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16. Abstract

Transportation infrastructure, a vital component to sustain economic prosperity, represents the largest public-owned infrastructure asset in the U.S. With over a trillion invested dollars invested into long-lived physical assets such as roads and bridges, transportation agencies are tasked with maintenance and rehabilitation efforts to ensure that the access to transportation facilities is readily available and that the infrastructure is properly preserved. The management of these assets and the determination of their value, however, have been at the forefront of discussions in many state agencies and local governments. As a consequence, asset valuation has become a key component in asset management because it links the performance of infrastructure and deterioration process with the value of the infrastructure and its depreciation, providing critical information for decision makers at various levels to make more informed decisions. A utility-based methodological framework for the valuation of transportation infrastructure is presented along with a case study to demonstrate its applicability. A general framework is presented with emphasis on the valuation of pavement infrastructure. The results from the framework is then compared to existing valuation methods in addition to a series of sensitivity analysis on the variation of performance measures and their effect on the value of an asset. The development of this valuation approach serves as a starting point for assessing, in addition to the physical condition of an asset, the operational measures that can often make an asset less useful to its customers and managing agency. Utility theory can be utilized to combine the effect of performance indicators of varying measures and scales on the value of an asset. The proposed framework can assist state and local transportation agencies in the optimization of resource allocation procedures for better coordination of asset investments, facilitating benefit-cost analyses to quantify the impact of infrastructure investments. This tool allows agencies to detect deficiencies if any, in the management of its assets, providing a feedback mechanism that can foster an introspective review of its current management practices that may need further refinement or possibly elimination.

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Productivity-based Approach to Valuation of Transportation Infrastructure

by

Diniece Peters
Graduate Research Assistant
The University of Texas at Austin

and

Zhanmin Zhang
Associate Professor of Civil Engineering
The University of Texas at Austin

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An Integrated Approach to Managing the Transportation Systems

Southwest Region University Transportation Center
Center for Transportation Research
The University of Texas at Austin
Austin, Texas 78712

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ABSTRACT

Transportation infrastructure, a vital component to sustain economic prosperity, represents the largest public-owned infrastructure asset in the U.S. With over a trillion invested dollars invested into long-lived physical assets such as roads and bridges, transportation agencies are tasked with maintenance and rehabilitation efforts to ensure that the access to transportation facilities is readily available and that the infrastructure is properly preserved. The management of these assets and the determination of their value, however, have been at the forefront of discussions in many state agencies and local governments. As a consequence, asset valuation has become a key component in asset management because it links the performance of infrastructure and deterioration process with the value of the infrastructure and its depreciation, providing critical information for decision makers at various levels to make more informed decisions. A utility-based methodological framework for the valuation of transportation infrastructure is presented along with a case study to demonstrate its applicability. A general framework is presented with emphasis on the valuation of pavement infrastructure. The results from the framework is then compared to existing valuation methods in addition to a series of sensitivity analysis on the variation of performance measures and their effect on the value of an asset. The development of this valuation approach serves as a starting point for assessing, in addition to the physical condition of an asset, the operational measures that can often make an asset less useful to its customers and managing agency. Utility theory can be utilized to combine the effect of performance indicators of varying measures and scales on the value of an asset. The proposed framework can assist state and local transportation agencies in the optimization of resource allocation procedures for better coordination of asset investments, facilitating benefit-cost analyses to quantify the impact of infrastructure investments. This tool allows agencies to detect deficiencies if any, in the management of its assets, providing a feedback mechanism that can foster an introspective review of its current management practices that may need further refinement or possibly elimination.

EXECUTIVE SUMMARY

Transportation infrastructure represents one of the largest public-owned assets in the United States (U.S.). In recent years, the costs of preserving and operating this $1.75 trillion investment have increased dramatically [FHWA, 2007]. With such enormous investments throughout the life cycles of transportation infrastructure: covering maintenance, rehabilitation, operations and improvements, much interest is centered on ensuring that value of these infrastructures is preserved.

While the existing valuation methods depict how well an agency preserves their assets' condition, the question yet to be addressed involves incorporating the operational efficiency of these assets into its value. There is a need for an asset valuation methodology that can quantify the value of transportation infrastructure, inclusive of the asset's performance both physically and operationally, in addition to its relative importance to other assets.

The objective of this study is to develop an asset valuation methodology for transportation infrastructure with a new perspective: a utility-based approach to valuing transportation infrastructure, using replacement cost as the base value for the asset and factors as the utility multipliers. The framework utilizes performance measures to capture the value of an asset based on its efficiency both physically and functionally, in addition to its relative utilization. The proposed methodological valuation framework addresses three main questions.

1. Is the transportation infrastructure properly maintained or preserved?
2. What quality of service is the transportation infrastructure providing?
3. What is the utilization of the transportation infrastructure with respect to its capacity and the safe and efficient movement of goods and people?

A segment of Mopac Expressway (Loop 1), bordered by US 290 on the south and US 183 on the North in Austin, Texas was selected as a case study to demonstrate the applicability of the valuation framework.

Of the methods used for the case study, there are two categories of methodologies: depreciation-based vs. condition-based asset valuations. The same input data yielded different asset values for different valuation methodologies under comparison, as many assumptions were used to conduct the valuation.

A large dispersion was observed amongst depreciation-based methods based on the coefficient of variation amongst the methods reported in Table 9. Compared to other methods, the proposed framework values the 12.2-mile segment much higher because of the additional utility. The SLD method estimated the lowest value of Mopac Expressway as it assumes that the asset's condition continuously decreases over time.

All the depreciation-based methods were on the lower end of the spectrum for valuation as there is no relationship between accounting based depreciation and condition. Since these methods rely heavily on the age and useful life of the asset, the expected life is consumed at a fast rate, resulting in significantly low value estimates. Road assets do exhibit initial deterioration but stabilize relatively quickly resulting in very small changes in condition provided adequate routine maintenance investments are employed until wear-out failures are inherent. The deterioration of the asset, however, is not accurately depicted by depreciation methods. As a consequence, these estimates can distort the true picture of the usefulness and/or importance of a particular asset.

In analyzing the dispersion of the condition-based methods, including the proposed utility-based method, it was observed that there was less variation amongst these. These methods showed less dispersion amongst each other and provide more stable estimates of the asset value.

The Written Down Replacement Cost (WDRC) indexes the replacement cost by a factor proportional to the condition of the asset to its best condition. Since the condition score for the case-study segment length was near the highest value of 100, this estimate of the segment's asset value did not differ significantly from the Replacement Cost (RC). The replacement costs used were based on unit costs for the reconstruction of the pavement. This estimate can exhibit bias due to the fact of improvement in technology, construction standards, and improved materials over the years. The proposed method, as expected, resulted in the largest value estimate due to the structure of multiplier, accounting for an additional utility and value. This method, inclusive of the physical condition of the asset, also accounts for functional and economic obsolescence and is representative the usefulness of the particular asset.

With respect to the safety indicator, an increase in the crash rate on the roadway corresponds to a decrease in the asset value of that segment. If the goal of an agency is to improve safety, then not only is there an incentive for providing safe travel for the system users, but also to increase the asset's functional efficiency and therefore, it's value. The results also indicate that if the crash rate were to decrease to zero, the asset value would increase by 4.72 percent from $399.6 M to $418.5 M, a significant improvement. On the contrary, if the safety conditions with respect to the crash rate were to decrease with an increased crash rate of 300, then the asset's value is expected to decrease by 2.21 percent from $399.6 M to $390.8 M.

With regards to the mobility indicator, a variation of the VMT shows that as the VMT increases, so too does the asset value of the segment but at a decreasing rate. If the VMT were to decrease to 1,000,000, the asset value is expected to decrease by 3.00 percent from $399.6 M to $387.5 M. Lastly, within the functionality indicators, variation of the average travel times indicates that as travel times increase, the asset value of the segment decreases. If the travel times were increased to 60 minutes, the asset value would then be decreased by approximately 1 percent from $399.6 M to $396 M.

The last sensitivity case involved analyzing the impact of the variation of the utilization measure, AADT presented in Figure 12. It can observed that as the average annual daily traffic reaches its optimal value, the asset value tends to increase, aligning with the notion that the system is operating at an optimal level and its efficiency is maximized. Similarly, a decrease in the AADT signifies that the system is not being utilized at its full potential. If the AADT were to decrease to 60,000 veh/day, then the asset value is expected to decrease by 4.70 percent from $399.6 M to $380.8 M.

In these analyses, all other parameters were held fixed when controlling for one variation. Additional sensitivity analysis can be performed to assess the combined effect of changing more than one of parameters on the asset value of the infrastructure

Additional research can be done to look at other factors that can affect the value of an asset. The framework does not account for environmental impacts such as air and noise pollution along a particular roadway, as this provides another area of improvement. Future work should explore the form of the utility multiplier, including a multiplicative form in which the utilities for physical condition, functionality and utilization factors are multiplied to produce a combined utility rather than adding these factors. Relating the replacement cost within the valuation formulation to the design standards of the infrastructure being valued can improve the accuracy of the asset value estimation. Overall, the approach presented raises an important area for more research and discussion with respect to how transportation agencies value their assets, along with the incorporation of other operational factors besides physical condition that can impact the value of an asset.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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CHAPTER 1: INTRODUCTION

1.1 Background & Motivation

Transportation infrastructure represents one of the largest public-owned assets in the United States (U.S.). Pavements, bridges and related infrastructure assets serve as mechanisms for social and economic development. As a crucial component of America's economic engine, transportation serves Americans' daily commuting needs through connecting people to families, jobs, recreational activities, and businesses, in addition to facilitating the movement of goods and services. Without these facilities in place today, much of the planned progress envisioned for the 21st century would be infeasible. In recent years, the costs of preserving and operating this $1.75 trillion investment have increased dramatically [FHWA, 2007]. With such enormous investments throughout the life cycles of transportation infrastructure: covering maintenance, rehabilitation, operations and improvements, much interest is centered on ensuring that value of these infrastructures is preserved.

Between the 1950s and 1980s, U.S. transportation agencies primarily focused on the construction and expansion of transportation infrastructure to meet the demands for national defense, mobility and accessibility of the military, corporations and private citizens. However, expansion of these types of infrastructure peaked after the completion of the Interstate Highway System as agencies turned their attention to the management and preservation of these assets. At a time when government agencies at all levels are required to do more with less, state and local transportation agencies have focused on managing their portfolio of assets in a more efficient manner, a shift from the notion that building new roadways is the best solution for all transportation problems. Agencies must now balance the needs for better service based on user demands with maintaining and upgrading existing infrastructure under budget constraints.

The beginning of the 21st century in transportation infrastructure management marked a fundamental shift in the way agencies managed their facilities, a movement to a business-oriented strategy. The need for increased credibility, accountability and transparency in governmental agencies was propelled by the requirement for financial reporting of assets in the Governmental Accounting Standards Board (GASB) Statement 34 in 1999 for state and local agencies. A primer on asset management soon followed and was published by the Federal Highway Administration (FHWA) [FHWA, 1999]. Additionally, the recent transportation bill, MAP-21 (Moving Ahead for Progress in the 21st Century), is aimed at fostering more efficient management, by transitioning to performance and outcome-based programs targeted towards preserving and improving the condition of transportation infrastructure inclusive of assets within the right of way and providing for more efficiency of investments.

This shift in infrastructure asset management involved 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. Proper management of transportation infrastructure ensures that: 1) the service life of these assets are extended, 2) their value is preserved at minimum, 3) agencies are held accountable for their expenditures 4) justification of funding needs can be clearly stated and 5) users are satisfied with the quality of transportation services received [FHWA, 1999; Cowe Falls et al, 2001; Cambridge Systematics, 2006]. The development of a sound asset valuation methodology, however, is crucial to ensuring that accountability of expenditures by agencies is met as well as serving as a tool to aid senior level and policy officials in their decision-making process especially when performing prioritization in the budget allocation process.

Asset valuation holds great promise as a readily understood (to the public and private sector) performance measure and, as an asset management integration mechanism for trade-off analysis between competing components such as pavements, bridges, traffic signals, etc. [Cowe Falls et al, 2005]. In addition, the emergence of cross-program and cross-asset resource allocation has placed emphasis on asset valuation as a comparative measure for assets of varying characteristics. It provides a direct reflection of how the assets are performing in a practical way so that managers and senior level officials can communicate effectively amongst each other.

In the valuation of transportation infrastructure, there are some valuation techniques and approaches that have been developed, each satisfying specific asset management objectives. However, research has revealed that different valuation approaches yield different values for a given asset [Herabat et al, 2003], some varying more significantly than others. For example, the costs of two separate road sections with the same condition could be the same to the managing agency in terms of accounting principles, but a more important heavily traveled section usually has a higher value than a less utilized section of road to the agency, its road users, and society [Kaldek & McNeil, 2001]. As a consequence, it is of great importance to choose an approach that not only aligns with the goals and objectives of the managing body of infrastructure, but also one that reflects the true value of the asset.

Replacement costs, historical costs, and depreciated value are the most common methods for the valuation of civil infrastructure [McNeil et al, 2000; OECD, 2001; Cowe Falls et al, 2004; Dewan & Smith, 2005]. Performance-based valuation methods in the early stages were not been readily accepted due to a lack of understanding by the private sector on the performance basis for valuation. Current asset valuation methodologies are based on a series of assumptions that are problematic when it comes to long-lived fixed and tangible assets such as pavements and bridges. The perspective of value is often held into question where the agency, users or other stakeholders perceive value differently. Moreover, there is a level of uncertainty associated with the data used to value these assets that can result in variability of the asset value within a specific range. The provision of more accurate and reliable data can improve these methodologies allowing them to capture a more accurate measure of the asset's value.

While the existing valuation methods depict how well an agency preserves their assets' condition, the question yet to be addressed involves incorporating the operational efficiency of these assets into its value. These methods are based on a particular type of condition, physical condition and/or deterioration, of the asset. They do not account for the functional and relative usefulness of the asset, as they are important measures of the operational performance. There is a need for an asset valuation methodology that can quantify the value of transportation infrastructure, inclusive of the asset's performance both physically and operationally, in addition to its relative importance to other assets. The proposed valuation methodology addresses these limitations.

1.2 Report Objective

The objective of this study is to develop an asset valuation methodology for transportation infrastructure with a new perspective: a utility-based approach to valuing transportation infrastructure. The framework utilizes performance measures to capture the value of an asset based on its efficiency both physically and functionally, in addition to its relative utilization. A case study is used to demonstrate the applicability of the framework and provide a comparison with existing methodologies.

