JOINT TRANSPORTATION
RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

A METHODOLOGY FOR HIGHWAY ASSET VALUATION IN INDIANA

Michelle S. Dojutrek
Graduate Research Assistant
School of Civil Engineering
Purdue University

Parth A. Makwana
Graduate Research Assistant
School of Civil Engineering
Purdue University

Samuel Labi
Associate Professor of Civil Engineering
School of Civil Engineering
Purdue University
Corresponding Author

SPR-3427
Report Number: FHWA/IN/JTRP-2012/31
DOI: 10.5703/1288284315035

RECOMMENDED CITATION

Dojutrek, M. S., P. A. Makwana, and S. Labi. *A Methodology for Highway Asset Valuation in Indiana*. Publication FHWA/IN/JTRP-2012/31. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2012. doi: 10.5703/1288284315035.

CORRESPONDING AUTHOR

Prof. Samuel Labi
School of Civil Engineering
Purdue University
(765) 494-5926
labi@purdue.edu

ACKNOWLEDGMENTS

The authors hereby acknowledge the constant support provided by Dr. Samy Noureldin of the INDOT Research Office, Mr. Brad Steckler and Mr. John Weaver of INDOT, and Dr. Kumares Sinha of Purdue University throughout the execution of the study. Also, Messrs. Khalil Dughaish, Gary Mroczka, and Dwane Myers of INDOT, and Daniel Keefer of FHWA served on the study advisory committee (SAC) and made valuable contributions at various stages of the project. All the SAC members played important roles by providing general support and readily providing general information or preliminary data. The contributions of Mr. Joel Bump and other data managers at INDOT are herein acknowledged. Finally, we recognize the efforts of Ashish Jain of Purdue University in helping to develop the implementation spreadsheet and Kevin Ford of Purdue University for his contributions at various stages of the study.

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure.
https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at: http://docs.lib.purdue.edu/jtrp/

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-2012/31		

4. Title and Subtitle	5. Report Date
A Methodology for Highway Asset Valuation in Indiana	November 2012
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Michelle S. Dojutrek, Parth A. Makwana, and Samuel Labi	FHWA/IN/JTRP-2012/31
9. Performing Organization Name and Address Joint Transportation Research Program Purdue University 550 Stadium Mall Drive West Lafayette, IN 47907-2051	10. Work Unit No.
	11. Contract or Grant No. SPR-3427
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.

16. Abstract
The Government Accounting Standards Board (GASB) requires transportation agencies to report the values of their tangible assets. Numerous valuation methods exist which use different underlying concepts and data items. These traditional methods have a number of shortcomings, such as their implicit assumption that assets are monolithic and their inability to simultaneously consider a satisfactory range of value-related asset attributes. In a bid to address these limitations, this report proposes a number of valuation methods. The elemental decomposition and multi-criteria (EDMC) method carries out asset valuation on the basis of cost, remaining service life, and the condition of the individual components of an asset. The proposed replacement-downtime-salvage (RDS) method considers only the life-cycle costs, including user cost during work zones and recycling benefits or disposal costs. The third proposed method, decommission-and-reuse (D&R), is based on the real-estate value of the land occupied by the asset. The total value of Indiana's state highway assets was determined in this study using the traditional and proposed methods; using the EDMC, this was estimated as approximately $68 billion. The value of pavements and bridges were $47.1B and $7.83B, respectively; together, these "large assets" constituted approximately 81.34% of total asset value. The total value of smaller assets was approximately $0.6B, constituting approximately 0.83% of the total value of assets; the breakdown was as follows: guardrails, $0.318B; underdrains, $0.005B; culverts, $0.214B; and road signs, $0.019B. The total value of the right-of-way was estimated at $12.04B. Using the straight line depreciation (SLD) method (the most common method used by other agencies), INDOT's pavement and bridge values were determined as $12.4B and $9.59B, respectively. It was observed that the EDMC yields values that are significantly different from those from the traditional method, which could be due to the former explicitly considering the asset as an assemblage of components and thus carries out valuation for each component rather than considering the structure as a monolithic entity. On the basis of the unit asset values derived for Indiana, the existing asset inventory of other states, and the state-specific cost factors, the total estimated value of state-owned highway bridge and pavement assets in the United States was estimated at $1.4T or $4.4T using the traditional SLD and the EDMC methods respectively. For all highways in the United States, the estimated values were found to be $6.54T and $20.8T for the SLD and the EDMC methods, respectively. The study also explored ways by which asset value could be incorporated in investment evaluation.

17. Key Words	18. Distribution Statement
asset valuation, asset management, Government Accounting Standards Board	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	75	

Form DOT F 1700.7 (8-69)

EXECUTIVE SUMMARY

A METHODOLOGY FOR HIGHWAY ASSET VALUATION IN INDIANA

Introduction

As recognized by the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA), a key element of highway asset management is the determination of the total value of the existing stock of assets. Highway agencies require knowledge of the total value of their assets for a variety of reasons, including financing, investment evaluation using asset value instead of individual criteria that have different units, and proper management of infrastructure by monitoring and focusing on value-added investments while minimizing value loss. Other rationales for asset valuation include guidance in measuring the accountability of a highway agency, not only in its disbursements but also in assessment of funding needs, and using asset value as a basis of support for requests for increased funding to maintain or improve current infrastructure. The need for correctly valuing highway infrastructure also stems from the Government Accounting Standards Board (GASB) Statement No. 34, which requires all government transportation agencies, such as the Indiana Department of Transportation (INDOT), to report their tangible capital assets. Thus, INDOT requires a robust and comprehensive method that yields a value of its assets at any year, as that would play many roles in highway management.

This research report provides explicit rationales for conducting asset valuation in the state of Indiana and discusses the role of asset value in INDOT's business processes. During the study, existing literature on the current valuation practices was reviewed and the general approaches and the methods associated with each approach were discussed. Research was then carried out to develop and demonstrate proposed valuation methods that address the limitations of traditional valuation practices. Values of the different asset types on the Indiana state highway network were determined, and the study went further to estimate the total value of highway assets in the United States.

Findings

This study found that the current valuation methods tend to underestimate asset value due to their monolithic consideration of the physical asset structure. In addressing this limitation, the first proposed method for asset valuation, the elemental decomposition and multi-criteria (EDMC) method, calculates the contribution of each component to the asset value. Also, the EDMC method incorporates both the condition and the remaining service life of an asset. The second proposed method incorporates replacement, downtime (user) cost, and recycling benefits or disposal costs and is aptly named the replacement-downtime-salvage (RDS) method; this method recognizes that recycling or disposal costs are associated with the end-of-life of an existing asset, and user costs during asset replacement can significantly influence the value of an asset and thus should be duly considered in asset valuation. Admittedly, the inclusion of user costs in asset valuation can be a controversial issue because they tend to exceed, by far, the agency costs, and also they are not borne directly by the agency. However, this component of the RDS method, hopefully, can spark a conversation on the larger issue of the role of user costs in asset management decision making in general. Decommission and re-use (D&R), the third proposed method of valuation, assumes that assets can be valued on the basis of the land they occupy, particularly in high-density urban areas where land is very expensive and where there exist opportunities for the asset relocation elsewhere. This method appears to be suitable only where the land value is very high. The fourth proposed method, the duration-cost method, uses probabilistic duration models to predict the probability of asset survival until the end of its typical service life, and calculates the product of the survival probability and the asset replacement cost to determine the asset value. For a given replacement cost, a lower asset value reflects an asset with low probability of surviving to the end of its service life, while a higher value reflects a higher probability of surviving to the end of its service life.

In this study, each of the proposed methods yielded asset values that differ due to their different mathematical formulations. Nevertheless, they all contribute additional information to the conversation of asset valuation and thus yield results that can help achieve the goals of asset valuation. Ultimately, the EDMC method is recommended for adoption by INDOT for valuation of their assets.

The total value of Indiana's state highway assets was determined in this study using the traditional and proposed methods. Using the EDMC, this was estimated at approximately $54 billion. The value of pavements and bridges were $47.1B and $7.83B, respectively; together, these "large assets" constituted approximately 81.34% of total asset value. The total value of smaller assets was approximately $0.556B, constituting approximately 0.83% of the total value of assets; the breakdown was as follows: guardrails, $0.318B; underdrains, $0.005B; culverts, $0.214B; and road signs, $0.019B. The total value of the right-of-way was $12.04B.

Using the most common method used by other agencies, namely, the straight line depreciation (SLD) method, INDOT's pavement and bridge values were determined as $12.4 billion and $9.59 billion, respectively. It is seen that the EDMC yields values that are significantly different than those from the traditional methods; this could be because EDMC explicitly considers the asset as an assemblage of components and thus carrying out valuation for each component rather than considering the structure as a monolithic entity.

Also, using the unit value of highway bridge and pavement assets in Indiana, a total value for bridge and pavement assets in the United States was determined. The total value of state-owned highway pavements and bridges in the country was determined as $4.97 trillion using the EDMC method and $2.1 trillion using SLD method, respectively; for pavements and bridges on all highways in the country, the EDMC and SLD methods yielded $20.8 trillion and $6.54 trillion, respectively. All values indicated are in 2010 dollars.

Implementation

This study can be used by personnel at a number of divisions, offices, program areas, and units at INDOT to assess the value of a specific highway asset or a collection of assets in a given jurisdiction or functional class for input in a variety of agency business processes. Specifically, knowledge of asset value not only can enhance financing opportunities, but also can facilitate the evaluation of investments that improve the nation's highway infrastructure. Past research has demonstrated that appropriate valuation of highway assets permits proper management of infrastructure by monitoring and minimizing the value loss through physical deterioration, congestion, underutilization, and safety hazard. Furthermore, the increase in total highway asset value from year to year can serve as a performance indicator for measuring the accountability of a highway agency in its disbursements and also for assessing funding needs. Thus, asset valuation can provide a link between investment planning and financial accountability. Ultimately, asset valuation can enable highway administrators to build a more formidable case when they petition the legislature and general public for increased funding to maintain or improve current infrastructure. The need for correctly valuing highway infrastructure also stems from GASB Statement No. 34, which requires all government transportation agencies, such as INDOT, to report their tangible capital assets. Higher asset values generally reflect satisfactory stewardship of assets that fall under a highway agency's jurisdiction. Thus, by presenting the year-to-year reduction in the value of assets within its jurisdiction, an agency can show the extent to which its assets are in need of repair or replacement and also can enable oversight of organizations to ascertain whether an agency is properly maintaining its highway assets.

A core group of five persons at INDOT under advisement of FHWA can further define and select implementation strategies relative to agency practices. The principal mission of this implementing panel could be to advance and institutionalize the most practicable methods outlined in this research report.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background Information

1.1.1 The Potential Role of Asset Valuation in Asset Management

There exists a growing movement to incorporate business practices into the public domain to facilitate logical decision-making processes for preserving the nation's highway system (*1*); and asset management provides an appropriate platform for doing this. A critical component of asset management is the valuation of facilities, because adequate knowledge of asset value not only can enhance financing opportunities, but also can facilitate the evaluation of investments that improve the nation's highway infrastructure (*2*). Past research has demonstrated that appropriate valuation of highway assets permits proper management of infrastructure by monitoring and minimizing the value loss through physical deterioration, congestion, underutilization, or safety hazard (*3*).

Furthermore, the increase in total highway asset value from year to year can serve as a performance indicator for measuring the accountability of a highway agency in its disbursements and also for assessing funding needs (*4*). Thus, asset valuation can provide a link between investment planning and financial accountability. Ultimately, asset valuation can enable highway administrators to build a more formidable case when they petition the legislature and general public for increased funding to maintain or improve current infrastructure.

The need for correctly valuing highway infrastructure also stems from the Government Accounting Standards Board (GASB) Statement Number 34, which requires all government transportation agencies such as INDOT to report the inventory and values of their tangible capital assets (*5*). The premise is that a higher asset value generally reflects satisfactory stewardship of assets that fall under a highway agency's jurisdiction. Thus, by presenting the year-to-year reduction or increase in the value of assets within its jurisdiction, an agency can show the extent to which its assets are in need of repair or replacement or to ascertain whether an agency is properly maintaining its highway assets. Finally, it is often stated that the value of a highway asset can serve as one of the evaluation criteria for comparing alternative investment strategies.

1.1.2 Problem Definition

Different valuation approaches yield different values for a given asset (*6*). For example, approaches that take a retrospective view of the asset generally produce different values compared to those that consider the future, prospective potential of the asset (*2*). Also, certain valuation methods do not properly account for the change in asset condition (*7*) and thus tend to yield values that differ from those provided by methods that account for asset condition. Any study in asset valuation, therefore, must compare the different asset valuation approaches and methods to ascertain the extent of deviation in their resulting values, and provide the reasons for such deviation, and then carefully select the appropriate approach that reflects the desires, policy, or mission of the agency or decision-maker.

There are a number of problems associated with the existing methods of asset valuation. The first limitation is that the existing methods consider the asset as a monolithic structure and thus assume (implicitly) a rate of deterioration that is uniform across all the asset components. However, far from being monolithic, any highway asset actually consists of multiple components that can (and do) have significantly different rates of depreciation or deterioration. In view of this, an agency may seek to account for these differences in asset valuation in order to properly account for such differences in the deterioration rates of the different components of an asset.

The second limitation is that the existing methods, by virtue of the parameters that exist in their mathematical structures, implicitly consider only the asset condition (which reflects the user perspective) or only the asset service life (which reflects the agency perspective). However, as both the highway agency and the users of an asset are the key stakeholders in its performance, it can be considered prudent policy to duly incorporate both perspectives, not only one, in the asset valuation process.

The third limitation is that certain agencies prefer to carry out their investment business process from a purely life cycle cost perspective. In this respect, most existing valuation methods are limited because they do not account for the entire gamut of cost types incurred by the stakeholders in operating and preserving an asset over its life cycle.

The fourth limitation is that existing traditional methods of valuation generally fail to acknowledge that it can be beneficial to view asset value purely from a business perspective. For example, re-use of the right-of-way could be considered a business option: the asset could be relocated to another location and the real estate occupied by the asset could be re-used for another purpose that yields higher returns due to the prime location of the real estate. This way, the asset and the space it occupies could be valued and managed efficiently in terms of their true market worth.

The fifth limitation is that existing methods carry out asset valuation from a purely deterministic viewpoint. However, it is well established that the factors that influence asset value (e.g., asset replacement cost, condition, service life, and deterioration rate) are all stochastic, and asset value is therefore inherently probabilistic and not deterministic. As such, more robust statements of asset value can only be developed using valuation techniques that recognize and incorporate these uncertainties. An agency's selection of any new method that obviates part or all of these limitations must be guided by the specific circumstances or objectives that the agency seeks to consider as a part of the valuation process.

1.2 Scope of This Study

In any discussion of asset management, it is important to establish the domain of assets under consideration. The Indiana Department of Transportation (INDOT) manages a wide range of asset types-physical transportation infrastructure (e.g., bridges) and service assets (e.g., traffic safety and mobility infrastructure) are only a few types of the overall asset holdings of the agency. Other asset types include INDOT's human resources, financial capacity, equipment and vehicle fleets, material stocks, real estate, corporate data and information.

This study focuses on only physical assets that are directly associated with highway operations, including pavements, bridges, culverts, and safety and mobility infrastructure such as guardrails and road signs. It does not include agency personnel, equipment, or material stocks. Also, the valuation of an asset is herein defined in terms of the inherent monetary worth of its physical structure and not necessarily on the basis of its "external" contributions such as safety benefits, congestion mitigation benefits, impacts on economic, social, or cultural development, and environmental benefits or costs. In developing new methods for asset valuation, this report considers a number of analysis parameters. In the first proposed method, the scope includes both the agency and the user perspectives of the asset physical value. In the second proposed method, the scope includes work-zone user costs. In the third proposed method, the scope considers only the land value. Finally, the scope of the fourth proposed method includes survival probability. The concepts have been developed for state highway facilities, but could be easily applied to facilities on local systems.

1.3 Contents of This Report

This report is organized in eight chapters. Chapter 1 provides the rationale for conducting asset valuation in the state of Indiana and the role of asset value in agency business processes. Chapter 2 presents a literature review of the current valuation practices and discusses the general approaches and the methods associated with each approach. Chapters 3, 4, 5, and 6 each describe the proposed valuation methods that were developed to address the limitations of traditional practices. Chapters 7 and 8 compare valuation results from the traditional and the proposed methods. Chapter 9 uses the values found in the report to estimate the total value of highway and bridge assets in the United States. Chapter 10 explores a number of considerations for incorporating asset value into investment evaluation, and Chapter 11 summarizes and concludes the report.

2. A SYNTHESIS OF CURRENT PRACTICE AND RESEARCH ON ASSET VALUATION

2.1 Introduction

To acquire insights into the various issues associated with highway asset valuation, an extensive information search on the subject and its related topics was carried out. This chapter synthesizes the outcomes of this task. Significant findings from previous studies are presented and discussed to: provide further understanding of the existing approaches and methods for asset valuation; serve as a basis for assessing the limitations of existing methods and for developing new methods; and examine the feasibility of incorporating asset value in the evaluation of investments related to highway assets.

Two approaches are currently defined by the GASB as acceptable for assessing the value of a highway asset (*5*). The first is the depreciation approach which comprises various alternative methods that consider the original cost of the asset and apply different forms of depreciation over the asset life. Some specific methods include the straight line, sigmoidal, sum-of-years digits, and double-declining balance rates depreciation. Starting with the original cost at the year of construction, the annual depreciation and accumulated depreciation are determined and subtracted from the original cost to yield the asset value at any year. The details of the depreciation approach are provided in Section 2.2.

The second approach, the modified approach, consists of alternative methods that consider the asset condition and its original cost in order to determine its value at each year. This method does not use depreciation explicitly (*2*). One of these methods, "the fixed value with respect to condition threshold" method, assigns a fixed asset value as long as the asset meets a certain minimum condition threshold. The "adjusted value with respect to condition threshold" method contains a condition ratio of the asset at a given year and incorporates this variable in the valuation calculation (*7*). Details are provided in Section 2.3.1.

The third approach includes methods that utilize only the historical (original) cost or the replacement cost of the asset and do not incorporate the depreciation or deterioration of the asset over its lifetime. The historical cost is the amount spent by the agency to construct the asset when it was first built. The replacement cost is the total cost that would be incurred if the asset were to be reconstructed at the current time. Figure 2.1 presents the methods associated with each approach. As seen in Table 2.1, preservation costs are treated differently across the approaches (*8*).

An assumption made in asset valuation approaches is that capitalized costs add to the asset value while expenses do not. Expenses are costs that recur every few years during an asset's service life to maintain its condition. For example, if a bridge received deck joint sealing, a routine maintenance activity, both the depreciation approach and the modified approach will consider this activity as an expense and thus will not

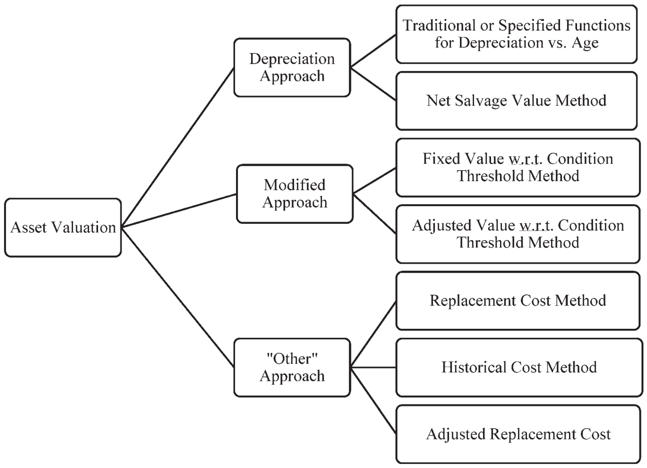

Figure 2.1 Categorization of scaling techniques.

consider it explicitly in the valuation. For the depreciation approach, a bridge that receives rehabilitation experiences a sudden increase in value due to the rehabilitation. The modified approach, on the other hand, considers rehabilitation as a recurring activity throughout the asset life and assumes that it does not add to the asset value. For both approaches, expansion is considered a capital expense, for example if the width of a bridge is increased to accommodate additional lanes, both the depreciation and modified approaches consider this activity as a capitalized cost that hence adds to the bridge value (*5*).

GASB (*9*) cautioned that due to the current funding challenges and the difficulty of adequately funding infrastructure maintenance to ensure attainment of the specified condition levels prescribed in the modified approach, a possibility exists that agencies will revert to using depreciation approaches at some point in the future. This suggests that in the future, more and more agencies may prefer to carry out valuation using methods consistent with the depreciation approach and less of the modified and other approaches.

2.2 The Depreciation Approach

The depreciation approach uses various functions that relate asset value to asset age to determine asset value at any specific year. The pattern of asset depreciation may follow any one of several forms, including straight line, declining balance, double-declining balance, sum-of-years digits, concave, convex, or sigmoidal. The increasing accumulated depreciation of the asset over the years causes the asset value to decrease gradually from its original value at the time of construction. Depreciation methods thus begin with the historical cost of asset construction and then make adjustments for deterioration.

2.2.1 The Traditional Depreciation Methods

In straight-line depreciation, it is assumed that the asset loses a fixed value every year. This annual loss in value, or constant depreciation rate, is simply calculated as the historical cost less salvage value, divided by the asset service life. The rate of straight-line depreciation (SLD) is given by:

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

Where, P is historical (original) construction cost; S is salvage value; t_S is the year of the salvage; t_P is the year of construction; thus $t_s - t_p$ is the analysis period, which is often equal to the asset service life.

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

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

Where, t is the current year. Other symbols have the same meaning as defined for Equation 2.1.

In Finland, road values have been estimated using linear depreciation (*10*). Also, the Catholic Church assesses and records the values of its assets (land, buildings, and equipment) using a straight-line function over the life of each asset (*11*). The straight-line depreciation function was found to be convenient because of its relative simplicity and ease of assessing the values of the Church's assets. However, it is not certain whether the Church's assets actually depreciate in a linear fashion. In the context of highway assets, however, it is well known that straight line depreciation does not reflect the depreciation pattern of these asset types appropriately. For example, bridge assets are known to exhibit sigmoidal patterns of deterioration (*12,13*) and pavement assets exhibit deterioration patterns that are generally curvilinear (*14–21*). Also, a study carried out in Ghana determined that straight-line depreciation does not accurately reflect the depreciation of an asset while the sum-of-years-digits and reverse sum-of-years-digits often provide more reliable results (*22*). Thus, the assumption of linear depreciation generally tends to lead to underestimation of the values of a young asset (or a network dominated

TABLE 2.1
How Costs are Treated in Valuation Approaches

Costs	Depreciation Approach	Modified Approach*
Maintenance costs	Expenses	Expenses
Rehabilitation costs	Capitalized cost	Expenses
Asset expansion and improvement costs	Capitalized cost	Capitalized cost

*Other approaches may vary, depending on the specific approach.

by young assets) and overestimation of the values of an old asset (or a network dominated by old assets).

As seen in Figure 2.2, the earlier years of an asset, depreciated linearly, would indicate value lower than that for the sigmoidal depreciation; in the later years, linear depreciation would indicate a value higher than that for sigmoidal depreciation.

The sum-of-years-digits depreciation (SOYD) method depreciates the value of an asset over time by computing a different fractional depreciation rate for each year. For SOYD, instead of dividing by the total number of years that the asset has been in service (as is the case for SLD), the difference between historical cost and the salvage value is multiplied by a ratio that is related to the remaining life, as shown in Equation 2.3.

$$SOYD_t = \frac{N-t+1}{\left(\frac{N}{2}\right)(N+1)} * (P-S) \qquad (2.3)$$

Where, $N-t+1$ is the useful remaining life at the beginning of year t; N is the analysis period or service life; t is the given year; P is the historical (original) construction cost; and S is the salvage value.

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

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

Where, t is the current year. Other symbols have the same meaning as defined for Equation 2.3.

The declining balance depreciation method uses a constant fraction (depreciation factor) of the End of the Previous Year (EOPY) book value to determine the extent to which an asset depreciates in each year (Equation 2.4). The double-declining balance depreciation, a special case of the declining balance depreciation, calculates depreciation as a constant fraction of the EOPY book value (Equation 2.5). The fraction is 2/N, where N, the analysis period, is typically taken as the asset life. The double-declining balance method yields a larger depreciation in the early years of an asset and the book value never reaches zero.

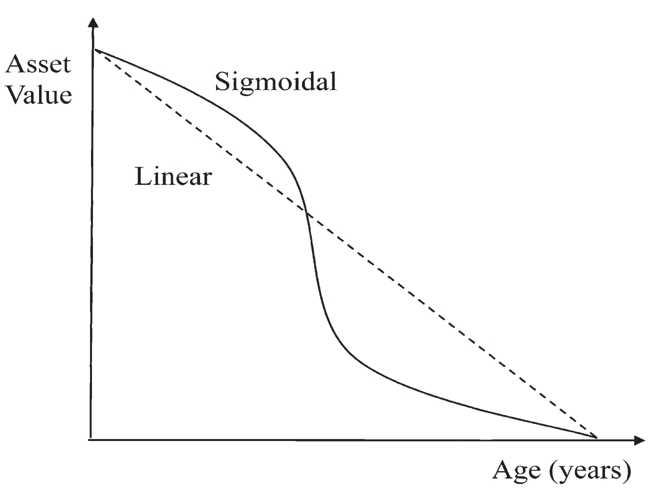

Figure 2.2 Linear vs. sigmoidal depreciation: possible distortions.

$$DB_t = \left(\frac{1}{N}\right) * BV_{t-1} \qquad (2.4)$$

Where, DB_t is the declining balance depreciation; *(1/N)* is the depreciation factor; N is the analysis period or service life; and BV_{t-1} is the asset value at the end of the previous year.

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

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

Where, t is the current year. Other symbols have the same meaning as defined for Equation 2.4.

The double-declining balance depreciation is given by:

$$DDB_t = \left(\frac{2}{N}\right) * BV_{t-1} \qquad (2.5)$$

Where, DDB_t is the double-declining balance depreciation at year t; *(2/N)* is the depreciation factor; N is the analysis period or service life; and BV_{t-1} is the asset value at the end of the previous year.

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

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

Where, t is the current year. Other symbols have the same meaning as defined for Equation 2.5.

Beside these depreciation functions (which are common in financial accounting practice), there are other mathematical functions that have been used in the literature to describe the depreciation trend of specific assets. For example, the Reverse Sum of Years Digits (RSOYD) is a depreciation method that has a slower deterioration rate in the early years of an asset, but increases toward the end of the asset's life (*22*). In RSOYD, the depreciation rate changes with each year of the asset's life, so the accumulated depreciation is summed and subtracted from the asset's original cost. Equation 2.6 shows how the annual RSOYD depreciation is calculated for a specific year.

$$RSOYD_t = \frac{t(t+1)}{N(N+1)} * (P-S) \qquad (2.6)$$

Where, $RSOYD_t$ is the reverse sum of years digits depreciation in year t; t is the given year; N is the analysis period or service life; P is the historical (original) construction cost; and S is the salvage value.

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

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

Where, t is the current year. Other symbols have the same meaning as defined for Equation 2.6.

Another less common mathematical function for depreciation, the sigmoidal depreciation (s-curve), has the functional form shown in Equation 2.7 and Figure 2.2. In this form, the asset has a slow depreciation at the beginning of its service life, a fast depreciation during its middle life, and then deteriorates rapidly at the end of its service life. The inverse sigmoidal form has a reverse order where the asset depreciates rapidly in its early life, slowly during its middle years, and rapidly again near the end of its service life.

$$V_t = E - \frac{A}{B + C * (t)^D} \tag{2.7}$$

Where, V_t is the asset value at year t; E is the original (historical) construction cost; A, B, C, D are coefficients, calibrated for a specific asset, which are also called shape parameters and dictate the shape of these curves; and t is the asset age.

Overall, the depreciation approach is considered an appropriate financial tool for accounting records. Amekudzi et al. (*2*) suggested that depreciation has no direct relationship with the actual condition of a civil infrastructure asset. Harlow (*23*) argued that the straight-line depreciation approach is unable to indicate how well an agency is caring for its assets. In spite of the limitations of the depreciation approach, its use is widespread due to its simplicity, ease of use, and familiarity to most financial officers (*8*). For most highway assets, a depreciation method that shows an asset depreciating slower at the beginning, faster in the middle years, and slower again at the end is more appropriate (*4*). Such a deterioration trend is consistent with the sigmoidal pattern presented in Equation 2.7 and Figure 2.3. A study that valued the Little Rock Wastewater Facility in Arkansas used the depreciation approach for valuing its assets and consequently for evaluating investments related to rehabilitation, construction financing, and divestiture purposes (*24*).

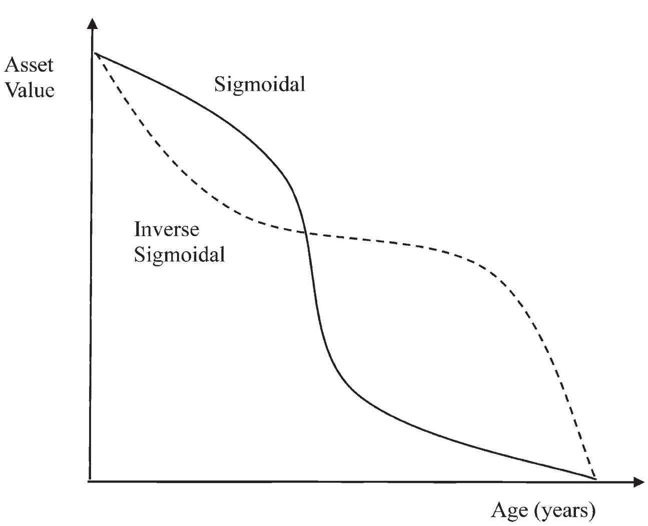

Figure 2.3 Sigmoidal and inverse sigmoidal depreciation.

2.2.2 Net Salvage Value Method

In the net salvage value (NSV) method, asset value at any time t, is calculated as the difference between its as-new cost and the expected cost of work needed at that time *t*, to upgrade it to as-new status. Thus, it is calculated as the difference between the replacement cost and the rehabilitation cost at the time of the analysis (*25*) (Equation 2.8). This method can be considered a depreciation approach because it assumes that the rehabilitation cost increases as the asset depreciates.

$$NSV_t = RC \quad RehabC_t \tag{2.8}$$

Where, *RC* is the replacement cost; *RehabC* is the expected cost of rehabilitation if carried out in year *t*.

Figure 2.4 demonstrates how rehabilitation cost could increase over time. The original asset value is surrogated by its historical construction cost. As the asset value decreases due to deterioration, more resources will be required to rehabilitate the asset to restore its original value. A disadvantage of this method is the rather unrealistic assumption that rehabilitation treatments can restore an asset to its pristine condition. The net salvage value method was identified as the preferred method for valuation of rail assets in Canada (*3*).

The country of Chile incorporated the net salvage method in HDM-4 for valuing low-volume roads: the value of each road section was calculated as the difference between its original construction cost and the cost of upgrading the road at any year to its as-new condition (*26*). In that study, three levels of funding were analyzed for their effect on the country's overall low-volume network value after a 20-year period. On the basis of the asset values, the maximum, median, and minimum needs for the network funding were determined. The study concluded that a low level of spending decreases the network value by 10%; a medium level increases the value by 3%; a maximum

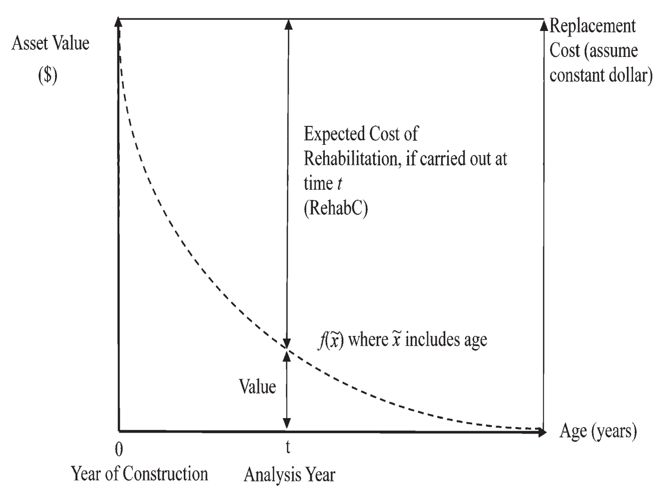

Figure 2.4 Conceptual illustration of net salvage value computation.

level increases the overall value by 12%; and no maintenance leads to a 24% decrease in value.

In the power generation industry, the net salvage value method is utilized by comparing existing depreciation approach values of power generating plants to newly-constructed plants of a similar type (*27*). Market analysis helps to examine the sales histories of comparable pipelines in varying circumstances and locales to derive the pipeline value (*28*), and the sales history information helps in estimating the value of a pipeline on the basis of its sale price.

2.3 Modified Approach

Contrary to the depreciation approach, the so-called modified approach takes into explicit consideration, the condition trends of an asset over time. As such, in order to use this approach, an agency must have an in-place management system that tracks the asset condition and helps ensure that maintenance occurs in a timely and orderly fashion on the basis of established condition thresholds (*29*). If the asset condition falls below the threshold, the asset would require some preservation action to return it to an acceptable condition. As such, the underlying philosophy of the modified approach is the assumption that the condition of an asset at any year reflects the asset value at that year.

Harlow (*23*) cautioned that the use of the modified approach is implicit with the assumptions that the agency has a firm grip on the management of its infrastructure and that the asset value is significant and constant as long as the agency adopts effective practices for asset preservation. Also, Maze et al. (*8*) stated that a simple asset management system would require the same record-keeping efforts when compared to the depreciation approach, and that the American Public Works Association endorses the modified approach because it is a simple and effective method to keep track of long-lived infrastructure assets. In addition, it has been suggested that the cost and effort needed to follow the requirements of the modified approach are significantly higher compared to the depreciation approach (*9*). Snaith and Orr (*30*) demonstrated how an asset management system, such as a Pavement Management System, used with the modified approach, can yield different asset values for different funding levels and showed that greater spending would result in higher asset values. A potential advantage of the modified approach is that its prerequisite documentation can serve as a valuable database from which asset condition could be monitored over time (*29*), which could be useful for performance modeling and other asset management tasks. In the remainder of this section, three methods associated with the modified approach are discussed: the written-down replacement cost, the "adjusted value with respect to condition threshold" method, and the "fixed value with respect to the condition threshold" method.

2.3.1 The Written-Down Replacement Cost Method

In the "written-down replacement cost method," the asset is calculated as the product of its historical (original) construction cost and a condition ratio, as seen in Equation 2.10. The condition ratio is the ratio of the current condition to the best condition. Thus, this method utilizes performance models that predict asset condition at any time (*3*). Unlike the "adjusted value with respect to condition threshold" method, this method does not consider a failure condition threshold and therefore could overestimate or underestimate asset value. Using the written-down replacement method, the value of an asset at any time t, V_t is calculated as follows:

$$V_t = HC * \left(\frac{P_t}{P_{best}}\right) \tag{2.9}$$

Where, HC is the historical (original) construction cost; P_t is the condition at time t; and P_{best} is the best possible condition of the asset.

2.3.2 The Adjusted Value with Respect to Condition Threshold Method

The "adjusted value with respect to condition threshold" method utilizes both current and past data to determine asset values (*31*). Baik et al. used this method for sewer pipes but the concept is easily transferable to highway assets. Equation 2.11 presents the calculation and the key variables associated with this method. Figure 2.5 demonstrates how value is affected by the condition of the asset.

$$V_t = HC * \left(\frac{P_t - P_{worst}}{P_{best} - P_{worst}}\right) \tag{2.10}$$

Where, V_t is the asset value at year t; HC is the historical (original) construction cost; P_t is the expected condition at year t (from the deterioration model); P_{worst} is the worst possible condition of the asset; and P_{best} is the best possible condition of the asset.

For example, a $1 million (1999$) bridge built in 1999 with a bridge index condition rating of 6 in 2010, the cost in 2010$ is $1.6 million using FHWA's CPI, and thus the value in 2010 is:

$$\$1.6M * \left(\frac{6-0}{9-0}\right) = \$1.1M \tag{2.11}$$

This expression (Equation 2.10) is conceptually different from one that uses a condition ratio. The latter considers only the asset condition at time t and the best possible condition (Equation 2.9). The condition ratio in Equation 2.10 considers a condition range for the asset and places the asset within this spectrum. If the worst condition happens to be zero, or given the assumption that the worst condition either is not typically encountered or is so bad that it can be taken as the least possible value (often zero, for many rating scales), then Equation 2.9 and Equation 2.10 are the

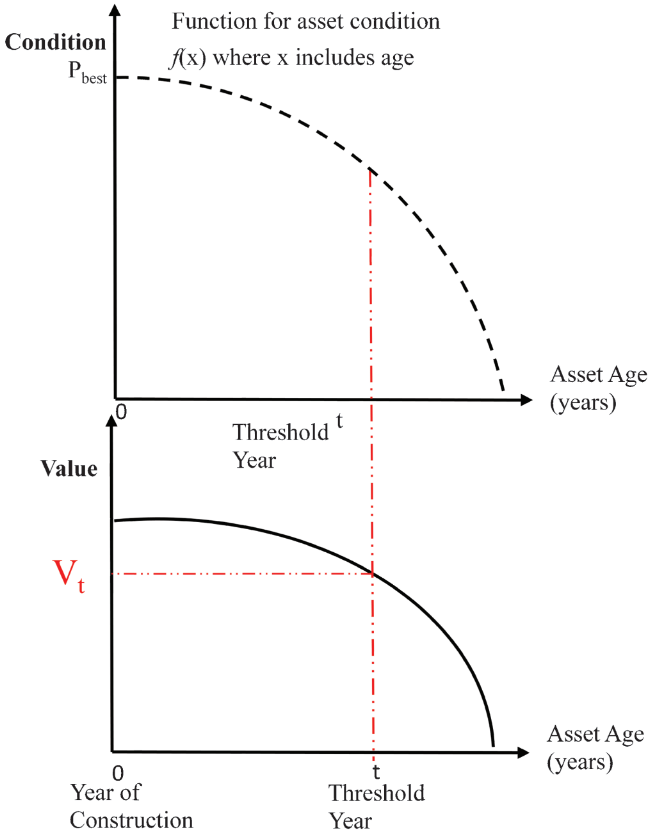

Figure 2.5 Adjusted value w.r.t. condition threshold illustration.

same. However, if the worst condition is a non-zero value, then the resulting condition ratio will be different. Placing the asset condition within a spectrum of quality (Equation 2.10) accounts for the range of conditions the asset could exhibit; on the other hand, a ratio of condition to best condition (Equation 2.11) may tend to overestimate the asset value because it does not consider the failure threshold condition.

