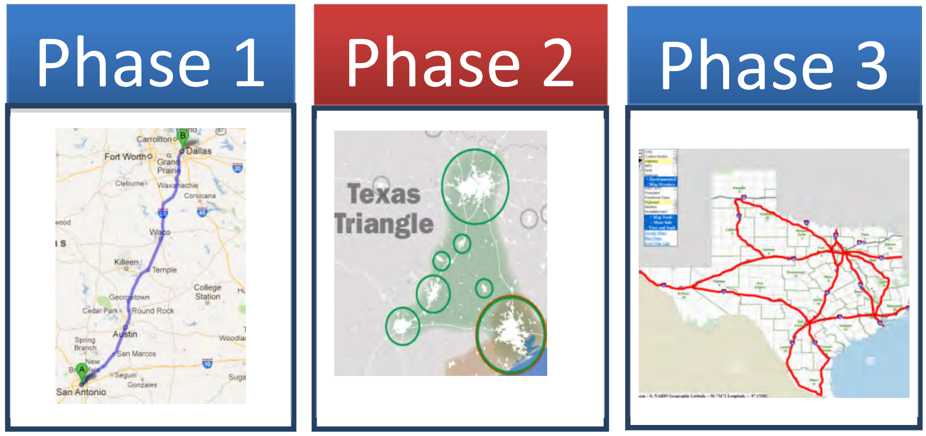


Figure 16. Suggested Implementation Strategy

6 Recommended Future Research

To successfully implement the proposed strategy, issues in several areas should be addressed through further research, including the following:

a) *Education and advertising:* The best way to implement usage fees is to educate the general public on the importance of having funds for future M&R of the existing infrastructure. A widespread understanding of the concept would help generate public support and increase the public's awareness. Researchers should survey the general public and other stakeholders such as engineering and construction professionals, system managers, and investment decision or policy makers, to craft plans suitable for specific areas of implementation.

b) *Potential managed lane usage:* Further analysis of the potential managed lane usage is important to estimate AADT values that will impact the generation of funds. Existing tolling facilities' performance, as well as demand forecasting for Texas, should be further studied for a potential usage fee implementation strategy. The willingness to pay is also an important subject of analysis. Would people in Texas pay to use managed lanes or toll roads if a faster and more reliable system is provided? Surveys could help understand the users' perspective and expectations.

c) *Congestion usage fees*: More research needs to be done on specific interstate segments with large AADT. The congestion charging in these sections could create an important source of revenue, while at the same time improving the mobility.

d) *Frontage roads*: The frontage roads system should be further analyzed as part of the Backup network. One of the problems is that gaps in the system break the continuity, particularly in the form of bridges. For this reason, a more comprehensive study of the frontage road system is needed to address potential costs to close the gaps.

e) *Truck and car fees*: Most of the analysis conducted in this project assumed an equal fee for cars and trucks. Future research should be conducted to generate a more equitable fee schedule for trucks and cars, given the greater impacts related to damage, mobility, and safety that trucks present. Moreover, the trucking industry should become an active member in a potential implementation to maintain or increase the efficiency of the transportation system for freight.

f) *Equity, fairness, and uniformity*: Further studies are needed in ways to incorporate equity analysis in the proposed framework. Additionally, equity impacts should be estimated and addressed.

g) *Technology*: The technology required to support toll collection should be further explored, analyzing the advantages and disadvantages of various technologies. The actual performance of electronic tolls in the state should be studied to learn from past experiences and implement more reliable tolling systems.

7 Conclusions

The most important feature of the proposed approach is that the user is NOT forced to pay for the service; rather, the user is given the flexibility to choose from three levels of service, paying an extra fee only if the Backbone network is chosen.

Texas pavement and bridge conditions will continue to significantly deteriorate in the future under current funding projections. This report proposes an integrated approach to solve the funding gap problem. A multi-tier infrastructure system is needed to optimize the resource allocation among the network. Moreover, this report proposes a usage-fee-based public finance system for using the Backbone system. The proposed integrated approach is expected to help maintain the state's economic competitiveness and support sustainable economic growth. More specifically, the benefits of the proposed strategy include the following:

1) The user is given the flexibility to choose from three levels of service and pays an extra fee only if they choose the Backbone network, with its Premier level of service.
2) The extra fee for the Backbone network will require a reduced amount of appropriated funds and could potentially be self-sustainable.

3) A potentially self-sustaining Backbone system frees up funding that can be reallocated to better address the needs of the Backup and Connection systems.
4) The analysis provides initial estimates for potential usage fees. Low usage fee values represent an important revenue source for the Texas highway infrastructure.
5) The proposed framework for optimizing the funding balance between infrastructure preservation and mobility projects presents an opportunity to improve the decision-making process in Texas.
6) The implementation cost is low.
7) It will make Texas the leader in reconfiguring and maintaining highway networks.

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