1.3 Report Scope

This research focuses on developing a methodology for the valuation of transportation infrastructure. Though the framework is applicable to different types of transportation infrastructure, the study focuses on the valuation of highways as an example. Furthermore, the concepts and procedures can be adopted for the valuation of other civil infrastructure systems.

1.4 Report Organization

The report is organized into six chapters. Chapter 1 discusses the background, objective, report scope and organization. Chapter 2 provides a thorough literature review of asset management, asset valuation practices and their limitations. Chapter 3 presents a methodological framework for asset valuation of highway infrastructure. Chapter 4 describes a case study to demonstrate the applicability of the framework. Chapter 5 compares the results obtained from the newly proposed valuation methodology results, with a comparison of traditional valuation approaches, along with the sensitivity analysis of the proposed method. Finally, Chapter 6 provides the concluding remarks for this research and potential improvements for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

This chapter first introduces the general background of asset management, transportation asset management, and asset valuation; then current asset valuation methodologies, practices, and policies are discussed along with legislations that affect them. The need for an improved asset valuation methodology is presented in the context of overcoming the shortcomings of current valuation methods.

2.2. Asset Management

Asset Management in the most basic terms is a business process that provides a holistic approach to managing assets to deliver an overall greater value to end users, while ensuring accountability for investment decisions. A long held definition by the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Highways, states that asset management is a "systematic process of maintaining, upgrading, and operating assets, combining engineering principles with sound business practice and economic theory, and it provides tools to facilitate a more organized logical approach to decision making" [FHWA, 1996]. This practice, derived from the private industry, has taken hold in the management of transportation assets across the U.S., placing emphasis on optimal performance and cost-effectiveness.

An asset management framework is policy-driven and performance-based; it analyzes alternative decisions through trade-offs. The decisions that are made are reliant on quality information in which a monitoring mechanism is implemented to provide clear accountability and feedback. Ideally, asset management principles need to be applied comprehensively across all of an agency's types of infrastructure expenditures, including preservation, operations, and system in order to be effective [Cambridge Systematics, 2006], as it is aimed at maximizing the overall performance of the system being managed.

2.3 Transportation Asset Management

Contrary to the private sector, profit is not the driving force for agencies in the public sector such as transportation agencies. Rather, relatable measures such as performance, public satisfaction, and cost effectiveness apply to government agencies. Transportation Asset Management (TAM) provides a link between the expectations of the user for the system performance and the strategies for system management and investment [FHWA, 2007]. This form of management involves a process of maintaining, enhancing and operating an infrastructure in a cost-effective manner to maximize the value of the overall system and the satisfaction of its users. This management strategy has tremendously evolved over years of implementation across the U.S. as well as internationally. Pavement management systems for roadways networks and bridge management systems have led the way for asset management on a holistic approach inclusive of other assets [Hudson & Hudson, 1994]. Through the advancement of information collection, data management and technology, agencies are now more equipped with knowledge and tools to effectively allocate resources to agency assets with varying competing needs. These management practices have not only improved the management of assets, but also facilitated more interactions amongst different agencies and levels of management while improving the decision-making process of senior level officials.

Striving for enhanced accountability and transparency, the asset management approach is based on a fundamental set of principles [AASHTO, 2002; Cambridge Systematics, 2006; NCHRP, 2010], include:

- **Policy-Driven:** Resource allocation decisions are based on a well defined set of policy goals and objectives that are reflective of the desired condition targets
- **Performance-Based:** Policy objectives are translated into system performance measures that are used for strategic management, monitoring and resource allocation
- **Analysis of Options and Tradeoffs:** The allocation of resources within and across different assets, programs, and types of investments are based on evaluating the alternatives and associated tradeoffs at every level of decision making in line with policy objectives
- **Decisions Based on Quality Information:** The use of reliable and quality data for the evaluation of the advantages of different options with respect to an agency's policy goals for improved decisions support.
- **Monitoring to Provide Clear Accountability and Feedback:** Performance results are monitored and reported, providing for a clearly defined criteria in making decisions

The principles have fostered an increased focus on performance-based investment decisions overlooking the whole life of an asset, from the planning and design phase to reconstruction or replacement at the end of its useful life. This strategic management approach focuses on asset preservation and reduces the life-cycle cost of maintaining the asset of time while improving performance levels and road user satisfaction as illustrated in Figure 1.

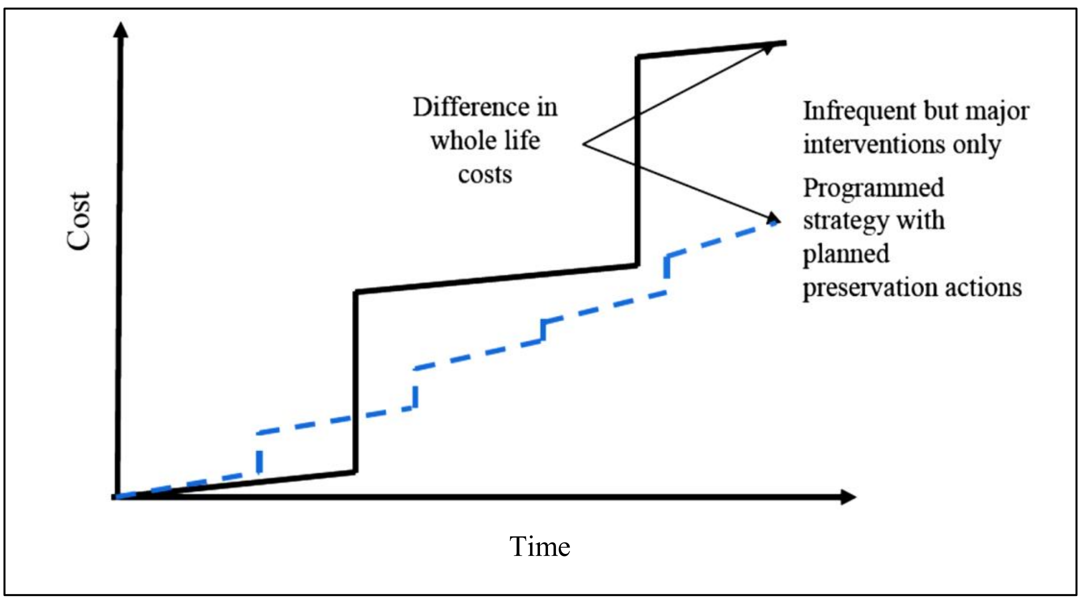

Figure 1 – Impacts of Asset Management on Life Cycle Costs [FHWA, 2013].

It can be seen that with strategic management for the preservation of assets, the total investments over the useful life of an asset can be reduced significantly. Unplanned interventions for the maintenance of infrastructure can be more costly to both the agency and the user, resulting in compromised overall satisfaction of infrastructure operations by both the agency and the user.

Table 1 summarizes the common features of current practices of transportation asset management in the U.S. by agency level based on an FHWA report on asset management [FHWA, 2007]. Current practices in transportation asset management across the U.S. vary tremendously based on needs, available resources and the intricacy of the transportation systems being managed.

Table 1 – Current Transportation Asset Management Practices [FHWA, 1999; Meyer & Miller 2001; U.S. DOT, 2006].

	Agency Level	Extent of Practices
BASIC ↓	Local Governments	• Greater variety of criteria and standards for asset performance • Lack of substantial resources and staff to invest in asset management programs • Less sophisticated data management systems • Limited Technology Usage
COMPLEX	State Departments of Transportation	• Well defined asset management plan, often multimodal and across agencies • Incorporates existing pavement & bridge management systems and ITS technologies to provide objective data on asset performance • Employ priority assessment methods for ranking & optimizing projects • Utilize analytical tools to evaluate risks and benefits of alternative initiatives

In general, local governments manage a basic asset management system and their tools exhibit non-uniform characteristics across cities, counties and among states. In addition, there is a lack of adequate resources to develop full-scale management plans. State Departments of Transportation (DOTs) retain a well-developed asset management plan that is backed by dedicated funding. With this level of variability, developing an asset management framework is context dependent and may provide different solutions based on the scope of assets to be managed and resources available.

2.3.1 Cross Program & Cross Asset Resource Allocation

With the nation's interstate highway system completed, focus shifted from new construction to maintaining, preserving, and rehabilitating highway assets [Garber & Hoel 2009]. This task of managing such a vast network of infrastructure has become more of a challenge as budget constraints represent the new reality. Though state budgets are limited, states are still tasked with maintaining infrastructure systems at an acceptable level. The traditional methods of funding transportation through the fuel tax, which has remained stagnant since 1993, are no longer adequate to meet the needs of an ever aging and growing transportation system. The fuel tax is anticipated to become an untenable long-term source of funding [U.S. DOT, 2006].

As illustrated in Figure 2, the allocation logic for State DOTs follows a process whereby the agency's policies, performance goals and priorities drive the allocation process. The overall highway budget is inclusive of revenue generated from taxes, user fees, federal funding, credits and other sources, all of which is joined together in "the pot". Based on the constraints of the funding type, each program's budget is prioritized and allocations within the programs are based on high-level strategies, and performance objectives [Wiegmann et al, 2012].

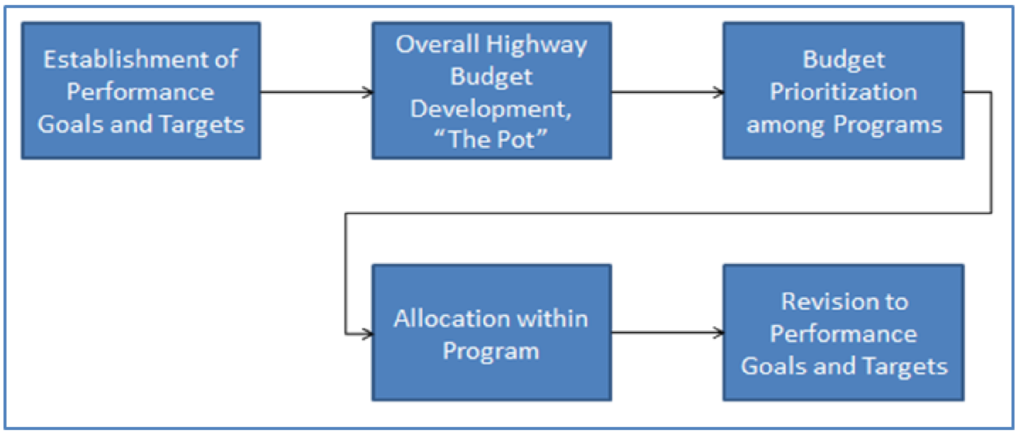

Figure 2 – State DOT Resource Allocation Process [Wiegmann et al, 2012].

There have been extensive developments of tools for the management of pavement and bridge infrastructure that are utilized for the prioritization of investments as well as predicting the impact of asset conditions. However, based on the current transportation asset management practices, resource allocation is limited to within each class of assets and not across assets, restricting the impact of the system's performance on a whole.

The number and diversity of asset category performance models (and scales) makes it very challenging to optimize decisions across asset categories within a network [Cowe Falls et al 2005]. The efficiency of the resource allocation process has become a major challenge to ensuring that transportation agencies meet their goals and objectives. Tools and techniques are constantly being employed to maximize the efficiency of expenditures and performance of assets given budget constraints. TAM provides a means for agencies to deal with the allocation of resources dilemma. Although much interest has been generated on the optimization of the cross-asset resource allocation process across the country, the need for a comprehensive implementation of cross-asset resource allocation within and across all asset classes is warranted [CTC & Associates, 2012; Lindquist & Wendt, 2012]. As a consequence, accepted allocation methods that account for evaluating the overall system performance of various assets are needed. Hence the interest in asset valuation as a measure of effectiveness for the allocation of resources across programs and assets becomes an important tool that normalizes asset values across programs with varying scales of measurement.

2.3.2 MAP-21 Implications for Asset Management

The most recent transportation legislation, Moving Ahead for Progress in the 21st Century (MAP-21) passed in 2012, has prompted transportation-managing agencies on state and local levels to shift their focus to a more performance-based management approach. The MAP-21 approach is anticipated to help address the issues of budget shortfalls where agencies are required to do more with less. This new legislation seeks to transform the highway programs and address their challenges. However, with such a daunting task, significant investments are required to achieve this goal in the future. Such challenges, as reported by the FHWA, include: improving safety, maintaining infrastructure condition, reducing traffic congestion, improving efficiency of the system and freight movement, protecting the environment, and reducing delays in project delivery [FHWA 2012]. This approach relies heavily on quality information and would therefore allow for more transparency and accountability in the decision-making process of senior level officials.

Under MAP-21, each state is required to develop a risk-based asset management plan for the National Highway System that is inclusive of all assets within the right-of-way of the highways. The plan requires states to include a summary listing of pavement and bridge assets that is representative of the condition of these assets, asset management objectives and measures, performance gap identification, life-cycle cost and risk management analysis, a financial plan and investment strategies [FHWA, 2012]. In addition, the inclusion of other assets within the right-of-way of highways such as pavement markings, culverts, guardrails, signs, traffic signals, Intelligent Transportation Systems (ITS) infrastructure and other appurtenances are encouraged. With the focus on performance and accountability of state and federal agencies, the need for an objective measurement tool or measure for comparing assets of various competing needs, such as asset value, has become more prominent.

2.3.3 Performance Measurement and Asset Management

Performance management is at the crux of an asset management plan. It provides a means for agencies to monitor and assess the effectiveness of their program investment strategies, condition of system assets, and the agency's stewardship as it pertains to their policy goals and objectives. The performance-based approach centered in asset management provides value across several areas of an agency [Cambridge Systematics, 2006]:

- **Improved Effectiveness of Policy:** policy goals and objectives are achieved through performance measurement and monitoring to facilitate improved long range planning and policy formulation.
- **Greater Accountability:** policy makers, agency, customers, and stakeholders obtain a level of transparency that provides more communication.
- **Organizational Efficiency:** it allows staff to focus on priorities to improve operations internally (provide greater decision support and align the agency's strategic business objectives) and externally (allocate resources efficiently to accomplish the mission)
- **Improved Communication:** information about system performance is communicated to customers, stakeholders and political leaders in a clear and concise manner.

