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PUTTING PRICE TAGS ON INTERNATIONAL TRADE USE OF STATE INFRASTRUCTURE – FINAL REPORT

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16. Abstract

As a major gateway to the entire U.S. for international trade both through seaports and land ports of entry, Texas pays the bills for the construction and maintenance of the infrastructure required to move the freight which benefits other parts of the country. Moreover, with the expansion of the Panama Canal and the land bridge from the Mexican port of Lazaro Cardenas to Texas, it is likely that international trade through Texas ports of entry will continue to grow, and continue to impact transportation infrastructure in Texas. In this sense, the effective and efficient management of this infrastructure has been at the forefront of discussions. However, there are no local studies that examine the current asset value of major freight corridors to move international trade in Texas; in other word, there is a need to develop a methodological process which can be used to put "price tags" on international trade use of Texas' transportation infrastructure. This research proposes a novel utility-based asset valuation framework that can consider loss in potential benefits if the infrastructure fails, as well as its construction and maintenance costs. As the result, the price tag assigned to the freight corridors was significantly different than its replacement cost, which is one of most frequently used asset valuation methods to estimate the value of transportation assets. The price tag was estimated at $366 billion, while the replacement cost was only $160 billion. The difference indicates that a failure to include the functionality and the utilization aspects of transportation assets can result in distorting their true values, by underestimating or overestimating the values. This research study is critical to TxDOT as the research findings provide TxDOT with a comprehensive asset value of the freight corridors, which is essential to maintain the freight corridors with high condition standards for the potential trade growth.

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Chapter 1. Introduction

1.1 Problem Statement

Texas is a major gateway to the entire U.S. for international trade both through seaports and land ports of entry. Movement of this freight which benefits other parts of the country impacts Texas infrastructure, yet Texas pays the bills for the infrastructure to move the freight. According to the International Trade Corridor Report of 2010, Texas has 17 marine ports and 13 commercial land ports (soon to be 14 with Guadalupe Tornillo near El Paso), and a number of airports that carry international cargo. Most routes that carry trade from these ports to markets are Interstate or major U.S. highways. However, there are also local connecting roads to the ports in many areas. With the expansion of the Panama Canal and the land bridge from Mexican port of Lazaro Cardenas to Texas, it is likely that international trade through Texas ports of entry will continue to grow, and continue to impact transportation infrastructure in the state. Additionally, state departments of transportation (DOTs) are increasingly facing freight planning issues due to their nature, which involves a combination of interests from the public sector, private sectors, and shipper/industry.

Efficient freight mobility is the result of successfully balancing the demand for infrastructure capacity with the infrastructure necessary to move the goods and services. Achieving this balance requires accurate assessment of construction and maintenance costs to maintain and expand the current infrastructure system provided by TxDOT. For this reason, it is imperative for TxDOT to quantify these costs in order to develop freight corridors plans to accommodate the expected international trade growth. These construction and maintenance costs can be associated with price tags (or total value of corridor), which can assist TxDOT to enhance decision-making process on international trade infrastructure with respect to preservation, safety, mobility, travel time reliability, and other features.

Moreover, putting price tags to international used infrastructure will serve in enhancing the linkage between TxDOT goals and performance, giving the agency the ability to reflect how they value their infrastructure in vital systems such as the movement of freight in, out, and within the state. These price tags will also allow enhance public planning and decision-making processes regarding freight by providing more effective and efficient resource allocation and management strategies in achieving its organizational goals.

1.2 Research Objective

The goal of this research project is to assign price tags on international trade use of state infrastructure. Price tags will aid TxDOT in making critical decisions with regards freight corridors maintenance and potential expansions. The primary objective of this project is to quantify the costs of construction and maintenance of the infrastructure required to move international trade, both imports and exports within Texas, and to other states in the Union.

Chapter 2. Literature Review

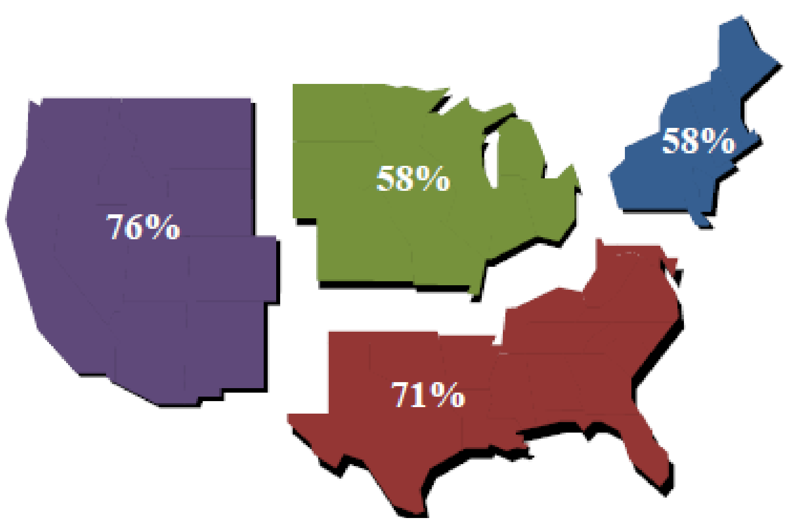
A literature review was conducted to investigate methodologies for assigning price tags to freight corridors. The review covers key methods and techniques to estimation the value of transportation infrastructure, and its findings will be used to develop a utility-based methodological framework.

2.1 Importance of Freight Corridors

Freight transportation is an important component of a country's economic development. All levels of government recognize the importance of the freight transportation infrastructure. For example, the Government Accountability Office made the following statement in 2008 [GAO, 2008]:

> "Continued development and efficient performance of the nation's freight transportation system is vital to maintaining a strong U.S. economy and sustaining our nation's competitive position in the global economy. Yet increasing congestion on our nation's roads and rail lines threatens to undermine the efficiency of our freight transportation system."

An efficient freight transportation system supports economic development and the expansion of international trade, stimulates national employment, maintain growth in personal income, increase the Gross Domestic Product (GDP) of a region, and improves the quality of life of its citizens. However, dramatic increases in freight volumes have also resulted in concerns about the growing disparity between demand and the capacity of the freight transportation system, resulting in, for example, bottlenecks and landside access concerns to ports and airports. Already, certain transportation corridors are having difficulty accommodating the growing freight transportation demand [Prozzi, 2011]. Figure 2.1 illustrates the anticipated growth in U.S. domestic freight tonnage between 2000 and 2020 for four geographic areas in the U.S. Clearly substantial freight demand growth is forecasted for all the four regions [AASHTO, 2007].



Source: AASHTO (2007)

Figure 2.1: U.S. Domestic Freight Tonnage Percentage Growth: 2000–2020

According to the recently released report entitled “U.S. Freight Transportation Forecast to 2022,” the trucking industry continues to dominate the freight transportation industry in terms of both tonnage and revenue, comprising 67 percent of tonnage and 81 percent of revenue in 2010. Moreover, the report indicates that total freight tonnage is expected to grow by 24 percent by 2022, and revenue for the freight transportation industry is projected to rise 66 percent in that same timeframe [ATA, 2014]. This outcome suggests that highway infrastructure will be exposed to increasing levels of traffic that will need to be addressed by transportation authorities.

Moreover, according to the Texas Freight Advisory Committee (2013), the transportation-related activities contributed 18.6 percent to the Texas GDP in 2010. Trucks move over 46 percent of all the freight in Texas. In 2013, 85 percent of the trade with Mexico and 73 percent of the Texan manufactured goods were transported by truck. Furthermore, 1 of 16 Texans are employed by the trucking industry [TFAC, --a]. These statistics suggest that the truck industry is vital to the Texas economy. Therefore, it is imperative for Texas transportation authorities to maintain roadway freight corridors at high condition standards to increase freight movement efficiency.

The geographic location of Texas benefits the international trade. Texas shares 1,241 miles of the international border with Mexico, which represents 64 percent of the total border length with Mexico. Moreover, Texas has 397 miles of coastline with the Port of Houston, the second busiest port in the country. In addition, Ports in Beaumont and Corpus Christi are in the top 10 among all U.S. ports for total cargo volume [KSG, 2006; TFAC, --b]. Since 2005, Texas has ranked first in exports revenues, which represents 17.8 percent ($289 billion) of the total exports in U.S in 2014. In 2014, NAFTA countries made up 46.3 percent of the exports of the state, with Mexico as the largest trading partner with 35.5 percent of the exports [Census Bureau, 2015]. Moreover, Texas has increased exports to the BRIC countries (Brazil, Russia, India, and China) and African nations. These increasing trends are expected to increase in the next years. The expansion of the Panama Canal could also potentially increase the freight movement of Texas. These new developments could provide low-cost access to new markets and the opportunity for Texas to become a national gateway [TTI, 2013].

If these trends continue in the following years, there will be an increase of the freight demand to and from the border with Mexico, and to and from the Ports of Texas. In fact, estimations indicate that truck VMT will grow 70 percent between 2014 and 2040 from 500 million to 800 million [TxDOT, 2015]. Therefore, freight transportation is and will be an important component of the economic development of the State of Texas. Therefore, Texas transportation authorities should plan accordingly to manage future freight demand and supply to keep Texas as a competitive economy.

2.1.2 Texas Freight Mobility Plan

In 2013, the Texas Freight Advisory Committee (TFAC) initiated efforts to develop the first comprehensive and multimodal Freight Mobility Plan for Texas. This Freight Mobility Plan’s main objectives were to enhance freight mobility and improve the state’s economic competitiveness. The plan would achieve this by providing an efficient, reliable, and safe freight transportation, while maintaining the quality of life in the State, to define policies and investments that will enhance Texas’s freight transportation system into the future, and to establish a framework for Texas’ comprehensive freight planning program and decision making [TFAC, 2014].

Two important outcomes of the Freight Mobility Plan were the identification of key freight transportation need and issues, and the definition of the Texas Freight Highway System. After obtaining feedback from the various stakeholders and studying available literature, the TFAC identified the key freight transportation needs and issues in Texas. These issues and needs were categorized as system capacity, system operations, safety, connectivity, border challenges, education and public awareness, and funding challenges. In addition, TFAC defined a Texas Freight Highway Network (TFHN). The TFHN is a system of roadways that includes the National Freight Network, and other roadways with interest to Texas. The development of this network was based on three main sources: the Texas Highway System, the Texas Trunk System, and the connections to freight generators and gateways [TFAC, 2014].

2.2 Price Tags in Transportation Asset Management

Transportation infrastructure represents one of the largest public-owned assets in the U.S. highway system. Composed of pavements, bridges, and other related infrastructure, the system serves as the backbone for social and economic development. In recent years, the cost of preserving and operating this highway infrastructure investment has increased dramatically. According to the American Society of Civil Engineers (ASCE) in 2011, an investment of roughly $220 billion annually would be needed from 2010 to 2040 to manage congestion and to preserve a transportation quality level defined as the minimum of tolerable conditions [EDRG, 2011]. With such enormous investments during the life cycles of transportation infrastructure through activities such as planning, building, operating, maintaining, and improving, much of the current interest is centered on ensuring that value of the investments on these infrastructures is preserved.

Assigning price tags to transportation infrastructure is closely related to asset management frameworks being implemented by transportation related organizations. These organizations have been focusing on asset management implementation by developing a systematic process for the maintenance, preservation, and operation of infrastructure in a cost-efficient manner that utilizes business principles and economic theory to aid in the decision-making process [AASHTO, 2002; FWHA, 2012]. Proper management of transportation infrastructure ensures that [AASHTO, 2002; Cambridge, 2006]:

- The service life of these assets is extended,
- Their value is preserved at minimum,
- Agencies are held accountable for their expenditures,
- Justification of funding needs can be clearly stated, and
- Users are satisfied with the quality of transportation services received.

Generally speaking, the goal of Departments of Transportation (DOTs) throughout the country is to provide the infrastructure to “efficiently and safely move people and goods” [FHWA, 2013]. State DOTs have often pursued this goal by seeking to maximize the extent and condition of the transportation network. When funding is limited, agencies must make strategic best use of the resources available. For this reason, the development of a framework for assigning price tags to international trade corridors could enhance decision-making processes within transportation agencies. Furthermore, this framework could serve as a key element in the communication between financial managers and decision makers within transportation agencies and between transportation agencies and the general public [OECD, 2001].

2.2.1 Price Tags and Asset Valuation

A price tag is generally defined as a label attached to a product indicating its price. In transportation infrastructure terms, a price tag can be associated to the infrastructure construction and maintenance costs. These costs can be assigned to a particular asset, infrastructure system, or a corridor depending on the needs to preserve their physical and functional conditions. However, construction and maintenance costs should not be confused with the value of an asset, which is basically the price tag, of infrastructure systems.

This difference between construction and maintenance costs and price tags should not be overlooked when assigning price tags to infrastructure system. Construction and maintenance costs are defined as the financial resources required for producing or obtaining something, whether to replace a physically deteriorated portion of a highway or to construct an interchange. However, price tags are a subjective quantity that must be addressed within the context of time, place, culture, potential owners, and users [Cowe Falls, 2005; Dewan, 2005]. For this reason, putting a price tag to transportation infrastructure should be linked to the interests of the stakeholders. These stakeholders are represented by users of the facility, financiers, engineering and construction professionals, system managers, general community, and marginal populations [Amekudzi, 2002].

Transportation agencies, road users, and society as a whole usually assign different values to a road segment. An accurate asset valuation approach should consider all of the stakeholders to characterize the asset value as realistically as possible. Characteristics of valuation perspectives are summarized as follows [Dewan, 2005]:

- **Value to agency:** Value is based on construction and maintenance and rehabilitation (M&R) costs. Depreciation is used to account for time and environmental impacts. Computation is usually easy and reliable.
- **Value to users:** Value is based on user costs such as traffic operation, user delay, accidents, and emissions. Value calculations are not as straightforward because monetary values need to be assigned to accidents and time.
- **Value to society:** Roads have the potential to have numerous positive and negative impacts on society including social and economic effects, aesthetics, and environmental impacts. Monetary estimating is complex and unreliable.

Moreover, there are many factors could potentially affect the value of an asset. Lack of maintenance and rehabilitation efforts often results in a decrease in the physical condition of assets and their functionality. There are several factors that are considered when depreciating transportation infrastructure: structural capacity, surface deteriorations, safety conditions (road geometry, environmental factors and road condition), congestion, traffic, operating performance, and remaining service life of asset [Cowe Falls 2005; Dowling, 2004]. For example, deteriorated physical conditions of a transportation facility affect the structural capacity and ride quality of the infrastructure, resulting in increased vehicle operating costs for road users. When the demand placed on a facility exceeds its capacity, it is no longer functioning at the level at which it was designed. As a consequence, the effectiveness of the facility is reduced, and in turn, the value of the transportation infrastructure is depreciated [Peters, 2014].

The development of a sound asset management methodology is crucial to ensuring that accountability of expenditures by agencies is met, at the same time, to serve as a tool to aid senior level and policy officials in their decision-making when performing prioritization in the budget allocation process. Infrastructure valuation could be focused on a specific asset, group of assets, or infrastructure corridors, depending on agencies' objectives and goals. Internationally, Canada, Australia, New Zealand, and Great Britain are identified by many authors as the leaders in implementing infrastructure valuation in their organizations [NCHRP, 2010]. In the United States, some DOTs in states such as Washington, Florida, North Carolina, Minnesota, and Oregon have already implemented infrastructure valuation for some specific programs.

2.2.2 Historical Asset Valuation Overview

The concept of transportation infrastructure valuation, i.e., assigning price tags, gained importance in the late 1990s after the Governmental Accounting Standards Board (GASB) issued new reporting requirements for state and local governments to provide the value of the infrastructure assets that they were managing. These requirements were specified in GASB Statement 34. The traditional methods employed by transportation agencies were based on revenues and expenses reports; however, the value of their infrastructure assets was not reported. With the requirement of reporting infrastructure value, the GASB Statement 34 intended to incorporate business practices into transportation agency practices and enhance public accountability [Parsons, 2008]. In addition, the GASB recognized asset valuation as a key element in successfully managing a corporation [PB Consult, 2004].

The implementation of the new standard required a shift in the way in which our public infrastructure was viewed. GASB emphasized that its intent was to allow agencies flexibility in the details of how the methods are actually applied (e.g., in defining types of assets and networks and sub-networks). Moreover, GASB allowed approximations and reasonable estimates of costs. Infrastructure assets are long-lived capital assets that normally are stationary in nature and can be preserved for a significantly greater number of years than most capital assets. Assets such as roads, bridges, tunnels, and other civil infrastructure often exhibit service lives that extend beyond the typical reporting period, which posed a challenge for declaring these assets in financial statements. For this reason, GASB 34 included two approaches to reporting infrastructure assets: depreciation approach and modified approach. Both of these approaches provided a means for capitalizing the net costs of the asset [PB Consult, 2004].

The depreciation approach requires agencies to report the book value of their assets, i.e., the total historical construction cost and capital expenditures of the asset depreciated to the present. For some agencies, most of the information needed for the valuation was readily available, and the data demands were not as great as that of the modified approach. However, for older assets, historical records were either no longer available or difficult to obtain due to record keeping and the formats of these historical documents. Many State DOTs also favored the depreciation approach because reporting boosted agency's credibility for the managing of public assets. However, this approach often inflates the value of assets, giving the false impression of efficient management of assets by the asset's managing agency [PB Consult, 2004; Parsons, 2008].

If historical costs are not available, the GASB guidelines suggested adopting the modified approach. This approach allows agencies to value the asset by estimating the infrastructure-related expenses in lieu of depreciation, provided the agency can demonstrate their stewardship in the maintenance of their assets at a minimum threshold or condition level with an asset management program. Rather, maintenance and rehabilitation costs are accounted for as additional expenses. The agencies are required to have a working inventory of their eligible assets, provide adequate condition measurements, and have a detailed estimate of annual expenditures for maintenance and preservation. The modified approach was expected to be more helpful in the decision-making process by the provision of valuable information regarding the way the agencies were persevering their assets. Still, there remained some underlying issues of concern, including: 1) the difficulty in estimating annual maintenance and preservation expenditures to achieve target condition levels, 2) the lack of consistency in evaluating the number of components and classes used to for historical cost estimation, and 3) the resulting effect on levels of funding for State DOTs provided that the assets were not being maintained to acceptable [PB Consult, 2004; Parsons, 2008].

2.3 Asset Valuation Methodologies

The International Infrastructure Management Manual (IIMM) [INGENIUM, 2006] defines an asset as a physical component of a facility, whose value enables services to be provided and has an economic life greater than 12 months. Transportation infrastructure is considered to be stationary components of a network that collectively serve communities and businesses. As there are a variety of assets for which an agency manages, it is important to classify these assets into more manageable groups. Assets can be divided into two main categories: tangible and intangible. Tangible or real assets are physical assets that are considered to be either current assets or fixed assets such as buildings, vehicles, equipment, and roadways. Harder to quantify, intangible assets are non-physical in nature and often provide a competitive advantage to the managing entity. Examples of intangible assets include but are not limited to, goodwill, patents, copyrights, computer programs, trademarks and financial assets [Downes, 2003]. The following sections discuss the factors that affect asset valuation from an accounting and civil engineering perspective.

2.3.1 Accounting Perspective

From an accounting perspective, asset valuation is determined through depreciation methods. The most common depreciation methods include: straight-line depreciation, sum-of-years-digits, and declining balance and double declining methods. Depreciation methods use either straight line or curvilinear patterns of asset deterioration; however, the straight line depreciation has been adopted by more case studies [Saarinen, 2007]. Moreover, these methods assume that loss of value is based on time or the age of the asset. Straight-line depreciation (SLD) is the most common form of depreciation because of the simplicity of the method and the minimal data requirements. Under straight-line depreciation, the depreciation of an asset is reduced by a constant yearly amount until the end of its service life as shown Equation 2.1.

$$SLD=\frac{(P-S)}{(t_S-t_P)} \tag{2.1}$$

where:
P = historical cost (original construction cost)
S = salvage value,
t_S = year of salvage,
t_P = year of construction,
$t_S - t_P$ = analysis period, which is often taken as the asset service life.

The asset value or book value (BV_t) can be calculated at the end of any year, t, as follows:

$$BV_t = P - \frac{(P-S)}{(t_S-t_P)}(t-t_P) \tag{2.2}$$

where:
t = year for which asset value is calculated

This method assumes a linear depreciation trend, a pattern that is seldom the case for transportation infrastructure such as highways. The performance of an asset in this approach is solely based on the age of the asset, which is a flawed assumption when valuing transportation infrastructure whose depreciation is linked to its condition.

The second depreciation method, sum-of-years-digits (SOYD), unlike the SLD, provides an accelerated depreciation with varying annual depreciation rates. The annual depreciation is calculated with Equation 2.3:

$$SOYD = \frac{N - t + 1}{\left(\frac{N}{2}\right)(N + 1)} \tag{2.3}$$

where:
$N - t + 1$ = useful remaining life at beginning of year t
N = analysis period or service life
t = given year.

Similarly as SLD, the asset value or book value (BV_t) can be calculated at the end of any year, t, as follows:

$$BV_{t,SOYD} = \frac{N - t + 1}{\left(\frac{N}{2}\right)(N + 1)}(P - S) \tag{2.4}$$

where:
$BV_{t,SOYD}$ = *asset value or book value using SOYD*

The SOYD factor captures the fraction of remaining life of the asset and assigns a larger deprecation rate at the beginning of the asset's life. The notion behind this depreciation method is that an asset loses a larger fraction of its value in the early stages of its useful life as a result of depletion and wear and tear over time. The rate at which the asset is depreciated, therefore, decreases over the lifetime of the asset.

Last, the Declining Balance (DB) and Double Declining Balance (DDB) methods are another set of approaches that estimate the accelerated annual depreciation rate as a constant fraction of its service life (N). The declining balance factor is (1/N) and the double-declining balance factor is (2/N). The double declining balance method yields a larger depreciation in the early years of an asset, and the book value never reaches zero. The declining balance depreciation method functional form is as follows:

$$BV_{t,DB} = \left(\frac{1}{N}\right) BV_{t-1} \tag{2.5}$$

where:
$BV_{t,DB}$ = asset value or book value using DB depreciation
$1/N$ = depreciation factor
BV_{t-1} = asset value at the end of previous year.

Moreover, the DDB is given by:

$$BV_{t,DDB} = \left(\frac{2}{N}\right) BV_{t-1} \tag{2.6}$$

Dojutrek and Labi (2012) have reports assuming a linear depreciation generally yields underestimate values for new assets and overestimate asset values for old assets. The reason is that most highway assets are known to exhibit sigmoidal, or at least curvilinear, patterns of deterioration. Consequently, the depreciation approach may not be the best way to value all infrastructure assets because it does not consider maintenance activities.

Researchers have developed methodologies that overcomes the limitation of the depreciation approach by incorporating the effects of maintenance on asset value [Snaith, 2016]. One of these methodologies is the modified approach. The modified approach determines asset value on the basis of its original cost and current condition. In the modified approach, maintenance and rehabilitation costs are effectively treated as expenses, while expansion and reconstruction are capitalized costs [Maze, 2010]. The modified approach methods, with their greater reliance on infrastructure condition and maintenance and rehabilitation effectiveness, are thus suitable for use by agencies that have an extensive asset management system already in place [PB Cosult, 2004; Parsons, 2008]. These approach is depicted in Equation 2.7.

$$V_{t,MA} = HC\left(\frac{P_t - P_{worst}}{P_{best} - P_{worst}}\right) \tag{2.7}$$

where:
$V_{t,MA}$ = asset value at year t
HC = historical cost
P_t = expected condition at year t (from the deterioration model)
P_{worst} = worst possible condition of the asset, and
P_{best} = best possible condition of the asset.

2.3.2 Civil Engineering Perspective

Determining the value of an asset depends on the valuation objectives of the agency. Valuation approaches must reflect the intent of valuation, which is usually linked to stakeholders' interests [Amekudzi, 2002]. Such stakeholders range from users of the facility, financiers, engineering and construction professionals, system managers, general community, to marginal populations as illustrated in Table 2.1.

Table 2.1: Value Measures for Transportation Facilities by Stakeholders Interests

Stakeholders	Measure or Indicators of Value
Users – General Public	Mobility/Accessibility, Safety, Durability, Environmental Quality, Functional Obsolescence
Financiers/Owners	Accountability and fiscal health of transportation agencies
Engineering and Construction Professionals	User objectives, infrastructure improvements opportunities
System Managers – Operation and Maintenance	Economic efficiency, user objectives
Investment Decisions/Policy Makers	Overall condition and level or service of the system
Community – General Public	Physical functionality, economic impact, environmental impact, social impact
Marginal Populations	Equity in benefits and burdens of transportation

Source: Amekudzi (2002)

These stakeholders also have various perspectives on value. For example, measures such as safety, mobility, accessibility, ride quality and environmental quality are all indicators of value from a user's point of view. On other end of the spectrum, managers of the system as well as engineering professionals measure asset value in terms of economic and system performance efficiency. Value is therefore, subjective, as it is context dependent [Cowe Falls, 2005]. Various valuation techniques have been applied to transportation infrastructure, which were summarized by Herabat (2002) in five categories: cost, productivity realized value or income capitalization, option value, relative value, and market comparison as shown in Table 2.2 [Herabat, 2002]. Moreover, Amekudzi (2002) proposed that asset valuation can be represented in past, current, or future value depending on an agency's objectives and goals. Past-based approaches rely primarily on historical expenditures and utilize book value and equivalent worth-in-place. Future-based valuation approaches use future and market value, which are subject to more volatility when estimated. Cowe Falls et al. (2005) presented the most referenced asset valuation methods for civil infrastructure, including: Book Value (BV), Written Down Replacement Cost (WDRC), Replacement Cost (RC), Net Salvage Value (NSV), and Market Value. Definition, features, and data requirements for each approach are shown in Table 2.3 and 2.4.

Table 2.2: Valuation Techniques Applicable to Pavements and Highways [Herabat, 2002]

Valuation Techniques	Description	Applications/Limitations
Cost	Derives pavement value from replacement cost, physical deterioration, physical & economic obsolescence	• Useful for valuing assets which are not frequently sold in the market or where no market exists • Relates pavements value with its performance and time
Productivity Realized Value or Income Capitalization	Based on the net present value of benefit stream of the pavement/highway for its remaining life	• Appropriate for toll highway by discounting its future cash flow • Possible to apply with public pavement/highway by studying current or future benefit of a pavement • Requires several assumptions
Option Value	Derives pavement value under certain circumstances, e.g., specified number of cumulative ESALs of minimum acceptable level of pavement roughness	• Can be applied as a decision making tool for maintenance or rehabilitation investments
Relative Value	Estimates value by comparison with other pavements based on common attributes such as traffic volume etc.	• Applicable to toll highway and public highway by estimating value based on traffic volume
Market Comparison	Based on market price by comparison with recent sales of pavements/highways	• Applicable to sales of highways • Only few pavements/highways are sold in an open market

Table 2.3: Asset Valuation Methods: Features, Pros, and Cons

Source: Cowe Falls (2001)

Method	Features	Pros	Cons
Book Value BV Current value based upon historical cost	• Commonly used for financial accounting purposes • Uses historical records of procurement (first cost plus any subsequent costs), depreciated to present worth • Provides direct comparisons in time series progressions	• Data is generally available. • Relatively	• Does not account for changes in prices. • Neglects usage. • Neglects technology and service standard changes. • Results can be misleading for older assets such as bridges, land.
Written Down Replacement Cost WDRC Current values based on replacement cost depreciated to current condition	• Commonly used for management accounting purposes • Uses current market prices to rebuild/replace. • Current condition used to establish write down value.	• Reflects current prices and technology • Easily understandable • Can compare assets • Basics for budgeting	• Conjectural on replacement costs (subject to external market forces) • Question of how to handle an upgraded/improved replacement
Equivalent Present Worth In Place EPWP Historic cost adjusted for inflation and wear	• Accounts for changes in prices and usage • Represents worth "as is" • Applicable to comparing with other investments • Based on historic costs adjusted for inflation, depreciation, depletion and wear	• Uses generally available data • Accounts for changes in prices and usage • Useful for comparing rates of return with other investments • Basis for budgeting, especially maintenance, within life cycle analysis	• Neglects changes in technology and service standards • Requires a number of conjectural assumptions
Productivity Realized Value PRV Net present value of benefit stream of remaining life	• Represents value in use (what it is worth not to lose it) • Reflects relative importance of the asset	• Realistic reflection of importance of the asset • Basis for budgeting	• Requires various assumptions and non-market estimates • Subject to market forces, in particular, supply and demand if parallel service exists
Market Value MV	• Price buyer is willing to pay	• Simple concept • Applicable to public agency disposal or sell off of assets	• Conjectural until offer is actually received • Limited applicability (e.g., few highway agencies sell assets)

Table 2.4: Valuation Methods and Data Requirements

Source: Cowe Falls (2005)

Valuation Approach	Classification (Amekudzi 2002)	Definition	Pavement Type	Year of Construction (Age)	Most Recently Measured Performance	Maintenance Activity		Rehabilitation Activity		Initial Construction Costs	Current Construction Costs
						$	Yr	$	Yr		
Book Value/ Historical Cost (BV/HC)	Past	Current value based on historical cost adjusted for depreciation (commonly used for financial accounting purposes)		X		X		X		X	
Replacement Cost (RC)	Current	Current value based on cost of replacing/rebuilding the asset	X								X
Written Down Replacement Cost (WDRC)	Current	Current value based on replacement cost depreciated to current condition of the asset (commonly used for management accounting purposes)	X		X						X
Net Salvage Value	Current	Cost to replace the facility less the cost of returning it to 'new condition'	X	X	X	X		X			X

2.3.3 Comparison between Approaches

Comparing asset values obtained from different valuation approaches is a difficult task. The complexity can be explained by the various construction standards and specifications used as input data to perform the asset valuation analysis. For example, some methods do not consider condition while others incorporate both deterioration and condition ratings. Hence, results from various valuation approaches should be treated carefully when a comparison analysis wants to be conducted. Typically, transportation agencies select a specific approach depending on data availability, meaning that various combination of input data could be considered to obtain asset values.

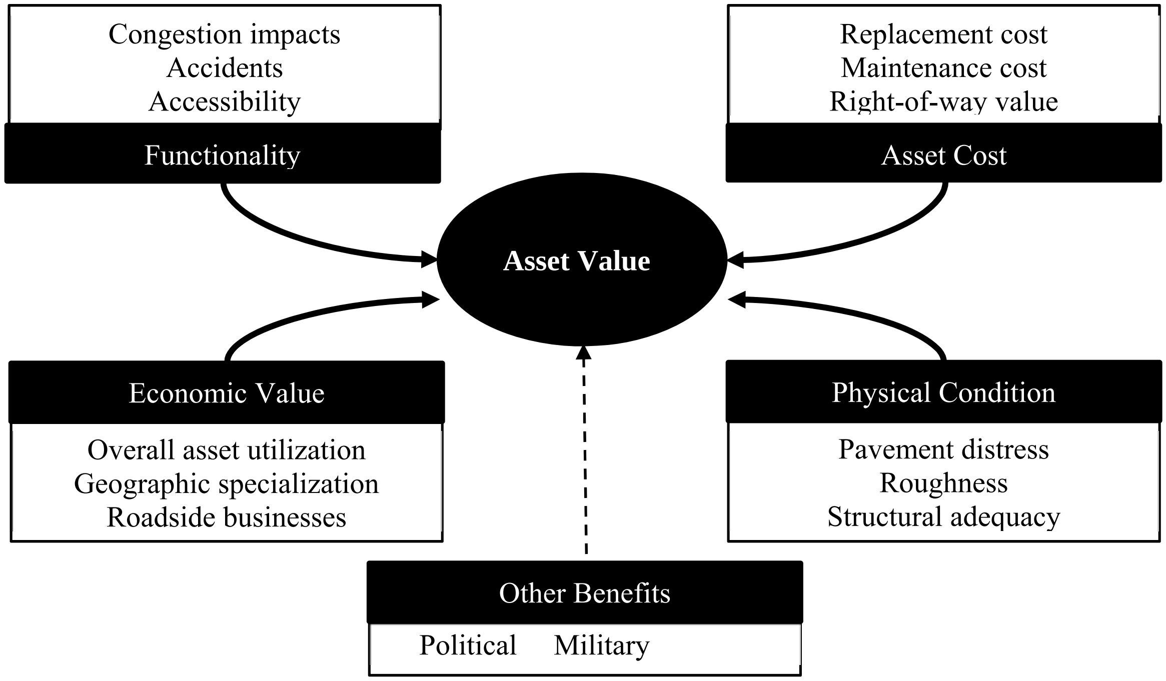
Cowe Falls et al (2004) compared straight-line depreciation and a method similar to the "adjusted value with respect to the condition threshold" (AVCT) method. For a sample road network, the latter method yielded a smaller value because, unlike the depreciation method where asset value does not increase in response to rehabilitation, the "adjusted value with respect to condition threshold" accounts for a jump in asset value after rehabilitation is applied. When no rehabilitation occurs, the depreciation method does not indicate a proportional decline in value with time while the AVCT method shows a steady loss in value. Additionally, according to Baik et al. (2004), assets tend to be valued 76 percent higher using the modified approach methods, compared to the depreciation approach. The authors reported that when the AVCT method was used the total asset value was 64 percent higher than the average value from all other depreciation methods.

Limitation of Infrastructure Valuation Methods

One of the limitations associated with the approaches previously described is that they yield significantly different values for a given asset, highway, or corridor [Herabat, 2002]. However, the most important limitation of these existing approaches is that they are primarily based on historical cost information and current physical conditions, giving no consideration to the functional characteristics and the level of utilization of the infrastructure. For example, the cost of two separate road segments with the same condition could be the same to the managing agency in terms of accounting principles, but, in terms of their values, the more heavily traveled segment should have a higher value than the less utilized segment to the agency, its road users, and society [Kadlec, 2001; Peters, 2014]. Furthermore, with all else being the same, a segment running through a densely populated urban area should have a higher value than a segment located in a remote area because of the different impact the segments have on society.

2.4 Current Trends in Asset Valuation for Transportation Infrastructure

Another perspective for assessing asset value is to quantify its social and economic benefits in addition to the cost of an asset. Benefits can be categorized by cost, physical condition, functionality, and socio-economic impacts. Figure 2.2 shows the categories of factors that will increase or decrease the value of an asset. The performance indicators associated with each category can be potentially used to quantify the impact of these factors on the value of the asset beyond the cost itself.



Source: Porras-Alvarado (2015)

Figure 2.2: Asset Value beyond Typical Replacement and M&R Costs

These concepts were used by Peters and Zhang (2014) to develop a utility-based methodological framework for the valuation of transportation infrastructure. The proposed valuation methodology uses the asset replacement cost as the base value. Additional value is then added to the base value by considering three key factors associated with the infrastructure: physical condition, functionality, and utilization [Peters, 2014; Porras-Alvarado, 2015]. Each factor is characterized by appropriate indicators that can be quantified with specific performance measures. Then, the utility theory is applied to combine the effect of performance indicators of varying measures and scales on the value of an asset. The proposed valuation methodology follows the generic structure shown below:

$$V = R_C \cdot U_{PC} \left(1 + U_{Fun} + U_{Util} + U_i\right) + SV \tag{2.8}$$

where:

V = highway infrastructure asset value
R_C = highway infrastructure asset replacement cost
U_{PC} = utility value for physical condition
U_{Fun} = utility value for functionality
U_{Util} = utility value for overall asset utilization
U_i = utility value for other factors
SV = highway infrastructure salvage value

As shown in Equation 2.8(2.8), the asset value is defined by the replacement cost multiplied by an indicator comprised of utilities for asset functionality and overall asset utilization. These utilities capture the effects of the asset functionality and overall asset utilization by increasing or decreasing their values, which have been overlooked in other valuation methodologies. Moreover, the replacement cost is multiplied by the utility for physical condition to reflect the "as-is" asset condition. Additionally, when the physical condition of the infrastructure is deteriorated to such a level that it can no longer support any service, the utility value for physical condition will be zero. Consequently, the only asset value left is the salvage value. For this reason, the utility for physical condition is multiplied by the addition of the other utilities.

Dojutrek et al. (2014) proposed a valuation methodology for transportation infrastructure based on elemental decomposition and multi-criteria methods. The authors suggest that traditional valuation methods consider assets as monolithic entities; therefore, the initial costs, characteristics, and behavior of individual asset elements are not adequately accounted for in the valuation. Each asset typically consists of multiple elements and therefore the asset can be decomposed accordingly for purposes of valuation. The decision maker can specify the appropriate level of granularity of such decomposition so long as sufficient data exist on the individual elements. For example, a bridge consists of the wearing surface, deck, superstructure, and substructure; a pavement section consists of a subbase, base, and surface layers [Dojutrek, 2014]. Then, the method proposed captures the perspective of the agency and users by incorporating both the remaining service life and the condition of an asset. These two attributes are introduced in the model using the attribute ratio. An example attribute ratio is the condition ratio that, for a given asset at time *t,* can be defined as the ratio of the condition at time *t* to the best possible condition regardless of time, as expressed in Equation 2.9(2.9), or it can be defined as the absolute difference between the condition at time *t* and the worst possible condition relative to the absolute difference between the best and worst condition, as expressed in Equation 2.10 [Dojutrek, 2014].

$$CR_t = \frac{P_t}{P_{best}} \tag{2.9}$$

$$CR_t = \left|\frac{P_t - P_{worst}}{P_{best} - P_{worst}}\right| \tag{2.10}$$

where:

CR_t = condition ratio for asset at time t

P_t = physical condition at year t

P_{best} and P_{worst} = best and worst physical condition of asset (typically at the beginning and end of its service life, respectively).

Similarly, a remaining-service-life ratio (RSLR) can be defined as the proportion of useful life that an asset has left compared with its full service life. Unlike the conditional ratio, which requires a prior knowledge of the best and worst physical conditions, service life always has a fixed start time (0 years) and an end time. The RSLR is expressed as follows:

$$RSLR_t = \frac{RSL_t}{SL} \tag{2.11}$$

where:

$RSLR_t$ = remaining-service-life ratio at time *t*

RSL_t = remaining service life at time t
SL = total service life of asset (beginning at t = 0)

Equation 2.12 shows the relationship proposed by Dojutrek et al. (2014) to value asset at time t:

$$V_t = [w_u \cdot (cost \cdot CR_t) + w_a \cdot (cost \cdot RSLR_t)] \tag{2.12}$$

where:
V_t = asset value at year t
w_u = relative weight of asset condition (user perspective)
w_a = relative weight of remaining service life (agency perspective)
cost = original (historical) cost or replacement cost of asset in constant dollars (adjusted for inflation)

2.5 Summary

As a major gateway to the entire U.S. for international trade both through seaports and land ports of entry, Texas pays the bills of construction and maintenance of the infrastructure to move the freight which benefits other parts of the country. Moreover, with the expansion of the Panama Canal and the land bridge from Mexican port of Lazaro Cardenas to Texas, it is likely that international trade through Texas ports of entry will continue to grow, and continue to impact transportation infrastructure in Texas. However, there are no local studies that examine current costs associated with maintenance and construction of major freight corridors to move international trade in Texas. Based on this comprehensive literature review, it is clear that an asset valuation methodology is necessary to accurate estimate construction and maintenance costs.

Price tags should not be solely based on construction and maintenance costs, but should also show a loss in potential benefits if the infrastructure fails its intended purpose. This chapter summarized the asset valuation methods that have been employed for transportation infrastructure. Moreover, it also included current trends in asset valuation practices. Findings from this literature review will be used to develop a utility-based methodological framework for assigning price tags to freight corridors.

Chapter 3. Workshop with Subject Matter Expert Working Group (SMEWG)

A subject matter expert working group (SMEWG) consisting of several TxDOT's administrators and engineers was assembled for a workshop to discuss critical project issues and provide insight to better conduct this research On September 30th, 2016. During the workshop, the research team presented the findings from the literature review conducted and a conceptual methodological framework for assigning price tags to the state highway infrastructure for international trade use. In addition, a preliminary list of potential issues that are considered important to estimating the price tags was presented and discussed. The followings organize the presentations and discussions made during the workshop.

3.1 Workshop Summary

The proposed workshop with the Subject Matter Expert Working Group was held on September 30, 2016, between 9:30am and 11:30am at the TxDOT Riverside Campus, Building 118. The workshop was organized as part of the research project and intended to acquire feedback and insights from the TxDOT officials on the proposed methodological framework for assigning the price tags, so as to ensure that the project is meeting TxDOT's needs.

3.1.1 Overview

The workshop was composed of two main parts: Project Introduction and Up-to-date Summary. The first part included a brief introduction on the project and information related to the workshop objectives. In the second part, concise updates of the project tasks completed to that point and future steps were presented. Figure 3.1 presents the workshop agenda.

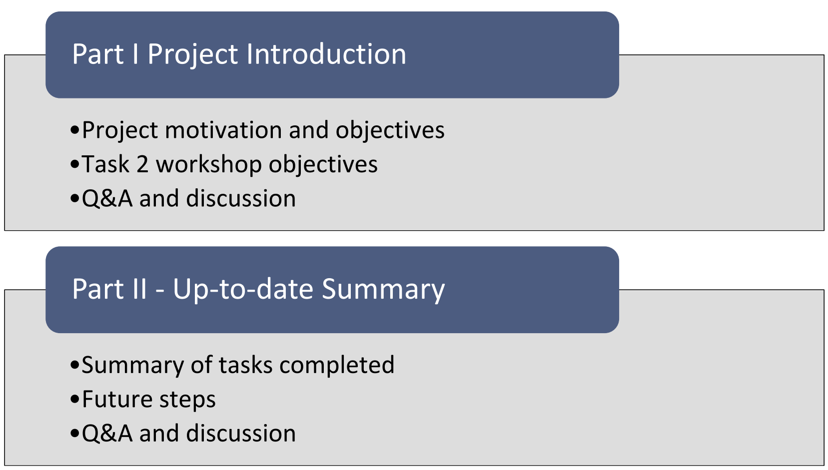


Figure 3.1: Workshop Agenda

In the first part, the project scope and objectives were briefly outlined. Then, various existing asset valuation methodologies in the current transportation asset management (TAM) practices were introduced along with their limitations, which are essentially the findings from the literature review in Chapter 2. Based on the gaps, the research team proposed a conceptual methodological framework for assigning price tags to the state highway infrastructure for international trade use and presented a list of potential information needed to develop the framework. Table 3.1 shows the list of potential information required for estimating the price tags.