2.3.3 The Fixed Value with Respect to Condition Threshold Method

The "fixed value with respect to condition threshold" method hinges on the attainment of an asset condition at a level that consistently exceeds the minimum performance threshold established for the asset. The asset value is considered to be constant over the asset service life as long as the asset condition is above the specific threshold; and is zero when the condition falls below the threshold (Figure 2.6). For example, if a pavement maintains an IRI below 170 inches per mile, then it is considered to have the same value as an "as-new" asset; if the IRI is above 170, the asset is considered to have zero value. A similar method, utilized in a study in Northern Ireland, was considered to be practical in operation and reasonable in solution for that region (*30*). The only drawback occurred when the roads were allowed to fall into the failure range, thus experiencing a drastic reduction in their overall value, and making preservation investments appear to be infeasible.

The "fixed value with respect to condition threshold" method does not directly take into account the pattern of asset deterioration over its service life. As such, asset managers who use this method are not expected to acquire pertinent information from the patterns associated with asset value until the point where the asset deteriorates to the point of repair. The asset value is considered stable over time, which may not necessarily be the case, because deterioration does decrease an asset's value irrespective of whether the asset is above the threshold condition. The "adjusted value with respect to condition ratio" method provides a superior technique that duly recognizes changes in value at each point in time: information on asset condition is known and a trend can be established to predict when repair is due. Unlike the fixed method, the adjusted method provides asset managers with different values that reflect changes in the current asset condition, not a steady value that changes only when the condition threshold is reached (Figure 2.6).

2.4 The "Other" Approach

The "other" approach includes the replacement cost and the historical cost methods. The three methods simply reflect the cost of an asset at a specific point in time, as explained in the following sections.

2.4.1 Replacement Cost Method

In this method, the value of an asset at the time of the analysis is represented by the amount that the agency would need to spend to replace it at that time (Equation 2.12). Thus, the replacement cost determines the current market price associated with replacing an asset (*3*).

$$Asset\ Value = RC_t \tag{2.12}$$

Where, RC is the replacement cost in any year t.

2.4.2 Adjusted Replacement Cost Method

The cost of replacing an asset differs from year to year, due to inflation. The Federal Highway Administration (FHWA) provides annual Construction Price Indices (CPI) to facilitate conversion of monetary values to account for inflation. Equation 2.13 can be used to determine the replacement cost of an asset at any time t.

$$RC_t = HC\left(\frac{CPI_t}{CPI_{year\ built}}\right) \tag{2.13}$$

Where, HC is the historical (original) construction cost; CPI_t is the construction price index in year t; $CPI_{year\ built}$ is the construction price index in the year it was built; and RC is the replacement cost in year t.

For example, for a bridge built in 1980 with a cost of $1 million in that year, the original cost should be converted into year 2010 dollars if its value in year 2010

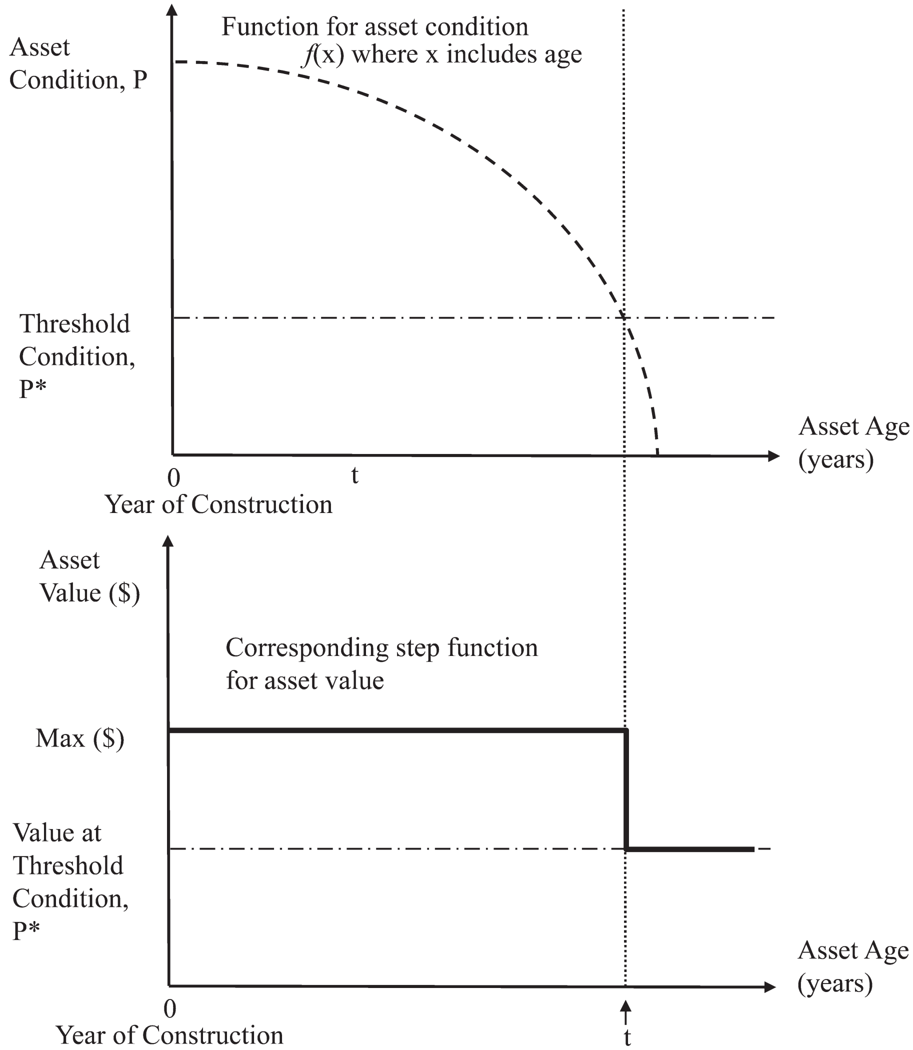

Figure 2.6 Fixed value w.r.t. condition threshold illustration.

is sought. For this example, HC = \$1 million dollars; CPI_t = 223.4 for year 2010; CPI_{1980} = 97.2. From Equation 2.14 the asset value in terms of its replacement cost in 2010, is calculated as follows:

$$RC = \$1M\left(\frac{223.4}{97.2}\right) = \$2.3M \qquad (2.14)$$

From past research, it has been found that, of the different asset valuation methods, the replacement cost and particularly, the adjusted replacement cost methods typically yield the highest asset value (*3*). This result is expected because these valuation methods assume that the asset is in a pristine state and thus do not consider deterioration or depreciation. On the other hand, the Written-Down Replacement Cost method adjusts for the asset condition, resulting in lower asset values calculated using these methods (*3*). The United Kingdom published an asset valuation guide that describes the Gross Replacement Cost method that is similar to the replacement cost method, for valuing most of the assets in its jurisdiction (*32*). The LoBEG method uses historical data to derive a unit average rate and applies this rate to other assets with due adjustments made to account for differences in asset dimensions.

The replacement cost method has been utilized for valuing highway assets in Finland (*10*). This method also has been used in Portugal as a general policy to value assets and uses the present value (using discounted cash-flow method), the sales comparison method, and the replacement cost method as backup methods if the first is not applicable (*33*). The United States Department of Defense (DOD) uses the total plant replacement value (PRV) to determine and compare the worth of its military bases as part of base hutting-down evaluation; in this method, the cost of replacing the facility and its supporting infrastructure is calculated using current construction costs for labor and material in the region where the military base is located (*34*). The property value and the replacement value are used to ascertain the worth of military bases by calculating their total values. It was determined that the countries where U.S. bases have the highest-ranking PRVs are located in Europe and Asia (*34*).

In the Catholic Church, power generation assets are valued using the replacement cost method (*11*). Where the historical costs for in-service assets are unavailable, cost-based appraisals, insurance appraisals, replacement cost values, or property tax appraisals are used instead of the depreciation method.

A drawback of the replacement cost method is its inability to accurately reflect the cost of constructing an asset that is very advanced in age. Construction standards have changed over time due to superior technology and, in certain cases, to account for higher traffic volumes and loads. Thus, the current replacement design and construction standards to be used for cost computations are often different from those at the time of the original construction. Thus, replacement costs would be, in most cases, an overestimation of historical costs even after the latter is corrected for inflation. On the other hand, for assets where more conservative designs have evolved over the years, the replacement cost will represent an underestimation of the duly-adjusted historical cost.

2.4.3 Historical Cost Method

In the historical cost method, the original cost of constructing the asset is considered. Unlike the replacement cost, which reflects new specifications and design standards evolution, the historical cost reflects what was originally spent in the field at the time of construction, often several decades ago. Ideally, the historical cost of the specific asset should be acquired and used in each of the previously mentioned methods to gain an accurate value for the asset (*35*). Difficulty arises, however, when the records of very old highway assets cannot be located. For example, in Portugal, problems were encountered in asset valuation due to lack of historical cost data (*33*). To solve the problem of missing historical costs, current replacement costs may be adjusted to yield their corresponding values at the year of asset construction, using the Construction Price Index (CPI) or similar inflation indices inflation (Equation 2.13).

2.5 Comparisons Between the Approaches/Methods

A rough classification of the valuation methods was found to include four dimensions: future- or historical-based, cost- or benefit-based, different sets of value indicators in the valuation function, and characterized investment risks (*2*). A comparison of the different valuation methods is a difficult task due to differences in construction standards and specifications, namely, past data incorporate historical specifications while future data consider improved or altered specifications and standards. Some methods do not consider condition while others incorporate both deterioration and condition ratings. As such, it may not always be prudent to compare state-by-state asset values that were determined using different methods. Also, each method requires different combinations of input data for the valuation, and agencies choose a specific approach or method, depending on data availability for that method.

In a sewer pipe valuation study, Park and Sinha (*7*) compared multiple methods: straight line depreciation, "fixed value with respect to condition rating," replacement cost, and "adjusted value with respect to condition rating." The values of each method were recorded for each sewer pipe section and year. For most of the methods, the assets were found to depreciate at different rates over time, causing values at any given point in time to vary widely. The asset value was found to decrease only when the asset condition ratio significantly outweighed the monetary inflation factor, but again increased when the asset was maintained. The results of that study indicates that reporting asset values over time in current dollars rather than constant dollars is flawed because asset value could increase over the years due to high inflation even as the asset deteriorates. As said, asset value should not be corrected for monetary inflation, and also should focus on the asset condition. The Park and Sinha (*7*) study exemplifies the inherent biases and difficulties in comparing the results from different methods. In comparing between the asset values at different highway agencies, cognizance should be taken of the possible differences in the valuation approaches and methods used by the agencies; a higher or lower total asset value in one state compared to another similar state may be due to the use of methods that are relatively liberal or conservative methods thus overestimating or underestimating the asset value.

Cowe Falls et al. (*3*) compared straight-line depreciation and a method similar to the "adjusted value with respect to the condition threshold" (AVCT) method. For a sample road network, the latter method yielded a smaller value because, unlike the depreciation method where asset value does not increase in response to rehabilitation, the "adjusted value with respect to condition threshold" accounts for a jump in asset value after rehabilitation is applied (*3*). When no rehabilitation occurs, the depreciation method does not indicate a proportional decline in value with time while the AVCT method shows a steady loss in value. Also, according to Baik et al. (*31*), assets tend to be valued 76% higher using the modified approach methods, compared to the depreciation approach. Their research found that when the AVCT method was used the total asset value was 64% higher than the average value from all other depreciation methods.

2.6 Asset Valuation Practices Currently Used in Various States

Currently, most states use at least one of the two approaches outlined in GASB Statement 34. States that have developed management systems for specific asset types typically utilize the modified approach methods to report their asset values (*36*) while others utilize depreciation methods. Some states use both, depending on the asset being valued. According to some states, the depreciation method is easier to use but tends to yield inaccurate values due to missing historical data or the inability to directly capture the effect of material price changes over time (*36*).

NCHRP Report 522 surveyed a number of state highway agencies to identify their preferred valuation methods in compliance with the GASB Statement 34 requirements (*36*). It was found that most states choose to use the depreciation method if they do not have an asset management system in place, as a management system is essential for using the modified approach. NCHRP Report 608 followed up, seeking more detailed answers regarding the approaches used by the states (*37*). It was found that state departments of transportation seek knowledge of how their counterparts in other states carry out valuation of their assets. Also, agencies that use the modified approach reported greater interaction between asset managers and financial units, leading to valuable collaboration between these entities. Compared to other elements of highway asset management, the subject of highway asset valuation has seen relatively little research.

2.7 Existing Techniques for Highway Project Evaluation

Existing techniques for highway project evaluation do not explicitly consider asset value. Life cycle cost analysis, a tool to help quantify all the costs of alternative investment options (*38*), allows decision-makers to evaluate competing alternatives over an analysis period based on their monetized benefits and costs (*39*). However, this is done without accounting explicitly for the value of the asset that receives the investment.

The net present value and equivalent uniform annual return methods consider the difference between costs and benefits to reflect the alternative's combined overall outcome (*40*), while the benefit-cost ratio divides the weighted and scaled benefit and cost criteria. The largest net present value or benefit-cost ratio is the optimal alternative. The cost-effectiveness method is similar to the traditional benefit-cost ratio, but does not express the costs and benefits in the same metrics. Instead, this method examines a trade-off between costs and benefits to find the optimal alternative (*41*).

Other techniques of investment evaluation utilize multi-criteria analysis tools: relevant criteria are weighted, scaled and calculated for each alternative. Examples of the criteria include agency cost, user cost, air and noise pollution added, economic development, community disruption, etc. Ranking and rating methods utilize weighting, scaling, scoring, and probability distributions that result in ranked final scores in which the highest is chosen as the optimal alternative (*41*). Currently, none of these methods consider the asset value as one of their evaluation criteria.

The non-consideration of asset value as an evaluation criterion in highway asset investment evaluation poses a severe limitation on demonstrating the financial prudence of the outcomes of traditional project evaluation and decision making, thus possibly jeopardizing the accountability of these investments. It is well known in business circles that the evaluation of an investment must duly consider the existing value of the investment target. It can be argued that all else being equal, higher-valued assets should deserve investment priority. Another school of thought holds the position that investments that yield the greatest *added* values are those that should receive higher priority. Thus, a framework is needed whereby asset value could be included as an evaluation criterion (or decision factor) in the evaluation process.

2.8 Summary and Discussion

Asset valuation methods fall into one of three approach categories. The depreciation approach includes methods that utilize asset depreciation to describe asset value trends over time. The second category, the modified approach, incorporates asset condition as a factor in determining asset value. The third, the "other" approach consists of methods that do not include asset depreciation or condition; these methods reflect asset cost either using historical information or estimating the cost based on current construction trends. For a given asset with specific attributes, these three approaches can yield different values. Current evaluation methods do not include value as an evaluation criterion which limits decision-making potential for accurate project evaluation.

3. PROPOSED METHODOLOGY I: ELEMENTAL DECOMPOSITION AND MULTI-CRITERIA (EDMC) METHOD

3.1 Introduction

In this chapter, a valuation method is proposed in a bid to address at least three of the identified limitations of traditional methods. The primary consideration is that assets are elemental in nature, thus each component deteriorates at a different rate and should be considered as a part of a whole in order to yield a more representative asset value. A more robust methodology for valuation is herein presented, and its application for highway asset valuation is illustrated.

3.2 Innovative Elements of the Proposed Methodology

The traditional valuation methods discussed in the previous chapter implicitly consider assets as monolithic entities. As such, the initial costs, characteristics, and behavior of individual asset components or elements are not adequately accounted for in the valuation. Also, traditional valuation methods consider only the asset attributes of condition or remaining service life, but not both. However, both the asset service life and condition, which reflect the user and agency perspectives of asset value, respectively, need to be considered. As seen in the following sections, the proposed methodology takes these concepts into consideration.

3.2.1 Recognition of Elemental Nature of Assets

Each asset typically is comprised of multiple components or elements. For example, a bridge consists of the deck, approach, superstructure, and substructure; a pavement consists of a subbase, base, and surface layers. Traffic signs, guardrails, street lights, traffic lights, retaining walls, sound barriers, and other transportation assets can each similarly be considered as a sum of individual elements. For a given asset type, the different components have different costs and deteriorate at different rates. For example, the wearing surface of a highly-traveled bridge can be expected to deteriorate at a rate faster than that of the substructure. Consideration of the wearing surface only in asset valuation would result in overestimated deterioration and thus underestimated value (Figure 3.1). On the other hand, consideration of each component separately could likely yield a total value that reflects the bridge value more reliably (Figure 3.2).

3.2.2 Incorporating Agency and User Perspectives of Asset Value

Agencies in the transportation industry are interested in maintaining their assets and allocating their budget to address such needs (*40*). Agency budget constraints lead to concern over how long an asset will continue to provide the needed service to its users. With their increasingly tight budgets, agencies seek best practices for planning their spending allocations. For example, in life cycle cost analysis, the life expectancy estimate allows for a proper basis for selecting an appropriate analysis period (*40*). In this respect, a valuation method that reflects asset value in terms of service life is of interest to agencies. As an asset approaches the end of its service life, a valuation method that reflects the imminent loss in value due to little remaining service life, would help alert an agency that the asset in question is nearing its reconstruction time and thus must be duly budgeted for. Thus, agencies are typically more concerned with the asset remaining service life compared to the asset condition.

On the other hand, users of transportation infrastructure are typically concerned with the condition of the assets because good condition is associated with high levels of service that yield minimum delay, hazard,

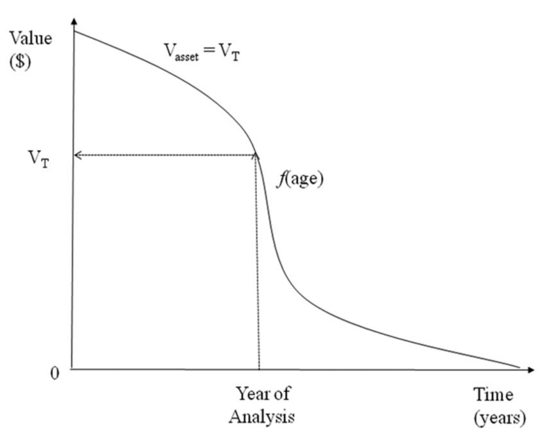

Figure 3.1 Simplified illustration of asset valuation using traditional methods (monolithic asset structure assumed).

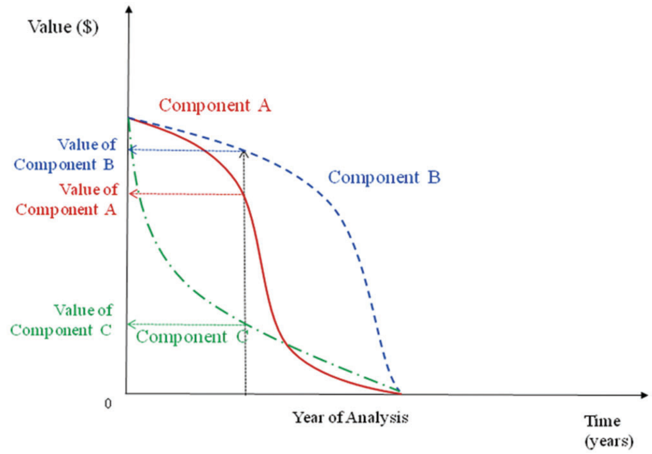

Figure 3.2 Simplified illustration of asset valuation that considers multiplicity of components for a given asset.

discomfort, or inconvenience [travel time delay, vehicle operating costs, or crash costs] (*42*). The asset service life, on the other hand, is of relatively little direct interest to highway users. Thus, users can be expected to place a higher premium on asset condition compared to asset remaining service life (*41*). Thus, valuation methods that reflect the user's perspective are valuable in cases where the asset is intended to serve the public interest.

A school of thought may argue that considering both asset condition and service life is overkill and that only one (not both) of these criteria needs to be considered. However, a counterargument is that while asset condition may be related to asset life, it is possible to have two assets with the same service life but different average condition (Figure 3.3 (a)). Similarly, it is possible to have two assets with different service lives but the same average condition (Figure 3.3 (b)).

3.2.3 Attribute Ratios

Attribute ratios are a statement of the comparison between a function of the current level of an asset attribute and a function of its desired level. Thus, "condition ratio" could be defined as the ratio of a function of current condition to a function of the desired condition. The condition ratio at time *t* could be expressed as a ratio of the current condition at time *t* to the best possible condition (Equation 3.1) or a ratio of the difference between the current and worst conditions to the difference between the best and worst condition (Equation 3.2). Condition ratios are of greater concern to asset users compared to other attribute ratios.

$$CR_t = \frac{P_t}{P_{best}} \tag{3.1}$$

$$CR_t = \frac{P_t - P_{worst}}{P_{best} - P_{worst}} \tag{3.2}$$

Where, CR_t is the condition ratio at time *t*; P_t is the current condition of the asset at time *t*; P_{best} is the

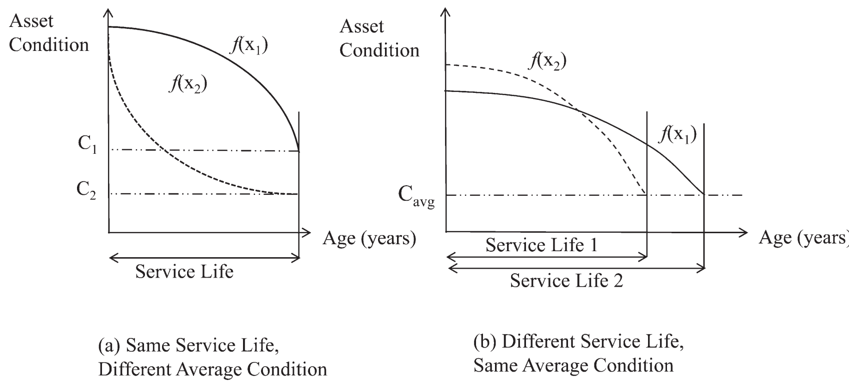

Figure 3.3 Relationships between condition and service life.

condition of the asset as new; and P_{worst} is the worst possible condition of the asset.

A "remaining service life" ratio can be similarly defined to measure the percent of life that an asset has left compared to its full service life. The "remaining service life" ratio at time t could be expressed as a ratio of the remaining life at the current time to the overall service life (Equation 3.3). Unlike the condition ratio that necessitates a condition spectrum to be established, service life always has a start time of zero and fixed end time.

$$RSLR_t = \frac{RSL_t}{SL} \tag{3.3}$$

Where, $RSLR_t$ is the remaining service life ratio; RSL is the remaining service life at time t; and SL is the service life of the asset.

3.2.4 Unified Equation for Multiple Attribute Ratios

By incorporating both the remaining service life and the condition of an asset, it is possible to derive an asset value that more comprehensively incorporates the perspectives of the two key stakeholders in asset management. A weighting system that measures the relative importance of the user and agency perspectives can be included to reflect such relative importance to an agency (Equation 3.4).

$$V_t = [w_u \cdot (Cost \cdot (CR_t)) + w_a \cdot (Cost \cdot (RSLR_t))] = \left[w_u \cdot \left(Cost \cdot \left(\frac{P_t - P_{worst}}{P_{best} - P_{worst}} \right) \right) + w_a \cdot \left(Cost \cdot \left(\frac{RSL_t}{SL} \right) \right) \right] \tag{3.4}$$

Where, V_t is the asset value at year t; w_u is the relative importance of the asset condition (user perspective); w_a is the relative importance of the remaining service life (agency perspective); $Cost$ is the original (historical) cost or the replacement cost of the asset in constant dollars (adjusted for inflation); P_t is the current condition of the asset at time t; P is the condition of the asset as new; P_{worst} is the condition of the asset at the point of failure; RSL_t is the remaining service life of the asset at time t; and SL is the service life of the asset.

3.3 Overall Mathematical Formulation for the EDMC Method

To develop a methodology that addresses the monolithic-structure limitation of past valuation methods, it is useful to consider the total asset value as a sum of its values of multiple components (Equation 3.5):

$$V_t = V_1 + V_2 + \cdots + V_I \tag{3.5}$$

Then, the unified attribute ratio equation must be applied to each component of the asset:

$$V_i = (cost\ of\ comp_i) \cdot (attribute\ ratio\ for\ comp_i) = 1,2,\ldots I \tag{3.6}$$

Where, $comp_i$ is any of the i (=1,2,…I) components that constitute the asset.

For k perspectives of k stakeholders with their associated attributes of concern, we have the following K attribute ratios for each asset:

$$AR_1, AR_2, \ldots\ AR_k,\ k = 1,2,\ldots,K \tag{3.7}$$

Where, attribute ratio or criteria ratio at year t is:

$$AR_k = \frac{function\ of\ the\ level\ of\ performance\ attribute\ at\ year\ t}{function\ of\ the\ \max\ or\ range\ of\ performance\ attribute} = \frac{f(AR_t)}{f(AR_{max}\ or\ AR_{range})} \tag{3.8}$$

Where only two attributes or criteria are considered, such as the asset condition (user perspective) and service life (agency perspective), then K = 2. Thus,

w_1 or $w_{k=1}$ is the relative importance of the agency perspective; and

w_2 or $w_{k=2}$ is the relative importance of the user perspective.

Applying the condition ratio and remaining service life ratio to each component i, yields:

$$V_t = \sum_{k=1}^{K} w_k \left(\frac{f(AR_t)}{f(AR_{max} \ or \ AR_{range})} \right) \quad (3.9)$$

Thus, for all I components, the compressed total asset value equation is given as:

$$V_t = \sum_{i=1}^{I} \sum_{k=1}^{K} (w_k \cdot cost\_comp_i) \left(\frac{f(AR_t)}{f(AR_{max} \ or \ AR_{range})} \right) \quad (3.10)$$

The formulation for the proposed method, incorporating the various elements (components) and for only two criteria (attributes or perspectives) is presented as (Equation 3.11):

$$V_t = \left[w_1 \left(cost\_comp_i \left(\frac{P_{t_i} - P_{worst_i}}{P_i - P_{worst_i}} \right) + \cdots + cost\_comp_I \left(\frac{P_{t_I} - P_{worst_I}}{P_I - P_{worst_I}} \right) \right) + w_2 \left(cost\_comp_i \left(\frac{RSL_{t_i}}{SL_i} \right) + \cdots + cost\_comp_I \left(\frac{RSL_{t_I}}{SL_I} \right) \right) \right] \quad (3.11)$$

Where, V_t is the asset value at year t; $w_1 = w_u$ is the relative importance of the asset condition (users) perspective; $w_2 = w_a$ is the relative importance of the asset service life (agency) perspective; $cost\_comp_i$ is the construction cost for asset component i; $P_{t,i}$ is the condition of asset component i at time t; P_i is the initial (as-new) condition of component i; $P_{worst,i}$ is the worst possible condition of component i; $RSL_{t,i}$ is the remaining service life of component i at time t; and SL_i is the expected service life of component i.

3.4 Probabilistic Monte Carlo Simulation

Monte Carlo simulation allows for the probabilistic description of an output variable on the basis of several different random combinations of input variables that have their individual probability distributions (Figure 3.4). The Monte Carlo technique has been used recently in highway asset life estimation (*43*). In the report, the uncertainty of each input variable was governed by a normal distribution since the input data were found to follow this distribution. Previous literature includes uncertainty assessments on bridge condition ratings (*44*) and bridge costs (*45*). This section describes the results of a Monte Carlo simulation of the input variables used in the EDMC valuation method.

3.5 Summary

This chapter discussed the proposed elemental decomposition and multi-criteria (EDMC) method which considers the characteristics of each asset component or element. The condition and remaining service life of each component represent the perspectives of the user (asset condition) and agency (asset remaining life), respectively, in asset value computation. This methodology addresses the limitation of the monolithic structure assumption that is implicitly made in traditional asset valuation methods. In a subsequent section of this report (Section 7.3.1.), valuation of pavement and bridge assets in Indiana are carried out using this method and the results are presented and compared with values obtained using traditional methods. The next chapter proposes another new asset valuation method that focuses solely on the costs associated with asset reconstruction that are incurred directly by the agency and indirectly by the users.

4. PROPOSED METHODOLOGY II: REPLACEMENT, DOWNTIME, AND SALVAGE (RDS) METHOD

4.1 Introduction

The replacement, downtime, and salvage method is based on the premise that an asset is considered valuable to the public when both the agency and the road users would incur "pain" in its replacement due to hypothetical destruction (e.g., earthquakes or floods). This "pain" is represented by the costs that would be incurred by the agency and users in the event of reconstruction. Thus, the avoidance of such pain when the asset is still standing is a reflection of the value of the asset.

This method involves all the costs of replacing the asset in a given year as the asset value at that year. In this method, the existing condition of the asset is not considered because the scenario involves complete asset replacement, and asset replacement costs are typically not influenced by asset condition.

For agencies that use this method for asset valuation, there is a need to consider all the costs associated with all phases of asset replacement, namely, recycling/salvage of the existing structure, agency cost of construction, and user cost of construction. These costs should be calculated separately and summed to yield a total cost. The user cost of construction, also referred to in some literature as the replacement downtime costs, or in the case of highways, work zone costs, (which includes travel time costs and vehicle operating costs), can have a significant impact on asset value from the perspective of asset users due to the inconvenience they would suffer in the event of a reconstruction. From anecdotal evidence, the inclusion of user cost in asset valuation appears to be controversial because a school of thought believes that the user costs represent money that is not spent by the agency and thus should be excluded from asset management processes such as investment evaluation and asset valuation. This is a debate that is still ongoing in the field of transportation. Recycling benefits are negative costs because the material is being re-used. If the salvage materials are disposed of in landfills, the cost of disposal should be reflected in the asset value. In most traditional methods, user inconvenience costs during asset replacement and the end-of-life costs and benefits are not incorporated.

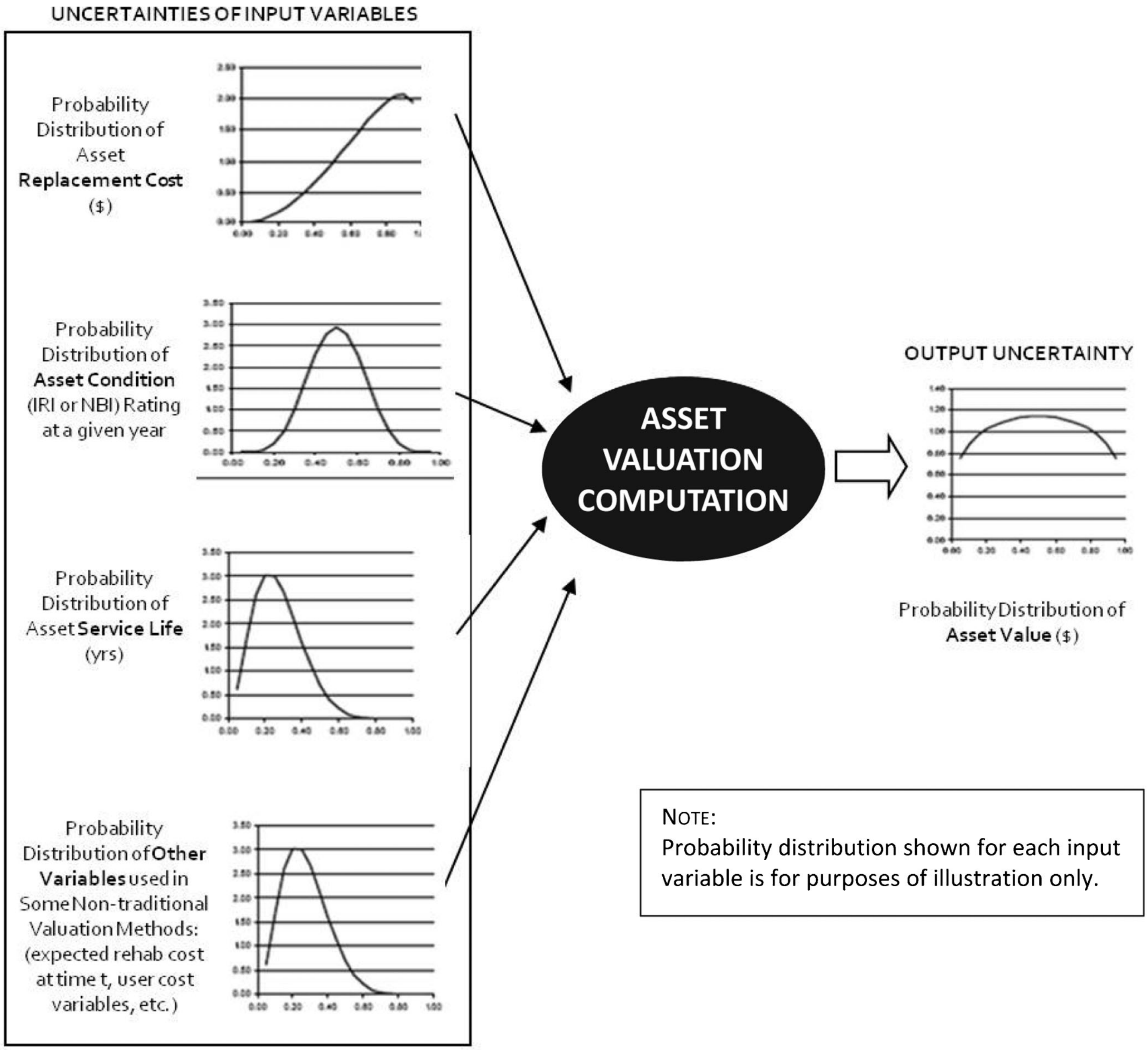

Figure 3.4 Monte Carlo simulation process (adapted from (*46*)).

4.2 Salvage Benefits/Disposal Costs of Existing Assets

Recycling and disposal costs can be significant. Recycling materials on site to re-use in the reconstruction of the existing structure subtracts from the cost of replacing the asset. If it is necessary to dispose of any material, the associated disposal cost is subtracted from the overall salvage value. Thus, the contribution of total salvage and disposal costs to asset value is given by:

$$V_{EOL} = Cost_{disposal} - Cost_{salvage} \tag{4.1}$$

4.3 Agency Cost of Replacement or Reconstruction

Asset end-of-life costs, specifically replacement cost, is the amount an agency spends to replace an asset. The estimation of this cost is similar to that of the traditional methods of asset valuation. The annual CPI provided by FHWA is used to adjust time, to account for inflation. The replacement cost method has been found to yield the highest asset value compared to all other valuation methods and thus is not considered as accurately reflecting the correct value of an aging asset.

4.4 Downtime User Costs

4.4.1 User Delay Cost

In a workzone, users incur travel time delays due to lane closure, congestion due to the reduced number of lanes available to traffic, reduced speeds through the workzone, detours around the construction workzone, and vehicle operating costs. For example, a bridge workzone will reduce load capacity on the bridge and reduce clearance over/under the bridge (*12*). In this case, the vehicles that do not meet the load or height restrictions must detour. To calculate user costs for bridges for this aspect of the RDS method, a number of equations and associated assumptions are necessary. The percentages of the AADT for specific vehicle classes can be obtained from FHWA VTRIS. The user's travel time cost can then be calculated as follows (*47*):

$$Cost_{ttc} = \sum_{i=1}^{m} U_{TTC}(i)\left(\frac{DL}{SP(i)}\right)N(i) \qquad (4.2)$$

Where, $U_{TTC}(i)$ is the unit travel time cost of vehicle class i (\$/mi); $N(i)$ is the number of class i vehicles that are affected by the workzone; and $SP(i)$ is the average speed of vehicle class i (miles/hour).

Thus, the contribution of travel time user cost, during replacement, to asset value is given by:

$$V_{t,ttc} = Cost_{ttc} \qquad (4.3)$$

Where, $Cost_{ttc}$ is the travel time user cost due to the work zone.

4.4.2 User Vehicle Operating Cost

Vehicle operating costs typically increase when road users detour or travel through a workzone. A vehicle incurs increased wear and tear when traveling under such conditions due to diminished travel conditions. For example, traveling over sub-standard pavement or gravel accelerates tire wear and increases the likelihood of damage to the vehicle's engine, drive train, or body. Also, increased fuel consumption may arise due to long detour routes or decreased speeds and delays through work zones. The vehicle operating cost for users in a workzone can be calculated as follows (*12,47*):

$$Cost_{VOC} = \sum_{i=1}^{m} U_{voc}(i)(DL)N(i) \qquad (4.4)$$

Where, $Cost_{VOC}$ is the vehicle operating cost due to the workzone; m is the number of vehicle classes; DL is the detour length (miles); $U_{VOC}(i)$ is the unit vehicle operating cost of vehicle class i (\$/mile); and $N(i)$ is the number of class i vehicles.

Thus, the contribution of user vehicle operating cost during replacement of the asset, to the asset value is given by:

$$V_{t,VOC} = Cost_{VOC} \qquad (4.5)$$

Where, $Cost_{VOC}$ is the vehicle operating cost due to the workzone.

4.5 Mathematical Formulation for the RDS Method

The total asset value at time t, V_t, can be estimated as the total cost of asset replacement that is avoided by not having to replace the asset at that time;

V_t = Agency cost of Reconstruction
+ User Cost associated with Reconstruction
+ Disposal Costs
− Salvage Benefits

$$= RC + (V_{t,ttc} + V_{t,VOC}) + V_{t,DISP} - V_{t,SALV} \qquad (4.6)$$

Where, RC is the asset replacement cost; V_t is the overall asset value; $V_{t,ttc}$ is the value associated with the avoidance of the user travel time by not reconstructing the asset; $V_{t,VOC}$ is the value associated with the avoidance of the vehicle operating cost by not reconstructing the asset; and $V_{t,DISP}$ and $V_{t,SALV}$ are the values associated with the recycling and disposal costs and benefits, respectively.

