PB98-110638

GUIDELINES FOR USING ECONOMIC FACTORS AND MAINTENANCE COSTS IN LIFE-CYCLE COST ANALYSIS

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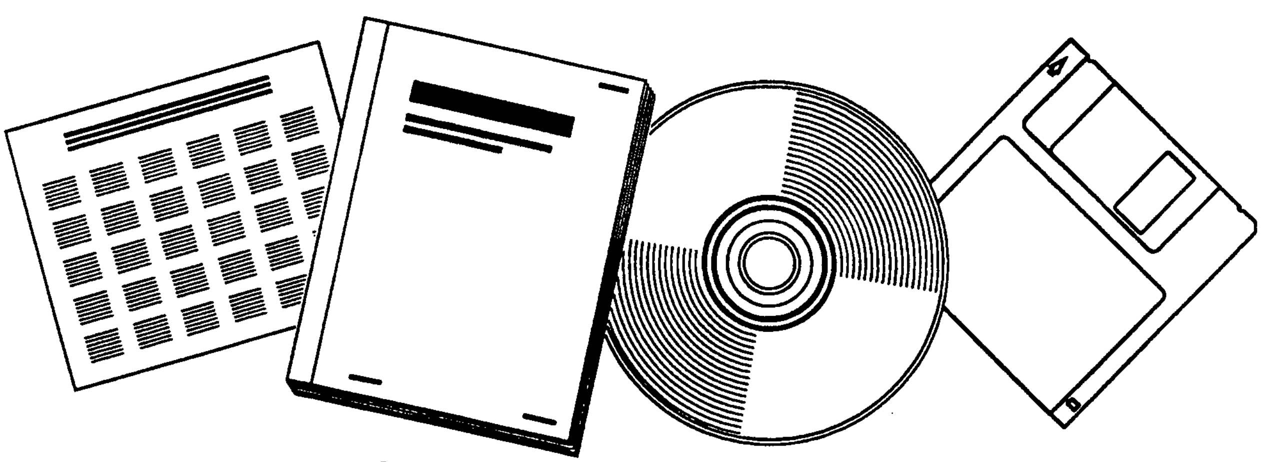

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

SD96-08-F

PB98-110638

SD Department of Transportation
Office of Research

Guidelines for Using Economic Factors and Maintenance Costs in Life-Cycle Cost Analysis

Study SD96-08
Final Report

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August 1997

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The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the South Dakota Department of Transportation, the State Transportation Commission, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

This work was performed under the supervision of the SD96-08 Technical Panel:

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Dennis Winters........................ Data Service/BIT
Johna Zeller ...Division of Fiscal & Public Asst.

The assistance of people within the SDDOT, who provided additional information whenever needed is gratefully acknowledged. The time of representatives from state highway agencies who participated in the project survey is also appreciated as is the information provided by Mr. Jim Walls of the Federal Highway Administration (FHWA) regarding the FHWA's activities in this area. The contributions to this project by Dr. Kumares Sinha, Purdue University, and Dr. Sam Carpenter, University of Illinois are also recognized. Finally, the assistance of Ms. Virginia Ripley of the SDDOT Office of Research is acknowledged and deeply appreciated.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SD96-08-F		

4. Title and Subtitle	5. Report Date
Guidelines For Using Economic Factors and Maintenance Costs in Life-Cycle Cost Analysis	August 30, 1997
	6. Performing Organization Code
7. Author(s) Kathryn A. Zimmerman, P.E.	8. Performing Organization Report No.
9. Performing Organization Name and Address Applied Pavement Technology, Inc. 1606 Willow View Rd, Suite 2F Urbana, IL 61802	10. Work Unit No.
	11. Contract or Grant No. 310461
12. Sponsoring Agency Name and Address South Dakota Department of Transportation Office of Research 700 East Broadway Avenue Pierre, SD 57501-2586	13. Type of Report and Period Covered Final; May 1996 to August 1997
	14. Sponsoring Agency Code

15. Supplementary Notes

An executive summary of this report is included in this report. Training materials on life-cycle cost analysis were provided separately but were not published.

16. Abstract

The ability to preserve the investment in the pavement infrastructure is dependent on an agency's ability to project maintenance and rehabilitation needs and select treatments that address existing deficiencies through cost-effective solutions. A life-cycle cost analysis (LCCA) is a tool used by transportation agencies to better estimate the costs involved in pavement maintenance and rehabilitation (M&R) programs. LCCA is important to transportation agencies because it permits the economic assessment of different rehabilitation alternatives based on an analysis of all significant costs expected over the economic life of each alternative in equivalent dollars.

LCCA is used by the SDDOT at two levels. At the network level, LCCA is an important component of a multi-year analysis used in the Department's pavement management system through the calculation of benefits and costs associated with each feasible strategy. At the project level, a LCCA is used by the SDDOT to select the most appropriate pavement type for newly designed pavements.

In 1996, the SDDOT initiated a research effort to improve the LCC activities used in the State's enhanced pavement management system and in the project selection process that recommends specific pavement treatments at the project level. The primary objective of the research effort was to develop overall guidelines to improve the accuracy of LCC projections while specifically addressing economic analysis and maintenance cost projection problems identified by the Department. This report documents the results of the research effort.

17. Keyword	18. Distribution Statement
Life-cycle cost analysis, pavement selection process, pavement management	No restrictions. This document is available to the public from the sponsoring agency.

19. Security Classification (of this report)	Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

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1.0 Executive Summary

Within the South Dakota Department of Transportation (SDDOT), as with any state highway agency, the ability to preserve the investment in the pavement infrastructure is dependent on the agency's ability to forecast maintenance and rehabilitation needs and then select treatments that address existing deficiencies most cost-effectively. As a public entity that competes with other state agencies for funding levels, it is important that the SDDOT be able to realistically estimate its pavement rehabilitation needs. It is also imperative that the cost projections and rehabilitation programs developed by the Department have a significant level of credibility with the State Legislature. Thus, the ability to reasonably estimate maintenance and rehabilitation costs is extremely important to the SDDOT.

A life-cycle cost analysis (LCCA) is a tool used by many transportation agencies to better estimate the costs involved in pavement maintenance and rehabilitation programs. Life-cycle costing (LCC) is important to transportation agencies because it permits the economic assessment of different rehabilitation alternatives based on an analysis of all significant costs expected over the economic life of each alternative in equivalent dollars (Kirk and Dell'Isola 1995).

LCC is used by the SDDOT at both the network and the project levels. At the network level, LCCA is an important component of a multi-year analysis. This analysis, conducted within the state's pavement management system, is designed to assist with the selection and prioritization of multi-year maintenance and rehabilitation programs. In order to conduct this analysis, the additional life associated with the application of a rehabilitation treatment (benefit) is analyzed in conjunction with the costs associated with the treatment over an analysis period. The benefits and costs associated with each feasible rehabilitation strategy are compared in order to determine the most cost-effective solutions for the preservation of the overall network.

At the project level, which represents the level at which individual projects are designed, a LCCA is used by the SDDOT to select the most appropriate pavement type for new pavement structures. At the project level, preservation actions can also be evaluated using a LCCA so that the treatment that best addresses agency goals can be identified.

The use of a LCCA has been receiving increased attention by transportation agencies over the last few years. In part, the attention has been driven by the agencies' interest in improving the effectiveness of their investment decisions. Another factor, however, has been legislative and regulatory requirements calling for greater consideration of LCCA. These requirements include the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) which required consideration of "the use of life-cycle costs in the design and engineering of bridges, tunnels, or pavement" in both Metropolitan and Statewide Transportation Planning. In 1994, additional direction was provided with Executive Order 12893, *Principles for Federal Infrastructure Investments*, which requires that benefits and costs be systematically analyzed in making infrastructure investment decisions, and that they be measured and discounted over the full life cycle of each project (Federal Register 1994). More recently, the NHS Designation Act of 1995 specifically requires that the Secretary of Transportation establish a program that directs states to a conduct LCCA on NHS projects where the cost of a useable project segment equals or exceeds $25 million (FHWA Memorandum 1996).

The involvement of the Federal Highway Administration (FHWA) in LCC was increased after the publication of a report by the Office of the Inspector General's Government Accounting Office (OIG/GAO) in 1994. This report on highway infrastructure provided cost comparisons of asphalt versus concrete pavements in FHWA Region 4. At that point in time, states made specific recommendations to the FHWA that additional technical guidance be provided on the factors used in a LCCA (FHWA 1997). As a result, the FHWA Pavements Division began preparation of a Technical Bulletin to provide guidance and recommendations on good or best practice for conducting a LCCA in pavement design. The document, which is currently being reviewed in draft form, is meant to identify sound practice rather than impart requirements on the states.

1.1 *Project Background*

In 1996, the SDDOT initiated a research effort to improve the LCC activities used in the state's enhanced pavement management system and in the project selection process that recommends specific pavement treatments at the project level. The primary objective of the research effort was to develop overall guidelines to improve the accuracy of LCC projections while specifically addressing economic analysis and maintenance cost projection problems identified by the Department. This report documents the results of the research effort that was conducted by Applied Pavement Technology, Inc. (APTech).