Table 3.1: List of Potential Information Required

Required Information		Potential Data Sources
Performance Data	Road / Bridge Inventory data	• Pavement Management Information System (PMIS) Database • Bridge Inventory, Inspection and Appraisal Program (BRINSAP)
	Pavement / Bridge Physical Condition Data	
	Traffic Data	
Cost Information Data	Historical Construction / Maintenance Costs for Highways and Bridges	• TxDOT Bid Price Database • TxDOT Project Tracker • National Highway Construction Cost Index (NHCCI) • Highway Cost Index (HCI) • Consumer Price Index (CPI) • Other literature
	Construction Costs Fluctuation Parameters	
International Freight Transportation Data	Border Crossing / Entry Data	• Bureau of Transportation Statistics Database • Freight Analysis Framework (FAF) • 2012 International Trade Corridor Plan • IHS Global Insight TranSearch Database
	International Freight Flows on Texas Highways	

Moreover, two potential issues pertaining to the price tag estimation were also presented and discussed. One was pertaining to the difficulties in obtaining data for international freight flows on Texas highways. The second issue was the need for cooperation of the TxDOT officials to complete a survey for calibrating utility functions of the performance measures to be selected in the further step, which is the most critical part of the proposed utility-based approach. In the utility-based approach, the asset replacement cost is set as the base price tag. The additional value of the asset based on three key factors (physical condition, functionality, and utilization) is then determined and applied to the base value by using the utility theory. Finally, the insights from the audience were sought to fine-tune the objectives and scope of the current project.

The second part of the workshop summarized the project activities (Table 3.2), followed by discussions.

Table 3.2: Project Up-to-date Summary

Project Objective	Achievements
Develop a Conceptual Framework for Putting Price Tags	• Utility-based asset valuation approach was developed
Define Freight Corridors in Texas	• Freight corridors were defined and compared to Texas Freight Highway Network in Texas Freight Mobility Plan (2014) • Freight corridor GIS map was prepared
Collect and Process Data	• Various databases were explored and integrated to the freight corridor GIS map defined in Task 4 • Preliminary maintenance cost analysis was conducted
Estimate Construction and Maintenance Costs	• Explored various historical cost information sources • Explored existing cost estimation methods • Explored factors that might affect the costs • Proposed highway / bridge reconstruction cost estimation method
Analyze Condition of Infrastructure in Texas Freight Corridors	• Summarized current physical condition of pavements and bridges on the freight corridors
Determine Base Price Tags for Texas Freight Corridors	• Treatments on missing physical condition data for pavements • Calculated base price tags for the freight corridors

3.1.2 Workshop Findings – Summary

During the workshop, the audience provided valuable information pertaining to the project. The following are the key findings from the workshop:

- The highway freight network to be defined for the project should comply with the Texas Freight Highway Network (TFHN) designated in the Texas Freight Mobility Plan and National Highway Freight Network established in the Fixing America's Surface Transportation Act.
- The Bureau of Transportation Statistics (BTS) collects border crossing/entry data, which is a useful source of information on incoming crossings at the US-Mexican border at the port level. Data available includes that of trucks, trains, containers, etc. One of the suggestions was that the BTS data could be useful to develop the freight highway network.
- The IHS Global Insight TranSearch database, which is commercially available, may be useful to identify international freight movements on Texas highways. It was agreed in the discussion that TxDOT would share the database with the researchers from the Center of Transportation Research, The University of Texas at Austin.

- Another potential data source for the international freight movements on Texas roadways is the International Trade Corridor Plan (ITCP), which is a research report prepared for TxDOT. The report estimated international trade flows on the Texas International Trade Corridor; however, the freight volumes are presented for major highway corridors only. It was agreed that TxDOT would contact the authors and provide the data if possible.
- The developed framework for assigning price tags to the state highways for international trade use involves utility functions to normalize performance indicators. However, the parameters in the utility functions should be calibrated to properly reflect the preference structure of the decision makers. For the calibration process, a survey of asset management experts within TxDOT is essential to finalize the parameters. During the discussion, TxDOT agreed to determine a list of the experts, and expedite the survey process once the survey questions are sent to them.

During the discussion, the attendees provided very helpful information on several aspects of the project, which could not be easily obtained from reviewing previous literature. The key findings from the workshop will form the basis to conduct this project successfully. Appendix A provides additional information about the workshop.

Chapter 4. Conceptual Framework for Putting Price Tags on International Trade Use of State Infrastructure

After carefully analyzing the challenges, opportunities, and gaps associated with the costs of maintenance and construction on major freight corridors in the State of Texas, a conceptual methodological framework to assign price tags to the infrastructure used for international trade is proposed in this chapter. The proposed methodological framework is based on a utility-based approach that incorporates maintenance and construction costs, and then adjusts for additional benefits such as mobility and functionality. The proposed approach is aimed to provide TxDOT with an innovative conceptual structure to communicate their decisions to policy makers to obtain the necessary funding to ensure Texas economic prosperity. Additionally, under limited resource scenarios, the framework will give TxDOT the opportunity to convey to policy makers and stakeholders the reasoning behind the need to minimize risks in these vital economic corridors.

4.1 Proposed Conceptual Methodological Framework

After reviewing the challenges in assigning the construction and maintenance costs of internationally-used transportation infrastructure, a utility-based methodological framework for assigning price tags to freight corridors is proposed. This proposed conceptual framework is generic in nature and can be customized to the various freight corridors existent in the State of Texas. The objective of this proposed approach is to provide a procedure applicable to various freight corridors instead of concentrating efforts on a specific freight corridor. The proposed conceptual methodological framework along with its various components is shown in Figure 4.1.

The proposed methodological framework is comprised of three major components: a scoping module, a method for estimating construction and maintenance costs, and a procedure to adjust price tags by a utility-based approach. The methodological framework starts with the scoping process. The objective of the scoping process is to identify major freight corridors for which price tags will be assigned, and will serve as the scope of the proposed methodological framework. The next component is development of a method to estimate construction and maintenance costs of the freight corridors identified. In this component, historical construction and maintenance costs information, as well as existing cost estimation methodologies, will be reviewed to develop a method that can estimate the costs for the purpose of this study. These costs will provide the base asset values for the price tags, which will also be referred to as base price tags. Then, the base price tags will be adjusted by a utility-based approach for asset valuation that utilizes the utility theory as its foundation. As part of this component, factors with the potential to increase the price tags will be identified. These factors are usually characterized by indicators, which at the same time are captured using performance measures. Finally, a percentage related to the international trade usage will be applied to the price tags to obtain the final price tags for the corresponding consumption of highway infrastructure. Framework details are discussed in following sections.

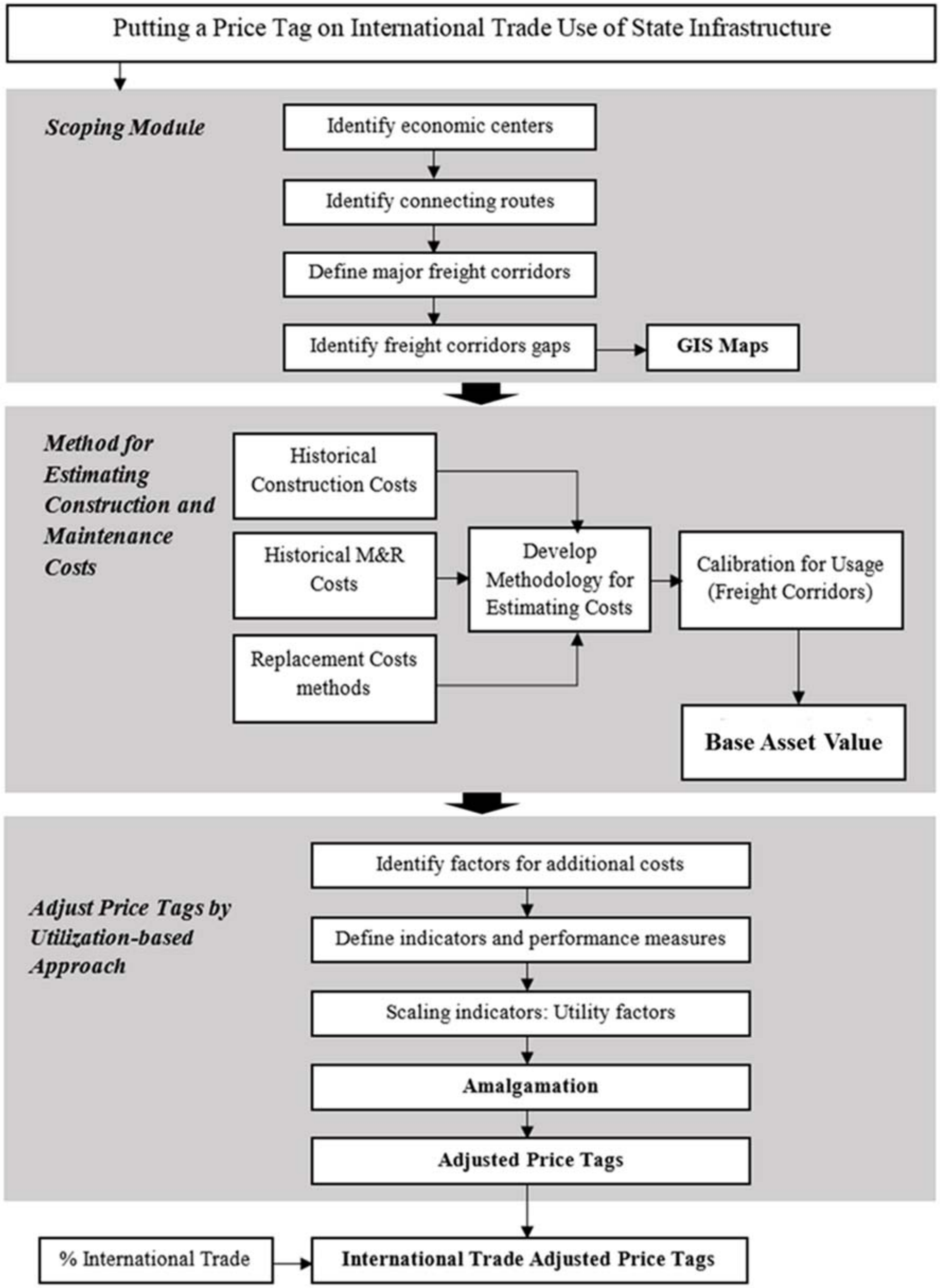


Figure 4.1: Proposed Methodological Framework for Assigning Price Tags to the State Highway Infrastructure for International Trade Use

4.2 Scoping Module

The objective of this study is to quantify the costs of construction and maintenance of the infrastructure required to move international trade to support the state's economic competitiveness. This international trade includes both imports and exports within Texas, and to other states in the Union. Therefore, the methodological framework begins with a scoping module. The scoping module objective is to identify major freight corridors in Texas. To achieve this objective, five steps will be considered: 1) identifying major economic centers and freight distributions centers, 2) identifying routes connecting such centers, 3) defining major freight corridors, 4) exploring potential freight corridor gaps to account for future international trade infrastructure, and 5) developing GIS maps.

4.2.1 Identify Major Economic Centers and Freight Distributions Centers

In this step, criteria to select the most important economic and distribution centers in the State of Texas will be defined. From the preliminary analysis, three criteria have been selected to define major economic centers: gross domestic product (GDP), truck flows, and geographical location. Other indicators will be added the analysis after further investigation. First, the GDP of each city can be evaluated using the Bureau of Economic data provided by the US Department of Commerce. This parameter will be used to identify the major economic centers and distribution centers, which will be an indication of higher movement of goods and services. The truck flows will define the metro areas with the largest truck movement in and out of major distribution centers. Lastly, freight corridors should connect all major economic and distribution centers in the State of Texas, which will be established by geographic location.

4.2.2 Identify Routes Connecting Major Economic Centers and Distributions Centers

Once the economic and distribution centers are clearly identified, the highway corridors can be defined by examining the existing routes connecting such centers. The characteristics of these routes will be examined in terms of their function to serve as major freight corridors.

4.2.3 Define Major Highway Freight Corridors

Based on the information gather from the previous steps, major highway freight corridors will be defined. Price tags will be assigned to major corridors defined in this step.

4.2.4 Identify Potential Gaps of Highway Freight Corridors

The objective of this step is to analyze potential missing highway freight corridors that can affect the movement of goods and services in the short and long term run. The analysis will be conducted in the area of planning, freight management, and policy to capture future construction or implementation plans.

4.2.5 Develop GIS Maps

GIS is a popular and powerful tool to visualize data, provide the capability to analyze data in relation to its location, and thus increase the value and utility of that information. For this reason, the highway freight corridors identified in the previous step will be mapped in a GIS with the objective of providing a user-friendly interface to communicate results more effectively.

4.3 Estimating Construction and Maintenance Costs

After the scope has been defined, a comprehensive procedure to estimate construction and maintenance costs will be developed. As seen in Figure 4.1, historical construction costs, historical maintenance costs, and replacement cost methodologies will be considered; however, additional indicators, methodologies, and cost estimator approaches will be also carefully analyzed. The information developed in this component will be utilized to determine the base price tag, which will be discussed briefly in the following sections.

4.3.1 Replacement cost methodologies

Replacement cost methodologies will be considered as one of input mathematical structures to develop the construction and maintenance estimation procedure. Several methodologies can be found in the literature varying in complexity, assumptions, purpose, and input parameters. Therefore, a careful analysis will be conducted to develop an accurate model that captures freight corridor costs. An example of such mathematical structures is shown in Equation 4.1, which is extracted from the Highway Economic Requirement System Technical (HERS-ST). This model is based on functional class and type of construction [HERS-ST].

$$R_{C,year} = UC_{2002} \cdot t_a \cdot SF_{2000} \cdot \frac{CPI_{year}}{CPI_{2000}} N_L \cdot L_S \cdot \frac{CPI_{year}}{CPI_{2002}} \tag{4.1}$$

where:

UC_{2002}	= unit cost construction per lane-mile in 2002 dollars
t_a	= terrain adjustment
SF_{2000}	= state adjustment factor
N_L	= number of lanes
L_S	= length of the segment in miles
CPI_{year}	= CPI for year of analysis

Initial values are based on national average estimates; thus, values must be adjusted for state costs differences. The HERS-ST provides unit construction costs in 2002 dollars. Therefore, in order to estimate the replacement cost within a specific year, these factors need to be indexed to the current year. The Consumer Price Index (CPI), for example, can be used as the indexing factor.

4.3.2 Historical Construction Costs

Construction and maintenance costs of highway projects are usually estimated from historical costs of similar highway projects. Therefore, transportation authorities can provide appropriate financing levels and target cost levels by benchmarking historical costs. However, there are two issues related to historical costs: each project has local conditions that affect the cost, and there are few databases related to historical highway construction, either because information is private or is not gathered [UNECE, 2014]. At the international level, the United Kingdom has developed a database to publish roadway construction costs. Also, the World Bank has developed a road construction database for developing countries with historical costs from 1984 to 2002 [Cabinet Office, 2013; World Bank, 2001]. In the U.S, some state DOTs maintain a highway construction database. As an example, Table 4.1 shows Highway Construction Costs in the State of Arkansas [AHTD, 2012]. Historical construction and maintenance construction costs will serve as input values to estimating construction and maintenance costs.

Table 4.1: Estimated Cost per Mile for New Roads in Arkansas in 2012

Road Type	Urban Areas	Rural-Mountains	Rural-Other
6 Lane Freeway	$10,850,000	N/A	N/A
4 Lane Freeway	$8,800,000	$10,400,000	$6,750,000
4 Lane With Painted Median	N/A	$5,675,000	$4,725,000
4 Lane Undivided	$5,525,000	N/A	N/A
4 Lane Divided	$5,675,000	$6,400,000	$4,725,000
4 Lane Arterial In A Floorplan With Borrow Ditches	N/A	N/A	$10,375,000
2 Lane Arterial	$3,175,000	$2,975,000	$2,750,000
2 Lane Collector	$2,100,000	$1,900,000	$1,700,000

4.3.3 Historical Maintenance Costs

The type of maintenance and rehabilitation treatments has a significant impact on cost estimation. In the order of increasing unit cost, these treatment types are preventive maintenance, light rehabilitation, medium rehabilitation, and heavy rehabilitation. Within each type of maintenance and rehabilitation treatments, the cost also varies on a project by project basis.

4.3.4 Construction and Maintenance Costs Fluctuations

Maintenance and construction costs fluctuate due to labor cost, material cost, contractor cost, transport cost, and the overall economic condition. Each of these variables contributes to a varying cost in performing maintenance and construction. Over the past several years, the construction industry has been experiencing a higher rate of inflation than the overall economy. In addition, according to Bureau of Labor Statistics (BLS), inflation in highway and street construction is much higher than residential construction, non-residential construction, and the overall economy.

To take cost fluctuations into consideration when performing engineering budget estimation, TxDOT currently maintains a Highway Construction Index (HCI) to compare the cost of business for a specific period to the cost of business in 1997 as the base year. Figure 4.2 shows the HCI over the last 15 years in Texas. This index is highly variable, creating many uncertainties for cost estimation. These fluctuations will also be considered in the development of the construction and maintenance cost estimation model.

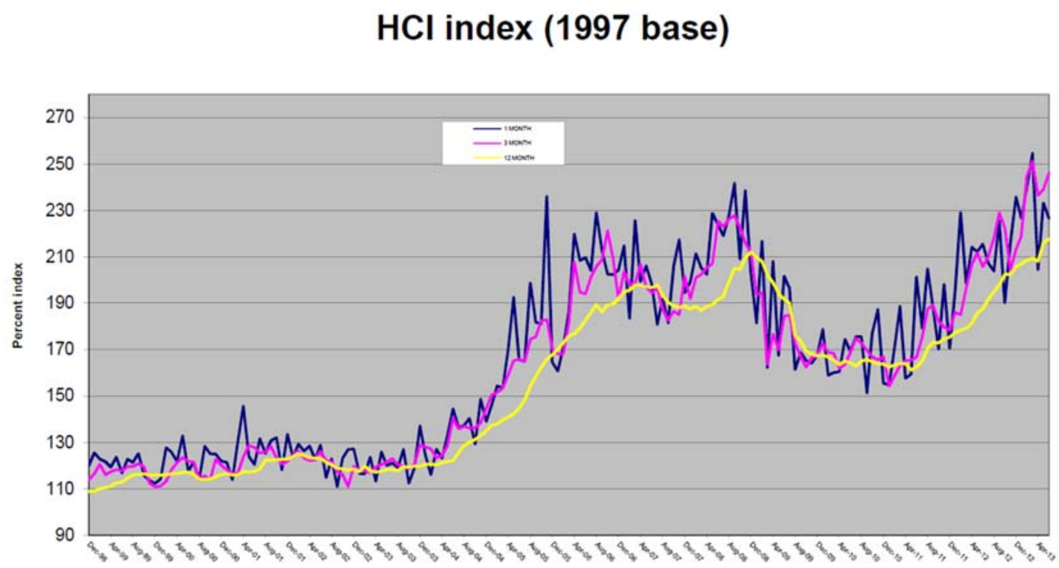


Figure 4.2: TxDOT HCI since 1997

4.4 Adjusting Price Tags by a Utility-based Approach

Transportation agencies, road users, and society as a whole usually assign different price tags to roadways or highway corridors. Agencies usually assign values based on construction and maintenance and rehabilitation (M&R) costs, while users focus on user costs such as traffic operations, user delays, accidents, and emissions. Moreover, society as a whole values infrastructure based on the impact it brings to the society, economy, and environment, and sometimes even based on the aesthetics. The proposed methodological framework assumes that price tag structures should consider all of these aspects. As such, the concept and techniques of infrastructure asset valuation can be applied to assign price tags to freight corridors.

One limitation of these existing approaches is that they are primarily based on historical cost information and current physical conditions, giving no consideration to the functional characteristics and the level of utilization of the infrastructure. For this reason, a utility-based approach to asset valuation developed by Peters and Zhang (2014) and modified by Porras-Alvarado et al. (2015) is proposed. The following sections briefly described the various steps of this component.

4.4.1 Key Factors

The first step is identifying factors that affect the value of the freight corridors. From preliminary analysis, three factors were identified: physical condition, functionality, and overall asset utilization. However additional factors can be added if necessary.

- **Physical Condition:** Represents the structural and surface condition of a facility. The physical condition factor provides a measure of how well the assets are being maintained.
- **Functionality:** Captures the operational efficiency of the transportation infrastructure and quantifies the quality of service provided by the asset for its intended purpose.

- **Overall asset utilization:** Reflects the relative importance of the asset being valued in terms of its capacity utilization. The overall asset utilization of a facility can then be linked to its contributions to the economic prosperity of a region. Factors such as connectivity, truck flow, roadside business, large scale production, and added employment can be used to characterize this factor.

4.4.2 Define Indicators and Performance Measures

The proposed methodology requires the identification of indicators for each of the key factors previously identified to characterize their effect on the asset valuation. At a minimum, one indicator should be specified for each factor. Once the attributes for each indicator have been chosen, the selection of performance measures or measures of effectiveness should be determined for each attribute under each indicator. Table 4.2 presents a list of potential indicators under each factor being considered, along with a list of potential performance measures to choose from for each of the indicators.

Table 4.2: Potential Indicators for Key Value Factors and Associated Performance Measures

Key Factors	Potential Indicators	Potential Performance Measures
Based Asset Value	-	- Replacement Cost (RC)
Physical Condition	**Structural Capacity & Surface Condition**	- International Roughness Index (IRI) - Pavement Serviceability Index (PSI), - Condition Score (CS) - Ride Score (RS) & Distress Score (DS) - Skid Number (SN)
Functionality	**Safety**	- Number of traffic fatalities - Number of serious injuries in traffic crashes (State crash data files) - Fatalities/VMT or Injuries/VMT - Response time to Incidents - Number of accidents per VMT, per year, per trip, per ton-mile, and per capita
	Mobility	- Average Travel Speed (mph) - Travel Rate (minutes/mile) - Delay Rate (minutes per mile) - Delay Ratio - Corridor Mobility Index
	Accessibility	- Average trip length - Travel Time Index (Urban Freeways) - Connectivity to Intermodal Facilities - Percent of employment sites within x miles of highway or a reasonable travel time - Average travel time to major regional destinations
Overall Asset Utilization	**Direct**	- Traffic Intensity (AADT/Capacity Ratio) - Volume/Capacity Ratio - AADT (Annual Average Daily Traffic) - Persons, Trucks, or Vehicles Moved
	Indirect	- Roadside Business - Truck Commodity - Added employment - Connectivity - Large Scale production - Tourism

Source: [Peters, 2014; Porras-Alvarado, 2015]

4.4.3 Scaling Indicators: Utility Factors

For different types of transportation infrastructure assets, and even for different performance indicators of the same type of infrastructure asset, different performance measures are used to reflect their condition. For this reason, scaling or normalization techniques should be employed to convert different units to a common scale [Porras-Alvarado, 2015]. The utility theory will be used to capture the relative preference of transportation infrastructure assets with regards to their performance in three key factors: physical condition, functionality, and overall asset utilization.

Various utility values define a utility function, which is used to map performance measures to a uniform scale between zero and one. They exhibit many forms and can be developed by customizing general function forms. Usually, utility functions are strictly decreasing or increasing. The functional forms are classified as risk taker, risk neutral, or risk-averse, as Figure 4.3 illustrates.

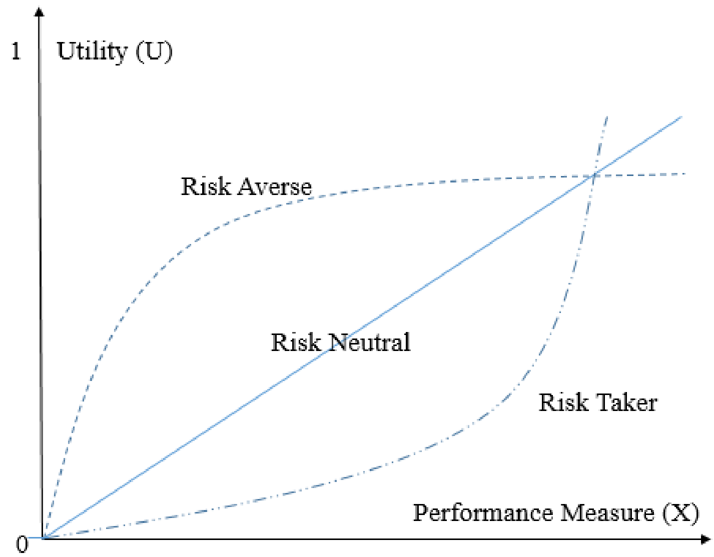


Figure 4.3: Relationship between Risk Attitude and Scaling Function [Bai, 2008]

Research studies have established utility function forms for various performance measures related to civil infrastructure as summarized by Bai et al. (2008). The most referenced mathematical forms to express utility functions are exponential and sigmoidal models. Equation 4.2 shows an example of the mathematical formulations.

$$U(x) = ke^{-ax}, k > 0, a > 0 \quad \textit{(Decreasing utility)} \tag{4.2}$$

where:
k and a = Calibration parameters

The calibration of the coefficient, a and k, is one of the most challenging steps in developing utility functions. Coefficients should be calibrated considering transportation agencies' objectives, goals, and local conditions. In some cases, previous research studies have established utility functions for some performance measures. If a utility function exists for a given performance measure, the coefficient(s) can be easily adjusted. However, for cases where utility functions do not exist, they must be developed and calibrated [Keeney, 1993]. For this reason, the calibration of utility functions will be conducted if required.

4.4.4 Amalgamation

After the utility functions are developed, mathematical procedures are needed to combine the individual values to obtain the overall utility values for each of the three key factors. The combination of utility values is referred to as amalgamation [Bai, 2008]. The multi-attribute utility method is an example of a multi-criteria decision analysis (MCDA) procedure available to combine different attributes, which can aid developing the amalgamated valuation function. Other methods, such the Analytical Hierarchy Process, Delphi prioritization process, outranking methods, and MCDA using fuzzy methods, can also be employed to amalgamate various attributes. Decision makers have various alternatives; however, the MCDA selected should reflect the objectives and goals of transportation agencies.

4.4.5 Utility-Adjusted Price Tag

The adjusted price tag will be obtained by amalgamating estimated construction and maintenance costs with the utility values computed in previous steps. The general structure of the proposed model is as follows:

$$V = B_C \cdot U_{PC} \left(1 + U_{Fun} + U_{Util} + U_i\right) + SV \tag{4.3}$$

where:

V = highway infrastructure price tag
B_C = highway infrastructure base price tag
U_{PC} = utility value for physical condition
U_{Fun} = utility value for functionality
U_{Util} = utility value for overall asset utilization
U_i = utility value for other factors
SV = highway infrastructure salvage value

As shown in Equation 4.3(2.8), the price tag (asset value) is defined by the base price tag multiplied by an indicator comprised of utilities for asset functionality and overall asset utilization. In this formulation, the base price tag indicates the value of the highway infrastructure being assessed without considering any of the factors that will be considered as utility values in the further steps. For instance, Written Down Replacement Cost (WDRC) cannot be adopted as the base price tag in this formulation since it is a current value based on replacement cost depreciated to the highway's physical condition. In addition, the utilities capture the effects of the asset functionality and overall asset utilization by increasing or decreasing their values, which have been overlooked in other valuation methodologies. It is important to point out that this general structure only represents a preliminary analysis. Further considerations will be incorporated as the study continues.

4.5 Price Tags Adjustment for International Trade

The utility-adjusted price tags will provide a quantification of the asset value considering physical condition, functionality, and overall asset utilization. However, these assets comprising the freight network serve other purposes such as passenger vehicles, bus services, and internal freight movement. These other purposes will also impact the condition of the freight corridors. Therefore, the proposed methodological framework will incorporate an adjustment coefficient for international trade use of transportation infrastructure to emphasize its role of carrying international freight. The mathematical formulation will be defined by the following structure:

$$V_{IT} = IT * V \tag{4.4}$$

where:

V = highway infrastructure asset value

IT = international trade coefficient

V_{IT} = highway infrastructure asset value for international trade

4.6 Summary

A conceptual methodological framework is intended to provide a logical process of assigning price tags to international trade use of state infrastructure. The proposed approach is comprised of three major components: a scoping module, a method for estimating construction and maintenance costs, and a procedure to adjust price tags by a utility-based approach. This conceptual methodological framework will allow TxDOT to maintain freight corridors with high condition standards and to be prepared for the potential trade growth.

Chapter 5. Identification of Highway Freight Corridors in Texas

In the previous chapter, the research team proposed a conceptual methodological framework to assign price tags to the infrastructure used for international trade to manage it more effectively and efficiently. This chapter contains the very first step of the framework, which is defining the scope of the infrastructure to which price tags will be assigned. To begin, efforts are made to spot major freight centers in which active freight movement takes place and to find highway routes connecting these centers. Then, the routes identified and the highway freight network specified in Texas Department of Transportation (TxDOT) Freight Plan are compared to finalize the scope of the project. Potential freight corridors are also addressed by investigating possible detours and new roads under construction. Figure 5.1 illustrates process taken to identify the freight corridors.

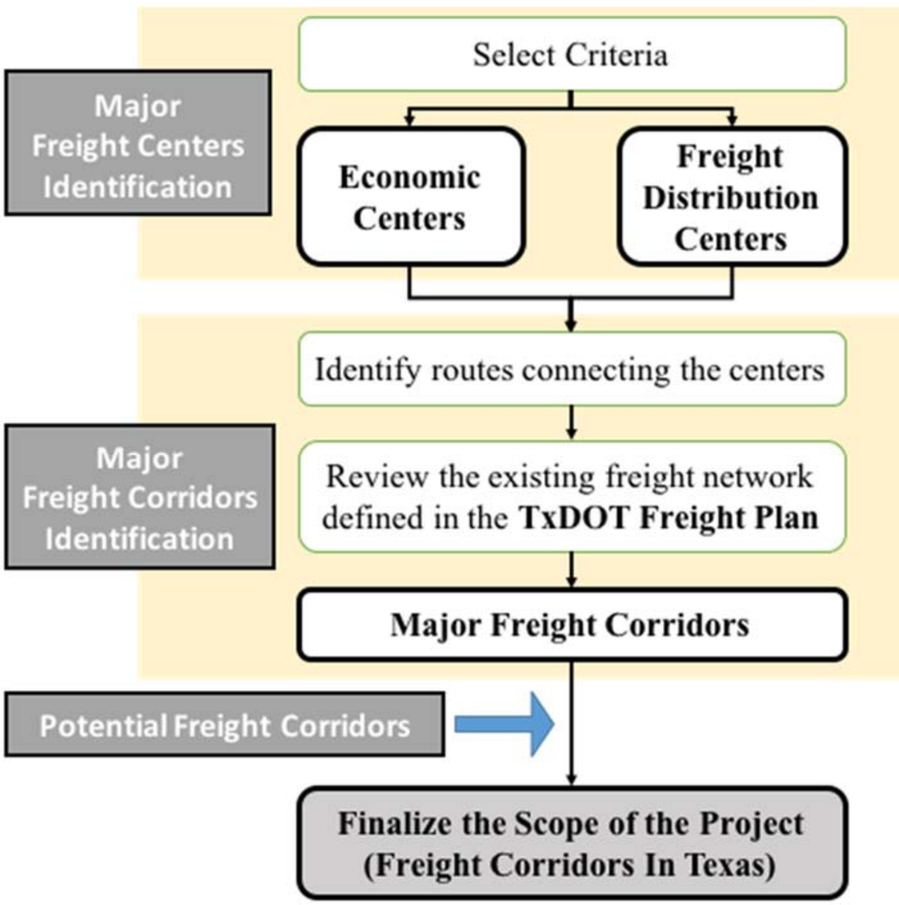


Figure 5.1: Definition Processes for Freight Corridors in Texas

5.1 Identification of Major Economic Centers / Freight Distribution Centers

In this step, the research team identifies the major centers where freight converges and disperses in the State of Texas. The centers are categorized into two groups: economic centers and freight distribution centers. In this study, the economic centers are defined as locations where economic activities boost up freight movements. Major cities may fall into this category. On the other hand, the freight distribution centers are places where freight from various regions is gathered and distributed to other places such as economic centers previously mentioned. The ports of entry in and near Texas may represent the freight distribution centers. In the following subsections, these centers are identified by investigating key factors and defining some criteria for each type of center.

5.1.1 Economic Centers in Texas

Three criteria are selected to define major economic centers in Texas: (1) gross domestic product (GDP), (2) traffic volume, and (3) geographical location. GDP is the monetary value of all products and services produced within a country (or specific region) during a specific time period. Therefore, it is a good indicator to assess the degree of current economic activity in a specific region. A region with high GDP is assumed to have more economic activity that triggers more freight movement. Traffic volume is also an important indicator, because it indirectly represents how much active economic activity is occurring in the region of interest. Two types of traffic volumes are considered: Annual Average Daily Traffic (AADT) and Truck AADT. The former is a measure that focuses more on the overall economic activity, while the latter shows the largest truck movement in and out of the region of interest. Lastly, the geographical location of each region is considered. Even if the region of interest has low GDP, it may be located on an intersection of two major highways that could possibly serve a number of trucks heading to other locations.

Metropolitan areas in and out of Texas are examined to find economic centers, because it is likely that these areas consume and produce more products than any other areas. GDP of each city is obtained from the Bureau of Economic data provided by the U.S. Department of Commerce. The AADT information is gathered from 2013 TxDOT's statewide flowband maps that depict the total traffic and truck volume produced on TxDOT-maintained roads. Other cities in the vicinity of Texas are also included in this evaluation in order to consider freight movements crossing the Texas border. Table 5.1 shows metropolitan areas in and out of Texas with their corresponding GDP, AADT, and truck AADT.

Table 5.1: Metropolitan Areas Within and Outside of Texas

Metropolitan Areas		GDP (2013) ($ Million)	Truck AADT (2013)		AADT (2013)		Truck Portion (B/A, %)
			Max (A)	Avg.	Max (B)	Avg.	
In Texas	**Houston**	517,367	22,807	14,836	313,017	202,168	7.29
	Dallas	447,574	24,235	16,986	264,908	175,016	9.15
	Austin	103,892	16,557	14,101	138,981	127,540	11.91
	San Antonio	96,030	43,534	18,822	241,792	173,930	18.00
	El Paso	27,458	14,736	12,022	192,280	108,988	7.66
	Midland	25,007	13,270	11,138	164,044	38,370	8.09
	Beaumont	24,147	14,187	11,954	92,000	47,759	15.42
	Corpus Christi	23,467	8,676	6,380	126,246	51,705	6.87
	McAllen	17,036	16,222	8,285	88,199	53,185	18.39
	Killeen-Temple	15,938	2,283	1,468	52,285	32,094	4.37
	Longview	12,547	12,673	9,968	34,649	25,344	36.58
	Lubbock	11,910	4,846	3,379	48,143	27,930	10.07
	Amarillo	11,587	18,235	9,261	99,306	57,517	18.36
	Tyler	10,876	4,116	3,229	37,010	23,993	11.12
	Waco	9,875	5,149	2,715	40,229	22,570	12.80
	Odessa	9,328	13,270	11,018	43,406	26,754	30.57
	Brownsville	8,631	-	-	-	-	-
	College Station	8,252	7,060	7,060	52,119	52,119	13.55
	Laredo	7,463	8,687	8,687	46,196	46,196	18.80
	Wichita Falls	7,038	17,210	9,398	59,649	32,336	28.85
	Abilene	6,452	9,429	7,061	34,401	20,723	27.41
	Victoria	5,298	1,780	1,780	13,038	13,038	13.65
	Texarkana	5,148	13,794	13,355	59,374	39,462	23.23
	San Angelo	4,536	3,129	1,808	31,316	22,611	9.99
	Sherman	3,862	6,289	4,364	45,132	24,316	13.93
Outside Texas	**Oklahoma City, OK**	71,951	-	-	-	-	-
	Albuquerque, NM	41,970	-	-	-	-	-
	Little Rock, AR	40,924	-	-	-	-	-
	Shreveport-Bossier City, LA	23,565	-	-	-	-	-
	New Orleans-Metairie, LA	81,843	-	-	-	-	-

Based on the information above and geographical locations, the major economic centers are identified in Table 5.2. Moreover, Figure 5.2 depicts the 22 identified economic centers.

Table 5.2: Major Economic Centers Within and Outside of Texas

Territory	In Texas		Outside Texas
Major Economic Center	Houston	Amarillo	Oklahoma City, OK
	Dallas	Waco	Albuquerque, NM
	Austin	Odessa	Little Rock, AR
	San Antonio	College Station	Shreveport-Bossier City, LA
	El Paso	Laredo	New Orleans-Metairie, LA
	Midland	Wichita Falls	-
	Beaumont	Abilene	
	Corpus Christi	Victoria	
	McAllen	Texarkana	
	Longview	Sherman	
	Lubbock	-	

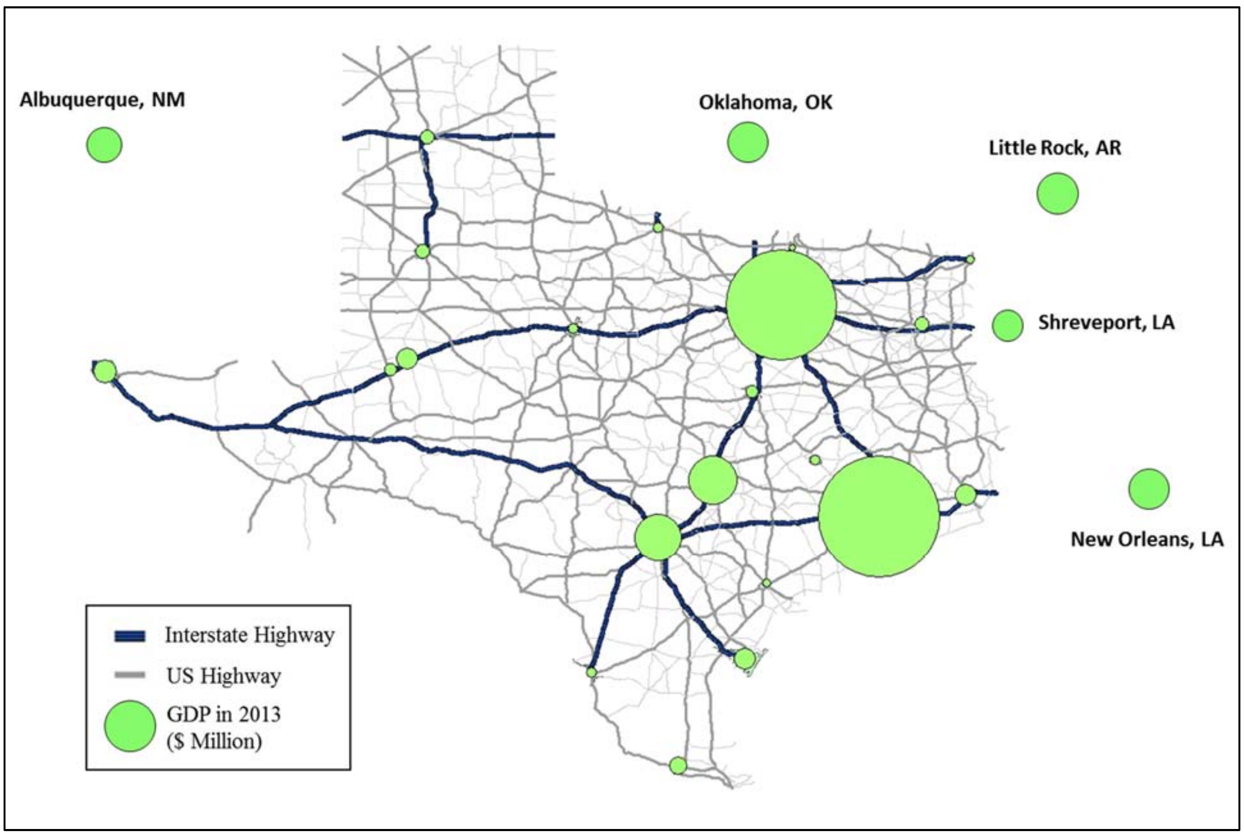


Figure 5.2: Location of Identified Major Economic Centers

5.1.2 Freight Distribution Centers in Texas

Besides the major economic centers identified in the previous subsection, freight distribution centers are other areas that play an important role as critical hubs in the Texas freight network. While the economic centers are where consumption and production of finished products actively take place, freight distribution centers process commodities from various locations to distribute them to other regions. Therefore, freight gathers at these economic centers for two main purposes: consumption and distribution. However, with the criteria defined in the previous section, the freight distribution centers cannot be properly captured since they may not be located in metropolitan areas and might have low GDP and AADT. Accordingly, a different approach is required to identify the freight distribution centers.

First, ports of entry (POEs) in Texas are examined to identify the major freight distribution centers by investigating the value of freight (export and import) each POE processes annually. As previously mentioned, there are 29 POEs located in Texas, and, according to U.S. Department of Transportation (2009), 15 of them are ranked in 'Top 125 Gateways in U.S.' by the freight value. Table 5.3 shows those 15 Texas POEs and the values of international freight handled by each of them. The Port of Houston was ranked number one among the POEs in Texas, and Laredo got the second place in terms of the total trading value.

Table 5.3: Texas Ports of Entry Ranked in Top 125 International Freight Gateways in U.S.