4.6 Summary

The replacement-downtime-salvage (RDS) method is based on the premise that an existing asset can be valued at any time on the basis of the costs that are avoided by not having to replace it at that time, due to reasons such as natural or man-made disaster. This includes the agency cost of replacement and the "pain" that would be incurred by the users in the event that the asset needed to be replaced. During asset downtime, users typically incur travel time delays and vehicle operating costs associated with subpar driving conditions. Also, asset replacement costs should include end-of-life costs associated with the existing structure before the replacement. Asset condition, service life, cost incurred during the asset life (rehabilitation and maintenance) are thus not considered in this method. Overall, this method considers asset value to reflect not only replacement costs, but also user inconvenience cost, and the costs and benefits of recycling and disposal. In Section 7.3.2, a valuation of sample pavement and bridge assets using this method is carried out, the results presented, and the obtained values compared to the values obtained using other proposed methods.

5. PROPOSED METHODOLOGY III: DECOMMISSION AND RE-USE (D&R) METHOD

5.1 Introduction

From a purely business perspective, the value of a highway asset can be determined on the basis of the monetary worth of the land it occupies. As such, a highway, for example, could be relocated to a different location or underground and the land it occupies could be reverted to farmland, green space, or real estate. This approach of asset valuation appears reasonable particularly where in densely populated areas where real estate prices are very high and feasible opportunities exist for the highway relocation.

In Boston, for example, the "Big Dig" was commissioned in the downtown area to relocate a major interstate highway that had been plagued with severe traffic congestion and unsightly views. The project involved relocation of the surface road to the subterranean location: 7.5 miles of underground roadway tunnels were built. The land formerly occupied by this highway section amounted to eight acres that is now used for purposes that are highly valued monetarily and non-monetarily in the form of public parks, housing, and retail (*48*). Thus, as demonstrated in the Big Dig example, if highly valuable land is occupied by a highway, it may be worth the investment to move the roadway to "open" the land for a different purpose. In another example, the New York City Department of Transportation (NYCDOT) recognizing that 25% of the city's land area is comprised of streets, is making an effort to reclaim underutilized street space for pedestrian plazas with their NYC Plaza Program (*49*). In these and other cases, valuing the highway, that is, valuing the land currently occupied by the highway, can aid decision-makers by providing additional information to evaluate proposals to move highways underground or elsewhere.

5.2 Land Valuation

To determine the total value of the land occupied by highway assets, the unit land value, and the length and total width (including right-of-way), of each highway section, are needed. The 2010 Indiana Design Manual for Roads (*50*) served as a valuable reference for the requisite data. The values of urban and rural land were expressed in year 2010 dollars. The following sections outline the assumptions and computational details of the various aspect of the land valuation analysis.

5.2.1 Unit Land Value

A Purdue University School of Agricultural Economics 2010 study determined the worth of farmland of average quality as $4,419/acre (*51*), which corresponds to $0.10/ft^2 for rural land. The urban land value was obtained from a Lincoln Institute of Land Policy national study of residential housing (*52*). For valuation purposes, that study assumed that each house occupies 1800 ft^2 of land area, and reported real estate values separately for the structure and the land. In Indiana, the resulting urban land value was found to be $14,578 (2010$) for the 1,800 ft^2 area or $8.10/ft^2 (Figure 5.1). It is worth noting that unlike the case for physical, man-made highway assets, land value appreciates over time.

5.2.2 Decomposition of Roadway Inventory

For the computation of land values, roadways can be categorized as interstates and non-interstates (to account for the differences in widths of the lanes and rights-of-way), and urban and rural (to account for the differences in land value for the different land uses). Each road class has different design criteria, as specified in the 2010 Indiana Design Manual. For the purposes of this report, interstates were assumed to have the minimum median width that is outlined in the design specifications. The left and right shoulder dimensions of existing roads were assumed to be consistent with the minimum widths specified in the design manual. Interstates and non-interstates were assumed to have the ditch dimensions shown in Table 5.1. The right-of-way width for interstates was assumed to be 15 ft. from the construction limit line in the design manual or the edge of the shoulder or ditch on either side. Figure 5.2 depicts a four-lane interstate section with dimensions shown for each component. The dimensions in Table 5.1 account for the components left and right of the centerline.

The dimensions for each cross-sectional component are listed in Table 5.1 for each classification category.

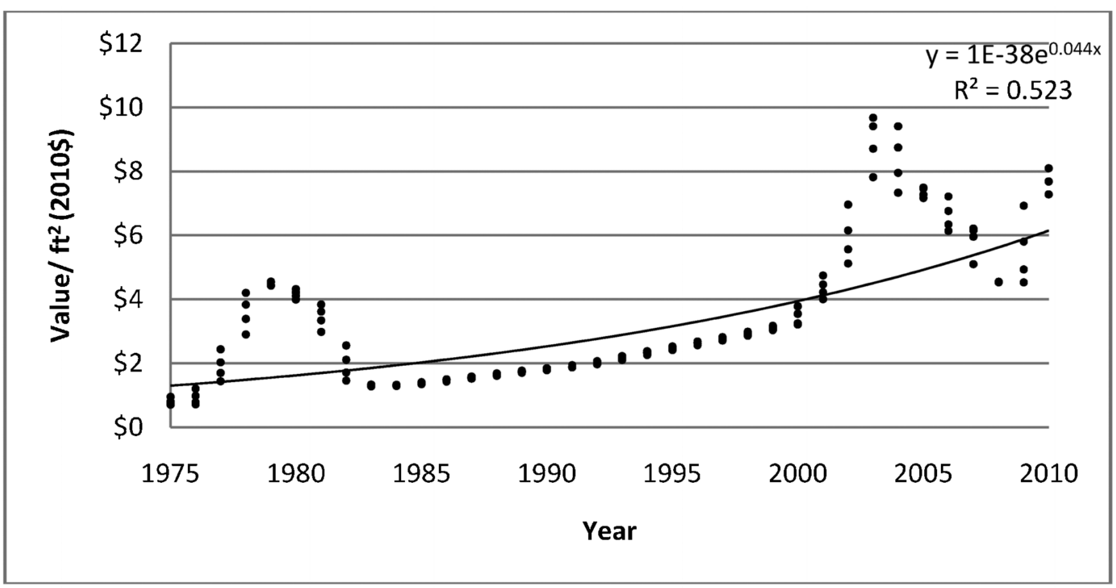

Figure 5.1 Indiana urban land value trends in 2010$ (data are from (*51*)).

TABLE 5.1
Typical Roadway Cross-Sectional Dimensions for Land Valuation Purposes

Component	Rural Interstate	Urban Interstate	Rural Non-Interstate	Urban Non-Interstate
Travel lane	12 ft.	12 ft.	12 ft.	12 ft.
Shoulders	11 ft. right and 4 ft. left	11 ft. right and 4 ft. left	6 ft. right and left	6 ft. right and left
Median	54.5 ft.	10 ft.	N/A	4 ft.
Ditch	1.2 ft. right and left	1.2 ft. right and left	4 ft. right and left	4 ft. right and left
Right-of-way	15 ft. right and left	15 ft. right and left	10 ft. right and left	10 ft. right and left

Source: (*50*).

On the basis of the existing or standard cross-sectional dimensions, the land area occupied by the highway assets can be calculated. The product of the unit land price and the total land area yields the total land value in monetary terms. The total value of land occupied by the highway is then considered to be the value of the existing highway. In cases where the valuation exercise is being undertaken as a precursor to possible relocation of the highway, the total highway value at the relocation areas should be compared with the cost of relocation: if the existing highway value far exceeds the cost of highway relocation, then the value could serve as an economic justification for the relocation. Relocation involves the decommissioning and re-use of the land occupied by the highway asset for another purpose and reconstruction of the highway at the same geographical location, but at a different level (underground or elevated) or at a different geographical location. In certain cases, decision-makers may choose to decommission the highway and re-use the land for other purposes without replacing the highway.

5.2.3 Numerical Example

As a numerical illustration of the method, consider a two-mile long section of Interstate 65 in downtown Indianapolis, Indiana. The section consists of six lanes with an assumed interstate lane width of 12 feet. Summing the widths for the urban interstate asset category in Table 5.1 yields a total length of two miles and a width of 144 feet of total land occupied by this interstate road section. The length of the section is 10,560 feet and thus the total area is 1.52 million square feet. Using an urban land value of $\$8.10/ft^2$ for this area yields a total value of \$12.3 million.

If the valuation purpose were to investigate the feasibility of relocation and re-use, the cost of relocation needs to be estimated. Using average highway tunnel costs of \$38 million per lane-mile (*53*), a tunnel would cost \$456 million. Thus, in this case, it is clear that it is not economically feasible to relocate this highway to an underground location on the basis of the market value of the land it occupies.

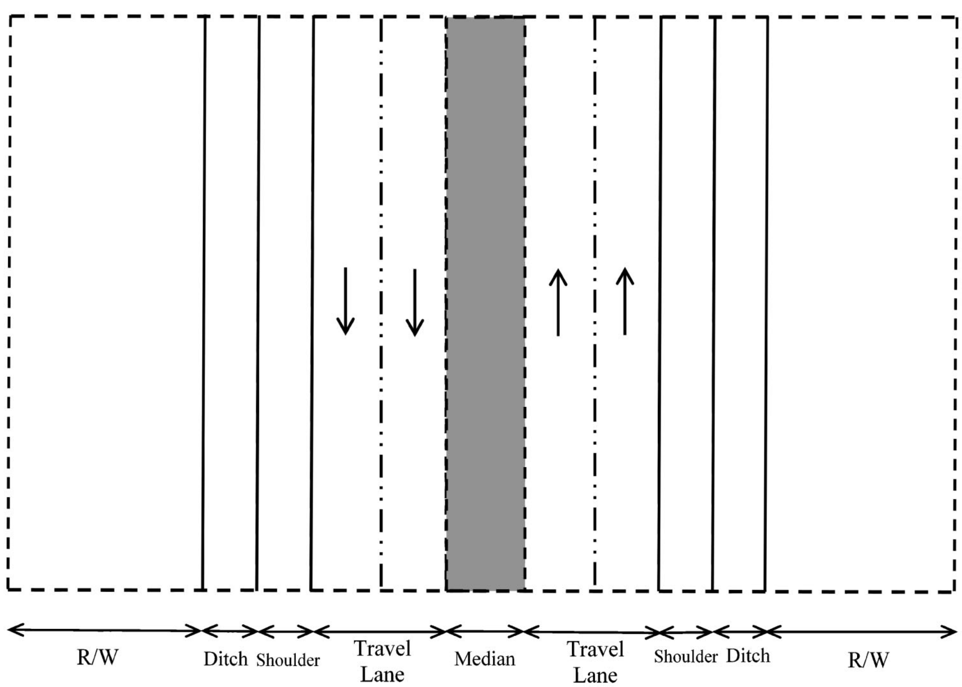

Figure 5.2 Dimensions for example purposes.

As seen in this section, the value of a highway in terms of the value of the land it occupies, can be determined by assigning a market value to the land it occupies, with the assumption that the highway can be relocated elsewhere or is no longer needed. Thus, for assets that are already being considered for decommissioning or re-use, asset valuation can play a key role in the decision making. In dense central business district areas, very significant value may be found for land that is currently occupied by highways and streets and these values could justify relocation investment decisions. New business could be attracted to the freed-up land or green space could be established to improve the quality of life and the environmental quality of those areas.

5.3 Chapter Summary

The monetary worth of the land occupied by a highway asset can provide a rationale for assessing the value of an asset in terms of the value of the land it occupies. The land value can thus play a vital role in decisions to relocate the assets to provide room for other purposes, including commercial development, recreational areas, real estate, farmland, or green space. The value of the real estate occupied by the asset could outweigh the cost of relocating the asset. In a subsequent section of this report (Section 7.3.3), the valuation of a sample pavement and bridge asset in Indiana is carried out using this method, and the results are presented and compared with those of other methods.

6. PROPOSED METHODOLOGY IV: PROBABLISTIC VALUATION METHODS

6.1 Introduction

As it is with all engineering systems, highway assets behave stochastically because they are subject to forces that are not deterministic but vary across time and space. One way of incorporating probabilistic elements in asset valuation is to provide ranges, rather than fixed amounts, for the valuation input parameters such as replacement cost, condition and remaining life. Within the ranges, the amounts could take any specific level depending on the nature of the distribution. Another way is to directly use probabilistic modeling techniques to describe the remaining life of the asset. As such, another method to determine the value of highway transportation assets could be proposed on the basis of the assumption that asset value is related to the probability that an asset will survive until time *t* if it has not failed as of time *t*-1. To calculate this probability, a Weibull distribution could be used. The asset value is then calculated as the product of the survival probability and the asset replacement cost. The following sections describe the steps for determining asset values in a probabilistic manner using survivor functions.

6.2 Theory of Duration Modeling Based on Weibull Distribution

Duration models capture the time until an occurrence of any event. These models are non-parametric, semi-parametric, or fully parametric. Non-parametric methods do not retain the parametric assumption of a covariate influence unless there is little knowledge of the hazard functional form or there is a small number of observations in the data (*54*). Therefore, they are less common in the transportation field. Semi-parametric models are useful for situations where the functional form of the hazard is unavailable. A fully parametric model, on the other hand, is applied when distribution of the hazard is known, and may take functional forms such as gamma, exponential, Weibull, log-logistic, or Gompertz. The Weibull survival curve is one of the most commonly-used distributions in parametric duration models (*55*). The equation for the Weibull function is:

$$S(t) = EXP\left[-1 * \left(\frac{t-\gamma}{\alpha}\right)^{\beta}\right] \tag{6.1}$$

Where, α represents the scaling factor; β represents the shape factor; and γ represents the location factor (shifts curve horizontally by representing value at which 100% survival probability occurs).

In this study, the Weibull probability (y_t) that the asset life is greater than or equal to time *t*, is given by:

$$y_t = e^{-1*\left(\frac{t}{e^{b_1 X_1 + \cdots + b_n X_n}}\right)^{\beta}} \tag{6.2}$$

Where, β represents the shape factor, $b_1, b_2, \ldots, b_n$ are parameter coefficients; and $X_1, X_2, \ldots, X_n$ are explanatory variables.

The Weibull distribution allows for positive duration dependence in other words, it can account for the situation where the probability of the duration ending increases over time ($\beta>1$). This means, as the asset nears the end of its service life, it has a higher probability of failure. The distribution does allow for a negative duration dependence ($\beta<1$) in which the probability of the duration ending decreases over time; however, this property obviously is uncharacteristic of bridge or pavement assets. Also, in contrast to the exponential distribution, the Weibull distribution is a more flexible means of capturing duration dependence. In this report, NLOGIT software was used for estimating the Weibull distribution parameters of the survival functions (*56*).

6.3 Pavement Survival Curve Model

For purposes of illustration, Table 6.1 presents the Weibull survival model estimates for the pavement assets, for a small sample of pavement sections.

A comparison of the exponential and Weibull models indicates whether or not a *t* statistic of the shaping parameter is significantly different from 1. A *t* statistic

TABLE 6.1
Weibull Model Parameter Estimates, Duration of Pavement Survival

Variable Description	Parameter	*t* Statistic
Constant	2.74	100.36
IRI (in./mile)	0.0038	18.60
Pavement type, 1 if pavement is flexible, 0 otherwise	-0.13	-8.22
1 if road section is an interstate, 0 otherwise	-0.087	-3.71
1 if road section located in urban area, 0 otherwise	-0.080	-7.14
Pavement section lane-miles	-0.0036	-11.23
Scale parameter	0.054	124.80
Shaping parameter	3.17	63.29
Log likelihood at convergence	-824.06	

greater than 1 indicates that the Weibull model is preferred over the exponential model (*54*).

$$t = \frac{P-1}{S.E.} \tag{6.3}$$

Where, P is the shaping parameter; S.E. is the standard error.

For the pavement data,

$$t = \frac{3.17-1}{0.050} = 43.4 \tag{6.4}$$

Thus, the t statistic is significantly different than 1 (Equation 6.3), indicating that the Weibull model is appropriate for modeling the survival of the pavement assets in the case study.

The model suggests that flexible surfaces, compared to rigid surfaces, increases the hazard and thus have lower duration of the service life, which is consistent with intuition: in contrast to rigid pavements, flexible pavements generally have shorter service lives and therefore reach the end of their service lives earlier. Also, interstate pavements, from the model results, exhibit an increased hazard and therefore a lower duration compared to their non-interstate counterparts. This is likely because interstates typically have higher truck traffic compared to non-interstates, so their rate of deterioration is generally faster than other roads, leading to a shorter service life, even though Interstates have higher design and construction standards than non-Interstates. This result seems to suggest that that the debilitating effect of truck traffic on Interstate pavements outweigh the benefits of the thicker pavements associated with that functional class. Also, the model results show that if the pavement is located in an urban area, it will have a lower duration of service life and increased hazard, suggesting that urban pavements, all other factors remaining the same, have shorter service lives than their rural counterparts. The survival curve is shown in Figure 6.1 and the Limdep output is located in Appendix A.

6.4 Valuation of Assets using Survival Models

The following equation represents the computation of the probabilistic valuation of assets using the asset's survival probability. The replacement cost is multiplied by the probability that the asset will survive to the end of its service life. Clearly, the asset value is higher if the asset has a high probability of survival and lower if the asset has a small probability of survival. The parameters for each asset type are presented in Table 6.1.

The value of the asset at any time *t*, V_t, is given by:

Vt = Probability of survival · replacement cost

$$V_t = (RC)e^{-1*\left(\frac{t}{e^{b_1X_1+\cdots+b_nX_n}}\right)^{\beta}} \tag{6.5}$$

Where, *RC* is the replacement cost; β represents the shape factor, $b_1, b_2, \ldots, b_n$ are parameter coefficients; $X_1, X_2, \ldots, X_n$ are explanatory variables; and *t* is age in years.

The value of a 2 lane-mile HMA pavement section (RP041+.95-PR042+.95) on State Route 23 in Indiana, with an estimated replacement cost $7.85 million, located in an urban area, with an IRI (in./mile) of 121.8 and an AADT of 7,703 is:

$$V_{13\ years} = (\$7.85M)e^{-1*\left(\frac{13}{e^{2.74+0.87(121.8)-0.11(1)-0.0078(0)-0.028(1)-0.042(2)}}\right)^{8.17}} \tag{6.6}$$

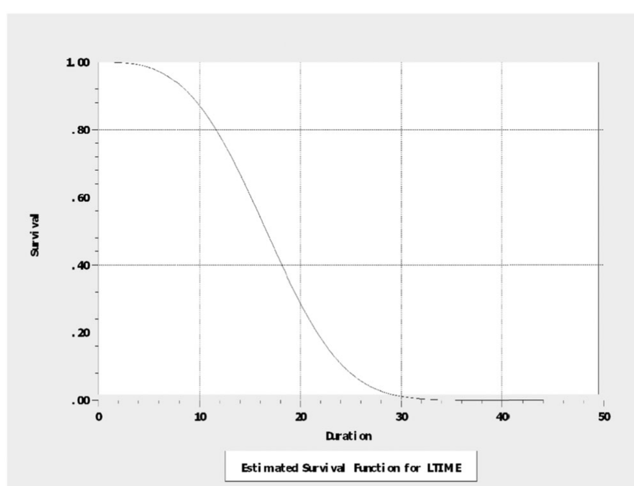

Figure 6.1 Pavement asset survival curve (duration in years).

$$V_{13\ years} = (\$7.85M)(0.98) \quad (6.7)$$

The survival probability is 98%. Thus, the value of this asset is:

$$V_{13\ years} = \$7.72M \quad (6.8)$$

6.5 Chapter Summary

The probability of surviving to the end of its service life can be a useful method to determine asset value based on the descriptive variables of each asset. However, in order to implement this method, an agency will need to develop appropriate hazard functions for each of its assets, preferably, different functions for each component of each asset type. The next chapter will demonstrate the new methods in comparison to traditional methods.

7. PROJECT-LEVEL DEMONSTRATION AND VALIDATION OF THE NEW METHODOLOGIES

7.1 Introduction

This chapter demonstrates how the developed methodologies could be used to value individual highway assets. As discussed in the preceding chapters, there are differences in the concepts utilized by each method and thus each method is expected to yield different asset values. The demonstrations, which can help compare and contrast the methods to discover or confirm any conceptual nuances, merits, and shortcomings associated with each method, were carried out at the project level for a specific highway bridge and pavement section. This chapter describes the collection and collation of data and presents the results of the project-level asset valuation calculations for each of the proposed methods.

7.2 Data Collection and Collation

The data collected to demonstrate the methods were from databases established for highway assets in the state of Indiana. The data collected for highway bridges included the year of construction, total deck width, length, superstructure material type, design type, and the historical cost, where available. The data collected for pavement assets included the road class (interstate, non-interstate, major, minor, or local), year of construction, the type of pavement (concrete, asphalt, or other specified materials) where available and historical cost was obtained from the replacement cost using the CPI dollar value for the historical year under consideration. Data on small assets, such as guardrails, culverts, road signs, and underdrains, included number, location, and size. Many assumptions were drawn to carry out the valuation of these asset types. Additionally, literature reviews of studies from other similar states were used to supplement these assumptions.

The sample bridge used for the demonstration of project-level valuations is a concrete slab bridge number 6737 on the Indiana state highway network. This bridge, built in 1990, has a length of 209 ft. and a total deck width of 48 ft. The bridge has an ADT of 7,830 vehicles per day and is located on the National Highway System. For the purposes of the RDS method, the following user cost-related data were also collected: the detour length of four miles and an assumed work zone speed limit of 45 mph.

The sample pavement section is an added travel lane HMA pavement along State Route 23, line miles RP041+.79 to RP044+.55; 2.76 miles in length with two lanes; and was constructed in 1997. It is not on the National Highway System and is located in an urban area. The AADT is 21,420 vehicles with an IRI of 91.2 and an area freeze index of 823 degree-days. Table 7.1 lists the data needs associated with each method.

7.2.1 Asset Replacement Cost Data

These data are needed for the replacement cost and adjusted replacement cost methods specifically, but may be used in place of the historical (original construction) cost where the latter is unavailable. As explained in an earlier section, the caveat is that the historical cost of an asset reflects what is actually in the field, in contrast to the replacement cost which reflects the expenditure of rebuilding the asset to current standards and specifications. Thus, using replacement costs for asset valuation may yield a value that overestimates its historical value. At most agencies, due to problems in record-keeping, the historical cost is typically unavailable so the replacement cost must be estimated. Then the historical cost is estimated by deflating the estimated replacement cost to the actual year of construction using the FHWA CPI. In the case

TABLE 7.1
Data Needs, the New Methodologies for Asset Valuation

Methodologies	Data Needs
Elemental Decomposition and Multi-criteria Method	Element historical construction cost Element deterioration trends Element service life Element age Element condition
Replacement-Downtime-Salvage Method	Historical construction cost User cost data (travel time, vehicle operating cost) Recycling material cost Service life Disposal costs Age
Decommission and Reuse Method	Land cost Area of land occupied by asset

study for this report, Table 7.2 presents the cost models used for bridge component replacement costs (*57*). The pavement replacement costs were either recorded from specific construction projects or taken as the average 2010 dollars per lane-mile for each section of roadway as per the HERS Technical Report (Table 7.3).

Major rehabilitation activities of a bridge were assumed to be its deck and superstructure rehabilitation (*59*); therefore, the rehabilitation cost equation only involved these components for this study (Equation 6.1). The average cost of bridge rehabilitation is given by Equation 7.1. Appendix A Table A.1 provides rehabilitation cost models for other bridge types.

$$REHB = 103.911 + .015(DA) + 91.13(NHS) - 35.787(STEEL) \quad (7.1)$$

Where, DA is the deck area (sq. ft.); NHS is 1 for bridges on the National Highway System, 0 otherwise; and $STEEL$ is 1 for steel bridges, 0 otherwise.

Pavement rehabilitation costs were obtained from the 2010 INDOT Project Cost Analysis. The average cost of pavement rehabilitation per lane-mile was $491,723/lane-mile in the year 2010, and road rehabilitation (3R/4R Standards) was $514,392/lane-mile (*60*).

Land prices were obtained from two research efforts. The current cost of rural land is from a study conducted for the 2010 Purdue University Agricultural Economics Report. The urban land cost is from a Lincoln Institute of Land Policy national residential housing study in the United States. Table 7.4 presents the land costs for urban and rural areas in 2010 dollars. Land cost is relevant in the Decommission and Reuse method of asset valuation.

7.2.2 Asset Condition Data

The condition of each asset was expressed in terms of an appropriate performance indicator. For pavements, the condition was described in terms of the International Roughness Index (IRI), a performance indicator that describes the user's perception of road quality in inches/mile units (*61*). Table 7.5 shows the ranges of IRI values and their corresponding condition meanings for pavements as used in the state of Indiana. For pavement assets that lacked IRI condition data, a model was used to predict the IRI for the EDMC method. Bridge condition was expressed in terms of the National Bridge Inventory Rating Scale (NBI) (Table 7.6). A zero rating indicates bridge failure and a rating of 9 indicates excellent bridge condition. The study used condition threshold values of 4 for bridge substructure and superstructure and 5 for bridge deck as outlined in the Indiana Bridge Management System (IBMS) Manual (*62*).

TABLE 7.2
Bridge Cost Data for the Demonstration of Project-Level Valuation

Type of Bridge	Cost ($/sq. ft.)
Concrete T beam	216.19
Concrete I beam	202.63
Concrete box beam	206.81
Concrete slab	188.45
Steel bridge	176.94
Wood	160
Masonry	170
Aluminum, wrought, CI	203

Source: (*57*).
NOTE: RC is the replacement cost of each asset in 2010$. RC = Length * number of lanes * unit cost.

TABLE 7.3
Pavement Cost Data for Demonstration of Project-Level Valuation

Functional Class	Cost (1000s, 2010$ per lane-mile)
Rural interstate	$896.87
Rural principal arterial	$783.66
Rural minor arterial	$557.24
Rural major collector	$571.08
Urban interstate (F&E wys)	$2728.35
Urban divided roads (4 and 6 lane)	$1554.74
Urban undivided roads (2 lane)	$1421.41

Source: (*58*).
NOTE: RC is the replacement cost of each asset in 2010$. RC = Length * number of lanes * unit cost.

TABLE 7.4
Unit Costs of Urban and Rural Land

Land	Cost ($/sq. ft.)
Urban	$8.10
Rural	$0.10

Sources: (*51,52*).

7.2.3 Data for Deterioration Modeling

This data is needed for the elemental decomposition and multi-criteria, written down replacement cost, and adjusted value with respect to condition threshold valuation methods. For bridge assets, deterioration models from the Indiana Bridge Management Manual were used to determine bridge condition and remaining service life at the year of the asset valuation analysis. Models were classified by highway class, bridge type

TABLE 7.5
IRI Range Descriptions

IRI Range (in./mile)	Description
>170	Poor
150–170	Marginal
115–150	Fair
80–115	Good
<80	Excellent

Source: (*50*).

TABLE 7.6
National Bridge Inventory Rating Scale

Rating	Description
9	Excellent condition
8	Very good condition-no problems noted
7	Good condition-some minor problems
6	Satisfactory condition-structural elements show minor deterioration
5	Fair condition-all primary structural elements are sound but may have minor corrosion, cracking or chipping; may include minor erosion on bridge piers
4	Poor condition-advanced corrosion, deterioration, cracking or chipping; also significant erosion of concrete bridge piers
3	Serious condition-corrosion, deterioration, cracking and chipping, or erosion of concrete bridge piers have seriously affected deck, superstructure, or substructure; local failures are possible
2	Critical condition-advanced deterioration of deck, superstructure, or substructure; may have cracks in steel or concrete, or erosion may have removed substructure support; it may be necessary to close the bridge until corrective action is taken
1	"Imminent" failure condition-major deterioration or corrosion in deck, superstructure, or substructure, or obvious vertical or horizontal movement affecting structure stability; bridge is closed to traffic but corrective action may put back in light service
0	Failed condition-out of service-beyond corrective action
N	Not applicable

Source: (*63*).

(steel or concrete) and components (deck, superstructure, and substructure). Highway classes are: National Highway System, non-National Highway System, and Local. For example, the deterioration models for a concrete bridge deck and its roadway classes are presented in Table 7.7 (*62*). Overall, bridges in the state of Indiana have an average service life of about 70 years depending on which material was used in their construction (*62*). Component service lives are provided in Table A.2 in Appendix A.

Service lives are defined as the amount of time an asset can adequately serve its users before requiring replacement. Remaining service lives are determined by subtracting the current or analysis year from the year of construction. FHWA (*64*) recommends a 45-year analysis period for new construction or reconstruction. The pavement wearing layer condition and remaining service life were predicted using the IRI deterioration model (*65*) (Equation 6.2).

In the case of pavement base layers, deterioration may occur from repeated traffic loading, fatigue, moisture intrusion, pumping, or other causes that manifests itself in pulverization of base aggregates (*66*). In extreme cases, even the subbase layer may suffer deterioration due to these conditions. Coring can reveal deterioration of the base and subbase layers, and this is demonstrated in the presence of fractures and instability of the core. A search through the literature did not indicate any study that has examined the deterioration rate of the base and subbase layer materials with respect to time. Even an outcome-based structural performance indicator, such as deflection, has been found to yield time trends that are so gentle that the gradual reduction in base or subbase quality, from the strength perspective, is barely perceptible (*67*).

Pavement base and subbase deterioration was therefore assumed to follow a sigmoidal functional form. For the purposes of this study, it was assumed that the base and subbase have service lives of 150% and 200%, respectively, of the wearing layer service life. For example, for a pavement that has a service life of 45 years, the base and subbase have the following deterioration equations based on a 0–100 scale (Table 7.8, Figure A.1). A value of 0 represents a failed layer and 100 represents a new pavement layer.

The model for the pavement roughness in inches per mile is:

$$IRI = e^{(\alpha + (\beta \cdot AATT \cdot t) + (\gamma \cdot ANDX \cdot t))} \qquad (7.2)$$

Where, $AATT \cdot t$ is the product of the average annual truck traffic volume (in millions) and time (years); $ANDX \cdot t$ is the product of the average annual freeze index (in thousands) and time (years); α, β, γ are the estimated parameters for specific pavement types and functional class; t is the age of the pavement in years.

The AADT for individual bridges and pavement sections were taken into consideration in estimating the

TABLE 7.7
Models for Concrete Bridge Deck Deterioration

Roadway Classification	Deterioration Model
NHS, Non-NHS, Major	$DCR = 3.588 - \dfrac{133.641}{37.399 + .000128 * AGE^{3.322}}$
Non-NHS, Minor and Local	$DCR = 4.702 - \dfrac{132.844}{35.202 + .000009 * AGE^{4.040}}$

NOTE: DCR is the deck condition rating; AGE is the age of the deck.

TABLE 7.8
Models for Pavement Base and Subbase Deterioration

Layer	Deterioration Equation (Scale 0–100)
Base	$100 - \left(\dfrac{10}{0.1 + e^{\left(\frac{-3age+68}{15}\right)}}\right)$
Subbase	$100 - \left(\dfrac{10}{0.1 + e^{\left(\frac{-3age+68}{29.5}\right)}}\right)$

current asset condition and also in some cost models (Section 7.2.1). Truck traffic was taken as 30% of the total traffic stream. County-level average freeze indices were used.

7.2.4 Asset Salvage Data

These data are needed for the replacement-down-time-salvage method and other valuation methods that consider salvage value. The salvage value in this study takes into consideration the on-site recycling and the removal of materials from the site. Recycling affects asset reconstruction cost because it reduces material transportation costs, costs of filling landfills, and uses non-renewable resources.

There are multiple ways to recycle asphalt pavement onsite. Hot- and cold-mix recycling is relatively cheaper than virgin asphalt cement; hot in-place recycling eliminates transportation costs and the use of virgin material; and cold in-place recycling eliminates fuel and emission control systems and transportation, and uses a small amount of virgin asphalt binder (*66*). Hot-mix recycling or recycled asphalt pavement (RAP) offers options for different mix quantities with virgin materials from 20% to 50% (*66*). The RAP quantity in Table 7.9 refers to the 50% mixture, but different percent ranges can be found in Appendix A of the FHWA Pavement Recycling Guidelines for State and Local Governments (*66*). Hot in-place recycling can be categorized into surface recycling, repaving, and remixing. Recycling and reusing concrete pavements can lead to an estimated cost savings of 50% to 60% compared to using new aggregate (*69*). For example, TxDOT saved 1.8 million tons of virgin aggregate with an estimated cost saving of $12.6 million (*70*). Options for recycling concrete pavement range from processing it into aggregate for granular base, subbase, or shoulder materials or to process it into recycled concrete aggregate (RCA) bedding, backfill, embankment, or hydraulic-cement concrete (*71*). The costs and benefits of using pavement recycling methods instead of virgin materials are shown in Table 7.9.

Another method for quantifying salvage value (Equation 7.3) takes into consideration the residual value of the last rehabilitation action and its remaining service life (*66*). If data on the last rehabilitation are available, this method of salvage value computation could be used in the end-of-life cost expression (see Equation 4.1) for the proposed replacement-downtime-salvage method (see Section 4.2). Figure 7.1 graphically illustrates how salvage value, SV, is calculated in this manner:

$$SV = 1 - \left(\frac{L_A}{L_E}\right) * C \qquad (7.3)$$

Where, SV is the salvage value of rehabilitation in the analysis year; L_A is the service life of the last rehabilitation in years (difference between year of construction and year of termination of life cycle analysis); L_E is the expected life of the last rehabilitation; and C is the cost of the rehabilitation.

7.3 Results from the New Methods of Valuation

Each of the three methodologies was used to calculate the value of a sample pavement section and bridge from the state of Indiana. The sample bridge is concrete slab bridge number 6730, built in 1990 with a length of 209 ft. and a total deck width of 48 ft. in Indiana. The bridge has an ADT of 7,830 vehicles per day on a major roadway and is on the National Highway System. The bridge also has a detour length of four miles and an assumed work zone speed limit of 45 mph. The sample pavement section is added travel lane HMA pavement along State Route 23 between line miles RP041+.95-RP042+.95 and is 1 mile in length with two lanes and was constructed in 1998. It is on the National Highway System and runs through an urban area. In this section, the results of calculations are provided for the sample pavement section and the sample bridge from the state of Indiana.

The compiled costs for Indiana pavements for new construction, added travel lanes, and multiple repair activities were used in the study. New construction and added travel lane costs were converted to year 2010 dollars using the FHWA CPI index. Repair costs were replaced with the corresponding average 2010 costs for pavement replacement from the HERS Technical Report (*58*). The total number of lane-miles in the database was cross-referenced with the 2009 HPMS

TABLE 7.9
Recycling Methods Cost and Savings

Recycling	Construction Cost	% Savings
Hot Mix (RAP), 50% mix	$7.80/ton	34% cost savings
Hot in-place		32% energy savings; 17%–50% cost savings
• surface recycling	$3.3/m^2	
• repaving	$3.62/m^2	
• remixing	$2.24/m^2	
Cold in-place	$1.71/m^2–$9.87/m^2	6%–67% cost savings
Full-depth reclamation	$7.25/m^2	45% cost savings
Recycled concrete aggregate	$7/ton	50%–60% cost savings

Sources: (*66,69,70*)
NOTE: Percent savings are in comparison to using virgin materials.

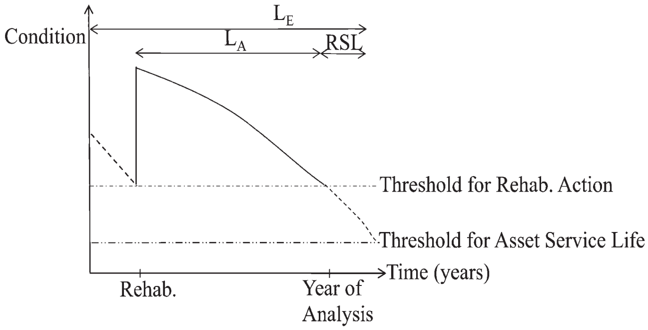

Figure 7.1 Asset rehabilitation cycle indicating salvage value.

database (*72*) total lane-miles to verify that all INDOT-owned pavement lane-miles were accounted for. Bridge costs were calculated using the cost models presented in a previous section.

7.3.1 The Elemental Decomposition and Multi-Criteria (EDMC) Method

This method determines the value attributed from each component in an asset which ultimately calculates to the total asset value. It also addresses different stakeholder perspectives with specific attribute ratios and relative weights.

Different bridge types, such as concrete and pre-stressed concrete, were grouped together and further sorted into slab or beam categories. Steel bridges were in a separate category. Each component of a bridge, namely, the superstructure, substructure, and deck were assigned a condition rating threshold of 4, 4, and 5 respectively based on the IBMS Manual (*62*). Using the thresholds, the deterioration equations in the IBMS Manual were rearranged to yield the service lives of each bridge component, for the "major" and "minor" categories of the highway classes. Service life equations for a steel bridge superstructure with a condition threshold of 4 yielded a service life of 82 years (Table 7.10).

Pavements were categorized into interstate or non-interstate and rigid or flexible classifications. Table 7.11 identifies each pavement type and their assumed thicknesses from field observations. Pavement costs were based on the ratio of the average cost of each pavement layer per lane-mile applied to the contract cost of each pavement section (Table 7.12).

Table 7.13 provides a breakdown of the sample bridge component costs, Table 7.14 lists the condition of each component, Table 7.15 lists the remaining service lives of each component, and Table 7.16 shows the user cost incurred in a work zone during bridge reconstruction. All values are in 2010 dollars.