Performance measurement within asset management provides a data-driven support tool that reinforces good management practice. The collection of data, however, is a time consuming and expensive process that is often constrained by an agency's availability of resources and budget. While the principles of asset management and performance management are aligned, performance management can apply to operational characteristics of assets such as mobility, accessibility and safety.

2.4 Asset Valuation of Transportation Infrastructure

The valuation process involves the evaluation or determination of the significance or worth of an asset through an appraisal process. An asset is deemed valuable when it has the ability to provide an acceptable level of service. Asset values can be expressed as an intrinsic value to the transportation network as a whole (the value of the safe and efficient movement of goods and people) or a capital value that is representative of the cost the repairing the asset to the as-built condition [OECD, 2001].

The valuing of assets, however, can be subjective by nature and must be addressed within a context of time, place, potential users and potential users [Smith & Parr 1994; Dewan & Smith, 2005]. As a consequence, there are various valuation techniques and approaches that have been developed, each satisfying specific asset management objectives. Public reporting of asset value should include asset condition and, as it is a performance measure, it should also provide some indication of asset management in terms of improved or maintained condition [Cowe Falls et al 2004].

As a key component in asset management, asset valuation provides a direct link to the performance of an asset and its depreciation over time. Asset valuation for transportation infrastructures is a crucial element of transportation asset management as it serves a mechanism for assessing whether facilities' values are to be preserved or enhanced. Valuing civil infrastructure functions as a benchmark tool for managing agencies to quantify the worth of their assets, managing changes over time through the development of maintenance and rehabilitation strategies.

The difference between the cost of an asset and its value is often overlooked. The cost can be defined as the financial resources required for producing or obtaining something, whether to replace a physically deteriorated portion on a highway or to construct an interchange. However, the worth and value of that investment can be more or less than the cost to acquire it, depending on who is performing the valuation from which perspective. The following sections describe the history of infrastructure reporting, factors affecting asset value, standards, practices and current methodologies

2.4.1 History of Infrastructure Reporting

Infrastructure reporting has influenced all phases of highway development ranging from planning, design, maintenance, rehabilitation, and demolition. The concept of reporting the performance of the nation's infrastructure received much interest during the 1980's as infrastructure facilities were deteriorating at faster rates than they were being replaced. The concern of a potential catastrophe was raised. There had been a failure of the managing agencies to consider the operation and maintenance costs associated with up-keeping the infrastructure across the United States. This identification brought context to the insufficient maintenance of existing public infrastructure for short and long-term preservation and capacity [Choate & Walter, 1981]. A council on Infrastructure Improvement was created by congress in 1987 to assess the state of the nation's infrastructure [PWIA, 1984]. Recommendations were provided to congress for the improvement of the infrastructure condition audit but were not enacted. Still, hopes of improving infrastructure performance and reporting were not lost. A study on Measuring and Improving Infrastructure Performance was published by the National Academy of Sciences that recommended agencies draft a list of infrastructure performance measures to adhere to [National Academy of Sciences, 1996]. These milestones in infrastructure reporting indicated the shift of the mindset of public agencies to a more proactive than reactive approach to with regards to their management strategies.

A drastic turn in infrastructure reporting was initiated in 1999, through the Government Accounting Standards Board's Statement 34 (GASB 34) [GASB, 1999]. An infrastructure-reporting standard was established in order to ensure governmental agencies were more accountable to their citizens, and business partners. The standard would serve as a measure of the financial standing of government agencies as they were mandated to report all their assets using accounting principles. From a transportation perspective, this meant the reporting of all long-lived infrastructure capital assets: roads and bridges, in financial statements. This impetus was met with numerous challenges as these requirements indicated an abrupt change to traditional practices. Nonetheless, the accounting requirement provided a catalyst for the development of many asset management programs today.

GASB Statement 34 provided agencies with the option of reporting assets on the network, subsystem, or individual level. The implementation of the new standard required a shift in the way in which our public infrastructure was viewed. 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. The obligation of this standard provided guidelines for two approaches to valuing public assets: 1) a depreciation approach, and 2) a modified approach, which takes the preservation of assets into account. Both of these approaches provided a means for capitalizing the net costs of the asset.

The first approach, 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. This approach has been favored in the early stages of the compliance with the new standards because of the simplistic nature of implementation. 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 it 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.

If historical costs are not available, the GASB guidelines suggest adopting the second approach: the modified approach. With emphasis on preservation, 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: difficulty in estimating annual maintenance and preservation expenditures to achieve target condition levels, lack of consistency in evaluating the number of components and classes used to for historical cost estimation and the effect on levels of funding for State DOTs provided that the assets were not being maintained to acceptable levels. Overall, the policy implementation of infrastructure reporting for public agencies, particularly, transportation agencies has had rippling effects, transforming the way in which transportation infrastructure is financed and managed.

2.4.2 Asset Valuation Methodologies

The International Infrastructure Management Manual (IIMM) [NAMS Group Ltd, 2006] defines an asset as a physical component of a facility, whose value, enables services to be provided and has 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 & Goodman, 2003]. The following sections discuss the factors that affect an asset's value, and asset valuation from an accounting and civil engineering perspective.

2.4.3 Factors Affecting Value

There are many factors that 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 et al, 2004; 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 depreciated.

2.4.2.2 Asset Valuation: 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. 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 in Equation 2.1:

$$D_{SLD} = \frac{C - S_N}{N} \qquad \text{(Equation 2.1)}$$

Where, D_{SLD} is the annual depreciation rate of the asset, C is the original construction costs, also known as historical cost of the asset, S_N is the salvage value of the asset in year N, and N is the useful life of the asset. The salvage value represents the price that an asset can be sold for or disposed of at the end of its useful life. The value is then calculated using Equation 2.2, where V_{SLD_j} is the value of the asset in year j according to the straight-line depreciation method:

$$V_{SLD_j} = C - D_{SLD}\left(\frac{j}{N}\right) \qquad \text{(Equation 2.2)}$$

The SLD method has been used in Finland to value their roadway infrastructure [Saarinen, 2007]. This method, however, in some instances, can underestimate or overestimate the value of an asset. 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, 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:

$$D_{SOYD_j} = \frac{N+1-j}{\frac{N}{2}(N+1)} \qquad \text{(Equation 2.3)}$$

$$V_{SOYD_j} = D_{SOYD_j}(C - S_N) \qquad \text{(Equation 2.4)}$$

Where D_{SOYD_j} is the sum-of-years-digits depreciation of the asset in the analysis year j, C is the original construction costs, also known as historical cost of the asset, S_N is the salvage value of the asset in year N, and N is the useful life of the asset. The depreciable cost $(C - S_n)$ is multiplied by the acceleration factor (Equation 2.3) to estimate the value (V_{SOYD_j}) of the asset (Equation 2.4). The acceleration factor captures the fraction of remaining life of the asset and assigns are 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 and Double Declining Balance 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 ($2/N$) as depicted in Equations 2.5 and 2.6 respectively:

$$D_{DB} = \left(\frac{1}{N}\right) \qquad \text{(Equation 2.5)}$$

$$D_{DDB} = \left(\frac{2}{N}\right) \qquad \text{(Equation 2.6)}$$

The depreciation factor for both methods is then multiplied by the book value of the year previous to the analysis year as displayed in Equations 2.7 and 2.8. The depreciation factors causes the asset value to decrease sharply in early years and slower nearing the end of the asset's useful life.

$$V_{DB} = D_{DB} \left(\frac{(C-S_N)(j-1)}{N}\right) \qquad \text{(Equation 2.7)}$$

$$V_{DDB} = D_{DDB} \left(\frac{(C-S_N)(j-1)}{N}\right) \qquad \text{(Equation 2.8)}$$

Compared to the SLD method, both the SOYD and DB methods have been reported to depict more accurate values of assets [Gyamfi-Yeboah, & Ayitey, 2006]. Common to all these methods, an asset's deterioration is deemed unrecoverable. These methods are not as suitable for estimating the value of long-lived fixed assets, such as roadways and bridges which, provided the asset's condition is preserved, can have an extended useful life. A shift in the focus to valuation methodologies for civil infrastructure that is representative of an asset's condition will be discussed in the following section.

2.4.2.3 Asset Valuation: 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 et al 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.

Table 2 – Value Measures for Transportation Facilities by Stakeholders Interests (After [Amekudzi et al 2002]).

Stakeholders	Measures 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 & 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. eg. low income, racial minority and elderly communities	Equity in benefits and burdens of transportation improvements

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. Asset value can be defined in terms of the users and owners within the limits of condition, utilization, and functional adequacy [Cowe Falls et al 2005]. There are various valuation techniques that have been applied to pavements and highways. Table 3 illustrates the valuation techniques for pavements and highways, highlighting the various applications and limitations associated with each. Asset valuation can be represented in past, current, or future value time periods [Amekudzi et al, 2002]. 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 (2004) presents the most referenced asset valuation methods for Civil Infrastructure includes: Book Value (BV), Written Down, Replacement Cost (WDRC), Replacement Cost (RC), and Net Salvage Value (NSV). These methods utilize the cost valuation technique utilized in Table 3.

The Book Value, also known as the Historical Cost, is a past-based approach that utilizes the historical costs adjusted for depreciation or consumption. Historical data on construction costs are used to carry out the valuation. If initial construction costs are not available, historical price factors through the FHWA Highway Price Index are applied to current replacement costs to adjust for inflation, similar to the GAS 34 deflated approach.

The Replacement Cost (RC) method is the cost at the current market that is required to return the asset to its existing original condition accounting for the current deficiencies as a result of deferred maintenance treatments [OECD, 2001; Herabat et al 2003; Cowe Falls et al, 2004; Dewan & Smith, 2005;].

Table 3 - Valuation Techniques Applicable to Pavements and Highways (After [Herabat et. al, 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

Based on its simplicity, the RC method can be communicated and understood with ease. This method was used to value the Chilean network of airport pavements where the degree of pavement distress was utilized as a means for depreciation [de Solminihac et al, 2004]. However, due to the volatility of the market factors, this method is not reliable for future estimates of value. Another, market based approach; the Written Down Replacement Cost (WDRC) is representative of the market value required to return the asset to as new condition adjusted for deterioration of the asset at the time of replacement [Herabat et al, 2003; Cowe Falls et al, 2004; Dewan & Smith, 2005]. The WDRC method provides an indication of the current deteriorated condition of the asset, and unlike the Replacement Cost, it can be predicted into the future through the use of performance models [Cowe Falls et al 2005]. The Net Salvage Value (NSV) represents the value of the materials used for constructing the asset inclusive of the associated disposal costs, the difference between the cost to replace to asset and rehabilitate the asset. Transport Canada has identified this method as a preferred method for the valuation of their rail assets [Cowe Falls et al, 2004].

While the current valuation methods depict how well an agency preserves an asset's condition, the question yet to be addressed involves incorporating the operational efficiency of these assets into the valuation method. There is a need for an asset valuation methodology that can quantify the value of transportation infrastructure, inclusive of the assets' performance both physically and operationally as well as the assets relative importance to other agency assets.

2.5 Summary

This chapter presented a thorough review of, transportation asset management, importance of performance management, the history of infrastructure reporting, pertinent legislation and affecting policies in the U.S, current asset valuation methodologies, practices and shortcomings. The policy implementation of infrastructure reporting for public agencies, particularly, transportation agencies has had rippling effects, transforming the way in which transportation infrastructure is financed and managed. Asset Value is subjective, as it is context dependent as it can be defined in terms of the users and owners. Commonly used methods for the asset valuation of transportation infrastructure were discussed: Book Value (BV), Written Down Replacement Cost (WDRC), Replacement Cost (RC) and Net Salvage Value (NSV). All of these methods are based on the cost approach with some variations. Depreciation methods that are based on accounting principles and the age of an asset, can severely distort the value and usefulness of an asset. The condition-based valuation methods have been the most applicable to transportation infrastructure such as road assets. These methods are more closely aligned to the actual deterioration of the infrastructure. However, they are based on a particular type of condition, physical condition and deterioration, of the asset. The existing asset valuation methods do not consider factors other than physical condition. They do not take into account or capture the functional and relative usefulness of the asset, even though they are an important measure of the operational performance of the asset and more representative of its true value. In contrast with these existing methodologies, the proposed valuation methodology, presented in Chapter 3 will addresses these limitations.

CHAPTER 3: METHODOLOGICAL FRAMEWORK

3.1 Introduction

This chapter presents a generic methodological framework for the valuation of transportation infrastructure that takes the major limitations of current valuation methodologies discussed in the previous chapter into consideration.

3.2 General Valuation Framework

The proposed valuation methodology, as shown in Figure 3, provides a utility-based approach to asset valuation of transportation infrastructure for transportation agencies, using replacement cost as the base value for the asset and factors as the utility multipliers.

The proposed methodological valuation framework addresses three main questions.

4. Is the transportation infrastructure properly maintained or preserved? This corresponds to the physical condition factor of the infrastructure.
5. What quality of service is the transportation infrastructure providing? This question addresses the functionality of the infrastructure to assess whether the services provided by infrastructure is carrying out the task to which it was designed for.
6. What is the utilization of the transportation infrastructure with respect to its capacity and the safe and efficient movement of goods and people? This is captured by the utilization factor that is captures the relative importance of a facility in terms of the amount of its servicing capacity that is utilized.

The proposed valuation framework is generic in nature and can be tailored to accommodate different types of transportation infrastructure. This feature provides flexibility to the framework by offering options at key steps of the methodology to be tailored to the objective at hand. The following sections will describe the components of the framework in more detail. The methodology is divided into three main sections: a scoping process, utility score determination, and lastly valuation, all of which will be discussed in detail in the following sections.