Ranked by Value (2008)	**Gateway Name**	**Mode**	**Total** ($ million)	**Exports** ($ million)	**Imports** ($ million)
4	Houston, TX	Water	147,695	68,821	78,873
6	Laredo, TX	Land	115,759	53,929	61,830
18	El Paso, TX	Land	48,174	20,156	28,018
24	Dallas-Fort Worth, TX	Air	39,488	16,403	23,085
31	Corpus Christi, TX	Water	29,685	4,965	24,721
35	Texas City, TX	Water	22,726	3,264	19,462
38	Hidalgo, TX	Land	22,149	9,853	12,296
39	Beaumont, TX	Water	21,338	2,847	18,490
46	Port Arthur, TX	Water	17,352	2,445	14,908
50	Freeport, TX	Water	15,785	1,989	13,796
55	Houston, TX	Air	13,545	8,283	5,261
58	Eagle Pass, TX	Land	12,830	5,037	7,793
59	Brownsville, TX	Land	12,605	7,911	4,694
79	Galveston, TX	Water	6,059	2,022	4,037
103	Del Rio, TX	Land	2,821	1,353	1,468

(Source: USDOT, 2009)

Another indicator that can be considered is the number of trucks passing through land border crossings. Due to geographical proximity to Mexico, Texas has a number of heavy trucks hauling commodities from Mexico that could have a huge impact on Texas highway infrastructure. Therefore, investigating these passing trucks helps not only to guess the amount of freight transported by trucks, but also to estimate the number of trucks on adjacent freight corridors. Table 5.4 presents the number of trucks passing through each POE located on the Texas-Mexico border.

Table 5.4: Number of Trucks Passing Texas Land Border Crossings

Port Name	2010	2011	2012	2013	2014
TX: Laredo	1,585,682	1,695,916	1,789,546	1,846,282	1,947,846
TX: El Paso	710,363	714,699	724,964	738,914	759,125
TX: Hidalgo	459,331	453,235	481,620	510,706	530,093
TX: Brownsville	207,408	208,021	218,187	208,148	209,989
TX: Eagle Pass	95,028	106,046	117,375	118,363	136,506
TX: Del Rio	55,852	62,723	65,477	67,718	69,048
TX: Progreso	43,327	42,494	44,510	42,761	41,416
TX: Rio Grande City	21,503	24,323	29,277	27,120	32,459
TX: Presidio	9,298	8,654	11,373	9,546	10,584
TX: Roma	6,417	6,921	7,139	7,479	7,556

(Source: USDOT *Border Crossing / Entry Data*)

Inland ports located in Texas also must be considered as freight distribution centers since they also facilitate international trades and shipment in and out of the states. Currently, there are two inland ports in Texas: AllianceTexas and Port San Antonio. A more detailed definition of an inland port is provided as follows:

> "A site located away from traditional land and coastal borders with the vision to facilitate and process international trade through strategic investments in multi-modal transportation assets and by promoting value-added services as goods move through the supply chain." [Prozzi et al, 2002]

After carefully examining the abovementioned information, the research team identifies major freight distribution centers in Texas as shown in Table 5.5 and Figure 5.3.

Table 5.5: Major Freight Distribution Centers in Texas

Major Freight Distribution Centers in Texas		
Houston	Texas City	Freeport
Laredo	Hidalgo	Houston
El Paso	Beaumont	Eagle Pass
Dallas-Fort Worth	Port Arthur	Brownsville
Corpus Christi	-	

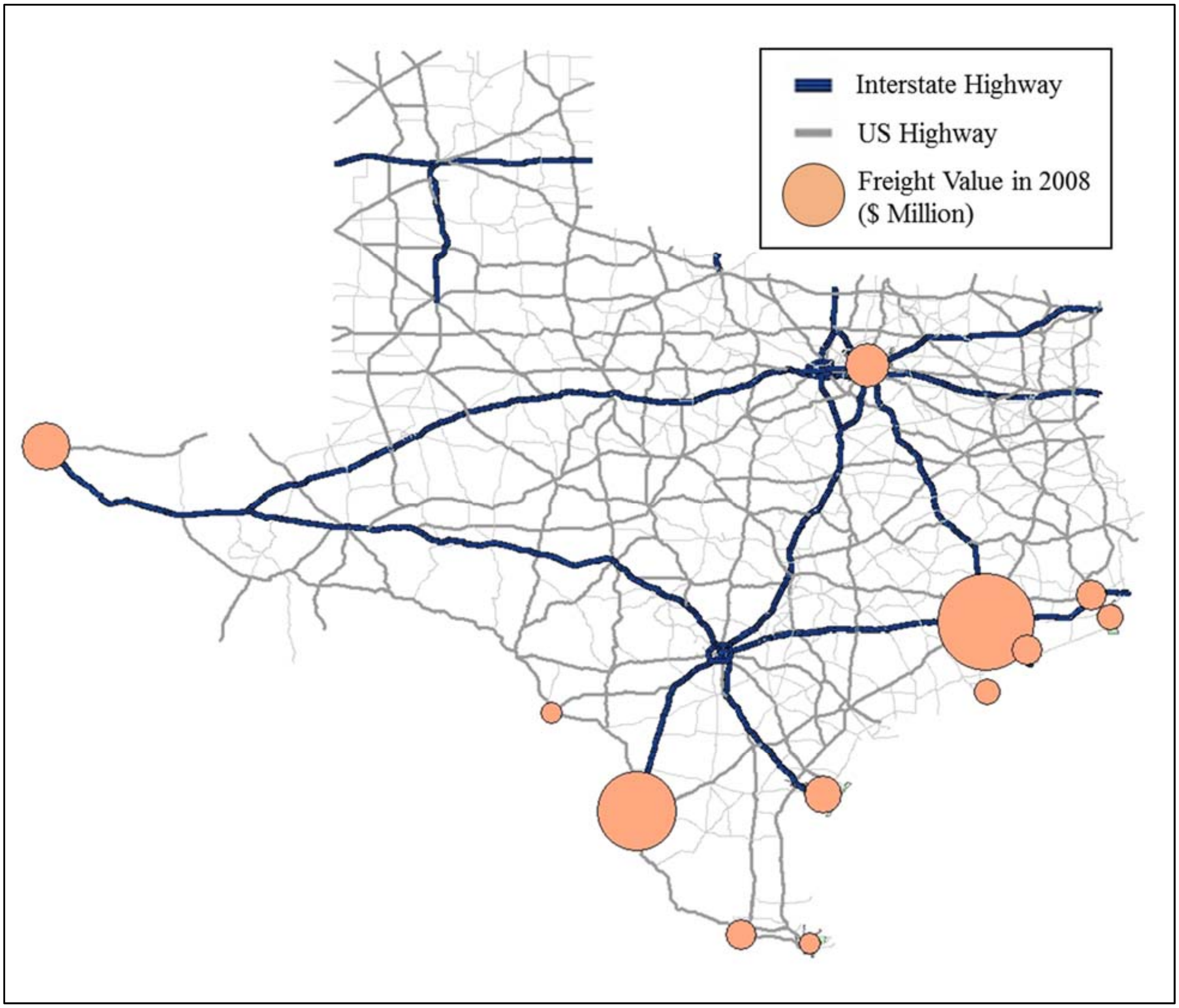


Figure 5.3: Location of Identified Major Freight Distribution Centers

5.1.3 Major Economic Centers and Freight Distribution Centers in Texas

Finally, major centers defined as critical nodes in the Texas freight network are depicted in Figure 5.4 by combining the results from the previous subsections. The number of centers here is less than the total of the economic centers and freight distribution centers since some of the major freight distribution centers overlaps with the economic centers. For instance, Dallas is not only one of the major economic centers, but also the region where the Dallas-Fort Worth airport (freight distribution center) is located.

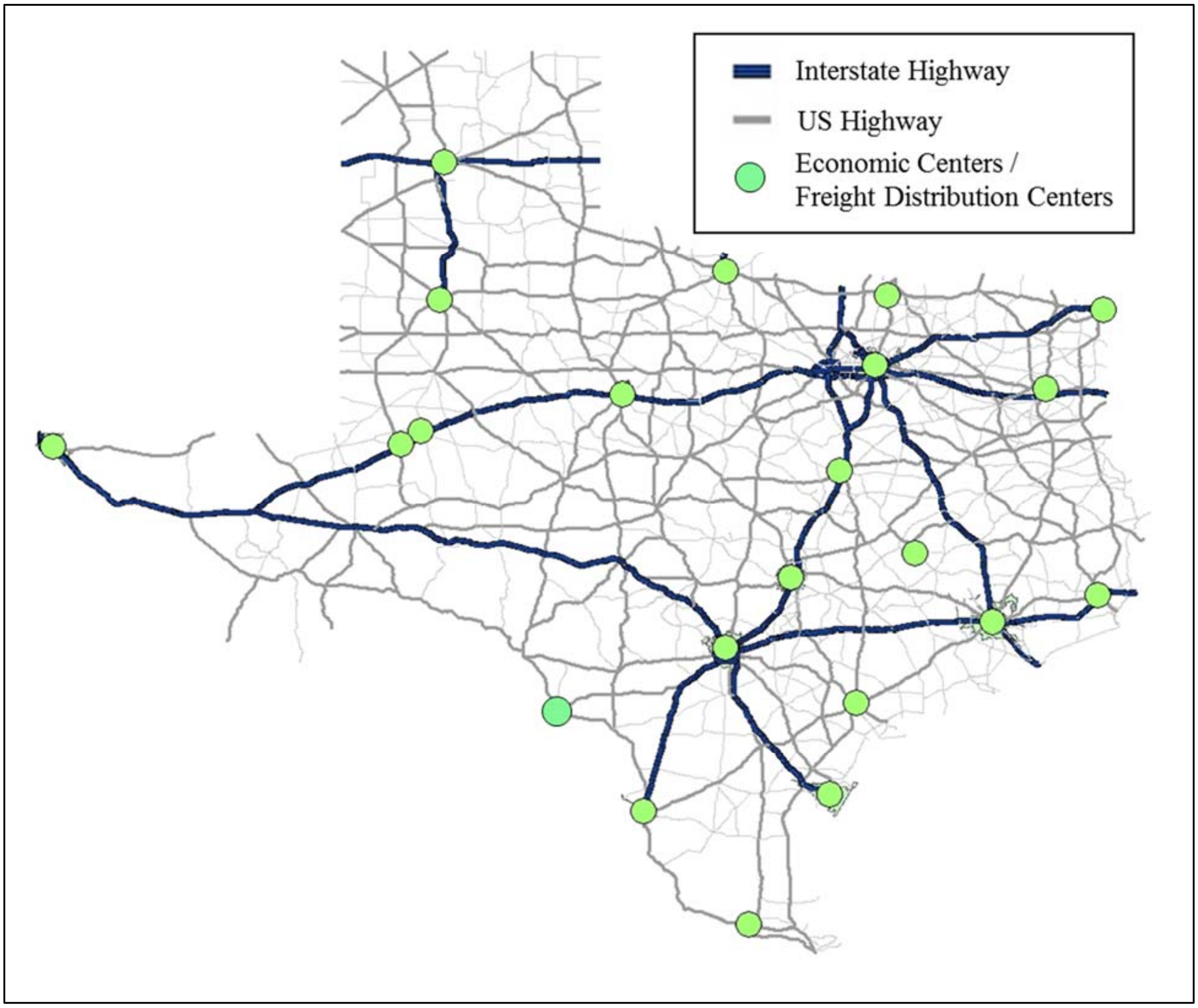


Figure 5.4: Major Economic Centers and Freight Distribution Centers in Texas

5.2 Identification of Major Highway Freight Corridors in Texas

Based on the major centers identified for freight movement, the research team defined major freight corridors connecting the centers this section. The process is performed by following three steps: (1) find main routes connecting the centers, (2) review the TxDOT Freight Plan, and (3) finalize major freight corridors in Texas. The identified freight corridors shall define the scope for which price tags will be assigned.

5.2.1 Routes Connecting Major Economic Centers and Freight Distribution Centers

The highway routes connecting two major centers can be developed in numerous ways on the existing highway network in Texas since there are many alternate roads connecting the two centers. Therefore, some criteria must be defined to identify the most favorable routes for freight carriers. To develop the criteria, a literature review on truck route behavior is conducted. Most of the research focused on value of time (VOT), which considers the trade-off between cost and travel time only [Zamparini and Reggiani, 2007; Wynter, 1995; Kawamura, 2000]. On the other hand, a few studies weighed more on other factors, such as travel speed and road types, to address the limitation of VOT studies [Knorring et al, 2005; Hyodo and Hagino, 2010]. In summary, the literature indicates that various factors need to be investigated along with travel time and cost to understand truckers' route choice behaviors.

Referring to the freight corridor criteria already defined by other states is another way to obtain helpful information. Florida defines its Strategic Intermodal System mainly on interstate facilities, the National Highway System (NHS), and the State Highway System (SHS) facilities, which satisfy such conditions as connectivity between economic regions and percent of trucks of the roadways. On the other hand, State Freight Economic Corridors of Washington are defined mostly based on the tonnage of freight that each corridor carries. It also includes alternative freight routes and connector routes that meet certain criteria developed. Ohio considers daily truck volume and connectivity between population centers for the multimodal corridor selection [Texas Freight Advisory Committee, 2013].

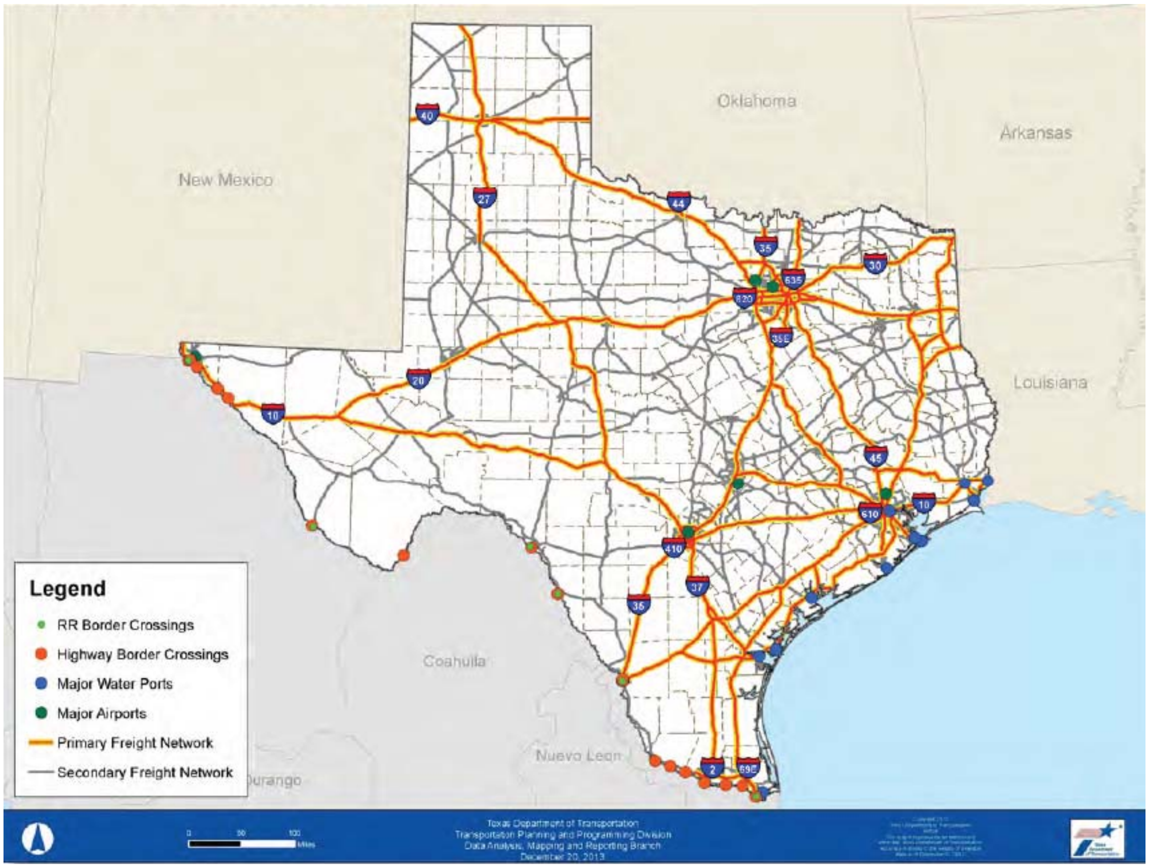
After scrutinizing the information reviewed, the research team developed the criteria to select routes that could be included in the Texas freight corridors. First, each route should be on the National Highway System (NHS). The U.S. Department of Transportation (USDOT) defines the NHS as a set of roadways critical to the United States' economy, defense, and mobility. It includes other principal roadways in U.S., as well as the Interstate Highway System (IHS) [FHWA, 2013]. Therefore, this criterion can ensure that the freight corridors being defined will not include local roadways with poor structural capacity for heavy trucks. Another criterion developed is that each route connecting two major centers should have an acceptable length in comparison with the straight-line distance between the centers. The idea originated from the fact that freight carriers value their travel time and so would take the shortest route if the conditions of all routes were the same. Even though the truckers may take detours to avoid any incidents like congestion in the real world, it still does not make sense for them to be on a route with the length of twice of the straight-line distance, especially in long distance traveling. Lastly, the truck AADT on roadways is considered as an important criterion since it directly indicates how heavily the roadway is used for freight transportation.

5.2.2 Texas Freight Mobility Plan Review

Before finalizing the newly defined Texas highway freight corridors, the research team conducted a review of previous freight plans for Texas to make sure that the new freight corridors are consistent with the previous plans. The most recent freight plan is the Texas Freight Mobility Plan initiated by the Texas Freight Advisory Committee (TFAC) to develop the first comprehensive and multimodal Freight Mobility Plan for Texas. This Freight Mobility Plan's main objectives were to enhance freight mobility and improve the state's economic competitiveness. The plan would achieve this by providing an efficient, reliable, and safe freight transportation while maintaining the quality of life in the State. In addition, the plan would help with developing policies and investment strategies that will perpetuate Texas's freight transportation system into the future, through a well-developed framework for Texas' comprehensive freight planning program and decision making [TFAC, 2014].

In the Texas Freight Mobility Plan, TFAC defined a Texas Freight Highway Network (TFHN). The TFHN is a system of roadways that includes the National Freight Network and other roadways with interest to Texas. The development of this network was based on three main sources: the Texas Highway System, the Texas Trunk System, and the connections to freight generators and gateways. The TFHN divided the entire freight network into two categories: a

Primary Network and a Secondary Network. The criteria used to define the primary network is the network with a commodity flow above or equal 10 million tons in 2040, or a network with connections to major freight generators, gateways, and ports-of-entry. Figure 5.5 illustrates the TFHN developed by TFAC.



(Source: TFAC, 2014)

Figure 5.5: Texas Freight Highway Network (TFHN)

Since the TFHN is closely related to the concept of Texas highway freight corridors being defined in this chapter, the network must be reviewed thoroughly to ensure important highway segments are not omitted. After discussions, the research team decided to include the Primary Freight Network defined in the TFHN to fill the gap between the connecting routes identified in the previous subsection and the TFHN.

5.2.3 Freight Roadway Network (FRN) in Texas

By combining the previously discussed findings, the research team defined the Freight Roadway Network (FRN) as shown in Figure 5.6, which is basically the major freight corridors identified in Texas based on the previous steps. The FRN include all of Interstate Highways in Texas, segments of major US highways, and segments of the State highways.

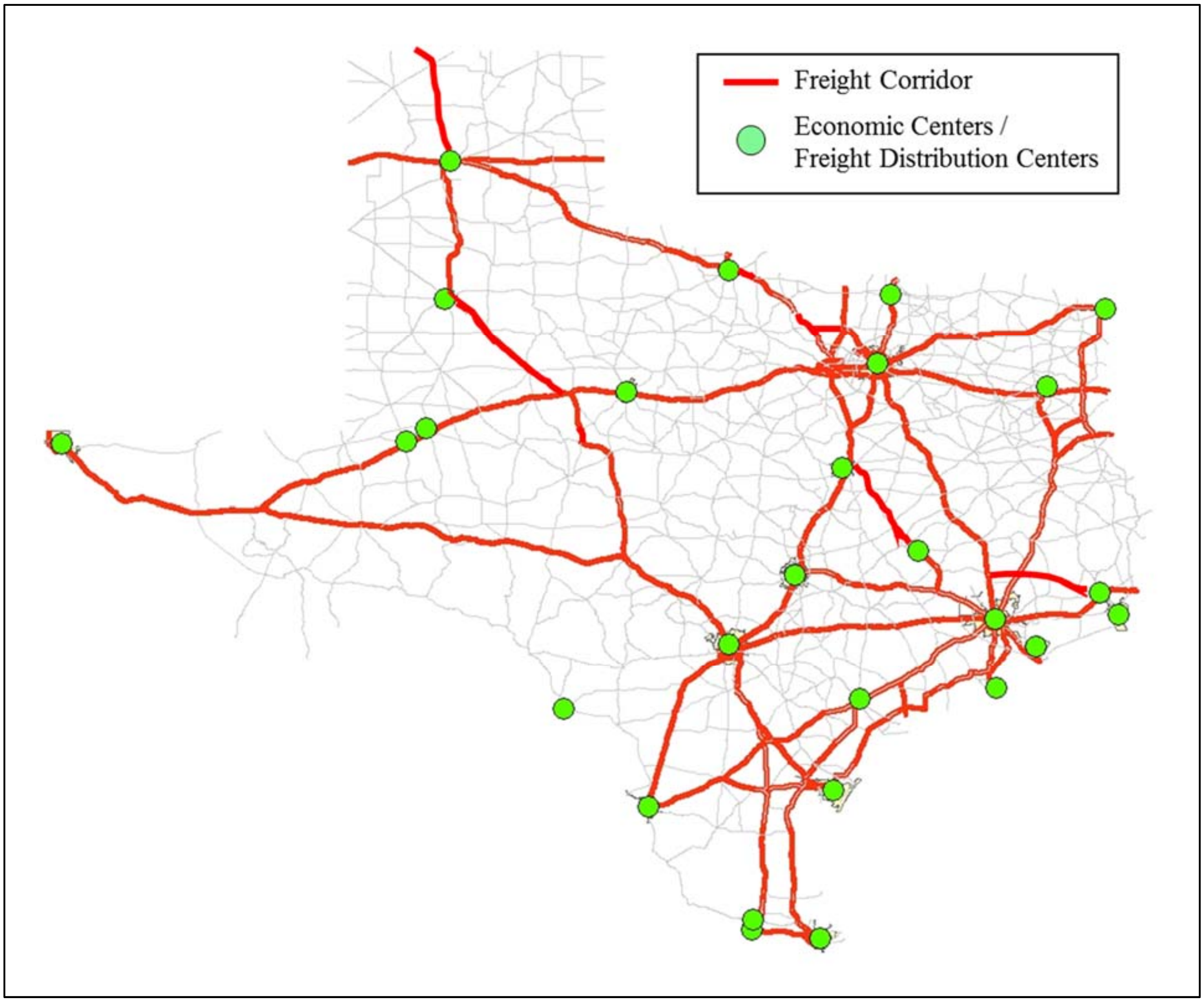


Figure 5.6: Identified Major Freight Corridors in Texas

5.3 Potential Highway Freight Corridors in Texas

This section describes the potential highway freight corridors that have been analyzed in the last ten years in the State of Texas.

5.3.1 U.S. 190/IH 10 Corridor

In 2007, the Texas Transportation Commission approved a study to analyze the potential impacts of the U.S. 190/ IH 10 corridor. This corridor would connect the New Mexico state line with the Louisiana state line, along the U.S. 190 and IH 10. The study evaluated the feasibility of a freeway or interstate type facility following the U.S. 190 alignment, and proposed some alternatives without choosing a preferred alternative. [TxDOT, 2012 b].

5.3.2 IH 69 Corridor

The IH 69 corridor, originally proposed in 1956, has an extension of 1,600 miles. The objective of this corridor is to connect Michigan with the Mexican border at Laredo. Within the State of Texas, the IH 69 goes from Laredo to Texarkana. Currently, the segments of the IH 69 include 230 miles within Texas. Segments of this corridor ae already considered in the Freight Network of Texas; however, the plan contemplates improvement in the physical condition. [Alliance for I-69 Texas, 2015].

5.3.3 Ports-to-Plains Corridor

The Ports-to-Plains corridor is a junction of various roadways that connect Laredo with Denver, going through Eagle Pass, Del Rio, San Angelo, Amarillo, and Lamax. The joint efforts of Colorado, New Mexico, Texas, and Oklahoma have led to the development of the Corridor Development and Management Plan (CDMP). The CDMP seeks to provide: (a) widening of 755 miles of 2-lane roads to 4-lane divided roads, (b) construction of 15 relief routes around larger towns, (c) improvements to or construction of overpasses for railroad crossings, and (d) replacement of obsolete or deficient bridges, among other things [TxDOT, 2012]. The project is expected to finish by 2025. Currently, there is no plan for the actions proposed in the CDMP. The Ports-to-Plain Alliance, a non-profit and non-partisan organization, is collecting signatures for a letter supporting the Interstate 27 Feasibility Study in Texas [PTPA, 2015].

5.3.4 U.S. 83 Corridor

A study conducted by Willbur Smith Associates, The Louis Berger Group, and AECOM Consulting analyzed the economic impacts of improving the U.S. 83. This corridor would connect the intersection of IH 35 and U.S. 83 to Uvalde. The study recommended that the U.S. 83 be developed as a 4-lane divided highway in the corridor [TxDOT, 2012].

5.3.5 Other Corridors Considered in the Texas Transportation Plan 2040

The Texas Transportation Plan (TTP) 2040 is the most recent long-range transportation plan adopted by the Texas Transportation Commission. Besides the corridors previously mentioned, this plan considered investments for the following corridors [TxDOT, 2015]:

- Western extensions of IH in South Texas.
- U.S. 190/Ports to Ports Corridor, connecting the mentioned U.S. 190 / IH 10 corridor with the ports of Beaumont and Corpus Christi.

5.4 Summary

As the very first step of assigning price tags to the infrastructure used for international trades, the scope of the research is defined by identifying the major freight corridors in Texas. The scoping process is performed by following steps: (1) select major economic centers and freight distribution centers, (2) identify routes connecting the centers, (3) reflect Texas Freight Mobility Plan (2014), and (4) investigate potential freight corridors considering future constructions.

Consequently, the identified major Texas freight corridors, which connect major economic centers and freight distribution centers in Texas, are defined mainly on Interstate Highway Systems (IHS), US Highway Systems, and State Highway System (SHS) under the specific criteria selected. The FRN will serve as an important basis for which price tags will be assigned in further steps.

Chapter 6. An Organized Procedure for Data Collection and Processing

One of the key components of the conceptual methodological framework developed in Chapter 3 is data collection and processing. Information gathered from the data collection module will be used to characterize the freight network in terms of its connectivity, condition, functionality, and utilization. The characterization of this infrastructure will provide the input to assign price tags towards enhancing decision-making processes. This chapter summarizes the procedure undertaken to collect and process available data.

6.1 Data Collection and Processing Methodology

The data collection and processing was divided into two modules: a database integration and a preliminary maintenance costs analysis. As seen in Figure 6.1, in the first module, various databases, such as PMIS, RHiNo, and BRINSAP, along with other needed data such as traffic volumes and fright flows, were integrated to the Texas Freight Roadway Network (FRN) GIS Map developed in Chapter 5. In addition, in the second module, a preliminary maintenance cost analysis was conducted to estimate maintenance costs at the network level.

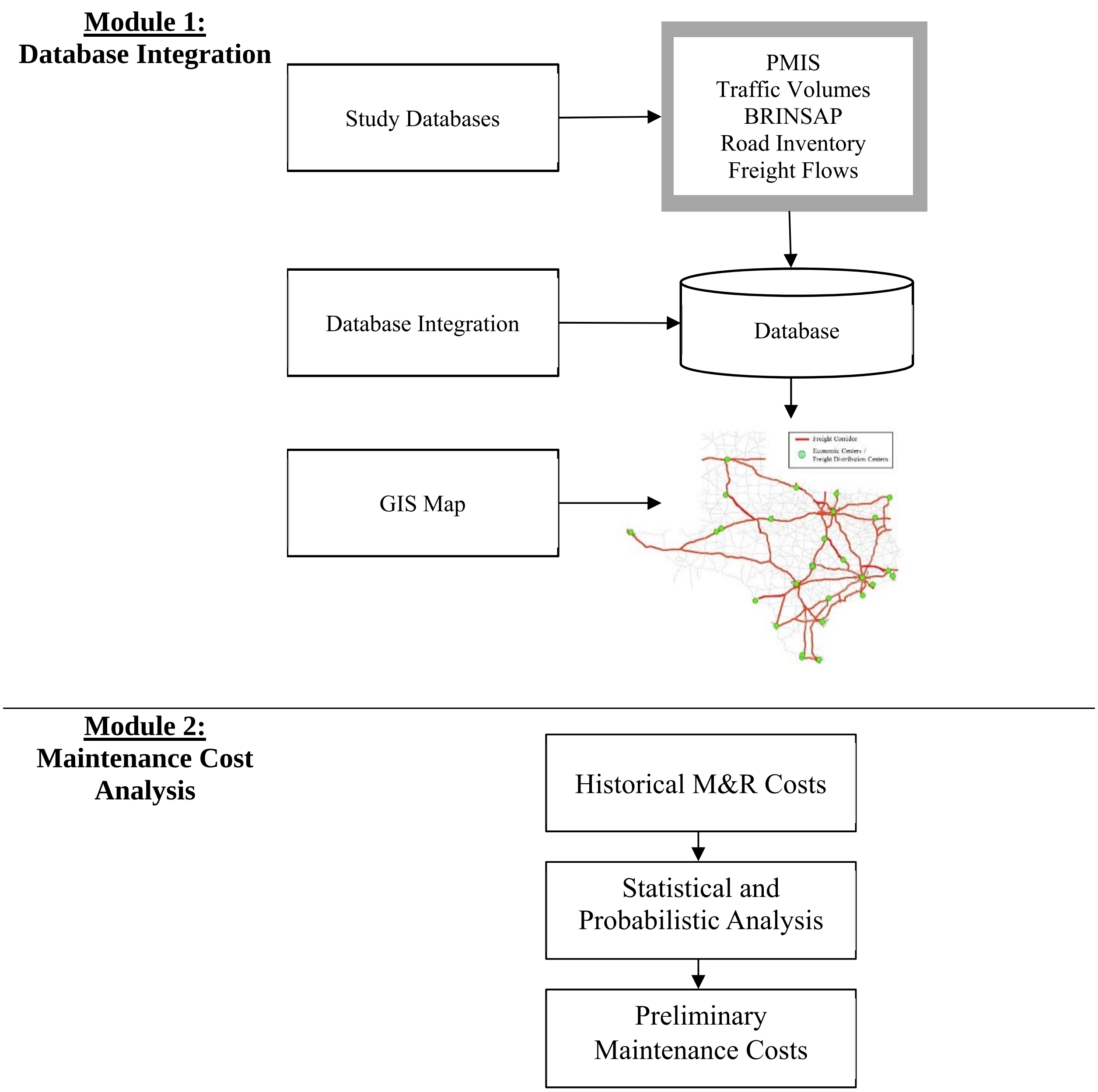


Figure 6.1: Data Collection Methodology

6.2 Module 1: Database Integration

In this section, steps to be followed for integrating the databases to the GIS-based FRN map are discussed. First, a brief discussion about the databases that were studied is presented. Then, the methodology to integrate the PMIS database to the GIS-based map is explained. Finally, an example is provided to illustrate the benefits of a visual map towards assigning price tags to roadways.

6.2.1 Description of Databases

This section provides a brief description of the databases studied to gather relevant information towards assigning price tags to infrastructure for international trade use. The databases studied are divided into two groups: primary and secondary databases. The primary databases include PMIS, RHiNo, and BRINSAP, which are related to inventory, physical condition, traffic volumes, and freight flows. The secondary databases include information about the freight flows and movement in Texas. These databases will be used to capture factors such as utilization, functionality, and freight movements, which will then be used to adjust price tags based on physical conditions.

Primary Databases

TxDOT Pavement Management Information System (PMIS): PMIS is the primary source of information on network-level pavement conditions and has been in use for over 25 years. The pavement data is collected annually on a 100 percent roadbed sample of the 195,000 lane-mile, state-maintained highway system. The majority of the attributes are also updated annually. The mainframe PMIS database is massive and contains data for location, inventory, roadbed, traffic, distress, ride, and skid [Stampley, 1996; Scullion, 1997].

Bridge Inventory and Appraisal Program (BRINSAP): BRINSAP contains data regarding which bridges are categorized as on-system versus off-system. The term 'on-system' refers to a bridge on the State and Federal Highway System. Off-system bridges are any bridges not on the State or Federal Highway System. The database includes inspection, inventory, and condition information relating to bridge decks, superstructures, substructures, and culverts. It also includes some information on traffic counts. The program has the capability of determining current needs and predicting future needs in funding for achieving bridge performance targets [TxDOT, 2013].

Secondary Databases

Commodity Flow Survey (CFS): The CFS is the primary source of national and state-level data on domestic freight shipments by American establishments in mining, manufacturing, wholesale, auxiliaries, and selected retail industries. Data is provided on the types, origins and destinations, values, weights, modes of transport, distance shipped, and ton-miles of commodities shipped. The CFS is a shipper-based survey and is conducted every five years as part of the Economic Census. It provides a modal picture of national freight flows, and represents the only publicly available source of commodity flow data for the highway mode. The CFS was conducted in 1993, 1997, 2002, 2007, and most recently in 2012 [USDOT, 2012].

***Freight Analysis Framework (FAF)*:** The FAF provides a comprehensive national picture of freight flows and trends, and a baseline forecast to support policy studies. The FAF informs states and localities about their major trading partners and the volumes and sources of traffic passing through their jurisdictions at the corridor level. Estimates of freight measures available in version three of the FAF (FAF3) include value, tons, domestic ton-miles, mode of transportation, and commodity type. This covers 123 domestic FAF regions and eight foreign regions. The FAF, though built primarily on the CFS, uses a variety of data and models to estimate shipments that are out of scope for the CFS, such as imports, crude petroleum by pipeline, and shipments from farms. The FAF is, however, only available every five years from 1997 to 2007 [FHWA, 2013]

County Business Patterns (CBP): The CBP is an annual series that provides subnational economic data by industry. It provides annual statistics for businesses with paid employees within the U.S. Those statistics include the number of establishments, number of employees, first quarter payroll, and annual payroll. Statistics are available on business establishments at the U.S. level, as well as by the state, county, metropolitan area, and ZIP code levels. CBP is used to study the economic activities of small areas and serves as a benchmark for other statistical series, surveys, and databases between economic censuses [US Census, 2015].

6.2.2 PMIS Integration to the GIS-based Map

Using the GIS-based map defining the FRN developed in Chapter 5, the 2015 PMIS database was integrated onto the map not only to properly present the database visually, but also to develop comprehensive inputs for assigning price tags for the freight corridors. The base map used for this task is 2014 Texas Roadway Inventory Map distributed by the Transportation Planning and Programming Division of TxDOT [TxDOT, 2015]. By using linear referencing tools in ArcGIS, the PMIS database was successfully embedded onto the freight corridors map. Figure 6.2 depicts how the whole integration process was performed in detail.

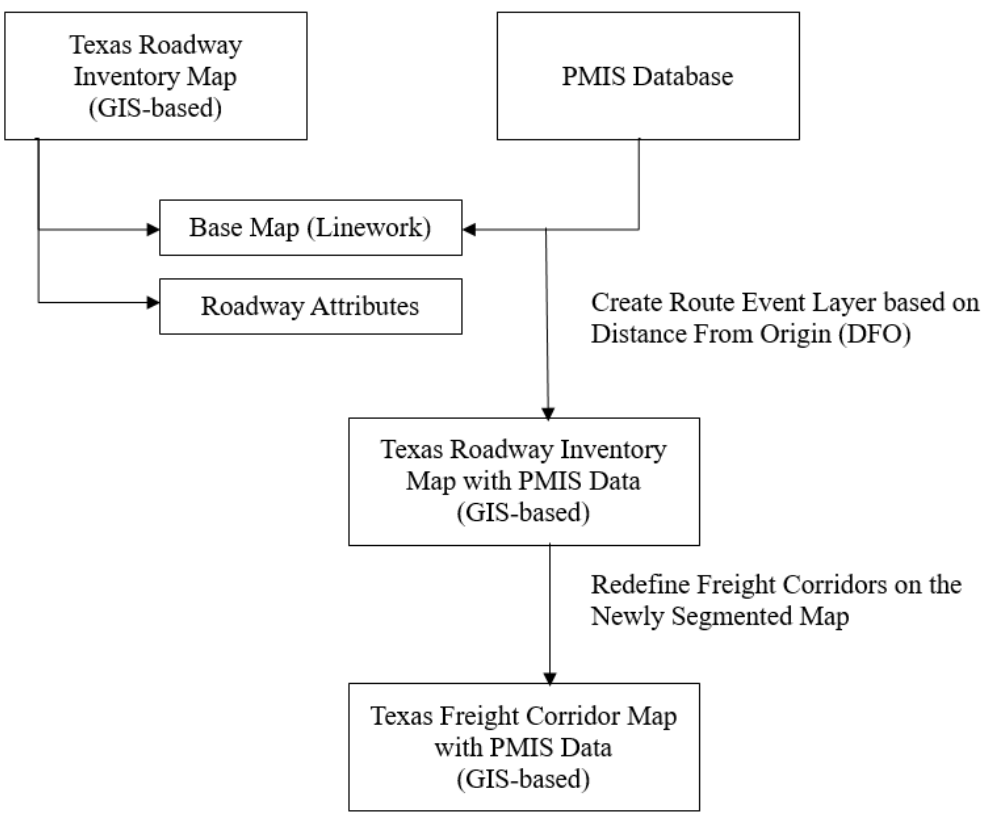


Figure 6.2: PMIS Database Integration Process Using ArcGIS

Linear referencing is a method of storing geographic locations by using relative positions along a measured linear feature [ESRI, 2012]. That is, distance measures are used to locate events along each route defined on a base map. For this case, the Distance From Origin (DFO) PMIS database is used as the distance measure. By providing route names and DFOs of each section defined in PMIS, ArcGIS can automatically segment the corresponding routes into the same segments defined in PMIS. Other databases can be integrated without any difficulty in the similar way, assuming that the data is well organized, and each record has information on distance measures such as Distance from Origin (DFO) or Texas Reference Marker (TRM), which can be converted to DFO. After the integration process, the Texas freight corridors were redefined on the newly segmented map again to depict relevant data only. Figure 6.3 shows the result of PMIS database integration when activating the AADT, condition scores, and International Roughness Index (IRI) layers, respectively. Moreover, Figure 6.4 illustrates a close-up of a roadway segment with its attribute table. This attribute table contains information related to the segment identification, physical condition, inventory information, and traffic volumes, which shows the results from the database integration.