For the EDMC method of valuation, the relative importance of the agency and user perspectives are needed. An agency weight of 0.6 assumes that the decision-maker assigns a 60% importance to the agency's perspective (asset remaining service life) and a 40% importance to the user perspective (asset condition). The highest possible condition rating for a bridge is 9. Thus, for the bridge under consideration, the elemental decomposition and multi-criteria method results in the following value:

$$V_{EDMC} = \left[0.4.\left(\$821{,}094\left(\frac{7}{9}\right) + \$232{,}907\left(\frac{6}{9}\right) + \$426{,}840\left(\frac{7}{9}\right)\right) + 0.6\left(\$821{,}094\left(\frac{80}{100}\right) + \$232{,}907\left(\frac{80}{100}\right) + \$426{,}840\left(\frac{62}{82}\right)\right)\right] = \$1.06\text{M} \quad (7.4)$$

This yields a value of \$106 per deck area (sq. ft.) of the sample bridge.

The estimated full service lives and remaining service lives of the pavement layers, for the given pavement section, are listed in Table 7.17. The cost of each layer is presented in Table 7.16 and the layer conditions are in Table 7.18. The method requires additional data for pavement layer components.

From the INDOT records spanning several years, the best possible IRI condition rating is 60 (theoretically, 0 is the best, but it is impractical to attain this value). The

TABLE 7.10
Steel Superstructure Service Life Equations (*62*)

	Equation	Threshold	Estimated Service Life (years)
Major	$SL = \left(\frac{\left(\frac{51.8}{(rating-1.7)}\right)-7}{0.009}\right)^{\frac{1}{1.7}}$	4	82
Minor	$SL = \left(\frac{\left(\frac{52.2}{(rating-2.5)}\right)-8}{0.005}\right)^{\frac{1}{1.84}}$	4	100

NOTE: SL is the service life; rating is the threshold condition rating based on the IBMS Manual.

TABLE 7.11
Typical Pavement Thicknesses

		Rigid Pavement	Flexible Pavement
Interstate	Top layer	0.75 ft. slab	0.75 ft. wearing and binder
	Lean concrete base	1 ft.	N/A
	Loose base	1 ft.	0.8 ft.
	Subbase	2 ft.	1.5 ft.
Non-Interstate	Top layer	0.5 ft. slab	0.5 ft. wearing and binder
	Treated base	0.8 ft.	N/A
	Loose base	1 ft.	0.8 ft.
	Subbase	2 ft.	1.5 ft.

TABLE 7.12
Pavement Layer Costs

Pavement Layer	Average Cost per Lane-Mile for Rigid Pavement (2010$)	Cost Ratio (% of total cost)	Average Cost per Lane-Mile for Flexible Pavement (2010$)	Cost Ratio (% of total cost)
Slab/wearing and binder	$109,545	0.32	$87,539	0.39
Base	$152,898	0.45	$91,852	0.41
Subbase	$76,449	0.23	$45,926	0.20

TABLE 7.13
Component Costs for the Sample Bridge

Component	Cost Equations	Cost
Superstructure	(56.66)(bridge length)(bridge width)	$821,094
Substructure	(17.12)(bridge length)(bridge width)	$232,907
Approach (deck)	$(0.769)(500^{0.823})$	$426,712
Other (deck)	(45.12)(bridge length)(bridge deck width)	$128
Total		**$1,059,417**

TABLE 7.14
Component Conditions for the Sample Bridge

Components	Condition Ratings (NBI Database)	Average
Deck	7	
Superstructure	6	6.67
Substructure	7	

TABLE 7.15
Component Remaining Service Life for the Sample Bridge

Components (age 26 years)	Threshold (NBI)	SL (years)	RSL (years) (sample age: 20)	Averages
Deck	5	82	62	
Superstructure	4	100	80	94 SL
Substructure	4	100	80	74 RSL

TABLE 7.16
Component Costs for the Sample Pavement

Component	Cost (2010$)
Wearing and binder	$1,108,698
Base	$1,165,554
Subbase	$568,563
Total	$2,842,816

TABLE 7.17
Remaining Service Life (Projected) for Components of the Sample Pavement

Components (current age: 12 years)	SL (years)	RSL (years)
Wearing surface and binder	45	33
Base	68	56
Subbase	90	78

TABLE 7.18
Component Conditions for the Sample Pavement

Components	Condition Equations (Deterioration Equations)	Condition Ratings (0–100)
Surface pavement	Given in data set (IRI in./mile)	121.8
Base	$100-\left(\frac{10}{0.1+e^{\left(\frac{-3age+68}{15}\right)}}\right)$	99
Subbase	$100-\left(\frac{10}{0.1+e^{\left(\frac{-3age+68}{29.5}\right)}}\right)$	97

worst, from the records, may be taken as 200. The base and subbase conditions were based on a scale of 100, with 100 as the best condition rating. The elemental decomposition and multi-criteria method yields the following asset value for the pavement case study:

$$V_{EDBC}=\left[0.4\left(\$1{,}108{,}698\left(\frac{121.8-200}{0-200}\right)+\$1{,}165{,}554\left(\frac{99-0}{100-0}\right)+\$568{,}563\left(\frac{97-0}{100-0}\right)\right)+0.6\left(\$1{,}108{,}698\left(\frac{33}{45}\right)+\$1{,}165{,}554\left(\frac{56}{68}\right)+\$568{,}563\left(\frac{78}{90}\right)\right)\right]=\$2.75M \tag{7.5}$$

This yields a value of $1.38 million per lane-mile.

7.3.2 The Replacement, Downtime and Salvage (RDS) Method

The replacement, downtime and salvage valuation method focuses on the value added due to replacement and other costs including recycling, disposal of materials, and user inconvenience costs. The replacement costs for the sample bridge and pavement sections are presented in Table 7.19.

TABLE 7.19
Replacement Cost of the Sample Assets

Asset	Total Replacement Cost (2010$)
Bridge #6730	$1,059,417
Pavement section RP041+0.95-RP042+0.95 on State Route 23	$2,842,816

The travel time costs for pavement workzones had a detour that was the length of the pavement section. The assumed workzone speed limit was 45 miles per hour. The pavement age was assumed to be the year of the last work done subtracted from the year of the analysis (i.e., 2010). Table 7.20 presents the total user inconvenience cost for the sample bridge and Table 7.21 presents the total user inconvenience cost for the sample pavement.

Two recycling options were selected for rigid and flexible pavements from the available recycling alternatives. Recycling for rigid pavements was assumed to save 50% of the total construction cost by crushing the old concrete pavement to serve as an aggregate base for the new pavement. Flexible pavements were assumed to save 34% of the construction cost by using RAP. Concrete bridges were assumed to have a 50% cost savings for re-use of the aggregate base, similar to rigid pavements. For this example, disposal costs were not applicable. Table 7.22 presents the recycling savings for the sample assets.

The final replacement, downtime and salvage value for each asset revealed a lower value compared to the replacement cost due to the recycling and user costs (Table 7.23). The sample bridge asset had a 66% difference in asset value while the pavement sample asset had a 98% difference in the asset replacement value.

7.3.3 The Decommission and Re-use (D&R) Method

Pavement section RP041+0.95 to RP042+0.95 on State Route 23 is an urban non-interstate which is a total width of 68 ft. (see Table 5.1) and a length of 5,280 ft. The total area of the asset is 359,040 sq. ft. The land value for urban land is $8.10/sq. ft. The total land value of the highway asset then, is $2,908,224.

7.3.4 The Probabilistic (Survivor Function) Method

The value of the asset at any time t, V_t, is given by: Vt = (Probability of survival)· (replacement cost)

$$V_t=(RC)e^{-1*\left(\frac{t}{e^{b_1X_1+\cdots+b_nX_n}}\right)^{\beta}} \tag{7.6}$$

Where, RC is the replacement cost; β represents the shape factor, $b_1, b_2,\ldots,b_n$ are parameter coefficients; $X_1, X_2,\ldots, X_n$ are explanatory variables; and t is age in years.

For example, the value of a HMA pavement section (RP041+.95-PR042+.95) on State Route 23 in Indiana,

TABLE 7.20
Workzone User Costs for the Sample Bridge

User Costs	Equations	Costs
Travel time (work zone)	$V_{t,ttc}=\sum_{i=1}^{m} U_{TTC}(i)\left(\frac{DL}{SP(i)}\right)N(i)$	\$2,822
VOC (work zone)	$V_{t,VOC}=\sum_{i=1}^{m} U_{VOC}(i)(DL)N(i)$	\$1,230
Total		**\$4,052**

Where, m is the number of vehicle classes; DL is the detour length (miles); $U_{VOC}(i)$ is the unit vehicle operating cost of vehicle class i (\$/mile); $U_{TTC}(i)$ is the unit travel time cost of vehicle class i (\$/mi); $N(i)$ is the number of class i vehicles that detour due to work zone; and $SP(i)$ is the average speed of vehicle class i on the detour (miles/hour).

TABLE 7.21
User Costs in Work Zone for the Sample Pavement

User Costs	Equations	Costs
Travel time (work zone)	$V_{t,ttc}=\sum_{i=1}^{m} U_{TTC}(i)\left(\frac{DL}{SP(i)}\right)N(i)$	\$16,884
VOC (work zone)	$V_{t,VOC}=\sum_{i=1}^{m} U_{voc}(i)(DL)N(i)$	\$7,360
Total		**\$24,244**

Where, m is the number of vehicle classes; DL is the detour length (miles); $U_{VOC}(i)$ is the unit vehicle operating cost of vehicle class i (\$/mile); $U_{TTC}(i)$ is the unit travel time cost of vehicle class i (\$/mi); $N(i)$ is the number of class i vehicles that detour due to the work zone; $SP(i)$ is the average speed of vehicle class i on the detour (miles/hour).

TABLE 7.22
Recycling Savings for the Sample Assets

Asset	Recycling Savings	Total Recycling Savings
Bridge #6730 (concrete slab)	50% of replacement cost	\$529,708
Pavement section RP041+.95-RP042+.95 on State Route 23 (flexible HMA)	34% of replacement cost	\$966,557

with a replacement cost of \$2,842,816, located in an urban area, containing 2 lane-miles, with an IRI (in./mile) of 121.8, and an AADT of 7,703 is:

$$V_{12\ years}=(\$2{,}842{,}816)\; e^{-1*\left(\frac{12}{e^{2.74+0.87(121.8)-0.11(1)-0.0078(0)-0.028(1)-0.042(5.52)}}\right)^{8.17}} \quad (7.7)$$

$$V_{12\ years}=(\$2{,}842{,}816)(1)$$

$$V_{12\ \text{years}}=\$2.84\text{M}$$

7.4 Probabilistic EDMC Method Using Monte Carlo Simulation

The variables that were normally distributed and randomly simulated for the valuation are the asset component costs, component conditions, and component remaining service lives. All costs are in dollars per lane-mile for the pavement and dollars per square foot for the bridge. A total of 5,000 iterations were run for the simulation. The starting parameters for population means and standard deviations were taken from the INDOT pavement and bridge data used in this study.

TABLE 7.23
Value of Sample Assets, the Replacement-Downtime-Salvage Method

Asset	$V_t=RC+(V_{t,ttc}+V_{t,VOC})+V_{t,EOL}$	Total RDS Value (2010\$)
Bridge #6730	\$1,059,417 + (\$4,052) − \$529.708	\$533,761
Pavement section RP041+.95-RP042+.95 on State Route 23	\$2,842,816 + (\$24,244) − \$966,557	\$1,900,503

NOTE: RC is the replacement cost of each asset in 2010\$.

TABLE 7.24
Monte Carlo Simulation Probabilistic EDMC Values

Statistics	Pavements	Bridges
No. of simulation runs	5,000	5,000
Sample mean	$9.06M/ln-mi	$149/sq. ft.
Median	$8.82M/ln-mi	$143/sq. ft.
Sample standard deviation	$4.55M/ln-mi	$146/sq. ft.
Quartile (.75), quartile (.25)	$12.0M, $5.97M	$1,167, −$427
Skewness	0.22	0.25
Kurtosis	0.09	0.87
Inter-quartile range	$6.04M	$187
Standard error	$64,390	$2
95% upper, lower confidence level	$9.19M, $8.93M	$153, $145
95% central interval limits	$0.62M, $18.42M	−$132, $455

Table 7.24 presents the statistics computed from the Monte Carlo simulation for the values of a given pavement section and bridge.

7.5 Chapter Summary

In summary, each proposed methodology results in a different value depending on the aspects of an asset in which decision-makers are interested (Figures 7.2. (a) and (b)). The elemental decomposition and multi-criteria method focuses on the stakeholder perspective relative weights, the asset component costs, and their conditions and remaining service lives (Method I). Secondly, the replacement, downtime and salvage method (Method II) takes into consideration the user inconvenience costs in a workzone, recycling and disposal costs, and their effects on the composite asset replacement cost to provide a value. Thirdly, the decommission and re-use method is concerned with the value of the land each asset occupies (Method III). Lastly, a probabilistic EDMC using Monte Carlo simulation was carried out and yielded a similar value per sq. ft. for bridges, but an increased value per lane-mile for pavements compared to the deterministic EDMC method.

8. PROJECT AND NETWORK-LEVEL COMPARISONS OF THE PROPOSED AND TRADITIONAL METHODS

8.1 Introduction

In this chapter, asset values calculated from the proposed methods are compared with those from the traditional methods. Also, for both the project-level and network-level asset valuations, the differences in the resulting asset values are quantified and explained in terms of the inherent structure of the computation expression for each method.

8.1.1 Project-Level Asset Values: Comparison across the Valuation Methods

Asset values for the different methods were calculated using data from selected assets in the state of Indiana. For bridges, the steel bridge with identification number 6730 in the NBI dataset was built in 1990 with a length of 209 ft. and a total deck width of 48 ft. With an ADT of 7,830 vehicles per day, this bridge is located on the National Highway System. Other small asset project-level values are presented in Appendix A. Table 8.1 lists the bridge values determined using the different valuation methods. All values are in 2010 dollars.

For pavements, the added travel lane HMA pavement section at State Route 23, RP041+0.95 to RP042+0.95 in Indiana was used for the comparison. This road section is 1 mile in length with two lanes and was constructed in 1998 at a total cost of $2.84 million (2010$). The AADT is 7,703, the wearing surface has an

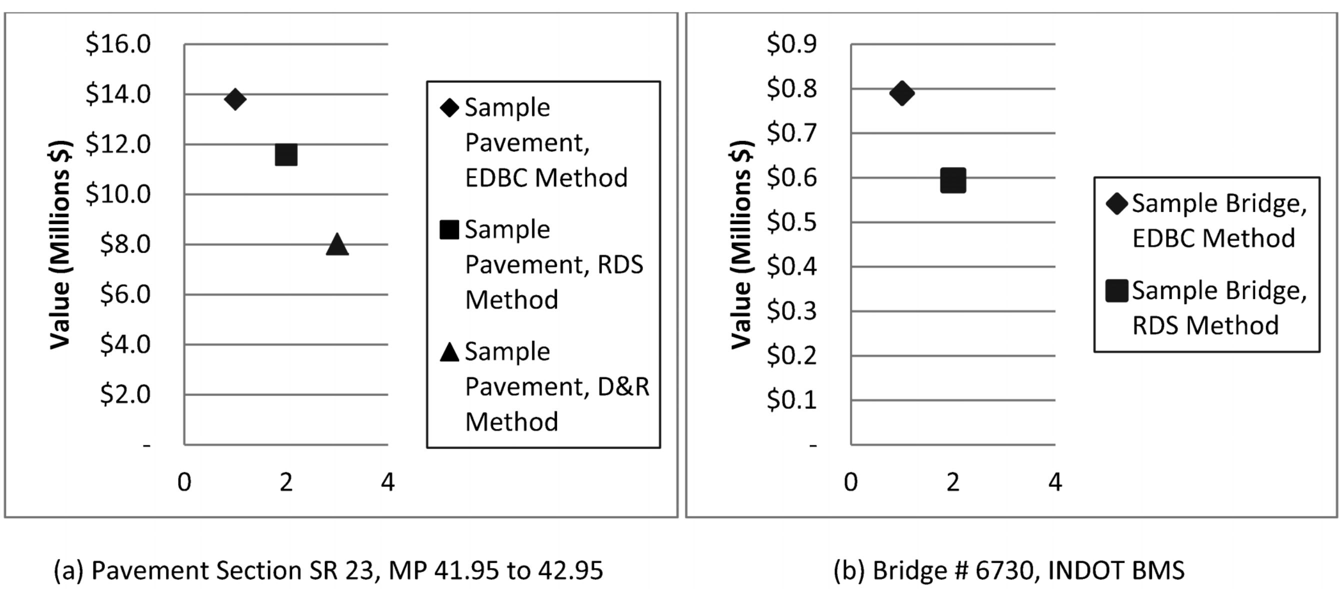

Figure 7.2 Sample asset value from proposed methods.

TABLE 8.1
Case Study Example for Bridge Valuation

Valuation Method	Value
Replacement cost	$1,673,371
Straight line depreciation	$1,439,668
Declining balance	$1,273,099
Sum of years digits	$892,913
Double declining balance	$964,715
EDMC method	$1,059,417

IRI of 121.8 in./mile, and the area has a freeze index of 823 degree-days. The following values were obtained for each method of valuation (Table 8.2).

The replacement cost value was found to be the highest because it depicts the as-new value of the asset. The net salvage value represents the difference between reconstruction and the expected rehabilitation cost. When the expected rehabilitation cost is high, the net salvage value is low. Each of the depreciation methods depreciates the asset (as a whole monolithic entity) over its service life, resulting in generally lower values compared to some other methods that consider asset condition. The EDMC method divides assets into individual components, each with its own condition and service life ratio. The values of the declining balance, adjusted value, and EDMC method differ significantly, irrespective of asset type. The "adjusted value with respect to condition rating" and the EDMC method each take into consideration the asset's overall and component conditions, respectively.

Comparing the methods for the bridge valuation (Figure 8.1), it is observed that next to the replacement cost method, the SLD and DB methods provide the higher values while the EDMC method provides a mid-range value. The DDB and SOYD depreciation methods utilize sharper deterioration rates for a bridge structure implicitly assumed to be monolithic, resulting in generally lower asset values. An exception is the declining balance method, which assumes that greater depreciation occurs early in the asset life.

In comparing the obtained values from the various methods for the pavement valuation (Figure 8.2), it is readily seen that the replacement cost method yields the highest pavement value. The values derived using the other valuation methods generally provide a more accurate reflection of the actual "ground" conditions in the field; these values do not represent the as-new pavement values.

TABLE 8.2
Case Study Example for Pavement Valuation

Valuation Method	Value
Straight line depreciation	$718,884
Replacement cost	$2,842,816
Declining balance	$1,741,821
Double declining balance	$1,045,208
Sum of years digits	$1,000,671
EDMC method	$2,750,782

The overall condition of sample bridge #6730, from a monolithic structure assumption (i.e., average of the component ratings) is 6.67, and the remaining service life is 50 years (i.e., the current age (20 years) subtracted from the 70-year service life).

Without breaking it down into components, the total bridge value, using the attribute ratios in a simple multi-criteria method (using only two criteria), is:

$$\begin{aligned} V_{MC,20} &= \left[w_u \left(Cost \left(\frac{P_t - P_{worst}}{P - P_{worst}} \right) \right) + w_a \left(Cost \left(\frac{RSL_t}{SL} \right) \right) \right] \\ &= \left[0.4 \left(\$1,673,371 \left(\frac{6.67}{9} \right) \right) + 0.6 \left(\$1,673,371 \left(\frac{50}{70} \right) \right) \right] \\ &= \$1.21\text{M} \end{aligned} \tag{8.1}$$

After breaking down the bridge into its respective components (and thus utilizing the expressions for the elemental decomposition and multi-criteria method), the total bridge value is:

$$\begin{aligned} V_{EDMC} = \Bigg[& w_1 \left(cost\_comp_i \left(\frac{P_{t_i} - P_{worst_i}}{P_i - P_{worst_i}} \right) + \cdots + \right. \\ & \left. cost\_comp_I \left(\frac{P_{t_I} - P_{worst_I}}{P_I - P_{worst_I}} \right) \right) + w_2 \left(cost\_comp_i \left(\frac{RSL_{t_i}}{SL_i} \right) \right. \\ & \left. \cdots + cost\_comp_I \left(\frac{RSL_{t_I}}{SL_I} \right) \right) \Bigg] \end{aligned} \tag{8.2}$$

$$\begin{aligned} V_{EDMC} = \Bigg[& 0.4 \left(\$821,094 \left(\frac{7}{9} \right) + \$232,907 \left(\frac{6}{9} \right) \right. \\ & \left. + \$426.840 \left(\frac{7}{9} \right) \right) + 0.06 \left(\$821,094 \left(\frac{74}{100} \right) + \right. \\ & \left. \$232,907 \left(\frac{74}{100} \right) + \$426,840 \left(\frac{56}{82} \right) \right) \Bigg] \\ & V_{EDMC,20} = \$1,06\text{M} \end{aligned}$$

For each of the bridge assets considered in this case study, a comparison of the EDMC method for the monolithic structure assumption and for the decomposed structure assumption yielded different values (Figure 8.3). Thus, it is clear that when the individual components are not considered, the traditional methods underestimate the value of highway assets. The EDMC method duly considers the fact that asset components deteriorate at different rates. One component may be in poor condition while the others may be in good condition; also, their replacement costs could be significantly different. Thus, to avoid skewing the results, one component only or even the average of all components should not be used to decide the value of the entire asset. Most asset components do not

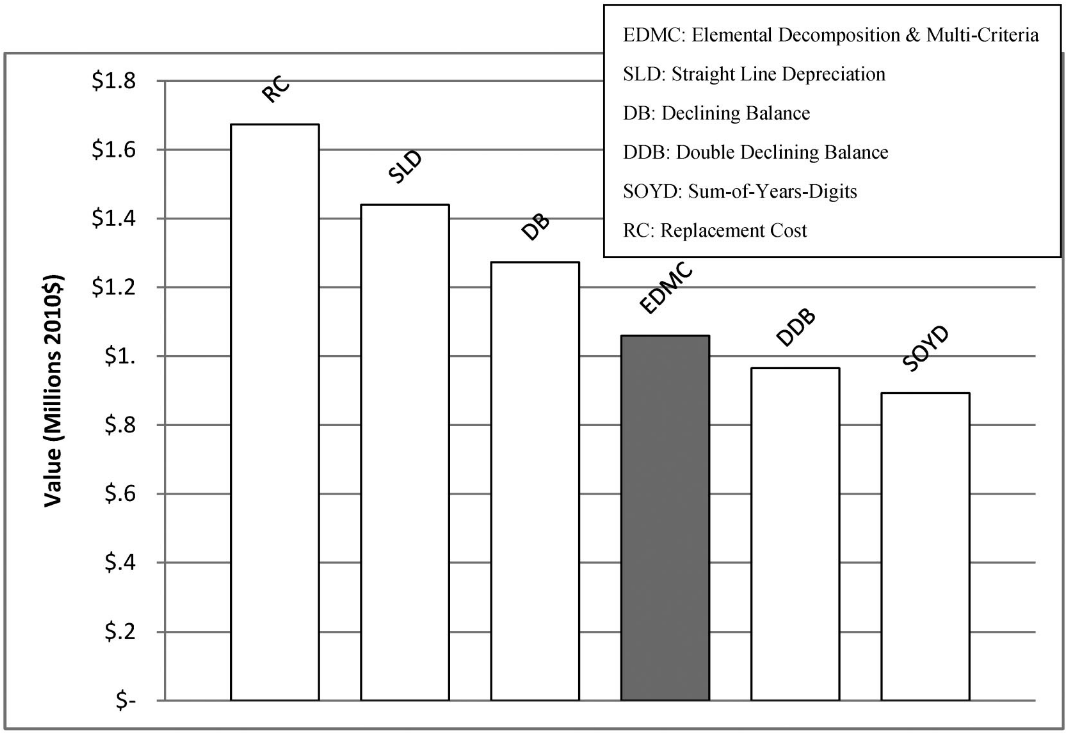

Figure 8.1 Results of asset valuation for bridge #6730.

deteriorate at the same rate and therefore do not need to be replaced at the same time.

8.2 Network-Level Asset Values: Comparison across the Valuation Methods

This section discusses traditional, EDMC, and back-of-envelope (BOE) valuation calculations of network-level pavement and bridge assets in the state of Indiana. These valuation methods are compared and the differences in their outcomes are discussed. The BOE calculation involves the use of an average replacement cost and the total inventory of each asset type in the state of Indiana. A more refined version of the BOE calculation breaks the calculation down by asset material type and

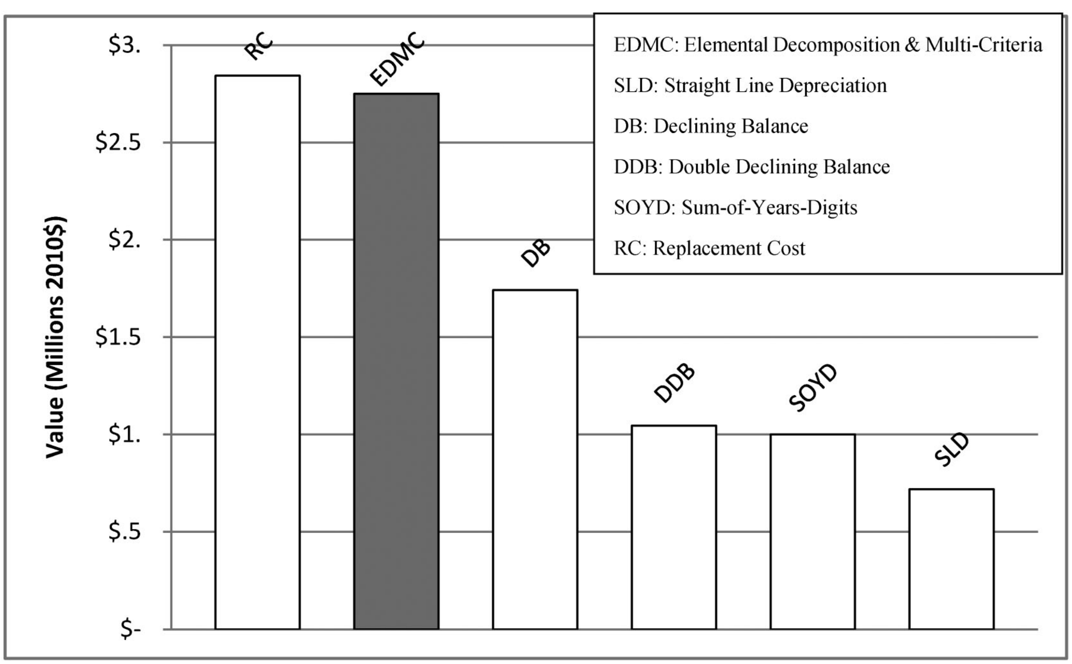

Figure 8.2 Results of asset valuation for pavement section SR 23, MP 41.95 to 42.95.

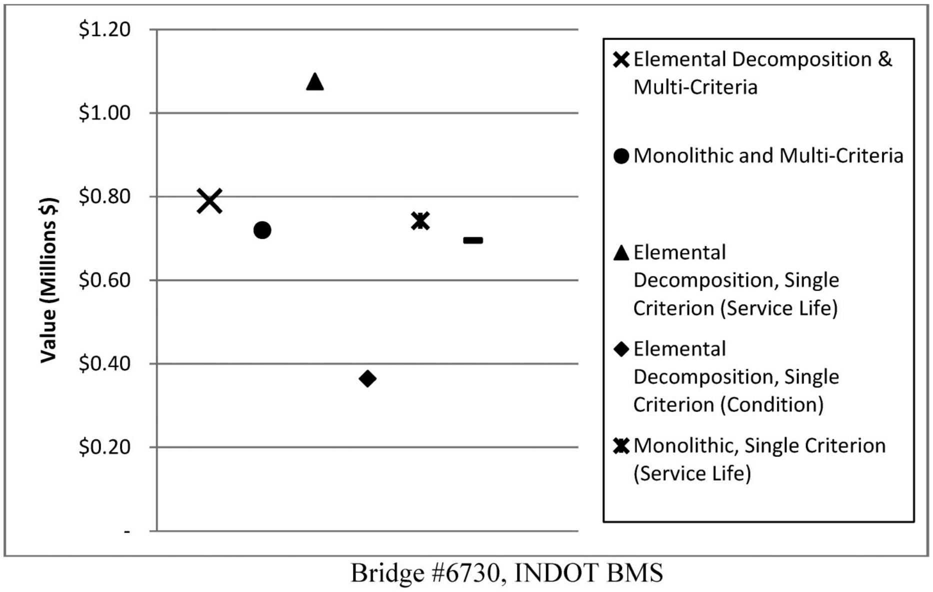

Figure 8.3 Comparison of asset values for monolithic vs. decomposition and bi-criteria vs. single-criterion considerations.

considers average condition (rather than the as-new condition) of each asset.

8.2.1 Bridges

Traditional methods of valuation yield a range of values for bridge assets based on different characteristics. Most deterioration methods yield relatively small values while modified approach methods yield mid-range values. The replacement cost and net salvage value methods yielded the highest values. The EDMC method utilizes the individual component deterioration rates and their individual costs and yields a value higher than those of other methods, with the exception of the replacement or net salvage value methods. Table 8.3 presents the asset values using the traditional valuation methods, and the EDMC method, for the state highway bridge network.

In the state of Indiana, there are 5,617 state highway bridges under the jurisdiction of the Indiana Department of Transportation. Assuming that each bridge costs $2 million to build, its coarsest computation would yield a back-of-envelope value as 5,600 bridges multiplied by $2 million for a total bridge value of $11.2 billion. Also, assuming 50% deterioration, the adjusted value is $5.0 billion. This value could be refined further by considering different costs for concrete and steel bridges and accounting for the fact that not all the bridges are in exactly 50% of their as-new condition.

According to INDOT's current statistics, the average replacement cost per steel and concrete bridge from 2006–2009 is $3,167,632 and $1,115,459, respectively (*72*). The average age of the bridges in Indiana is approximately 27.6 years for steel bridges and 28 years for concrete bridges according to the NBI database. With a 70-year service life, the remaining service life is 42.4 and 42 for steel and concrete bridges, respectively. Of these bridges, approximately 3,792 are steel bridges and 3,684 are concrete bridges. Using straight-line depreciation for a quick approximation, the bridge asset value for the state of Indiana is calculated as approximately $6.59 billion (Table 8.4).

Figure 8.4 compares the BOE calculations and the other valuation methods. The BOE calculations are rough estimates only and do not consider the cost to build each bridge component separately (deck, approach, superstructure, and substructure) or scale economies associated with bridge size. In actuality, the ages of bridges in Indiana are distributed over a wider range than as assumed in the BOE calculations; also, their deterioration trend does not necessarily follow a straight-line depreciation rate as assumed in the BOE computation. Due to the highly aggregated and approximate nature of the BOE calculations, this method should be used only sparingly for estimating asset value.

TABLE 8.3
Estimated Values of Indiana's State-owned Bridge Assets at Network Level

Valuation Method	Value
Straight line depreciation	$9.59B
Replacement and downtime-salvage	$13.39B
Declining balance	$8.80B
Replacement cost	$6.58B
Double declining balance	$12.37B
Sum of years digits	$5.73B
EDMC method	$7.83B

8.2.2 Total Value of Pavements on Indiana's State Highway Network

The traditional methods of valuation yielded a wide range of total values for the state highway pavements.

TABLE 8.4
Back-of-Envelope Computations for Bridge Values in Indiana

Bridge Type	Approximated Avg. Bridge Replacement Cost (2010$)	Total Value As-New	Total Value Adjusted for Deterioration
Steel (n=3,792); SL = 70 years; avg. age = 27 years*	$3.3M	3,792 · $3.3M = $12.5B	$\frac{27}{70} \cdot \$12{,}5B = \$4.82B$
Concrete (n=3,684); SL = 50 years; avg. age = 28 years*	$1.2M	3,684 · $1.2M = $4.42B	$\frac{28}{50} \cdot \$4{,}42B = \$1.77B$
Total			**$6.59B**

*Sources: (*62,63*).

Most of the methods associated with the depreciation approach yield relatively small values for the network while methods utilizing asset condition tend to yield relatively higher values. The replacement cost value method yielded the highest values in this case study. The EDMC method uses individual component deterioration rates and their individual costs; and for this network, the EDMC method yielded a value higher than those of the depreciation methods but a value lower than that of the replacement cost method. The replacement cost method relies on current replacement standards so the costs are much higher than the historical construction costs and also that method makes no correction for the current asset condition. Table 8.5 lists the traditional value methods, the EDMC method, and their results for the network-level pavement assets.

INDOT has approximately 11,175 centerline miles, or about 30,000 lane-miles of roadway under its jurisdiction (*73*). Assuming that each lane-mile costs $2.0M to build, then a very rough approximation of pavement value (as-new) is 30,000 multiplied by $2.0 million, which results in a value of $60 billion. Assuming 50% deterioration, the adjusted value is $30 billion. This value could be refined further by considering different costs for concrete and asphalt pavements and due recognition of the fact that most pavements are actually not in conditions that correspond to 50% of their original (as-new) conditions.

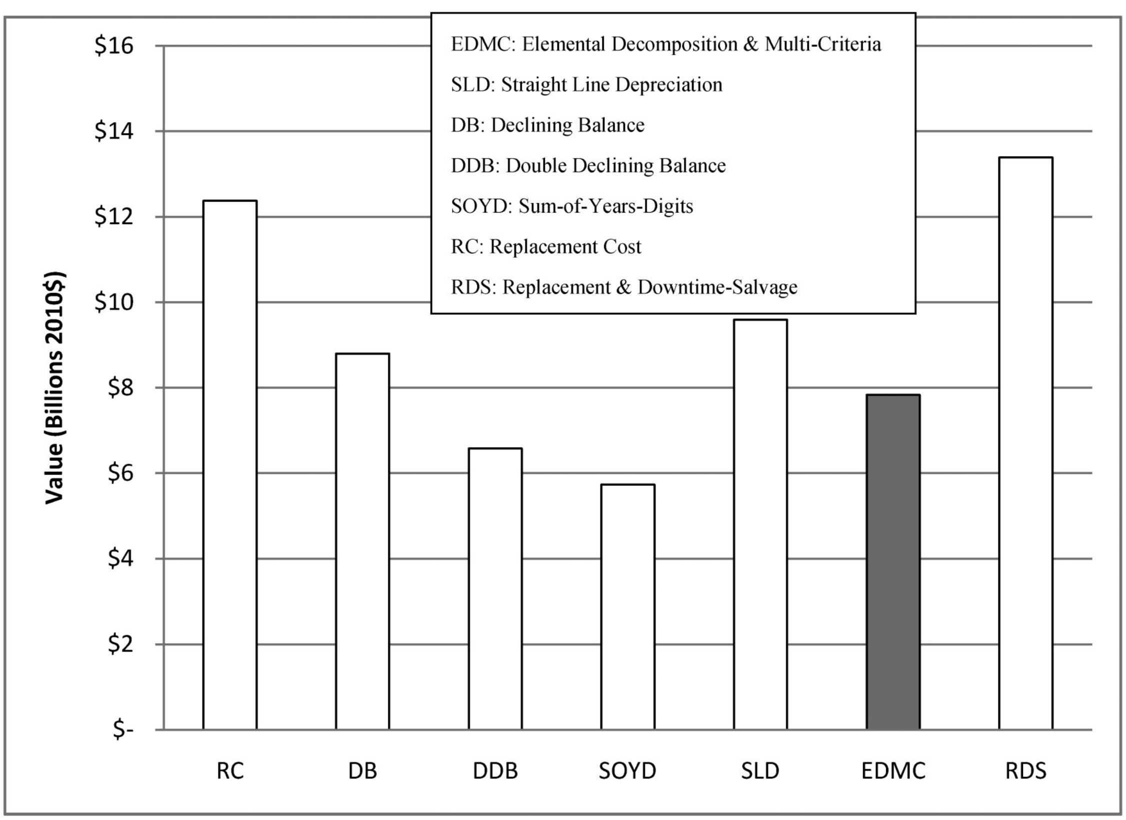

Figure 8.4 Network-level bridge asset values (2010$).

TABLE 8.5
Estimated Values of Indiana's State Highway Pavement Assets at Network Level

Valuation Method	Value
Straight line depreciation	$12.4B
Net salvage value	$38.1B
Declining balance	$28.5B
Double declining balance	$16.2B
Replacement cost	$49.6B
Sum of years digits	$15.1B
EDMC method	$47.1B
Replacement and downtime-salvage	$53.4B

To obtain the actual inventory size in terms of lane-miles, Table 8.6 presents the breakdown by the number of through lanes and their overall percentage of the total. The source of the data is the INDOT 2009 Highway Performance Monitoring System (HPMS) database (*71*).

From this data, the estimated total lane-miles for INDOT is 28,428 lane-miles. Using an average total replacement cost of both flexible and rigid pavements (Table 7.3) of $1,930,852 per lane-mile (2010$), the pavement asset total amounts to $55 billion. The average age of INDOT pavements in the HPMS dataset is 17 years. A pavement's assumed average life is 45 years for analysis purposes (*64*). Assuming straight line depreciation, the amount of depreciation is $34.5 billion ($55-((28/45). $55B)). The overall BOE value for pavement assets thus is $20.5 billion ($55B–$34.5B). Table 8.7 presents the results for each pavement type. The total BOE for pavements and bridges is presented in Table 8.8. The BOE value is a rough estimate of the actual value of the pavement assets. It does not consider different pavement types, different deterioration rates or conditions, and assumes straight line depreciation, which does not accurately reflect most pavement deterioration. Due to the BOE nature of computation that groups assets together in a very aggregate fashion, this method should be used sparingly as an indicator or comparison for asset value. Each valuation method yields a total pavement value that differs from the BOE value so the BOE value constrains asset characteristics to similar levels and limits the range of asset variance, skewing the total network-level asset value. Figure 8.5 compares the BOE asset values to those from other methods.

8.2.3 Network-Level Small Asset Values

"Small" assets are defined as those that are relatively small in size but large in number, and these include culverts, guardrails, underdrains, and road signs. In the present study, these assets were valued on the basis of a number of assumptions due to the lack of adequate data for carrying out the valuation. For example, the guardrail database did not contain information on the age or condition of the guardrails. It was assumed that 33% of each of the three types of guardrail have ages of 5, 10, and 15 years. Tables 8.9 and 8.10 outline the assumptions made for each small asset type based on their cost, age, service life, and condition if it was not located in the associated database. Table A.5 in Appendix A lists the references associated with each assumption.