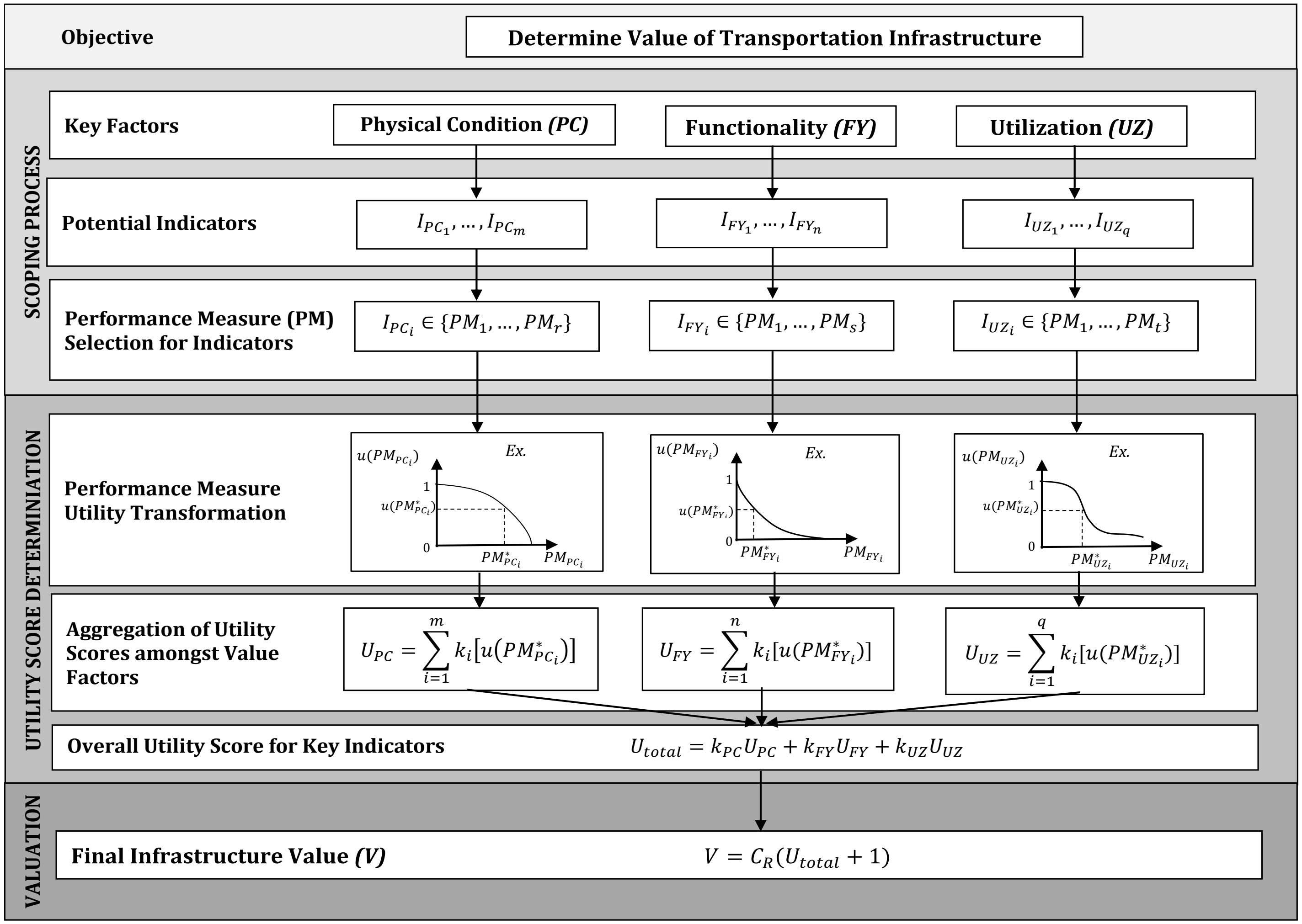

Figure 3 – Proposed Valuation Framework.

3.3 Scoping Process

The scoping process involves the first part of the proposed framework as illustrated in Figure 4. Here, the necessary inputs for facilitating the valuation method are gathered. The framework identifies three key factors that affect the valuation of transportation infrastructure: physical condition, functionality, and utilization.

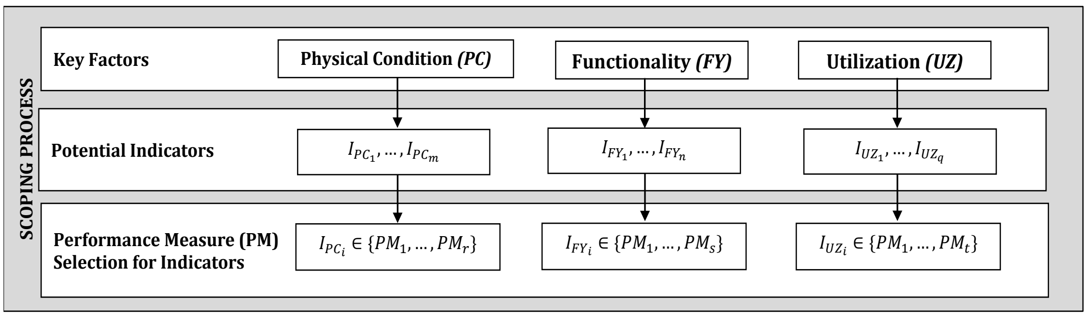

Figure 4 – Scoping Process.

The second level within the scoping process requires the identification of indicators for each of the three key factors. It can be noted that for a particular factor, there could be multiple indicators or attributes contributing to the factor. At a minimum, one indicator must be specified for each factor. The third level within the scoping process requires that performance measures are identified for each indicator. In the initial stages of development, there can be multiple, alternative performance measures to describe each indicator. In addition, it is also possible that an indicator can be described by a combination of one or multiple performance measures. Once all the indicators and their set of performance measures are selected, the next step within the framework transforms the performance level(s) of the particular assets to a uniform scale. The following sections will further discuss the components of the scoping process in detail. It is important to note that the indicators and performance measures should be evaluated using a panel of subject matter experts that are knowledgeable in pavement design, construction and maintenance.

3.3.1 KEY FACTORS

Physical Condition

The first key factor of valuing transportation infrastructure is the physical condition of the asset, representative of the condition of the facility, structurally and on the surface. The physical condition factor provides a measure of how well the assets are being maintained. It is noted that roadway deterioration is not usually the result of poor design and construction practices, rather, is caused by the inevitable wear and tear that occurs over a period of years [Garber & Hoel, 2009]. However there are some instances where the construction and asset management practices provide short-term rather than long-term improvements. Ongoing deterioration of a pavement asset can be a result of variable factors: environmental and climatic conditions, traffic loading conditions, the distribution of truck traffic, drainage issues, and prevailing soil conditions. Low quality and poorly maintained pavement infrastructure also provide a dis-benefit for users in the form of increased vehicle operating costs due to severe damage to their vehicles as a result of vibration from rough surfaces. Failure to invest in maintenance and rehabilitation of deteriorating infrastructure at timely intervals can reduce the effectiveness of the facility, its useful service life, and consequently, its asset value.

There are four characteristics of pavement condition: 1) pavement roughness (rideability), 2) pavement distress (surface condition), 3) pavement deflection (structural adequacy), and 4) skid resistance (safety). The physical condition of an infrastructure is a measure for which the agency can assess whether their management strategies are effective. Its effectiveness is also indirectly evaluated through road user satisfaction representative of their perception of safety and comfort when using the facility. There are series of performance measures that are used to represent the physical condition of a pavement asset. Such performance indicators vary dependent on the functional class of roadway. Commonly used performance measures include the international roughness index (IRI), pavement serviceability index (PSI), ride score (RS) for the ride quality, condition score (CS) as a combined index of ride quality and surface condition in terms of distress, and skid number (SN) as a measure of pavement safety representative of the friction on the pavement surface. The pavement distress refers to the condition of a pavement surface in terms of its general appearance [Haas et al 1999; Garber & Hoel 2009]. The performance measures aforementioned have reliable data and are readily available to many transportation agencies for their highway assets.

Functionality

In addition to the physical condition factor, the second factor for consideration is functionality. Functionality captures the operational efficiency of the transportation infrastructure and quantifies the quality of service provided by the asset for its intended purpose. Within the context of transportation infrastructure, the purpose of transportation systems is to provide for the safe and efficient movement of goods and people. The overall performance of transportation system can therefore exhibit interdependence with other systems such as the economy, environment, and community [Meyer & Miller, 2001]. As a crucial component of a transportation system, the infrastructure provides the modal networks, facilities, and services required for mobility and accessibility in a safe manner. The operational performance of a facility can be described through ease of travel, the quality of service provided and service reliability [Meyer & Miller, 2001]. The overall effectiveness of a transportation system is a measure of the degree of the infrastructure's connectivity between cities, and across modes. On the functional level, transportation is of importance to many activities and services, ranging from employment centers, to the timely delivery of goods, to government services. An asset's functionality can therefore affect its usability and therefore has the potential of impacting customers' level of satisfaction with the services provided by the asset.

Utilization

The last key factor of value as provided in the proposed valuation framework, is the utilization factor. The utilization factor captures the relative importance of the asset being valued in terms of its capacity utilization. If a facility is designed for carrying an anticipated amount of traffic, the efficiency in terms of its usage can be captured by how much of the capacity is utilized. Moreover, if the infrastructure being valued were at or near its servicing capacity, this signifies that it is heavily utilized and thus important for the mobility of road users. The utilization of a facility can then be linked to contribution in the economic prosperity of a region. It also signifies importance to managing agencies whose goal is to provide a service to its customers.

Performance Measures
Table 4 presents a list of potential indicators for the factors of value as well as a list of potential performance measures to choose from. Common measures of for each factor's indicator are listed.

Table 4 – Potential Indicators for Key Value Factors and Associated Performance Measures.

Key Factors	Potential Indicators	Potential Performance Measures
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 (SK)
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 • Number of locations with high crash rates or hazard indexes (exceeding defined threshold)
	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
Utilization	**Capacity Utilization**	• Traffic Intensity (AADT/Capacity Ratio) • Volume/Capacity Ratio • AADT (Annual Average Daily Traffic) • Persons miles traveled • Persons, Trucks, or Vehicles Moved
Sources: [Cambridge Systematics, 2006; Meyer & Miller, 2001; Garber & Hoel, 2009]		

3.3.3 Indicators

For each of the listed factors of value, a decision maker is given the option of choosing one or a set of indicators that provide the best representation of that factor. Selected indicator(s) must be comprehensive and measurable. An indicator is said to be comprehensive if, by knowing the level in a particular situation, the decision maker has a clear understanding of the extent that the associated objective is achieved [Keeney & Raiffa 1993]. In addition, the indicator must be measurable; meaning that the decision-maker's preference for different levels of the attribute is clearly distinguishable. Careful attention must be given to the indicators selected for each indicator, as some indicators may possess overlapping characteristics that must be accounted for.

3.3.4. Performance Measure Selection

Once attributes for each indicator have been chosen, the selection of performance measures or measures of effectiveness must be determined for each attribute under each indicator. The usefulness of performance measures depend on a series of characteristics [Cambridge Systematics, 1980]:

- **Measurability:** data required must be readily available with the tools to perform any calculations
- **Pertinence:** a measure of how well the performance measure captures the objectives for which is was developed
- **Clarity:** indicate the ease of understanding of the measure to policymakers and senior level officials
- **Sensitivity & Responsiveness:** the degree to which the performance measure can detect a level of change in the transportation activity system
- **Appropriate level of detail:** determines whether the measure selected has a level of detail that is suitable for its desired use
- **Insensitivity to exogenous factors:** ensures that measures are not influenced by events other than transportation that could misrepresent the performance indicator
- **Comprehensiveness:** degree to which the performance measure can be applicable to various scenarios and locations
- **Discrimination between influences**: evaluates the extent to which the components that affect the performance can be distinguishable.

Senior level officials and subject matter experts should undergo an evaluation process to establish criteria for selecting indicators and their performance measures. The simplest way to choose these indicators is through an expert opinion. This can be facilitated through the gathering of a group of subject matter experts to determine the best measures to be used. There are a series of methods that can be employed:

- **Direct Weighting Methods [Dodgson et al, 2001**] asks the decision-maker to identify numerical values directly for individual alternatives between 1 and 10 on an interval scale.
- **Analytical Hierarchy Process [Saaty, 1977]** assigns weights based on subjective factors, goals and objectives providing for the synthesis of priorities.
- **Delphi Prioritization Process [Cline, 2000]** allows stakeholders and experts to rank factors of importance in relation to the decision making process.

- **Gamble Method [Keeney & Raiffa, 1993]** prompts the decision maker to select a weight for one measure at a time to compare a surety to a gamble to establish the relative importance amongst the measures.

3.4 Utility Score Determination

The second section of the framework seeks to establish a utility score for each value factor transformed on a uniform scale to combine the effects of physical condition, functionality, and utilization to the value of an asset. Utility theory is based on economics to capture the consumers' preference over a variety of goods, as well as their indifference. Utility functions are used to transform their values into a range from zero to one. A review of utility theory will be presented along with common utility function forms that are used to transform measures.

Utility refers to the measure of satisfaction for a good or service. Utility theory, with its basis in mathematics and economics, has been applied in diverse areas [Keeney & Raiffa, 1993]. It has been expanded in many fields to address decision-making, budget allocation, and many other issues. According to [Keeney & Raiffa, 1993], multi-attribute theory captures a 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. In this valuation framework, utility theory will be used to capture the relative utility of a transportation infrastructure asset with regards to its performance in three key factors: physical condition, functionality and utilization.

Multi-attribute utility theory is used to capture this multi-dimensional utility. A detailed explanation of the theory can be found in [Keeney and Raiffa 1993]. For a given set of attributes: $x_1, x_2, x_3 \ldots x_n$, their utility is represented by Equation 3.1 where f_i is a function of attribute x_i, for $i=1, 2 \ldots n$:

$$U(x_1, x_2, \ldots, x_n) = f[f_1(x_1), f_2(x_2), \ldots, f_n(x_n)] \qquad \text{(Equation 3.1)}$$

Additive Utility: $U(x_1, x_2, x_3 \ldots x_n) = \sum_{i=1}^{n} k_i U_i(x_i)$ (Equation 3.2)

Multiplicative Utility: $U(x_1, x_2, x_3 \ldots x_n) = \prod_{i=1}^{n} (k + kU_i(x_i))$ (Equation 3.3)

The utility function, f_i, has a simple form, an additive or multiplicative as shown in Equations 3.2 and 3.3 respectively. Equations 3.2 or 3.3 must satisfy the following assumptions: preferential independence and utility independence amongst attributes ($x_1, x_2, x_3 \ldots x_n$). Preferential independence ensures that tradeoff between x_1 and x_2 attributes are not dependent on ($x_3 \ldots x_n$) attribute levels. Utility independence states that the value of one attribute's utility function does not depend on the utility of other attributes. The k_i's serve as scaling constants that represent the relative importance of attributes to one another. This may vary by agency and system goals. Estimation of importance factors can be achieved using a scoring/weighted method, where senior level officials weigh the importance of the performance measures within a program combined with the utility achieved based on the program performance. Questionnaire surveys can also be deployed by the agency to capture the relative importance scaling factors from the perspective of an agency and the user.