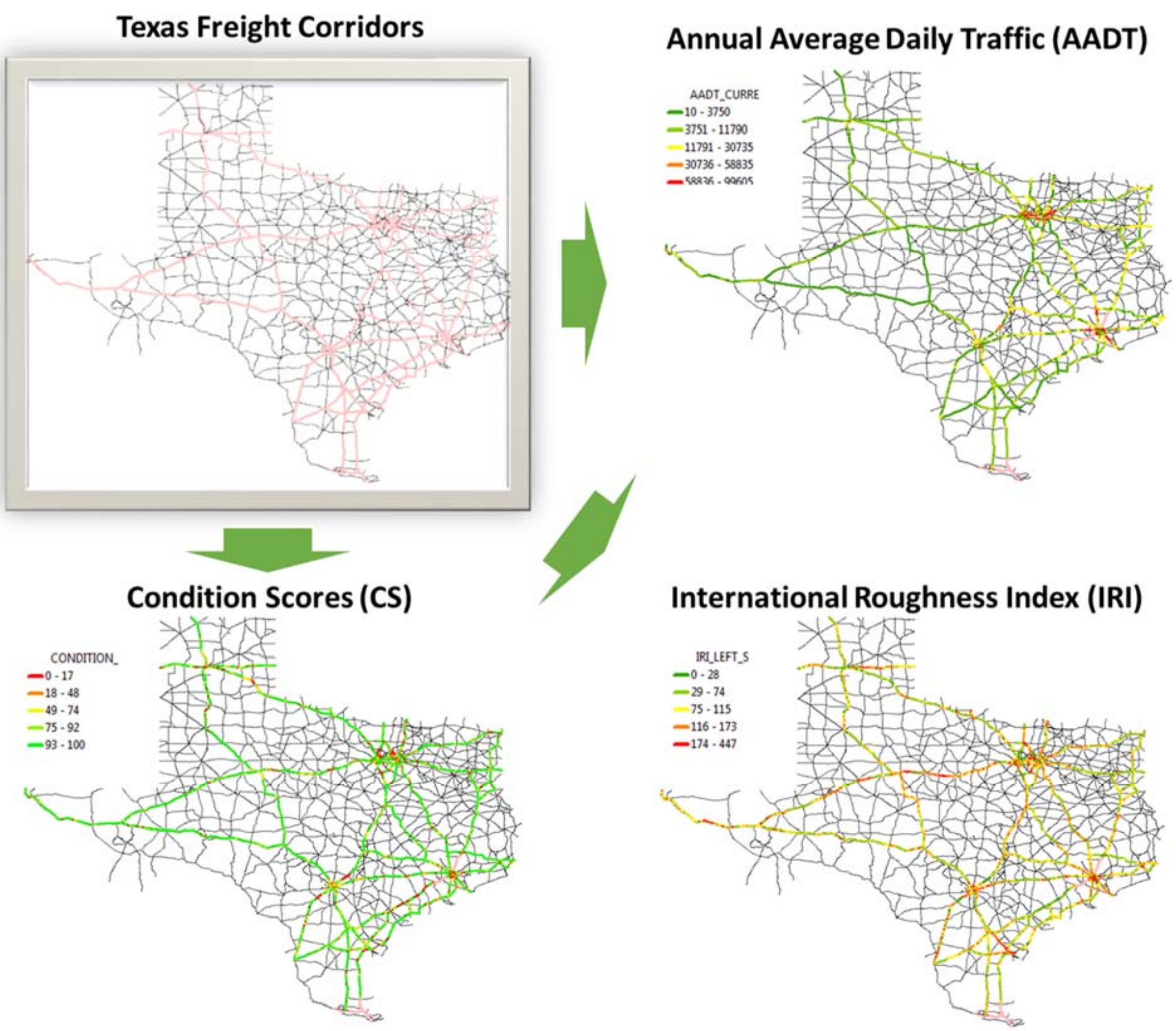


Figure 6.3: Texas Freight Corridor Map with PMIS data

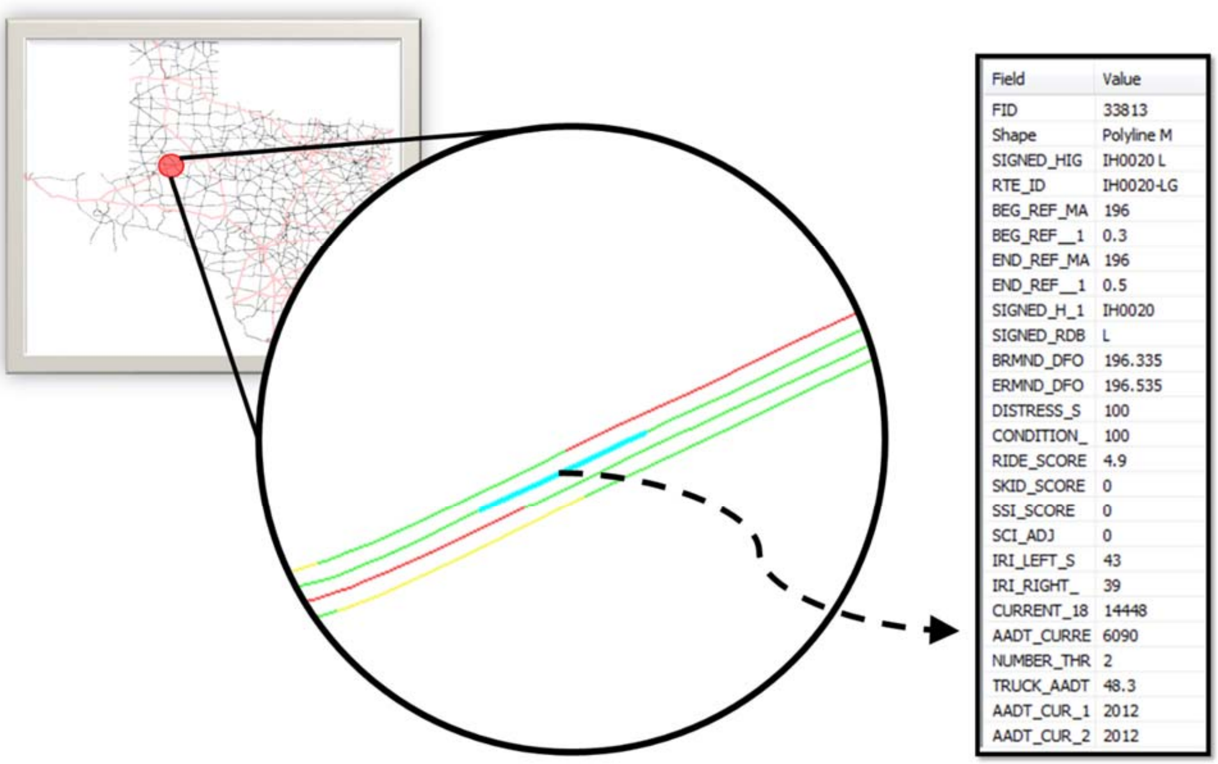


Figure 6.4: Example: GIS-based Freight Network Map

6.3 Module 2: Maintenance Cost Analysis

The objective of this project is to examine the current construction and maintenance costs of the FRN. For this reason, this section presents a preliminary analysis of maintenance costs using historical data. At the network level, the type of maintenance and rehabilitation treatments is a variable that has a significant impact on cost estimation. In the order of increasing unit cost, these treatment types can be categorized as preventive maintenance, light rehabilitation, medium rehabilitation, and heavy rehabilitation. Within each type of maintenance and rehabilitation treatments, the cost still varies on a project by project basis. Figure 6.5 shows statistical values from several projects built in the last decade in Texas.

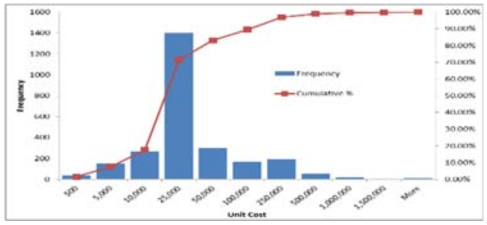
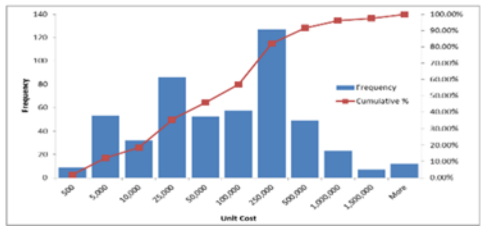
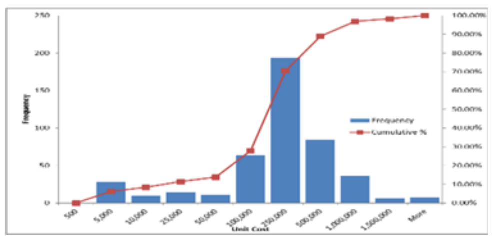
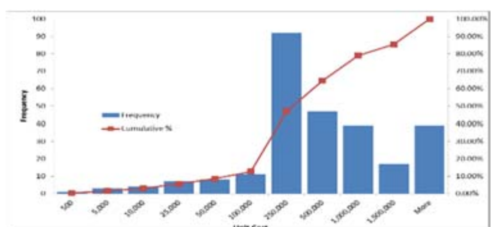
Treatment Type	Cost Distribution	Summary Statistics ($/lane-mile)
Preventive Maintenance		Min: 43.13 Max: 7,603,021 **Mean: 55,246** Std: 278,085
Light Rehabilitation		Min: 52.46 Max: 10,000,000 **Mean: 229,333** Std: 742,767
Medium Rehabilitation		Min: 501.22 Max: 2,880,556 **Mean: 259,273** Std: 358,426
Heavy Rehabilitation		Min: 328.75 Max: 15,200,000 **Mean: 872,167** Std: 1,782,575

Figure 6.5: Illustration of Variations Associated with Unit Costs

6.4 Summary

Data collection and processing is a key component of the conceptual methodological framework to assign price tags to international used infrastructure. This chapter summarizes the methodology employed to develop an integrated database in a GIS-based format. The methodology was divided into two modules: data integration and maintenance costs analysis. These modules provide the necessary input to develop models to estimate construction and maintenance costs for the FRN.

Chapter 7. Estimation of Maintenance and Construction Costs

In this chapter, the second step of the proposed methodological framework investigates a way to estimate proper construction costs and maintenance costs for the Texas Freight Roadway Network (FRN) defined in Chapter 5. In order to obtain fair estimates for the costs, the research team gathered and processed historical costs information related to roadway infrastructure to examine the current costs of construction and maintenance. First, historical costs related to highway construction and maintenance in Texas were reviewed. Texas is one of the states that manages construction and maintenance costs databases. Considering that the costs can vary depending on local conditions, reviewing the costs information is an essential step. As the next step, the research team developed estimation methods for the construction and maintenance costs based on the review results so that the estimates represent the current costs properly. Later on, the estimates will be used to develop the base price tag of the FRN in Texas, and finally, price tags will be assigned on these freight corridors by adjusting the base value to their utilization as proposed in Chapter 4.

Figure 7.1 shows the development process of the estimation method for highway construction and maintenance costs. As previously discussed, the procedure is comprised of three components: a review of historical costs, a review of existing cost estimation methods, and an evaluation of cost fluctuation parameters.

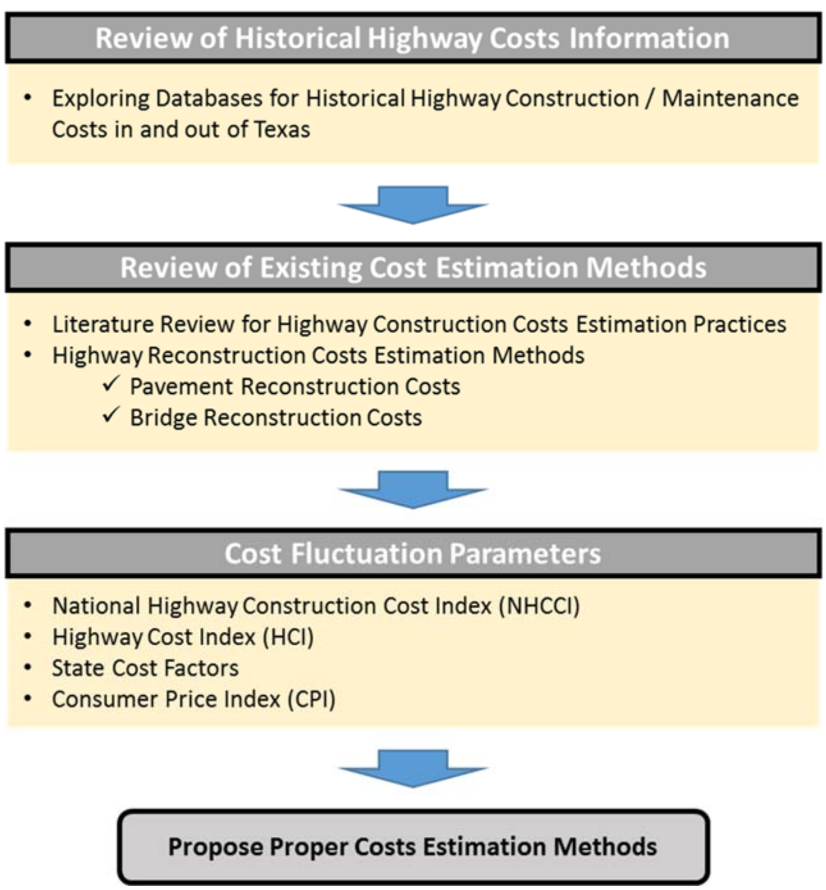


Figure 7.1: Development Process of Highway Construction and Maintenance Costs Estimation Methods

7.1 Highway Construction Costs

Traditionally, transportation authorities have estimated the construction and maintenance costs of highway projects from historical costs of similar projects and used those estimates to provide appropriate financing levels and target cost levels. However, there are two issues with this process: each project has local conditions that affect the cost, and there are few databases related to historical highway construction costs, either because information is private or is not gathered [UNECE, 2014]. At the international level, the United Kingdom has developed a database to publish roadway construction costs. In addition, the World Bank has developed a road construction database for developing countries with historical costs from 1984 to 2002 [Cabinet Office, 2013; World Bank, 2001]. However, the information may not be directly applicable to the State of Texas because of the first reason specified above. To address this issue, historical construction costs in Texas and other construction costs estimation methods are examined in this section.

7.1.1 Historical Highway Construction Costs in Texas

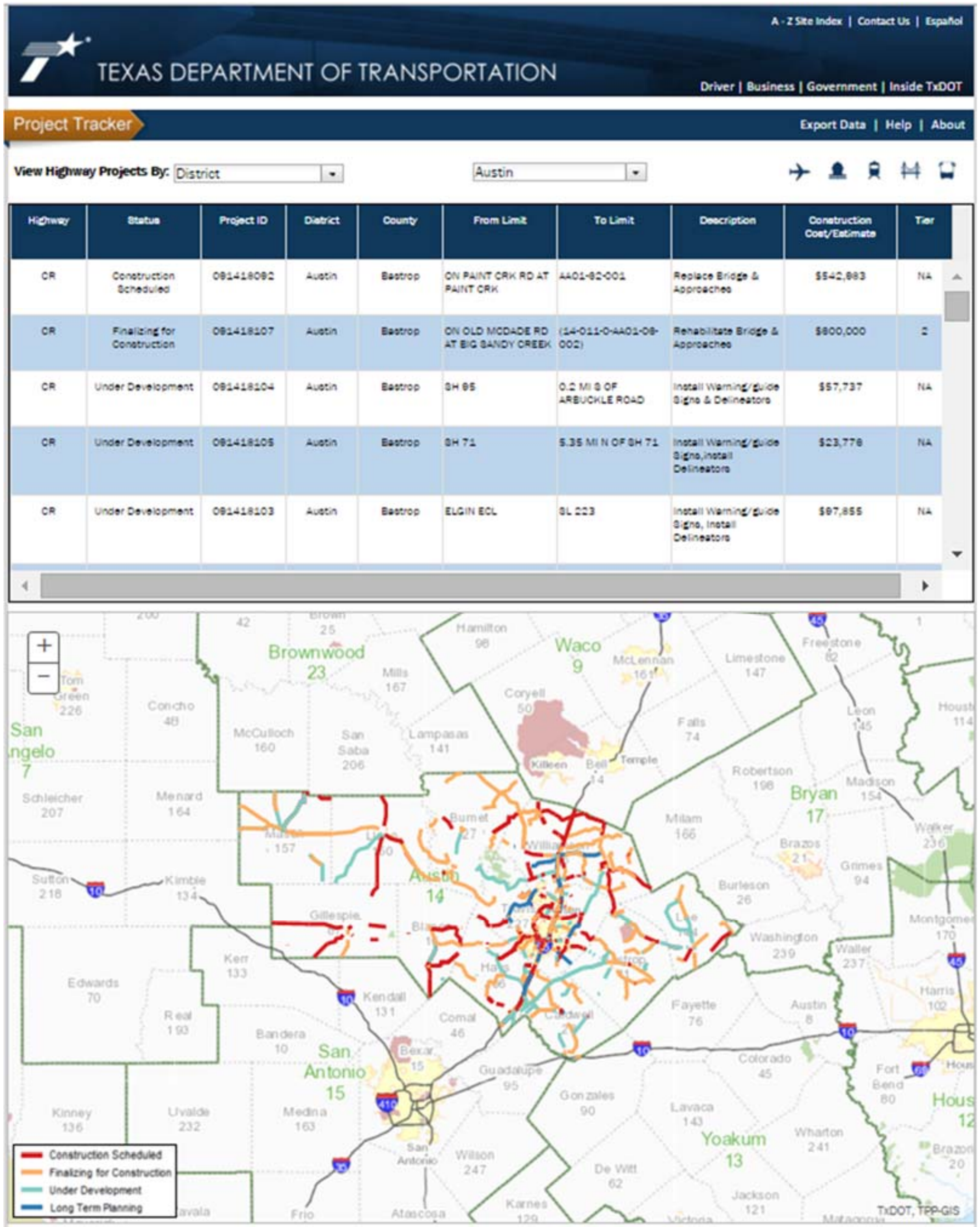
In the U.S, some state Departments of Transportation (DOTs) maintain a highway construction database and the State of Texas is one of them. The Texas Department of Transportation (TxDOT) periodically makes public not only statewide average low bid unit prices, but also district ones for each bid item of highway construction projects, as making projects available for bidding would help TxDOT get the most competitive pricing on a project [TxDOT, 2016]. The data contains the most recent twelve-month moving average of bid unit prices for each construction item specified in TxDOT construction specification manual [TxDOT, 2014]. Table 7.1 is an example of the data provided by TxDOT.

Table 7.1: Texas Statewide Average Low Bid Unit Prices for Construction Bid Items

Item No.	Description	Units	Twelve-month moving average	
			Quantity	Average Bid
100 2001	PREPARING ROW	AC	199.95	14123.52993
100 2002	PREPARING ROW	STA	9240.14	1107.34712
100 2004	PREPARING ROW(TREE)(12" TO 24" DIA)	EA	28	723.82143
100 2006	PREP ROW (TREE)(LESS THAN 24" DIA)	EA	12	200
100 2011	PREPARING ROW(TREE)(24" TO 36" DIA.)	EA	15	1140.33333
100 2012	PREP ROW (TREE) (18"-36" DIA.)	EA	6	3250
100 2016	PREPARING ROW (TREE) (36" TO 48" DIA)	EA	5	2715
100 2017	PREP ROW (TREE)(GREATER THAN 8 IN DIA)	EA	96	300
100 6001	PREPARING ROW	AC	153.14	23713.96565
100 6002	PREPARING ROW	STA	41828.72	3048.65896
100 6003	PREPARING ROW(TREE)(5" TO 12" DIA)	EA	163	336.3865
100 6004	PREPARING ROW(TREE)(12" TO 24" DIA)	EA	21	786.42857
100 6006	PREP ROW (TREE)(LESS THAN 24" DIA)	EA	2534	376.90292
100 6007	PREP ROW (TREE)(GREATER THAN 24" DIA)	EA	519	656.29094
100 6008	PREPARING ROW (TREE) (0" TO 6" DIA)	EA	76	90.47487
100 6009	PREPARING ROW (TREE) (6" TO 24" DIA)	EA	162	590.24488
100 6011	PREPARING ROW(TREE)(24" TO 36" DIA.)	EA	42	1501.66667
100 6013	PREP ROW (TREE) (2" TO 12" DIA)	EA	130	142.30738
100 6014	PREPARING ROW (TREE)(20" TO 42" DIA)	EA	2	2500
100 6015	PREPARING ROW (HAND CLEARING)	AC	1.7	517.40588
100 6016	PREPARING ROW (TREE) (36" TO 48" DIA)	EA	2	2340
100 6017	PREP ROW (TREE)(GREATER THAN 8 IN DIA)	EA	25	320
104 2001	REMOVING CONC (PAV)	SY	95730	9.63452
⋮				

Source: http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/bidprice/s_0101.htm
(Last Update: Thursday, December 17, 2015)

In addition, TxDOT provides some project costs information for specific types of work, such as adding a new lane on a highway, via TxDOT Project Tracker website [TxDOT, 2016]. TxDOT Project Tracker is a GIS-based system that shows transportation projects under either development or construction in Texas, and the database is updated daily. It contains detailed information about projects ongoing in Texas: including scope, description, status, total cost of each project, and more. Figure 7.2 depicts TxDOT Project Tracker showing transportation related projects in Austin district.



Source: http://apps.dot.state.tx.us/apps-cq/project_tracker/ (Accessed 22 January 2016)

Figure 7.2: TxDOT Project Tracker – Austin District

In addition, TxDOT has released average highway construction costs per lane-mile for urban freeways, rural interstates, and new truckline and farm-to-market roads in a legislative testimony requested by the House Select Committee on Transportation Funding in 2011. The testimony was about the efficient use of tax dollars by TxDOT in the construction of transportation projects. The Committee asked TxDOT to provide information on the average cost per mile of construction projects. TxDOT stressed that there were many factors that affect the construction costs including current labor and material costs, fuel prices, environmental clearances, utility relocation, land acquisition, locations of the project, and the weather during construction. On average, the conversion of an urban non-freeway to a freeway costs $8,300,000 per lane mile; widening an existing freeway generally ranges from $7,600,000 to $11,000,000 per lane mile, depending on right-of-way costs. The cost for the construction of a new rural interstate is about $2,000,000 per lane mile; for a new location trunk system facility is $1,200,000 per lane mile; and for a new farm-to-market road is $1,500,000 per lane mile [Gallego, 2010].

7.1.2 Existing Highway Construction Costs Estimation Methods

Estimating cost for a transportation project has become a topic of interest for transportation agencies to prevent cost overruns and underruns, which can influence the fate of the project heavily. The project cost related problems may result in losing faith in the performing agencies' competency due to sudden disruption of plans, reduction in project scope, or extension in construction durations until additional funds become available [Alavi and Tavares, 2009]. Considering that most of the state DOTs are facing inadequate funds for managing transportation infrastructure, the importance of the project cost estimation cannot be emphasized enough.

For this reason, substantial research has been devoted to predicting project costs using historical data, and a wide arrange of estimation models applying different methodologies have been developed. Some of them developed regression models: Lowe et al. (2006) predicted construction cost using multiple regression analysis, and Shretha et al. (2014) proposed regression models to predict a future project's bid cost for unit item prices, based on the quantities of items. Touran (1993) developed a probabilistic cost estimating system using Monte-Carlo simulation technique to account for 13 inherent variables present in cost estimate. There are also other studies adopting state of the art techniques using artificial intelligence. Chou et al. (2015) adopted artificial neural networks (ANN) for the estimation, while Kim et al. (2012) proposed an estimation model based on genetic algorithm at the planning stage for a construction project of a river facility for irrigation. However, even after the availability of sophisticated estimation models, many state DOTs are not able to predict actual costs within acceptable deviations [Singh, 2016].

One of the most recent studies conducted to predict unit item prices for the state of Texas is Singh (2016). This study developed quantile regression models, which are not sensitive to outlier data leading to better price estimates. The validation results show that the proposed models predict the unit bid cost more accurately than an engineer's estimate. Figure 7.3 shows the analysis tool developed by Singh (2016).

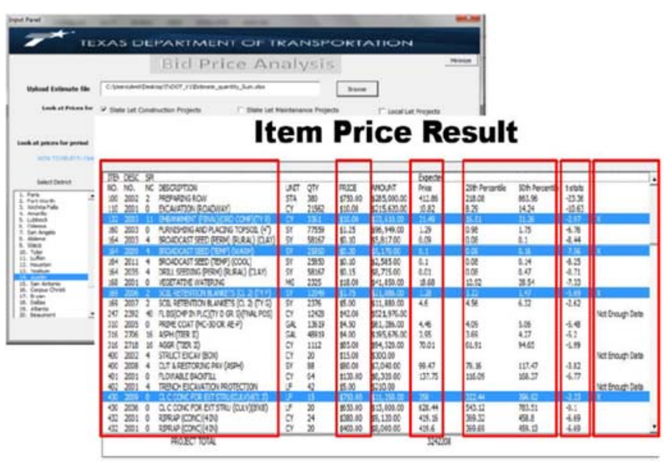
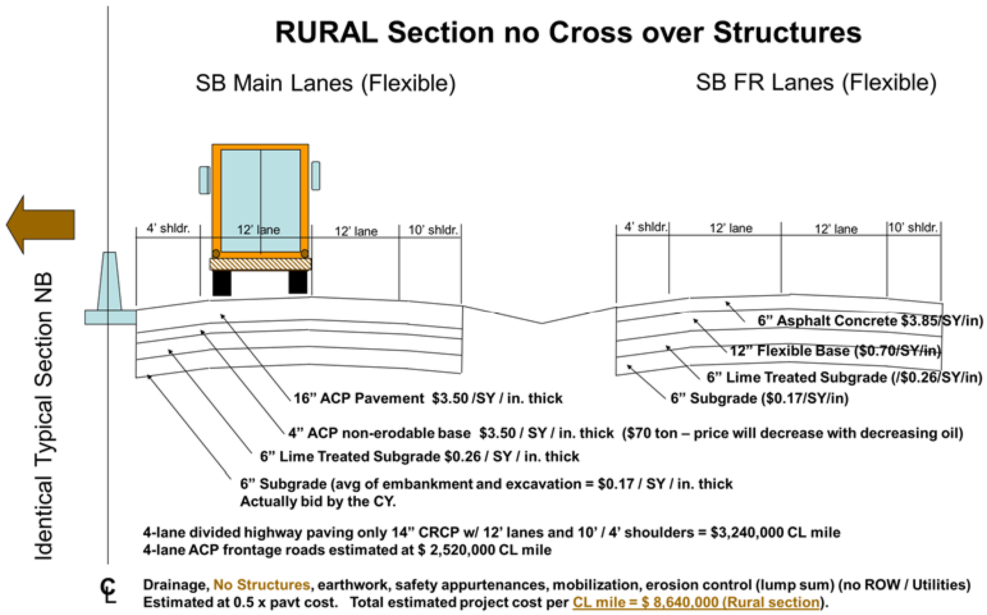


Figure 7.3: Bid Tab Analysis Tool [Singh, 2016]

Another effort to estimate highway construction costs in Texas was made by the Center for Transportation Research (CTR) at the University of Texas at Austin. Murphy (2015) estimated the general highway construction costs per centerline mile for typical types of roads with and without bridge structures. Since the cost per mile can vary significantly if bridges are present, roads with and without bridges were analyzed. Figure 7.4 shows total estimated project cost for highway sections in rural areas.



Source: Murphy (2015)

Figure 7.4: Total Estimated Project Cost for Rural Highway Section without Bridges

7.2 Highway Maintenance Costs

Maintenance costs are also pivotal elements in transportation asset valuation since the asset value of a highway section can be significantly affected by highway maintenance works applied to the section. The type of maintenance and rehabilitation treatments has a significant impact on cost estimation. In the order of increasing unit cost, these treatment types can be categorized into four groups: preventive maintenance, light rehabilitation, medium rehabilitation, and heavy rehabilitation. The cost also varies from project to project within each type of maintenance and rehabilitation treatment. In this section, a thorough review is conducted to develop a maintenance costs estimation method that will be used for this research project.

7.2.1 Historical Highway Maintenance Costs in Texas

TxDOT also stores low bid unit prices of highway maintenance projects and publicizes statewide average low bid unit prices and district ones for each bid item for highway maintenance projects periodically [TxDOT, 2016]. Like the construction costs information managed by TxDOT, which is presented in the previous section, the data contains the most recent twelve-month moving average of bid unit prices for each item used in the maintenance projects. Table 7.2 shows an example of the data provided by TxDOT.

Table 7.2: Austin District Average Low Bid Unit Prices for Maintenance Bid Items

Item No.	Description	Units	Twelve-month moving average	
			Quantity	Average Bid
100 6002	PREPARING ROW	STA	1	12000
104 2009	REMOVING CONC (RIPRAP)	SY	14	121.42857
104 2015	REMOVING CONC (SIDEWALKS)	SY	34	250
104 2017	REMOVING CONC (DRIVEWAYS)	SY	40	75
. . .				
316 2705	ASPH (TIER I)	GAL	487659	3.27077
316 2706	ASPH (TIER II)	GAL	9790	4
316 2717	AGGR (TIER I)	CY	11594	56.25772
316 2718	AGGR (TIER II)	CY	224	60
316 6004	ASPH (TIER I)	GAL	118006	3.4
316 6005	ASPH (TIER II)	GAL	116985	3.18438
316 6026	ASPH (HFRS-2P)	GAL	110491	3.8
316 6175	AGGR(TY-B GR-4 SAC-B)	CY	1879	100
316 6191	AGGR(TY-D GR-4 SAC-B)	CY	852	51.57
316 6240	AGGR(TY-PD GR-4 SAC-B)	CY	3526	91.80656
316 6397	AGGR(TY-D GR-4 OR TY-L GR-4)	CY	1353	80
340 6120	D-GR HMA(SQ) TY-D SAC-B PG70-22	TON	1729	77
340 6246	D-GR HMA (SQ) TY-D PG64_22(LEVEL-UP)	TON	5628	78.56167
341 6042	D-GR HMA TY-D SAC-B PG70-22	TON	24483	95.08619
341 6064	D-GR HMA TY-D PG 70-22 (LEVEL-UP)	TON	4486	88
347 6001	TOM (ASPHALT) PG 76-22	TON	2153.02	133.11836
347 6002	TOM-C (AGGREGATE) SAC-A	TON	23309	130.87178
347 6006	TOM - C (AGGREGATE) SAC - B	TON	4534	144.64539
351 2004	FLEXIBLE PAVEMENT STRUCTURE REPAIR(8")	SY	24927	36.48686
351 2008	FLEXIBLE PAVEMENT STRUCTURE REPAIR(12”)	SY	11557	45
. . .				

Source: http://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/distinfo/bidpricm/avgd14m.txt
(Last Update: Thursday, December 31, 2015)

7.2.2 Analysis on Highway Maintenance Costs

Due to differences between the pavement treatment costs specified in Pavement Management Information System (PMIS) and the actual project costs of TxDOT, the Statewide 4-year plans of 2013 and 2014 were reviewed. The project costs were collected, and the projects were classified into four groups based on the project descriptions: preventive maintenance (PM), light rehabilitation (LR), medium rehabilitation (MR) and heavy rehabilitation (HR) for Asphalt Concrete Pavement (ACP). In addition, the projects were also categorized based on the districts where they took place as presented in Table 7.3.

Table 7.3: Classification of the Districts in Metro, Urban, or Rural Areas

Metro	Urban	Rural
Austin	Beaumont	Amarillo
Dallas	Bryan	Abilene
Ft. Worth	Corpus Christi	Atlanta
Houston	El Paso	Brownwood
San Antonio	Laredo	Childress
	Lubbock	Lufkin
	Pharr	Odessa
	Tyler	Paris
	Waco	San Angelo
		Wichita Falls
		Yoakum

To enhance precision of the estimation, projects with unusual characteristics were eliminated from dataset for the analysis. The criteria were:

- Short length (less than 0.01 miles), and
- Projects where other activities (e.g., traffic signal related activities or bridge related activities) could affect the project cost significantly.

The results show extremely large variations in the project costs per lane-mile. For this reason, the projects within the ranges of the top and bottom 1% were removed again to avoid potential outliers. Furthermore, the interquartile range was employed to set the lower and the upper bounds of the costs of the projects, using the following estimation formula:

$$Lower/Upper\ bounds = Median\ \pm (\beta) * (Q3 - Q1) \tag{7.1}$$
$$(With\ \beta = 3)$$

where:

Q1 = First Quartile of the Data (25% of the data is below that value).
Q2 = Second Quartile of the Data (75% of the data is below that value).
β = Factor to estimate the range of valid data.

Table 7.4 summarizes the pavement treatment costs.

Table 7.4: Summary of Pavement Treatment Costs for ACP per Lane-mile

Treatment Type		Area		
		Metro	Urban	Rural
Preventive Maintenance (PM)	Count	442	952	527
	Average	$97,299	$32,766	$35,388
	STDV	$179,515	$56,152	$62,915
Light Rehabilitation (LRhb)	Count	124	413	96
	Average	$281,922	$86,187	$159,813
	STDV	$274,349	$211,886	$204,973
Medium Rehabilitation (MRhb)	Count	111	194	56
	Average	$313,323	$195,250	$227,440
	STDV	$365,898	$260,627	$205,974
Heavy Rehabilitation (HRhb)	Count	31	95	77
	Average	$716,781	$401,265	$485,421
	STDV	$836,931	$462,485	$450,365

7.3 Highway Reconstruction Cost

As defined in Chapter 2, a price tag is defined as a label attached to a product indicating its price. In transportation infrastructure terms, a price tag can be associated with the infrastructure construction and maintenance costs. These costs can be assigned to a particular asset, infrastructure system, or a corridor depending on the needs to preserve their physical and functional conditions. Moreover, construction and maintenance costs should not be confused with the value of an asset or infrastructure systems.

This difference between construction and maintenance costs and asset value should not be overlooked when assigning price tags to an infrastructure system. Construction and maintenance costs are defined as the financial resources required for producing or obtaining something, whether the financial resources are used to replace a physically deteriorated portion of a highway or to construct an interchange. However, price tags are a subjective quantity that must be addressed within the context of time, place, culture, potential owners, and users [Cowe Falls, 2005; Dewan, 2005]. For this reason, putting a price tag on transportation infrastructure should be linked to concepts of asset valuation. In this sense, the objective of this study is to estimate the value of an asset rather than simply estimating construction cost, though cost estimation methodologies enable decision makers to quantify some of the necessary inputs for characterizing the asset value. In this section, reconstruction cost methodologies for both pavement and bridges are discussed.

7.3.1 Pavement Reconstruction Cost

In the case of pavements, the Highway Economic Requirement System Technical (HERS-ST) Report proposed a reconstruction cost methodology proposed. The reconstruction cost methodology provide a method to estimate the replacement cost of pavement infrastructure by functional class and type of construction [U.S DOT, 2005]. Equation 7.2 shows the HERS-ST model.

$$R_C = UC \cdot N_L \cdot L_S \tag{7.2}$$

where:
UC = unit cost construction per lane-mile
N_L = number of lanes
L_S = length of the segment in miles

Initial values are based on national average estimates; thus, the values must be adjusted for state costs differences. The HERS-ST provides unit construction costs in 2002 dollars. Therefore, in order to estimate the replacement costs within a specific year, these factors need to be indexed to the current year. The Consumer Price Index (CPI) (reference) was used as the indexing factor. Equation 7.3 shows the HERS-ST model adjusted for the various factors previously discussed.

$$R_{C,year} = UC_{2002} \cdot t_a \cdot SF_{2000} \cdot \frac{CPI_{year}}{CPI_{2000}} N_L \cdot L_S \cdot \frac{CPI_{year}}{CPI_{2002}} \tag{7.3}$$

where:
$R_{C,year}$ = replacement cost for the year of analysis
UC_{2002} = unit cost construction per lane-mile in 2002 dollars
t_a = terrain adjustment
SF_{2000} = state adjustment factor
N_L = number of lanes
L_S = length of the segment in miles
CPI_{year} = CPI for year of analysis
CPI_{2000} = CPI for the year 2000
CPI_{2002} = CPI for the year 2002

7.3.2 Bridge Reconstruction Cost

Bridge reconstruction costs are also important inputs in assigning price tags to transportation infrastructure. The Texas Transportation Needs Report (2030 Committee) research team performed an evaluation of 2008 bridge rehabilitation and replacement costs to estimate the present and future costs needed to maintain the Texas bridge network at acceptable levels of service. For this purpose, the research team used bridge data to generate unit costs for bridge rehabilitation and replacement. An estimated average rehabilitation cost of $120/per square foot and a bridge replacement cost of $194/per square foot were used to estimate future bridge replacement costs [Texas 2030 Committee, 2009]. These estimates, based on the TxDOT experience, are only provided for use as a top level analysis for decision making, and should not be used as a substitute for detail engineering estimates.

Similarly, transportation agencies across the country have developed their own reconstruction cost estimates. For example, the Florida Department of Transportation (FDOT) has presented bridge costs for new construction as shown in Table 7.5.

Table 7.5: FDOT Bridge Cost Estimates

Bridge Type	Low ($)	High ($)
Short Span Bridges:		
Reinforced Concrete Flat Slab Simple Span	115	160
Pre-cast Concrete Slab Simple Span	110	200
Reinforced Concrete Flat Slab Continuous Span	NA	NA
Medium and Long Span Bridges:		
Concrete Deck/ Steel Girder - Simple Span	125	142
Concrete Deck/ Steel Girder - Continuous Span	135	170
Concrete Deck/ Pre-stressed Girder - Simple Span	95	145
Concrete Deck/ Pre-stressed Girder - Continuous Span	95	211
Concrete Deck/ Steel Box Girder – Span Range from 150' to 280' (for curvature, add a 15% premium)	140	180
Segmental Concrete Box Girders - Cantilever Construction, Span Range from 150' to 280'	140	160

Source: FDOT Transportation Costs Report (www.dot.state.fl.us/planning/policy/costs/Bridges.pdf)

The FHWA reported through their Bridges and Structures program that the average 2012 cost to replace or rehabilitate structurally deficient bridges was $167 per square foot for the National Highway System (NHS) and $160 for non-NHS bridges [FWHA, 2012].

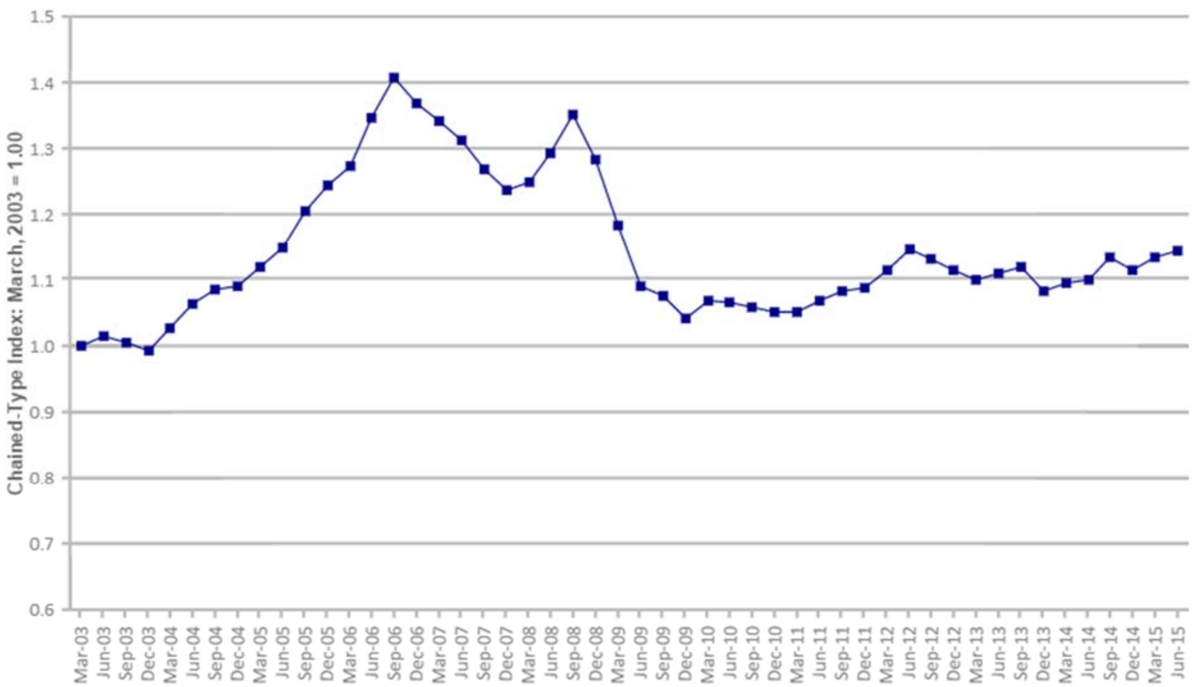
7.4 Highway Construction Cost Fluctuation

Maintenance and construction costs fluctuate depending on labor cost, material cost, contractor cost, transport cost, and the overall economic condition. Each of these variables contributes to a varying cost in performing maintenance and construction. Over the past several years, the construction industry has experienced a higher rate of inflation than the overall economy. In addition, according to Bureau of Labor Statistics (BLS), inflation in highway and street construction is much higher than residential construction, non-residential construction, and the overall economy. Therefore, the cost fluctuation should be properly considered when analysts need to estimate or compare the construction and maintenance costs of highways. In this section, two highway cost indices capturing the cost fluctuation over time are presented and reviewed.

7.4.1 National Highway Construction Cost Index

The National Highway Construction Cost Index (NHCCI) is a price index that can be used both to track pure price-changes associated with highway construction costs and to convert current-dollar expenditures on highway construction to real- or constant-dollar expenditures [FHWA, 2014]. It was developed to replace the Bid-Price Index (BPI), which was used by many state DOTs trying to develop an accurate estimate of the cost of new projects previously.

The NHCCI is updated quarterly with data that has been collected since March 2003. Although many states maintain their own excellent cost indices, the NHCCI can provide a national view for highway construction cost changes [White and Erickson, 2011]. Figure 7.5 shows how the NHCCI has changed over time.



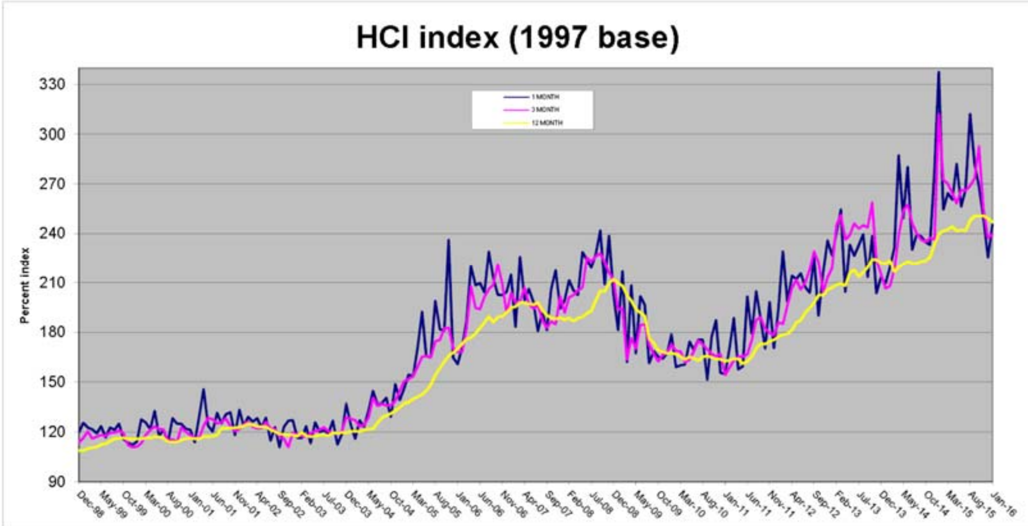
Source: https://www.fhwa.dot.gov/policyinformation/nhcci/pt1.cfm (Last Update: 15 November 2015)

Figure 7.5: National Highway Construction Cost Index (NHCCI)

7.4.2 Highway Cost Index

To consider cost fluctuations when performing engineering budget estimation, TxDOT currently maintains a Highway Construction Index (HCI) to compare the cost of business in a specific period to the cost of business in 1997 as the base year. TxDOT tracks cost fluctuation in not only overall highway construction costs, but also other major highway cost elements such as earthwork and pavement surface.

Figure 7.6 shows the overall HCI over the last 17 years in Texas. The index is highly variable, creating many uncertainties for cost estimation.



Source: TxDOT, TxDOT Highway Cost Index (1997 Base) Index Report for January 2016

Figure 7.6: TxDOT Highway Cost Index (HCI)

7.4.3 State Cost Factors

As mentioned previously, highway construction and maintenance costs also vary depending on local conditions, as well as time. To consider this variation, the Highway Economic Requirement System Technical (HERS-ST) Report proposed State Cost Factors (Table 7.6) to adjust all capital costs associated with highway improvements to each state's local conditions.