Figure 8.6 shows the range of culvert values for the state of Indiana based on the different methods. Again, the EDMC falls in the middle range of values. The methods consider depreciation over the asset service life fall on the lower end of the range, while the replacement cost is still on the higher end. The small assets in the state of Indiana (Figures 8.7 through 8.9), including guardrail, underdrain and road signs, follow a similar pattern. The percentages of the total Indiana asset value by asset type are presented in Table 8.11. Pavements, bridges, and culverts constitute the majority of the total value while some small assets constitute a relatively small overall percentage.

8.3 Comparison of Highway Asset Values in Indiana to Values Obtained by Other States

To put Indiana's highway and bridge values in context, the following table lists the asset values of various states in terms of their book value. The book value suggests that any of the several different valuation methods that depreciate asset value could have been used; therefore, comparing the values across other states is not necessarily a reliable way to compare the asset values across states. Thus, the comparison of value as shown in Table 8.12 should be considered only

TABLE 8.6
INDOT Road Inventory by Number of Mainline Travel Lanes (2009)

No. of Through Lanes	No. of Centerline Miles	% by Centerline Miles of Total
1	1.1	0.009%
2	8,331	74.551%
3	15.8	0.141%
4	2,625.6	23.495%
5	10.8	0.097%
6	182.6	1.634%
7	2.6	1.634%
8	4.2	0.023%
10	1.4	0.013%

TABLE 8.7
Back-of-Envelope Computations for Pavement Values

Pavement	Average Replacement Cost (Approximated from Table 7.3)	Total Value As-New	Total Value Adjusted for Deterioration
Rigid (10%); 2,840 lane-miles; SL = 30 years; avg. age = 15 years	$2.0M/lane-mile	$5.68B	$2.84B
Flexible (90%); 25,600 lane-miles; SL = 20 years; avg. age = 10 years	$1.0M/lane-mile	$25.6B	$12.8B
Total			**$15.64B**

Data sources:
Service life: (*64*), Fig. 52-8A;
Rigid/flexible split: (*71,75*);
Average age: Expert opinion.

TABLE 8.8
Summary of Back-of-Envelope Computations

	Very Coarse Estimation	Coarse Estimation (Tables 8.4 and 8.7)
Pavements	$30B	$15.64B
Bridges	$5.6B	$5.08B
Total	**$35.6B**	**$20.72B**

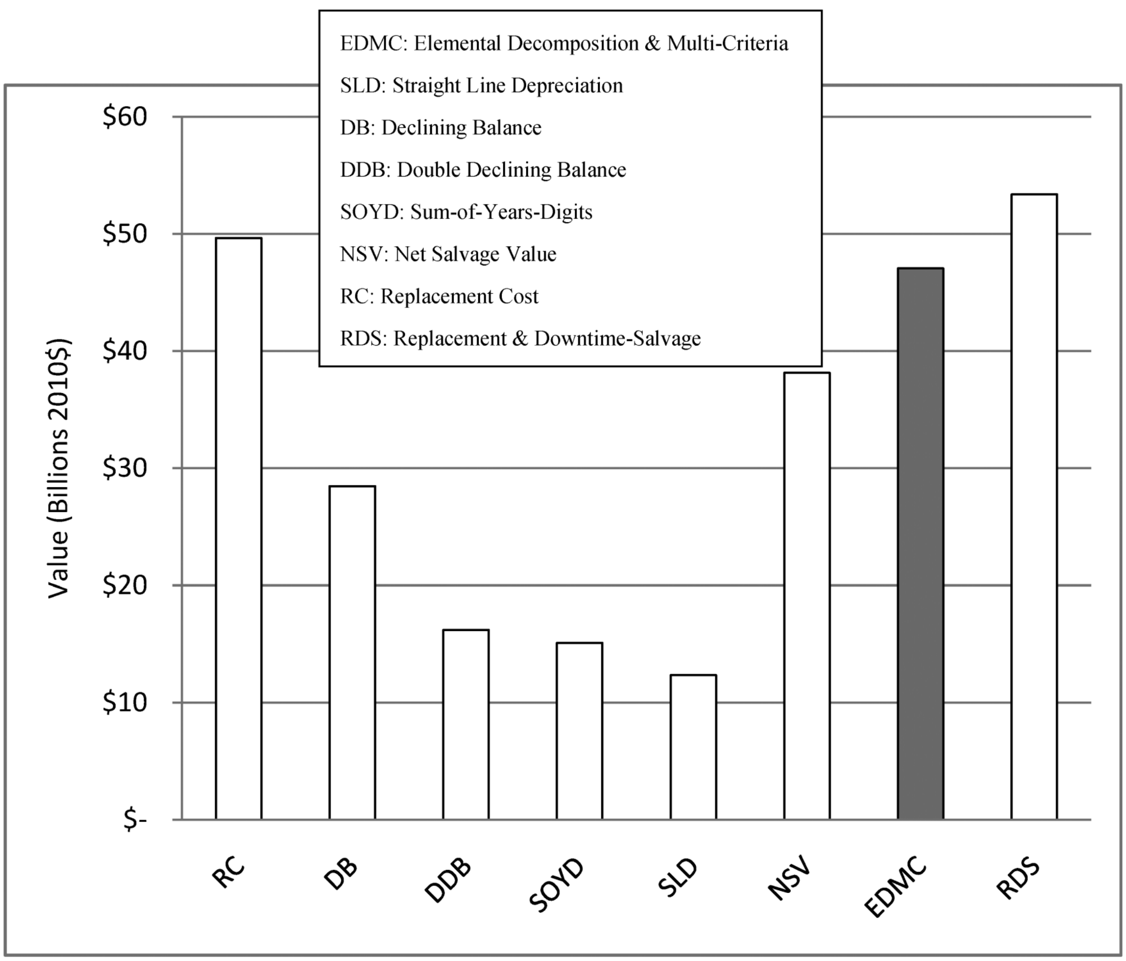

Figure 8.5 Pavement comparison with other valuation method results (2010$).

TABLE 8.9
Assumptions for Guardrail and Culvert Assets

	Guardrails	Culverts
Type	• 90% of database are W-beam (G-4) • 5% of database are W-beam (G-2) • 5% of database are 2 cable guardrail • 5% of database are 2 cable guardrail	• Assume concrete pipes • Assumed length of 50′ if length of culvert not listed in database
Cost	• W-Beam (G-4) $24.40/ft. • W-Beam (G-2) $15.71/ft. • Cable $7.57/ft • End treatment costs: ▪ W-Beam(G-4) $3,397 ▪ W-Beam (G-2) $2,573 ▪ Cable $2,141	• Costs of box culvert $0.08/in^3 • Costs non-box culverts based on diameter size • 2010$/LF (see chart) ▪<18 = $254.28 ▪18–24 = $294.44 ▪30 = $321.20 ▪36 = $388.12 ▪42 = $441.65 ▪48 = $468.42 ▪54 = $535.34 ▪60 = $682.55
Age	• 33% of each type of guardrail is 5 years old • 33% of each type of guardrail is 10 years old • 33% of each type of guardrail is 15 years old	• 33% of each type and age 30 years old • 33% of each type and age 10 years old • 33% of each type and age 55 years old
Service life	• 20 years	• Box culvert 63 years • Other culvert types 60 years
Condition	• Condition Rating Scale (1–3) [1:poor, 3:good] • 90% of each guardrail type & age have condition 3 • 5% of each guardrail type & age have condition 2 • 5% of each guardrail type & age have condition 1	• Condition scale (0–9) • 33% of each type & age have condition 6 • 33% of each type & age have condition 8 • 33% of each type & age have condition 3

for general purposes. For the Indiana values in this table, the straight line depreciation method was used. This is not an endorsement of that method. Rather, it was used because the other states used a similar method and thus a comparison across states would be less biased. However, the value from EDMC (the valuation method proposed by this report) is also presented in brackets for Indiana.

The values in Table 8.12 reflect the state highway system lane-miles for both roads and bridges. Studies for the other four states were conducted about 10 years ago, thus their resulting values were converted

TABLE 8.10
Small Asset Assumptions for Road Signs and Underdrains

	Road Signs	Underdrains
Type	• 90% of database are Type III • 5% of database are Type I • 5% of database are Type II • Average size 30”x30”	• Assumed 6” pipe • Pipe Length assumed 48” for Interstate and State Routes • Pipe Length assumed 24” for US Road
Cost	• Type III cost $116.09 per sign • Type I & II cost $146.23 per sign	• Cost $9.69/ft
Age	• 33% of road signs are aged 3 • 33% of road signs are aged 5 • 33% of road signs are aged 7	• 50% of the underdrains are 0–10 years (midpoint 5 yrs) • 50% of the underdrains are 10–14 years (midpoint 12 yrs)
Service life	• Type III 10 yrs • Type I & II 7 years	• 25 years
Condition	• Assumed condition rating scale (0–10) • 33% of each sign type & age has condition 3 • 33% of each sign type & age has condition 5 • 33% of each sign type & age has condition 7	• Assumed Condition Rating Scale (0–10) • 50% of each age category is 9 • 50% of each age category is 5

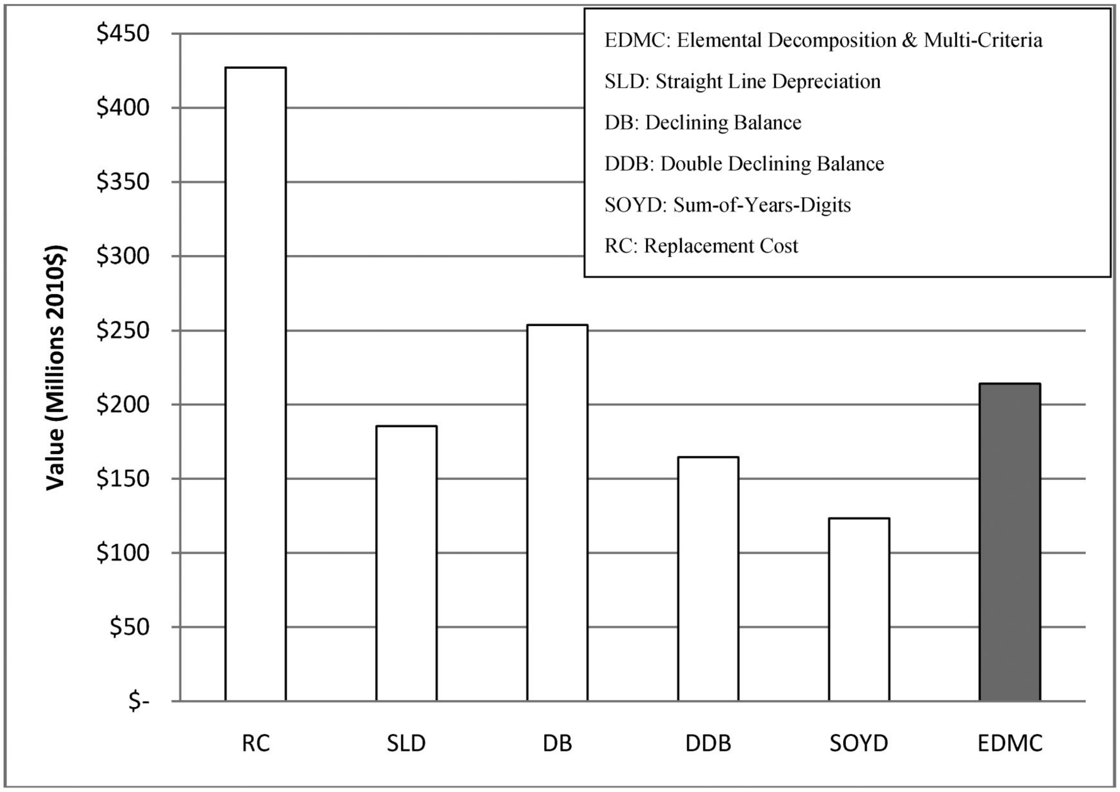

Figure 8.6 Indiana state highway network culvert values.

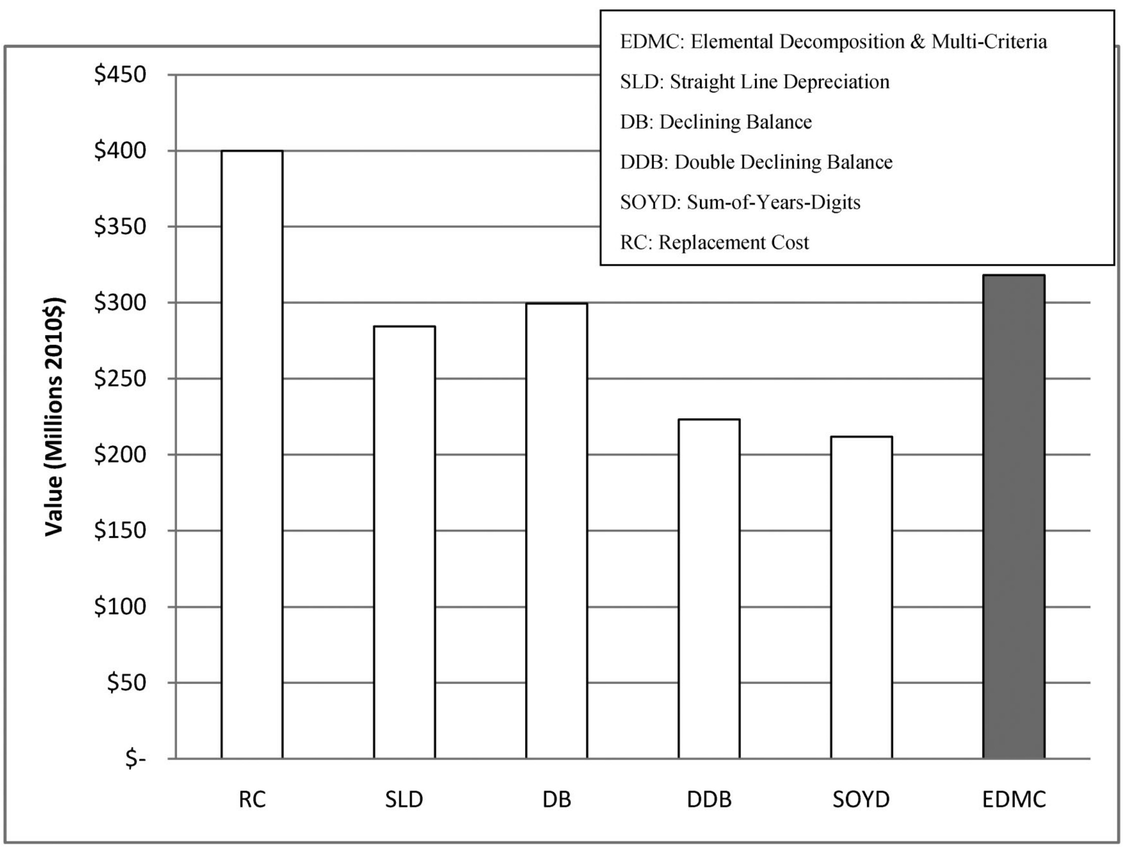

Figure 8.7 Indiana state highway network guardrail values.

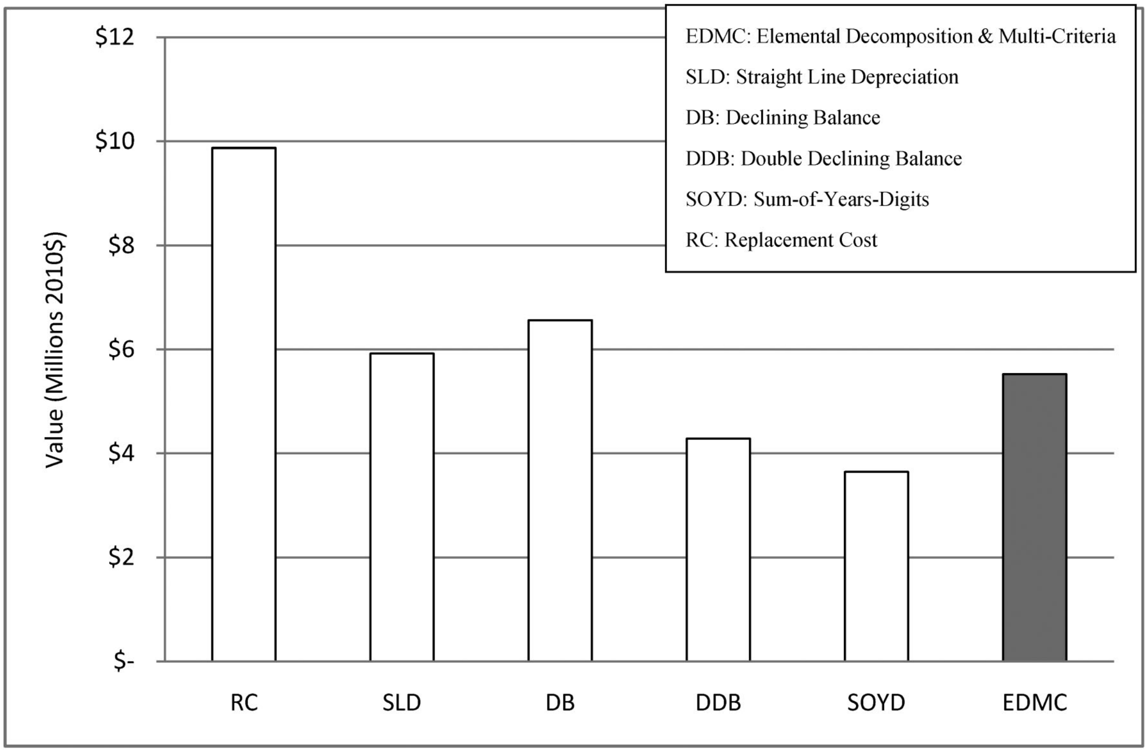

Figure 8.8 Indiana state highway network underdrain values.

to 2010 dollars using the FHWA CPI for comparison purposes. As seen, the states have generally similar values per lane-mile; however, what remains unanswered is the specific depreciation method used by each state. The average SLD value per lane-mile for the five states is $1.34M. The next chapter estimates the total network-level value for each state in the U.S., on the basis of the results for Indiana and the average SLD value per lane-mile using the average of the five state studies.

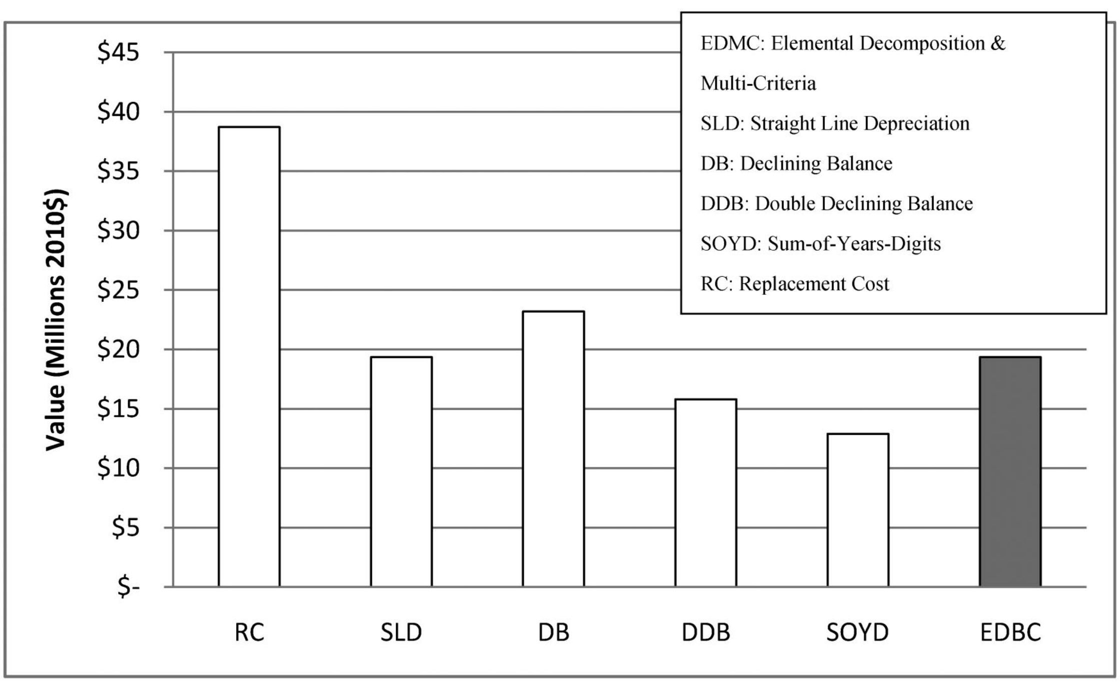

Figure 8.9 Indiana state highway network road sign values.

TABLE 8.11
Summary of Indiana's Assets

Asset Type	Value* (Billion 2010$)	% of Total Value	Small and Large Structure% of Total Value
Guardrails	$0.318	0.47%	0.83%
Underdrains	$0.005	0.01%	
Culverts	$0.214	0.32%	
Road signs	$0.019	0.03%	
Bridges	$7.83	11.59%	81.34%
Pavement	$47.1	69.75%	
Right-of-way	$12.04	17.83%	17.83%
Total	**$68**	**100%**	**100%**

*EDMC Values

8.4 Summary

This chapter presented the range of bridge and pavement asset values at both the project level and at the network level for the different valuation methods (traditional and proposed). The spreadsheets and user manual developed to calculate these values can be found in Appendix B and Appendix C. The values obtained using the proposed (EDMC) method were found to be consistently higher than those obtained from the traditional methods. This result suggests that considering assets in terms of their individual components yields a combined value that may be representative of the true value. Thus, there appears to be clear merit in asset decomposition into elements and also in the consideration of multiple attributes or criteria in the valuation process.

It may be noticed that in certain cases, the asset value obtained using straight line depreciation (SLD) method is sometimes smaller and sometime larger than that obtained using the Declining Balance (DB) or Double-Declining Balance (DDB) depreciation methods. This is largely influenced by the specified salvage value in the SLD and the asset life. Also, typically, when the asset is new, the value obtained using SLD is higher than that obtained using DB or DDB. At a certain point as the asset grows older, however, the DB or DDB curve crosses the SLD curve. After that age, the values obtained from DB or DDB curve will always be higher than values obtained by SLD curve. This relation can be seen in Figure 8.10, which shows the trend line for values obtained through SLD and DB method. The age at which the DB- or DDB-based asset values equals

TABLE 8.12
State-Reported Asset Values, for Selected States

	Indiana	Ohio	Virginia	Tennessee	Texas
Value at Year of Study	$21.99B[1] [$54.88B][2] (2010)	$13.2B[1] (2000)	$13.6B[1] (2001)	$14.7B[1] (2000)	$52.02B[1] (2000)
Value of Pavement	$12.4B	$10.6B	$10.7B	$29.3B	$32.7B
Value of Bridges	$9.59B	$2.6B	$2.9B	$5.08B	$19.32B
Value (2010$)	$21.99B[1] [$54.88B][2]	$22.00B[1]	$20.41B[1]	$22.55B[1]	$79.82B[1]
Total NHS Lane-Miles[3]	27,680	17,644	14,652	13,096	51,768
2010 Value ($/lane-mile)	$0.80M[1] [1.98M][2]	$1.25M[1]	$1.39M[1]	$1.72M[1]	$1.54M[1]
Source	Present report	ODOT (*76*)	Bailey (*77*)	Marston (*78*)	Sullivan et al. (*79*)

NOTE: Bridge and pavement assets only.
[1]Value based on straight-line depreciation.
[2]Value from EDMC method.
[3]Lane-miles valued in study.

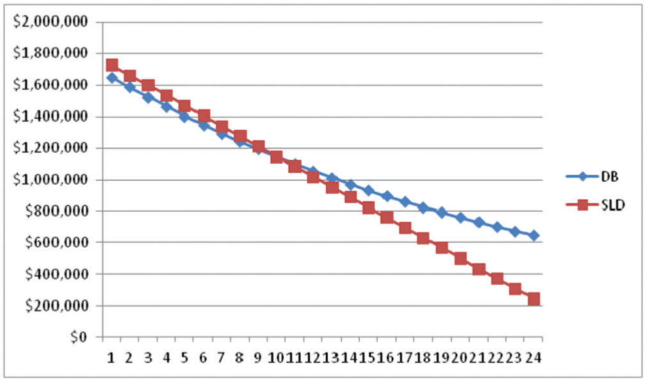

Figure 8.10 Explanation for differences between SLD and DB asset values.

that obtained using SLD, is different for different assets. In this chapter, it is seen that for certain assets, SLD gives a higher asset value, while for other assets, it gives a lower value compared to DB and DDB, as shown in Figure 8.10.

9. ESTIMATED TOTAL VALUE OF PAVEMENT AND BRIDGE ASSETS IN THE UNITED STATES

9.1 Introduction

The unit values obtained for the Indiana bridge assets (dollars per sq. ft.) and pavement assets (dollars per lane-mile) can be applied, with the requisite assumptions, to the highway assets of other states to estimate their values. The sum of asset values from all the states can reflect the values of the overall highway network and state-owned network in the United States. Also, it is useful from a federal oversight viewpoint, to assess each state's performance on the basis of how much they are spending on asset preservation (normalized by their total inventory values) and how much they are "getting back" in terms of pavement or bridge condition. This chapter provides details on how these tasks were carried out in this study and discusses the results.

9.2 Estimation of Total Value of National Highway and Bridge Assets in the U.S.

An estimate of the United States' highway and bridge assets can be computed using Indiana's unit values, each state's total lane-miles of pavement and each state's total bridge area, and respective state price adjustment factors and highway cost factors. The state price adjustment factors account for the differences in the labor and material costs in different states. The FHWA Policy Information Department was the source of the data on state inventory size. The 2009 highway statistics for the functional system lane-length provided the total lane-miles for each of the 50 states (*75*). Also, the National Bridge Inventory was the source of data for the total square area of bridge assets in each state. Inventory sizes for all highway assets and also for state highway assets were obtained from the FHWA statistics website (*63*). (See Figure 9.1.)

9.2.1 Inventory Sizes

Figure 9.1 lists the inventory sizes of the states as of 2008.

9.2.2 Unit Value of Pavement and Bridge Assets in Indiana

Table 9.1 presents the unit values of pavement assets (dollars per lane-mile) and bridge assets (dollars per sq. ft.) in Indiana.

These unit values served as the basis for determining the asset values for other states. Assuming no correction or adjustment, the value of assets for other states could simply be calculated as the product of the inventory size for that state and the unit value of that asset in Indiana. For example, in Illinois:

- Total pavement inventory size (state highways) = 42,150 lane-miles;
- Unit value of pavement (from this study) = $1,707,651/lane-mile;
- Thus, total value of state highway pavements in Illinois = $53.8 billion.

However, in reality, the cost of constructing a lane-mile of pavement is not the same for Indiana as in Illinois because Illinois may have higher prices of labor and materials. Also, the terrain in Illinois may be different than that of Indiana, thus a given stretch of highway may cost more due to extra terrain-related expenditure, such as embankment construction, excavation at cut sections, drainage, turnouts, culverts, slope protection of embankments and cut surfaces, etc. Thus, it is necessary to apply, to the Indiana unit value, appropriate adjustment factors that account for the differences in resource costs and in terrain across the states. This is explained in the next section.

9.2.3 Adjustment for Resource Prices across the States

As discussed in the proceeding section, to reduce the bias of asset values across the states, it is necessary to consider the differences in the prices of the factors of production from state to state. FHWA (*82*) and Sinha and Labi (*41*) provided state price factors for highway capital improvements (Figure 9.2).

9.2.4 Adjustment for Implementation Cost Differences due to Terrain

As stated earlier, there is a need also to adjust highway asset implementation costs across the states. Two states may have similar resource prices (and thus, state price factors), but one state may be located in a region with flat terrain while another may be located in a mountainous region. It is generally more costly to construct highway facilities in mountainous terrain compared to flat terrain. Using data from the HERS

State	State Highway Agency-Owned Only		All Highways	
	Bridges (sq. ft.)	Pavements (lane-miles)	Bridges (sq. ft.)	Pavements (lane-miles)
Alabama	71,904,200	28,121	98,769,940	194,126
Alaska	5,870,640	11,699	7,073,712	31,945
Arizona	34,211,331	18,819	50,436,830	131,356
Arkansas	53,469,506	37,119	63,805,542	204,710
California	231,593,566	50,541	298,621,562	385,860
Colorado	31,959,434	22,948	49,430,571	183,587
Connecticut	32,061,719	9,800	35,134,316	45,638
Delaware	7,433,716	11,693	10,075,287	13,656
Florida	121,242,871	42,439	167,401,939	268,350
Georgia	73,661,136	47,498	94,536,087	256,952
Hawaii	12,987,888	2,477	14,227,808	9,539
Idaho	10,906,201	12,137	17,029,477	98,590
Illinois	81,631,644	42,150	134,735,570	292,845
Indiana	48,007,853	28,458	82,409,308	198,265
Iowa	40,028,431	23,036	84,876,156	235,751
Kansas	39,207,219	23,988	85,772,225	286,962
Kentucky	53,881,240	61,499	59,161,307	164,491
Louisiana	143,201,452	38,501	163,636,906	129,034
Maine	11,141,945	18,115	12,924,629	46,771
Maryland	29,256,887	14,671	51,628,313	69,049
Massachusetts	35,780,007	8,659	40,318,649	76,332
Michigan	48,137,130	27,459	66,210,671	255,882
Minnesota	44,447,816	29,266	65,850,243	283,378
Mississippi	61,090,893	27,743	89,931,818	156,532
Missouri	81,900,144	75,656	106,462,993	270,903
Montana	16,277,405	24,490	20,616,390	150,125
Nebraska	22,163,000	22,487	41,324,649	190,478
Nevada	11,279,154	13,055	14,406,552	73,242
New Hampshire	6,910,826	8,825	11,659,004	33,008
New Jersey	33,534,411	8,480	70,526,566	84,463
New Mexico	15,204,223	29,237	17,539,285	142,939
New York	76,776,083	38,142	135,864,622	242,920
North Carolina	88,859,388	170,084	90,375,116	262,871
North Dakota	7,465,322	16,986	12,767,907	175,976
Ohio	100,770,015	49,034	140,191,496	262,024
Oklahoma	48,716,894	30,114	87,447,263	234,747
Oregon	35,927,215	18,264	50,801,670	122,163
Pennsylvania	104,755,851	88,475	132,640,117	255,552
Rhode Island	6,899,858	2,923	7,857,320	13,513
South Carolina	68,173,534	89,976	69,300,488	139,952
South Dakota	10,444,175	18,071	17,966,847	169,359
Tennessee	73,136,740	36,521	97,500,215	196,969
Texas	351,383,091	193,188	435,138,904	669,190
Utah	16,517,338	15,699	19,112,798	94,410
Vermont	6,418,276	6,038	8,964,156	29,672
Virginia	78,006,782	125,281	95,685,268	160,727
Washington	53,360,479	18,443	72,668,873	174,723
West Virginia	33,740,392	70,792	3,909,839	79,452
Wisconsin	47,763,151	29,481	67,153,455	231,264
Wyoming	10,724,278	15,594	13,187,514	58,387

Figure 9.1 Inventory sizes of the states (*80,81*).

TABLE 9.1
Indiana Network-Level Value per Asset Dimension

Asset	Total Network-Level Asset Dimensions	Value
Bridges	35,960,132 sq. ft.	\$218/sq. ft. (EDMC) \$267/sq. ft. (SLD)
Pavements	28,428 lane-miles	\$1,701,651/lane-mile (EDMC) \$447,993/lane-mile (SLD)

Technical Report Version 3.26 (*83*), the average ratios of costs can be estimated as follows:

Flat: 1.0

Rolling: 1.2

Mountainous: 1.6

In other words, all other factors remaining the same, the cost of an asset is 20% more for states in rolling terrain compared with those in flat terrain; and 60% more for those in mountainous terrain compared to flat terrain. Figure 9.3 shows the terrain adjustment cost factors for each state.

Figure 9.3 assumes that the terrain adjustment factors are uniform across functional classes. However, it may also be recognized that (a) adjustment factors actually differ across the different functional classes (*82*), and (b) states have different inventory size proportions for the different highway functional classes. Thus, for a finer breakdown, the terrain adjustment cost ratios for different functional classes could be applied to account for the different inventory sizes of the different functional classes in each state.

9.2.5 Calculation of Asset Values for Each State

The total highway asset value for each state was calculated as follows:

Pavements:

$$Value = I \cdot U \cdot A_1 \cdot A_2 \quad (9.1)$$

Where, I is the total size of a state highway pavement inventory (lane-miles) as shown in Table 9.1; U is the unit value of pavement assets in Indiana (\$/lane-mile) as shown in Table 9.1; A_1 is the adjustment for state-by-state differences in prices of factors of production (see Figure 9.2); and A_2 is the adjustment for differences in terrain across the states (Figure 9.3).

Bridges: similar as shown in Equation 9.1 for pavements, but in this case, I is in square feet of deck area and U is \$/sq. ft. of deck area. The value of Illinois is found in Table 9.2.

Tables A.6 to A.9 in Appendix A present the estimated value of pavement and bridge assets in each state, yielding a national value of \$20.8 trillion for the

State	Cost Factor	State	Cost Factor	State	Cost Factor
Alabama	1.21	Louisiana	1.32	Ohio	**0.85**
Alaska	1.30	Maine	1.10	Oklahoma	**0.95**
Arizona	0.95	Maryland	0.83	Oregon	**1.25**
Arkansas	0.95	Massachusetts	0.78	Pennsylvania	**0.95**
California	1.56	Michigan	1.24	Rhode Island	**0.98**
Colorado	1.26	Minnesota	1.11	South Carolina	**1.32**
Connecticut	0.88	Mississippi	1.51	South Dakota	**1.19**
Delaware	1.51	Missouri	0.81	Tennessee	**0.90**
Florida	1.19	Montana	1.19	Texas	**1.19**
Georgia	1.15	Nebraska	1.15	Utah	**1.33**
Hawaii	0.76	Nevada	1.49	Vermont	**1.27**
Idaho	1.12	New Hampshire	1.30	Virginia	**0.80**
Illinois	0.90	New Jersey	0.70	Washington	**1.39**
Indiana	1.28	New Mexico	0.69	West Virginia	**0.70**
Iowa	0.94	New York	0.90	Wisconsin	**1.08**
Kansas	0.59	North Carolina	0.97	Wyoming	**1.24**
Kentucky	1.39	North Dakota	1.42		
Source: FHWA (2005).					

Figure 9.2 2004 state price factors (*82*).

State	Dominant Terrain Type and Adjustment Factor	State	Dominant Terrain Type and Adjustment Factor	State	Dominant Terrain Type and Adjustment Factor
Alabama	Rolling (1.2)	Louisiana	Flat (1.0)	Ohio	Flat (1.0)
Alaska	Mountainous (1.6)	Maine	Rolling (1.2)	Oklahoma	Rolling (1.2)
Arizona	Rolling (1.2)	Maryland	Rolling (1.2)	Oregon	Mountainous (1.6)
Arkansas	Rolling (1.2)	Massachusetts	Rolling (1.2)	Pennsylvania	Rolling (1.2)
California	Mountainous (1.6)	Michigan	Flat (1.0)	Rhode Island	Rolling (1.2)
Colorado	Mountainous (1.6)	Minnesota	Flat (1.2)	South Carolina	Flat (1.0)
Connecticut	Rolling (1.2)	Mississippi	Flat (1.0)	South Dakota	Rolling (1.2)
Delaware	Rolling (1.2)	Missouri	Rolling (1.2)	Tennessee	Mountainous (1.6)
Florida	Flat (1.0)	Montana	Mountainous (1.6)	Texas	Rolling (1.2)
Georgia	Flat (1.2)	Nebraska	Rolling (1.2)	Utah	Mountainous (1.2)
Hawaii	Mountainous (1.6)	Nevada	Mountainous (1.6)	Vermont	Rolling (1.2)
Idaho	Mountainous (1.6)	New Hampshire	Rolling (1.2)	Virginia	Rolling (1.2)
Illinois	Flat (1.0)	New Jersey	Rolling (1.2)	Washington	Mountainous (1.6)
Indiana	Flat (1.0)	New Mexico	Mountainous (1.6)	West Virginia	Mountainous (1.6)
Iowa	Flat (1.0)	New York	Rolling (1.2)	Wisconsin	Flat (1.2)
Kansas	Rolling (1.2)	North Carolina	Rolling (1.2)	Wyoming	Mountainous (1.6)
Kentucky	Rolling (1.2)	North Dakota	Rolling (1.2)		

Figure 9.3 Terrain adjustment cost factors Source: Appendix Figures A.6 and A.7; (*58*).

EDMC method and $6.54 trillion for the traditional SLD method. Table 9.3 presents the total values of all highway assets and for state-maintained highway assets in the United States, using the EDMC and SLD methods. As seen, the traditional SLD method yields a lower value than the EDMC method for the reasons explained in an earlier chapter. The state-owned assets were found to have a value of $4.97 trillion using the elemental decomposition and multi-criteria (EDMC) method and $2.1T using the SLD method. These values should be considered as rough estimates only.

9.3 Aggregate Relationships between Asset Performance and Asset Preservation Ratio

Top-level national administrators seek to compare and contrast, in an unbiased manner, highway system performance across states or provinces. Thus, it is vital to establish a link between the ratio of spending to the existing stock, on one hand, and the level of attainment of highway performance on the other hand. However, a key tool largely remains missing: a quantification of asset value. If asset values can be obtained for all highways in each state, it would facilitate, from a strategic system monitoring perspective, the examination of the linkage between highway preservation spending per asset value to bridge or pavement condition or longevity. With increasingly abundant data on state highway system performance and expenditure on an annual basis (published by FHWA in its *Highway Statistics* series (*75*)), it has become feasible to investigate quantitatively an unbiased description of the link between funding and performance outcomes, at an aggregate, national level. Also, the current report has derived approximate values for each state's highway pavement and bridge assets. In attempting to throw some light on this issue, this section of the report investigates the relative performance of each state in terms of the amount it spends on asset preservation per asset value, and the average condition of its pavements and bridges.