In order to address the overall project objective, a number of research activities were conducted. These activities included the following, which are described in more detail later in the report.

- Meetings with the Technical Panel, which included representatives of the SDDOT (from Data Inventory, Data Services/Bureau of Information Technology, Planning & Programming, Materials and Surfacing, Office of Research, Operations Support, Division of Fiscal and Public Assistance, and the Brookings Area), FHWA, and industry.
- A literature search and review of relevant information. As part of this task, a questionnaire was distributed to other state highway agencies to identify LCCA practices in other states.
- The development of criteria that could be used to evaluate various economic analysis strategies and maintenance cost forecasts.
- The evaluation of existing SDDOT economic analysis strategies used in the enhanced pavement management system and the pavement selection process to compare their consistency and reliability.
- A review and analysis of SDDOT construction cost and funding histories to determine the feasibility of forecasting economic factors used in a LCCA.

- A sensitivity analysis on the economic factors to determine how they affect the results of a LCCA.
- The evaluation of existing SDDOT procedures for reporting and forecasting maintenance costs.
- The development of guidelines to improve SDDOT's procedures for using economic factors and forecasted maintenance costs in its LCCA.
- The development of a short course to be presented to pavement management and design personnel on economic analysis strategies and their effect on LCCA.
- The preparation of a final report and executive summary to document the results of the project and the presentation of the findings to the SDDOT Research Review Board.

As the work on this project was being conducted, the FHWA initiated the development of a demonstration project on LCCA. The demonstration project provides guidelines on the factors to be used in a LCCA and promotes the use of a probabilistic approach to the analysis.

1.2 Project Findings

The results of this research effort are fully documented in this final report. The following summarizes some of the most significant findings from this study.

- The pavement management system and pavement selection process are not consistent in their use of economic inputs as part of the LCCA.
- Historical data do not currently exist to improve the maintenance cost reporting used in the LCCA. The SDDOT has initiated changes to the maintenance cost reporting process so that over time, historical information may become available.
- The results of a sensitivity analysis showed that maintenance costs do not have a significant influence on the results of a LCCA.

1.3 Conclusions and Recommendations

Based on the results of the research study, the following recommendations are presented to the SDDOT to improve the use of economic factors and maintenance costs in their LCCA at both the network- and project-levels. The study sought to address two issues affecting the Department's use of LCCA at the pavement management and pavement selection levels. First, the study investigated the use of more reliable economic factors in the analysis itself. The results are presented in the form of guidelines for the use of economic factors in LCCA. These guidelines include the following recommendations.

- The use of a present worth analysis. At the present time, a present worth analysis is being used by Materials and Surfacing for the pavement selection process. Planning and Programming also use a form of present worth analysis for the network-level analysis in its pavement management system. Instead of presenting the present worth in terms of a total dollar figure, Planning and Programming report the present worth in terms of an equivalent uniform annual cost (EUAC). Since both approaches rely on a present worth analysis, both systems meet this recommendation.

- The use of real dollars and a real discount rate.
- The use of a 1997 discount rate of approximately 4% based on a 5-year average of the discount rate for a 30-year analysis period (as published in the OMB Circular A-95 and presented in chapter 6). In future years, the 5-year average discount rate can be updated using the most recently published OMB Circular. The use of a national discount rate is easy to justify to the legislature, industry, and Department staff and is easy to obtain each year. It also balances local fluctuations in economic factors with national trends.
- The use of a 40-year analysis period.
- The standardization of construction, maintenance, and rehabilitation treatment consideration through the development and updating of policies.
- The use of a salvage value to represent the remaining serviceable life of a treatment at the end of the analysis period. This recommendation provides a means for taking into account the remaining life of a pavement treatment that has not yet exceeded its expected performance period. This is an important consideration in a LCCA so that high cost treatments applied late in the analysis period are treated equitably. The use of a salvage value allows the agency to consider only the costs that are actually used during the analysis period in the determination of a life cycle cost. The portion of the cost that is used in another analysis period, represented by the percent of remaining life of the treatment, is removed from the cost analysis. Another component of the salvage value, the residual value of the pavement (such as the value from recycling) is reported by FHWA to be a minimal value, especially when discounted over a period of 40 years. For that reason, the use of the residual value is not included in the recommendation for determining a salvage value.
- The use of the number of closure days associated with each rehabilitation strategy as a means of representing user costs. Although the number of closure days associated with each strategy is not used to calculate the present worth of the strategy, a supplemental evaluation of this value may be an important consideration in selecting the most appropriate rehabilitation strategy.

The relative effect each of these recommendations has on the results of a LCCA is illustrated in figure 1-1. The impacts for each variable were determined by increasing each variable individually by 100%. The resulting percentage change in present worth is depicted in the pie chart. The pie chart clearly illustrates that initial costs have the most substantial impact on the results of a present worth analysis. Because of this, it is important that initial cost estimates be a realistic as possible when conducting this type of analysis. Because of the significant impact these values have on the results, it is also important that both Materials and Surfacing and Planning and Programming use similar values in their analyses or the resulting recommendations my vary dramatically.

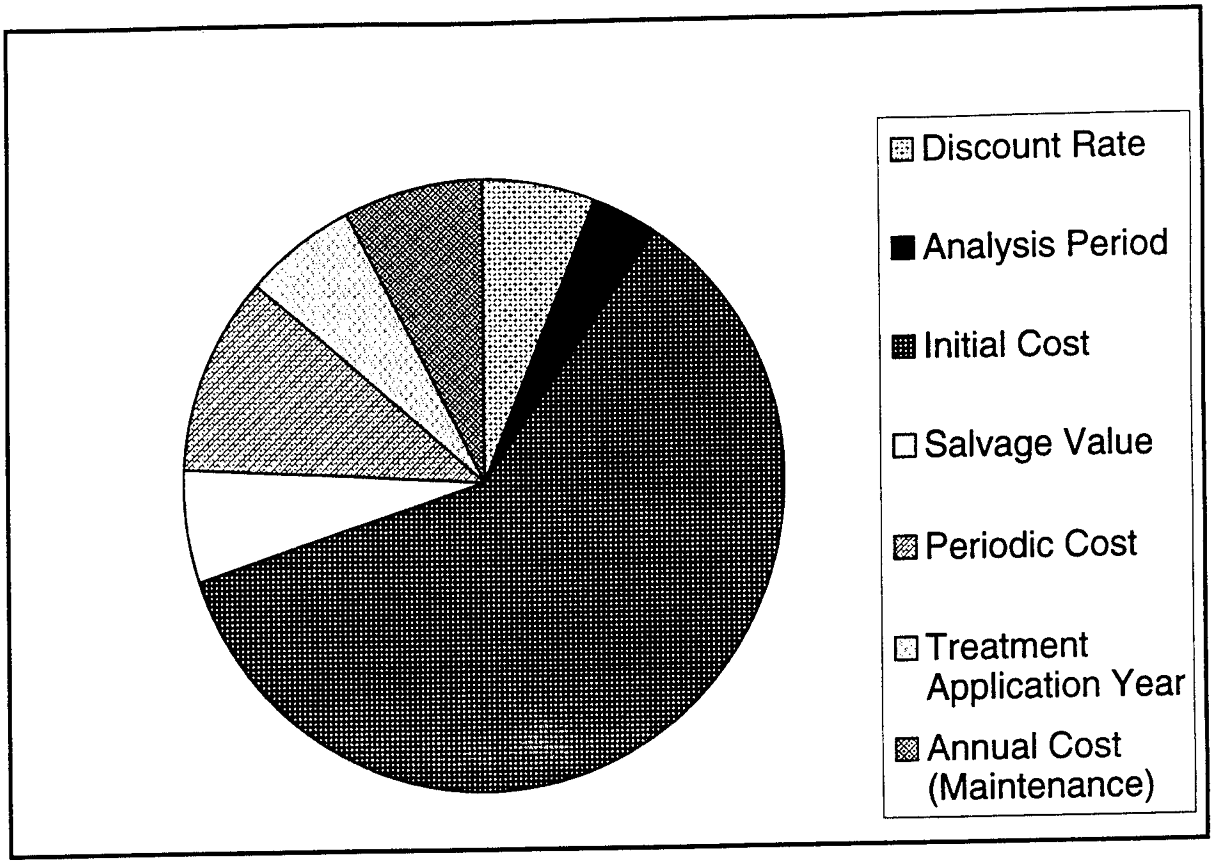

Figure 1-1. Relative Impact of Each Variable on Present Worth Calculation.

Secondly, the study investigated the importance of various factors on the results of a LCCA. Most importantly, the impact of improved reporting of maintenance costs was evaluated because of the expressed concern by the SDDOT on their maintenance cost estimates. The study found that maintenance costs did not have a significant impact on the results of a LCCA and that the SDDOT did not currently have the historical records available to improve the current maintenance estimates. The Department has implemented improved maintenance cost reporting activities that should refine the existing maintenance estimates in future years.

Most importantly, there should be more consistency between the LCCA conducted as part of the pavement management system and the pavement selection process. Although some differences in the analyses are inherent because of the different levels of analysis, the two approaches should use consistent inputs as much as possible. The pavement performance information from the pavement management system should also be used to improve the rehabilitation timing and service life estimates considered in the pavement selection process.