Utility functions are used to map the physical measure to a uniform scale between zero and one. They can exhibit many forms and can be developed by customizing general function forms. In general, the utility function can be strictly decreasing or increasing. The functional forms can be classified as risk prone, risk neutral, or risk-averse, as illustrated in Figure 5. The functional form of the utility function determines the rate at which the utility changes over the performance measure. A risk-averse function provides a more conservative approach in of utility and therefore receives a lower marginal increase in utility when compared to a decision-maker who is risk-prone. Although Figure 5 displays strictly increasing utility function forms, utility can be represented with a decreasing trend. For example, if a utility function were chosen for the crash rate on a facility, the functional form could be described by a decreasing risk-prone utility function. As the crash rate increases on a facility (less safe), the utility of the highway with regards to safety would be expected to decrease, and probably at a fast rate. The evaluation of a utility function requires the following steps: identification of qualitative characteristics, specification of quantitative restrictions, choice of utility function and check for consistency [Keeney & Raiffa, 1993].

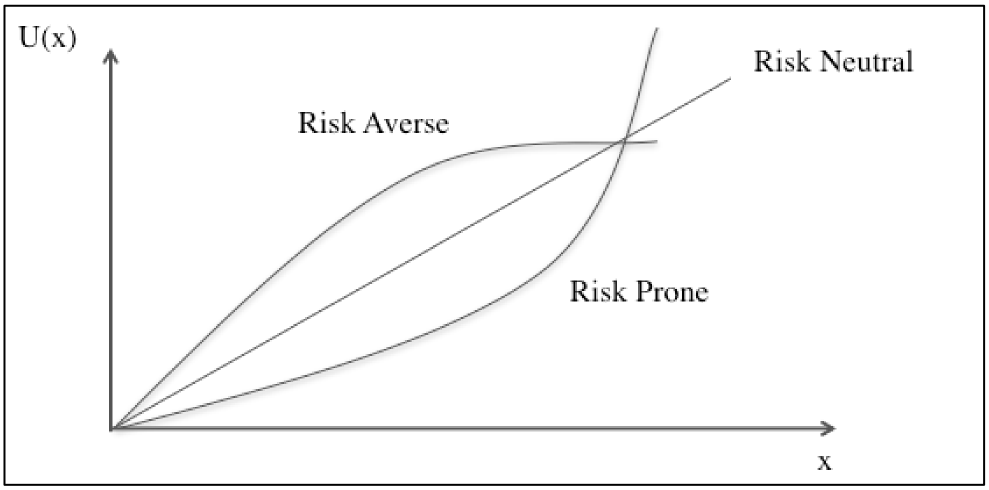

Figure 5 – Relative Shape of Utility Functions.

The consistency of the choice of utility function must hold for all possible values of the measure. If a measure exhibits increasing utility where each additional unit of the measure is more preferable than the previous, an increasing utility functional form should be selected such that if $x_1 \prec x_2 \dots \prec x_n$ $then$ $U(x_1) \prec U(x_2) \dots \prec U\ (x_n)$. The opposite holds true for a decreasing utility function whereby, each additional unit of the measure results in a decreased utility (preference), i.e., if $x_1 \succ x_2\ \dots \succ x_n$ $then$ $U(x_1) \succ U(x_2) \dots \succ U\ (x_n)$. In assessing the type of utility functions to be used for the framework, one must decide whether the utility function is increasing or decreasing and whether the function is risk-prone, risk-neutral, or risk-averse. Typical utility functional forms are presented in Table 5. They have strictly increasing or decreasing characteristics.

Table 5 – Utility Function Forms.

Type	Function Form
Exponential	Decreasing Utility: $u\ (x) = ke^{-\alpha x}$, $k > 0$, $a > 0$ Increasing Utility: $u(x) = k\ (1 - e^{-\alpha x})$, $k > 0$, $a > 0$
Sigmoidal (S-Shape)	Decreasing Utility: $u\ (x) = ke^{-\alpha x^2}$, $k > 0$, $a > 0$ Increasing Utility: $u(x) = k\ (1 - e^{-\alpha x^2})$, $k > 0$, $a > 0$

The coefficients (k) and (a) are to be calibrated so that a utility of one (1) yields the most preferable option and a utility of zero (0), the worst. A five-point assessment method can be deployed to calibrate the utility function by providing values of the desired utility function at five points from, between, and inclusive of the extremities, zero and one. Then, using a simple tool such as Excel Solver, one can calibrate the functions. Within the proposed methodology, the calibration of the utility functions is a daunting task, as a substantial effort in determining the scales of utility functions is required. In addition, the establishment of the thresholds for the highest utility (1) for a particular indicator and lowest (0) is challenging and requires the discussion and consensus amongst subject matter experts for the infrastructure being valued.

3.5 Valuation Framework Formulation

A utility score for each indicator is calculated and then combined for each key factor of value: physical condition, functionality, and utilization as illustrated in Equations 3.1, 3.2, and 3.3 respectively. The expressions $[u(PM^*_{PC_i})], [u(PM^*_{FY_i})], and\ [u(PM^*_{UZ_i})]$ represent the mapping of the performance measures selected for indicators on a scale between zero and one. The number of indicators for physical condition, functionality, and utilization are represented by m, n, and q respectively. The (k_i's) in Equations 3.1 to 3.3 are relative importance of the indicators selected for each factor of value, ranging between zero and one. The utility scores for each factor of value ($U_{PC}, U_{FY}\ and\ U_{UZ}$) are then calculated by summing the contributions of each factor's indicator. Once the utility for each of the factors are determined, an overall utility score is computed for the asset shown in Equation 3.4. The terms, $k_{PC}, k_{FY}\ and\ k_{UZ}$, are the relative importance terms for the factors of value whose sum equates to one.

$$U_{PC} = \sum_{i=1}^{m} k_i[u(PM^*_{PC_i})] \quad \text{(Equation 3.1)}$$
$$U_{FY} = \sum_{i=1}^{n} k_i[u(PM^*_{FY_i})] \quad \text{(Equation 3.2)}$$
$$U_{UZ} = \sum_{i=1}^{q} k_i[u(PM^*_{UZ_i})] \quad \text{(Equation 3.3)}$$
$$U_{total} = k_{PC}U_{PC} + k_{FY}U_{FY} + k_{UZ}U_{UZ} \quad \text{(Equation 3.4)}$$

The final step of the methodology is to estimate the value of the asset, V, as a function of the asset's replacement cost and its utility. The process involves multiplying the replacement costs (C_R) by a utility multiplier, $(U_{total} + 1)$ as shown in Equation 3.5. The valuation method implies that at minimum, the value of an asset should be equal to its replacement cost.

$$V = C_R(U_{total} + 1) \quad \text{(Equation 3.5)}$$

Based on the performance of the asset in terms of the factors of value aforementioned, an increased value capturing the asset's productivity is factored into the multiplier. With an overall utility score of one, the value of the asset will be twice the value of its replacement cost. The physical, functional, and utilization efficiencies of the transportation infrastructure to be valued is captured, providing a measure of how well the assets are maintained, the quality of service provided, and its relative importance to the movement of goods and people within a region.

If an agency is interested in assessing the extent to which their assets' value increase or decrease, the proposed framework can help achieve this objective. Since the framework is condition-based and the utility functions are calibrated by performance measures, a range of sensitivity analysis can be performed to assess how the asset value fluctuates. With regards to performance management, agencies can set thresholds for these performance measures to indicate whether action or no action needs to be taken for improving the asset's performance and value.

3.6 Summary

In this valuation framework, utility theory is used to capture the relative utility of a transportation infrastructure asset with regards to its performance. The asset value of infrastructure is related to performance in a unique way, namely, by the physical, functional, and utilization efficiencies. Unlike other valuation methods, this method captures the physical and operational productivity of the infrastructure. The framework provides flexibility in allowing the users to select indicators for the key factors of value as well as the performance measures associated with them. Measures and procedures are suggested for each section of the framework, providing the asset-managing agency with a valuation method that can be tailored to their needs and/or availability of data and resources. Utility functions were normalized based on performance data obtained and were used to capture the physical, functional and economic attributes of the asset value. The following chapter will demonstrate the applicability of the framework with a case study.

CHAPTER 4: CASE STUDY

4.1 Introduction

A segment of Mopac Expressway (Loop 1), bordered by US 290 on the south and US 183 on the North in Austin, Texas was selected as a case study to demonstrate the applicability of the valuation framework. Located in Travis County, Mopac Expressway in general runs north-south, parallel to Interstate Highway 35 (IH-35). It is a 6-Lane freeway with 3 lanes northbound and another 3 southbound. As illustrated in Figure 6, this roadway is one of Texas's most congested roadways, ranking No. 41 on Texas Department of Transportation's "100 Congested Roadways" list for 2011.

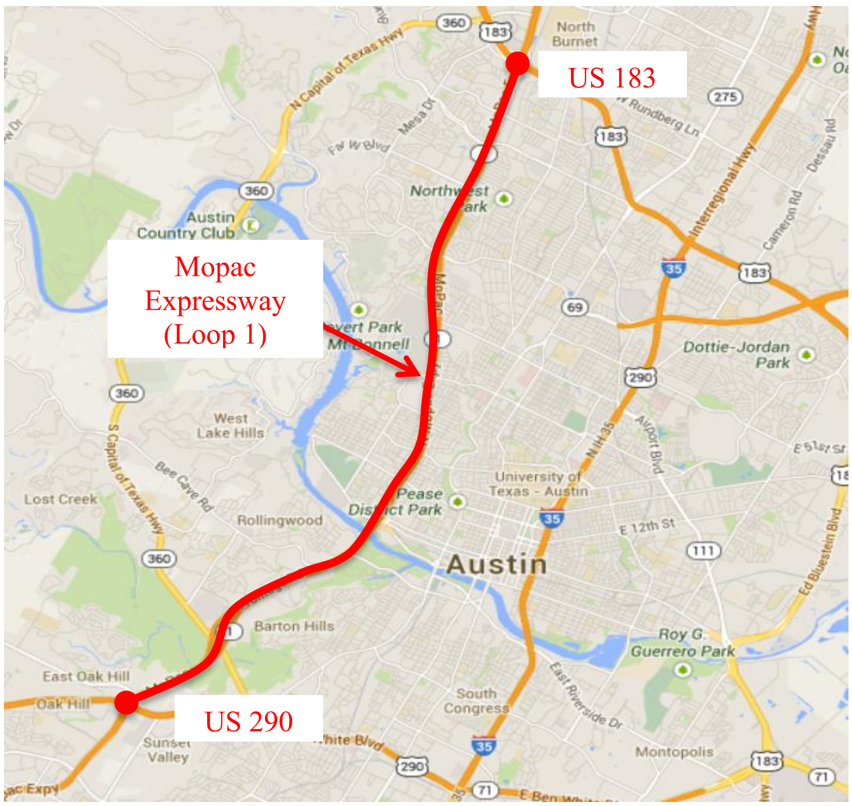

Figure 6 – Highway Case Study Geographic Location [Google Maps, 2013].

It has become even more congested in 2012, increasing its rank to 27 out of 100. On a given day, congestion during morning and evening peak periods are often high on Mopac Expressway and its parallel counterpart, IH-35. While the congestion poses a negative feature of delay and longer average travel times, the utilization of this facility also reveals its importance to the transportation system. Due to the increase in population in Travis County and the development of commercial and residential units parallel to the highway, heavy congestion during rush hours is experienced daily. The importance of this highway is also notable since these business and residential areas rely on the highway for mobility and access to many other parts of the city. Recent improvements are underway for Loop 1 to address congestion and provide enhancements to the highway that were not there previously. Changes include adding managed lanes in the existing right of way, in addition to bicycle and pedestrian improvements, and noise mitigation devices (sound barriers) for neighboring residential areas.

4.2 Valuation Methodology Applied to Pavement Infrastructure

Figure 7 illustrates the application of the proposed framework for the valuation of a highway in the case study with the indicators and their respective performance measures, selected from Table 4. The condition score was used to estimate its physical condition utility. The condition score is a measure of the overall structural and surface performance of the highway. The Pavement Condition Score, unique to Texas is often used to measure the percentage of state-maintained lane miles in "good" or better condition, as reported in the TxDOT's Pavement Management Information System (PMIS). This is a combined index of the distress and ride quality of a pavement. In this case, two measures were accounted for under this indicator.

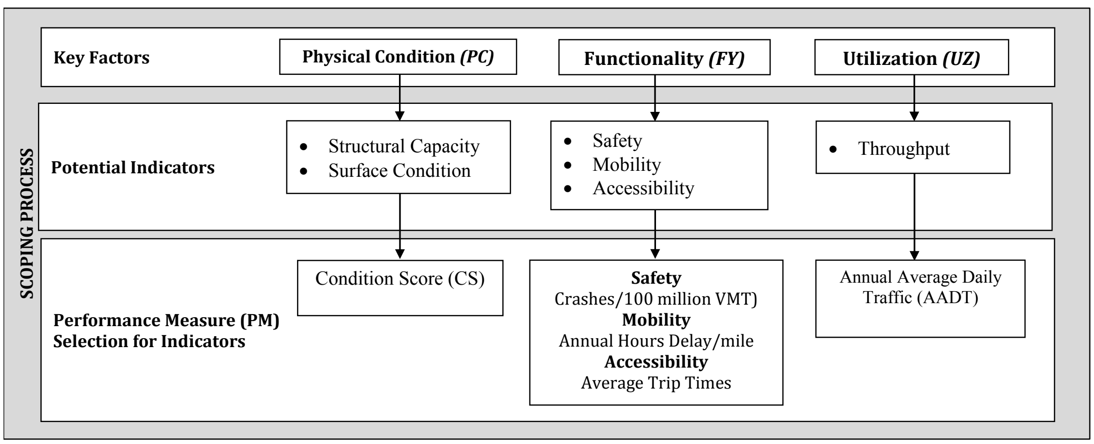

Figure 7 – Scoping Process for Case Study.

The functionality factor captures the operational productivity of the transportation infrastructure and quantifies the quality of service provided by the highway. In the transportation infrastructure context, the purpose of transportation systems is to provide mobility and accessibility in a safe and efficient and timely manner. It is, therefore, fitting the selection of these characteristics as indicators: safety, mobility and accessibility. The performance measures for these indicators include: crash rate (crashes/100 million vehicle miles traveled) for the indicator of safety, vehicle miles traveled (VMT) for mobility, and average trip times for accessibility. Lastly, when it comes to the utilization of a highway and its importance to a region or to specific business industries, one can refer to the simplest indicator, the throughput or traffic volume. One measure that is representative of this throughput is the annual average daily traffic (AADT).