TABLE 9.2
Illustration: Illinois Network-Level Value

Asset	Total Network-Level Asset Dimensions	Value	Total Value
Bridges	134 M sq. ft.	$218/sq. ft. (EDMC)	134M •$218•0.90•1 = $26.3B
		$267/sq. ft. (SLD)	134M •$267•0.90•1 = $32.2B
Pavements	292,845 lane-miles	$1,707,651/lane-mile (EDMC)	292,845•$1.7M•0.90•1 = $448B
		$447,993/lane-mile (SLD)	292,845•$0.4M•0.90•1 = $118B

TABLE 9.3
Total Value of Highway Pavement and Bridge Assets in the United States

Asset	Total US EDMC Value	Total US SLD Value	Total State-owned EDBC Value	Total State-owned SLD Value	Total State-owned Avg. SLD	Total Avg. SLD
Highways	$19.7T	$5.20T	$4.15T	$1.1T		
Bridges	$1.09T	$1.35T	$251B	$308B		
Total	**$20.8T**	**$6.54T**	**$4.4T**	**$1.4T**	**$2.48T**	**$11.4T**

SLD = straight line depreciation.

State highway pavement maintenance data were collected from the FHWA website (Table SF-4C); weighted average IRI data were obtained from Table HM-47 (*84*) and converted to PSI (present serviceability index). State bridge maintenance data were collected from the FHWA website (Table SF-12A); average bridge ratings for each state were obtained from the NBI database on a scale from zero to nine with nine being the best (*63*). Preservation ratios were developed to gage how well a state agency is caring for its assets in terms of the funds it spends on preserving its assets and the value of the state's assets. If the state spends a small amount and has a high value, the small ratio will reflect that the state is caring well for its assets. If the state spends a significant amount of money to preserve their assets, yet has a small overall asset value, either their methods of preservation are inadequate or there are other underlying factors contributing to the decrease in overall asset value. The preservation ratio can determine whether asset preservation and maintenance spending has an effect on the overall asset values in the state or agency.

In Figures 9.4 and 9.5, a state with a low preservation ratio (the x-axis) implies that the state's preservation spending is relatively little compared to its asset stock. This could be because the state probably lacks financial resources to keep up with its preservation program or because relatively little spending is needed to maintain its assets due to favorable climate, lighter truck loading, good highway administrative and cultural practices, etc. Thus, an ideal situation is where a state has a low preservation ratio (the x-axis), but a very good asset condition (the y-axis). For states with a low preservation ratio and a poor asset condition, it could be argued that the poor asset condition is probably due to the low level of spending per asset value. Similarly, a state with a high preservation ratio implies that the state's preservation spending is relatively large in terms of its asset stock. While a school of thought may argue that this is likely due to wasteful spending and unhealthy cultural and administrative practices, it is more likely that this situation is due to the fact that, compared to other states, such states need relatively greater levels of funding to maintain their assets due to unfavorable climate conditions or heavier truck loads. Thus, the most unfavorable situation is where a state has a high preservation ratio, but a very poor asset condition. This difficult position of an agency is exacerbated further when the state has favorable climate and light truck loads (thus removing any excuse for the poor asset

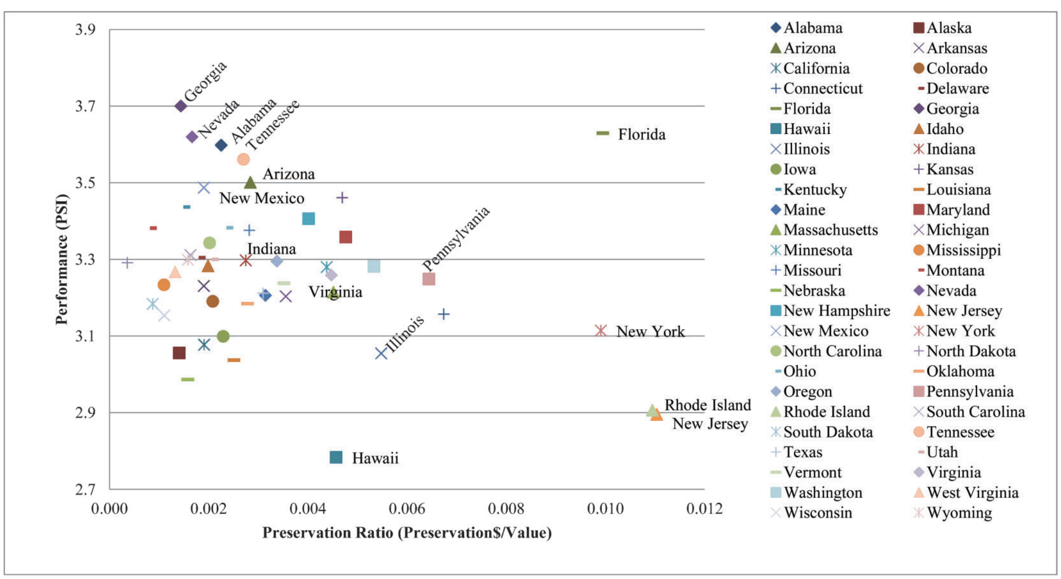

Figure 9.4 Relationship between asset performance and ratio of maintenance expenditure to value for state-owned pavements.

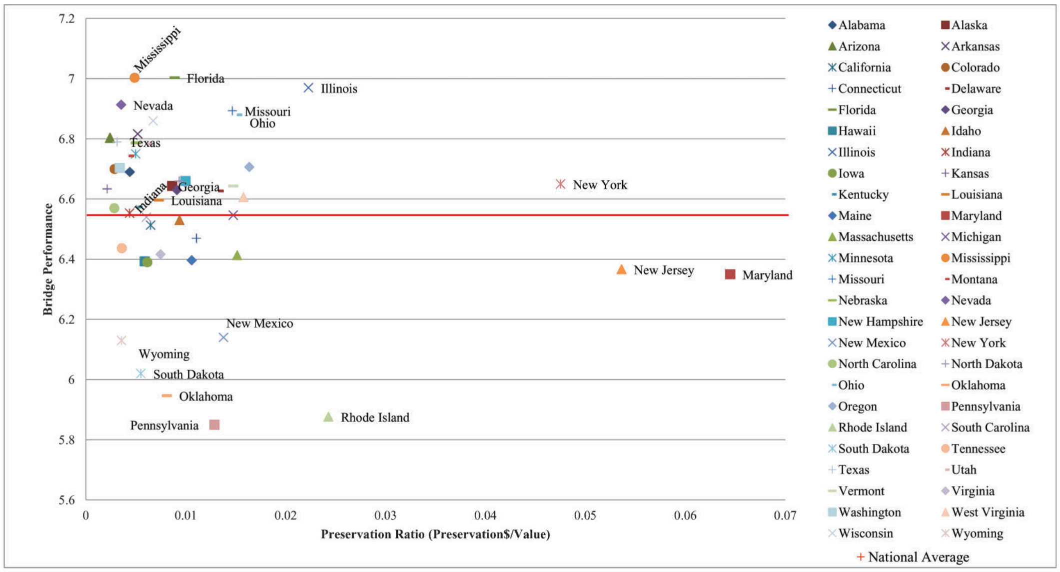

Figure 9.5 Relationship between asset performance and ratio of maintenance expenditure to value for state-owned bridges.

performance or high preservation spending per asset value). Such a situation could bring into serious question, the accountability of the state highway agency.

9.4 Summary

This chapter provided an estimated value for highway pavement and bridge assets in the United States using the EDMC and GASB 34 methods. This was done for state-owned bridges and pavements and also for all such highway assets in the country. The chapter also reviewed the performance of assets across the states on the basis of the average asset condition, preservation spending, and estimated asset values.

10. EXPLORATORY CONSIDERATIONS FOR INCORPORATING ASSET VALUE INTO INVESTMENT EVALUATION

10.1 Introduction

This chapter explores the incorporation of asset valuation into project evaluation and its application to financial planning. As stated previously, asset valuation outputs could provide asset managers with an additional dimension to compare between projects.

In ascertaining the prudence of including asset value into highway project investment evaluation, it is useful to go back to the basics to consider the motivation for such evaluations. Highway investment evaluation studies are typically carried out for a number of reasons (*41,85*). These include (a) the assessment of proposed investments for purposes of decision-support: an agency may seek to determine the impacts of several alternative project designs or locations; (b) fulfillment of regulatory mandate: government regulation and policy requires agencies to carry out impact assessments for projects exceeding a certain threshold monetary value; (c) post-implementation evaluation: where it is sought to assess the actual impacts that are measured after project implementation, and to evaluate such findings vis-à-vis the levels predicted at the pre-implementation phase, as well as base year levels; and (d) public education: in cases of controversial projects or for the purposes of public relations, a transportation agency may carry out evaluations with the objective of increasing general public awareness of the expected benefits to the citizenry.

The rationale for the investment drives the selection of evaluation technique and the choice of performance measures. The most common evaluation technique is life cycle cost analysis where the economic efficiency of competing investments are assessed on the basis of both the costs and benefits associated with cash flows over a given analysis period. However, highway asset managers are beginning to find that investment analysis based on least cost only often do not yield solutions that are acceptable from a wide range of perspectives. In recent times, there have been increasing calls to include other performance measures in investment evaluation. A number of measures under consideration include system vulnerability, social justice, security, operational accountability of public infrastructure. This report examines the possibility that the existing asset value could also be considered for use in project evaluation.

In financial and business circles, the value of a financial asset often plays a critical role in deciding whether or not to pursue an investment intended to increase the asset. The decision could be based either on the existing asset value before the investment, the added value due to the investment, or both.

Existing Value: For assets with very little existing value at a given time, it is typically not considered feasible to undertake the investment. For example, there seems to be very little wisdom in spending $1 million to renovate a house that is worth only $50,000, unless in the extreme case where the land location is very valuable, in that case the value of the land must be considered and renders the house value much more than $50,000.

Added Value: Assets for which significant added value can be earned due to an investment can be considered appropriate for the investment. In that case, all other factors remaining equal, assets with higher added values are considered higher priorities for investment.

Existing Value and Added Value: Both existing value and added value could be considered in investment analysis. While priorities may be given to investments with higher added value or existing value, there could be bias towards higher valued-assets and larger investments that yield greater added values. Thus, a ratio of the added value to the existing value could be used for the evaluation, to avoid scale bias.

10.2 Estimating Added Value due to an Investment

The process of asset valuation incorporates the use of at least one of several asset attributes that are directly affected by an investment. "Investment" in the context of highway asset management, typically refers to an action that is undertaken with the objective of replacing an asset, prolonging the life of an existing asset, correcting minor or localized physical defects, or preventive maintenance to retard the onset of significant deterioration.

With regard to the valuation features or input factors for asset valuation computations, the effect of such investments can take any one of at least three forms: (i) the cost associated with the investment, (ii) an increase in the physical condition of the asset, (iii) an increase in the asset longevity in the form of an increase in its remaining service life. Depending on the valuation method, at least one of these three forms can be used to establish the added value due to the investment.

10.2.1 Replacement Investments

Asset replacement and expansion costs are considered as capitalized costs in all the traditional asset valuation approaches. For investments that replace the asset, the added value for the asset is simply the difference between the value of the asset before replacement and that after replacement. The amount, or cost, associated with the investment inherently increases the intrinsic value of the asset. To account for this, the value is divided by the construction (or historical) cost to compare the values of assets that have different costs that can inflate the value.

$$\Delta V = \frac{V_{REPLACEMENT} - V_t}{C} \quad (10.1)$$

The construction (or historical) cost C, is the cost associated with building the asset. The value after replacement, $V_{REPLACEMENT}$, is the cost of the replacement which can be determined from historical records of similar investments or through a buildup of unit rates. The value before replacement, V_t can be determined using any one of the traditional approaches or methods where desired. In the traditional depreciation methods, V_t is the salvage value of the asset at the time of replacement. In the net salvage method, V_t is the difference between the historical replacement value and the cost of possible repair (if that option were chosen instead of replacement) at the time of the replacement. In certain cases, it may cost more to repair than to replace the asset, and in such cases, ΔV would be negative. In all the methods associated with the modified approach, V_t can be determined without difficulty. In the written-down replacement method, the value just before replacement can be determined using Equation 2.10 on the basis of the historical cost of the asset construction; the condition at the time of asset replacement, and the best possible condition of the asset. In the "adjusted value with respect to condition threshold" and "fixed value with respect to condition threshold" methods, the value just before replacement can be determined using Equation 2.11 and Figure 2.7 respectively, on the basis of the historical cost of the asset construction; the condition at the time of asset replacement. In the EDMC method, the value just before replacement can be determined using Equation 3.11, on the basis of the historical cost, service life, and condition of each component of the asset. In the replacement-downtime-salvage method, the value just before replacement can be determined using Equation 4.5, on the basis of the historical asset construction cost, the value associated with the avoidance of the user travel time by not reconstructing the asset at time t, the value associated with the avoidance of the vehicle operating by not reconstructing the asset at time t, and the value associated with possible recycling and disposal costs and benefits at time t.

10.2.2 Rehabilitation Investments

Asset rehabilitation (improvement) costs are considered as capitalized costs only in the depreciation approaches and the proposed methods (EDMC and RDS). In the methods associated with the modified approach, asset rehabilitation is considered merely as an expense. For depreciation approaches, the EDMC and RDS methods, the added value for the asset, due to rehabilitation, is simply the difference between the value of the asset before the rehabilitation and that after the rehabilitation divided by its construction (or historical) cost.

$$\Delta V = \frac{V_{REHABILITATION} - V_t}{c} \quad (10.2)$$

For each of the methods, the value before rehabilitation, V_t can be determined as explained in Section 10.2.1.

The value of the asset after rehabilitation, $V_{REHABILITATION}$, is generally a function of a combination of at least one of the following attributes of the rehabilitation: the rehabilitation cost, the increase in condition due to the rehabilitation, and the increase in asset longevity (remaining service life) due to the rehabilitation. In the traditional depreciation methods, $V_{REHABILITATION}$ is the post-rehabilitation level of the deterioration function and serves as a reset value for the function. In the net salvage method, $V_{REHABILITATION}$ is the difference between the historical replacement value and the post-rehabilitation value. In the EDMC method, $V_{REHABILITATION}$ is calculated separately for each component because the cost and impact of the rehabilitation are expected to be different for each component; this is a weighted function of the fraction of the rehabilitation cost expended on that component, the increase in condition of that component due to the rehabilitation, and the increase in the component longevity (remaining service life) due to the rehabilitation (using Equation 3.11). In the replacement-downtime-salvage method, the value just after the rehabilitation can be determined as the cost of the rehabilitation.

10.2.3 Forms of Added Value due to an Investment

As discussed in the prelude to Section 10.2.1, the added value due to an investment could take any one of three forms: (i) a cost associated with the investment, (ii) an increase in the physical condition of the asset, (iii) an increase in the asset longevity in the form of an increase in its remaining service life. As seen in the Section, depending on the level of the investment (reconstruction or rehabilitation) and the valuation approach and method, at least one of these three forms can be used to establish the added value due to the investment.

For methods that estimate added value as a function of the improved asset condition or extended service life, it is needed to know the levels of these attributes after the investment is carried out. For different asset types, there exist models in the literature that, on the basis of the investment or asset attributes (such as the type or intensity of the investment, the cost of the investment, asset condition before the investment) have provide the expected increase in asset condition or increase in asset life. A few of these are discussed in the next paragraph.

Performance jump (PJ), the vertical or instantaneous elevation in asset condition due to an investment, is computed using values of asset condition taken just-before and just-after the investment (*86,87*). Levels of asset condition just-before and/or just-after the investment, if unavailable, may be extrapolated using measured conditions preceding or subsequent to the investment. Examples in the literature include Colucci-Rios and Sinha (*88*), who used the PJ concept to estimate the instantaneous reduction in roughness due to overlays of varying thicknesses; Rajagopal and George (*89*), who expressed performance jump as the difference in PCR just after treatment and PCR just before treatment, and then proceeded to model such effectiveness as a function of overlay thickness; Markow (*90*), who expressed maintenance effectiveness as a function of treatment and asset attributes; and Mouaket et al. (*91*), who measured the effectiveness of seal coating in terms of a jump in PSI, and then modeled such effectiveness as a function of initial pavement condition; Jiang and Sinha (*92*), who developed condition improvement models for each type of bridge investment; and Sobanjo and Thompson (*93*), who developed and applied condition enhancement models in bridge investment analysis.

The extension in asset service life is the number of additional years that an investment provides to an asset before it reaches some established threshold failure condition. This concept has been used in the asset management literature (*94–97*). Also, Sobanjo and Thompson (*93*) used this concept to develop the extension in bridge life for different bridge preservation investments using Markov transitional probability matrices.

In certain cases, the increase in asset condition is known but the corresponding increase in asset service life is not known, or vice versa. To address these situations, Labi et al. (*98*) developed functions that relate the increase in asset condition due to an intervention to asset remaining life. Figure 10.1 and Figure 10.2 show these relationships.

10.2.4 Discussion

In incorporating the added value of an asset during investment evaluation and decision making, a choice has to be made with regard to choosing which of the three key forms of added value (or valuation features) should play a role. For example, two alternative preservation investments may have the same cost, but one offers a greater increase in asset condition and/or service life compared to the other. Clearly, consideration of the cost differential alone will not suffice in establishing the superior alternative. Similarly, two alternative preservation investments may yield a similar increase the asset condition, but may differ in their cost and/or the extent to which they increase the asset's remaining service life but have different costs and offer different condition increases. Yet another similar situation is realized for projects that yield similar extensions in the assets remaining life. As seen in previous sub-sections, different valuation methods use at least one of these forms of added value. However, it may be preferred to estimate added value using all three forms, not just one, for purposes of investment evaluation and decision making. In that case, the

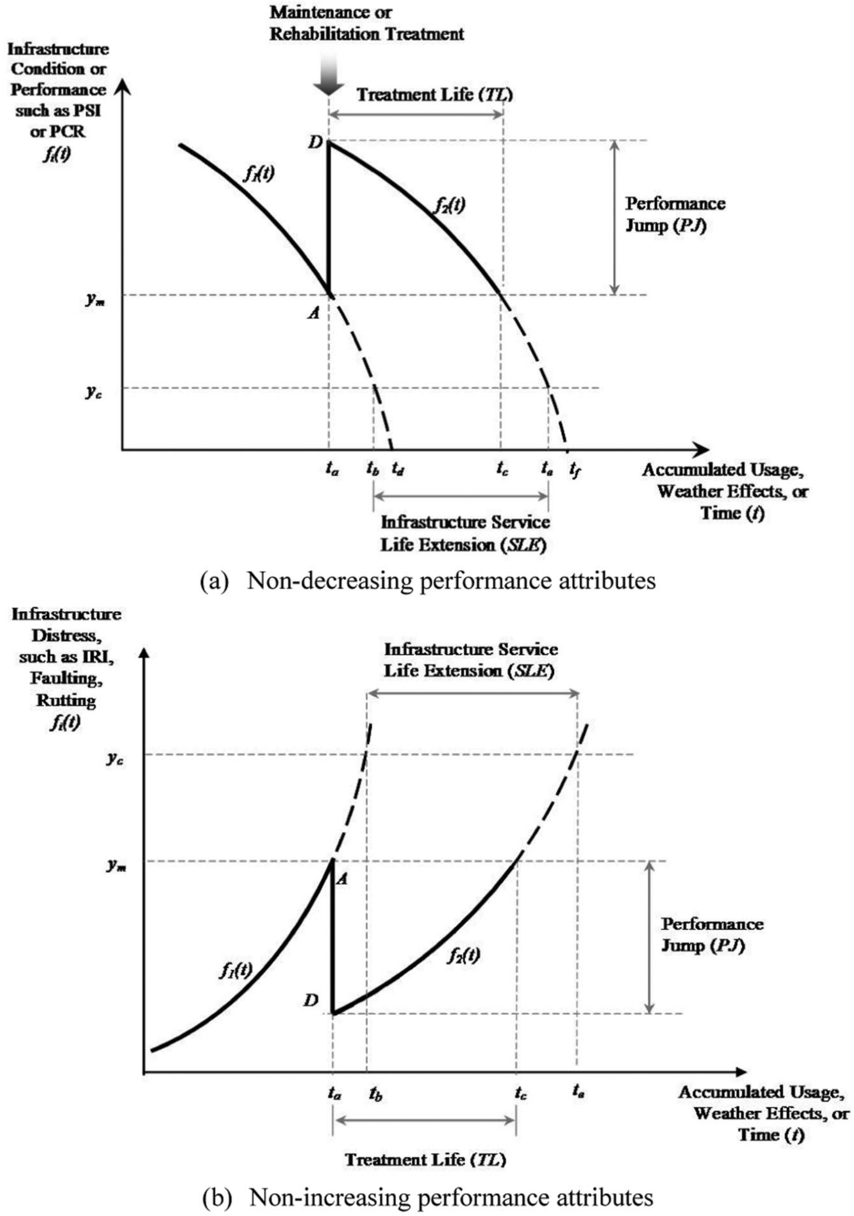

Figure 10.1 Conceptual relationships between increase in asset condition and life extension.

EDMC method of valuation can be considered most appropriate. By incorporating all three forms of added value, the EDMC concept holds much promise in comprehensively and fairly reflecting how an asset value could increase due to an investment.

For example, consider a bridge with pre-investment EDMC value of \$135,000. It is sought to determine the added value due to a planned rehabilitation investment. The rehabilitation costs are as follows for each component: Superstructure, \$50,000; substructure \$110,000; deck, \$300,000. Assuming that the condition and remaining service lives are expected to increase to the following levels after the investment: Superstructure, 7 units, 50 years; Substructure, 6 units, 40 years; Deck, 8 units, 20 years). For this example, the EDMC method yields the following added value:

$$V_{EDMC} = \left[0.4\left(\$50{,}000\left(\frac{7}{9}\right) + \$100{,}000\left(\frac{6}{9}\right) + \$300{,}000\left(\frac{8}{9}\right)\right) + 0.6\left(\$50{,}000\left(\frac{50}{100}\right) + \$100{,}000\left(\frac{40}{100}\right) + \$300{,}000\left(\frac{20}{82}\right)\right)\right] = \qquad (10.3)$$

$$V_{EDMC} = \$231{,}800$$

The added value, ΔV, is the difference between the pre-investment value and the expected value after investment

Functional Form Pairs		Relationships
$f_1(t)$ and $f_2(t)$ are linear	$f_1(t) = m_1 t + c_1$ $f_1(t) = m_1 t + c_1$	$SLE = \frac{(y_m - y_c)(m_2 - m_1) - PJ * m_1}{m_1 m_2} \cdot TL = -\frac{PJ}{m_2}$
$f_1(t)$ is linear and $f_2(t)$ is 2nd order polynomial	$f_1(t) = m_1 t + c_1$	$SLE = \left[\frac{y_m - y_c}{m_1}\right] + \frac{\left(\sqrt{b_2^2 - 4a_2(c_2 - PJ - y_m)} - \sqrt{b_2^2 - 4a_2(c_2 - y_c)}\right)}{2a_2}$ $TL = \frac{\sqrt{b_2^2 - 4a_2(c_2 - y_m - PJ)} - \sqrt{b_2^2 - 4a_2(c_2 - y_m)}}{2a_2}$
$f_1(t)$ is linear and $f_2(t)$ is exponential	$f_1(t) = m_1 t + c_1$ $f_2(t) = a_2 e^{-b_2 t} + c_2$	$SLE = \left(\frac{y_m - y_c}{m_1}\right) + \frac{1}{b_2}\ln\left[\frac{PJ + y_m - c_2}{y_c - c_2}\right]$ $TL = \frac{1}{b_2}\ln\left[\frac{PJ + y_m - c_2}{y_m - c_2}\right]$
Both $f_1(t)$ and $f_2(t)$ are exponential	$f_1(t) = a_1 e^{-b_1 t} + c_1$ $f_2(t) = a_2 e^{-b_2 t} + c_2$	$SLE = \ln\left[\left\{\frac{y_c - c_2}{a_2}\right\}^{\left(\frac{-1}{b_2}\right)} * \left\{\left(\frac{PJ + y_m - c_2}{a_2}\right)^{\left(\frac{b_1}{b_2}\right)} - \left(\frac{y_m - y_c}{a_1}\right)\right\}^{\left(\frac{1}{b_1}\right)}\right]$ $TL = \frac{1}{b_2}\ln\left[\frac{PJ + y_m - c_2}{y_m - c_2}\right]$
$f_1(t)$ is exponential and $f_2(t)$ is linear	$f_1(t) = a_1 e^{-b_1 t} + c_1$ $f_2(t) = m_2 t + c_2$	$SLE = \left[\frac{y_c - c_2}{m_2}\right] + \frac{1}{b_1}\ln\left[\left(\frac{y_c - y_m}{a_1}\right) + e^{\frac{-b_1}{m_2}(PJ + y_m - c_2)}\right],$ $TL = -\frac{PJ}{m_2}$
$f_1(t)$ is 2nd order polynomial and $f_2(t)$ is linear	$f_1(t) = a_1 t^2 + b_1 t + c_1$ $f_2(t) = m_2 t + c_2$	$SLE = \frac{y_c - c_2}{m_2} + \frac{b_1}{2a_1} + \sqrt{\left(\left\{\frac{b_1}{2a_1} + \frac{PJ + y_m - c_2}{m_2}\right\}^2 - \frac{y_m - y_c}{a_1}\right)},$ $TL = -\frac{PJ}{m_2}$
Both $f_1(t)$ and $f_2(t)$ are 2nd order polynomial	$f_1(t) = a_1 t^2 + b_1 t + c_1$ $f_2(t) = a_2 t^2 + b_2 t + c_2$	$SLE = -\left[\frac{b_2}{2a_2} - \frac{b_1}{2a_1}\right] - \left[\frac{\sqrt{b_2^2 - 4a_2(c_2 - y_c)}}{2a_2}\right]$ $+ \left[\sqrt{\left(\left\{\frac{b_1}{2a_1} - \frac{b_2}{2a_2} - \frac{\sqrt{b_2^2 - 4a_2(c_2 - PJ - y_m)}}{2a_2}\right\}^2 - \frac{(y_m - y_c)}{a_1}\right)}\right]$ $TL = \frac{1}{2a_2}\left(\sqrt{b_2^2 - 4a_2(c_2 - PJ - y_m)} - \sqrt{b_2^2 - 4a_2(c_2 - y_m)}\right)$

Figure 10.2 Relationships between increase in asset condition life extension.

divided by the construction cost = (\$231,800–\$135,000)/\$450,000 = 0.215 or 21.5% increase in value.

10.3 Investment Evaluation based on Asset Value Only

As an example of investment evaluation involving asset value only, consider the seven investments shown in Table 10.1. The table provides the values of the assets before the investment, the added value to the asset due to the investment, and the relative added value (ratio of the added value to the existing value). The table also shows the priority rankings for the investments using three separate evaluation criteria that are based on two performance measures (both of which are related to asset value: existing value and added value). It is seen that the priorities can be very different depending on the performance measure.

10.4 Evaluation Based on Economic Efficiency Using Asset Values

The benefit-cost ratio (BCR) or incremental benefit-cost ratio (IBCR) is often used to distinguish between alternative investment options. Costs and benefits are presented in terms of monetary worth incurred over the analysis period. A project with ratio that exceeds 1.0 is considered to be economically feasible. Also, the greater the BCR or IBCR ratio, the more superior the alternative. The value of an asset can play a role as an additional performance measure by multiplying the

TABLE 10.1
Hypothetical Example of Investment Evaluation Based on Existing Value and Added Value

Project	Value of Existing Asset (millions), V	Added Value (millions), Δ	Relative Added Value (millions), V/Δ	Priority Rank on the Basis of Existing Value	Priority Rank on the Basis of Added Value	Priority Rank on the Basis of Relative Added Value
Pavement replacement, PCC	$0.99M	0.75	0.73	4	2	3
Added travel lanes, PCC	$1.31M	0.91	0.82	1	1	1
Bridge deck widening	$0.90M	0.63	0.65	3	3	4
Road reconstruction, HMA	$0.88M	0.41	0.41	7	6	7
Bridge deck overlay	$0.74M	0.35	0.64	6	7	5
Bridge deck replacements	$0.92M	0.57	0.76	5	4	2
Curve corrections	$1.23M	0.48	0.47	2	5	6

NOTE: Values are all hypothetical, for purposes of illustration.

benefit cost ratio or IBCR of the investment with the asset value.

10.4.1 Using Added Value

The economic efficiency parameter can be multiplied with the relative added value divided by asset construction (or historical) cost to yield an intuitive criterion for investment evaluation.

$$\text{Criterion} = \Theta * \Delta/C \qquad (10.4)$$

Where Θ = a criterion of economic efficiency, such as the benefit-cost ratio; Δ = added value; and C is the construction (or historical) cost of the asset.

As an example of investment evaluation involving this evaluation criterion, consider the seven investments shown in Table 10.2. The table provides the values of the assets before the investment, the added value to the asset due to the investment, and the relative added value (ratio of the added value to the existing value). The table also shows the benefit-cost ratio of each investment and the product of the benefit cost ratio and the relative added value.

10.5 Multi-Criteria Decision Making

Asset values can be used in the framework for multi-criteria decision making (MCDM). This technique allows decision-makers to provide a combined level of "desirability" of alternative projects on the basis of multiple performance measures that are often not commensurate. In transportation, multi-criteria decision making can be used to account for social, technical, political, economic, and environmental factors (*99*). MCDM concepts include weighting and scaling of the performance measures. Different methods for scaling include point allocation or ranking for direct weighting and direct rating, mid-value splitting, and regression analysis for scaling. Figure 10.3 illustrates the typical steps in MCDM.

10.5.1 Factor Rating Method

The factor rating method, also called the ranking and rating method (*41*), rates alternative transportation projects based on each performance measure, or "factor" (*100*). In this method, decision makers weigh each evaluation criteria in order of importance. For example, an agency may weigh the project cost higher than the travel time costs compared to the asset's users. Weights for all evaluation criteria should sum to 1 or 100%. Secondly, the evaluation criteria within each alternative must be given a factor rating score on an ordinal scale. The project cost of alternative 1 may be higher than that of alternative 2. The higher the factor rating score, the higher the preference for the alternative. Multiplying each criteria factor score by their specified weight and summing the results for each

TABLE 10.2
Alternative Added Value Example

Project	Project Cost (millions)	Project Benefits (millions)	Added Value, Δ/C	Benefit/Cost Ratio, BCR	BCR*Δ/C	Priority Rank on the Basis of (BCR/V/Δ)
Pavement replacement, PCC	$0.99	$0.75	0.23	0.78	0.18	7
Added travel lanes, PCC	$1.31	$0.91	0.52	0.69	0.36	3
Bridge deck widening	$0.90	$0.63	0.86	0.70	0.60	1
Road reconstruction, HMA	$0.8	$0.41	0.38	0.51	0.19	6
Bridge deck overlay	$0.74	$0.35	0.44	0.47	0.21	5
Bridge deck replacements	$0.92	$0.57	0.69	0.62	0.43	2
Curve corrections	$1.23	$0.48	0.90	0.39	0.35	4

*Values are all hypothetical, for purposes of illustration.

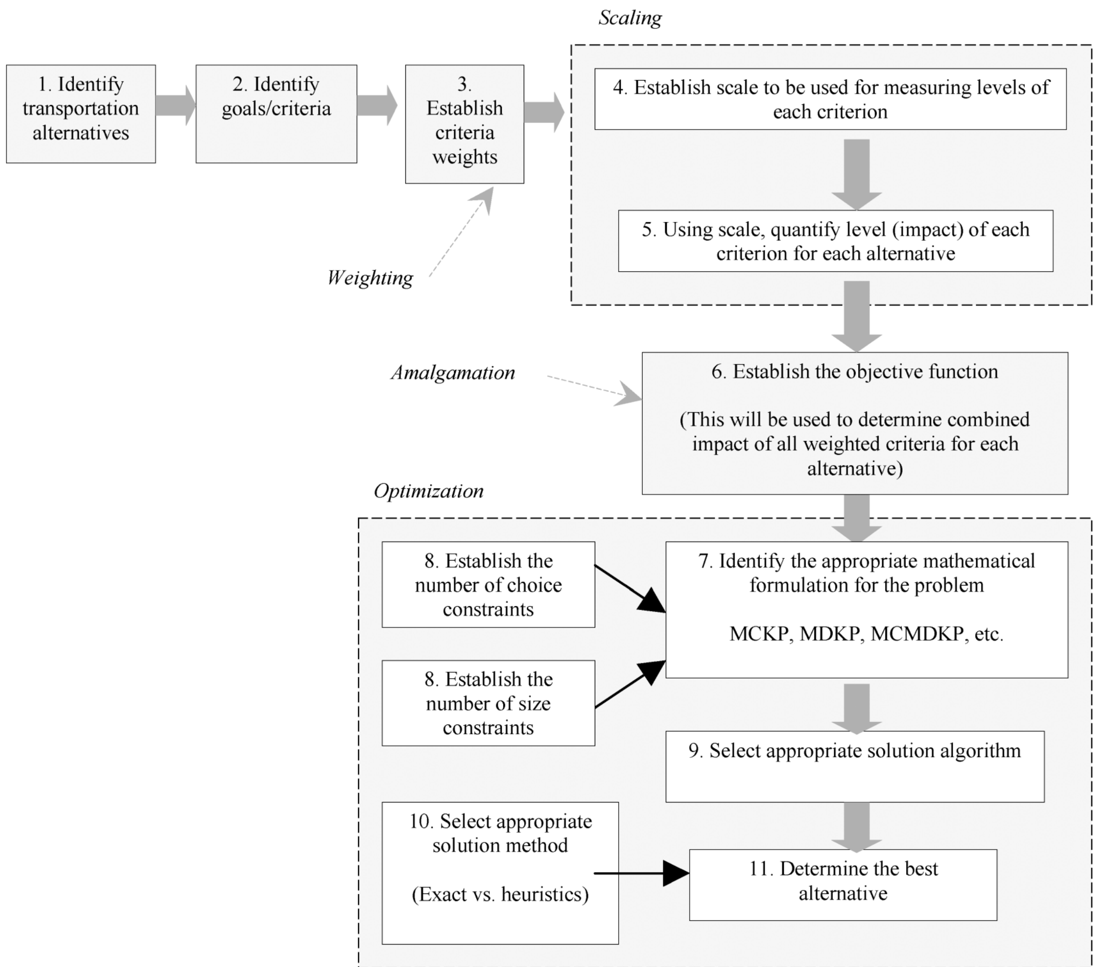

Figure 10.3 Steps in multi-criteria decision making (*41*).

alternative yields a total weighted score. The highest total weighted score of all the alternatives is the highest ranking project. For example, using the alternatives outlined in Table 10.1, the rankings in Table 10.3 were given to each factor: 0.3, 0.2, and 0.5 for cost, benefits, and added value, respectively.

Asset value can be incorporated in MCDM as an evaluation criteria factor. Depending on the preferences of the decision-maker, assets with large values will likely be given a higher factor score for that specific decision-maker if value is more important than other factors.

10.5.2 Analytic Hierarchy Process

The analytic hierarchy process enables decision-makers to use subjective and quantitative information in the evaluation process. In this process, eigenvectors are used to convert pairwise comparisons into a ranking of priorities (*101*). Value can be incorporated as a criterion for each alternative. Using the previous example alternatives, assume the following ranking for the criteria: cost is four times as important as value, cost is two times as important as benefits, and benefits is three times as important as value. Computation of the eigenvectors for the criteria yields the weights presented in the second row of Figure 10.4. Priority weights were assigned to each alternative based on subjective preferences (bottom row of Figure 10.4).

Matrix multiplication of each criteria weight to each alternative weight yields the recommended alternative. The alternative with the greatest product is the best alternative. In this simple example, the highest ranked

TABLE 10.3
Example Rating and Ranking Method of Evaluation

Factor	Ranking	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8	Alt. 9	Alt. 10
Cost	0.3	3	4	2	2	2	3	5	4	2	1
Benefit	0.2	4	2	4	3	2	3	2	1	4	5
Added value	0.5	5	3	5	4	2	4	1	2	3	5
Weighted total	**4.2**	**3.1**	**3.9**	**3.2**	**2.0**	**3.5**	**2.4**	**2.4**	**2.9**	**3.8**	**4.2**

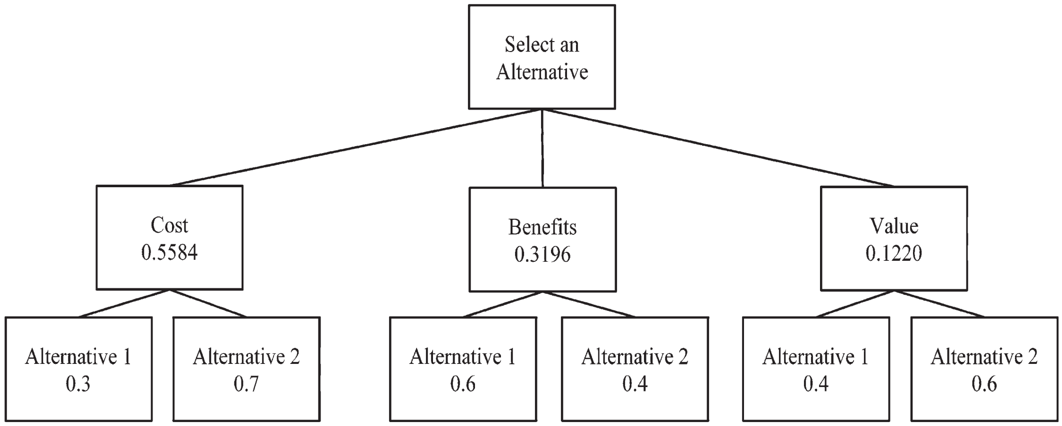

Figure 10.4 Example analytic hierarchy process with value.

alternative is Alternative 1 with a product of 0.4876 which exceeds that of Alternative 2 (0.3815). As a performance measure, value was given a relatively lower weight overall, but a higher preference in Alternative 2. In this example, cost was assigned a very large weight and this led to Alternative 2 emerging as the highest ranked project. If asset value were assigned a larger weight, the outcome would likely be different.