Table 7.6: 2000 State Cost Factors

State	Factor	State	Factor	State	Factor
AL	0.936	**LA**	1.016	**OK**	1.054
AK	1.831	**ME**	1.541	**OR**	1.329
AZ	0.855	**MD**	1.274	**PA**	1.295
AR	0.64	**MA**	1.805	**RI**	0.84
CA	1.262	**MI**	1.324	**SC**	1.416
CO	1.06	**MN**	1.222	**SD**	0.857
CT	1.009	**MS**	1.211	**TN**	0.929
DE	1.349	**MO**	0.846	**TX**	0.687
DC	1.018	**MT**	1.052	**UT**	0.957
FL	1.02	**NE**	0.927	**VT**	1.232
GA	1.091	**NV**	1.019	**VA**	1.081
HI	1.146	**NH**	0.556	**WA**	1.139
ID	0.733	**NJ**	0.771	**WV**	1.196
IL	1.159	**NM**	0.983	**WI**	0.974
IN	0.74	**NY**	1.318	**WY**	0.99
IA	0.745	**NC**	0.911	**PR**	0.725
KS	0.765	**ND**	0.782		
KY	1.888	**OH**	1.152		

Source: USDOT, Highway Economic Requirement System – State Version, 2005

7.4.4 Consumer Price Index

The Consumer Price Index (CPI) measures the average change in prices over time of goods and services purchased by households. The Bureau of Labor Statistics (BLS) publishes CIPs for two population groups: the CPI for Urban Wage Earners and Clerical Workers (CPI-W) and the CPI (and the Chained CPI) for All Urban Consumers (CPI-U and C-CPI-U). The indices are based on prices of goods and services that people buy for day-to-day living such as food, fuel, and doctors' services. Like HCI, the CPI measures price change from a designed reference date. For the CPI-U and the CPI-W, the reference base is set so that dates between 1982 and 1984 equal 100. The reference base for the C-CPI-U is December 1999 equals 100 [U.S. DOL, 2016]. Table 7.7 shows historical average CPI-Us over time for all U.S. cities and all items (goods and services) considered.

Table 7.7: Historical Consumer Price Index for All Urban Consumers (CPI-U): U.S. City Average, All Items

Year	CPI	Year	CPI	Year	CPI
1990	130.7	2000	172.2	2010	218.056
1991	136.2	2001	177.1	2011	224.939
1992	140.3	2002	179.9	2012	229.594
1993	144.5	2003	184	2013	232.957
1994	148.2	2004	188.9	2014	236.736
1995	152.4	2005	195.3	2015	237.017
1996	156.9	2006	201.6		
1997	160.5	2007	207.3		
1998	163	2008	215.303		
1999	166.6	2009	214.537		

Source: U.S. DOL, 2015 Consumer Price Index Detailed Report – December 2015, 20 January 2015

7.5 Proposed Highway Reconstruction Costs Estimation Method

After the comprehensive review of historical highway-related costs information and some existing cost estimation methodologies, a reconstruction cost estimation model is developed and proposed to be used to estimate the base price tag in the further steps. The proposed model is based on reconstruction methodologies and reconstruction cost values presented in the previous sections. These reconstruction costs will comprise an essential input in assigning values or price tags to the transportation assets serving for international trade in Texas.

Equation 7.4 presents the generic mathematical expression to compute the reconstruction cost for a highway corridor.

$$R_C = R_{C,pav} + R_{C,bridge} \tag{7.4}$$

where:

R_C = replacement cost of a highway corridor
$R_{C,pav}$ = replacement cost of pavement assets
$R_{C,bridge}$ = replacement cost of bridge assets

By substituting Equation 7.3 and bridge reconstruction costs into Equation 7.4, the following expression is obtained:

$$R_{C,year} = UC_{2002} \cdot t_a \cdot SF_{2000} \cdot \frac{CPI_{year}}{CPI_{2000}} N_L \cdot L_S \cdot \frac{CPI_{year}}{CPI_{2002}} + C_{B,year} \cdot DeckArea \cdot \frac{CPI_{year}}{CPI_{year(C_B)}} \quad (7.5)$$

where:

$R_{C,year}$	= replacement cost of a highway corridor for the year of analysis
UC_{2002}	= unit cost construction per lane-mile in 2002 dollars
t_a	= terrain adjustment
SF_{2000}	= state adjustment factor
N_L	= number of lane
L_S	= length of the segment in miles
CPI_{year}	= CPI for year of analysis
CPI_{2000}	= CPI for the year 2000
CPI_{2002}	= CPI for the year 2002
$C_{B,year}$	= Bridge replacement cost per square feet for Texas at year *i*
$Deck\ Area$	= Deck area in square feet in the highway corridor
$CPI_{year(C_B)}$	= Deck square feet in the highway corridor

For simplicity, let us consider a four-lane highway corridor comprised of eight miles of pavements and half a mile of bridges in the state of Texas. Also, let us assume that the functional classification of this highway corridor is an expressway in a rolling type terrain. Table 7.8 summarizes the input parameter for this simple highway corridor.

Table 7.8: Summary of Input Parameters for Model Demonstration

Parameter	Value
Functional Class	Expressway
Unit Recons. Cost ($/lane-mile, 2002)	$2,272
CPI (2002)	179.9
CPI (2015)	237.017
Texas State Factor (2000)	0.687
CPI (2000)	172.2
Terrain Adjustment	1.2
Number of lanes	4
Bridge Replacement Cost (Texas, 2009)	$194 / square feet
Deck area (ft^2)	26400 x 70 = 1,848,000
CPI (2009)	214.537

By plugging the input parameter from Table 7.8 into Equation (7.4), the following replacement cost is obtained:

$R_{C,2015}$=108,690,000 + 358,512,000 = 467,202,000

Therefore, the replacement cost for the highway corridor at year 2015 is $467 million.

7.6 Summary

Estimation of highway construction and maintenance costs is a key component in transportation infrastructure asset valuation since it can greatly affect the asset values. This chapter explored available historical highway related costs information and cost estimation models to propose proper cost estimation methods for putting price tags on the FRN. The proposed estimation methods will provide reasonable base price tag for the freight corridors in the further steps.

Chapter 8. Infrastructure Physical Condition of Freight Roadway Network (FRN)

In this chapter, the physical condition of the Freight Roadway Network (FRN) (as defined in Chapter 5) comprised of pavements and bridges is investigated. It is worth noting that the physical condition of pavements and bridges is a key input parameter in assigning price tags to FRN corridors. Therefore, the research team has gathered and processed physical condition related databases to examine both asset classes: bridges and pavements. This report summarizes the physical condition of the infrastructure on the defined FRN.

Figure 8.1 illustrates the systematic procedure used to evaluate the physical condition of pavements and bridges. The procedure initiates with the FRN defined in Chapter 5. Furthermore, Texas Pavement Management Information System (PMIS) and the Bridge Inventory and Appraisal Program (BRINSAP) were integrated to the FRN as discussed in Chapter 6. Information provided by PMIS and BRINSAP was used to investigate the physical condition of pavements and bridges, respectively. The physical condition was evaluated in terms of physical indicators. Examples of indicators of the physical condition of pavements and bridges are shown in Figure 8.1.

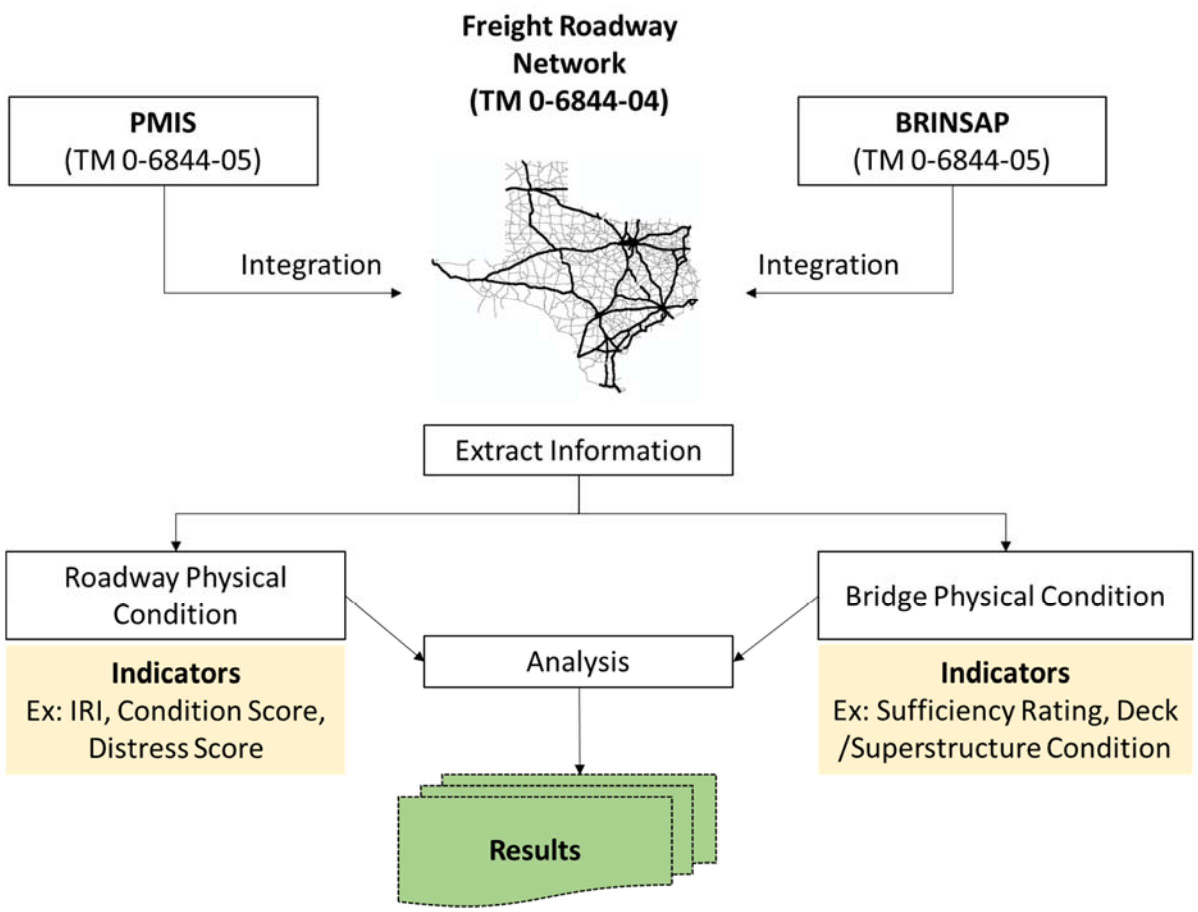


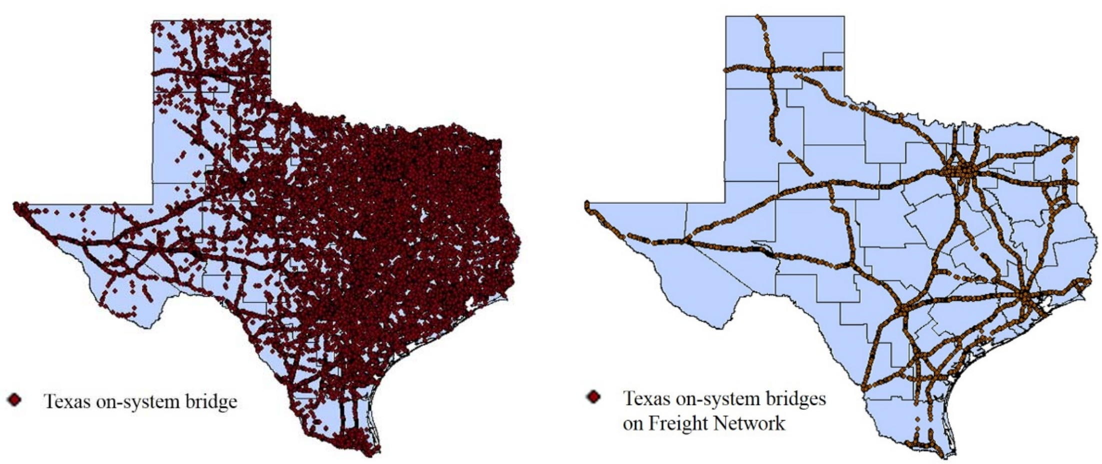
Figure 8.1: Systematic Procedure to Evaluate Physical Condition of Infrastructure Assets

8.1 Bridge Physical Condition

In August 2001, TxDOT adopted a goal that within ten years at least 80 percent of the bridges in Texas would be in good or better condition. This goal was met in 2010, one year ahead of schedule, and the percentage has continued to climb steadily in the following years [TxDOT, 2014a]. It is worth noting that TxDOT spent a total of $658.3 million in FY 2014 for on-system bridge maintenance, bridge replacement and rehabilitation, and construction of new-location bridges. Approximately 60 percent of the total expenditure was invested in maintenance and rehabilitation [TxDOT, 2014a].

TxDOT categorizes Texas bridges into two groups: on-system and off-system. The on-system bridges are located on the designated state highway system, and are maintained by TxDOT. These bridges are typically funded with a combination of federal and state or state-only funds. On the other hand, the off-system bridges are not part of the designated state highway system, and are under the direct jurisdiction of local agencies [TxDOT, 2014a]. This study is focused on the on-system bridges mainly because the freight roadway network is comprised of major roadways, such as interstates, freeways, and principal arteries.

Figure 8.2a shows the on-system bridges identified from BRINSAP and mapped in a Geographical Information System (GIS). Figure 8.2b illustrates the bridges located in the FRN identified in Chapter 5. As presented in the 2014 Texas Bridge Report, the Texas on-system bridge system was comprised of 34,892 total bridges. From this total number, 8,432 are located within the FRN. This number represents slightly less than the 25 percent of the total on-system bridge network. Summary tables of various bridge infrastructure features, such as location, area, and condition, are presented in this section.



(a) Texas on-system bridges (b) Freight network bridges

Figure 8.2: Texas On-system Bridges and Freight Rodway Network Bridges

The bridges within the FRN were classified following the functional classification system provided in the BRINSAP Coding Guide [TxDOT, 2010]. This guide defines eight functional systems as shown in Table 8.1. Moreover, Figure 8.3 shows the distribution of the more than eight thousand bridges comprising the FNR in the eight functional categories. The values on top of the bars represent the percentage of the total bridges comprising the FRN.

Table 8.1: Bridge Functional Classification according to BRINSAP

Functional Group Number	Functional Classification
01	Interstate
02	Other Freeway & Expressway
03	Other Principal Arterial
04	Minot Arterial
05	Collector
06	Major
07	Minor
08	Local

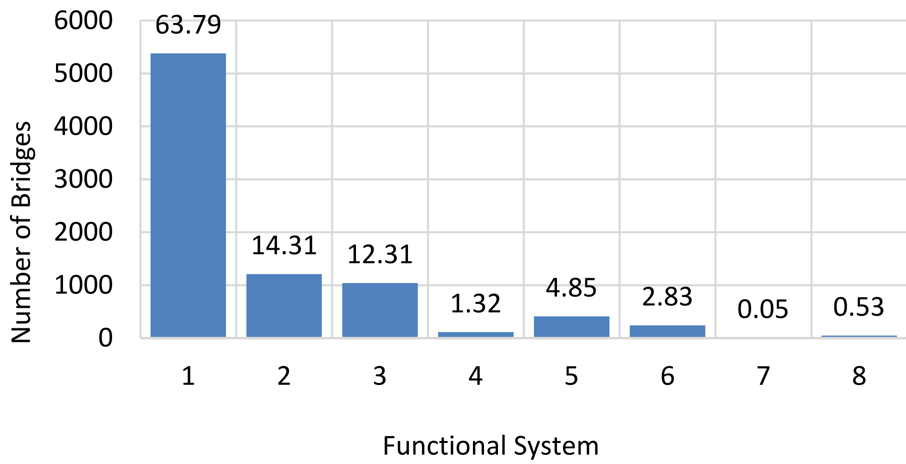


Figure 8.3: Functional System Distribution of Bridges on the FRN

The majority of the bridges comprising the FRN (more than 5,000 or 60 percent) are classified as bridges in the "Interstate System." These results are expected since the freight is mobilized across the state by the most important highway corridors. In addition, slightly more the two thousand bridges are categorized as bridges in the "Other Freeway and Expressways" and "Other Principal Arteries." These results indicate that more than 90 percent of the bridges comprising the FRN are classified as bridges in top-tier systems.

Figure 8.3 shows the distribution of the number of bridges on each of the eight function systems previously discussed. However, the deck area parameter provides a more representative indicator for categorizing bridges. Figure 8.4 illustrates the distribution of the total bridge deck into the eight functional systems. As can be seen, the total bridge deck area follows a similar trend compared to total number of bridges.

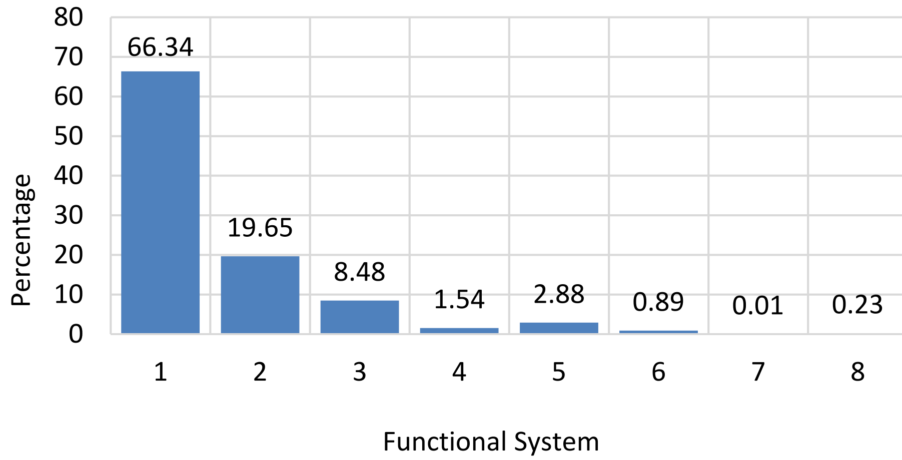


Figure 8.4: Functional System Distribution of Total Bridge Deck Area

In this study, the bridge condition is evaluated using the Sufficiency Rating (SR). The SR is a performance measure used to characterize bridges' structural adequacy and safety, serviceability and functional obsolescence, and essentiality or traffic service [TxDOT, 2014a]. This performance index is used to determine whether a bridge is eligible for Highway Bridge Program funding. Table 8.2 shows the average SR and the percentage of bridges in "Good" or better condition for the functional systems discussed earlier. It is worth noting that TxDOT's goal regarding bridge condition is defined in terms of percent of bridges in Good" or better condition; therefore, this percentage was calculated and presented in Table 8.2 and Figure 8.5.

Table 8.2: Average Sufficiency Rating and Percent Bridges in Good or Better Condition

Functional System	Average SR	Percent Bridges in Good or Better Condition
Interstate	88.20	80.50
Other Freeway & Expressway	88.79	78.29
Other Principal Arterial	90.40	94.22
Minot Arterial	67.26	90.99
Collector	85.35	73.84
Major	85.06	86.19
Minor	79.45	75.00
Local	84.31	91.11

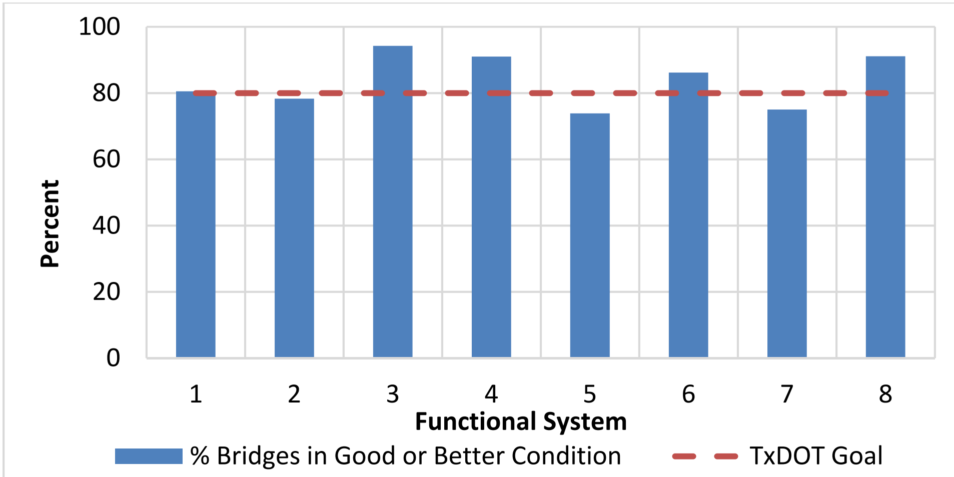


Figure 8.5: Functional Systems Percent Bridges in Good or Better Condition

As seen in Table 8.2, the top-tier system's SR is above 80, which indicates that bridges in vital corridors are in good condition. The bridges in "Minor Arteries" and "Minor" functional systems present values below the 80 SR threshold; however, the contribution deck area of these bridges systems is insignificant compared to the three top tiers. Nonetheless, Figure 8.5 shows that bridges in top-tier corridors (except for "Other Principal Arterial") are slightly above or below the bridge condition goal adopted by TxDOT 15 years ago. Out of the 78 percent of the bridges comprising the two top tiers, approximately 20 percent are classified as structurally deficient or functionally obsolete (according to FWHA criteria). Decision makers should take note of this statistic value to avoiding bridge condition issues in the future, which could affect the efficiency of freight movement in Texas**.**

The results discussed previously were based on the functional system classification according BRINSAP. Moreover, an analysis was performed to evaluate bridge condition at the district level. TxDOT is divided in 25 districts that oversee the construction and maintenance of state highways. Table 8.3 shows the summary of the results in terms of inventory data, average SR, and percentage of bridges in "Good" or better condition. Moreover, Table 8.3 is organized from the largest deck area district to the lowest deck area district.

Table 8.3: Average Sufficiency Rating and Percentage of Bridges in Good or Better Condition by District

District		Number of Bridges	Deck Area (sq. ft.)	Average SR	Percent Good or Better Condition	Meet TxDOT Goal
12	Houston	1352	52,290,763	87.12	73.52	NO
18	Dallas	1378	35,176,569	85.23	72.13	NO
15	San Antonio	862	9,475,308	89.77	83.76	YES
2	Fort Worth	708	4,305,476	89.33	78.25	NO
14	Austin	298	8,449,193	90.17	76.17	NO
20	Beaumont	192	6,282,023	88.62	86.98	YES
21	Pharr	299	6,176,121	93.74	90.97	YES
16	Corpus Christi	347	5,649,921	87.81	93.95	YES
13	Yoakum	293	4,971,597	84.38	94.54	YES
24	El Paso	294	4,115,598	89.41	83.67	YES
9	Waco	242	3,924,939	87.79	82.23	YES
19	Atlanta	213	3,397,571	86.72	95.31	YES
3	Wichita Falls	181	2,988,878	90.06	87.29	YES
4	Amarillo	202	2,548,575	90.05	89.11	YES
17	Bryan	198	2,447,614	87.78	88.38	YES
8	Abilene	286	2,230,588	90.29	75.17	NO
6	Odessa	205	2,225,798	92.62	94.63	YES
5	Lubbock	129	2,040,850	91.71	84.50	YES
7	San Angelo	143	1,849,961	92.91	93.01	YES
1	Paris	194	1,819,925	89.80	79.90	NO
11	Lufkin	93	1,465,398	90.14	96.77	YES
22	Laredo	83	1,374,542	90.80	89.16	YES
10	Tyler	136	1,337,841	91.04	92.65	YES
25	Childress	53	617,400	92.43	92.45	YES

The top six districts shown in Table 8.3 comprise the Texas Triangle Megaregion (one of the eleven megaregions in the U.S.). This megaregion accounts for approximately 75 percent of the deck area comprising the FRN and represents a strategic region for international trade not only for Texas, but also for the entire nation. For this reason, it is expected that the bridge condition of these districts will be in a good condition range. These conditions are clearly shown by the average SR as seen in Table 8.3. The average SR is above 80, which represents the trigger for rehabilitation and maintenance actions. Nonetheless, two out of the six districts fail to meet the TxDOT goal of 80 percent of bridges in good or better condition, which translates to approximately 25 percent of the bridges classified as structurally deficient or functionally obsolete.

In the previous discussion, the physical condition of bridges was evaluated using the SR and the percentage of bridges in good or better condition. In addition to these two indicators, bridges can be characterized by condition ratings of their components. Condition ratings are used to describe the existing in-place bridges compared to their as-built condition. Figure 8.6 to Figure 8.11 show the condition ratings for various bridge components, such as the deck, superstructure, substructure, channels and channels protections, and culverts. Moreover, Table 8.4 shows the description of each of the nine categories.

Table 8.4: Bridge Functional Classification according to BRINSAP

Condition Rating	Description
Excellent	-
Very Good	No problems noted.
Good	Some minor problems.
Satisfactory	Structural elements show some minor deterioration.
Fair	All primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
Poor	Advanced section loss, deterioration, spalling or scour.
Serious	Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken
“Imminent” Failure	Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
Failed	Out-of-service beyond corrective action.

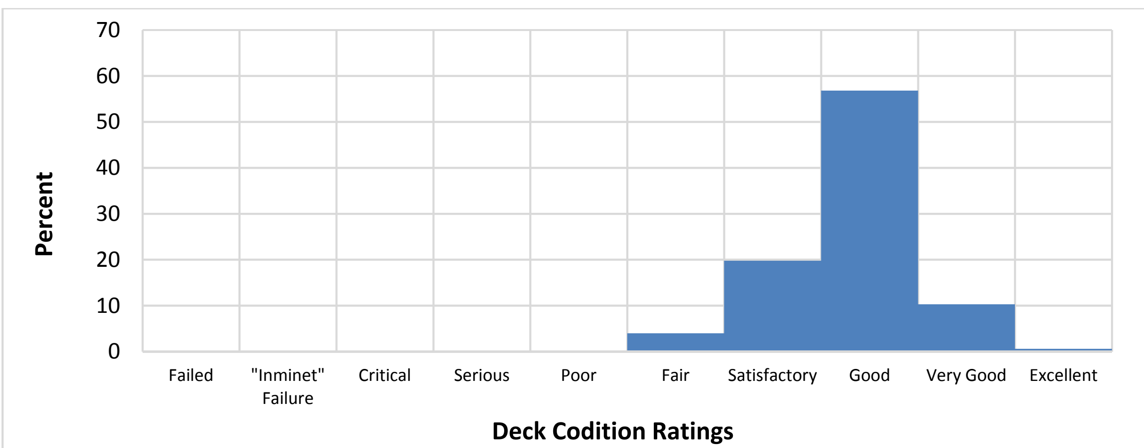


Figure 8.6: Distribution of the Deck Condition Ratings for the FRN

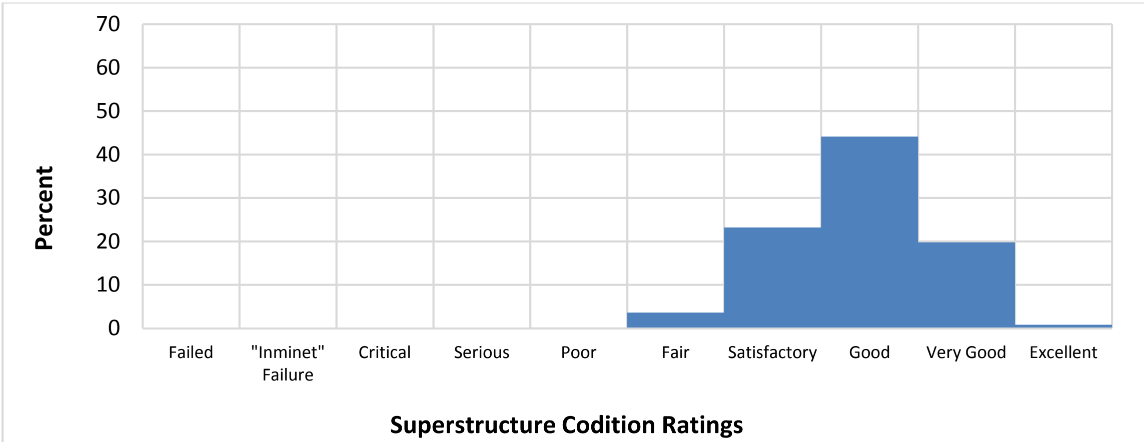


Figure 8.7: Distribution of the Superstructure Condition Ratings for the FRN

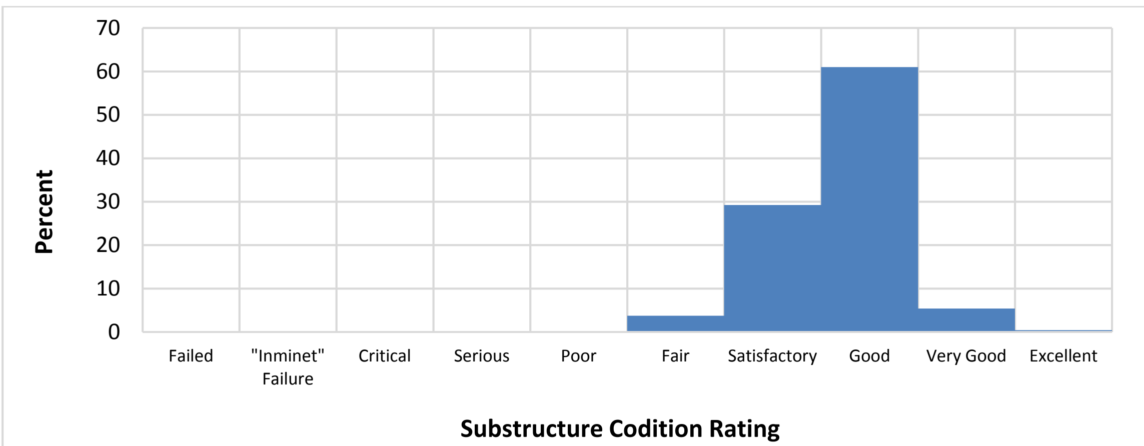


Figure 8.8: Distribution of the Substructure Condition Ratings for the FRN

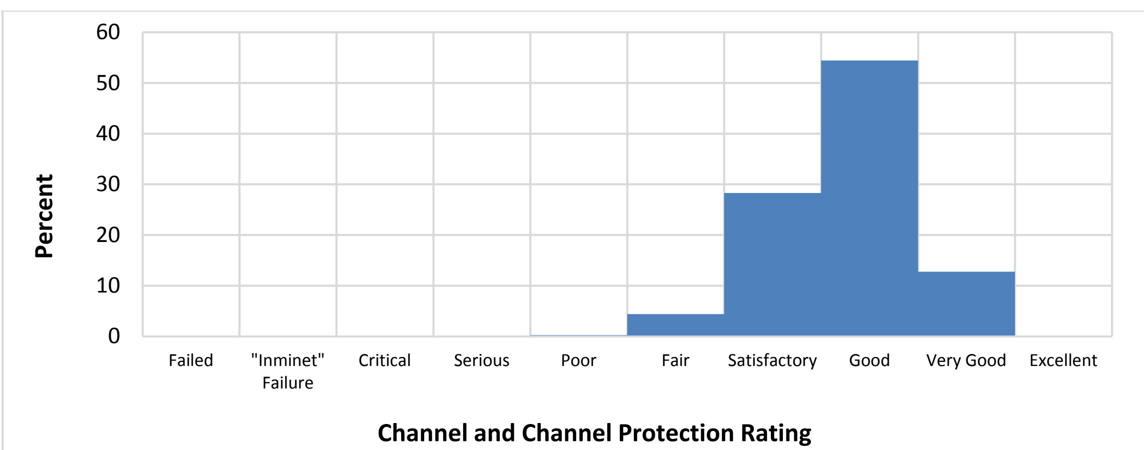


Figure 8.9: Distribution of the Substructure Condition Ratings for the FRN

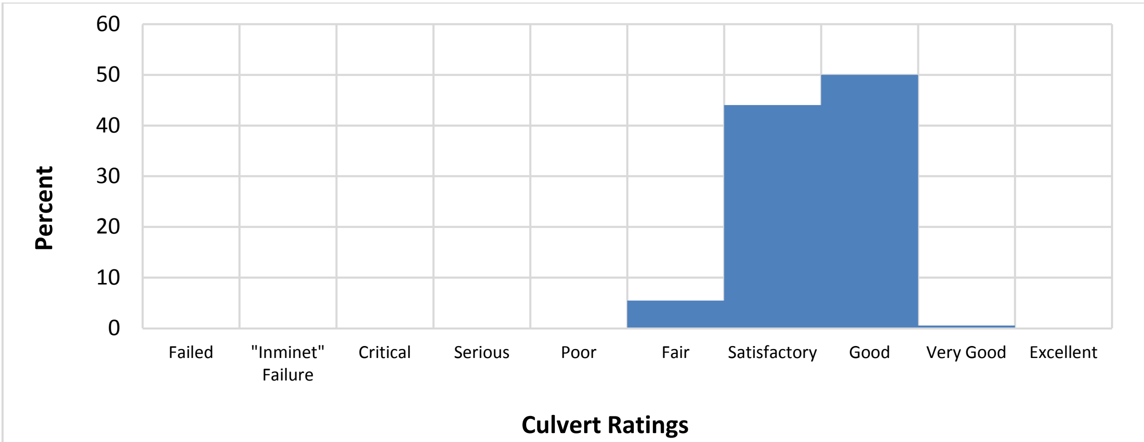


Figure 8.10: Distribution of the Substructure Condition Ratings for the FRN

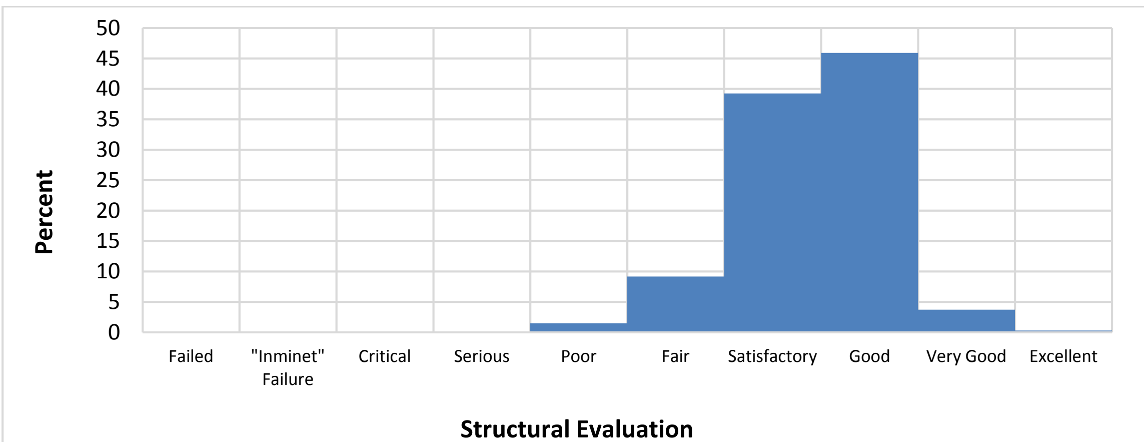


Figure 8.11: Distribution of the Structural Evaluation of the bridges of the FRN

As seen from Figure 8.6 to Figure 8.11, most components of the bridges of the FRN are rated as “Satisfactory” or “Good,” which suggests that bridges are providing the necessary conditions for efficient international trade. Moreover, the “Fair” rating for all bridge components shows small values ranging from 3.6 to 9.2 percent. It is worth noting that none of the components of the bridges were evaluated lower than the condition rating “Poor,” which indicates that the majority of the bridges are far from deteriorating to critical conditions.

Finally, Figure 8.12 shows the distribution of the bridges in the FRN by the year constructed or last year reconstructed. These parameters were considered to evaluate the service life of the structures, which will play an important role in estimating their asset value.

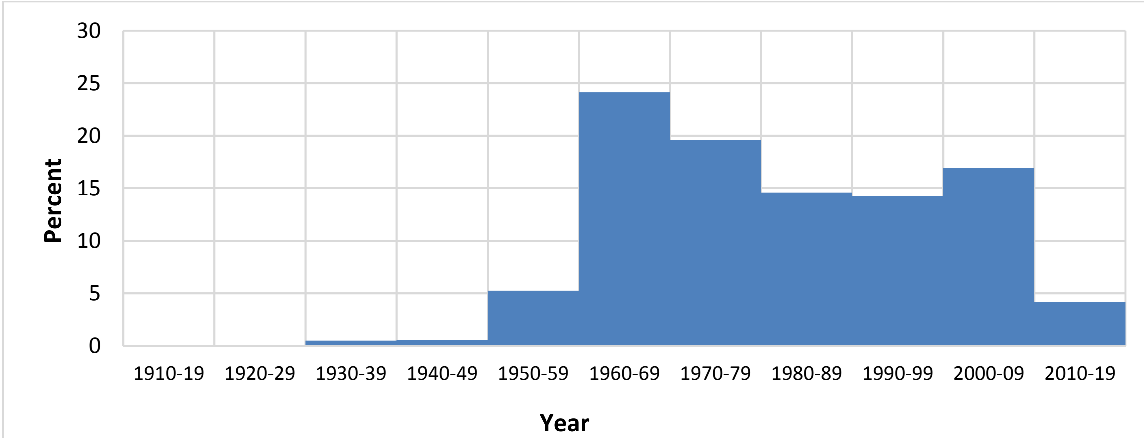


Figure 8.12: Distribution of Year Built or Last Year Reconstructed of the Bridges of the FRN

8.2 Pavements Physical Condition

Pavement infrastructure is one of the largest publicly owned infrastructure assets in the United States where the infrastructure plays a key role in social and economic development. State agencies have gone the extra mile to preserve and operate the highway systems properly to keep the highway infrastructure at acceptable levels of service, and TxDOT is no exception. According to recent literature, TxDOT maintains approximately 80,423 centerline miles of roadways, and the average daily vehicle miles traveled on the state-maintained highways was 481.7 million miles in 2014 [TxDOT, 2015]. Table 8.5 shows mileage of highways maintained by TxDOT by highway system.

Table 8.5: Mileage of Highways Under the Jurisdiction of TxDOT by Highway System

Highway System	Main Lanes	Left Frontage Road	Right Frontage Road
IH	3,416.971	2,455.887	2,371.000
US	11,675.613	657.225	646.402
UA	220.879	1.875	2.581
UP	8.318	0.320	0.320
SH	14,073.374	404.916	410.299
SA	-	-	-
SL	980.654	190.495	190.634
SS	393.136	20.955	20.154
BI	193.031	23.213	5.084
BU	538.333	5.895	3.204
BS	203.628	0.259	0.764
BF	8.032	-	-
FM	37,891.825	19.539	19.547
RM	2,966.437	-	-
RR	6.587	-	-
PR	252.085	1.030	1.120
RE	79.485	-	-
FS	44.045	-	-
RS	1.542	-	-
RU	-	-	-
RP	-	-	-
PA	16.089	-	-
State Grand Total	72,970.064	3,781.609	3,671.109

Source: Texas Department of Transportation, *Roadway Inventory Report – 2014*, 2015

It is essential to understand the current physical conditions of the pavements in order to efficiently allocate limited funds. Currently, TxDOT is operating the Texas Pavement Management System (PMIS). The PMIS is an automated system for storing, retrieving, analyzing, and reporting pavement condition information of highways, so that the agency can compare maintenance and rehabilitation treatment alternatives, monitor current pavement conditions, and estimate total pavement needs [TxDOT, 2014b]. The PMIS provides decision-makers with several indices showing pavement conditions, such as condition score, skid score, International Roughness Index (IRI), and texture score.

As presented in Chapter 6, the 2015 PMIS database was mapped on the 2014 Texas Roadway Inventory Map. Figure 8.13 presents the roadway sections of the FRN successfully integrated with 2015 PMIS data.