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2.0 Introduction

The NHS Designation Act defines LCCA as (FHWA 1997):

> *" a process for evaluating the total economic worth of a useable project segment by analyzing initial costs and discounted future costs, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment".*

In practical terms, a LCCA is a tool that can be used to support more informed, and perhaps more realistic, investment decisions at both the network and the project level. Within the SDDOT, a LCCA is used in the following two ways.

- The identification of optimum network-level pavement treatment strategies in the pavement management system.
- The recommendation of specific pavement treatments at the project level as part of the pavement selection process.

This report documents the results of SDDOT research project SD96-08, *Guidelines for Using Economic Factors and Maintenance Costs in Life-Cycle Cost Analysis.* The results of each task conducted as part of the study are documented in this report and the recommendations to the SDDOT to improve their existing practices are included. In addition to this report, a short course was developed on economic analysis strategies and their effect on LCCA. The course was presented to pavement management and design personnel at the conclusion of the project.

2.1 Problem Description

Although the principles involved in a LCCA are based on economic analysis techniques that have been used for many years, there is a great deal of variation in the selection of LCCA components and factors used in the analysis. This is true within the SDDOT as well as in other state highway agencies throughout the country.

SDDOT research study SD96-08, *Guidelines for Using Economic Factors and Maintenance Costs in Life-Cycle Cost Analysis,* was initiated due to o evaluate the life-cycle cost estimates that were being generated by the Department's pavement management system and pavement selection process. One problem that was identified by the Department was that present maintenance cost reporting and analysis procedures prevented the development of accurate maintenance cost forecasts for various treatments. At the time the study was begun, one of two average maintenance costs were considered in the LCCA, depending on the pavement surface type (asphalt concrete (AC) pavements or portland cement concrete (PCC) pavements). The Department felt it was unlikely that the two average costs were representative to the variety of pavement designs, geographic locations, and functional classifications that impact the State's pavement network. Prior to the start of the project, revisions were made to the reporting of maintenance data so that improved estimates could be developed if recommended as part of this study.

In addition to problems with the maintenance reporting and analysis, the Department identified a number of factors not being considered in the existing LCCA. The following questions were raised and included in the Request for Proposals (RFP) for this project.

- Which financial measure should be used?
- How should inflation and interest rates be incorporated into the analysis?
- How should analysis periods be chosen?
- How should unequal lives of alternative pavement treatments be handled?
- How should salvage value be used in the analysis?
- How should maintenance costs be used in the analysis?
- How can future levels of Federal and State funding be predicted?
- How can the impacts of Federal and State funding uncertainty be assessed?
- How does uncertainty of economic factors affect pavement management and pavement selection decisions?
- How can the risk of the LCCA not accounting for actual costs be minimized?

As the selected contractor for this project, Applied Pavement Technology, Inc. (APTech) conducted the research necessary to develop guidelines that could be used by the SDDOT to address these economic and maintenance cost issues using pavement practices and economic conditions experienced by the Department.

2.2 Project Objectives

To define the Department's intent for this research effort, the following four research objectives were identified in the RFP.

- To develop guidelines for using economic factors in LCCA.
- To develop guidelines for forecasting and using maintenance costs in LCCA.
- To assess how the selections generated by the enhanced pavement management system and pavement selection process are impacted by uncertainty of the economic factors.
- To provide recommendations on how to incorporate the guidelines into SDDOT's enhanced pavement management system and pavement selection process.

2.3 Research Tasks

In order to meet the objectives outlined for this project, a total of eleven tasks were identified. A summary of each task, as listed in the RFP, is provided in table 2.1. There were no modifications to the list of tasks as the work progressed, except that task 1, the meeting with the technical panel, was scheduled several months after the start of the project so the research team could complete the literature search.

In addition to defining the project tasks to the reader, table 2.1 assists with finding the results of individual project tasks in this report. Each row in table 1 represents one of the tasks conducted during this project and the chapter in which the results can be found, as discussed in the next section on report format.

Table 2.1 Location of Task Discussions in Final Report.

Task	Final Report Chapter Discussing Findings
1. Meet with the project's technical panel to review project scope and work plan.	5.0
2. Review and summarize literature relevant to the use of economic analysis strategies and maintenance costs forecasts in LCCA, including information on procedures being used by other transportation departments and associations.	4.0
3. Establish criteria for evaluating economic analysis strategies and maintenance cost forecasts.	4.0
4. Evaluate present SDDOT economic analysis strategies used in the enhanced pavement management system and the pavement selection process and compare their consistency and reliability.	5.0
5. Review and analyze SDDOT construction cost and funding histories to determine if it is possible to forecast values for the economic factors (inflation and interest rates, cost, funding, etc.).	6.0
6. Perform a sensitivity analysis on the economic factors to determine how they affect LCC estimates.	7.0
7. Evaluate SDDOT's procedures for reporting and forecasting maintenance costs.	6.0
8. Recommend changes to SDDOT's procedures for using economic factors and forecasting maintenance costs.	9.0
9. Present an informal short course to pavement management and design personnel on economic analysis strategies and their effect on LCCA.	9.0
10. Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions, and recommendations.	1.0-10.0
11. Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.	10.0

2.4 Report Format

Although normally SDDOT research reports are prepared on a task by task basis, the structure of this report has been modified somewhat to better address the issues affecting the results of a LCCA. Immediately after this chapter, which introduces the project to the reader, chapter 3.0 discusses the typical components of a LCCA and the issues involved in selecting factors for the analysis. This information is general in nature, providing an introduction to LCCA.

Chapter 4.0 provides a summary of the state of the practice within transportation agencies, based on the results of the questionnaire that was distributed during task 2 of the project. This chapter is followed by chapter 5.0, which focuses on the application of a LCCA within the SDDOT. Chapter 5.0 summarizes the life-cycle cost components being used within the SDDOT enhanced pavement management system and pavment type selection process. Inconsistencies in the conduct of the LCCA within the Department are identified and other factors influencing the performance of a LCCA within the SDDOT are discussed.

Chapter 6.0 presents the results of the project tasks focusing on the forecasting of future economic factors and maintenance costs. This chapter discusses the feasibility of improving the reliability of LCCA results through improved economic and maintenance cost figures.

The results of the sensitivity analysis, which provides some information about the relative importance of each factor in a LCCA, are presented in chapter 7.0. This chapter is important because the recommendations and guidelines presented later in the report are based in large part on the relative influence each factor has on the results of a LCCA.

Chapter 8.0 provides a summary of the LCCA recommendations being developed by the FHWA as part of a demonstration project. Although the Technical Bulletin from this project has not yet been published, the draft recommendations have been reviewed to provide a federal perspective on the factors used in this type of analysis.

A summary of the recommendations provided to the SDDOT are presented in chapter 9.0 along with the impact of these changes on previous LCCA results within the Department. This comparison allows the members of the Technical Panel to evaluate the impacts of the recommendations on in-state projects that have previously been analyzed using existing LCCA procedures.

Finally, chapter 10.0 summarizes the results of the project in terms of findings and conclusions. This chapter reiterates the significant findings discussed earlier in the report and their impact on the final recommendations presented in chapter 9.0. Implementation recommendations are also provided as part of this chapter.

Chapter 10.0 is followed by a summary of the references cited throughout the document. Several appendices follow the body of the report. Appendix A provides present worth factor tables for the reference of the reader. Appendix B contains a summary of literature that was compiled during the project as a result of the literature search and state survey. Appendix C contains a copy of the questionnaire distributed to the states as part of the state survey and Appendix D contains their responses. Appendix E provides the results of the sensitivity analysis discussed in chapter 7.0. Finally, Appendix F contains samples of the results of a LCCA conducted using existing criteria as well as the results calculated using the project recommendations.

3.0 Introduction to a Life-Cycle Cost Analysis

Transportation agencies are constantly required to identify and prioritize pavement maintenance and rehabilitation needs. A LCCA provides an agency with a tool to conduct an economic evaluation of each feasible design alternative over a specified analysis period. As a result, this type of analysis provides an agency with techniques that enable public agencies to determine which alternative provides the best economic value for the agency. An incremental benefit cost analysis, such as the one used in the SDDOT pavement management system, enhances the economic analysis further by providing a measure of effectiveness for each alternative in addition to its life-cycle cost.

A LCCA is important to an agency in order to determine whether the agency can afford the *total* costs associated with a project, including both the initial costs and any follow-up costs that may be expected. Due to the fact that various maintenance and rehabilitation costs are associated with them, it is important that a LCCA compare various alternatives in terms of equivalent dollars. The use of equivalent dollars enables the agency to compare projects with funding requirements that may be spread across different points in time. For example, the use of equivalent dollars allows the comparison of one project that has high initial costs and low annual maintenance costs with another that may have a lower initial cost but higher annual maintenance costs. In order to compare projects that distribute money differently over an analysis period, all costs are brought to a baseline period; typically this is the design year or the year in which the project will be constructed.