10.6 Chapter Summary

In summary, the use of asset value or added value as a performance measure for evaluation holds great promise in asset investment analysis and decision making. From the perspective of the valuation features or input factors for asset valuation computations, the impact of a highway investment can take at least one of three forms: cost of the investment, increase in condition, and increase in remaining life. The consideration of these features in investment evaluation depends on the approach/method of valuation and the level of the investment (reconstruction or rehabilitation). Asset value or a function thereof, if appropriately applied, can help decision-makers base their investment choices not only on the benefits and costs of competing investments, but also on the added value and/or the existing value to be earned due to the investment.

11. SUMMARY, DISCUSSION, AND CONCLUSIONS

11.1 Summary and Discussion

Traditional methods of valuation are categorized into three approaches. The depreciation approach includes methods such as straight-line depreciation, declining balance, double-declining balance, sum-of-years-digits, and the sigmoidal. These methods use a form of a depreciation trend line for a monolithic asset to determine the value at any given year. The second approach, the modified approach, consists of methods that consider asset condition as a key factor in asset valuation. In the modified approach methods, the asset generally decreases in value as its condition decreases and increases if any maintenance or repair is carried out to enhance the asset condition. The third approach, the "other" approach, consists of methods that consider only asset replacement cost or historical cost as an indicator of value. These traditional approaches and methods are listed in Table A.4.

The proposed elemental decomposition and multi-criteria (EDMC) method views an asset not as a monolithic structure as implicitly assumed by traditional methods, but rather in terms of its multiple components. Each component deteriorates at different rates and has individual costs associated with its construction. The components are valued separately on the basis of their individual conditions and remaining service lives, and then the individual values are summed up to yield the total asset value. Condition and remaining service life reflect the perspectives of the user and the agency, respectively. The probabilistic EDMC valuation of an asset considers individual ranges and probability distributions for the key EDMC analysis parameters, namely, asset condition, reconstruction cost, and remaining service life to yield a probabilistic outcome in the form of a range of asset values with a probability distribution.

The second proposed method, the replacement-downtime-salvage (RDS) method is based solely on cost parameters: the cost to demolish an existing asset or the cost to remove a damaged asset, the agency cost of reconstructing the asset, and the user cost associated with the asset replacement.

The third proposed method, the decommission and re-use (D&R) method, considers the real estate value of the land occupied by an asset. If an asset is located on very valuable land, then the asset is said to have a high value. In such cases, decision-makers may opt to move the asset to less valuable land or underground to open the valuable land for new development or green space. If the asset is located on farmland, then the land could be reverted for farming purposes only if the asset is decommissioned for any reason.

The fourth proposed method, the duration-cost method, uses probabilistic (Weibull) duration models to predict the probability of asset survival until the end of its typical service life, and calculates the product of the survival probability and the asset replacement cost to determine the asset value. For a given replacement cost, a lower asset value reflects an asset with low probability of surviving to the end of its service life while a higher value reflects a higher probability of surviving to the end of its service life.

Each of the proposed methods yielded asset values that differed due to their different mathematical formulations. The EDMC method typically yields a higher value than most depreciation methods, but a lower value than the "other" approach methods. The RDS method typically yields values that exceed the other methods unless the recycling benefits far outweigh the replacement and user inconvenience costs. The D&R method values land, which can vary significantly depending on asset location. Thus, the values from this method can be either significantly higher or lower than values obtained from traditional methods. Finally, the duration-cost probabilistic method yields asset values that fall in the mid-to-high spectrum of the range of results from the traditional methods. Also, compared to the proposed methods, the duration-cost probabilistic method falls in the middle of the range of values produced by these methods.

The total value of Indiana's state-owned pavements and bridges was found to be \$47.1 billion and \$7.83 billion, respectively, using the EDMC method. Using the SLD method, the values were \$12.4 billion and \$9.59 billion, respectively. The EDMC thus yields a higher value than the traditional SLD method, which could be because the former explicitly considers the asset as an assemblage of components and thus carries out valuation for each component rather than considering the structure as a monolithic entity. Also, using the unit value of highway bridge and pavement assets in Indiana, a total value for bridge and pavement assets in the United States, was determined. For state-owned highway pavements and bridges the value was determined as \$4.97 trillion from the EDMC method and \$2.1 trillion from the SLD method. For pavements and bridges on all highways in the country, the EDMC and SLD methods yielded \$20.8 trillion and \$6.5 trillion, respectively. In each case, the EDMC method yielded a value higher than that of the traditional SLD method.

Asset value, if known, can play an important role in determining the outcome of investment evaluation and project decision making. Specifically, the existing asset value or added asset value could also be included as a performance criterion. All other items being equal, projects that yield a higher added value, relative to their existing values, could be assigned higher investment priority.

11.2 Conclusions

Current valuation methods tend to underestimate asset value due to their monolithic view of assets and should be used only with explicit recognition of this limitation. The attributes and behavior of a single individual component should not dictate the overall value of an asset that is comprised of multiple components. In addressing this limitation, the first proposed method for asset valuation, the elemental decomposition and bi-criteria (EDMC) method allows for the opportunity to calculate the contribution of each component to the asset value. The EDMC method incorporates the asset condition (which reflects the user perspective) and the asset remaining service life (which reflects the agency perspective). The second proposed method incorporates replacement, downtime (user) cost, and recycling benefits or disposal costs and is aptly named the replacement-downtime-salvage (RDS) method; this method reflects the recognition that recycling or disposal costs are associated with the end-of-life of an existing asset, and user costs during asset replacement can significantly influence the value of an asset and thus should be duly considered in asset valuation. Admittedly, the inclusion of user costs in asset valuation can be a controversial issue because user costs tend to exceed, by far, the agency costs and user costs also are not borne directly by the agency. However, the RDS method, hopefully, can ignite a conversation on the larger issue of the role of user costs in asset management decision making in general. The decommission and re-use (D&R) method of valuation, assumes that assets can be valued on the basis of the land they occupy, particularly in high density urban areas where land is very expensive and where there exist opportunities for relocation elsewhere. This method appears to be suitable only where the land value is very high. Each of the proposed methodologies contributes additional information to the larger philosophy of asset valuation and can yield results that can aid in investment evaluation. Ultimately, the elemental decomposition and multi-criteria (EDMC) method is strongly recommended for adoption by INDOT for valuation of their assets for reasons stated in this report.

REFERENCES

1. USDOT. *Asset Management Primer*. Federal Highway Administration Office of Asset Management, U.S. Department of Transportation, 1999, pp. 1–30.
2. Amekudzi, A., P. Herabat, S. Wang, S, and C. Lancaster. Multipurpose Asset Valuation for Civil Infrastructure: Aligning Valuation Approaches with Asset Management Objectives and Stakeholder Interests. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1812. Transportation Research Board of the National Academies, Washington D.C., pp. 211–218, 2002.
3. Cowe Falls, L., R. Haas, and S. Tighe. *A Comparison of Asset Valuation Methods for Civil Infrastructure*. Transportation Association of Canada, Ottawa, Ontario, 2004.
4. Dewan, S. A., and R. E. Smith. Valuing Pavement Network Assets and Use of Values as Decision Supports. *ASCE Journal of Infrastructure Systems*, Vol. 11, No. 4, 2005, pp. 202–210.

5. GASB. *GASB Statement No.* 34: *Basic Financial Statements-and Management's Discussion and Analysis-for State and Local Governments.* Governmental Accounting Standards Board, Norwalk, Connecticut, 1999.
6. Herabat, P., A. Amekudzi, and P. Sirirangsi. Capturing the Effects of Sound Maintenance Practices in Highway Asset Valuation: The Replacement Cost Approach vs. the Book Value Method. In *Compendium of Papers*, Transportation Research Board Annual Meeting CD-ROM, Washington, D.C., January 12–16, 2003, pp. 57–65.
7. Park, T., and S. K. Sinha. Asset Valuation Model for Sewer Pipe Infrastructure System. *ASCE Journal of Pipelines Systems Engineering and Practice*, 2009, pp. 1312–1321. doi: 10.1061/41069(360)123.
8. Maze, T., and O. Smadi. *GASB 34: Look before You Leap*. Center for Transportation Research and Education, Iowa State University and Howard R. Green Company, 2010, pp. pp. 1–4. http://www.ctre.iastate.edu/gasb34/gasb34mayjun01long.pdf. Accessed 4/7/2010.
9. GASB. *GASB Statement 34 Implementation Issues: Infrastructure Reporting-Modified Approach vs. Depreciation*. Governmental Accounting Standards Board, Norwalk, Connecticut. G:\Gasb34\Issues, Procedures, & Tasks\Infrastructure Reporting.doc. Accessed: 4/6/2010.
10. Jani, S. *Road Asset Valuation and Management-Case Study Finland. RAKLI-The Finnish Association of Building Owners and Clients*. http://www.roadsfundtz.org/web/pdf/session%207/Road%20Asset%20Valuation%20and%20Management%20FINLAND.pdf. Accessed 4/15/2010.
11. Catholic Bishops, Inc. *Property and Equipment: Recognition of Fixed Assets*. United States Conference of Catholic Bishops, Inc., Washington, D.C., 2002. http://www.usccb.org/bishops/dfi/property.htm
12. Bai, Q., S. Labi, K. C. Sinha, and P. D. Thompson. Bridge User Cost Estimation-A Synthesis of Existing Methods and Addressing the Issues of Multiple Counting, Work Zones, and Traffic Capacity Limitation. In *Compendium of Papers*, Transportation Research Board Annual Meeting CD-ROM, Washington, D.C., January 23–27, 2011.
13. Thompson, P. D., and J. O. Sobanjo. Estimation of Enhanced Pontis Deterioration Models in Florida. In *Proceedings of the 5th International Conference on Bridge Maintenance, Safety, and Management*, Philadelphia, 2010.
14. Chan, P. K., M. C. Oppermann, and S. Wu. North Carolina's Experience in Development of Pavement Performance Prediction and Modeling. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1592, Transportation Research Board of the National Academies, Washington D.C., 1997.
15. Chen, X., S. Hudson, G. Cumberledge, and E. Perrone. Pavement Performance Modeling Program for Pennsylvania. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1508, Transportation Research Board of the National Academies, Washington D.C., 1995.
16. George, K. P., A. S. Rajagopal, and L. K. Lim. Models for Predicting Pavement Deterioration. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1215, Transportation Research Board of the National Academies, Washington, D.C., 1991.
17. Jackson, N. C., R. Deighton, and D. L. Huft. Development of Pavement Performance Curves for Individual Distress Indexes in South Dakota Based on Expert Opinion. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1524, Transportation Research Board of the National Academies, Washington D.C., 1996.
18. Johnson, K. D., and K. A. Cation. Performance Prediction Development Using Three Indexes for North Dakota Pavement Management System, *Transportation Research Record: Journal of the Transportation Research Board*, No. 1344, Transportation Research Board of the National Academies, Washington, D.C., 1992.
19. Martin, T. *Pavement Behavior Prediction for Life-Cycle Costing*. Australian Road Research Board Publication #255, Australian Road Research Board Ltd., Victoria, Australia, 1994.
20. Sadek, A. W., T. E. Freeman, and M. J. Demetsky. Deterioration Prediction Modeling of Virginia's Interstate Highway System. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1524, Transportation Research Board, National Research Council, Washington D.C., 1996.
21. Sebaaly, P. E., S. Lani, A. Hand, J. Epps, and C. Bosch. Performance Models for Flexible Pavement Maintenance Treatments. *Transportation Research Record: Journal of the Transportation Research Board*, No.1508, Transportation Research Board, National Research Council, Washington D.C., 1995.
22. Gyamfi-Yeboah, F., and J. Ayitey. Assessing Depreciation for Valuation Purposes-A Decompositional Approach. In *Promoting Land Administration and Good Governance, Proceedings of the 5th FIG Regional Conference*, Accra, Ghana, 2006, pp. 1–11.
23. Harlow, K. *GASB 3 -An Infrastructure Heresy*. Brown and Caldwell, Irvine, California, 2010, pp. pp. 1–5. http://www.bcwaternews.com/AssetMgt/AM02_Heresy.pdf. Accessed 4/12/2010.
24. Williams, D., L. Hals, and E. DeGeorge. Little Rock Wastewater Asset Valuation and Asset Management Development Project. In *Pipelines 2009: Infrastructure's Hidden Assets*. American Society of Civil Engineers, Reston, Virginia, 2009.
25. TAC. *Primer on Highway Asset Management Systems*. Transportation Association of Canada, Ottawa, Ontario, 1999.
26. Solminihac, H. E., P. Hidalgo, and A. Chamorro. Asset Valuation of Low-Volume Road Networks: Application to Chilean Unpaved Roads. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1989, Vol. 1, Transportation Research Board of the National Academies Washington, D.C., 2007, pp. 72–79.
27. FPSC. *Replacement Cost Method of Valuing Utility Generation Assets*. Florida Public Service Commission, Division of Policy Analysis & Intergovernmental Liaison, Tallahassee, Florida, 2001, pp. 1–6.
28. Howell, D. What is the value of your pipeline? *Pipeline and Gas Journal*. May, 2010, pp. 37–38.
29. USDOT. *Primer: GASB 34*. Federal Highway Administration Office of Asset Management, U.S. Department of Transportation, 2000, pp. 1–50.
30. Snaith, M. S., and D. M. Orr. Condition-based Capital Valuation of a Road Network, *Proceedings of the Institution of Civil Engineers-Municipal Engineer* Vol. 159, No. ME2, 2006, pp. 91–95. doi: 10.1680/muen.2006.159.2.91.

31. Baik, H. S., D. M. Abraham, and D. J. Gipson. Impacts of Deterioration Based Life Cycle Cost Analysis (LCCA) on the Assessment of Values of Wastewater Infrastructure Assets. *ASCE Journal of Pipelines Systems Engineering and Practice*, 2004, pp. 1–10.
32. LoBEG Technical Note. *Asset Valuation for Highway Structures*. Version1.0. London Bridges Engineering Group, 2007, pp. 1–12.
33. Alves, J., and J. Lopes. *Valuation of Local Government Assets in Portugal. Braganca Polytechnic Institute*. Braganca, Portugal, 2010. https://bibliotecadigital.ipb.pt/bitstream/10198/1670/1/Valuation%20of%20Local%20Government%20Assets%20in%20Portugal.pdf. Accessed April 15, 2010.
34. DOD. *Department of Defense Base Structure Report (BSR) Fiscal Year 2007 Baseline, A Summary of DOD's Real Property Inventory*. Office of the Deputy Under Secretary of Defense (Installations & Environment), U.S. Department of Defense, Washington, D.C., 2007. http://www.defenselink.mil/pubs/BSR_2007_Baseline.pdf.
35. PIARC Technical Committee on Road Management (C6). *Asset Management for Roads-An Overview*. World Road Association, Paris, France, 2005. Available at http://www.piarc.org/en/order-library/4539-en-Asset%20Management%20for%20Roads%20-%20An%20Overview.htm.
36. Smith, F., W. McDaniel, L. Eagle, and N. Amrhein. *NCHRP Report 522*. Project A19-4 FY'02. Transportation Research Board of the National Academies, Washington D.C., 2004.
37. McDaniel, W., E. P. Chait, and K. Gunasekera. *GASB 34-Methods for Condition Assessment and Preservation*. NCHRP Report 608, Project 19–07. Transportation Research Board of the National Academies, Washington D.C., 2008.
38. FHWA. *Life Cycle Cost Analysis*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., updated 4/7/2011 http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm.
39. AASHTO. Life Cycle Cost Analysis for Pavements. In *Guide for Design of Pavement Structures Part 1*. American Association of State Highway and Transportation Officials, Washington, D.C., 2003.
40. Walls, J. III, and M. R. Smith. *Life Cycle Cost Analysis in Pavement Design-In Search of Better Investment Decisions*. Publication FHWA-SA-98-079, Federal Highway Administration, Washington, D.C., 1998.
41. Sinha, K. C., and S. Labi. *Transportation Decision Making Principals of Project Evaluation and Programming*. John Wiley & Sons, New York, 2007. doi: 10.1002/9780470168073.
42. AASHTO. *Manual of User Benefit Analysis for Highways*. American Association of State Highway and Transportation Officials, Washington D.C., 2004.
43. Ford, K. Uncertainty and Risk Management in Travel Demand Modeling. M.S. Thesis. Purdue University, West Lafayette, Indiana, 2009.
44. Pan, N. F. Forecasting Bridge Deck Conditions Using Fuzzy Regression Analysis. *Journal of the Chinese Institute of Engineers*, Vol. 30 No. 4, 2007, pp. 593–603. doi: 10.1080/02533839.2007.9671288.
45. Sadeghi, N., A. R. Fayek, and W. Pedrycz. *Fuzzy Monte Carlo Simulation and Risk Assessment in Construction. Computer-Aided Civil and Infrastructure Engineering*, Vol. 25, No. 4, 2010, pp. 238–252. doi: 10.1111/j.1467-8667.2009.00632.x.
46. Van Dorp, J. R. Course Notes, Engineering Management and Systems Engineering. George Washington University Faculty Home Page-Dr. Johan René van Dorp. 2009. http://www.seas.gwu.edu/~dorpjr/EMSE271/Project%20Files.html. Retrieved 4/16/2011.
47. Son, Y., and K. C. Sinha. Methodology to Estimate User Costs in Indiana Bridge Management System. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1597, Transportation Research Board of the National Academies, Washington, D.C., 1997, pp. 43–51.
48. MASSDOT. *The Central Artery/Tunnel Project-The Big Dig*. Massachusetts Department of Transportation. http://www.massdot.state.ma.us/Highway/bigdig/bigdigmain.aspx. Accessed 5/15/2011.
49. NYCDOT. *NYC Plaza Program*. http://www.nyc.gov/html/dot/html/sidewalks/publicplaza.shtml. Accessed 6/20/2011.
50. INDOT. *The Indiana Design Manual*. Indiana Department of Transportation, 2010. http://www.in.gov/dot/div/contracts/standards/dm-Archived/10English/index.html.
51. Dobbins, C., and K. Cook. *Indiana Farmland Values & Cash Rents: Renewed Strength in a Weak Economy*. Purdue Agricultural Economics Report, Purdue University, West Lafayette, Indiana, 2010. http://www.agecon.purdue.edu/extension/pubs/paer/2010/august/dobbins.asp.
52. Davis, M. A., and J. Heathcote. The Price and Quantity of Residential Land in the United States. *Journal of Monetary Economics*, Vol. 54, 2007, pp. pp. 2595–2620. Data located at Land and Property Values in the U.S., Lincoln Institute of Land Policy. http://www.lincolninst.edu/resources/.
53. Poole, R. W., and Y. Sugimoto. *Congestion Relief Toll Tunnels*. Policy Study No. 164. Reason Foundation, July, 1993. http://reason.org/files/77739a0fd14f9a64e4fc41d6c7d79259.pdf.
54. Washington, S. P., M. G. Karlaftis, and F. L. Mannering. *Statistical and Econometric Methods for Transportation Data Analysis*. Chapman & Hall, a CRC Press Company, Boca Raton, Florida, 2003.
55. Van Noortwijk, J. M., and H. E. Klatter, H. E. The Use of Lifetime Distributions in Bridge Maintenance and Replacement Modelling. *Computers and Structures*, Vol. 82, Nos. 13–14, 2004, pp. 1091–1099. doi: 10.1016/j.compstruc.2004.03.013.
56. Green, W. H. *NLOGIT 4, User's Guide*. Econometric Software, Inc., Plainview, News York, 2007. http://pages.stern.nyu.edu/~wgreene/DiscreteChoice/Software/NLOGIT-Short-Student-Manual.pdf.
57. Rodriguez, M. M., S. Labi, and Z. Li. Enhanced Bridge Replacement Cost Models for Indiana's Bridge Management System. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1958. Transportation Research Board, National Research Council, Washington D.C., 2006, pp. 13–23.
58. FHWA. *HERS-ST Highway Economic Requirements System-State Version: Technical Report*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., August 2005.
59. Gkritza, K., M. M. Rodriguez, S. Labi, and Z. Li. Development of Bridge Preservation Cost Models for Planning, Programming, and Budgeting. In *Compendium of Papers*, Transportation Research Board Annual

Meeting CD-ROM, Washington, D.C., January 21–25, 2007.
60. INDOT. *INDOT Project Cost Analysis*. Indiana Department of Transportation, 2010.
61. Sayers, M. W., and S. M. Karamihas. *Little Book of Profiling*. University of Michigan Transportation Research Institute, 1998. http://www.umtri.umich.edu/content/LittleBook98R.pdf. Accessed 3/7/2010.
62. Sinha, K. C., S. Labi, B. G. McCullouch, A. Bhargava, and Q. Bai. *Updating and Enhancing the Indiana Bridge Management System (IBMS)*. Publication FHWA/IN/JTRP-2008/30. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2009. doi: 10.5703/1288284314306.
63. FHWA. *National Bridge Inventory (NBI)*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., updated 4/6/2011. http://www.fhwa.dot.gov/bridge/nbi.htm. http://www.fhwa.dot.gov/asset/hersst/pubs/tech/tech00.cfm.
64. FHWA. *Pavement Recycling Guidelines for State and Local Governments Participant's Reference Book, Appendix A*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2007. http://www.fhwa.dot.gov/pavement/recycling/98042/20.cfm.
65. Irfan, M., M. B. Khurshid, S. Labi, and W. Flora. Evaluating the Cost Effectiveness of Flexible Rehabilitation Treatments Using Different Performance Criteria. *ASCE Journal of Transportation Engineering*, Vol. 135, No. 10, 2009, pp. 753–763. http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000041.
66. OPE. *Flexible Pavement Rehabilitation Using Pulverization*. Division of Pavement, Office of Pavement Engineering, California Department of Transportation Sacramento, California, 2008.
67. Flora, W. Development of Structural Index for the Indiana Department of Transportation. M.S. Thesis. Purdue University, West Lafayette, Indiana, 2009.
68. ACPA. Natural Advantage Recycle and Reuse Concrete. American Concrete Pavement Association, Skokie, Illinois, 2009. http://www.pavements4life.com/QDs/Environment_2Recycle.asp.
69. Kuennen, T. Two for the Price of One: Recycled Concrete Aggregate Prove its Value, But it Demands an Engineered Approach. *Better Roads*, Vol. 80. No. 4, 2010, pp. 16–29.
70. Bukowski, J. *Technical Advisory: Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement*. U.S. Department of Transportation Office of Pavement Technology, 2007. http://www.fhwa.dot.gov/pavement/t504037.cfm
71. INDOT. 2009 Highway Performance Monitoring System (HPMS) Database. Indiana Department of Transportation, 2009.
72. INDOT. *Project Construction Costs Presented in Terms of Lane-Miles, by Project Work Type, Fiscal Years 2006–2009*. Indiana Department of Transportation, 2009.
73. INDOT (2010a). *Facts and Photos*. Indiana Department of Transportation, 2010. http://www.in.gov/indot/2337.htm. 2010.
74. INDOT. *MPDEG Pavement Design Guide*. Indiana Department of Transportation.
75. FHWA. *Highway Statistics 2009: Functional System Lane-Length 2009*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., updated 4/4/2011. http://www.fhwa.dot.gov/policyinformation/statistics/2009/hm60m.cfm.
76. ODOT. *GASB. Infrastructure and Land Valuation Summary*. Ohio Department of Transportation, 2010. http://www.dot.state.oh.us/DIVISIONS/FINANCE/Pages/GASB34.aspx. Accessed 5/15/2010.
77. Bailey, A., and J. Keck. *Virginia and GASB 34*. Virginia Department of Transportation, 2000.
78. Marston, J. Tennessee, Using the Modified Approach. Presented at the GASB 34 Peer Exchange Meeting. Tennessee Department of Transportation, 2001.
79. Sullivan, D., and J. Graff. *GASB 34-A Texas Approach*. Texas Department of Transportation, 2000.
80. FHWA. Highway Statistics 2008. *Table HM-81: State Highway Agency-Owned Public Roads Estimated Lane-Miles and Daily Travel*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., October 2009. http://www.fhwa.dot.gov/policyinformation/statistics/2008/hm81.cfm.
81. FHWA. Highway Statistics 2010. *Highway Bridge by Owner*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., December 2010. http://www.fhwa.dot.gov/bridge/nbi/ownerarea10.cfm.
82. FHWA. *Price Trends for Federal Aid Highway Construction*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2005.
83. Weinblatt, H., and G. Camus. *Highway Economic Requirements System-v. IV. Technical Report (Version 3.26)*. DOT No. FHWA-PL-00-028, NTIS Report No. PB2001-104286. Federal Highway Administration, Washington, D.C., 2000.
84. FHWA. Highway Statistics 2004. *National Highway System Length Miles by Measured Pavement Roughness*. Table HM-47. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., October 2005. http://www.fhwa.dot.gov/policy/ohim/hs04/htm/hm47.htm.
85. Forkenbrock, D., and G. Weisbrod. *Guidebook for Assessing Social & Economic Effects of Transportation Projects*. NCHRP Report 456, National Academy Press, Washington D.C., 2001.
86. Lytton, R. L. Concepts of Pavement Performance Prediction and Modeling. In *Proceedings: Volume 2*. Second North American Conference on Managing Pavements, 1987, Toronto, Ontario, Canada.
87. Labi, S., and K. C. Sinha. Life-cycle Cost Effectiveness of Flexible Pavement Preventive Maintenance, *J. Transp. Eng*., Vol. 131, No. 10, 2005, pp. 114–117. doi: 10.1061/(ASCE)0733-947X(2005)131:10(744).
88. Colucci-Rios, B., and K. C. Sinha. Optimal Pavement Management Approach Using Roughness Measurements. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1048, Transportation Research Board of the National Academies, Washington, D.C., 1985.
89. Rajagopal, A. S., and K. P. George. Pavement Maintenance Effectiveness. Transportation Research. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1276. Transportation Research Board of the National Academies, Washington, D.C., 1991.
90. Markow, M. J. Life-Cycle Costs Evaluations of Effects of Pavement Maintenance. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1276, Transportation Research Board of the National Academies, Washington, D.C., 1991.

91. Mouaket, I. M., K. C. Sinha, and T. D. White. Guidelines for Management of Chip and Sand Seals Coating Activities in Indiana. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1344, Transportation Research Board of the National Academies, Washington, D.C., 1992.
92. Jiang, Y., and K. C. Sinha. *The Development of Optimal Strategies for Maintenance, Rehabilitation, and Replacement of Highway Bridges: Volume 6-Performance Analysis and Optimization.* Publication FHWA/IN/JHRP-89/13. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1989. doi: 10.5703/1288284314172.
93. Sobanjo, J. O., and P. D. Thompson. *Enhancement of the FDOT's Project Level and Network Level Bridge Management Analysis Tools*. Florida Department of Transportation, 2010.
94. O'Brien, L. G. *NCHRP Synthesis of Highway Practice 153: Evolution and Benefits of Preventive Maintenance Strategies*. Transportation Research Board, National Research Council, Washington, D.C., 1989.
95. Raza, H. *State of the Practice: Design, Construction, and Performance of Micro-surfacing*. Report FHWA-SA-94-051. Federal Highway Administration, U.S. Department of Transportation, Washington D.C., 1994.
96. Geoffroy, D. N. *Synthesis of Highway Practice 223: Cost-effective Preventive Pavement Maintenance*. Transportation Research Board, National Research Council, Washington, D.C., 1996.
97. Mamlouk, M. S., and J. P. Zaniewski. *Pavement Preventive Maintenance: Description, Effectiveness and Treatments, Flexible Pavement Rehabilitation and Maintenance*. ASTM STP 1348. Kandhal, P. S., and M. Stroup-Gardner, Eds. American Society for Testing and Materials, West Conshohocken, Pennsylvania, 1998.
98. Labi, S., B. R. Vanga, and G. P. Ong. *Relationships between Long-term and Short-term Effectiveness of Transportation Infrastructure Interventions*. Presented at the 10th International Conference on Applications of Advanced Technologies in Transportation (AATT 2008), Athens, Greece, 2008.
99. Shang, J. S., Y. Tjader, and Y. Ding. A Unified Framework for Multicriteria Evaluation of Transportation Projects. *IEEE Transactions on Engineering Management*. Vol. 51, No. 3, 2004, pp. 300–313. doi: 10.1109/TEM.2004.830848.
100. Keeney, R. L., and H. Raiffa. *Decisions with Multiple Objectives: Preferences and Value Trade-offs*. John Wiley & Sons, New York, 1976.
101. Saaty, T. Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, Vol. 1, 2008, pp. 83–98. doi: 10.1504/IJSSCI.2008.017590.

APPENDIX A. DETAILED EXPLANATION OF COST, SERVICE LIFE, AND VALUATION EQUATIONS AND CALCULATIONS

TABLE A.1
Bridge Rehabilitation Cost Models

Rehabilitation	Cost Model
Deck rehabilitation	$0.136(BL)^{0.668}(TDW)^{.949}+13.510SKEW$
Deck and superstructure rehabilitation	$103.911+0.015DA+91.130NHS-35.787STEEL$
Deck replacement, superstructure and substructure rehabilitation	$67.50DA$
Deck replacement and superstructure rehabilitation	$-626.297+9.80TDW+1.895BL+291.510NHS+36.753SECAGE$
Superstructure replacement and substructure rehabilitation	$(BL)^{0.890}(TDW)^{0.498}(ADT)^{0.487}(SUPERC)^{-1.975}+203.492NHS-162.565PRESTRESSED$

Source: (*59*).

NOTE: Costs in 1,000s of 2002$ constant dollars. BL is the bridge length in ft; TDW is the total deck width in ft; SKEW is the bridge skewness in degrees; DA is the deck area in sq. ft; NHS is 1 for bridges on the National Highway System, 0 otherwise; STEEL is 1 for steel bridges, 0 otherwise; ADT is the average daily traffic; SUPERC is the superstructure condition rating; PRESTRESSED is 1 for prestressed bridges, 0 otherwise.

TABLE A.2
Bridge Deterioration Models

Bridge Component	Service Life Equation
Steel superstructure (major road)	$1.7+\left(\frac{51.8}{7.03+0.0086(age^{3.16})}\right)$
Steel superstructure (minor road)	$2.5+\left(\frac{52.2}{7.95+0.0053(age^{1.8})}\right)$
Steel substructure (major and minor road)	$2.7+\left(\frac{24.9}{3.9+0.00038(age^{2.28})}\right)$
Steel deck (major road)	$3.4-\left(\frac{134.7}{7.95+0.0054(age^{1.84})}\right)$
Steel deck (minor road)	$2.5+\left(\frac{52.2}{7.95+0.0054(age^{1.84})}\right)$
Concrete superstructure (major road)	$2.1+\left(\frac{19.8}{2.8+0.00037(age^{2.23})}\right)$
Concrete superstructure (minor road)	$2.7+\left(\frac{55.2}{8.75+0.000084(age^{2.27})}\right)$
Concrete substructure (major and minor road)	$2.7+\left(\frac{24.9}{3.9+0.00038(age^{2.28})}\right)$
Concrete deck (major road)	$3.6-\left(\frac{133.64}{27.4+0.00013(age^{3.32})}\right)$
Concrete deck (minor road)	$4.7-\left(\frac{132.8}{35..+0.00009(age^{4.04})}\right)$

Source: (*62*).

TABLE A.3
Bridge Service Life Equations

Bridge Component	Service Life Equation	Service Life (Years)
Steel superstructure (major road)	$\left(\frac{\frac{51.8}{rating-1.7}-7.03}{0.0086}\right)^{\frac{1}{1.7}}$	82
Steel superstructure (minor road)	$\left(\frac{\frac{52.2}{rating-2.5}-7.95}{0.0053}\right)^{\frac{1}{1.84}}$	>100
Steel substructure (major and minor road)	$\left(\frac{\frac{24.9}{rating-2.7}-3.95}{0.00038}\right)^{\frac{1}{2.28}}$	>100
Steel deck (major road)	$\left(\frac{\frac{-134.4}{rating-3.4}-22.2}{0.00018}\right)^{\frac{1}{3.15}}$	67
Steel deck (minor road)	$\left(\frac{\frac{-134.7}{rating-2.4}-26.6}{0.000021}\right)^{\frac{1}{3.17}}$	>100
Concrete superstructure (major road)	$\left(\frac{\frac{19.2}{rating-2.1}-2.8}{0.00039}\right)^{\frac{1}{2.2}}$	30
Concrete superstructure (minor road)	$\left(\frac{\frac{55.2}{rating-2.7}-8.8}{0.000084}\right)^{\frac{1}{2.3}}$	>100
Concrete substructure (major and minor road)	$\left(\frac{\frac{24.9}{rating-2.7}-3.9}{0.00038}\right)^{\frac{1}{2.3}}$	36
Concrete deck (major road)	$\left(\frac{\frac{-133.6}{rating-3.6}-27.4}{0.00013}\right)^{\frac{1}{3.3}}$	63
Concrete deck (minor road)	$\left(\frac{\frac{-132.8}{rating-4.7}-35.0}{0.000009}\right)^{\frac{1}{4.0}}$	82

Source: (*62*).

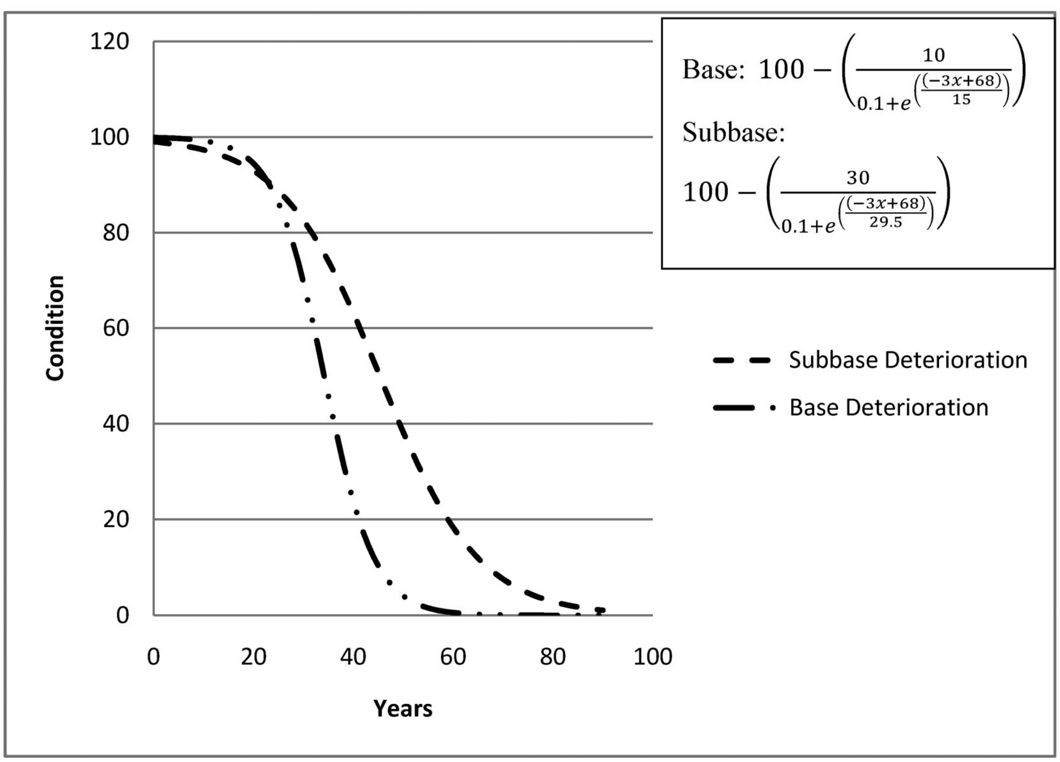

Figure A.1 Pavement base and subbase deterioration curves based on expert opinion.

TABLE A.4
Valuation Methodologies-Summary of Expressions

Method	Equation
Straight line depreciation	$BV_t = RC - \frac{RC - S}{t_S - t_P}(t - t_P)$
Net salvage value	$NSV = RC - \mathrm{Re}habC$
GASB 34	$HC * (SL - RSL) * \left(\frac{RC - S}{SL}\right)$
Adjusted value w.r.t. condition rating	$RC * \left(\frac{P_t - P_{worst}}{P_{best} - P_{worst}}\right)$
Declining balance	$\left(\frac{1}{N}\right) * BV_{t-1}$
Double declining balance	$\left(\frac{2}{N}\right) * BV_{t-1}$
Sum of years digits	$\frac{N - t + 1}{\left(\frac{N}{2}\right)(N+1)} * (RC - S)$
EDBC method	$V = \left[w_1\left(comp_i * \left(\frac{P_{t_i} - P_{worst_i}}{P_i - P_{worst_i}}\right) + \cdots + comp_m * \left(\frac{P_{t_m} - P_{worst_m}}{P_m - P_{worst_m}}\right)\right) + w_2\left(comp_i * \left(\frac{RSL_{t_i}}{SL_i}\right) + \cdots + comp_{t\pi} * \left(\frac{RSL_{t_{t\pi}}}{SL_{t\pi}}\right)\right)\right]$
RDS method	$V_t = RC + (V_{t,ttc} + V_{t,VOC}) + V_{t,EOL}$
Probabilistic duration valuation	$V_t = (RC)e^{-1*\left(\frac{t}{e^{b_1 X_1 + \cdots + b_n x_n}}\right)^0}$
D&R method	• \$8.10/sq. ft. (urban land) • \$0.10/sq. ft. (rural land)

EDBC = elemental decomposition and bi-criteria.
D&R = decommission and re-use.