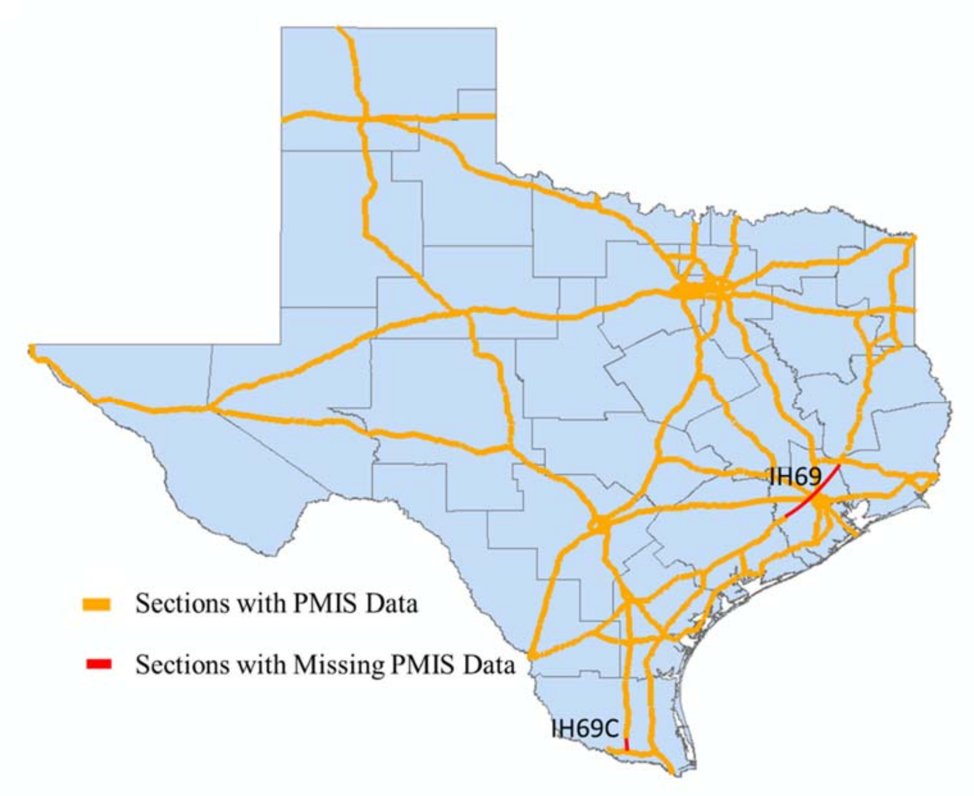
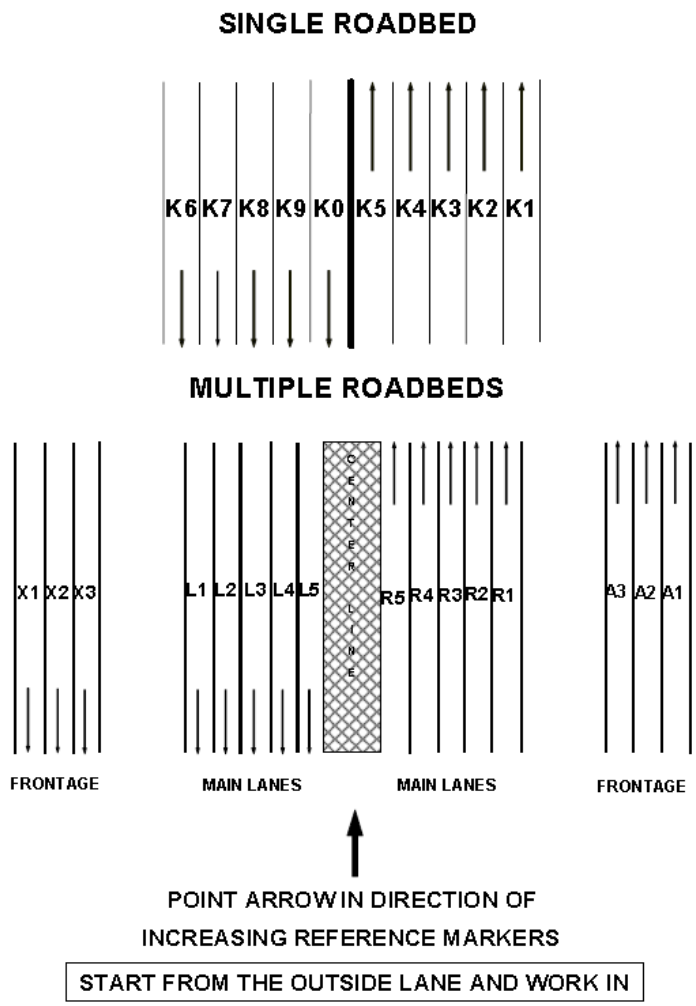


Figure 8.13: FRN Sections Integrated with PMIS 2015 Database

Unfortunately, issues with missing data exist with the up-to-date databases. The most critical issue is that the PMIS data of Interstate Highway 69, which is passing through the Houston area, is missing the Distance from Origin (DFO) distance measure. This issue prevents using the Linear Referencing tool in ArcGIS; therefore, the pavement information cannot be located along the roadways properly. Considering that the IH69 is expected to play a vital role in the FRN, the research team will address this problem together with other roadway sections with missing data in the next chapter. For the contents of this chapter, only the FRN with PMIS data is discussed.

As stated in Chapter 5, the FRN was defined on the Interstate Highways, the U.S. Highways, and the State Highways. Table 8.6 shows the total mileage of the FRN based on PMIS data collection sections by highway system and roadbed type. The roadbed types defined in the PMIS database are depicted in Figure 8.14. All of the Interstate Highways in Texas are included as a part of the FRN, and they comprise 71.3% of the total mileage. Moreover, the U.S. Highways and the State Highways compose 22.7% and 5.98% respectively.



Roadbed Type	Description
A	Right Frontage
K	Single Mainlane (undivided)
L	Left Mainlane
R	Right Mainlane
X	Left Frontage

Source: TxDOT, *Pavement Management Information System – Rater's Manual*, 2015

Figure 8.14: Roadbed Types Defined in PMIS

Table 8.6: Total Mileage of FRN by Highway System

Highway System	Roadbed Type	Mileage	# of PMIS Data Collection Sections	Percentage (%)
IH	A	2,858.6	6,370	12.05
	L	5,420.5	12,309	22.84
	R	5,635.3	12,777	23.75
	X	3,010.1	6,677	12.68
US	A	286.0	673	1.21
	K	801.8	1,704	3.38
	L	1,993.8	4,289	8.40
	R	2,003.5	4,312	8.44
	X	303.0	704	1.28
SH	A	90.5	206	0.38
	K	474.7	993	2.00
	L	386.5	835	1.63
	R	375.6	809	1.58
	X	92.0	215	0.39
Total		**23,731.9**	**52,873.0**	**100.0**

This study will use mainly the Condition Score (CS) to evaluate the condition of pavement structures. The CS is a PMIS measure, which describes the overall condition of a pavement structure in terms of ride quality and pavement distress, and ranges from 1 (worst condition) to 100 (best condition) [TxDOT, 2013]. It is a mathematical combination of the Distress Score and the Ride Score that refers to the degree of the pavement deterioration and smoothness of the pavement surface, respectively. TxDOT categorizes the performance indices into five based on their values as indicated in Table 8.7. In addition, a pavement section with a CS of 70 or above is considered to be in "Good" or better condition. This percentage of "Good" or better condition roadways is often used to measure overall effectiveness of the pavement maintenance works performed.

Table 8.7: PMIS Score Definitions

Category	Distress Score	Ride Score	Condition Score
	Describes "distress"	Describes "ride"	Describes "condition"
"Very Good"	90 to 100	4.0 to 5.0	90 to 100
"Good"	80 to 89	3.0 to 3.9	70 to 89
"Fair"	70 to 79	2.0 to 2.9	50 to 69
"Poor"	60 to 69	1.0 to 1.9	35 to 49
"Very Poor"	1 to 59	0.1 to 0.9	1 to 34

Source: Texas Department of Transportation, *Condition of Texas Pavements – PMIS Annual Report FY 2011-2014*, 2014

The State agency usually uses CS to determine whether a roadway segment needs maintenance work or not. Figure 8.15 shows how the CS varies along with the FRN, and Table 8.8 presents the average CS of each highway system with the percentage of pavement sections in "Good" or better condition in the FRN. The overall average CS of the FRN is 89.53, and the percentage of pavement sections in Good or better condition is 86.71%. Note that the condition of roadbed types K, L, and R, which are main lanes, are maintained in better condition in comparison with frontage lanes. Moreover, there is little difference in the average CS between each highway system. The average CS of the Interstate Highways is 89.29, while those of the U.S. Highways and State Highways are 90.07 and 90.22 respectively.

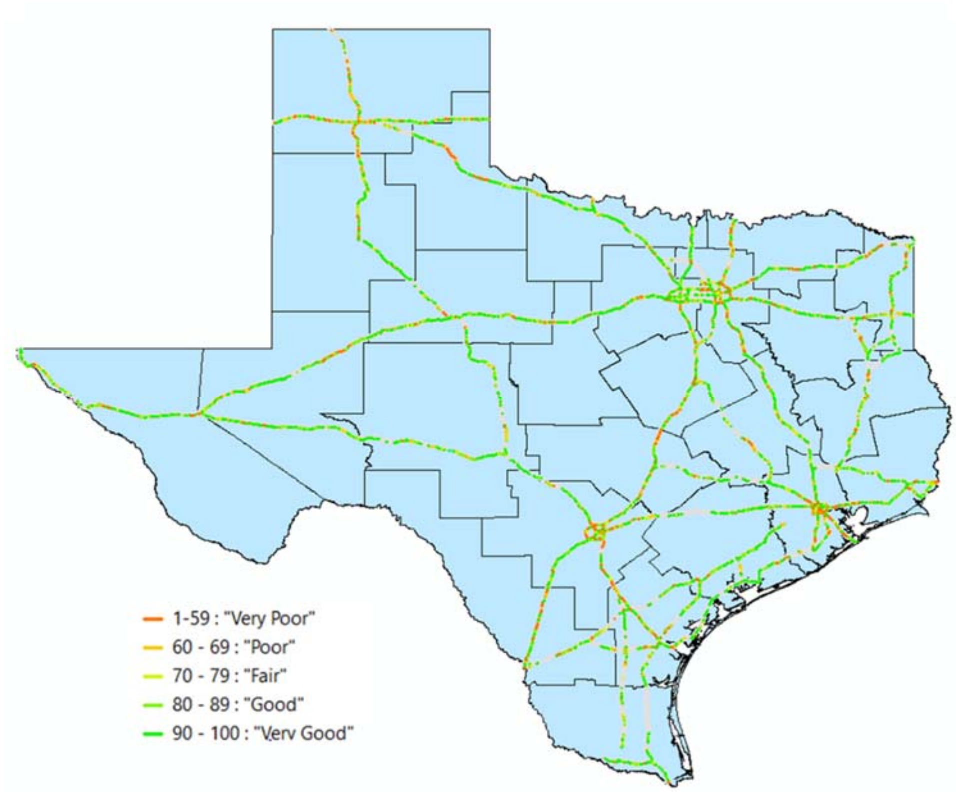


Figure 8.15: PMIS 2015 Condition Scores of FRN

Table 8.8: Average Condition Score and Percentage of Pavements Sections in Good or Better Condition in FRN

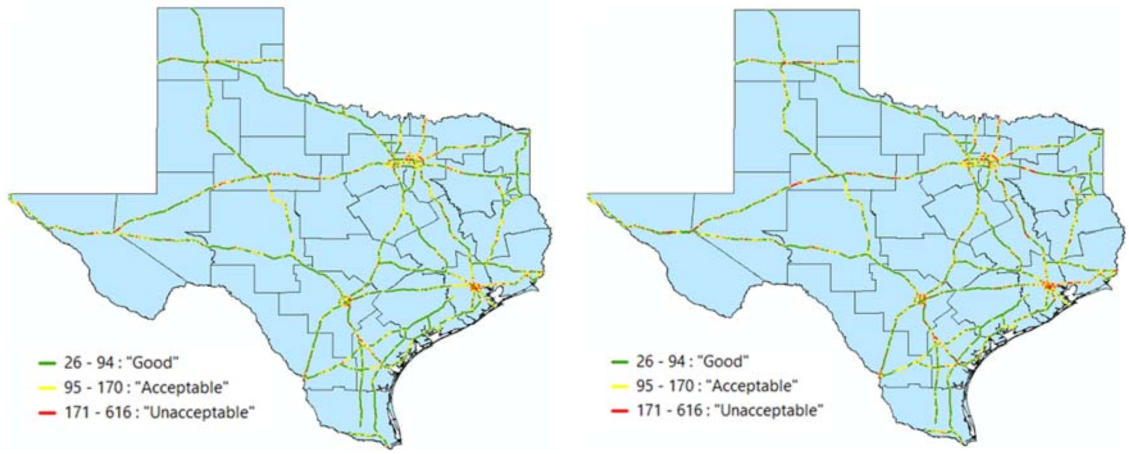
Highway System	Roadbed Type	Average Condition Score (CS)	% of Sections with "Good" or better Condition (CS ≥ 70)
IH	A	84.94	79.86%
	L	92.38	91.24%
	R	92.25	90.75%
	X	84.21	78.95%
	Subtotal	89.29	86.48%
US	A	79	69.89%
	K	88.7	84.76%
	L	92.38	89.93%
	R	91.77	89.83%
	X	78.97	72.27%
	Subtotal	90.07	86.99%
SH	A	77.17	68.00%
	K	92.19	91.84%
	L	92.05	89.46%
	R	92.94	92.66%
	X	75.34	69.48%
	Subtotal	90.22	88.34%
Total		**89.53**	**86.71%**

Another widely used performance indicator of the condition of pavement structure is International Roughness Index (IRI). IRI is a scale for roughness based on the simulated response of a generic motor vehicle to the roughness in a single wheel path of the road surface. PMIS also provides the average of the IRI for both left and right wheelpaths. According to FHWA's Condition and Performance Report [USDOT, 2013], FHWA recommend a threshold of 170 in/mi for acceptable ride quality as presented in Table 8.9.

Table 8.9: FHWA's International Roughness Index (IRI) Thresholds

Ride Quality	IRI Threshold
"Good"	IRI < 95 in/mi
"Acceptable"	95 in/mi ≤ IRI ≤170 in/mi

The IRI along the FRN is as shown in Figure 8.16. The average IRI and percentage of pavement sections with "Acceptable" IRI is presented in Table 8.10 by highway system and roadbed type. The overall average IRI of the FRN is 96.88, which is in the "Acceptable" range. In addition, the percentage of pavement sections with "Acceptable" IRI is 91.12%. Similar to the CS, this result indicates the IRIs for mainlanes are maintained better relative to frontage roads.



Left Wheelpath IRI *Right Wheelpath IRI*

Figure 8.16: PMIS 2015 International Roughness Index of FRN

Table 8.10: Average IRI and Percentage of Pavements Sections with "Acceptable" IRI

Highway System	Roadbed Type	IRI Left (in/mi)	IRI Right (in/mi)	Average IRI (in/mi)	% of Sections with "Acceptable" IRI (IRI ≤ 170 in/mi)
IH	A	134.91	151.01	142.96	74.55%
	L	80.56	82.63	81.595	98.42%
	R	81.02	82.57	81.795	98.30%
	X	136.35	154	145.175	72.05%
	Subtotal	99.38	106.3	102.84	85.85%
US	A	146.16	154.98	150.57	70.39%
	K	93.48	100.76	97.12	95.39%
	L	80.42	82.17	81.295	98.25%
	R	80.26	83.86	82.06	97.76%
	X	143.23	151.36	147.295	71.58%
	Subtotal	89	92.95	90.975	94.78%
SH	A	149.67	157.82	153.745	72.32%
	K	92.08	98	95.04	95.86%
	L	85.28	97.34	91.31	97.11%
	R	82.33	84.8	83.565	97.39%
	X	149.81	154.85	152.33	68.65%
	Subtotal	94.86	98.87	96.865	93.41%
Total		**96.88**	**103**	**99.94**	**91.12%**

8.3 Summary

Managing freight corridors used for international trade is pivotal for Texas to maintain and promote its competitiveness and economic growth. For this reason, analyzing the physical condition of the bridges and pavements comprising the freight corridors is essential to enhance effectiveness and efficiency of the management process. This chapter analyzes the physical condition of bridges and pavements comprising the FRN. The bridges are evaluated using the

Sufficiency Rating and condition ratings for various elements. Pavement structures are characterized using the Condition Score and the IRI. The analysis result will provide an important building block to assigning a price tag to international trade corridors.

Chapter 9. Base Price Tags for Texas Freight Roadway Network (FRN)

The first part of this chapter addresses the missing data problem in the physical condition database described in Chapter 6 to complete the database that will comprise key inputs to evaluate asset values of the Freight Roadway Network (FRN). Then, the research team evaluates and presents the base price tags of the FRN using the current physical condition data only as preliminary analysis results before assigning final price tags to the FRN. The final price tags will be prepared in the next chapter by adjusting the base price tags by various key factors, other than the physical condition, to be more representative.

Figure 9.1 illustrates a series of procedures taken to treat the missing data in the pavement physical condition database and to evaluate the preliminary asset values of the FRN. To complete the pavement physical condition database, the previous year's Texas Pavement Management Information System (PMIS) database (2014) is used to substitute the missing data as the first step. Then, the rest of the missing data is imputed by a data imputation technique and through engineering judgement. Once the physical condition database becomes complete, the research team evaluates preliminary asset values of the FRN by applying the utility-based approach proposed in Chapter 3.

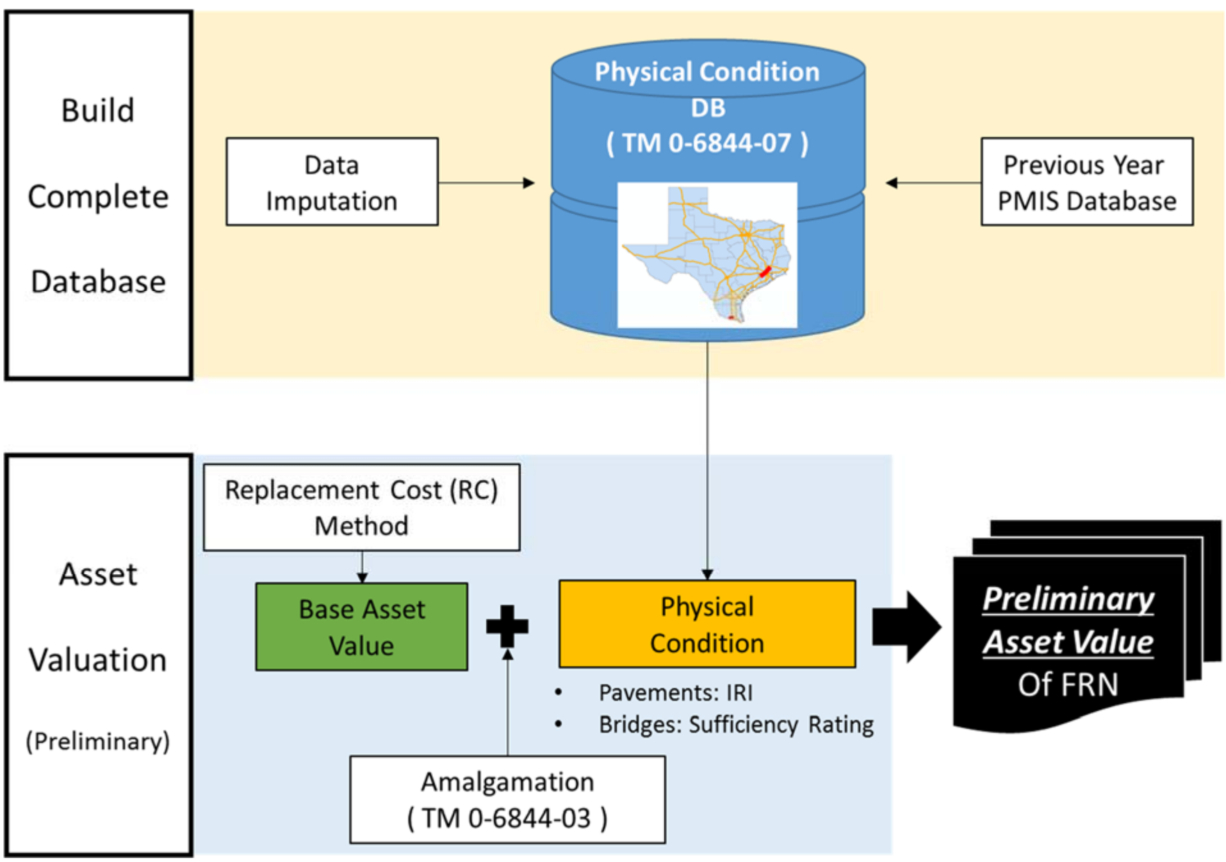


Figure 9.1: Systematic Procedures for Missing Data Treatment and Preliminary Analysis

9.1 Missing Pavement Physical Condition Data

Physical condition data of the FRN is crucial, and the database must be complete in order to assign price tags to the FRN. In this section, the characteristics of the missing data in the pavements physical condition database are briefly discussed, and treatments for the missing data are proposed.

9.1.1 Overview

As discussed in Chapter 8, four available performance measures represent the overall physical condition of pavement structure in the Texas PMIS: Distress Score (DS), Condition Score (CS), Ride Score (RS), and International Roughness Index (IRI). A summary of the missing data on each of the physical condition performance measures is presented by highway systems and roadbed types in Table 9.1. Generally, the proportion of missing data was relatively higher for frontage roads than for the main roads. The proportions of missing values for DS, CS, RS, and IRI were 4.21 %, 5.06 %, 3.22 %, and 3.22 % respectively. It is worth noting that the lane-miles of the sections with missing RS and those of the sections with missing IRI are identical. This is because RS is calculated with IRI, and thus, RS is also available when IRI is available. Along the same lines, CS exists when both DS and RS are available in the data set since CS is also a mathematical combination of DS and RS.

Table 9.1: Overview of Pavement Sections with Missing Physical Condition Data on FRN

(unit: lane-mile)

Highway System	Roadbed ID	Lane-Mile	Missing DS	Missing CS	Missing IRI
IH	AG	4,915.8	313.4 (6.38%)	439.8 (8.95%)	351.8 (7.16%)
	KG	77.4	77.4 (100%)	77.4 (100%)	77.4 (100%)
	LG	8,162.3	171.8 (2.1%)	180.8 (2.22%)	50.2 (0.62%)
	RG	8,216.5	195.2 (2.38%)	229.3 (2.79%)	74.9 (0.91%)
	XG	5,052.4	336.9 (6.67%)	436.1 (8.63%)	319.2 (6.32%)
US	AG	550.5	80.0 (14.53%)	94.4 (17.15%)	79.3 (14.41%)
	KG	1,377.0	58.9 (4.28%)	58.9 (4.28%)	26.6 (1.93%)
	LG	2,963.8	58.8 (1.98%)	60.5 (2.04%)	13.7 (0.46%)
	RG	2,972.2	101.6 (3.42%)	102.6 (3.45%)	27.0 (0.91%)
	XG	595.9	86.0 (14.43%)	108.0 (18.12%)	98.5 (16.53%)
SH	AG	205.2	35.6 (17.35%)	38.2 (18.62%)	38.2 (18.62%)
	KG	917.1	14.2 (1.55%)	16.0 (1.74%)	8.8 (0.96%)
	LG	716.1	9.7 (1.35%)	16.6 (2.32%)	7.1 (0.99%)
	RG	741.2	10.4 (1.4%)	10.7 (1.44%)	5.3 (0.72%)
	XG	211.6	35.5 (16.78%)	36.7 (17.34%)	33.7 (15.93%)
Total		**37,675.1**	**1585.5 (4.21%)**	**1906.1 (5.06%)**	**1211.8 (3.22%)**

9.1.2 Managing Missing Data

Missing data problems are frequently encountered in actual analyses regardless of fields of study. Generally, missing data can be categorized into three categories depending on their missingness mechanisms as follows [Graham, 2009]:

- *Missing at Random (MAR):* The missingness may depend on observed data, but not on unobserved data
- *Missing Completely at Random (MCAR):* A special case of MAR in which missingness does not depend on the observed data either
- *Missing Not at Random (MNAR):* Missingness does depend on unobserved data

Most of the data imputation techniques currently available are well applicable to MCAR or MAR, but are not applicable to MNAR. Table 9.2 presents common data imputation techniques. Traditional imputation methods usually perform deterministic single imputation for the missing values, but some other recently developed imputation methods produce multiple plausible values for the missing data, taking advantage of advances in computer technology. Traditional deterministic single imputation methods tend to suffer from the fact that they fail to reflect the true distributional relationship between observed data and missing values, and they treat imputed data deterministically as though the data were actually measured [Farhan and Fwa, 2014].

Table 9.2: Data Imputation Methods [Farhan and Fwa, 2014; Zhang, 2015]

Category	Imputation Method	Details
Traditional	Mean Substitution	Substitutes by a single constant value for a particular variable, commonly arithmetic mean of the available values of the variable.
	Interpolation Substitution	Replaces missing values using a linear interpolation approach. The last valid value before the missing value and the first valid value after the missing value are used for the interpolation.
	Regression Substitution	Predicts missing data based on the variable's relationship with other variables in the data set.
New	Maximum Likelihood (ML)	Does not impute any data, and instead uses available data to compute maximum likelihood estimates based on a database with missing data.
	Multiple Imputation (MI)	Adds a stochastic component to missing data imputation process by generating multiple imputed values for a single missing value.

In this research, the missing data was managed by taking several steps of data substitution and imputation. Figure 9.2 depicts the sequence of the procedures. First, the previous year's PMIS database (2014) was integrated to substitute missing values in the current data set with the previous year's data, assuming that the physical condition of pavement structure did not change dramatically in a short period time. Then for the second step, for the rest of the missing data, Interpolation Substitution method was used to estimate plausible values for the missing ones. Though Interpolation Substitution method has limitations as widely discussed in various studies, other improved data imputation techniques are not suitable for this research due to several aspects. For instance, one of advantages of using Maximum Likelihood method (ML) or Multiple Imputation (MI) is the capability of reflecting uncertainty (variance) about missing data into the final estimates of statistical models developed; however, statistical models will not be developed based on the imputed data set in this research. Moreover, ML does not provide actual imputed values for the missing data and MI generates multiple values for a single missing value, but our current research requires a single deterministic value for each of the missing physical performance data to evaluate the asset values of the entire infrastructure on the FRN. Table 9.3 shows how much the missingness in the data set was addressed by the substitution with the previous year's PMIS database and the Interpolation Substitution method. As the result, the total amount of missing data was reduced by approximately 67.2%.

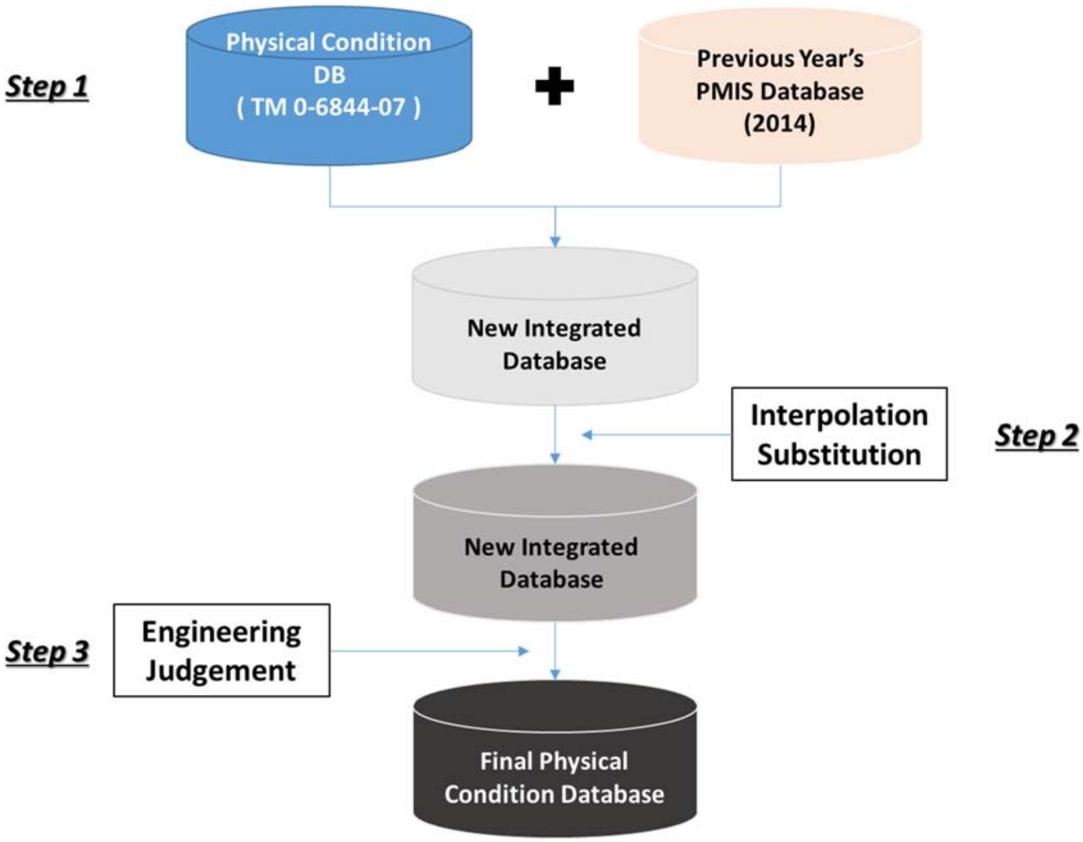


Figure 9.2: Systematic Approach to Manage Missing Data in Pavement Physical Condition Data Set

Table 9.3: Reduction in Missing Data by Data Imputation Process

(unit: lane-mile)

Category	Missing DS	Missing CS	Missing IRI
Original	1585.5	1906.1	1211.8
	(4.21%)	(5.06%)	(3.22%)
Step 1 (Data Substitution)	652.5	887.0	733.5
	(1.73%)	(2.35%)	(1.95%)
Step 2 (Interpolation Substitution)	362.808	529.108	523.508
	(0.96%)	(1.40%)	(1.39%)
% reduced	77.12%	72.24%	56.80%

However, the missing data issue still remains after conducting the two procedures mentioned due to the Interpolation Substitution method's inability to fill missing values if there is insufficient data available in the vicinity of the missing ones. Hence, for the rest of missing data, the research team imputed those values based on engineering judgement.

In addition to this problem, the missing Distance from Origin (DFO) distance measure issue was also addressed by using the TxDOT Statewide Planning Map [TxDOT, 2016]. The map provides the Texas Reference Markers (TRMs) and the corresponding DFOs, so that the missing

DFOs could be imputed with the TRM information for each pavement management section in the PMIS database.

9.2 Freight Roadway Network (FRN) Base Price Tags

This section provides a brief review of common asset valuation methods for civil infrastructure and their data requirements to decide on a proper asset valuation method to develop the base price tags for the FRN. In addition, the estimated base price tags for the FRN are also presented by applying the proposed asset valuation technique.

9.2.1 Review of Asset Valuation Techniques

In Chapter 2, the research team reviewed various asset valuation techniques applicable to civil infrastructure along with their data requirements. Depending on the method selected, the data requirements vary significantly, and the data requirements could be an obstacle in the asset valuation process due to data availability and processing effort. According to Cowe Falls et al. (2005), the most referenced asset valuation techniques for civil infrastructure and their data requirements are as presented in Table 2.4. As indicated in Table 2.4, Book Value / Historical Cost (BV/HC) and Net Salvage Value require whole historical information of both maintenance and rehabilitation activities; however, collecting the historical information is often an arduous task due to data availability, especially for a large network like the FRN. Therefore, Replacement Cost (RC) method or Written Down Replacement Cost (WDRC) method are viable options for the purpose of this research since current construction costs information to replace pavements can be obtained with relative ease. Moreover, considering that the utility-based approach developed in this research will adjust the base price tags to the physical condition of the infrastructure, Replacement Cost (RC) method, which does not depreciate the costs to current condition, is more reasonable in this case to obtain the base price tags. Thus, the research team proposes a methodology to estimate replacement costs for pavements and bridges in the following section in more detail.

9.2.2 Proposed Base Price Tag Estimation Method

As stated in Chapter 7, a replacement cost estimation model is proposed to estimate the base price tags of the FRN after a comprehensive review of historical construction costs, historical maintenance costs, and reconstruction cost methodologies (as per Equation 9.1). The proposed model is based on reconstruction cost information presented in the Highway Economic Requirement System Technical (HERS-ST) Report and the 2030 Committee Texas Transportation Needs Report [USDOT, 2005; Texas 2030 Committee, 2009].

Equation 9.1 presents the generic mathematical expression to compute the reconstruction cost for a highway corridor.

$$R_{C,\,year} = R_{C,pav,\,year} + R_{C,bridge,\,year}$$

$$= UC_{2002} \cdot SF_{2000} \cdot \frac{HCI_{year}}{HCI_{2000}} N_L \cdot L_S \cdot \frac{HCI_{year}}{HCI_{2002}} + C_{B,year} \cdot DeckArea \cdot \frac{HCI_{year}}{HCI_{2008}} \tag{9.1}$$

where:

$R_{C,year}$ = replacement cost of a highway corridor for the year of analysis
$R_{C,pav,year}$ = replacement cost of a pavement structure for the year of analysis

$R_{C,bridge,year}$ = replacement cost of a bridge structure for the year of analysis
UC_{2002} = unit construction cost per lane-mile in 2002 dollars
SF_{2000} = state adjustment factor
N_L = number of lane
L_S = length of the segment in miles
HCI_{year} = Highway Cost Index (HCI) for year of analysis
HCI_{2000} = Highway Cost Index (HCI) for the year 2000
HCI_{2002} = Highway Cost Index (HCI) for the year 2002
$C_{B,year}$ = Bridge replacement cost per square feet for Texas at year i
$Deck\ Area$ = Deck area in square feet in the highway corridor
HCI_{2008} = CPI for the year 2008

Table 9.4 shows unit pavement reconstruction costs used for this research. The unit pavement reconstruction costs are presented for each functional class of pavement structure in 2002 dollars per lane-mile, and the costs were reorganized based on the information in the HERS-ST Report [USDOT, 2005].

Table 9.4: Pavement Reconstruction Costs

(unit: thousands of 2002 dollars per lane-mile)

Functional Class	Reconstruction Unit Cost
Rural Interstate	826.67
Rural Principal Arterial	657.67
Rural Minor Arterial	610.33
Rural Major Collector Rural Minor Collector Rural Local	607.00
Urban Interstate Urban Other Freeway	1678.67
Urban Principal Arterial	1362.00
Urban Minor Arterial Urban Collector Urban Local	990.00

Source: Reorganized pavement reconstruction costs information from USDOT (2005)

Bridge reconstruction costs are also important inputs along with the pavement reconstruction costs. In the 2030 Committee Texas Transportation Needs Report, the research team used bridge data to generate unit costs for bridge rehabilitation and replacement, and the estimated average bridge replacement cost was \$194 per square foot of bridge deck area in 2008 dollars [Texas 2030 Committee, 2009]. The current research will use this estimate to evaluate reconstruction costs for the bridge structures on the FRN.

Since the reconstruction cost estimates for pavements and bridges are in different dollar units, 2002 dollars and 2008 dollars respectively, the estimates must be adjusted to the same dollar unit by reflecting costs fluctuation in construction industry. In Chapter 7, several cost indices capturing the costs fluctuation over time were introduced. In this research, the selected index reflect cost fluctuation is the Highway Cost Index (HCI) developed and maintained by the Texas Department of Transportation (TxDOT). The HCI is more appropriate choice since it specifically tracks the cost fluctuation in the highway construction industry in Texas, while the others indexes are not specifically tailored to Texas or highway construction. For instance, the National Highway Construction Cost Index (NHCCI) only provides a nationwide view of the highway construction cost changes, and the Consumer Price Index (CPI) measures price changes in goods and services purchased by households. Table 9.5 presents the HCI for given years.

Table 9.5: Highway Cost Index (HCI)

Year	Highway Cost Index (12-month Moving Average)
2000	115.88
2002	117.44
2008	209.95
2015	247.06

Source: TxDOT, TxDOT Highway Cost Index (1997 Base) Index Report for April 2016

Though the reconstruction costs used in this research may seem to be rough estimates considering the various factors that may affect the reconstruction costs, those estimates are still accurate enough to estimate the asset value of the entire FRN. Since the costs variation will be balanced later on, decomposing the structures in detail and applying more precise costs information will result in only a relatively small improvement in the final asset value, resulting in diminishing returns when compared with the amount of effort additionally required.

9.2.3 Estimation of FRN Base Price Tags

The estimated base price tags for pavements and bridges on the FRN are presented in Table 9.6 and Table 9.7 respectively. As the result, the total base price tag of the FRN was estimated at approximately \$160 billion: \$117 billion for the pavements and \$43 billion for the bridges. The pavement structure comprised 73.2% of the total asset value while the bridges represented 26.8%. In addition, the Interstate Highway system, including bridges on the system, accounted for 71.9% of the total base price tag.

Table 9.6: Estimation Result of FRN Pavements Base Price Tags

(unit: thousands of 2015 dollars)

Highway System		Estimated Base Price Tags (RC)
IH	Main lanes	62,502,395.0
	Frontage roads	24,086,411.9
	Sub Total	86,588,806.9
US	Main lanes	19,266,432.9
	Frontage roads	3,020,206.1
	Sub Total	22,286,639.0
SH	Main lanes	7,070,686.7
	Frontage roads	1,157,922.0
	Sub Total	8,228,608.6
Grand Total		**117,104,054.6**

Table 9.7: Estimation Result of FRN Bridges Base Price Tags

(unit: thousands of 2015 dollars)

Functional Classification	Estimated Base Price Tags (RC)
Interstate	28,406,496.7
Other Freeway & Expressway	8,413,828.6
Other Principal Arterial	3,630,210.7
Minor Arterial	657,376.3
Collector	1,232,089.6
Major	381,030.7
Minor	3,495.5
Local	97,257.6
Grand Total	**42,821,785.5**

9.3 Physical Condition Adjustment of FRN Base Price Tags

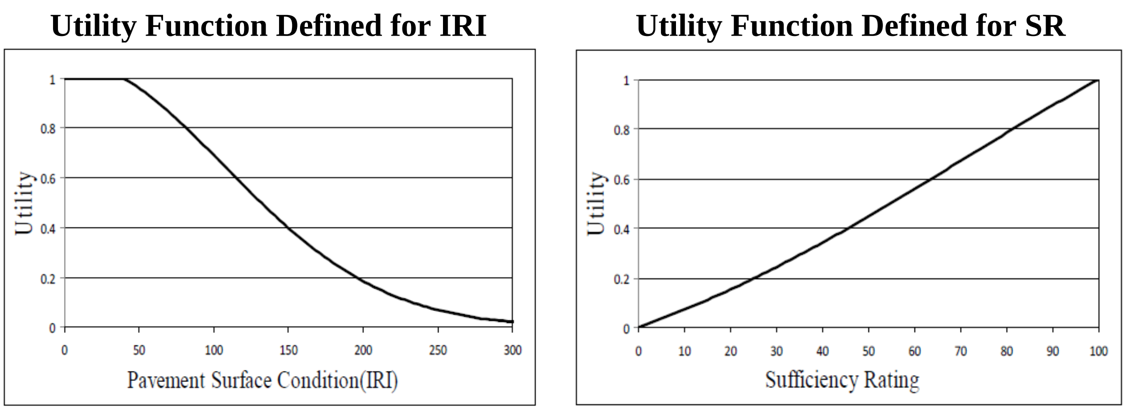
The base price tags of the FRN, which were calculated in the previous section, are adjusted by the FRN's physical condition as a preliminary analysis in this section. First of all, one performance measure representing physical condition is selected for each pavement structure and bridge structure. Then, the FRN's base price tags are adjusted by incorporating utility functions previously developed by Bai et al. [Bai et al., 2008]. The validity of these utility functions have been also proven by being adapted in various studies.

9.3.1 Selected Physical Condition Performance Measures and Utility Functions

To reflect the physical condition of the FRN to the base price tags, proper physical condition performance measures must be selected for each structure: pavements and bridges. The selected performance measures must have well established utility functions to transform their various units to a unit-less scale for comparison purposes. These utility functions are obtained by developing functions based on the preferences of decision makers and experts through a survey-based approach. This survey-based approach will be conducted in further analysis of this research project to calibrate Texas conditions to the utility functions for more reliable results.

After an exhaustive review, the International Roughness (IRI) for pavements and the Sufficiency Rating (SR) for bridges were selected for this analysis. As mentioned in Chapter 8, IRI is a scale for roughness based on the simulated response of a generic motor vehicle to the roughness in a single wheel path of the road surface. The SR is a performance measure used to characterize bridges' structural adequacy and safety, serviceability and functional obsolescence, and essentiality or traffic service.

The utility functions proposed by Bai et al. are illustrated in Figure 9.3. The utility value of IRI tends to decrease as IRI increases, which means that less rough pavements will have a higher utility value compared to rougher pavements. On the other hand, the utility value of SR increases as SR increases, which indicates that bridges with higher SR will have a higher utility value. It is worth noting that the IRI ranges from zero to infinity and the SR ranges from zero to 100.



$$U = 1.0729e^{-0.000044x^2}$$

$$U = 0.3796 \times \left(\frac{5.54}{1 + e^{0.0216(70-x)}} - 1 \right)$$

Figure 9.3: Utility Functions of IRI and SR [Bai et al., 2008]

9.3.2 FRN Asset Values Adjusted by Physical Condition

Once the utility functions are defined for each performance measure for pavements and bridges, the base price tags of the FRN can be adjusted by Equation 9.2.

$$\boldsymbol{V_{PC,FRN}} = B_{C,\,pav} \cdot U_{PC,\,pav} + B_{C,\,bridge} \cdot U_{PC,\,bridge} \tag{9.2}$$

where:

$V_{PC,FRN}$ = FRN price tag adjusted by physical condition
$B_{C,pav}$ = base price tag (replacement cost) for pavements on FRN
$U_{PC,pav}$ = pavement physical condition utility value
$B_{C,bridges}$ = base price tag (replacement cost) for bridges on FRN
$U_{PC,bridges}$ = bridge physical condition utility value

Table 9.8 and Table 9.9 show the adjusted FRN asset values. Overall, the asset values decreased from the base price tag since the utility values, which are between 0 and 1, were multiplied to those base price tags. The total adjusted price tag of the FRN was approximately \$118 billion: \$80 billion for the pavements and \$37 billion for the bridges. As seen from the result tables, the asset value of the frontage roads dropped by more than 50%, while the asset value of the main lanes decreased by less than 30%. This indicates the main lanes on the FRN have been maintained better than the frontage roads. In addition, it is worth noting that the proportion of the pavements asset value reduced from 73.2% to 68.2%. The result can be interpreted as showing that the physical condition of the bridges on the FRN is better in comparison to that of the pavements.