A comprehensive LCCA requires that all significant costs associated with a project be considered. This requires that a number of costs be considered, including agency costs, costs associated with the time value of money, user costs, and salvage values. The definition of LCCA implies that the following issues will be addressed before any type of analysis is performed (Kirk and Dell'Isola 1995).

- What analysis approach is to be used?
- What is a realistic discount rate for use in the analysis?
- How are the effects of inflation and increases in individual costs to be taken into account?
- Over what specific period of time are the total costs of ownership to be determined?
- When is that time period to begin?
- What types of costs are to be included in the analysis, and what costs (if any) may be ignored?

From a practical point of view, the selection of values used to represent costs can be a daunting task. The purpose of this chapter is to introduce the typical components of a LCCA and the options that can be considered to address each of the questions listed above.

3.1 Expenditure Stream Diagrams

In order to conduct a LCCA on any project, it is important that all money to be spent on a project, or money to be received from a project, be identified. Expenditure stream diagrams are a useful tool to help visualize the expenditures and income over an analysis period. To develop an expenditure stream diagram, a horizontal line is used as the time axis with time periods typically graduated in years. Cash outlays (or income) associated with a project are represented by vertical arrows whose length is proportional to the cost (or income) magnitudes, and whose position on the time line indicate when they occur.

An example of an expenditure stream diagram is shown in figure 3-1. This example reflects the initial costs associated with a pavement rehabilitation project, the annual costs for preventive maintenance, and additional periodic costs for activities such as seal coats or other rehabilitation actions. If a salvage value is considered at the end of the project, it is reflected as an income that can be expected from the project at the end of the analysis period.

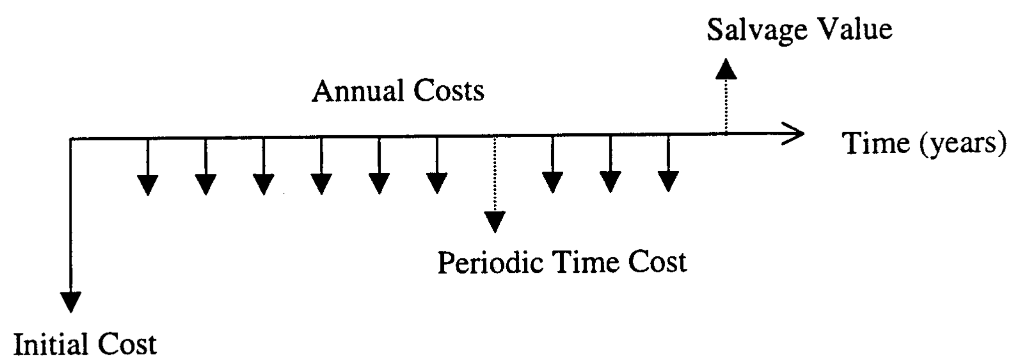

Figure 3-1. Example Expenditure Stream Diagram.

3.2 Methods To Consider The Time Value of Money

Because costs included in a LCCA are incurred at various points in time, it is necessary to convert these costs to a common basis. For example, an investment of $100 today in a savings account that earns 7 percent annual interest would grow to $197 by the end of the 10th year (assuming compound growth). It is fair to say that $100 today is equivalent to $197 at year 10. Similarly, it can be said that the $197 in year 10 is equivalent to $100 today invested at 7 percent. This concept is important for understanding the fundamental concepts of a LCCA.

A number of different techniques may be used to equate costs at various points in time. The most common techniques for converting present and futures costs to a common basis are the present worth (PW) and the annualized (equivalent uniform annual cost [EUAC]) methods (Kirk and Dell'Isola 1995). Both of these methods account for the time value of money so they are interchangeable as measures of life-cycle costs. In these approaches, future costs are discounted to a smaller value when converted to the present time. Because of this, it is common to use the term discount rate rather than interest rate to determine the time value of money.

Other techniques may be used to conduct a LCCA. These include the Internal Rate of Return (IRR) approach that represents the discount rate necessary to make discounted cost and benefits exactly equal to one another. The IRR is primarily used by private industry to evaluate various investment options (FHWA 1997). A fourth approach, a Benefit Cost Analysis (B/C) represents the net benefits of an alternative divided by net costs. B/C ratios greater than one indicate that the benefits provided by an alternative exceed its costs. An Incremental Benefit Cost (IBC) analysis technique is commonly used in pavement management systems for prioritizing project needs for given funding levels (FHWA 1996). It is not commonly used for the project selection process because of the difficulty in identifying benefits associated with each treatment option (FHWA 1997).

3.2.1 Present Worth Method

The present worth method converts all present and future costs to a single point in time, usually at or around the time of the first expenditure. The present worth of a single cost is determined by adding the present worth of each cost component in the analysis. Each of the cost components is calculated by multiplying the cost by the appropriate present worth factor, as shown below. The present worth of an initial cost is equal to the initial cost if the base line is the year the initial cost is incurred.

> Present worth factor for a future amount discounted at interest rate *i* for *n* periods: $1/(1+i)^n$.
>
> Present worth factor for a series of equal periodic installments discounted at interest rate *i* for *n* periods (Uniform Capital Recovery Factor [UCR]): $i(1+i)^n /(1+i)^n-1$

Tables are available in the literature to determine the present worth factors for different interest rates and analysis periods. Appendix A contains sample interest rate tables for various interest rates and analysis periods.

The following example illustrates the calculation of the present worth for a project with initial costs, periodic costs, and annual costs.

Present Worth Example

> Assume a project has an initial cost of $10,000. Annual maintenance costs for the 20 year analysis period are $500. A periodic cost of $3000 must be applied in year 10. Using a discount rate of 10%, calculate the present worth.

The expenditure stream diagram for this example is shown in figure 3-2.

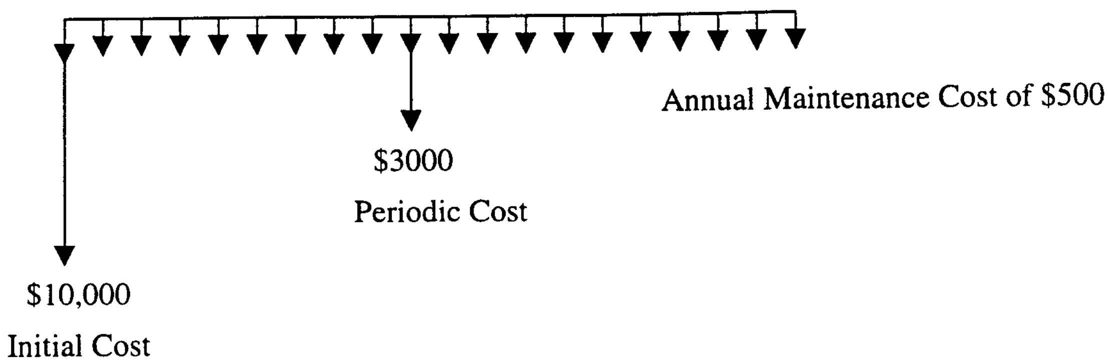

Figure 3-2. Expenditure stream diagram for example.

Present worth of the initial cost:	$10,000
Present worth of annual maintenance costs:	
$\$500\ [((1+0.1)^{20}-1)/(0.1(1+0.1)^{20})] = \$500*8.514$	$ 4,257
Present worth of periodic cost in year 10:	
$\$3000[1/(1+0.1)^{10} = \$3000*0.3855$	<u>$ 1,157</u>
Total Present Worth Cost:	$15,414

3.2.2 Annualized Method

The annualized method is also used to convert dollars expended at various points in time to an equivalent cost. In this method, instead of expressing the value as a one-time present worth cost, the costs are converted to an equivalent uniform annual cost (EUAC). The EUAC is representative of the amount that would have to be invested each year over the analysis period to match the total present worth of the project. This value is determined by multiplying the present worth of the alternative by the UCR presented earlier.

Annualized Method Example

Using the same costs provided in the PW example, the EUAC of this alternative can be determined.

EUAC of the initial cost:	
$\$10{,}000[(0.1(1+0.1)^{20})/((1+0.1)^{20}-1)] = \$10{,}000 * 0.11746$	$1,175
EUAC of the maintenance cost:	$ 500
EUAC of periodic cost in year 10:	
Present worth * EUAC factor	
$\$1157\ [(0.1(1+0.1)^{20})/((1+0.1)^{20}-1)] = \$1{,}157*0.117$	<u>$ 135</u>
Total EUAC:	$1,810

3.3 *Economic Values Used in LCCA*

A LCCA requires the analysis of future costs (and benefits) of an alternative be converted to the present point in time. As a result, the analysis requires that costs be converted to reflect anticipated changes due to factors such as inflation. There is a great deal of discussion regarding the procedures that should be used to represent the factors that affect project costs in the future. The discussions center on the use of nominal or real dollars and interest, inflation, and discount rates. Each of these topics is discussed further in the following sections.

3.3.1 Nominal Versus Real Dollars

The costs used in a LCCA can be reported in terms of either nominal or real (constant) dollars. Real dollars reflect dollars that have the same, or some constant level, of purchasing power over time. In this situation, the costs of conducting some type of activity in the future would be no different than performing the activity today.