Table 6 provides the data used for the valuation of the Mopac Expressway for the case study. All measures used are representative of statistics from the year 2011. Texas Department of Transportation (TxDOT) has an extensive database of performance data. The Texas Statewide Planning Map was used to estimate the average AADT along the segment, which are listed in Appendix A.

Table 6 – Case Study Profile.

Measure	Value
Segment Length (L)	12.2 miles
Number of Lanes	6 Lanes (3/direction)
Replacement Cost ($2011)[5]	$223,935,000
Functional Class	Urban Principal Arterial, Freeway & Expressway
Average Trip Time (Urban Area)	30 minutes
AADT[3]	143,500 vehicles/day
VMT (AADT x L)	1,750,700 vehicle-miles traveled
Number of Crashes (2011)	199
Crash Rate[4]	113.67 crashes per million VMT
Average Condition Score [4]	97.12
Source: [1] TxDOT – Texas 100 Congested Roadways [2] TxDOT Statewide Planning Map, [3] Texas Crash Records Information System (CRIS) [4] Highway Economic Requirements System Technical Report [USDOT, 2005] [5] Appendix A	

4.3 Valuation Method Comparison

To assess how the results of the proposed valuation framework compare to traditional approaches, a total of six methods were used: Straight-line depreciation (SLD), Some-of-Years-Digits (SOYD), Declining Balance (DB), Double- Declining Balance (DDB), Replacement Cost (RC), and Written Down Replacement Cost (WDRC). Most of these traditional methods require the use of the historical cost in their computations. However, if historical information is not available about the particular infrastructure being valued, the historical cost can be estimated by deflating the replacement cost to the year of construction by a cost index. In the case of 12.2-mile segment of Mopac Expressway, the latter method was used. The replacement cost for an asset varies on a yearly basis as it is tied to the market forces.

The Highway Economic Requirement System Technical (HERS-ST) Report provides a method to estimate the Replacement Cost (RC) of pavement infrastructure by functional class and type of construction [U.S DOT, 2005, Appendix A]. These cost estimates are based on a national average and therefore must be adjusted for state costs differences as well as terrain. State adjustments factors listed in Appendix C are applied to Equation 4.1 to adjust for the cost variation by region.

$$RC = UC \times N_L \times L_S \qquad \text{(Equation 4.1)}$$

Where *RC* is the replacement cost of the asset, *UC* is the unit construction cost per lane-mile for the replacement of that asset, N_L represents the number of lanes of the roadway and lastly, L_S is the length of the segment in miles. The Texas state factor was used to estimate the cost of the Mopac Expressway segment. Rolling Terrain was assumed for Texas with a factor of 1.2. The HERS-ST provides unit construction costs in 2002 dollars. Therefore, in order to estimate the replacement cost within a specific year, these factors needs to be indexed to the current year. The Consumer Price Index (CPI) was used as the indexing factor listed in Appendix E. Appendix A demonstrates the calculations for the replacement costs.

The Written Down Replacement Cost indexes the replacement cost by a condition factor equivalent to the ratio of the current condition of the highway to the best condition as shown in Equation 4.2:

$$WDRC_j = RC_j \times \left(\frac{CN_j}{CN_{best}}\right) \qquad \text{(Equation 4.2)}$$

Where WDRC is the value of the asset in terms of the written down replacement cost of the asset in year j, RC_j is replacement cost of the asset in year j, CN_j is the current condition score of the asset and CN_{best} is the best possible condition score.

In the estimation of the other methods, a series of estimations were made. The year of construction and analysis was assumed to be 1982 and 2011 respectively. The year of construction was an estimate for the segment since the segments of the highway were built at different times. The average service life for the flexible pavement was assumed to be 30 years. In addition, the salvage value was assumed to be 10 percent of the replacement cost.

4.4 Sensitivity Analysis

The framework allows for the demonstration of what-if scenarios, allowing agencies to evaluate how their assets' value fluctuates based on changes of the key factors of value: physical condition, functionality and utilization. This feature can allow agencies to evaluate the changes of their infrastructure value due to either improving or worsening conditions, allowing them to take corrective actions if applicable. Additionally, this feature can allow agencies to assess overall network performance. A series of scenarios were analyzed with the variation of one indicator keeping other indicators at the base (current year) condition. The first scenario assessed the variation of the physical condition measure, condition score as (CS), and its effect on the Mopac Expressway segment's value. The second scenario assessed the variation of the functionality indicators, safety, mobility and accessibility, and their effect on the value of the Mopac Expressway segment's value. Lastly, the effect of variation of the utilization measure was assessed as well.

CHAPTER 5: RESULTS

5.1 Proposed Valuation Method Estimation

Based on the performance measures reported in the case study, utility functions were calibrated by scaling their values with a one for the most desirable or the maximum possible value of the performance measure and a zero for the worst potential value of the performance measure. Table 7 provides the list of calibrated utility functions for each performance indicator.

Table 7 – Case Study Utility Function Calibration.

Value Factors	**Performance Indicator *(x)***	**Utility Functions *U (x)***
Physical Condition (PC)	Condition score	$U_{PC} = 1.01\left(1 - e^{-0.0004x^2}\right)$
Functionality (FY)	Safety: Crash Rate	$U_{SAFETY} = 1.0(e^{-0.0088x})$
	Mobility: VMT	$U_{MOBILITY} = 1.0(1 - e^{-0.000051x})$
	Accessibility: Average Trip Times	$U_{ACCESSIBILITY} = 1.002\left(1 - e^{-0.0025x^2}\right)$
Utilization (UZ)	Capacity Utilization: AADT	$U_{UZ} = 1.0(1 - e^{-0.00002x})$

Once the utility functions were chosen and calibrated, the utility scores for Mopac Expressway based on physical condition and utilization were calculated as displayed in Table 8. For the purpose of the case study and to demonstrate the applicability of the proposed method, the importance factors for the three key factors (physical condition, functionality, and utilization) were distributed evenly and were assumed to be 0.33. A more accurate representation of the degree of importance amongst these key factors can be obtained through a synthesis of a panel of subject matter experts' in the areas of pavement design and operations, and transportation asset management. Of the three indicators of functionality, safety, mobility and accessibility, the importance factor for safety (0.4) was weighted higher than both mobility (0.3) and accessibility (0.3). This was based on the notion that for any transportation infrastructure, the highest priority is to provide a safety means of travel.

Table 8 – Utility Score & Valuation Estimates.

Value Factors	Utility Scores	
Physical Condition (U_{PC})	$U_{PC} = 1.01\left(1 - e^{-4\times10^{-3}(97.11)^2}\right) = 0.987$ $k_{PC} = 0.33$	
Functionality (U_{FY})	$U_{SAFETY} = 1.0\left(e^{-8.8\times10^{-3}(113.67)}\right) = 0.367$ $k_{SAFETY} = 0.4$	$U_{FY} = 0.4(0.367) + 0.3(0.590) + 0.3(0.223) = 0.391$
	$U_{MOBILITY} = 1.0\left(1 - e^{-5.1\times10^{-5}(1750700)}\right) = 0.59$ $k_{MOBILITY} = 0.3$	
	$U_{ACCESSIBILITY} = 1.0\left(1 - e^{-2.5\times10^{-3}(30)^2}\right) = 0.223$ $k_{ACCESSIBILITY} = 0.3$	$k_{FY} = 0.33$
Utilization (U_{UZ})	$U_{UZ} = 1.0\left(1 - e^{-2\times10^{-5}(143500)}\right) = 0.943$ $k_{UZ} = 0.33$	
$U_{TOTAL} = 0.33(0.987) + 0.33(0.391) + 0.33(0.943) = 0.784$		
$V = C_R(U_{total} + 1) =$ \$223,935,300$(0.784 + 1) \cong$ \$ 399.6 *Million*		

It can be seen that the utility score for the physical condition measure is very high. However, the overall utility score is reduced because of the functionality characteristics. In other words, the highway functional efficiency significantly affected the overall utility of the asset due to longer than average trip times and a relatively high crash rate. The asset value of the 12.2-mile roadway segment was estimated and the replacement cost reported in Table 6, the final value of the 12.2 mile Mopac Expressway segment bordered by US 290 on the south and US 183 on the north, was estimated to be \$399.6 Million.

5.2 Comparison of Valuation Methods

Of the methods used for the case study, there are two categories of methodologies: depreciation-based vs. condition-based asset valuations. The same input data yielded different asset values for different valuation methodologies under comparison, as many assumptions were used to conduct the valuation. There is a noticeable inherent bias in comparing all the valuation methods of varying approaches and techniques, as their foundation and data requirements are not aligned. Hence, the reason the depreciation-based methods were analyzed separately from the current and condition-based methods. Figure 8 presents the value of the Mopac Expressway using the depreciation-based methods discussed previously.

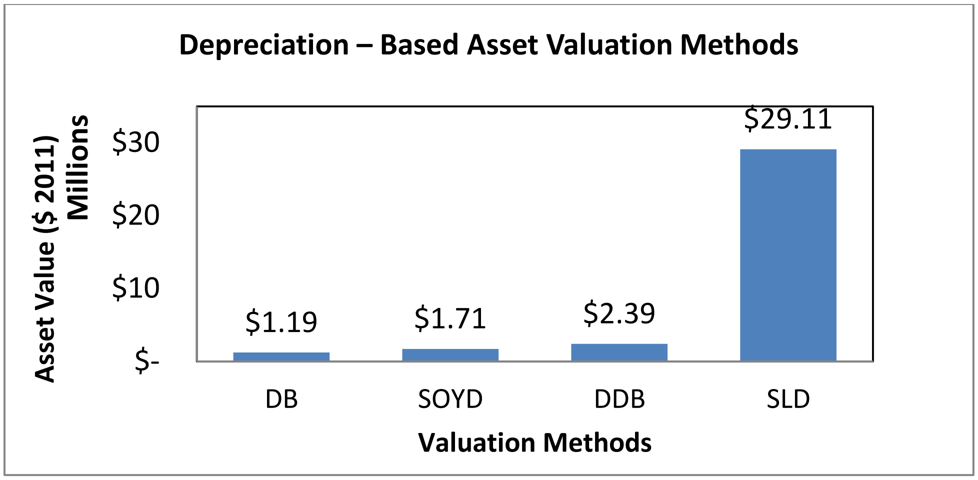

Figure 8 – Comparison of Depreciation – Based Valuation Methods.

A large dispersion was observed amongst depreciation-based methods based on the coefficient of variation amongst the methods reported in Table 9. Compared to other methods, the proposed framework values the 12.2-mile segment much higher because of the additional utility. The SLD method estimated the lowest value of Mopac Expressway as it assumes that the asset's condition continuously decreases over time.

Table 9 – Comparative Statistics for Depreciation-Based Methods.

Comparative Statistics	
Range ($)	$ 27,917,270
Average ($)	$ 8,600,697
Standard Deviation ($)	$ 13,682,676
Coefficient of Variance (COV)	1.591

All the depreciation-based methods were on the lower end of the spectrum for valuation as there is no relationship between accounting based depreciation and condition. Since these methods rely heavily on the age and useful life of the asset, the expected life is consumed at a fast rate, resulting in significantly low value estimates. Road assets do exhibit initial deterioration but stabilize relatively quickly resulting in very small changes in condition provided adequate routine maintenance investments are employed until wear-out failures are inherent. The deterioration of the asset, however, is not accurately depicted by depreciation methods. As a consequence, these estimates can distort the true picture of the usefulness and/or importance of a particular asset.

In analyzing the dispersion of the condition-based methods, including the proposed utility-based method, it was observed that there was less variation amongst these methods as seen in Figure 9 and Table 10. These methods showed less dispersion amongst each other and provide more stable estimates of the asset value.

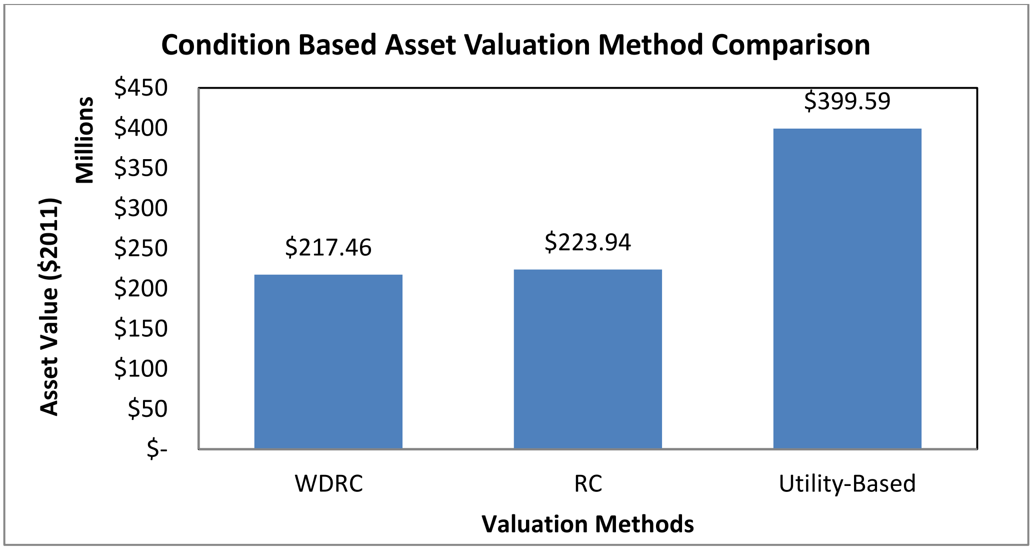

Figure 9 – Comparison of Condition-Based Valuation Methods.

Table 10 – Comparative Statistics for Condition-Based Methods.

Comparative Statistics	
Range ($)	$182,123,850
Average ($)	$280,328,785
Standard Deviation ($)	$103,331,705
Coefficient of Variance (COV)	0.369

The Written Down Replacement Cost (WDRC) indexes the replacement cost by a factor proportional to the condition of the asset to its best condition. Since the condition score for the case-study segment length was near the highest value of 100, this estimate of the segment's asset value did not differ significantly from the Replacement Cost (RC). The replacement costs used were based on unit costs for the reconstruction of the pavement. This estimate can exhibit bias due to the fact of improvement in technology, construction standards, and improved materials over the years. The proposed method, as expected, resulted in the largest value estimate due to the structure of multiplier, accounting for an additional utility and value. This method, inclusive of the physical condition of the asset, also accounts for functional and economic obsolescence and is representative the usefulness of the particular asset.