Table 9.8: Physical Condition Adjustment of FRN Pavements' Base Price Tags

(unit: thousands of 2015 dollars)

Highway System		Base Price Tag	Adjusted Base Price Tag	% Change
IH	Main lanes	62,502,395.0	47,733,970.0	-23.6%
	Frontage roads	24,086,411.9	11,241,207.7	-53.3%
	Sub Total	86,588,806.9	58,975,177.7	-31.9%
US	Main lanes	19,266,432.9	14,456,776.0	-25.0%
	Frontage roads	3,020,206.1	1,322,026.0	-56.2%
	Sub Total	22,286,639.0	15,778,802.0	-29.2%
SH	Main lanes	7,070,686.7	4,995,476.9	-29.4%
	Frontage roads	1,157,922.0	531,920.8	-54.1%
	Sub Total	8,228,608.6	5,527,397.7	-32.8%
Grand Total		117,104,054.6	80,281,377.4	-31.4%

Table 9.9: Physical Condition Adjustment of FRN Bridges' Base Price Tags

(unit: thousands of 2015 dollars)

Functional Classification	Base Price Tag	Adjusted Base Price Tag	% Change
Interstate	28,406,496.7	24,854,377.2	-12.5%
Other Freeway & Expressway	8,413,828.6	7,431,688.5	-11.7%
Other Principal Arterial	3,630,210.7	3,267,207.8	-10.0%
Minor Arterial	657,376.3	426,293.5	-35.2%
Collector	1,232,089.6	1,043,621.6	-15.3%
Major	381,030.7	321,591.7	-15.6%
Minor	3,495.5	2,715.9	-22.3%
Local	97,257.6	81,474.8	-16.2%
Grand Total	42,821,785.5	37,428,970.9	-12.6%

9.4 Summary

Managing freight corridors used for the international trade is important for Texas to maintain and promote its competitiveness and economic growth, and estimating fair asset values for the pavements and the bridges on the freight corridor is essential to enhance effectiveness and efficiency of the management process. This chapter not only addressed missing data in the PMIS database, but also estimated preliminary asset values of the FRN using physical performance measures: IRI for the pavements and SR for the bridges. The results showed the proposed utility-based asset valuation methodology can be successfully applied to assign a price tag to international trade corridors.

Chapter 10. Adjusting the Base Price Tags of the Texas Freight Roadway Network (FRN)

This chapter is the final piece of this research project, and is intended to estimate the final price tag for the FRN by adjusting the base price tags (Chapter 9) according to the utility-based asset valuation method (Chapter 4). In this chapter, several performance measures representing the current status (physical condition, functionality, and overall utilization) of the infrastructure comprising the FRN were selected. Then, the research team reviewed previous studies to adopt developed utility functions for each of the selected performance measures. As the last step, the base price tags are adjusted, and the final price tags will be assigned to the FRN by using the utility functions adopted from other studies. Figure 10.1 illustrates the series of procedures to be performed in order to estimate the final price tag.

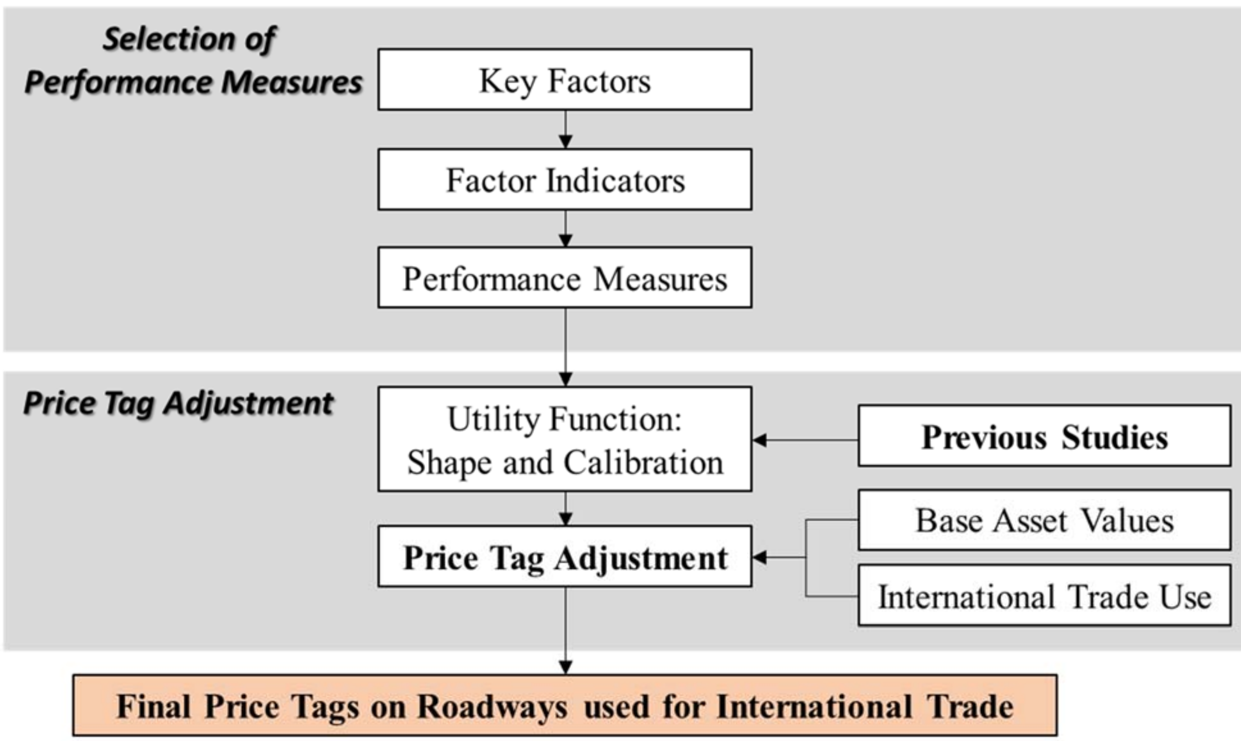


Figure 10.1: Procedures for Estimating the Final Price Tag of the FRN

10.1 Selection of Performance Measures

Transportation agencies, road users, and society as a whole usually assign different price tags to roadways or highway corridors. Agencies usually assign values based on construction and maintenance and rehabilitation (M&R) costs, while users focus on user costs, such as traffic operations, user delays, accidents, and emissions. Moreover, society as a whole values infrastructure based on the impact it brings to the society, economy, and environment, and sometimes even based on the aesthetics. As documented in Chapter 4, the proposed methodological framework assumes that price tag should be the value that can consider all of these aspects.

The first step is identifying factors that affect the value of the FRN. In this research, three key factors were identified as follows: physical condition, functionality, and overall asset utilization.

- **Physical Condition:** Represents the structural and surface condition of a facility. The physical condition factor provides a measure of how well the assets are being maintained.
- **Functionality:** Captures the operational efficiency of the transportation infrastructure and quantifies the quality of service provided by the asset for its intended purpose.
- **Overall asset utilization:** Reflects the relative importance of the asset being valued in terms of its capacity utilization. The overall asset utilization of a facility can then be linked to its contributions to the economic prosperity of a region.

Based on the identified key factors, proper indicators and performance measures that can characterize the effects of the key factors must be selected. As shown in Chapter 4, multiple indicators or performance measures can exist for each factor; however, the selection of the indicators and the performance measures should be performed depending on the objectives and available data within a transportation agency. At least one indicator should be specified for each factor, and the selected indicator(s) should be comprehensive and measurable. Then, performance measures or measures of effectiveness should be specified according to each indicator. Careful attention must be given to the selection, as some indicators or performance measures may possess overlapping characteristics that must be accounted for [Porras-Alvarado et al., 2015]. Table 10.1 presents a list of the indicators under the key factors, along with the performance measures selected and their data sources for this research.

Table 10.1: Key Factors and Associated Performance Measures

Key Factors	Potential Indicators	Structure	Performance Measures	Data Source
Physical Condition	**Structural Capacity & Surface Condition**	Pavements	- Condition Score	- PMIS
		Bridges	- Sufficiency Rating	- BRINSAP
Functionality	**Safety**	Pavements	- Crash Rate (the number of accidents per 100 million VMT)	- Texas Motor Vehicle Crash Statistics
		Bridges	- Bridge Load Inventory Rating (metric ton)	- BRINSAP
	Mobility	Pavements	- Peak-hour Average Speed (mph)	- Estimated
		Bridges	- Detour Length (mi)	- BRINSAP
Overall Asset Utilization	**Direct Factor**	Pavements	- AADT (Annual Average Daily Traffic) - Truck Percentage (%)	- PMIS - BRINSAP
		Bridges		

As indicated in Table 10.1, most of the performance measures can be extracted without any difficulties from the two major databases integrated in Chapter 5: Pavement Management Information System (PMIS) database and Bridge Inventory, Inspection and Appraisal Program (BRINSAP). However, for the rest of the performance measures, such as crash rates and average speeds on pavement sections, additional efforts are required to collect or create the corresponding data. The following sections provide details on this issue.

10.1.2 Crash Rate

Crash rate is defined as the number of traffic accidents per 100 million vehicle-miles traveled (VMT), and this information can be obtained from Texas Crash Records Information System (CRIS), which provides detailed information on each traffic accident that occurred in Texas, including locations, highway conditions, drivers' personal data, etc. TxDOT annually summarizes the data and publicizes Texas Motor Vehicle Crash Statistics [TxDOT, 2016]. Table 10.2 shows Texas statewide traffic crash rates by highway system in 2015.

Table 10.2: Texas Statewide Traffic Crash Rates by Highway System

Highway System	Traffic Crashes per 100 million vehicle miles (Crash rates)	
	Rural	Urban
Interstate	63.31	142.21
US Highway	73.32	187.44
State Highway	91.14	257.38
Farm-to-Market	125.17	284.69

Source: TxDOT, Texas Motor Vehicle Crash Statistics – 2015, 2016

The crash rates in Table 10.2 were adopted for this research. The crash rates were assigned to each pavement segment based on their highway system and functional classification (rural / urban) defined in the PMIS database.

10.1.3 Peak-hour Average Speed

The estimation process of the average speed during peak hours for each roadway segment is twofold: (1) estimation of the peak-hour volume, and (2) estimation of the average speed during the peak hours. Considering that the FRN database developed in Chapter 6 does not provide detailed information on hourly traffic flows, a general method to estimate the peak-hour volume needs to be developed. Since both the PMIS database and the Texas Roadway Inventory provide AADTs on each roadway segment, Equation 10.1 is used to estimate the peak-hour traffic volumes in a similar way to determining the directional peak-hour demand volume (DDHV).

$$v_p = AADT \times D \times PF \quad (10.1)$$

where:

v_p = peak-hour traffic volume
AADT = Annual Average Daily Traffic (AADT)
D = directional distribution factor
PF = peak hour traffic distribution factor

The D factor is set as the typical value indicated in Highway Capacity Manual 2010, which is 0.55 for both urban and rural highways [Transportation Research Board, 2010]. In addition, the peak hour traffic distribution factor is determined as 0.0931 based on the hourly time of day factors utilized in Capital Area Metropolitan Planning Organization 2010 Planning Model [CAMPO, 2015].

Once the peak-hour volumes for roadway segments on the FRN are estimated, the peak-hour average speed can be calculated based on the pre-defined volume-delay relationship, such as the Bureau of Public Roads (BPR) function. Here, a speed estimation model developed by Dresser and Perkinson (2001) is adopted to obtain the peak-hour average speed estimates. Equation 10.2 presents how the speed estimates can be calculated by using their method [Dresser and Perkinson, 2001]. Also, the default values used for the parameters of Equation 10.2 are presented in Table 10.3 and Table 10.4.

$$AS_p = \frac{60}{\frac{60}{FFS} + Min\left[Ae^{B\left(\frac{V}{C}\right)}, M\right]} \qquad (10.2)$$

where:

AS_p = peak-hour average speed
FFS = freeflow speed
V/C = peak-hour directional volume to capacity ratio
A & B = volume-delay equation coefficients
M = maximum minutes of delay per mile

Table 10.3: Freeflow Speeds and Hourly Lane Capacities by Roadway Functional Class

Functional Class	Freeflow Speed (mph)	Hourly Lane Capacity (veh/hr/ln)
Rural Interstate	70	2200
Rural Principal Arterial	55	1003
Rural Minor Arterial	50	920
Rural Major Collector	40	836
Rural Minor Collector	35	669
Rural Local	30	502
Urban Interstate	70	2200
Urban Other Freeway	65	2100
Urban Principal Arterial	40	673
Urban Minor Arterial	35	617
Urban Collector	30	504.5
Urban Local	30	336

Source: Reorganized information from Dresser and Perkinson (2001)

Table 10.4: Volume-Delay Equation Parameters

Facility Category	A	B	M
High Capacity Facilities (>3,400 vehicles per hour)	0.015	2.5	5.0
Low Capacity Facilities (≤3,400 vehilces per hour)	0.050	3.0	10.0

Source: Dresser and Perkinson (2001)

10.2 Utility-based Price Tags of FRN

10.2.1 Determination of Utility Functions

As briefly introduced in Chapter 4, for different types of transportation infrastructure assets, and even for different performance indicators of the same type of infrastructure asset, different performance measures are used to reflect their condition. Generally, these performance measures have dissimilar units, so direct comparison or combination between them cannot be made. For this reason, scaling or normalization techniques should be employed to convert different units to a common scale [Porras-Alvarado et al., 2015]. The utility theory is one of these scaling techniques and is applied in this research to capture the relative importance of transportation infrastructure assets with regards to their performance in the three key factors defined in Table 10.1.

The utility theory uses the utility (or value) functions, which are comprised of utility values, to convert various performance measures with different units to a common scale. The utility values, according to Keeney and Raffia (1993), capture decision maker's preferences regarding levels of attributes and the attitudes towards risk for other attributes at the same time, with the least desired outcome assigned the value zero, and most desired outcome, one. Usually, utility functions are strictly decreasing or increasing. The functional forms and the mathematical formulations are presented in Figure 4.3 and Equations 10.3–10.6 as documented in Chapter 4 [Bai et al., 2008].

Exponential:

$$U(x) = ke^{-ax}, k > 0, a > 0 \quad \text{(Decreasing utility)} \tag{10.3}$$

$$U(x) = k(1 - e^{-ax}), k > 0, a > 0 \text{ (Increasing utility)} \tag{10.4}$$

Sigmoidal (S-shaped):

$$U(x) = ke^{-ax^2}, k > 0, a > 0 \quad \text{(Decreasing utility)} \tag{10.5}$$

$$U(x) = k\left(1- e^{-ax^2}\right), k > 0, a > 0 \text{ (Increasing utility)} \tag{10.6}$$

where:
k and a = Calibration parameters

The calibration parameters, *a* and *k*, should be estimated in a way that can properly reflect the preference structure of the decision makers towards each performance measure. Several methods were proposed by Keeney and Raffia (1993) to support decision makers in developing utility functions and calibrating their corresponding parameters: Direct Rating, Midvalue Splitting

Technique, Direct Questioning Approach, and Certainty Equivalent Approach. The first two methods are applicable under certainty scenarios, while the others are for risk scenarios [Keeney and Raffia, 1993].

Utility Functions Adopted from Previous Studies

As briefly mentioned in the previous section, a survey of transportation asset management experts should be developed and conducted to assess their preference towards the selected performance measures to obtain complete utility functions. However, conducting a survey is not often a viable option in many studies due to several difficulties, such as time and budget constraints. In this case, the research can use various utility functions developed in other previous studies. For instance, Bai et al. (2008) summarized and listed utility functions developed by Li and Sinha (2004) and Patidar et al. (2007). The report contains a total of 47 utility functions for transportation infrastructure related performance measures in its appendix, and the functions are categorized into six groups: system preservation, user cost, mobility, safety, environment, and protection from extreme events. In addition, Porras-Alvarado et al. (2015) developed and calibrated seven utility functions based on Bai et al. (2008) and Stone (2014). The utility functions for the selected performance measures (Table 10.1) in this research were adopted from these studies, and they are shown in Table 10.5.

Table 10.5: Selected Performance Measures and Utility Functions

Key Factors	Potential Indicators	Structure	Performance Measures	Utility Function	Source
Physical Condition	**Structural Capacity & Surface Condition**	Pavements	- Condition Score	$U_{CS} = 1.01 \times \left[1 - e^{(-0.0004 \times CS^2)}\right]$	- Porras-Alvarado et al. (2015)
		Bridges	- Sufficiency Rating	$U_{SR} = 0.3796 \times \left[\frac{5.54}{1 + e^{\{0.0216 \times (70 - SR)\}}} - 1\right]$	- Bai et al. (2008)
Functionality	**Safety**	Pavements	- Crash Rate (the number of accidents per 100 million VMT)	$U_{CR} = e^{(-0.0088 \times CR)}$	- Porras-Alvarado et al. (2015)
		Bridges	- Bridge Load Inventory Rating (metric ton)	$U_{IR} = 1 - e^{(-0.0404 \times IR^2)}$	- Bai et al. (2008)
	Mobility	Pavements	- Peak-hour Average Speed (mph)	$U_{AS} = 1.0425 \times \left[1 - e^{(-0.0005 \times AS^2)}\right]$	- Bai et al. (2008)
		Bridges	- Detour Length (mi)	$U_{DL} = e^{(-0.2045 \times DL)}$	- Bai et al. (2008)
Overall Asset Utilization	**Direct Factor**	Pavements	- AADT (Annual Average Daily Traffic) - Truck Percentage (%)	$U_{AADT} = 1 - e^{-0.000023 \times AADT}$ $U_{TP} = 1 - e^{(-0.055 \times TP^2)}$	- Porras-Alvarado et al. (2015)

10.2.2 Amalgamation of Utility Values

Once the utility functions are prepared, mathematical procedures are required to combine the individual utility values for the performance measures to obtain the overall utility values for each of the three key factors to adjust the base price tags for the FRN. This process is referred to as amalgamation [Bai et al., 2008], and Multi-attribute utility method is used to capture this multi-dimensional utility.

The weighted sum method and the weighted product method are two of the most frequently used methods for amalgamation. The formulations for the two methods are presented in Equation 10.7 and Equation 10.8 respectively.

$$U(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} k_i U_i(x_i) \tag{10.7}$$

where:

x_i = i^{th} performance measure for each indicator
$U_i(x_i)$ = utility function of the i^{th} performance measure
$0 \leq U(x_1, x_2, \ldots, x_n) \leq 1$
k_i = the weight of the i^{th} performance measure

$$U(x_1, x_2, \ldots, x_n) = \frac{1}{k} * \left(\prod_{i=1}^{n} [1 + k k_i U_i(x_i)] - 1 \right) \tag{10.8}$$

where:

x_i = i^{th} performance measure for each indicator
$U_i(x_i)$ = utility function of the i^{th} performance measure
$0 \leq U(x_1, x_2, \ldots, x_n) \leq 1$
k_i = the weight of the i^{th} performance measure
k = scaling constant that is calculated solving $1+k = \prod_{1=1}^{n}(1+kk_i)$

In this research, the weighted sum method is adopted because of its simplicity. The weight of the i^{th} performance measure, k_i, can be determined based on the result of a survey of the decision makers using direct rating method as shown in Equation 10.9.

$$\boldsymbol{k_i = \frac{IP_i}{\sum_{j=1}^{n} IP_j}} \quad \textbf{and} \quad \boldsymbol{\sum_{i=1}^{n} k_i = 1} \tag{10.9}$$

where:

IP_i = the importance (rating points on a certain point scale) of the i^{th} performance measure among the other performance measures selected for a key factor
n = the total number of performance measures selected for a key factor

However, in this project, all the performance measures are assigned the same weights, and the sum of weights is set to 1, because the survey could not be conducted. Hence, the weight of the i^{th} performance measure, k_i, can now be determined as below.

$$\boldsymbol{k_i = \frac{1}{n} \ \text{ and } \ \sum_{i=1}^{n} k_i = 1} \tag{10.10}$$

where:

n = the total number of performance measures selected for a key factor

The equal weighting method does not require any survey so that it can be implemented with ease in comparison to other weighting methods. Nevertheless, given that it does not reflect the different importance among the different performance measures, it is better to use this method only in situation where there is no information about the weights of the performance measures or it is unable to conduct the survey [Bai et al., 2008].

10.2.3 Utility-adjusted Price Tag

The utility-adjusted price tag can be obtained by multiplying the estimated base price tags (Chapter 9) to the amalgamated utility values computed in the previous steps. The general structure of the valuation function is described as Equation 10.11.

$$V_{FRN} = B_C \cdot U_{PC} \left(1 + U_{Fun} + U_{Util}\right) + SV \tag{10.11}$$

where:

V_{FRN} = FRN utility-adjusted Price Tag
B_C = FRN base price tag
U_{PC} = utility value for physical condition
U_{Fun} = utility value for functionality
U_{Util} = utility value for overall asset utilization
SV = highway infrastructure salvage value

According to Equation 10.11, the price tag adjustment process can be divided into two steps: physical condition adjustment and functionality/utilization adjustment. First, the base price tag is directly multiplied to the utility value for physical condition to reflect the "as-is" asset condition. By doing so, the salvage value is the only element that comprises the price tag when the physical condition of the FRN is deteriorated to such a level that it can no longer support any service, since the utility value for physical condition will be zero. On the other hand, the role of utility values for functionality and overall utilization is to capture the effects of the asset's functionality and utilization in the asset value by increasing the asset value adjusted by physical condition, which has been overlooked in other existing valuation methodologies [Porras-Alvarado et al., 2015].

However, the configuration can vary since it is highly dependent on how analysts define the relationships among the key factors. Depending on the definition, the utility values of each key factor may be related to one another in multiplication or summation, or in a combination of multiplication and summation. Table 10.6 illustrates two examples of the configurations that combine the utility values for this research, based on the concept of defining reliability of systems.

The *w* factor is introduced to increase or decrease the relative weight of functionality or overall asset use, if desired.

This research adopted the first introduced configuration in Table 10.6, and the final valuation functions with the *w* factors set as 1 are presented below with more detailed information.

$$V_{FRN} = V_{FRN,pav} + V_{FRN,brid} \tag{10.12}$$

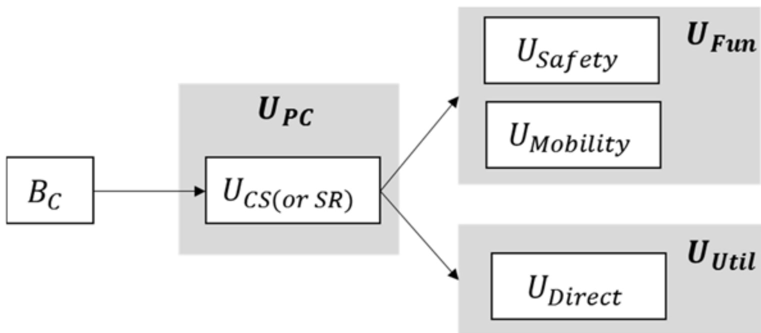
$$V_{FRN,pav} = \sum_{\forall Pavements} B_{C,pav} \cdot U_{CS} \left[1 + (0.5U_{CR} + 0.5U_{AS}) + (0.5U_{AADT}^{pav} + 0.5U_{TP}^{pav})\right] + SV_{pav} \tag{10.13}$$

$$V_{FRN,brid} = \sum_{\forall Bridges} B_{C,brid} \cdot U_{SR} \left[1 + (0.5U_{IR} + 0.5U_{DL}) + (0.5U_{AADT}^{brid} + 0.5U_{TP}^{brid})\right] + SV_{brid} \tag{10.14}$$

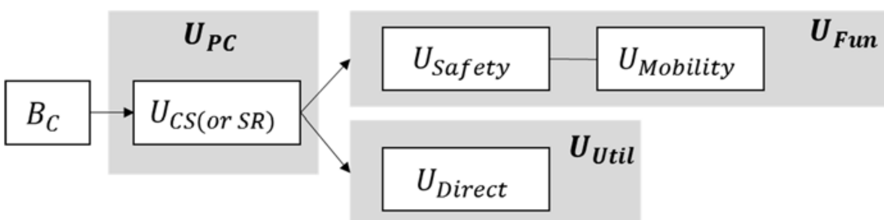
where:

V_{FRN}	= FRN utility-adjusted price tag
$V_{FRN,pav}$	= utility-adjusted price tag for pavements on FRN
$V_{FRN,brid}$	= utility-adjusted price tag for bridges on FRN
$B_{C,pav}$	= base price tag (replacement cost) for pavements on FRN
U_{CS}	= utility value for condition score
U_{CR}	= utility value for crash rate
U_{AS}	= utility value for condition score
U_{AADT}^{pav}	= utility value for AADT (pavements)
U_{TP}^{pav}	= utility value for truck percentage (pavements)
SV_{pav}	= salvage value for pavements on FRN (15% of its replacement cost)
$B_{C,bridges}$	= base price tag (replacement cost) for bridges on FRN
U_{SR}	= utility value for sufficiency rating
U_{IR}	= utility value for bridge load inventory rating
U_{DL}	= utility value for detour length
U_{AADT}^{brid}	= utility value for AADT (bridges)
U_{TP}^{brid}	= utility value for truck percentage (bridges)
SV_{brid}	= salvage value for bridges on FRN (15% of its replacement cost)

Table 10.6: Examples of Key Factor Configurations for Price Tag Adjustment

<table>
<tr><th>#</th><th>Configurations</th><th>Equation</th></tr>
<tr><td>1</td><td>


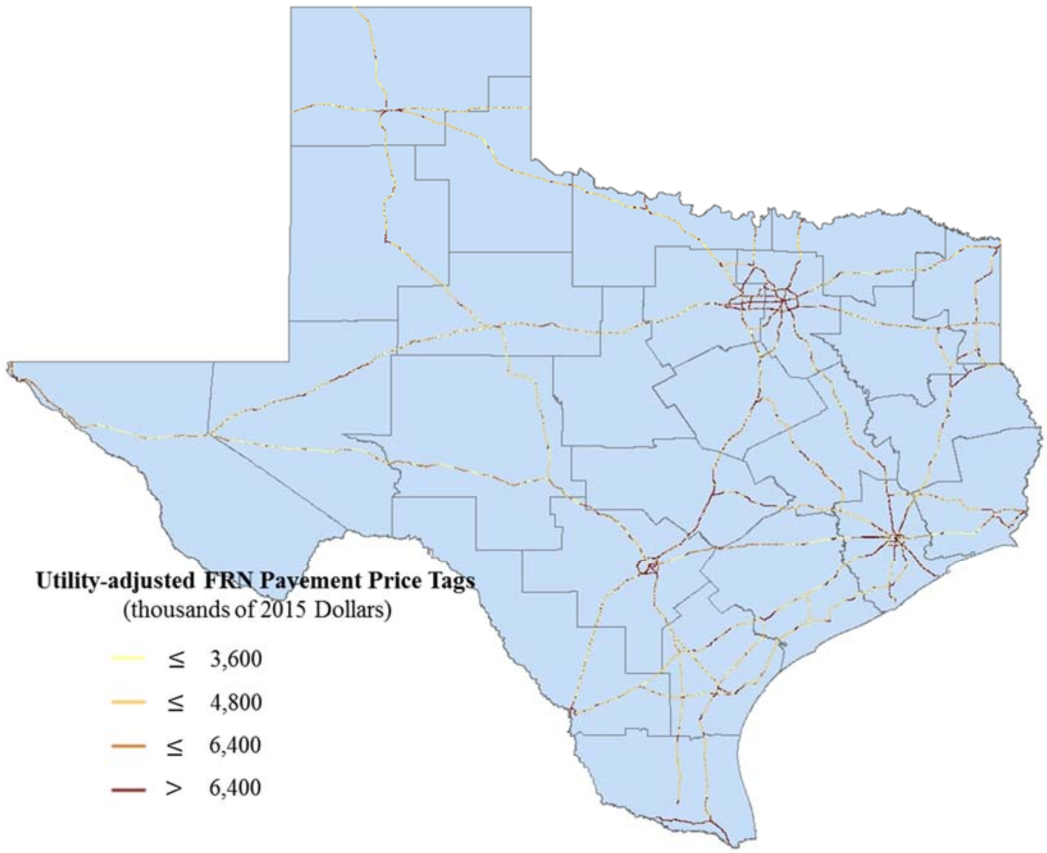
</td><td>
$V = B_C \cdot U_{PC}\,(1 + w_{Fun}U_{Fun} + w_{Util}U_{Util}) + SV$
$= B_C \cdot U_{PC}\left(1 + w_{Fun}(U_{Safety} + U_{Mobility}) + w_{Util}U_{Util}\right) + SV$

where:
$U_{PC}, U_{Fun}, U_{Util} \leq 1$
SV = salvage value
w = factor to increase importance
</td></tr>
<tr><td>2</td><td>


</td><td>
$V = B_C \cdot U_{PC}\,(1 + w_{Fun}U_{Fun} + w_{Util}U_{Util}) + SV$
$= B_C \cdot U_{PC}\left(1 + w_{Fun}(U_{Safety} \times U_{Mobility}) + w_{Util}U_{Util}\right) + SV$

where:
$U_{PC}, U_{Fun}, U_{Util} \leq 1$
SV = salvage value
w = factor to increase importance
</td></tr>
</table>

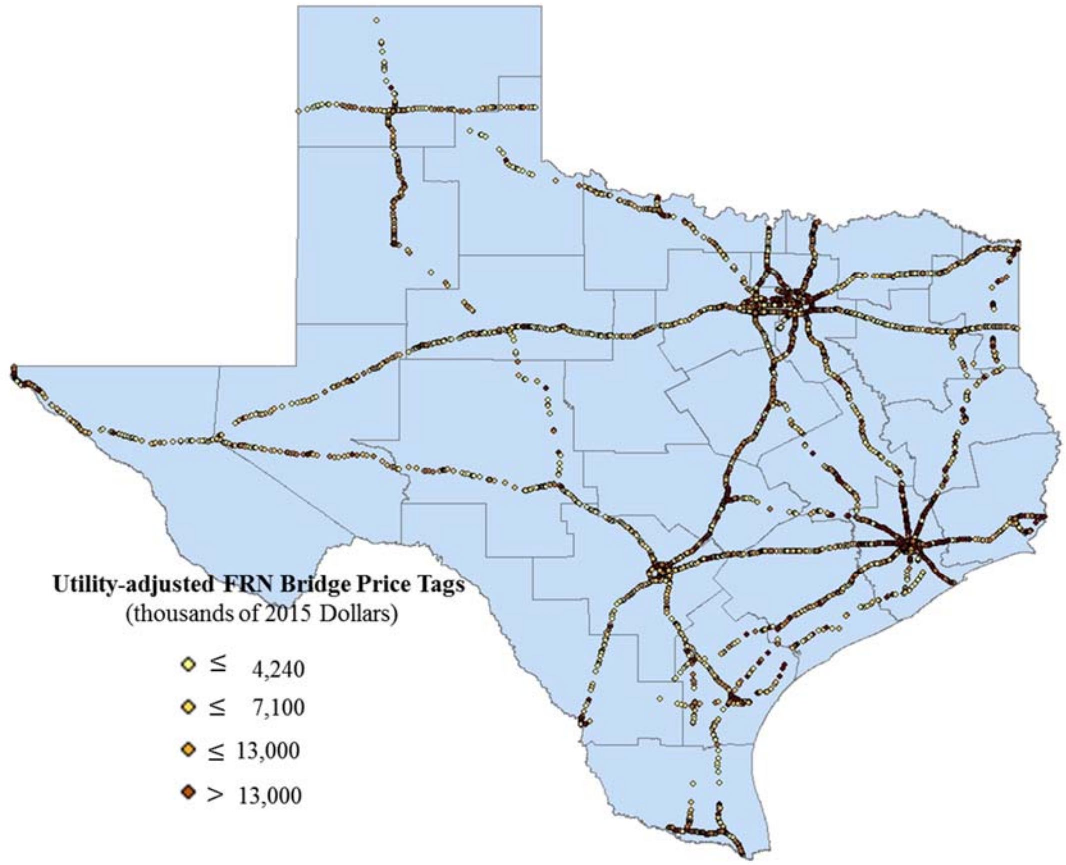
As the result, the utility-adjusted price tags using the aforementioned formulations for pavements and bridges on the FRN are presented in Figure 10.2 and Figure 10.3 respectively. The total utility-adjusted price tag of the FRN was estimated at approximately $366 billion: $252 billion for the pavements and $114 billion for the bridges. The pavement structure comprised 68.9% of the total asset value, while the bridges represented 31.1%. In addition, the Interstate Highway system, including bridges on the system, accounted for 72.8% of the total FRN price tag.



(unit: thousands of 2015 dollars)

Highway System		Base Price Tag	Utility-adjusted Price Tag	% Change
IH	Main lanes	62,502,395.0	149,448,203.4	139.1%
	Frontage roads	24,086,411.9	40,527,028.4	68.3%
	Sub Total	*86,588,806.9*	*189,975,231.8*	*119.4%*
US	Main lanes	19,266,432.9	40,806,309.1	111.8%
	Frontage roads	3,020,206.1	4,861,596.4	61.0%
	Sub Total	*22,286,639.0*	*45,667,905.5*	*104.9%*
SH	Main lanes	7,070,686.7	15,028,386.9	112.5%
	Frontage roads	1,157,922.0	1,800,141.1	55.5%
	Sub Total	*8,228,608.6*	*16,828,528.0*	*104.5%*
Grand Total		117,104,054.6	252,471,665.3	115.6%

Figure 10.2: Utility-adjusted Price Tags of FRN Pavement Structures



(unit: thousands of 2015 dollars)

Functional Classification	Base Price Tag	Utility-adjusted Price Tag	% Change
Interstate	28,406,496.6	76,922,015.2	170.8%
Other Freeway & Expressway	8,413,828.5	22,668,619.1	169.4%
Other Principal Arterial	3,630,210.7	9,049,123.0	149.3%
Minor Arterial	657,376.3	1,491,193.7	126.8%
Collector	1,232,089.6	2,783,432.1	125.9%
Major	381,030.7	814,127.6	113.7%
Minor	3,495.5	7,905.3	126.2%
Local	97,257.6	205,037.9	110.8%
Total	*42,821,785.5*	*113,941,453.9*	*166.1%*

Figure 10.3: Utility-adjusted Price Tags of FRN Bridge Structures

It is worth noting that the utility-adjusted price tag of the FRN is much larger than its base price tag; the base price tag of the FRN was estimated at \$160 billion, whereas the utility-adjusted price tag was \$366 billion. The base price tag, which is basically the replacement cost of the FRN, does not capture the functionality and the utilization of the FRN, and thus can underestimate the value of the FRN. On the other hand, as shown in Equation 10.12–10.14, the functionality and the utilization aspects of the FRN are captured in the utility-based price tag by amplifying the base price tag based on various performance measures scaled by the utility functions. Hence, the 129%

increase in the price tag can be interpreted as additional benefit from the functionality and the use of the FRN, and this difference could become an important input for the management of the FRN.

10.3 Price Tag Adjustment for International Trade Use

The utility-adjusted price tag in the previous section provides a quantification of the asset value of the pavements and the bridges on the FRN, as adjusted for physical condition, functionality, and overall asset utilization. However, considering that these assets comprise the FRN that specifically serves international freight transportation, it would be better if the proposed methodological framework was also capable of adjusting the utility-adjusted price tag for international trade use of transportation infrastructure. In order to perform the adjustment, information about international freight movement on Texas roadways needs to be identified and collected. Then, a methodology that adjusts the utility-based price tags is discussed.

10.3.1 Data Sources for International Trade on Texas Roadways

Identifying the amount of freight flows for international trade on Texas corridors is an essential step to adjusting the utility-based price tags of the FRN for its international trade use. However, it is not an easy task due to the lack of available data specifically designed to contain the freight movements for international trade only. The research team has reviewed potential data sources in order to gather information on how heavily each freight corridor in Texas is utilized for international trade. This section presents a summary of the gathered information.

First of all, the Freight Analysis Framework (FAF) is considered to be a potential source of international freight movements on Texas roadways. The FAF integrates data from various sources, such as Commodity Flow Survey (CFS) and international trade data from the Census Bureau, to create a comprehensive picture of freight movement among states and major metropolitan areas. It provides truck flows assigned to the U.S. highway networks, as well as estimates for tonnage and value by regions, commodity type, and mode. The latest version, which is version 4, was released through 2015 and 2016. However, its highway assignment result only contains the total amount of freight flow on each highway section, but not the international freight flow separated from the total flow.

Next, *Texas International Trade Corridor Plan* is another potential data sources for international freight movements in Texas. The most recent available report is Bujanda and Villa (2012). They assigned the international freight flows (in tons) by truck on Texas International Trade Corridors by using data from the Federal Highway Administration's (FHWA) FAF version 3. Bujanda and Villa (2012) includes valuable information for identifying the international freight movements on Texas roadways; however, it presents the estimates for the international freight tonnage carried only for several major highway corridors in Texas. Figure 10.4 illustrates their estimated international trade tons by truck in 2011, even though the exact tonnage is not provided in detail.

Source: Bujanda and Villa (2012)

Figure 10.4: International Trade Tons by Truck 2011

Finally, another data source identified is the *IHS Global Insight TranSearch* database. It contains data for predicting US freight flows over 30 years by origin, destination, commodity, and transportation mode [IHS, 2016]. The database provides information on the freight flows at the national and state level. It also provides information on the business economic area and county levels within the U.S., including transportation demand by commodity and location. Data provided by TranSearch includes i) outbound, inbound, intra, and through shipments by geography, ii) geographies including 172 BEAs, iii) over 3,000 counties, iv) routed volumes along individual trade lanes or corridors, v) tonnage, value, and units of shipment, vi) seven major transportation modes, including truck, rail, waterborne, and air, vii) over 340 commodities, and viii) cross-border flows to and from Canada and Mexico. However, access to the database is limited since it is commercially available.

10.3.2 International Trade Proportion

As stated in the previous section, the availability of the data sources for international trade flows on Texas roadways is limited. For example, the access to the IHS Global Insight TranSearch database was not granted for the research team. In addition, Bujanda and Villa (2012) contains international freight volumes on the 27 top-ranked (by the volumes) highway corridors only. Due to the limited availability of the data sources, Bujanda and Villa (2012) is the only data source available to the research team at this point in time, and the research team was only able to collect complete international freight flows for four of the major Interstate Highways on the FRN: IH10, IH20, IH30, and IH35. The further analyses will be performed for these Interstate Highways only.

To analyze how heavily those Interstate Highways in Texas are utilized for international trade, it is imperative to identify the total freight volumes, as well as the international freight volumes moved on the highways. This is because a highway is more likely to have more international freight as the total amount of freight moved increases; therefore, using the international freight volume as a sole measure to determine how heavily each highway is used for international trade could distort what the research team is trying to achieve. As briefly mentioned in the previous section, the Federal Highway Administration (FHWA) Freight Analysis Framework (FAF) provides the total freight volumes on the highways. Recently, the FHWA has released its network database with the freight flow assignment results for the FAF version 4. The flow assignment data contains the total freight flows estimated for the years of 2012 and 2045. Based on the two data sources, the research team defined the International Trade Proportion (ITP) as a measure for the international trade use of the highways on the FRN.

$$ITP_{str} = {}^{IF_{Vol}}/_{TF_{Vol}} \tag{10.15}$$

where:
ITP_{str} = International Trade Proportion for a structure (pavement or bridge)
IF_{Vol} = international freight volume estimated for 2011 (Bujanda and Villa [2012])
TF_{Vol} = total freight volume estimated for 2012 (FAF version 4)

It is worth noting that there is a discrepancy in the time points for the estimates of the international freight volumes and the total freight volumes. It would be better if both estimates (the international freight volume and the total freight volume) can be adjusted for the same year; however, this could not be performed because of the data availability. Considering that the time points are close enough, it should provide fairly good estimates for the ITP. Figure 10.5 illustrates the calculated ITPs for the four Interstate Highways on the FRN.

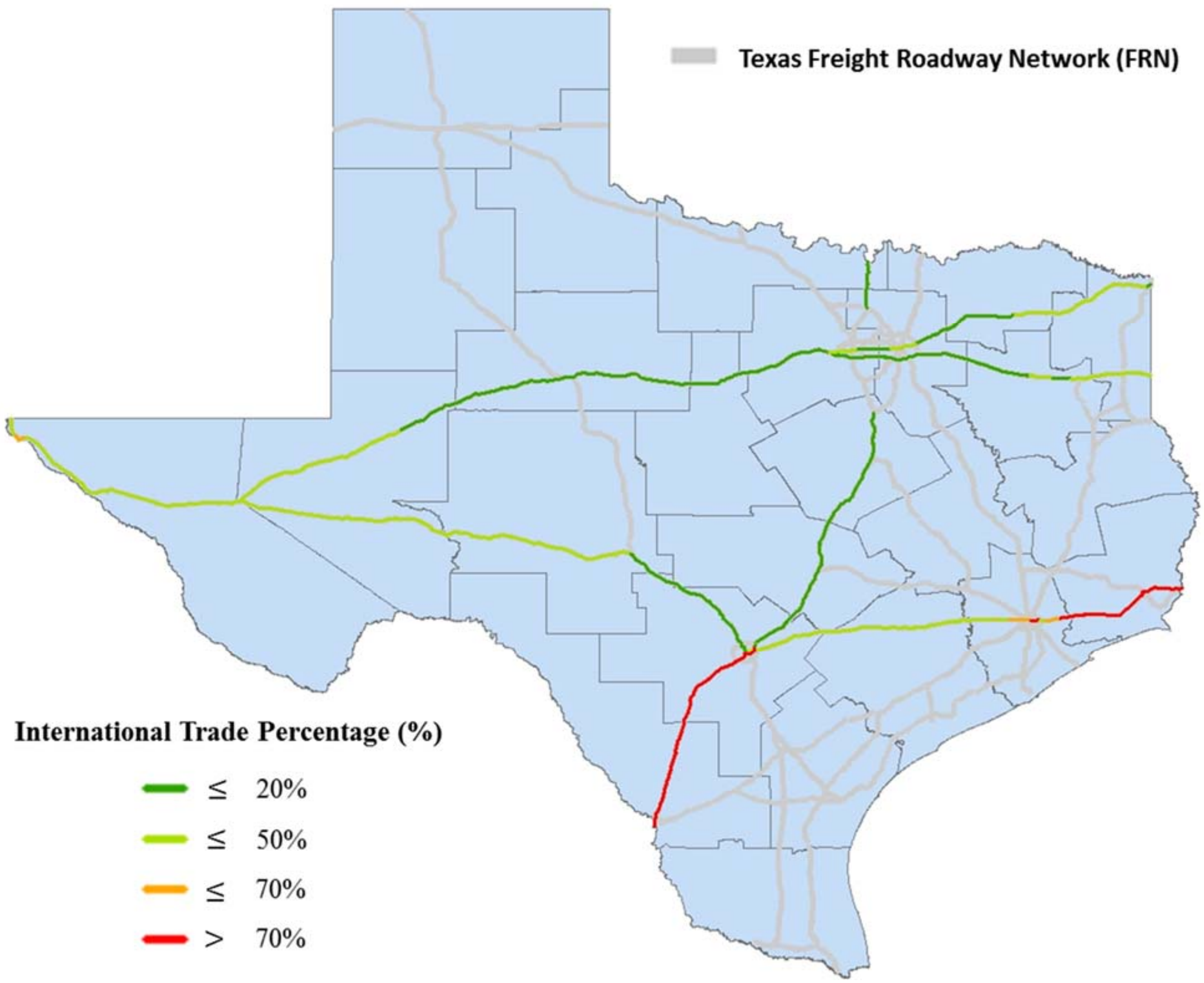


Figure 10.5: International Trade Proportions for corridors on the FRN (IH10, IH20, IH30, and IH35)

10.3.3 Price Tags Adjustment for International Trade

With the ITP obtained in the previous section, the utility-based price tags estimated (in Section 10.3) for the four Interstate Highways (IH10, IH20, IH30, and IH35) are then adjusted by the following structures presented in Equations 10.16–10.18. The reasoning behind these structures is that the price tags of corridors heavily used for international trade purposes should be higher than the ones of other corridors not serving international trade.

$$V_{cor}^{IT} = V_{cor,pav}^{IT} + V_{cor,brid}^{IT} \tag{10.16}$$

$$V_{cor,pav}^{IT} = V_{cor,ml} \times (1 + ITP) + V_{cor,fr} \tag{10.17}$$

$$V_{cor,brid}^{IT} = V_{cor,brid} \times (1 + ITP) \tag{10.18}$$

where:

V_{cor}^{IT} = adjusted price tag of a corrdor for intenational trade

$V_{cor,pav}^{IT}$ = adjusted price tag of pavement structures on a corridor for international trade

$V^{IT}_{cor,brid}$ = adjusted price tag of bridge structures on a corridor for international trade
$V_{cor,ml}$ = utility-adjusted price tag of mainlanes on a corridor
$V_{cor,fr}$ = utility-adjusted price tag of frontage roads on a corridor
$V_{cor,brid}$ = utility-adjusted price tag of bridge structures on a corridor
ITP = International Trade Proportion (ITP)

Note that the price tag adjustment for the pavement structures is only performed for mainlanes. This is because not only do the databases used to identify the freight volumes on the highways not provide detailed information for the frontage roads, but also trucks carrying the international freight are less likely to use the frontage roads instead of the mainlanes. As a result, the international trade-adjusted price tags of the corridors are estimated at $83 billion, $40 billion, $23 billion, and $49 billion for IH10, IH20, IH30, and IH35 respectively. Overall, there is 29.1% increase in the total price tag; however, the changes vary with the corridors. For instance, the price tag of IH10 increased by 43.3% after the adjustment, while there is only 10% increase in the one of IH10. The difference in price tags originated from the difference in the International Trade Proportions (ITP) between two corridors: 42.1% for IH10 and 14.0% for IH20 on average.