Nominal dollars, on the other hand, reflect dollars whose purchasing power fluctuates over time. In most cases, this technique is used to factor in the costs associated with inflation.

A LCCA can be conducted using either nominal or real dollars. However, it is important to keep in mind two factors that must be considered when deciding which approach to use (FHWA 1997).

- The use of nominal and real dollars should not be mixed in the same analysis. In other words, all costs must be either in real dollars or in nominal dollars.
- The discount rate used must be consistent with the dollar type used. In other words, real discount rates must be used with real dollars or nominal discount rates should be used with nominal dollars. Real discount rates reflect the true time value of money with no inflation premium, while nominal discount rates include an inflation component.

The FHWA supports the use of real dollars and real discount rates in its Technical Bulletin based on their analysis of best practice (FHWA 1997). This approach eliminates the need for an agency to estimate and include an inflation premium for both costs and discount rates. As a result, the analysis is less impacted by subjective influences.

3.3.2 Interest, Inflation, and Discount Rates

The calculation of PW requires the use of equations that incorporate interest rates. Because the future costs are discounted to a smaller value when converted to the present time, it is common to use the term discount rate rather than interest rate to determine the time value of money in a LCCA. Discount rates can incorporate an inflation rate, depending on whether real discount rates or nominal discount rates are used. Nominal discount rates include an inflation component and should only be used in conjunction with inflated future dollar cost estimates of future investments. Real discount rates, on the other hand, reflect the true time value of money with no inflation premium and should be used in conjunction with un-inflated dollar cost estimates of future investments. The FHWA suggests the use of real discount rates in a LCCA (FHWA 1997). This approach is supported in the literature (Kirk and Dell'Isola 1995).

Because of the diversity of opinion on this particular topic, much has been written on the use of discount rates. In general, the discount rate is established as the actual rate of increase in the value of money or the rate over and above the general economy inflation rate. As a result, many agencies consider the discount rate to be the difference between the interest and inflation rate. The following are some of the approaches are used to select the discount rate in various agencies (Kirk and Dell'Isola 1995).

- The cost of borrowing money: This approach establishes the discount rate as the highest interest the organization expects to pay to borrow the money needed for a project. This is a relatively simple way to select the discount rate. However, for private industry, it does not take into account the risk of loss associated with the loan or the expected return from the investment itself. This method does, however, indicate the marketplace value of money over time.
- The minimum attractive rate of return: This approach establishes the discount rate as the lowest attractive rate of return as stipulated by the owner (or policy maker). This approach usually includes the basic cost of borrowing the money plus an increment which reflects the risk associated with the endeavor requiring the money. Because it is not easy to quantify the risk as a percent increment, this selection criterion is difficult to apply. However, it is a better indicator of the value of money to its user than the simple cost of borrowing money.
- The opportunity rate of return: In this instance, the discount rate is set at the rate of return that could be earned from some alternative investment opportunity that is foregone in favor of the project in question. This approach is a realistic one since it is based on the actual earning power of money. However, it is difficult to apply to public sector jobs.
- The after-inflation discount rate: This approach is based on the assumption that private industry will seek a certain set rate of return over and above the general inflation rate, no matter what the inflation rate may be. The after-inflation discount rate is equal to the average rate of return in the private sector (interest rate), less the inflation rate. Because the effect of inflation is removed from the discount rate, there is no need to predict the inflation rates for future years. However, all costs in the analysis must be stated in terms of real (constant) dollars. Since the LCCA is used to compare various alternatives, the use of the after-inflation discount rate and constant dollars produces the same result as any other reasonable method of analysis and is favored by the authors of the reference material.

3.4 Analysis Period

The analysis period refers to the time period over which the future costs are evaluated. Analysis periods should generally be long enough to reflect the long-term cost differences associated with feasible design strategies. It is also generally accepted that the analysis period should be longer than the design life of the pavement, unless an agency is designing a pavement with an extremely long life. The following criteria are used for establishing the analysis period (Kirk and Dell'Isola 1995).

- Component life: If the alternatives being considered all have the same economic life, then that life (or a multiple of it) may be used as the analysis period. This criterion is a simple one that has the advantage of representing the life of the item or system under consideration.
- Common multiple of component lives: If the design alternatives have different economic lives, it may be possible to choose, as the analysis period, a common multiple of these lives. For example, if the economic lives of two competing alternatives are 8 years and 12 years, a 24-year analysis period could be selected as the analysis period. This approach simplifies calculations involving unequal lives, and it eliminates residual values. However, not all combinations of economic lives have a common multiple that may be used as a realistic analysis period.
- Facility life: At times, the analysis period may be based on the technological or useful life of the facility as a whole. This criterion has the advantage of reflecting the "total facility" life and allowing the comparison of alternative life cycle costs over that life. It has the disadvantage of not always reflecting the life of the item being considered in the analysis or the mission life of the facility.
- Investment or mission life: In this case, the analysis period is established by limiting it to some investment or mission life for the facility. As a result, the analysis period is set as the expected number of years until the owner's investment objective is fulfilled, and it depends very much on that objective. The difficulty with this approach is that all parties involved in the project must agree on the objective.
- Arbitrary life: With this approach, a somewhat arbitrary analysis period is selected even when it appears there is good reason to maintain a facility for an indefinite period of time. In this case, the analysis period is established through an organizational policy or as the limit of a planning horizon. This approach provides a commonality among projects and within the agency. The authors of the reference recommend an analysis period of 25 to 40 years.

The FHWA's Technical Bulletin states that an analysis period of **at least** 35 years is recommended for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects (FHWA 1997). A shorter analysis period may be considered when alternatives are designed to *buy time* until more permanent solutions can be constructed.

The 1993 *AASHTO Guide for the Design of Pavement Structures* (AASHTO 1993) also provides some guidelines on the selection of an analysis period. The AASHTO guidelines are presented below.

Highway Conditions	Analysis Period (years)
High Volume Urban	30 to 50
High Volume Rural	20 to 50
Low Volume Paved	15 to 25
Low Volume Aggregate Surface	10 to 20

3.4.1 Setting the Base Year

Closely related to the decision about the length of the analysis period is the identification of the baseline year. In a present worth analysis, the base year represents the time to which all of the life-cycle costs are discounted for combining and comparison. The most common choices for the baseline are a point during the design period, a point halfway through construction, or a point at which construction is completed and the road is opened to traffic. According to the literature, the most realistic baseline costs are obtained from a point during the design period (Kirk and Dell'Isola 1995). This is largely because the analysis can be conducted using contractor quotes or other sources of today's costs. As a result, the projections of future costs are typically more accurate using this approach.

3.5 Costs

It is obvious that costs are an important component of a LCCA. Different types of costs may be treated in different ways and may or may not be included in the analysis. In general, all significant costs that are attributable to an alternative are normally included in the analysis. Two factors should be considered in deciding whether a cost is included in the analysis. First, it must be determined whether the cost is relevant for the particular facility under design and for the specific construction element under consideration. Secondly, it must be determined whether the projected magnitude of the cost is significant in comparison to the other relevant costs for the analysis. Since LCCA comparisons are made between mutually exclusive competing alternatives, only differential cost differences between alternatives must be considered. As a result, costs that are common to all alternatives cancel out and are merely noted rather than included in the LCCA calculations. The different types of costs normally included in a LCCA are discussed below.

3.5.1 Initial Costs

Initial costs generally include those costs associated with the initial design and construction of the facility. Construction costs include all normal costs associated with labor, materials, equipment, overhead, and profit. These prices are normally determined from state highway agency historical data on previous jobs of comparable scale. Initial costs that are equal for each alternative, such as right of way purchasing, are normally excluded from the analysis.

3.5.2 Periodic Costs

Periodic costs include those costs associated with rehabilitation activities that must be applied periodically over the life of an alternative. These costs differ from annual costs because they are not applied each year. These costs are typically noted as part of a rehabilitation strategy within the agency. Both the costs and the year in which the treatment is applied must be noted. An example of a periodic cost includes a seal coat on asphalt pavements or concrete pavement restoration (CPR) on concrete pavements.

3.5.3 Annual Costs

This category represents any costs associated with the annual maintenance and repair of the facility. For a LCCA, the maintenance costs should exclude costs common to each alternative, such as the cost of mowing. Maintenance costs are generally difficult to obtain except for general estimates of cost per lane mile for different surface types. These costs are generally relatively small and after being discounted to the present, have a minimal impact on the total PW value of an alternative. This finding is illustrated later in the report.

3.5.4 Salvage Costs (FHWA 1997)

At the end of the analysis period, an agency may consider the use of a salvage value. There are generally two components associated with a salvage value: its residual value and the serviceable life. From the point of view of an highway agency, the residual value refers to the net value from recycling the pavement. In most cases, the differential residual value between strategies is not very large and the impact is negligible after being discounted over the analysis period.

The serviceable life of a pavement facility is the more significant salvage value component. It represents the remaining life of the pavement facility at the end of the analysis period. In highway agencies, the serviceable life is used to account for the differences in remaining life between alternatives. To illustrate this concept, consider one alternative that reaches its terminal serviceability level at the end of the analysis period of 35 years. A second alternative received a 10-year rehabilitation treatment in year 30. As a result, the serviceable life of the second alternative would be 5 years in this example.