TABLE A.5.
Small Asset Assumption References

Asset	Assumption Reference
Road signs	• Montebello, D., and J. Schroeder. *Cost Effectiveness of Traffic Sign Materials*. Minnesota Local Road Research Board, St. Paul, Minnesota, 2000. http://www.lrrb.org/media/reports/200012.pdf • Carlson, P. J., and M. S. Lupes. *Methods for Maintaining Traffic Sign Retroreflectivity*. FHWA-HRT-08-026. Federal Highway Administration, 2007. • USDOT. *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, Washington, D.C., 2009.
Underdrains	• Shanahan, J. Engineer Supervisor Project Diary. 6" Shallow Pipe Underdrain Average Unit Price. 2011. http://www.dot.state.oh.us/districts/D01/ProjectDiary/EngineerSupervisor/01JohnShanahan/10-5004/_layouts/mobile/mbllists.aspx • WSDOT. Chapter 8: Pipe Classifications and Materials. In *WSDOT Hydraulics Manual M23-03.01*. Washington State Department of Transportation, 2008. • ASTM F758: *Highway Underdrain Pipe*. North American Pipe Corporation, 2008. http://www.northamericanpipe.com/downloads/prod_specs/ASTM_F758_Highway_Underdrain_spec.pdf.
Guardrails	• Fitzgerald, W. J. *W-Beam Guardrail Repair*. FHWA-SA-08-002. Federal Highway Administration, Washington, D.C., 2008. http://safety.fhwa.dot.gov/local_rural/training/fhwasa08002/. • Rys, M. J., and E. R. Russell. *Use of Guardrail on Low-Volume Roads According to Safety and Cost Effectiveness*. Kansas State University. Kansas Department of Transportation, 1997. • Zhu, K., and S. Li. *Risk Management and Assessment of Upgrading and Standardizing Guardrail*. Publication FHWA/IN/JTRP-2009/07. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2009. doi: 10.5703/1288284314298.
Culverts	• NCHRP Synthesis 371. *Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks*. Transportation Research Board of the National Academies, Washington, D.C., 2007. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_371.pdf. • Oregon Department of Forestry State Forests Program. Appendix 3: Costs Related to Road Construction/Improvement. In *Forest Roads Manual*. Oregon Department of Forestry, 2000. http://www.oregon.gov/ODF/STATE_FORESTS/docs/management/roads_manual/RMAppendix3.pdf?ga=t • Ocean Heidelberg Cement Group. *Precast Concrete Product Price List*. Ocean Construction Supplies Ltd., Vancouver, British Columbia, Canada, 2007. • Jefferson County, Missouri. *Bid Tabulation-Concrete Box Culverts*. 2008. http://www.jeffcomo.org/uploads/Purchasing/Invitation%20for%20Bid/BID%20TABULATION%20-%20CONCRETE%20BOX%20CULVERTS.pdf

State	No. Bridges[1]	Total Bridge Area (sq. ft.)[1]	Total Pavement (lane-miles)[2]	State Cost Factor	State Terrain Factors	EDMC Bridge Value	EDMC Pavement Value
Alabama	9,867	98,769,940	194,126	1.21	1.2	$31,264,241,774	$479,645,777,698
Alaska	1,084	7,073,712	31,945	1.3	1.6	$3,207,503,858	$113,067,221,686
Arizona	3,462	50,436,830	131,356	0.95	1.2	$12,534,560,908	$254,815,158,382
Arkansas	9,564	63,805,542	204,710	0.95	1.2	$15,856,953,404	$397,113,651,783
California	21,081	298,621,562	385,860	1.56	1.6	$162,488,353,174	$1,638,871,240,931
Colorado	6,717	49,430,571	183,587	1.26	1.6	$21,724,142,842	$629,800,472,950
Connecticut	3,584	35,134,316	45,638	0.88	1.2	$8,088,200,585	$82,008,905,445
Delaware	622	10,075,287	13,656	1.51	1.2	$3,979,899,467	$42,106,795,853
Florida	9,539	167,401,939	268,350	1.19	1	$43,427,411,068	$543,400,042,349
Georgia	9,126	94,536,087	256,952	1.15	1.2	$28,440,236,501	$603,394,826,298
Hawaii	964	14,227,808	9,539	0.76	1.6	$3,771,621,151	$19,738,171,449
Idaho	3,984	17,029,477	98,590	1.12	1.6	$6,652,667,250	$300,636,263,585
Illinois	21,875	134,735,570	292,845	0.9	1	$26,435,118,773	$448,487,988,386
Indiana	16,836	82,409,308	198,265	1.28	1	$22,995,493,185	$431,843,629,459
Iowa	20,872	84,876,156	235,751	0.94	1	$17,392,821,889	$377,095,969,407
Kansas	17,666	85,772,225	286,962	0.59	1.2	$13,238,428,297	$345,722,895,377
Kentucky	10,836	59,161,307	164,491	1.39	1.2	$21,512,471,103	$466,883,666,101
Louisiana	10,833	163,636,906	129,034	1.32	1	$47,088,156,026	$289,833,502,377
Maine	2,071	12,924,629	46,771	1.1	1.2	$3,719,191,124	$105,056,052,976
Maryland	4,013	51,628,313	69,049	0.83	1.2	$11,209,952,245	$117,027,310,699
Massachusetts	4,736	40,318,649	76,332	0.78	1.2	$8,226,939,687	$121,577,436,988
Michigan	9,394	66,210,671	255,882	1.24	1	$17,898,068,569	$539,923,107,866
Minnesota	7,931	65,850,243	283,378	1.11	1.2	$19,121,330,283	$642,304,555,488
Mississippi	13,572	89,931,818	156,532	1.51	1	$29,603,755,869	$402,207,879,841
Missouri	19,306	106,462,993	270,903	0.81	1.2	$22,559,082,381	$448,074,854,749
Montana	4,775	20,616,390	150,125	1.19	1.6	$8,557,286,173	$486,396,518,538
Nebraska	12,275	41,324,649	190,478	1.15	1.2	$12,432,107,462	$447,295,369,266
Nevada	1,010	14,406,552	73,242	1.49	1.6	$7,487,258,181	$297,123,456,940
New Hampshire	2,143	11,659,004	33,008	1.3	1.2	$3,964,994,188	$87,622,082,679
New Jersey	6,040	70,526,566	84,463	0.7	1.2	$12,914,824,741	$120,730,300,667
New Mexico	2,198	17,539,285	142,939	0.69	1.6	$4,221,214,785	$268,528,450,687
New York	15,641	135,864,622	242,920	0.9	1.2	$31,987,966,658	$446,434,265,794
North Carolina	12,984	90,375,116	262,871	0.97	1.2	$22,932,866,554	$520,674,620,996
North Dakota	3,534	12,767,907	175,976	1.42	1.2	$4,742,919,924	$510,262,350,785
Ohio	26,262	140,191,496	262,024	0.85	1	$25,977,484,260	$378,991,927,085
Oklahoma	16,831	87,447,263	234,747	0.95	1.2	$21,732,393,824	$455,382,415,792
Oregon	6,912	50,801,670	122,163	1.25	1.6	$22,149,528,281	$415,757,582,226
Pennsylvania	20,566	132,640,117	255,552	0.95	1.2	$32,963,721,912	$495,740,760,641
Rhode Island	710	7,857,320	13,513	0.98	1.2	$2,014,365,427	$27,041,426,116
South Carolina	8,175	69,300,488	139,952	1.32	1	$19,941,908,419	$314,357,288,193
South Dakota	4,645	17,966,847	169,359	1.19	1.2	$5,593,151,214	$411,535,393,177
Tennessee	11,311	97,500,215	196,969	0.9	1.6	$30,607,267,444	$482,648,393,979
Texas	32,341	435,138,904	669,190	1.19	1.2	$135,460,481,340	$1,626,103,345,081
Utah	2,327	19,112,798	94,410	1.33	1.2	$6,649,877,717	$256,401,981,972
Vermont	2,527	8,964,156	29,672	1.27	1.2	$2,978,179,479	$76,948,876,031
Virginia	10,450	95,685,268	160,727	0.8	1.2	$20,025,012,936	$262,561,209,866
Washington	7,350	72,668,873	174,723	1.39	1.6	$35,232,195,252	$661,234,270,505
West Virginia	6,522	3,909,839	79,452	0.7	1.6	$954,626,396	$151,423,524,282
Wisconsin	11,903	67,153,455	231,264	1.08	1.2	$18,972,731,351	$510,014,977,894
Wyoming	2,600	13,187,514	58,387	1.24	1.6	$5,703,758,101	$197,118,925,123
				Totals:		**$1,098,634,723,436**	**$19,748,967,092,437**
				Grand Total:		**$20,847,601,815,873**	

[1]Bridge total area by state was obtained from the National Bridge Inventory Database (FHWA, 2011). This is for all structures designated as bridges on the state system, including state highways and non-state highways.
[2]Total Pavement lane-miles for total functional system by state found on FHWA Statistics website Table HM-60 (FHWA, 2011).

Figure A.2 EDMC Estimated network value based on state asset dimensions (*63*).

State	No. Bridges*	Total Bridge Area (sq. ft.)[1]	Total Pavement (lane-miles)[2]	State Cost Factor	State Terrain Factors	SLD Bridge Value	SLD Pavement Value
Alabama	9,867	98,769,940	194,126	1.21	1.2	$38,291,525,476	$126,276,158,206
Alaska	1,084	7,073,712	31,945	1.3	1.6	$3,928,456,560	$29,767,163,681
Arizona	3,462	50,436,830	131,356	0.95	1.2	$15,351,962,213	$67,085,088,099
Arkansas	9,564	63,805,542	204,710	0.95	1.2	$19,421,131,004	$104,547,957,368
California	21,081	298,621,562	385,860	1.56	1.6	$199,010,964,668	$431,464,997,134
Colorado	6,717	49,430,571	183,587	1.26	1.6	$26,607,092,380	$165,807,326,695
Connecticut	3,584	35,134,316	45,638	0.88	1.2	$9,906,190,625	$21,590,452,788
Delaware	622	10,075,287	13,656	1.51	1.2	$4,874,464,026	$11,085,439,843
Florida	9,539	167,401,939	268,350	1.19	1	$53,188,618,142	$143,060,718,780
Georgia	9,126	94,536,087	256,952	1.15	1.2	$34,832,766,724	$158,855,522,324
Hawaii	964	14,227,808	9,539	0.76	1.6	$4,619,370,860	$5,196,460,756
Idaho	3,984	17,029,477	98,590	1.12	1.6	$8,147,991,540	$79,148,392,727
Illinois	21,875	134,735,570	292,845	0.9	1	$32,376,957,396	$118,073,259,077
Indiana	16,836	82,409,308	198,265	1.28	1	$28,164,204,956	$113,691,305,146
Iowa	20,872	84,876,156	235,751	0.94	1	$21,302,217,634	$99,277,909,878
Kansas	17,666	85,772,225	286,962	0.59	1.2	$16,214,038,327	$91,018,332,824
Kentucky	10,836	59,161,307	164,491	1.39	1.2	$26,347,843,049	$122,916,282,027
Louisiana	10,833	163,636,906	129,034	1.32	1	$57,672,191,096	$76,304,353,966
Maine	2,071	12,924,629	46,771	1.1	1.2	$4,555,156,101	$27,658,066,396
Maryland	4,013	51,628,313	69,049	0.83	1.2	$13,729,620,410	$30,809,734,782
Massachusetts	4,736	40,318,649	76,332	0.78	1.2	$10,076,114,204	$32,007,644,769
Michigan	9,394	66,210,671	255,882	1.24	1	$21,921,028,936	$142,145,347,584
Minnesota	7,931	65,850,243	283,378	1.11	1.2	$23,419,243,970	$169,099,271,664
Mississippi	13,572	89,931,818	156,532	1.51	1	$36,257,811,088	$105,889,112,817
Missouri	19,306	106,462,993	270,903	0.81	1.2	$27,629,701,816	$117,964,493,544
Montana	4,775	20,616,390	150,125	1.19	1.6	$10,480,712,882	$128,053,423,134
Nebraska	12,275	41,324,649	190,478	1.15	1.2	$15,226,480,240	$117,759,278,703
Nevada	1,010	14,406,552	73,242	1.49	1.6	$9,170,174,010	$78,223,577,482
New Hampshire	2,143	11,659,004	33,008	1.3	1.2	$4,856,208,478	$23,068,231,785
New Jersey	6,040	70,526,566	84,463	0.7	1.2	$15,817,698,192	$31,784,619,518
New Mexico	2,198	17,539,285	142,939	0.69	1.6	$5,170,019,943	$70,695,381,255
New York	15,641	135,864,622	242,920	0.9	1.2	$39,177,922,467	$117,532,576,325
North Carolina	12,984	90,375,116	262,871	0.97	1.2	$28,087,501,697	$137,077,805,898
North Dakota	3,534	12,767,907	175,976	1.42	1.2	$5,808,989,082	$134,336,571,550
Ohio	26,262	140,191,496	262,024	0.85	1	$31,816,460,080	$99,777,057,922
Oklahoma	16,831	87,447,263	234,747	0.95	1.2	$26,617,197,940	$119,888,352,311
Oregon	6,912	50,801,670	122,163	1.25	1.6	$27,128,091,977	$109,456,337,718
Pennsylvania	20,566	132,640,117	255,552	0.95	1.2	$40,372,998,856	$130,513,478,135
Rhode Island	710	7,857,320	13,513	0.98	1.2	$2,467,135,638	$7,119,185,785
South Carolina	8,175	69,300,488	139,952	1.32	1	$24,424,263,982	$82,760,721,564
South Dakota	4,645	17,966,847	169,359	1.19	1.2	$6,850,327,404	$108,344,763,642
Tennessee	11,311	97,500,215	196,969	0.9	1.6	$37,486,882,603	$127,066,655,832
Texas	32,341	435,138,904	669,190	1.19	1.2	$165,908,020,724	$428,103,598,137
Utah	2,327	19,112,798	94,410	1.33	1.2	$8,144,575,002	$67,502,850,531
Vermont	2,527	8,964,156	29,672	1.27	1.2	$3,647,586,793	$20,258,300,803
Virginia	10,450	95,685,268	160,727	0.8	1.2	$24,526,047,954	$69,124,388,075
Washington	7,350	72,668,873	174,723	1.39	1.6	$43,151,358,405	$174,082,890,408
West Virginia	6,522	3,909,839	79,452	0.7	1.6	$1,169,198,384	$39,865,212,616
Wisconsin	11,903	67,153,455	231,264	1.08	1.2	$23,237,244,361	$134,271,445,785
Wyoming	2,600	13,187,514	58,387	1.24	1.6	$6,985,795,473	$51,895,423,105
				Totals:		**$1,345,575,555,768**	**$5,199,302,920,894**
				Grand Total:		**$6,544,878,476,662**	

[1]Bridge total area by state was obtained from the National Bridge Inventory Database (FHWA, 2011). This is for all structures designated as bridges on the state system, including state highways and non-state highways.
[2]Total Pavement lane-miles for total functional system by state found on FHWA Statistics website Table HM-60 (FHWA, 2011).

Figure A.3 Estimated network value based on SLD method (*63*).

State	No. Bridges[1]	Total Bridge Area (sq. ft.)[1]	Total Pavement (lane-miles)[2]	State Cost Factor	State Terrain Factors	EDMC Bridge Value	EDMC Pavement Value
Alabama	9,867	6,680,118	28,121	1.21	1.2	$22,762,487,778	$69,481,289,523
Alaska	1,084	545,400	11,699	1.3	1.6	$2,662,242,511	$41,407,839,302
Arizona	3,462	3,178,336	18,819	0.95	1.2	$8,503,029,327	$36,506,641,993
Arkansas	9,564	4,967,479	37,119	0.95	1.2	$13,289,537,753	$72,006,485,155
California	21,081	21,515,745	50,541	1.56	1.6	$126,028,835,278	$214,663,845,405
Colorado	6,717	2,969,128	22,948	1.26	1.6	$14,047,157,803	$78,723,766,090
Connecticut	3,584	2,978,631	9,800	0.88	1.2	$7,381,584,169	$17,610,045,869
Delaware	622	690,615	11,693	1.51	1.2	$2,936,723,129	$36,054,098,119
Florida	9,539	11,263,831	42,439	1.19	1	$31,455,893,387	$85,937,476,479
Georgia	9,126	6,843,343	47,498	1.15	1.2	$22,162,377,670	$111,538,526,493
Hawaii	964	1,206,614	2,477	0.76	1.6	$3,443,268,955	$5,125,427,265
Idaho	3,984	1,013,219	12,137	1.12	1.6	$4,260,988,415	$37,010,065,231
Illinois	21,875	7,583,827	42,150	0.9	1	$16,017,690,671	$64,552,130,685
Indiana	16,836	4,460,075	28,458	1.28	1	$13,397,418,050	$61,984,747,722
Iowa	20,872	3,718,763	23,036	0.94	1	$8,203,426,155	$36,847,278,490
Kansas	17,666	3,642,470	23,988	0.59	1.2	$6,051,989,283	$28,899,996,565
Kentucky	10,836	5,005,731	61,499	1.39	1.2	$19,594,423,174	$174,555,924,528
Louisiana	10,833	13,303,849	38,501	1.32	1	$41,211,669,273	$86,480,149,999
Maine	2,071	1,035,121	18,115	1.1	1.2	$3,206,518,927	$40,689,538,382
Maryland	4,013	2,718,054	14,671	0.83	1.2	$6,353,108,974	$24,865,062,134
Massachusetts	4,736	3,324,071	8,659	0.78	1.2	$7,301,551,071	$13,791,581,864
Michigan	9,394	4,472,085	27,459	1.24	1	$13,013,698,258	$57,939,787,163
Minnesota	7,931	4,129,337	29,266	1.11	1.2	$12,907,837,926	$66,334,290,197
Mississippi	13,572	5,675,529	27,743	1.51	1	$20,111,861,529	$71,285,444,576
Missouri	19,306	7,608,772	75,656	0.81	1.2	$17,356,005,586	$125,135,385,030
Montana	4,775	1,512,220	24,490	1.19	1.6	$6,756,954,131	$79,346,216,413
Nebraska	12,275	2,059,010	22,487	1.15	1.2	$6,668,167,376	$52,805,735,931
Nevada	1,010	1,047,868	13,055	1.49	1.6	$5,862,483,399	$52,960,688,271
New Hampshire	2,143	642,037	8,825	1.3	1.2	$2,350,463,042	$23,426,629,317
New Jersey	6,040	3,115,449	8,480	0.7	1.2	$6,141,420,255	$12,121,200,403
New Mexico	2,198	1,412,518	29,237	0.69	1.6	$3,659,587,577	$54,925,291,997
New York	15,641	7,132,731	38,142	0.9	1.2	$18,077,924,092	$70,096,722,237
North Carolina	12,984	8,255,307	170,084	0.97	1.2	$22,550,446,772	$336,889,080,508
North Dakota	3,534	693,551	16,986	1.42	1.2	$2,773,428,687	$49,252,831,582
Ohio	26,262	9,361,840	49,034	0.85	1	$18,674,505,052	$70,922,941,864
Oklahoma	16,831	4,525,947	30,114	0.95	1.2	$12,108,303,507	$58,417,610,764
Oregon	6,912	3,337,747	18,264	1.25	1.6	$15,665,793,426	$62,157,907,728
Pennsylvania	20,566	9,732,136	88,475	0.95	1.2	$26,036,463,443	$171,631,072,337
Rhode Island	710	641,018	2,923	0.98	1.2	$1,769,075,269	$5,849,336,827
South Carolina	8,175	6,333,528	89,976	1.32	1	$19,619,529,643	$202,102,230,496
South Dakota	4,645	970,296	18,071	1.19	1.2	$3,251,630,563	$43,911,764,296
Tennessee	11,311	6,794,625	36,521	0.9	1.6	$22,961,324,790	$89,490,234,486
Texas	32,341	32,644,555	193,188	1.19	1.2	$109,397,631,223	$469,438,654,238
Utah	2,327	1,534,511	15,699	1.33	1.2	$5,747,404,784	$42,635,893,602
Vermont	2,527	596,277	6,038	1.27	1.2	$2,132,564,609	$15,658,442,757
Virginia	10,450	7,247,067	125,281	0.8	1.2	$16,326,851,711	$204,657,157,374
Washington	7,350	4,957,350	18,443	1.39	1.6	$25,873,391,221	$69,797,013,850
West Virginia	6,522	3,134,585	70,792	0.7	1.6	$8,238,857,593	$134,918,870,903
Wisconsin	11,903	4,437,342	29,481	1.08	1.2	$13,495,743,708	$65,015,619,578
Wyoming	2,600	996,318	15,594	1.24	1.6	$4,638,831,187	$52,646,522,657
Totals:						**$824,440,102,112**	**$4,150,502,494,676**
Grand Total:						**$4,974,942,596,788**	

[1]Bridge total area by state was obtained from the FHWA Statistics website "Highway Bridge by Owner" (FHWA, 2010).
[2]Pavement lane-miles by state found on FHWA Statistics website Table HM-81 (FHWA, 2009).

Figure A.4 Estimated state-owned network value based on EDMC method (*80,81*).

State	Nr. of Bridges[1]	State Bridge Area (sq. ft.)[1]	State Pavement (lane-miles)[2]	State Cost Factor	State Terrain Factors	SLD Bridge Value	SLD Pavement Value
Alabama	5,734	71,911,213	28,121	1.21	1.2	$27,878,826,774	$18,292,312,194
Alaska	788	5,871,212	11,699	1.3	1.6	$3,260,636,470	$10,901,425,823
Arizona	4,637	34,214,668	18,819	0.95	1.2	$10,414,260,690	$9,611,089,504
Arkansas	7,182	53,474,721	37,119	0.95	1.2	$16,276,635,689	$18,957,119,470
California	12,190	231,616,155	50,541	1.56	1.6	$154,356,417,519	$56,514,467,476
Colorado	3,444	31,962,551	22,948	1.26	1.6	$17,204,546,483	$20,725,575,422
Connecticut	2,794	32,064,846	9,800	0.88	1.2	$9,040,747,584	$4,636,189,958
Delaware	826	7,434,441	11,693	1.51	1.2	$3,596,812,273	$9,491,948,454
Florida	5,423	121,254,697	42,439	1.19	1	$38,526,254,745	$22,624,726,163
Georgia	6,593	73,668,321	47,498	1.15	1.2	$27,143,829,532	$29,364,704,689
Hawaii	723	12,989,154	2,477	0.76	1.6	$4,217,214,729	$1,349,369,252
Idaho	1,295	10,907,265	12,137	1.12	1.6	$5,218,733,517	$9,743,625,545
Illinois	7,706	81,639,606	42,150	0.9	1	$19,617,997,290	$16,994,614,455
Indiana	5,201	48,012,536	28,458	1.28	1	$16,408,764,309	$16,318,700,536
Iowa	4,106	40,032,335	23,036	0.94	1	$10,047,315,520	$9,700,768,743
Kansas	4,913	39,211,043	23,988	0.59	1.2	$7,412,298,801	$7,608,490,907
Kentucky	8,929	53,886,496	61,499	1.39	1.2	$23,998,674,255	$45,955,270,674
Louisiana	7,906	143,215,420	38,501	1.32	1	$50,474,842,642	$22,767,595,611
Maine	1,964	11,143,032	18,115	1.1	1.2	$3,927,250,246	$10,712,319,017
Maryland	2,559	29,259,741	14,671	0.83	1.2	$7,781,101,358	$6,546,215,282
Massachusetts	3,447	35,783,497	8,659	0.78	1.2	$8,942,725,394	$3,630,904,418
Michigan	4,400	48,141,825	27,459	1.24	1	$15,938,795,573	$15,253,785,336
Minnesota	3,627	44,452,151	29,266	1.11	1.2	$15,809,140,946	$17,463,802,900
Mississippi	5,676	61,096,851	27,743	1.51	1	$24,632,417,560	$18,767,291,396
Missouri	10,302	81,908,132	75,656	0.81	1.2	$21,257,126,107	$32,944,344,373
Montana	2,497	16,278,993	24,490	1.19	1.6	$8,275,719,050	$20,889,447,677
Nebraska	3,496	22,165,162	22,487	1.15	1.2	$8,166,975,640	$13,902,145,656
Nevada	1,017	11,280,254	13,055	1.49	1.6	$7,180,197,558	$13,942,939,898
New Hampshire	1,290	6,911,500	8,825	1.3	1.2	$2,878,778,130	$6,167,519,631
New Jersey	2,381	33,537,682	8,480	0.7	1.2	$7,521,831,229	$3,191,143,738
New Mexico	2,968	15,205,706	29,237	0.69	1.6	$4,482,155,427	$14,460,160,360
New York	7,437	76,783,572	38,142	0.9	1.2	$22,141,310,700	$18,454,336,926
North Carolina	17,000	88,868,055	170,084	0.97	1.2	$27,619,125,175	$88,692,657,804
North Dakota	1,127	7,466,050	16,986	1.42	1.2	$3,396,814,034	$12,966,773,903
Ohio	10,386	100,779,844	49,034	0.85	1	$22,871,985,546	$18,671,855,448
Oklahoma	6,787	48,721,646	30,114	0.95	1.2	$14,829,894,662	$15,379,581,770
Oregon	2,692	35,930,719	18,264	1.25	1.6	$19,187,003,875	$16,364,288,304
Pennsylvania	14,960	104,766,069	88,475	0.95	1.2	$31,888,696,052	$45,185,245,970
Rhode Island	595	6,900,531	2,923	0.98	1.2	$2,166,711,453	$1,539,952,642
South Carolina	8,355	68,180,184	89,976	1.32	1	$24,029,423,920	$53,207,375,982
South Dakota	1,803	10,445,194	18,071	1.19	1.2	$3,982,501,653	$11,560,633,186
Tennessee	8,128	73,143,874	36,521	0.9	1.6	$28,122,356,508	$23,560,059,388
Texas	33,036	351,417,364	193,188	1.19	1.2	$133,987,007,049	$123,588,932,765
Utah	1,748	16,518,949	15,699	1.33	1.2	$7,039,252,648	$11,224,735,203
Vermont	1,078	6,418,902	6,038	1.27	1.2	$2,611,902,526	$4,122,392,163
Virginia	11,816	78,014,391	125,281	0.8	1.2	$19,996,648,655	$53,880,010,592
Washington	3,194	53,365,684	18,443	1.39	1.6	$31,688,969,982	$18,375,432,815
West Virginia	6,779	33,743,683	70,792	0.7	1.6	$10,090,710,905	$35,520,038,911
Wisconsin	5,096	47,767,810	29,481	1.08	1.2	$16,529,190,688	$17,116,636,996
Wyoming	1,944	10,725,324	15,594	1.24	1.6	$5,681,504,252	$13,860,229,639
				Totals:		**$1,345,575,555,768**	**$1,092,701,184,965**
				Grand Total:		**$2,102,451,218,286**	

[1]Bridge total area by state was obtained from the FHWA Statistics website "Highway Bridge by Owner" (FHWA, 2010).
[2]Pavement lane-miles by state found on FHWA Statistics website Table HM-81 (FHWA, 2009).

Figure A.5 Estimated state-owned network value based on SLD method (*80,81*).

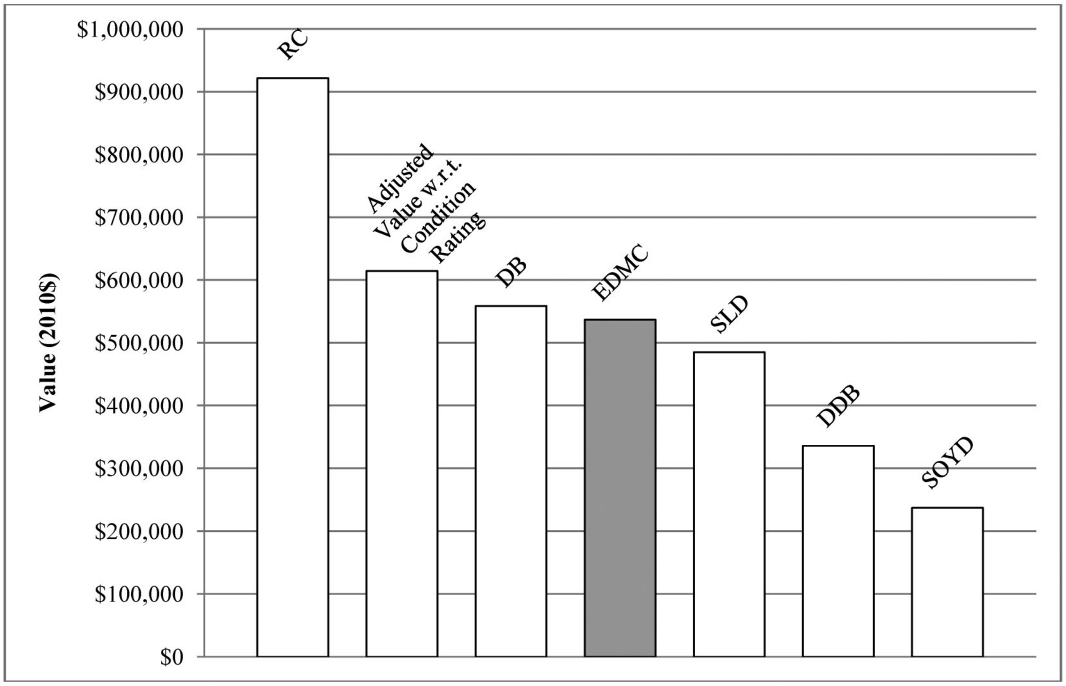

Figure A.6 Sample box culvert valuation. Sample box culvert with ID#913,915 is located on SR105 with length 100 ft. and width 48 inches. It is 30 years old with a condition of 8 on a scale of 0 (fail) to 9 (new). It has a service life of 63.3 years and a remaining service life of 33.3 years. The box culvert's replacement cost is $921,600.

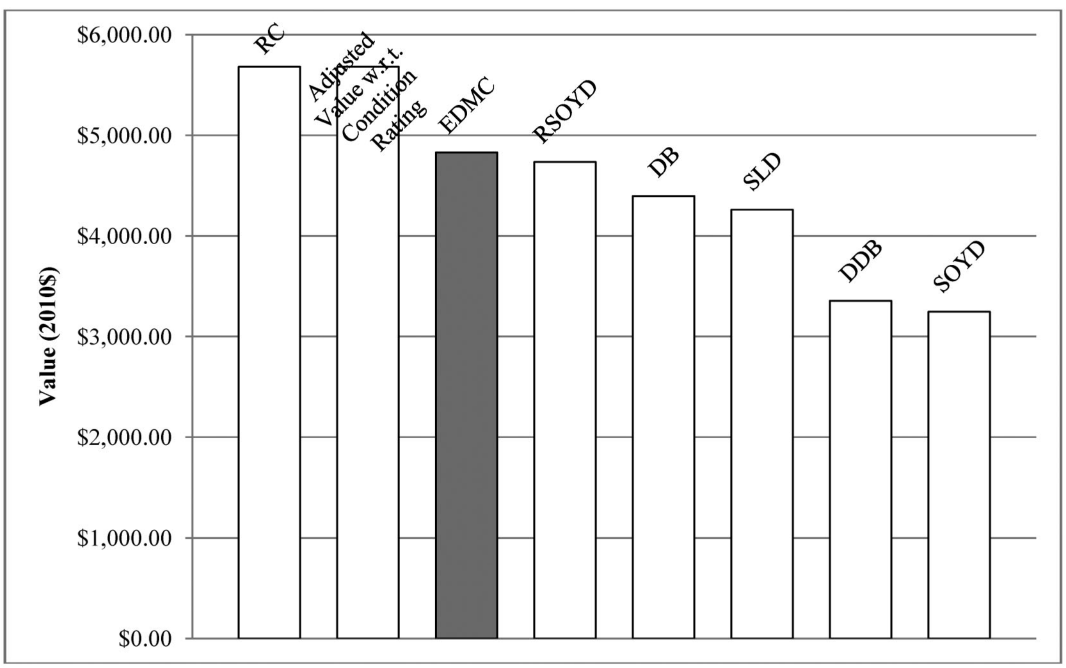

Figure A.7 Sample guardrail valuation. Sample W-beam guardrail with ID#335,253 located on I-65 (MP 24.9034-24.9384) has a length 184.4 ft. and condition 3 out of a maximum of 10. The guardrail is 5 years old and has a service life of 20 years. Its remaining service life is 15 years and the cost to replace this asset is $5,682.

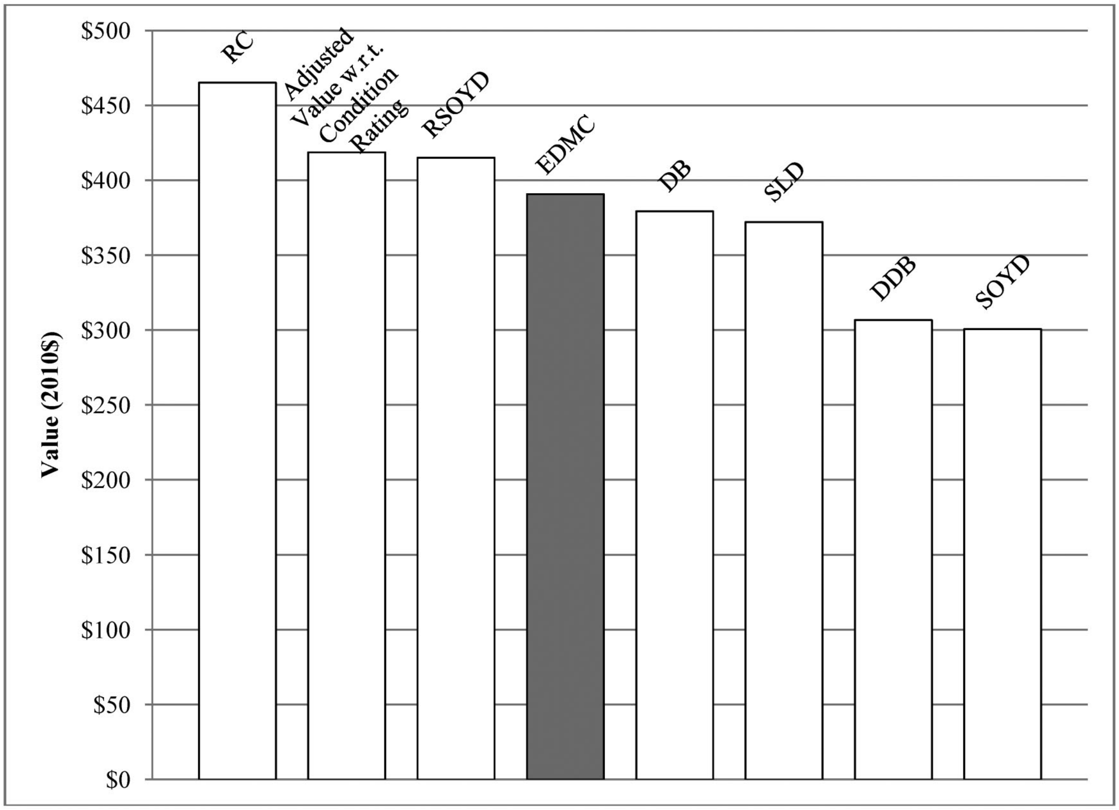

Figure A.8 Sample underdrain valuation. Sample underdrain with ID#871,116 is located on I-64 in Indiana with a length of 48 ft. The underdrain is 5 years old with a condition of 9 out of 10. Its service life is 25 years and it has a remaining service life of 20 years. The cost to replace this asset is $465.12.

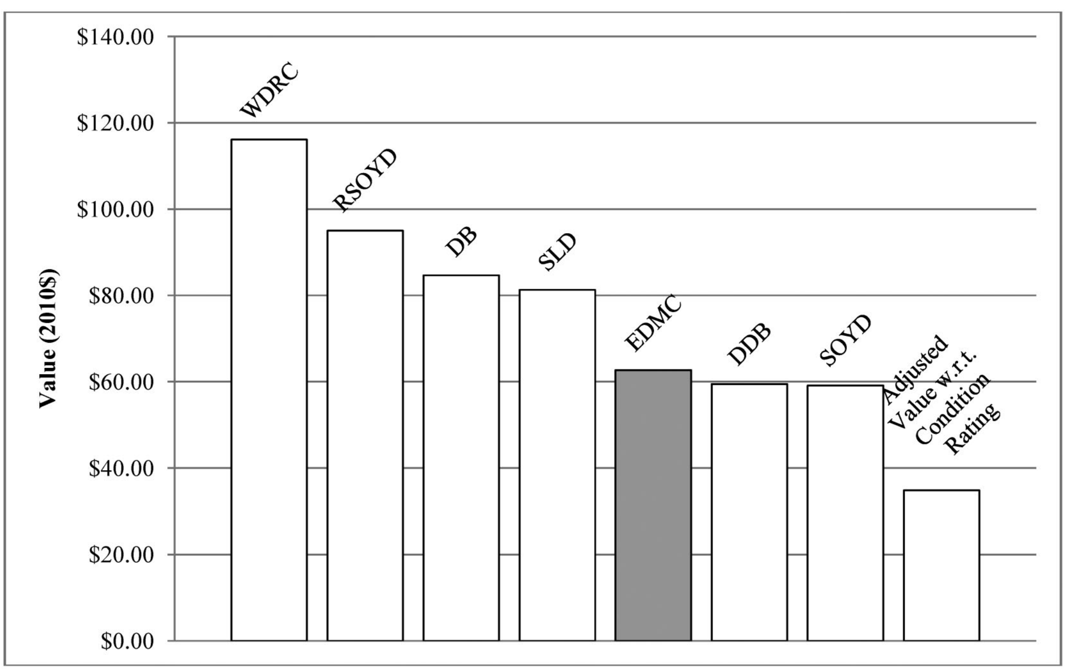

Figure A.9 Sample road sign valuation. The sample road sign is a type III model with ID #1,292,651. The sign is located on SR14 and has an age of 3 years. The service life of a type 3 road sign is 10 years, therefore the remaining service life is 7 years. The cost to replace this road sign is $116.09.

APPENDIX B. VALUATION SPREADSHEETS

http://docs.lib.purdue.edu/cgi/viewcontent.cgi?filename=4&article=3003&context=jtrp&type=additional

APPENDIX C. USER MANUAL FOR ASSET VALUATION TOOLS

http://docs.lib.purdue.edu/cgi/viewcontent.cgi?filename=5&article=3003&context=jtrp&type=additional