Table 10.7: ITP-adjusted Price Tags for Corridors on the FRN (IH10, IH20, IH30, & IH35)

(unit: thousands of 2015 Dollars)

Category		Utility-adjusted Price Tag	International Trade-adjusted Price Tag	% Change
IH10	Pavements	38,508,579.0	53,182,673.4	38.1%
	Bridges	19,479,682.4	29,915,956.9	53.6%
	Sub Total	*57,988,261.4*	*83,098,630.3*	*43.3%*
IH20	Pavements	28,642,125.5	31,426,836.2	9.7%
	Bridges	7,851,160.3	8,700,632.2	10.8%
	Sub Total	*36,493,285.7*	*40,127,468.4*	*10.0%*
IH30	Pavements	11,774,235.1	13,980,841.0	18.7%
	Bridges	7,182,697.9	9,050,620.6	26.0%
	Sub Total	*18,956,933.0*	*23,031,461.6*	*21.5%*
IH35	Pavements	26,631,986.7	33,845,595.5	27.1%
	Bridges	11,052,253.5	14,991,053.0	35.6%
	Sub Total	*37,684,240.2*	*48,836,648.5*	*29.6%*
Total		151,122,720.4	195,094,208.8	29.1%

10.4 Summary

In this chapter, a set of performance measures that represent various aspects of the FRN was defined, and the corresponding utility functions for each of the performance measures were identified and adopted from other studies. In addition, more detailed information on the methodology to estimate the utility-adjusted price tags of the FRN was provided with its estimation results. The results indicate the proposed utility-based asset valuation methodology was successfully applied to assign price tags to the FRN, and it was pointed out that failure to include the functionality and the utilization aspects of transportation assets can result in distorting their true values.

Chapter 11. Conclusion

Texas pays the bills of construction and maintenance of the infrastructure to move the freight which benefits other parts of the country. There has been a need to develop a methodological process which can be used to put "price tags" on international trade use of Texas' transportation infrastructure, which is critical to maintain freight corridors with high condition standards effectively. As one of the research studies initiated to aid TxDOT in addressing this emerging issue, Project No. 0-6844, *Putting a Price Tag on International Trade Use of State Infrastructure*, was initiated on January 1, 2015.

The objective of this project is to propose a utility-based asset valuation methodological framework that can incorporate various aspects of transportation assets, and assign reasonable price tags to the Texas international trade highway corridors. Throughout the 24-month duration of the project, the research team successfully conducted following procedures to apply the proposed methodology:

(1) Extensive literature review on existing transportation asset valuation techniques and practices,

(2) Workshop with Subject Matter Expert Working Group (SMEWG),

(3) Identification of highway freight corridors in Texas (referred as Texas Freight Roadway Network (FRN)),

(4) Data collection and processing,

(5) Development of highway construction/maintenance costs estimation methodologies, and

(6) Estimation of a price tag for the FRN by using the proposed utility-based asset valuation approach.

The developed valuation approach adopted the utility theory in order to capture several factors that can affect the FRN: physical condition, functionality, and utilization. Various performance measures in different units could be successfully scaled and amalgamated together by using the utility functions developed in other studies. However, more reliable results can be expected if the utility functions are further studied and calibrated based on a survey of transportation asset management experts from TxDOT.

As the result, a price tag was assigned to the FRN, and it turned out to be significantly different than its replacement cost, which is one of most frequently used asset valuation techniques to estimate the value of transportation assets. In the case of this study, the price tag was estimated at $366 billion while the base price tag (replacement cost) was $160 billion. The 129% increase in the price tag can be interpreted as additional benefit from the functionality and the use of the FRN. The difference indicates that failure to include the functionality and the utilization aspects of transportation assets can result in distorting their true values, by underestimating or overestimating the values.

The research findings of this project will play an important role in maintaining Texas' highway freight corridors in a more effective and efficient way. The discovery can not only assist TxDOT in optimizing their resource allocation procedures for better coordination of asset investment for the highway freight corridors, but can also serve as a link between TxDOT's goals on freight transportation and its performance. With the methodology developed in this research, TxDOT will be able to be prepared for the potential trade growth and to communicate their decisions to policy makers, so that the necessary funds can be obtained to retain Texas' economic competitiveness.

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Appendix A. Workshop Materials

CTR Presentation

Research Team

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Juan Diego Porras

Srijith Balakrishnan

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Agenda

- **Part I – Project Introduction**
  - Project Motivation & Objective
  - Task 2 Workshop Objectives
  - Q&A and Discussion
- **Part II – Up-To-Date Summary**
  - Summary of Tasks Completed
  - Future Steps
  - Q&A and Discussion

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Part I

Project Introduction

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Motivation

- The trucking industry continues to dominate the freight transportation industry:
  - 67% of total tonnage
  - 81% of revenue
- In Texas:
  - Trucks move more than 46% of all freight.
  - In 2013, 85% of the trade with Mexico and 73% of the Texan manufactured goods were transported by trucks.

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Motivation

- Since 2005, Texas ranks first in exports revenues, which represents 17.8 percent ($289 billion) of the total exports in U.S. in 2014.
- Texas has increased their exports to the BRIC countries (Brazil, Russia, India, and China) and African nations.
- These trends are expected to increase in the next few years, specially due to Panama Canal Expansion.

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Motivation

- For these reasons, it is imperative for Texas transportation authorities to maintain roadway freight corridors at acceptable condition levels to sustain the freight movement efficiency in Texas.

0-6844
Putting a Price Tag on International Trade Use of State Infrastructure

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Research Objective

- Develop an **utility-based** methodological framework for assigning **price tags** to freight corridors in order to maintain them at acceptable condition levels, preparing Texas to keep its economic competiveness for potential growth in trades.

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Research Benefits

- Keep freight corridor infrastructure within acceptable levels or service; and
- Assist decision making at various levels, including legislature, administration and management, and engineering.

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Task 2: Workshop Objectives

- Present findings from literature review
- Develop a list of potential information needed to develop a framework
- Present a preliminary list of issues that are considered important to estimating the price tag
- Getting insight from the agency for fine-tune the objectives and scope of this research

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Workshop Objective #1

Present findings from literature review

- Price Tags in TAM
- Price Tags vs. Costs
- Asset Valuation Overview
- Asset Valuation Methodology
- Limitations

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Price Tags in TAM

- **Input parameter** into the TAM practices, with the following objectives:
  - The service life of assets is extended;
  - Their value is preserved at minimum;
  - Agencies are held accountable for their expenditures;
  - Justification of funding needs can be clearly stated; and
  - Stakeholders are satisfied with the quality of transportation services received.

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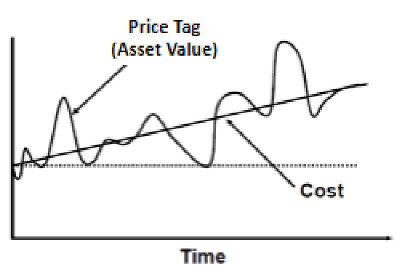
Price Tags vs. Cost



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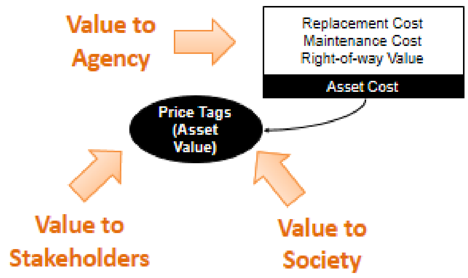
Price Tags vs. Costs



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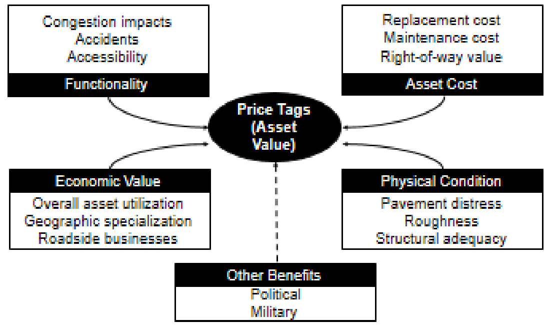
Price Tags vs. Costs



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Asset Valuation Overview

- **Asset valuation** gained importance in the late 1990s after the Governmental Accounting Standards Board **(GASB34)** issued new reporting requirements:
  - Provide the value of the infrastructure assets being managed by state and local governments
  - Incorporate business practices to enhance public accountability

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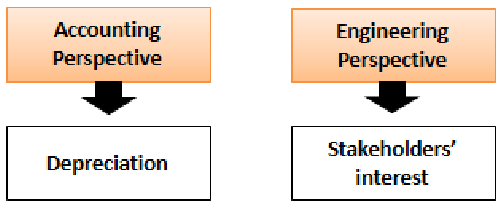
Asset Valuation Overview

- **Methodologies:**



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Asset Valuation Overview

Stakeholders	Measure or Indicators of Value
Users – General Public	Mobility/accessibility, safety, durability, environmental quality, functional obsolescence
Financiers/Owners	Accountability and fiscal health of transportation agencies
Engineering and Construction Professionals	User objectives, infrastructure improvement opportunities
System Managers – Operation and Maintenance	Economic efficiency, user objectives
Investment Decisions/Policy Makers	Overall condition and level of service of the system
Community – General Public	Physical functionality, economic impact, environmental impact, social impact
Marginal Populations	Equity in benefits and burdens of transportation

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Asset Valuation Methodologies

- Book Value
- Replacement Cost
- Written Down Replacement Cost
- Market Value
- Productivity Realized Value

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Asset Valuation Limitations

- Yield significantly different values for a given asset, highway, or corridor
- Primarily based on historical cost information and current physical conditions, ***giving no consideration to the functional characteristics and the level of utilization of the infrastructure***

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Workshop Objective #2

Develop a list of potential information needed to develop a framework

- Performance Data
- Cost Information Data
- International Freight Transportation Data
- Missing Data

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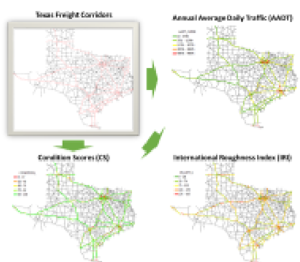
Performance Data

- **PMIS**
  - Road Inventory Data
  - Physical Condition Data
  - Traffic Data



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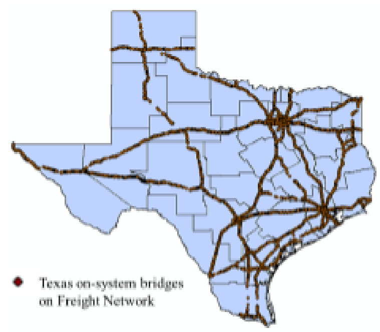
Performance Data

- **BRINSAP**
  - Bridge Inventory Data
  - Physical Condition Data



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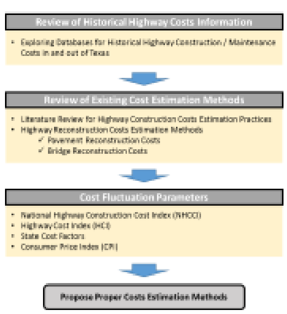
Cost Information Data

- Determination of Base Asset Value



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International Freight Transportation

- **Potential Data Sources #1**
  - Freight Analysis Framework (FAF)
    - Based on Commodity Flow Survey (CFS)
    - Provides truck flows assigned to the highway network
    - Does not provide truck flows for international trade separately
    - Assignment results of the FAF Version 4 has not been released

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International Freight Transportation

- **Potential Data Sources #2**
  - 2012 International Trade Corridor Plan
    - Assigned international freight on Texas International Trade Corridors
    - Could not obtain the freight assignment database

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International Freight Transportation

- **Potential Data Sources #3**
  - IHS Global Insight TranSearch Database
    - Commercially available
    - May contain useful data for international trade in Texas
    - TxDOT has purchased the database

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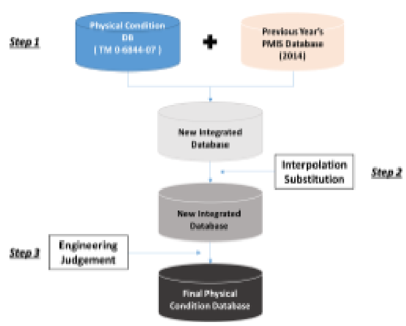
Missing Data



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Workshop Objective #3

Present a preliminary list of issues that are considered important to estimating the price tag

- Asset Valuation: Current Trends
- Utility-based Approach
- Selection of Performance Measures
- Calibration of Utility Functions

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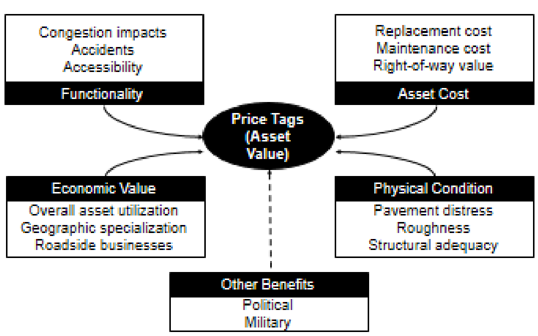
Asset Valuation: Current Trends



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Utility-based Approach

- Asset replacement cost is set as the base value.
- Additional value is then added to the base value by considering three key factors: physical condition, functionality, and utilization.
- Each factor is characterized by appropriate indicators that can be quantified with specific performance measures.
- The utility theory is applied to combine the effect of performance indicators of varying measures and scales on the value of an asset.

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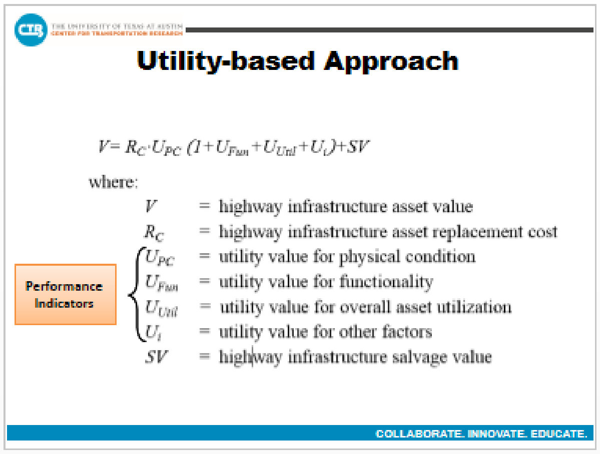

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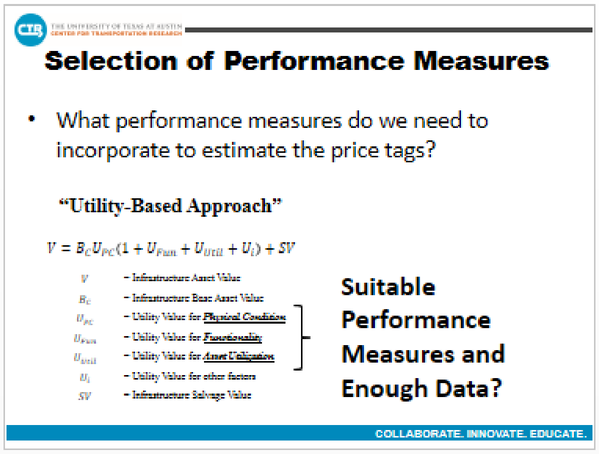

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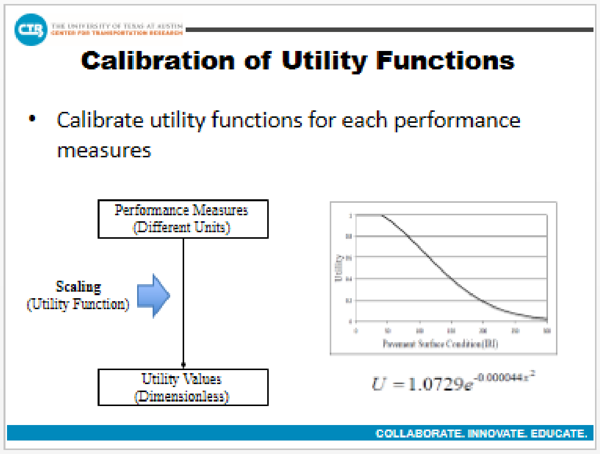

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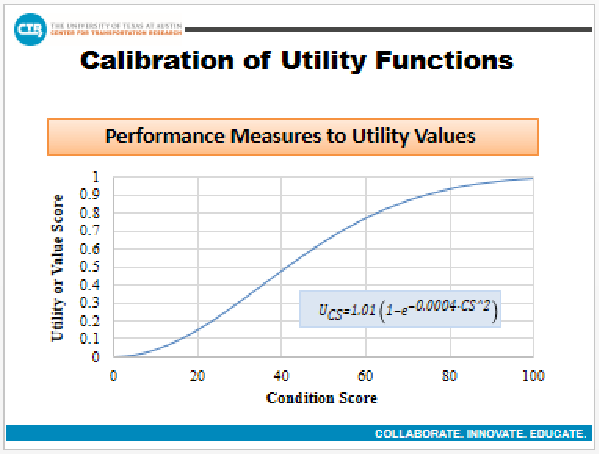

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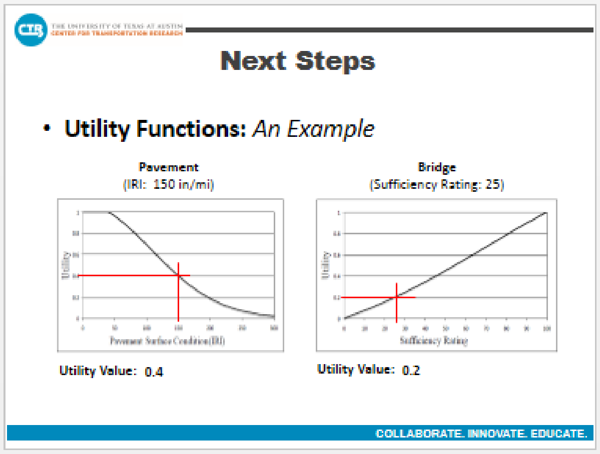

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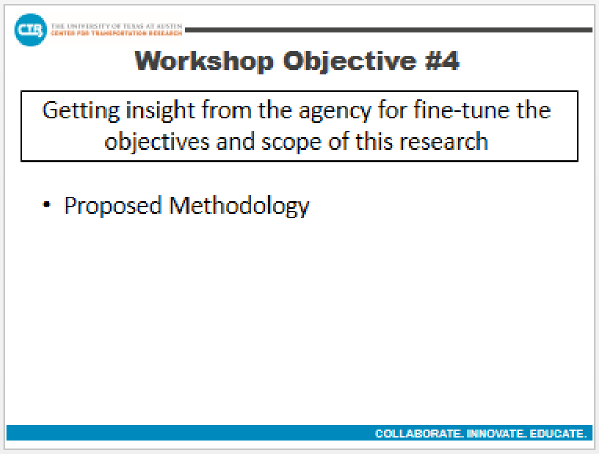

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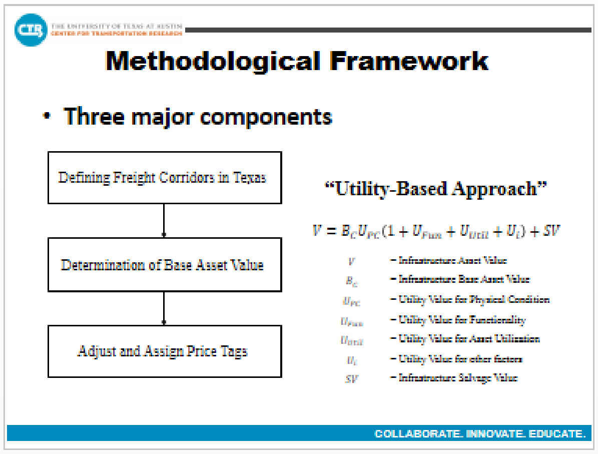

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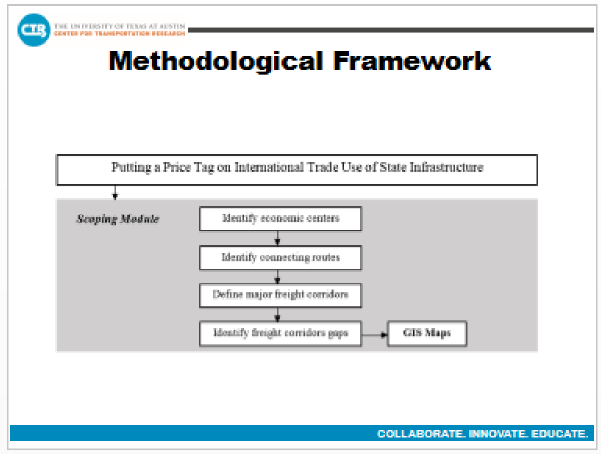

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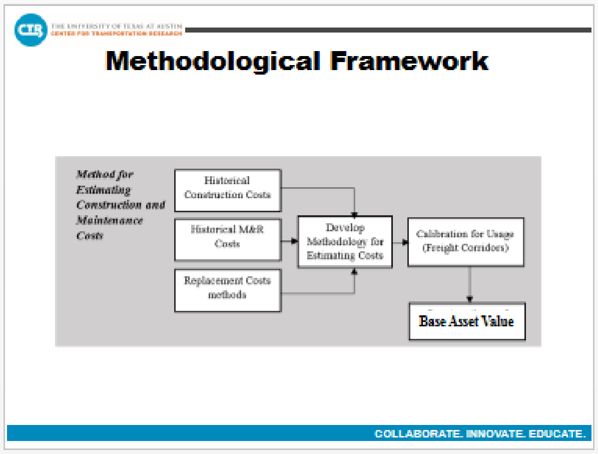

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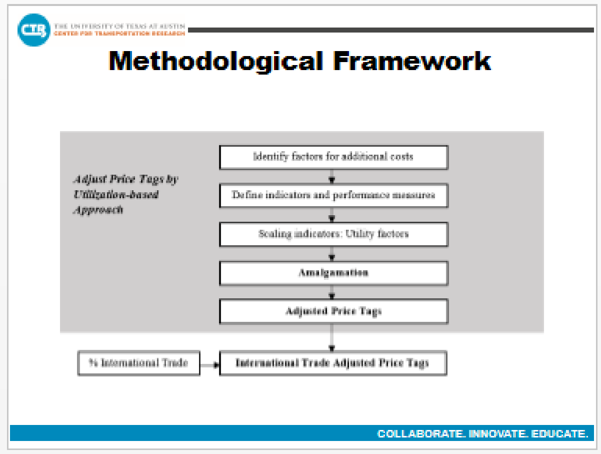

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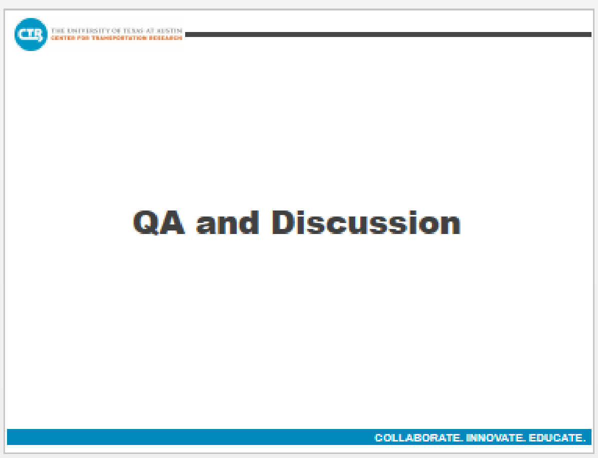

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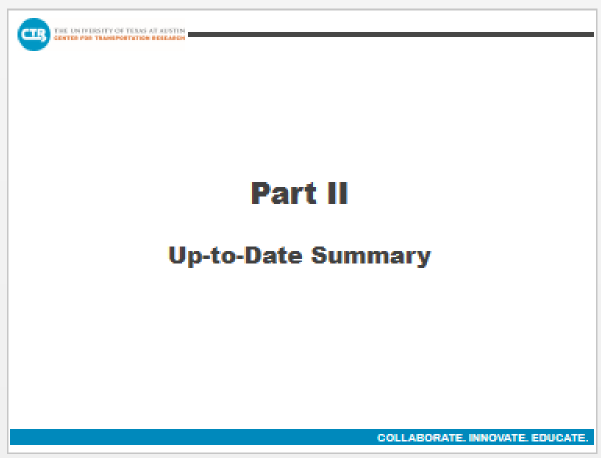

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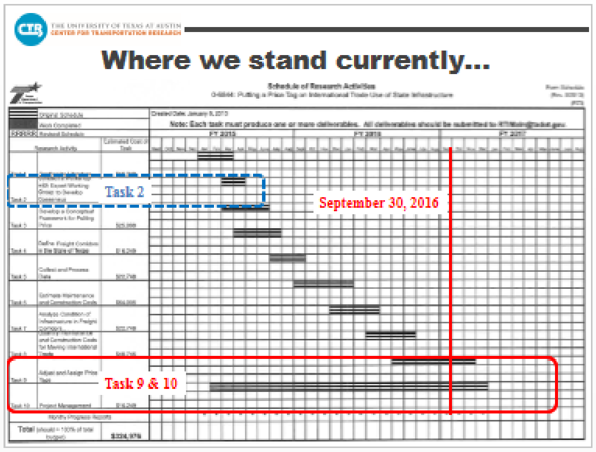

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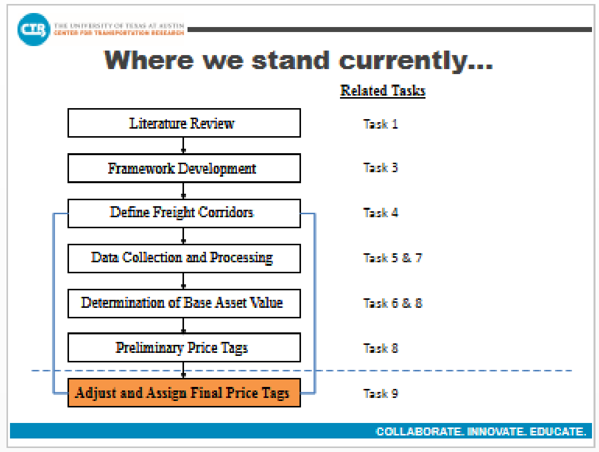

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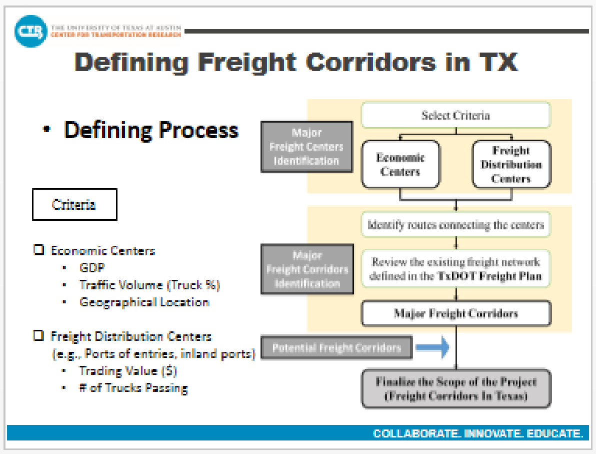

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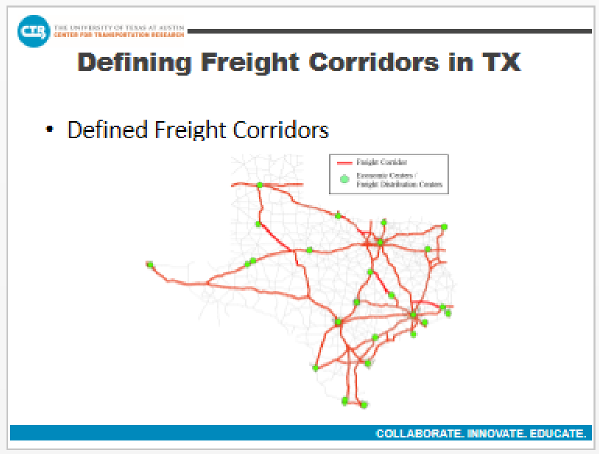

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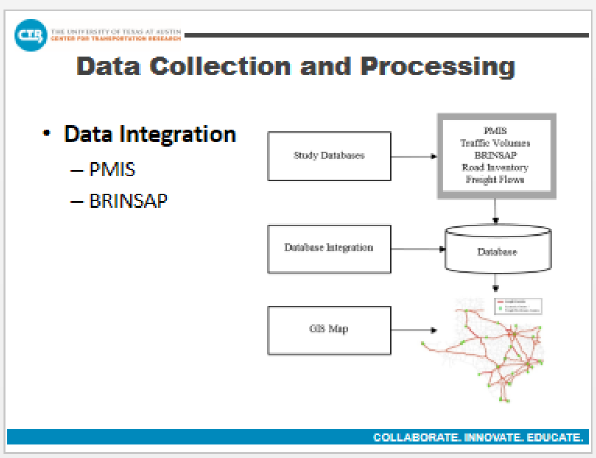

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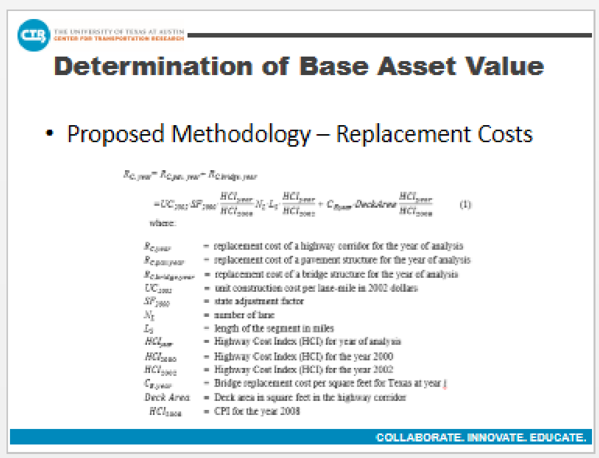

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Next Steps

- TxDOT Assistance for calibrating the utility functions as part of the valuation methodology.

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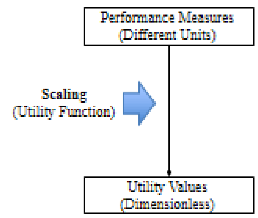
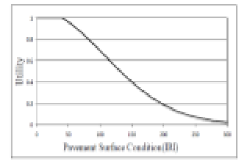
Next Steps

We need ***your input*** to calibrate the ***utility functions*** for each performance measures.





$$U = 1.0729e^{-0.000044x^2}$$

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Next Steps

- **Utility Functions?**
  - Reflects the preference structure of decision makers
  - Requires a survey of asset management experts

No.	Question	Notation	Answer
1.	If we assign v = 100 to the perfect condition when CS is 100, and assign v = 0 to the failed condition when CS is 1, to reflect the degree of your satisfaction, what is the number you will assign to the case when CS is 10?	v(10) =?	
2.	So what number will you assign to the case when CS is 20?	v(20) =?	
3.	And what number will you assign to the case when CS is 30?	v(30) =?	

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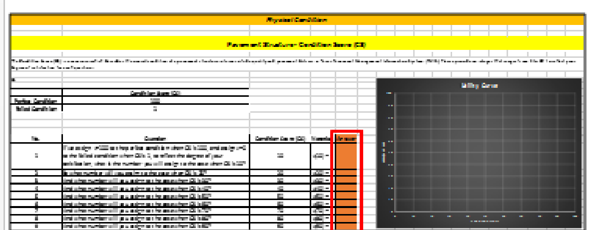
Next Steps

- **Survey Example** – Preference-based scaling



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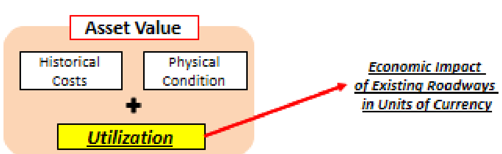
New Research Project

- **Findings from 0-6844**
  - Supporting a short-duration TxDOT research requested by the Texas Transportation Commission: *"Estimating Current Economic Impact of TxDOT Roadways."*



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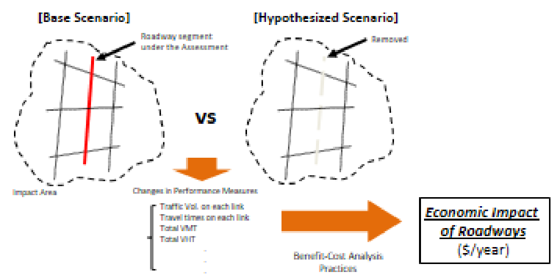
New Research Project

- "Estimating Current Economic Impact of Roadways"



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QA and Discussion

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Thank you for your attention

Contact Information:

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Additional Information

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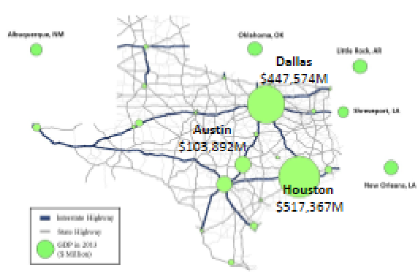
Defining Freight Corridors in TX

- Economic Centers



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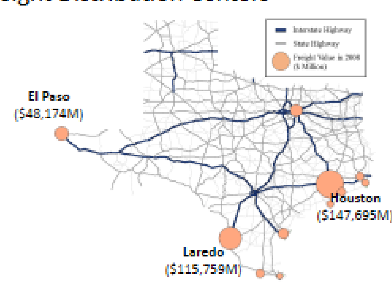
Defining Freight Corridors in TX

- Freight Distribution Centers



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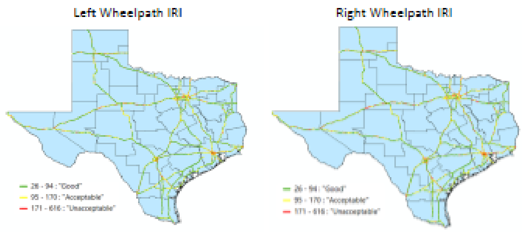
Data Collection and Processing

- Physical Condition – Pavements
  - International Roughness Index (IRI)



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Data Collection and Processing

- Physical Condition – Pavements
  - International Roughness Index (IRI)

Highway System	Roadbed Type	IRI Left (in/mi)	IRI Right (in/mi)	Average IRI (in/mi)	% of Sections with "Acceptable" IRI (IRI ≤ 170 in/mi)
IH	A	124.01	161.01	142.06	74.55%
	L	80.56	82.63	81.595	98.42%
	R	81.02	82.57	81.795	98.30%
	X	136.35	154	145.175	72.05%
	Subtotal	99.38	106.3	102.84	85.85%
US	A	146.16	154.98	150.57	70.39%
	K	93.48	100.76	97.12	95.39%
	L	80.42	82.17	81.295	98.25%
	R	80.26	83.86	82.06	97.76%
	X	143.23	151.36	147.295	71.58%
	Subtotal	89	92.95	90.975	94.78%
SH	A	149.67	157.82	153.745	72.32%
	K	92.08	98	95.04	95.86%
	L	85.28	97.34	91.31	97.11%
	R	82.33	84.8	83.565	97.39%
	X	149.81	154.85	152.33	68.65%
	Subtotal	94.86	98.87	96.865	93.41%
Total		96.88	103	99.94	91.12%

Mainlanes

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Data Collection and Processing

- Physical Condition – Bridges
  - Sufficiency Rating (SR)

Functional System	Average SR	Percent bridges in Good or Better Condition (%)
Interstate	88.20	80.50
Other Freeway & Expressway	88.79	78.29
Other Principal Arterial	90.40	94.22
Minot Arterial	67.26	90.99
Collector	85.35	73.84
Major	85.06	86.19
Minor	79.45	75.00
Local	84.31	91.11

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Preliminary Price Tags

- Base Asset Value is adjusted by physical condition only.

$$V_{PC,FRN} = B_{C,pav} \cdot U_{PC,pav} + B_{C,bridge} \cdot U_{PC,bridge} \quad (2)$$

where:

$V_{PC,FRN}$ = FRN asset value adjusted by physical condition
$B_{C,pav}$ = Base asset value (replacement cost) for pavements on FRN
$U_{PC,pav}$ = Pavement physical condition utility value
$B_{C,bridges}$ = Base asset value (replacement cost) for bridges on FRN
$U_{PC,bridges}$ = Bridge physical condition utility value

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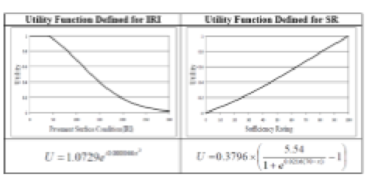
Preliminary Price Tags

- Selected Physical Condition Measures
  - Pavements: *International Roughness Index (IRI)*
  - Bridges: *Sufficiency Rating (SR)*
- Utility Functions [Bai et al., 2008]



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Preliminary Price Tags

- Preliminary Price Tags for Freight Corridors
  - Pavements

(Unit: thousands of 2015 Dollars)

Highway System		Base Asset Value	Adjusted Asset Value	% Change
IH	Main lanes	62,502,395.0	47,733,970.0	-23.6%
	Frontage roads	24,086,411.9	11,241,207.7	-53.3%
	Sub Total	86,588,806.9	58,975,177.7	-31.9%
US	Main lanes	19,266,432.9	14,456,776.0	-25.0%
	Frontage roads	3,020,206.1	1,322,026.0	-56.2%
	Sub Total	22,286,639.0	15,778,802.0	-29.2%
SH	Main lanes	7,070,686.7	4,995,476.9	-29.4%
	Frontage roads	1,157,922.0	531,920.8	-54.1%
	Sub Total	8,228,608.6	5,527,397.7	-32.8%
Grand Total		117,104,054.6	80,281,377.4	-31.4%

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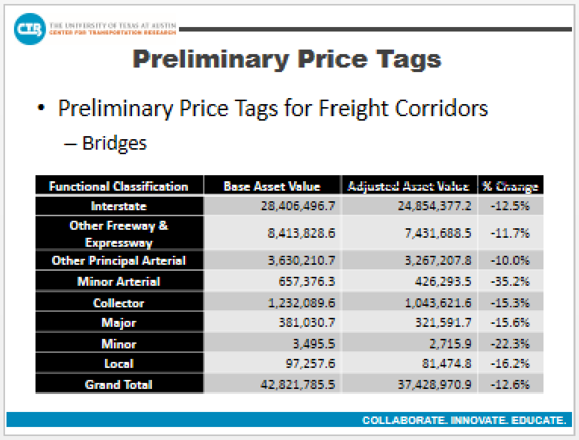

Preliminary Price Tags

- Preliminary Price Tags for Freight Corridors
  - Bridges

Functional Classification	Base Asset Value	Adjusted Asset Value	% Change
Interstate	28,406,496.7	24,854,377.2	-12.5%
Other Freeway & Expressway	8,413,828.6	7,431,688.5	-11.7%
Other Principal Arterial	3,630,210.7	3,267,207.8	-10.0%
Minor Arterial	657,376.3	426,293.5	-35.2%
Collector	1,232,089.6	1,043,621.6	-15.3%
Major	381,030.7	321,591.7	-15.6%
Minor	3,495.5	2,715.9	-22.3%
Local	97,257.6	81,474.8	-16.2%
Grand Total	42,821,785.5	37,428,970.9	-12.6%

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Attendee List

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