Once the serviceable life is established, the salvage value must be determined. The salvage value for the first alternative would be 0, based on the fact that the terminal serviceability level has been reached. The salvage value of the second alternative would be calculated as the product of the percent of design life remaining from the last alternative (5 years of a 10-year life, or 50%) and the cost of the treatment.

Some agencies opt not to use salvage values in their LCCA. These agencies base this decision on the fact that at the end of the analysis period, all treatments have equal serviceable lives remaining.

3.5.5 User Costs

One of the most controversial cost components of a LCCA is the calculation of user costs, which may represent vehicle operating costs, accident costs, user delay costs, discomfort costs, and other types of costs associated with the use of the pavement facility by passenger and vehicular traffic. Some costs, such as user delay costs, are not directly related to the cost of using the facility, but are more representative of the costs associated with not being able to use the facility due to detour requirements or closure of the facility. User costs could also include delay costs if the capacity of the facility is reduced due to lane closures.

As with other types of costs in a LCCA, the primary focus of user costs is in the differential costs incurred by the traveling public between competing rehabilitation alternatives over the analysis period. In a highway agency, this implies consideration of the differences in user costs that result from long-term pavement design decisions and the supporting maintenance and rehabilitation implications (FHWA 1997).

The difficulty in the use of user costs lies in the calculation of these costs. Highway users include both passenger and commercial vehicles; each with different operating characteristics and associated operating costs. The impact of delays between these two types of vehicles is also varied. In general, commercial vehicles would be more negatively impacted by delays than leisure passenger vehicles.

In order to calculate user costs, two components must be analyzed: normal operating costs and work zone operating costs. Normal operating costs reflect those costs associated with the use of the facility during regular operating conditions. As a general rule, there should be little difference in normal operating costs provided the pavement performance levels are relatively high and the performance models for the alternatives are similar. If the performance models or performance levels do vary significantly, this difference in vehicle operating costs can be substantial.

Work zone operating costs reflect the costs associated with the use of the facility during periods of construction that restrict the normal capacity of the facility. During construction periods, there can be significant differences in design alternatives in terms of delay periods, number of accidents, and vehicle operating costs. Indirect costs, such as the delay in delivering products, should also be considered in the analysis.

There are a number of different approaches used to incorporate user costs into a LCCA. Some agencies define detailed work zone characteristics, traffic characteristics, and traffic diversion plans for each alternative being considered. Other agencies estimate the delay time associated with each alternative and use the information as a separate factor in the LCCA. These agencies typically identify the life-cycle costs associated with each alternative (without consideration of user costs) and then compare the delay times associated with each option. Both factors are then taken into account to determine the most appropriate strategy for the agency to implement.

3.6 Special Aspects of Economic Evaluations for Governmental Agencies

In general terms, the decision making process involved in governmental outlays for pavement maintenance and repair are similar to expenditures made in the private industry. For example, in both public and private industries, the following procedures are commonly implemented in order to determine the best choice among several alternatives (Grant and Ireson 1960).

- First, each feasible alternative is identified and differences between the alternatives are identified.
- Secondly, the differences are defined in terms of money as much as possible.
- Next, some criterion is applied to the monetary figures to provide a basis for determining which investments are justified. The time value of money is commonly used to establish the criterion.
- Finally, the agency chooses among its alternatives using the criterion defined in the previous step. However, consideration is also given to other factors that could not easily be reduced to monetary terms.

Although the decision making process is similar between these two types of agencies, there are also some very specific differences. For instance, private industry is focused on making profit for its shareholders. There is no such objective for public agencies because funds not used by one agency are distributed to other public needs. Politics also has a larger interest in public agencies than in private industry. Governmental agencies are frequently asked to justify projects to legislative bodies that do not have technical backgrounds and view projects from a political basis. This is further complicated by the fact that public officials must be re-elected on a periodic basis so constituents must be satisfied regularly. As a result, decisions are not always made on the basis of engineering or economic sense.

Differences between public and private agencies can also be attributed to the fact that the public, the beneficiaries of public agencies, pay for services in the form of taxes which may or may not be related to the *benefit* derived from public works projects. In other words, the public pays taxes for transportation issues whether they drive cars or not. The exception to this is the gas tax that is more directly related to the amount of driving an individual does. Even so, because the benefit is not made in terms of a purchase price (as it would be in private industry), there is constant pressure on public officials to undertake projects and activities that may or may not be economical but address the demand for a high standard of service. Individuals who do not utilize public works projects to the extent they are being taxed are frequently opponents to public works projects of any type, whether they make economic sense or not.

Perhaps one of the most disputed differences between public and private industries is the economic evaluation of alternative uses of money. In private industry, it seems obvious that alternatives are considered in terms of money and their effect on the ability of the agency to make a profit. Investment decisions are frequently made in terms of the rate of return and alternative investments that could be made with given funds.

In a public agency, the reason for evaluating alternatives in monetary terms is different. Although it is true that governmental agencies are not organized to make a profit, they collect taxes and other revenues that otherwise might have been invested by the taxpayers to increase their standard of living through expenditures on goods and services. From a socially responsible point of view, public works projects are not advantageous to society unless they yield a return that is at least as high as the return from the private investments that are displaced by the diversion of taxpayers' funds to public uses (Grant and Ireson 1960). In order to identify the return that is achieved by public works projects, a standard of value must be determined. Because a monetary standard makes the most sense, economic studies of public works projects are made in monetary terms as much as possible.

4.0 The Use of LCCA in State Highway Agencies

Before beginning any research project, it is important to ascertain the state of the industry so that previous work in the technical area can be used as the basis for new developments. As part of this research study, two separate activities were conducted in this area. First, a literature review was conducted to identify journals, reports, and other technical documents that discuss the use of economic analysis strategies and maintenance cost forecasts in LCCA. The results of the literature search are included in Appendix B.

In addition to the literature search, a questionnaire was distributed to state highway agencies in order to identify the prevalence and type of LCCA procedures currently used in the United States and to document the best practices that are found. The responses of the forty-one (41) state agencies that responded to the survey are summarized in this chapter of the report. Appendix C includes a copy of the questionnaire distributed to the states. Appendix D lists the responses provided by each of the responding agencies.

4.1 Findings

Life-cycle costing is widely used in state highway agencies, primarily for pavement design purposes. When asked how LCCA is used within the agency, thirty-three (33) agencies indicated that it was used in pavement design activities. A total of twelve (12) agencies currently use LCCA in their pavement management systems for project selection purposes. In addition, nineteen (19) agencies indicated that they will consider incorporating LCCA into their pavement management activities in the future and six (6) indicated that they will add LCCA to their design practices. These results are summarized in figures 4-1 and 4-2.

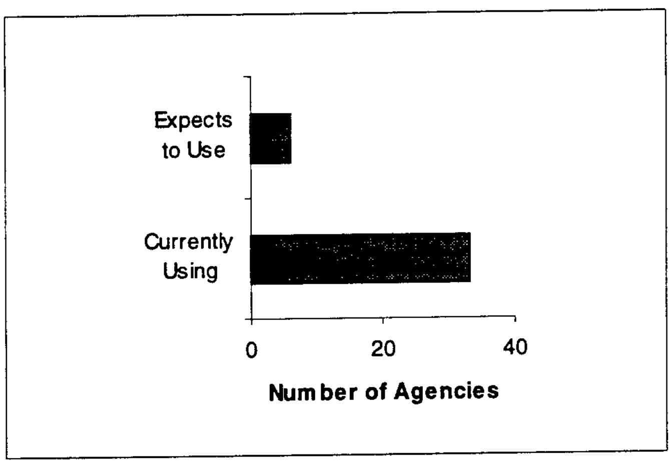

Figure 4-1. Use of LCCA in Pavement Design Activities.

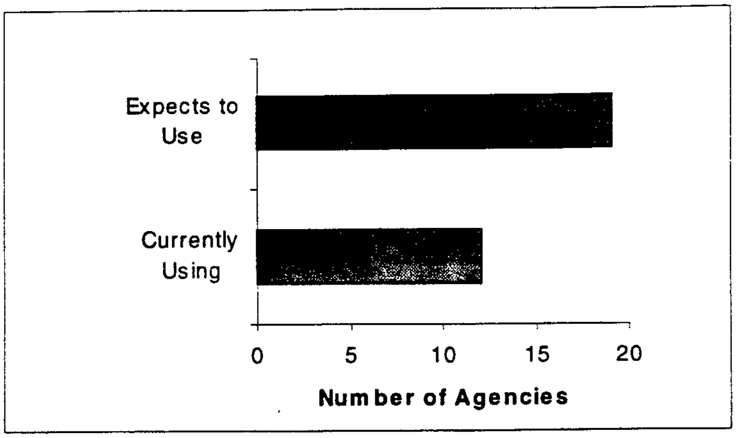

Figure 4-2. Use of LCCA in a Pavement Management System.