5.3 Sensitivity Analysis Results

To demonstrate the application of the framework, a series of sensitivity analyses were conducted to assess the impact of the variation of asset value parameters on asset value. In each sensitivity scenario, holding all other parameters fixed, one parameter was allowed to change to see its individual effect on changes in asset value.

A series of scenarios were evaluated and are illustrated in Figure 10, Figure 11 and Figure 12. The red round markers were used to indicate the base condition on each of the figures. The first sensitivity case involved looking at the effect of variation of the condition score, physical condition measure, on the asset value, shown in Figure 10.

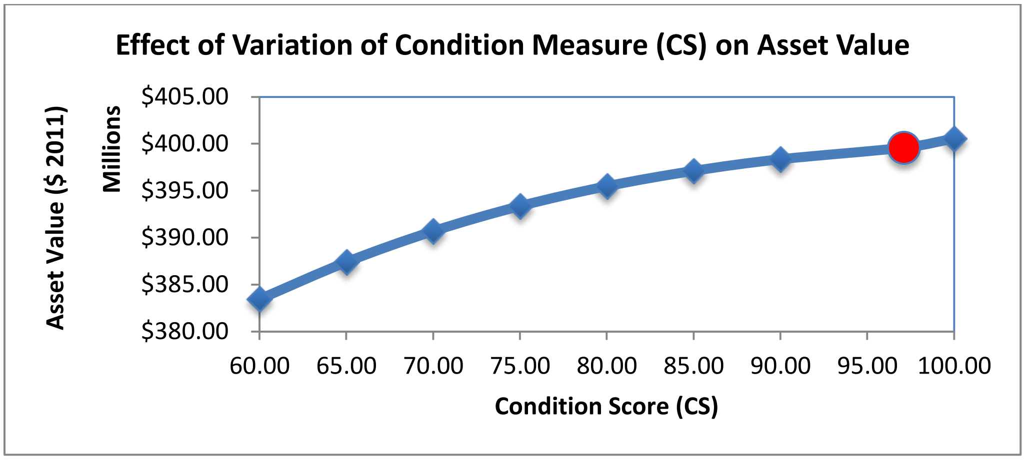

Figure 10 – Effect of Variation of Physical Condition Indicator on Asset Value.

It can be seen that the condition score for the current (actual) condition of the Mopac Expressway (SL 0001) is near its maximum value of a condition score of 100. If the condition score were to increase to 100, the segment's Asset Value is expected to increase by 0.24 percent as detailed in Appendix F. On the other hand, if the condition score were dramatically decreased to 60 from 97, its asset value will be expected to decrease by 4.04 percent. Since monetary terms can be easily communicated, transportation officials can demonstrate why the physical condition of their assets should be maintained, citing that the range of the asset's value can decrease if corrective actions are not taken.

The effect of variation of the functionality indicators on asset value were analyzed next as illustrated in Figure 11. The tables for the graphs are listed in Appendix F. It can be seen that there are most noticeably different trends in the figures. These are solely dependent on the type of utility function form used and the performance measure selected for that indicator.

With respect to the safety indicator, an increase in the crash rate on the roadway corresponds to a decrease in the asset value of that segment. If the goal of an agency is to improve safety, then not only is there an incentive for providing safe travel for the system users, but also to increase the asset's functional efficiency and therefore, it's value. The results also indicate that if the crash rate were to decrease to zero, the asset value would increase by 4.72 percent from $399.6 M to $418.5 M, a significant improvement. On the contrary, if the safety conditions with respect to the crash rate were to decrease with an increased crash rate of 300, then the asset's value is expected to decrease by 2.21 percent from $399.6 M to $390.8 M.

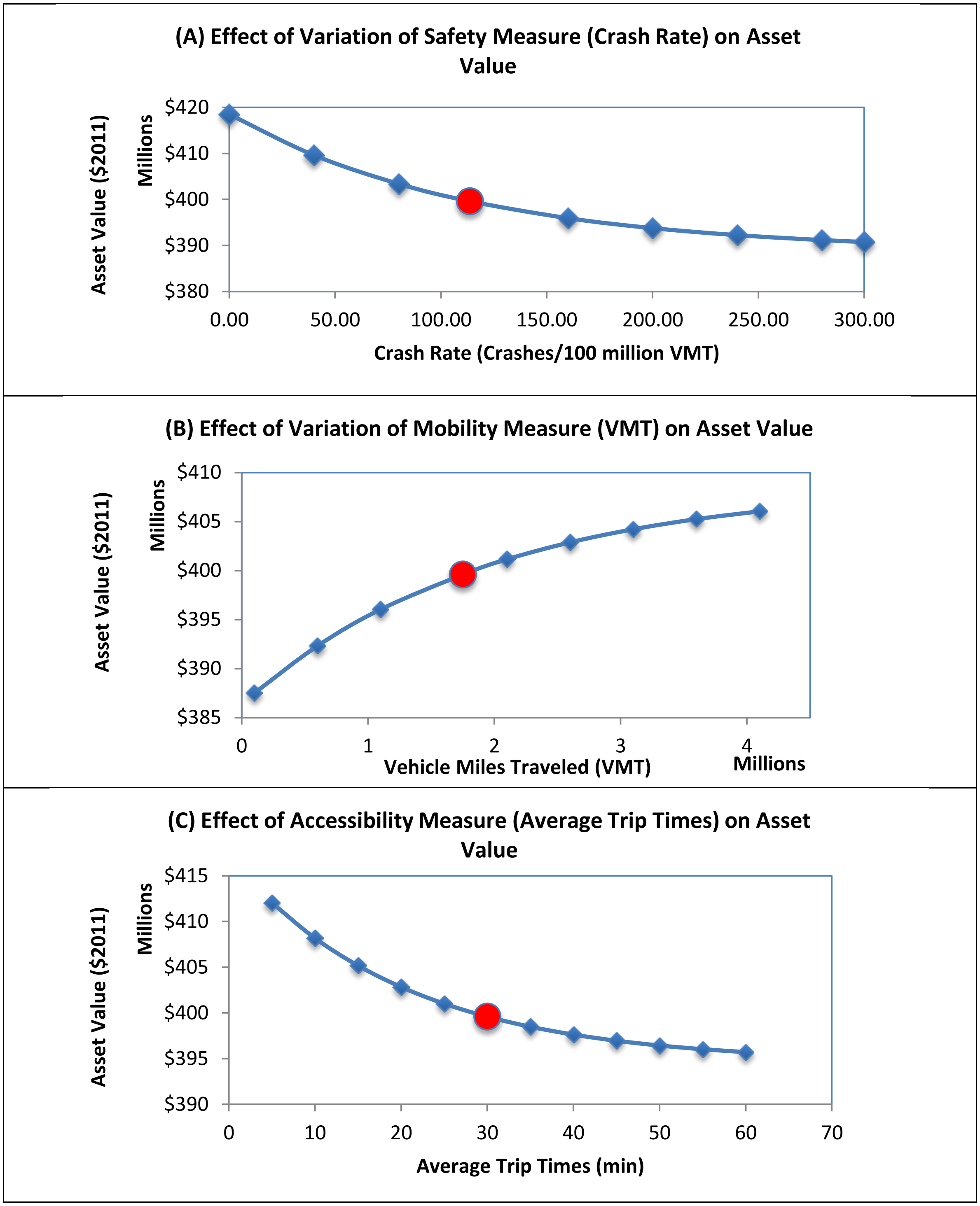

Figure 11 – Effect of Variation of Functionality Indicators on Asset Value.

With regards to the mobility indicator, a variation of the VMT shows that as the VMT increases, so too does the asset value of the segment but at a decreasing rate. If the VMT were to decrease to 1,000,000, the asset value is expected to decrease by 3.00 percent from $399.6 M to $387.5 M. Lastly, within the functionality indicators, variation of the average travel times indicates that as travel times increase, the asset value of the segment decreases. If the travel times were increased to 60 minutes, the asset value would then be decreased by approximately 1 percent from $399.6 M to $396 M.

The last sensitivity case involved analyzing the impact of the variation of the utilization measure, AADT presented in Figure 12. It can observed that as the average annual daily traffic reaches its optimal value, the asset value tends to increase, aligning with the notion that the system is operating at an optimal level and its efficiency is maximized. Similarly, a decrease in the AADT signifies that the system is not being utilized at its full potential. If the AADT were to decrease to 60,000 veh/day, then the asset value is expected to decrease by 4.70 percent from $399.6 M to $380.8 M.

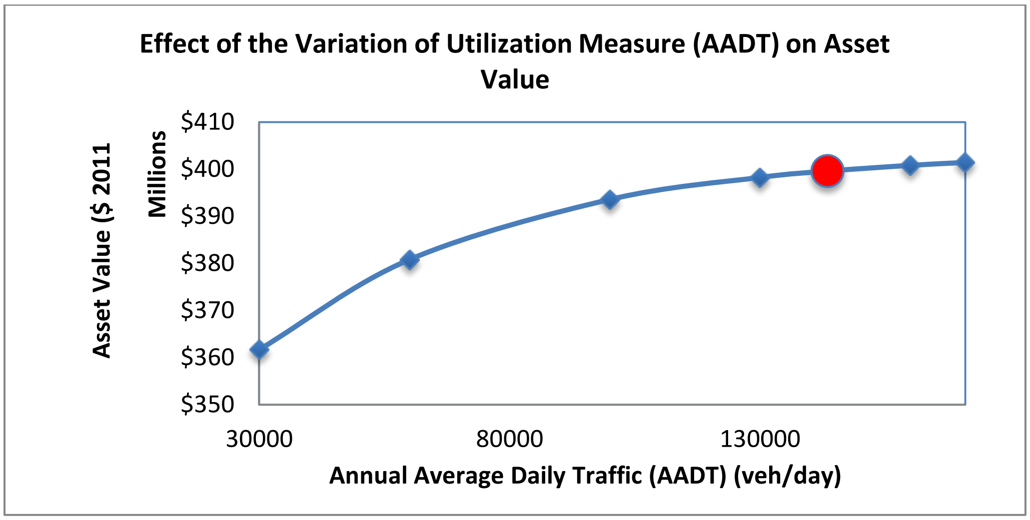

Figure 12 - Effect of Variation of Utilization Measure on Asset Value.

In these analyses, all other parameters were held fixed when controlling for one variation. However, it is likely in the case of highways, that more than one performance indicator changes at the same time. Additional sensitivity analysis can be performed to assess the combined effect of changing more than one of parameters on the asset value of the infrastructure. Overall, these sensitivity analyses highlight an important area of discussion for decision-makers of transportation agencies with regards to the added value obtained from investments to their transportation infrastructure and the prioritization of these investments with regards to the agency's goals.

CHAPTER 6: CONCLUSIONS

The primary objective of this research was to develop and present a methodological framework for the valuation of transportation infrastructure. A case study was used to demonstrate its applicability to the valuation of highways. This chapter presents the conclusions drawn from the analysis performed in this research.

6.1 Concluding Remarks

Transportation infrastructures, as many other critical group of infrastructure, are embedded in our communities. A staple of a thriving nation, the purpose of transportation infrastructure is to transport goods and people in a safe and efficient manner, providing a valuable service to its users. The degree of interdependency of a transportation system with other infrastructure systems indicates that they are to be maintained not only for today, but also indefinitely. The failure of one component of the system can compromise its functionality and overall value to its users and a region, indicating the importance of preserving these assets for the present and future.

Asset management and asset valuation are of emerging interest as state and local agencies are pressed with being more accountable in their expenditures and improvements to social capital such as transportation infrastructure. Asset management places emphasis on the effective managing strategies as well as the performance and condition of the managed assets. At the frontier of innovation and efficiency, technological advancements in asset management coupled with higher quality materials and enhanced construction designs and standards have made it possible for agencies to provide cost-effective management strategies in preserving their infrastructure. The importance of performance monitoring is therefore a crucial aspect of sound asset management practices.

There are various approaches to the valuation of transportation infrastructure, all of which are context dependent and based on the objectives of the valuing entity. These differences affect the stability of valuation estimates as they can be time-based (past, present, future), condition-based, productivity-based, and income-based, all of which are based on many assumptions. Depreciation methods that are based on accounting principles and the age of an asset, can severely distort the value and usefulness of an asset. The condition-based valuation methods have been the most applicable to transportation infrastructure such as road assets. These methods are more closely aligned to the actual deterioration of the infrastructure. However, they are based on a particular type of condition, physical condition and deterioration, of the asset.

The existing asset valuation methods do not consider factors other than physical condition. They do not take into account or capture the functional and relative usefulness of the asset, even though they are an important measure of the operational performance of the asset and more representative of its true value. In contrast with these existing methodologies, the proposed valuation methodology addresses these limitations. The framework developed provides a utility-based approach to asset valuation of pavements for transportation agencies, using replacement cost as the base value for the asset and a utility multiplier to account for factors that affect the asset value. The framework also provides flexibility for the application of other transportation infrastructure in that it allows the user to determine the major indicators of the value factors with three main components, physical condition, functionality and utilization. Failure to include such additional factors can result in the distortion of the true value of an infrastructure asset, underestimating the value in some cases and overestimating in others.

The use of Asset valuation as one of many decision-support tools can be a valuable mechanism for the management of infrastructure assets as it is an easily understood measure that can facilitate better communication on the performance of the assets between the users, managing agencies, legislative representatives and stakeholders. The development of this valuation approach serves as a starting point for assessing, in addition to the physical condition of an asset, the operational measures that can often make an asset less useful to its customers and the managing agencies. Utility theory can be utilized to combine the effect of performance indicators of varying measures and scales on the value of an asset.