There are a number of different factors that can be incorporated in a LCCA. These factors include the initial cost of the rehabilitation or reconstruction treatment; future maintenance and/or rehabilitation costs expected over the analysis period; discount, interest and/or inflation rates to factor in the time cost of money; the salvage value of the pavement at the end of the analysis period; and user costs associated with the construction of the facility (and subsequent roughness of the pavement). State agencies were asked to identify which, if any, of these factors are considered in their LCCA. The most common factors considered include initial costs and some combination of discount, interest, and/or inflation rates. Thirty-five (35) of the responding agencies use initial costs in the analysis and an almost equal number (32) use the economic factors. Maintenance costs and salvage value were the next most common factors used in the analysis. Twenty-two (22) agencies indicated that they use maintenance costs and nineteen (19) indicated that they use salvage values. Only seven (7) agencies include user costs in their LCCA, primarily in the form of a delay assessment. Ten (10) other factors were listed by highway agencies as being considered in their LCCA, including such items as the cost of shoulder construction, constructibility, rehabilitation life, and experience. This information is summarized in figure 4-3.

These trends are expected to change over time, as indicated by the questionnaire responses. As shown in figure 4-4, the largest number of changes are expected in the number of agencies planning on using maintenance costs (15) and/or user costs (14) in their LCCA at some point in the future. A smaller number of agencies indicated that they would add initial costs (6), economic factors (7), and/or salvage value (8) to their analysis.

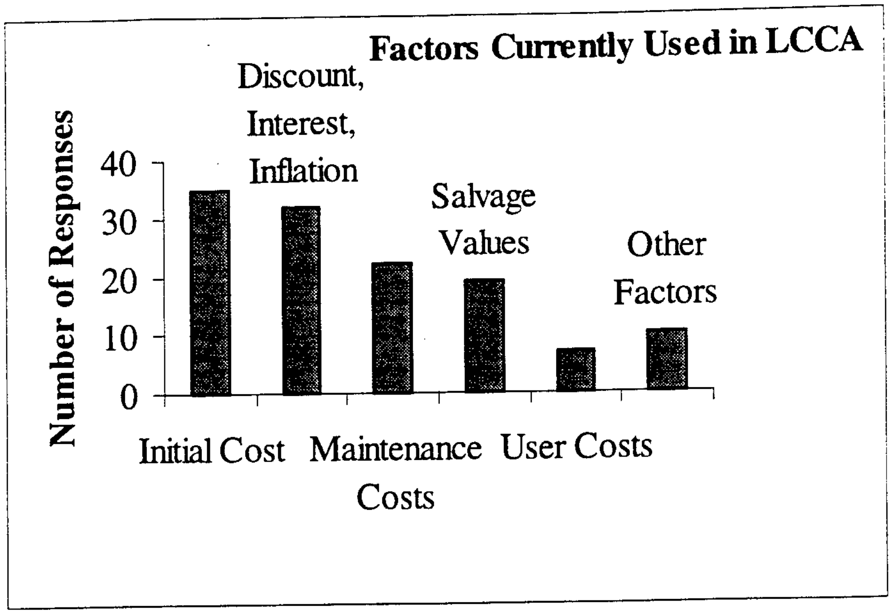

Figure 4-3. Factors Currently Used in LCCA.

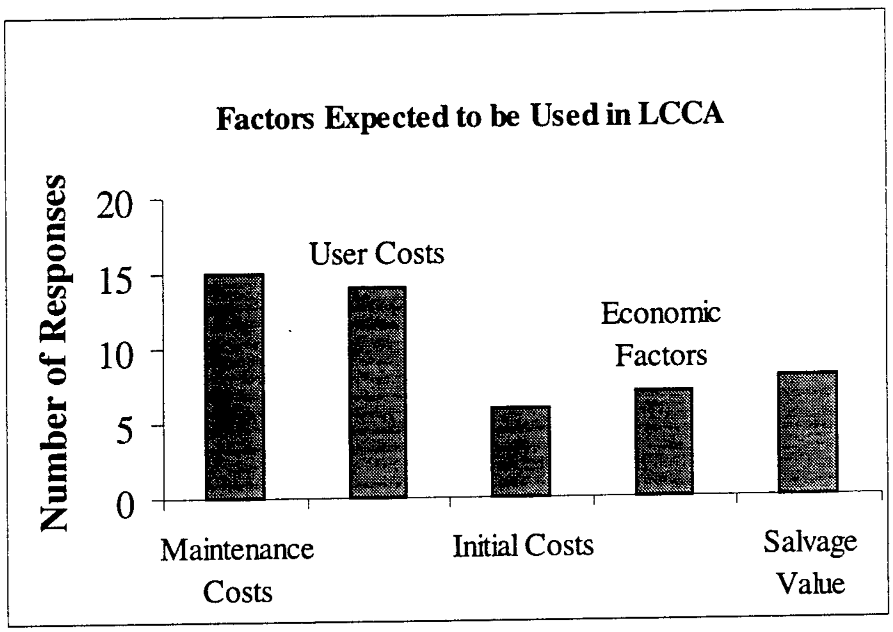

Figure 4-4. Factors Expected To Be Used in LCCA.

As discussed earlier, initial costs were the most commonly used factor in the LCCA conducted by state agencies. The survey indicated that there are two primary methods of obtaining initial costs: from departmental estimates or from historical estimates prepared within the agency. Twenty-eight (28) agencies rely on departmental estimates for identifying the initial costs used in the analysis. Nineteen (19) agencies use historical estimates prepared by individuals in the Contracts, Estimating, PS&E, Design, Programming, or similar divisions within the agency. One agency indicated that the initial cost estimates were provided by their pavement management department. Three agencies specified some other method of obtaining this information, with one listing the cost of construction and the other two listing bid summary tabulations. One additional agency indicated that in the future they would be obtaining this information from their congestion management system and maintenance management system. These trends are reflected in figure 4-5. The survey indicated that these trends were not expected to change significantly in the forthcoming years. This figure shows a total of 50 responses to the question, indicating that some agencies obtain initial costs from two or more sources.

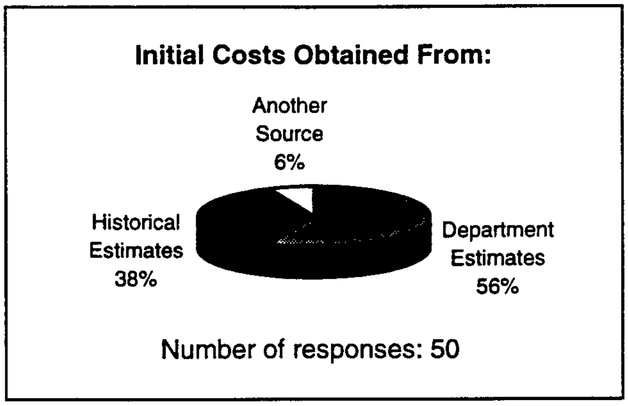

Figure 4-5. Source of Initial Cost Information.

Although maintenance costs are not as commonly used as initial costs in a LCCA, over half of the responding agencies try to incorporate these costs into their analysis. These costs are primarily obtained through departmental estimates (18) or historical estimates prepared within the agency (16). The maintenance divisions were listed as the primary suppliers of the information within the department, with Operations, Contracts, office engineers, and the pavement division also being mentioned. Six (6) agencies identified other sources of the information, including contracting costs, regional estimates, or some other area within the department. One of the six agencies stated that equal maintenance costs are set for each alternative considered. These trends are illustrated in figure 4-6.

Some of the responding agencies indicated how they would be estimating maintenance costs in the future. Seven (7) agencies stated that in the future this information would be provided through departmental estimates. Four (4) stated that they would obtain this information from historical estimates prepared in-house and one (1) indicated that in the future the information would come from a maintenance management system.

The highway agencies were also asked to indicate whether maintenance costs were prepared for each of the alternatives considered in their analysis. Fifteen (15) agencies do currently estimate different maintenance costs for their rehabilitation and reconstruction alternatives, but sixteen (16) agencies also stated that they did not.

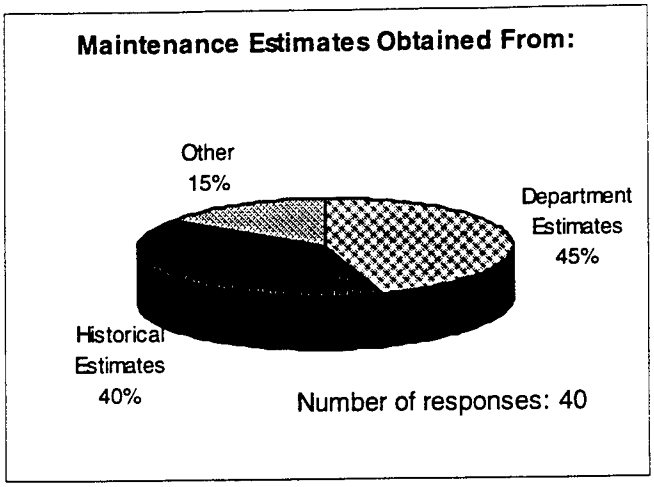

Figure 4-6. Source of Maintenance Cost Estimates.