The proposed framework can assist state and local transportation agencies in the optimization of resource allocation procedures for better coordination of asset investments. In particular this can help decision-makers prioritize their investments and provide an indication of how the agency values the operational aspects of a transportation system with respect to safety, preservation, mobility, travel time reliability and other features. Integration of this tool in existing performance management systems can enhance the decision-making process of senior level officials by providing a clear and effective measure that is easy to communicate. The benchmarking of condition and performance in a transportation agency can ensure that assets are managed in an efficient manner. The linking of an agency's goals and performance, both physically and functionally, to asset value provides a true indication of asset value. It is important to provide agencies with decision-support tools that can provide indications of future investments that are aimed at effective and efficient management strategies. This tool allows agencies to detect deficiencies if any, in the management of its assets, providing a feedback mechanism that can foster an introspective review of its current management practices that may need further refinement or possibly elimination. The proposed method can be used to facilitate benefit-cost analyses to quantify the impact of infrastructure investments.

6.2 Future Work

Development of the proposed- utility based methodology serves as a starting point for assessing the usefulness of a particular pavement asset. The framework currently uses three main factors of value. Additional research can be done to look at other factors that can affect the value of an asset. The framework does not account for environmental impacts such as air and noise pollution along a particular roadway, as this provides another area of improvement. Future work should explore the form of the utility multiplier, including a multiplicative form in which the utilities for physical condition, functionality and utilization factors are multiplied to produce a combined utility rather than adding these factors. The utility multiplier of the proposed valuation ranges from zero to two, where at minimum, the value of an asset is its replacement cost and at maximum, the value of an asset can be twice its replacement cost. This can be improved by establishing utility thresholds to scale the multiplier. Relating the replacement cost within the valuation formulation to the design standards of the infrastructure being valued can improve the accuracy of the asset value estimation. Overall, the approach presented raises an important area for more research and discussion with respect to how transportation agencies value their assets, along with the incorporation of other operational factors besides physical condition that can impact the value of an asset.

Appendix A: Case Study Data

Annual Average Daily Traffic (AADT) Estimates [TxDOT 2013]

AADT Mopac Expressway (SL0001)	
Count	AADT
1`	102000
2	139000
3	155000
4	151000
5	135000
6	158000
7	144000
8	164000
Average AADT	143500

Appendix B: Replacement Cost Calculations

Replacement Costs Estimation [USDOT, 2005, BLS, 2013]

Step 1: Index Unit Replacement Cost to Analysis Year

Functional Class	**Urban Principal Arterial Freeway & Expressway**
UNIT RECONSTRUCTION COST ($/LANE-MILE) 2002	$2,272.00
CPI 2002	179.9
CPI 2011	224.939
Unit Replacement Cost ($2011/LANE-MILE)	$2,840.81

Step 2: Index Texas State Factor to Analysis Year

TEXAS STATE FACTOR (2000)	0.687
CPI (2000)	172.2
Texas State Factor (2011)	0.897404721

Step 3: Terrain Adjustment Factors

TERRAIN ADJUSTMENT	**Factor**
FLAT	1
ROLLING	1.2
MOUNTAINOUS	1.6

Step 4: Estimate Replacement Cost

SEGMENT LENGTH (mi)	12.2
# Lanes	6
Terrain: Rolling	1.2
Unit Replacement Cost ($2011/lane-mile)	$2,840.81
TEXAS STATE FACTOR (2011)	0.897404721
RC=Unit Replacement Cost x #lanes x State Factor x Terrain Factor	
Replacement Cost $	$223,935,321.66

Appendix C: Capital Costs by Functional Class [U.S. DOT, 2005]

Table 6-1. Elemental Capital Improvement Costs (Thousands of 2002 Dollars per Lane-Mile)

	A Reconstruct and Widen Lanes	B Reconstruct Pavement	C Resurface and Widen Lanes	D Resurface Pavement	E Improve Shoulders	F Add Lane at Normal Cost	G Add Lane at High Cost	H Re-Align Pavement at Normal Cost	I Re-Align Pavement at High Cost
Rural Interstate									
Flat terrain	1182	772	669	274	51	1899	2633	2106	10948
Rolling terrain	1325	792	770	292	84	2059	3331	2665	11444
Mountainous terrain	1564	916	927	322	129	2638	8315	3120	12458
Rural Other Principal Arterials									
Flat terrain	923	618	558	220	34	1521	2178	1742	8882
Rolling terrain	1042	635	634	245	57	1629	2629	2103	9396
Mountainous terrain	1197	720	739	267	89	1981	7368	12000	12000
Rural Minor Arterials									
Flat terrain	844	543	520	195	32	1383	1941	1553	1553
Rolling terrain	1019	601	647	210	59	1585	2500	2000	2000
Mountainous terrain	1182	687	761	232	90	1951	7368	11500	11500
Rural Major Collectors									
Flat terrain	889	575	537	199	41	1436	1436	1553	8838
Rolling terrain	973	584	604	211	55	1468	1468	1910	10054
Mountainous terrain	1111	662	699	231	87	1730	6911	11000	11000
Urban Interstate, Other Freeways and Expressways									
Small Urban	1987	1376	1566	334	61	3116	11094	5235	13290
Small Urbanized	2136	1388	1620	395	81	3405	12121	5720	14939
Large Urbanized	3407	2272	2509	530	306	5699	60000	9574	60000
Urban Other Principal Arterials									
Small Urban	1732	1169	1433	280	62	2649	9430	4450	11131
Small Urbanized	1853	1183	1498	331	83	2870	10218	4822	12401
Large Urbanized	2647	1734	2192	416	267	4200	14953	6216	14288
Urban Minor Arterials and Collectors									
Small Urban	1276	883	1084	205	45	1956	6964	3287	8929
Small Urbanized	1337	893	1094	233	55	2061	7338	3463	10003
Large Urbanized	1800	1194	1496	286	150	2858	10173	4801	11179

Appendix D: State Cost Factors [FHWA, 2005]

Table 6-2. 2000 State Cost Factors[a]

State	Factor	State	Factor	State	Factor
AL	0.936	LA	1.016	OH	1.152
AK	1.831	ME	1.541	OK	1.054
AZ	0.855	MD	1.274	OR	1.329
AR	0.640	MA	1.805	PA	1.295
CA	1.262	MI	1.324	RI	0.840
CO	1.060	MN	1.222	SC	1.416
CT	1.009	MS	1.211	SD	0.857
DE	1.349	MO	0.846	TN	0.929
DC	1.018	MT	1.052	TX	0.687
FL	1.020	NE	0.927	UT	0.957
GA	1.091	NV	1.019	VT	1.232
HA	1.146	NH	0.556	VA	1.081
ID	0.733	NJ	0.771	WA	1.139
IL	1.159	NM	0.983	WV	1.196
IN	0.740	NY	1.318	WI	0.974
IA	0.745	NC	0.911	WY	0.990
KS	0.765	ND	0.782	PR	0.725
KY	1.888				

a. Source: Derived from FHWA, "Price Trends for Federal-Aid Highway Construction," quarterly.

Appendix E: Consumer Price Index [BLS, 2013]

Year	CPI
1913	9.9
1914	10
1915	10.1
1916	10.9
1917	12.8
1918	15.1
1919	17.3
1920	20
1921	17.9
1922	16.8
1923	17.1
1924	17.1
1925	17.5
1926	17.7
1927	17.4
1928	17.1
1929	17.1
1930	16.7
1931	15.2
1932	13.7
1933	13
1934	13.4
1935	13.7
1936	13.9
1937	14.4
1938	14.1
1939	13.9
1940	14
1941	14.7
1942	16.3
1943	17.3
1944	17.6
1945	18

Year	CPI
1946	19.5
1947	22.3
1948	24.1
1949	23.8
1950	24.1
1951	26
1952	26.5
1953	26.7
1954	26.9
1955	26.8
1956	27.2
1957	28.1
1958	28.9
1959	29.1
1960	29.6
1961	29.9
1962	30.2
1963	30.6
1964	31
1965	31.5
1966	32.4
1967	33.4
1968	34.8
1969	36.7
1970	38.8
1971	40.5
1972	41.8
1973	44.4
1974	49.3
1975	53.8
1976	56.9
1977	60.6
1978	65.2

Year	CPI
1979	72.6
1980	82.4
1981	90.9
1982	96.5
1983	99.6
1984	103.9
1985	107.6
1986	109.6
1987	113.6
1988	118.3
1989	124
1990	130.7
1991	136.2
1992	140.3
1993	144.5
1994	148.2
1995	152.4
1996	156.9
1997	160.5
1998	163
1999	166.6
2000	172.2
2001	177.1
2002	179.9
2003	184
2004	188.9
2005	195.3
2006	201.6
2007	207.342
2008	215.303
2009	214.537
2010	218.056
2011	224.939

Appendix F Sensitivity Analysis Tables

Legend	Current Condition

Case 1: Variation of Condition Score

CS	$U_{PHYSICAL}$	U_{TOTAL}	Δ% U_{TOTAL}	Asset Value $	Δ Asset Value $	% Δ Asset Value
100.00	1.000	0.789	0.55%	$ 400,557,827.65	$970,386.39	0.24%
97.11	0.987	0.784	0.00%	$ 399,587,441.26	$0.00	0.00%
90.00	0.970	0.779	-0.70%	$ 398,351,651.65	-$1,235,789.61	-0.31%
85.00	0.954	0.773	-1.41%	$ 397,114,301.45	-$2,473,139.81	-0.62%
80.00	0.932	0.766	-2.34%	$ 395,476,153.88	-$4,111,287.38	-1.03%
75.00	0.904	0.757	-3.55%	$ 393,358,066.94	-$6,229,374.32	-1.56%
70.00	0.868	0.745	-5.07%	$ 390,684,742.88	-$8,902,698.39	-2.23%
65.00	0.824	0.730	-6.94%	$ 387,393,064.28	-$12,194,376.98	-3.05%
60.00	0.771	0.712	-9.19%	$ 383,441,925.80	-$16,145,515.46	-4.04%

Case 2: Functionality

a) Safety

Crash Rate	U_{SAFETY}	$U_{FUNCTIONALITY}$	U_{TOTAL}	Δ% U_{TOTAL}	Asset Value $	Δ Asset Value $	% Δ Asset Value
0.00	1.000	0.644	0.869	10.75%	$418,487,582.41	$18,876,998.94	4.72%
40.00	0.703	0.525	0.829	5.70%	$409,628,121.32	$10,017,537.85	2.51%
80.00	0.495	0.442	0.801	2.16%	$403,397,434.37	$3,786,850.90	0.95%
113.67	0.368	0.391	0.784	0.00%	$399,610,583.47	$0.00	0.00%
160.00	0.245	0.342	0.768	-2.09%	$395,933,793.15	-$3,676,790.32	-0.92%
200.00	0.172	0.313	0.758	-3.33%	$393,766,479.27	-$5,844,104.20	-1.46%
240.00	0.121	0.292	0.752	-4.19%	$392,242,249.50	-$7,368,333.97	-1.84%
280.00	0.085	0.278	0.747	-4.80%	$391,170,288.30	-$8,440,295.17	-2.11%
300.00	0.071	0.272	0.745	-5.04%	$390,760,257.84	-$8,850,325.63	-2.21%

b) Mobility

VMT	$U_{MOBILITY}$	$U_{FUNCTIONALITY}$	U_{TOTAL}	Δ% U_{TOTAL}	Asset Value $	Δ Asset Value $	% Δ Asset Value
100000	0.050	0.229	0.730	-6.88%	$387,495,833.04	-$12,091,608.22	-3.03%
600000	0.265	0.293	0.752	-4.14%	$392,311,730.96	-$7,275,710.30	-1.82%
1100000	0.431	0.343	0.769	-2.02%	$396,037,488.85	-$3,549,952.41	-0.89%
1750700	0.593	0.392	0.784	0.00%	$399,587,441.26	$0.00	0.00%
2100000	0.660	0.412	0.791	0.89%	$401,149,794.13	$1,562,352.87	0.39%
2600000	0.737	0.435	0.799	1.87%	$402,874,943.47	$3,287,502.21	0.82%
3100000	0.796	0.453	0.805	2.63%	$404,209,583.22	$4,622,141.96	1.16%
3600000	0.843	0.466	0.810	3.22%	$405,242,110.21	$5,654,668.94	1.42%
4100000	0.878	0.477	0.813	3.67%	$406,040,911.51	$6,453,470.25	1.61%

c) Accessibility

Average Trip Length	$U_{ACCESSIBILIT}$	$U_{FUNCTIONALITY}$	U_{TOTAL}	Δ% U_{TOTAL}	Asset Value $	Δ Asset Value $	% Δ Asset Value
5	0.779	0.557	0.840	7.08%	$412,033,783.97	$12,443,427.97	3.11%
10	0.607	0.506	0.823	4.89%	$408,176,047.43	$8,585,691.42	2.15%
15	0.472	0.466	0.809	3.18%	$405,171,639.18	$5,581,283.17	1.40%
20	0.368	0.434	0.799	1.85%	$402,831,803.69	$3,241,447.68	0.81%
25	0.287	0.410	0.791	0.81%	$401,009,537.97	$1,419,181.97	0.36%
30	0.223	0.391	0.784	0.00%	$399,590,356.01	$0.00	0.00%
35	0.174	0.376	0.779	-0.63%	$398,485,095.98	-$1,105,260.03	-0.28%
40	0.135	0.364	0.776	-1.12%	$397,624,318.61	-$1,966,037.40	-0.49%
45	0.105	0.355	0.773	-1.50%	$396,953,944.51	-$2,636,411.49	-0.66%
50	0.082	0.348	0.770	-1.80%	$396,431,856.64	-$3,158,499.36	-0.79%
55	0.064	0.343	0.768	-2.03%	$396,025,254.20	-$3,565,101.80	-0.89%
60	0.050	0.339	0.767	-2.21%	$395,708,591.90	-$3,881,764.10	-0.97%

Case 3:Utilization						
AADT	$U_{UTILIZATION}$	U_{TOTAL}	Δ% U_{TOTAL}	Asset Value $	Δ Asset Value $	% Δ Asset Value
30000	0.4676421	0.615	-21.58%	$361,681,081.23	-$37,906,360.03	-9.49%
60000	0.7236561	0.700	-10.70%	$380,791,276.51	-$18,796,164.75	-4.70%
100000	0.8946618	0.757	-3.43%	$393,556,014.70	-$6,031,426.56	-1.51%
130000	0.9574312	0.778	-0.77%	$398,241,438.19	-$1,346,003.07	-0.34%
143500	0.9754632	0.784	0.00%	$399,587,441.26	$0.00	0.00%
160000	0.9917947	0.790	0.69%	$400,806,507.00	$1,219,065.74	0.31%
170948.72	1	0.793	1.04%	$401,418,993.82	$1,831,552.56	0.46%

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