Twelve (12) agencies indicated that different costs would be estimated in the future. One of the eleven agencies indicated that they are not currently estimating different maintenance costs, but hope to soon. This information is presented in figure 4-7.

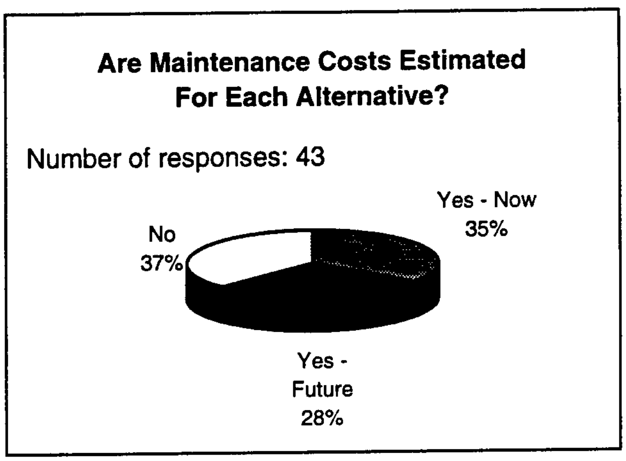

Figure 4-7. Use of Maintenance Cost Estimates for Each Alternative.

The state agencies were also asked to indicate their level of confidence in the initial and maintenance cost estimates being used in the LCCA. The survey indicated that agencies have a much greater level of confidence in the estimation of initial costs than in the estimation of maintenance costs. Thirty-three (33) state agencies reported that they have a good degree of confidence in the initial cost estimates. Only seven (7) reported that they only had a fair degree of confidence in the initial cost data and no one reported having a poor degree of confidence. This information is summarized in figure 4-8.

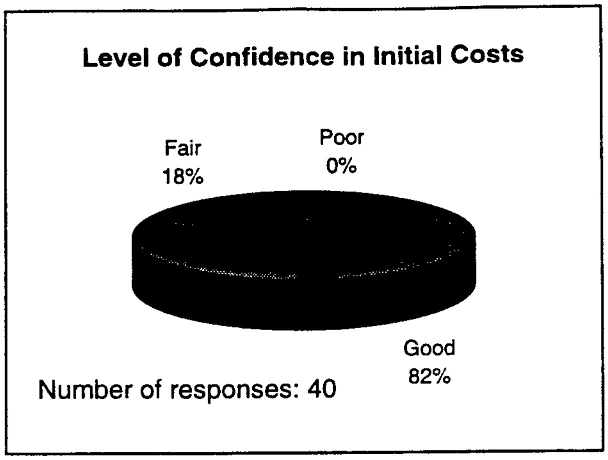

Figure 4-8. Level of Confidence in Initial Cost Estimates.

As shown in figure 4-9, confidence in maintenance cost data was not nearly as high. Six (6) agencies reported that they had a good degree of confidence, twenty-two (22) reported it as fair, and nine (9) indicated it was poor. This lack of confidence in the maintenance data contributed to the fact that maintenance cost data was not as common a factor in the LCCA being conducted by state agencies.

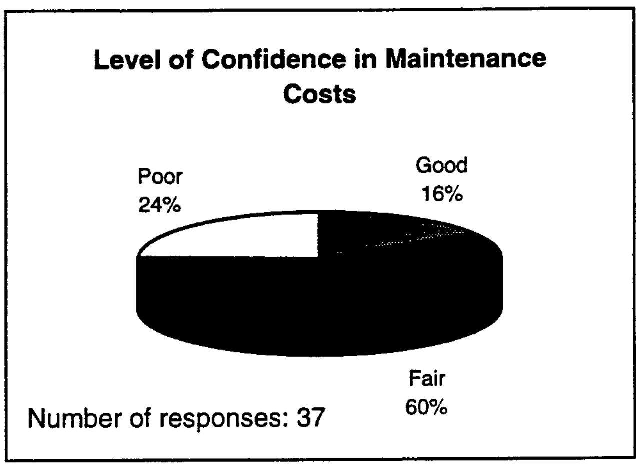

Figure 4-9. Level of Confidence in Maintenance Cost Estimates.

Economic factors, such as discount, interest, and inflation rates, were also commonly used in the LCCA conducted by the state agencies responding to the survey. States were asked to indicate the frequency with which they update the economic factors used in their analysis. The results to the question are summarized in figure 4-10. This chart summarizes both current practices and anticipated practices in the future. It reflects all responses provided by the responding agencies so the total number of responses reflects more than one response by some agencies.

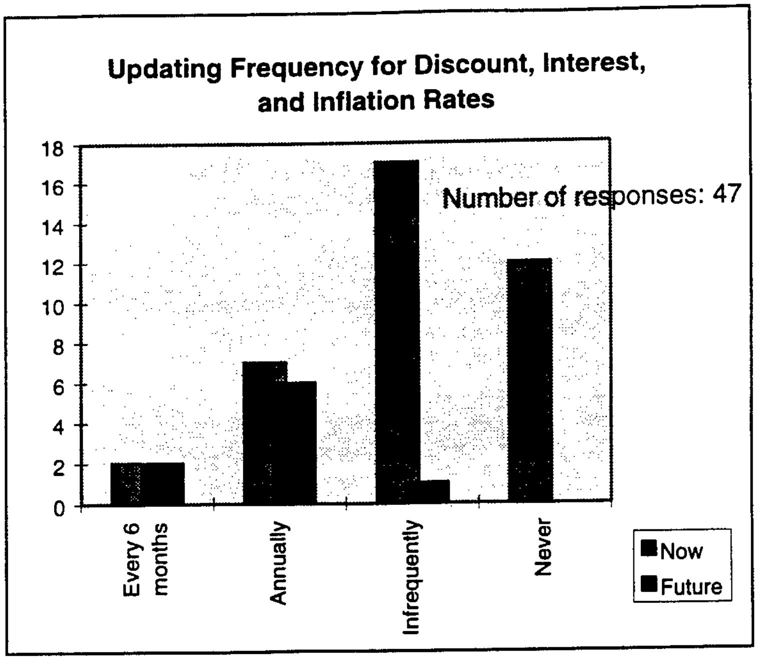

Figure 4-10. Frequency of Updating Economic Factors

Some agencies conducted their LCCA differently for rehabilitation activities than for reconstruction alternatives. For both types of construction, agencies were asked to specify which of a number of different types of analyses best reflected their practices when evaluating rehabilitation options or reconstruction options. The following options were offered for both rehabilitation and reconstruction.

- The analysis period is fixed at ____ years.
- A series of two or more rehabilitation alternatives are considered to be one rehabilitation strategy for a potential project over the analysis period.
- Only one rehabilitation alternative is considered to be one rehabilitation strategy over the analysis period, even if its expected life is shorter than the analysis period.
- The additional life provided by the alternative is measured in terms of the length of time until the condition value that triggered the repair is met.
- The additional life provided by the alternative is measured in terms of the length of time until a condition that represents failure is met.

Agencies were asked to identify all options that fit their situation, so a number of agencies selected more than one answer to these questions.

When rehabilitation options are considered, twenty-five (25) states indicated that they use a fixed analysis period ranging from 4 to 40 years. Sixteen (16) agencies consider two rehabilitation alternatives as a strategy, although eight (8) consider only one alternative over the analysis period. Eleven (11) agencies measure the additional life provided by the alternative considered in terms of the time until a trigger point is reached and eleven

(11) measure it in terms of the length of time until a failure condition is reached. These results are summarized below in figure 4-11.

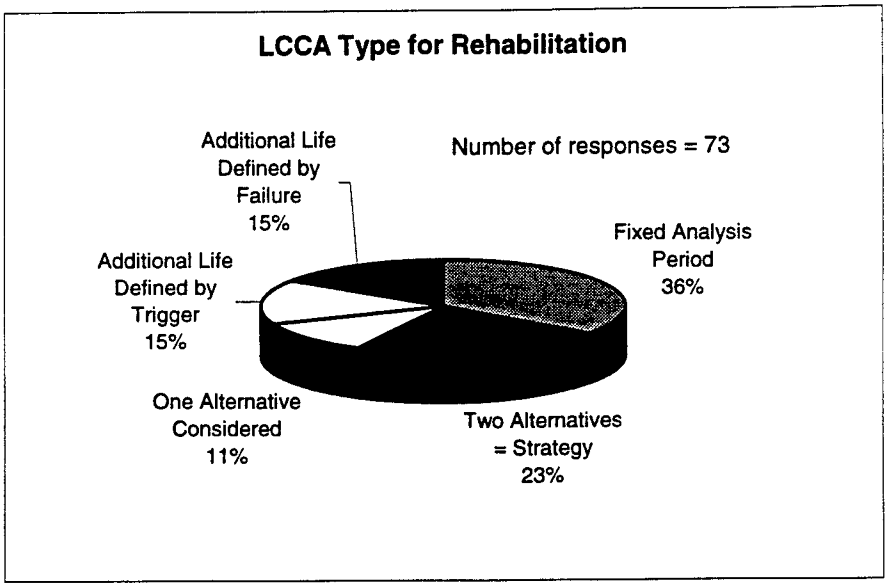

Figure 4-11. Rehabilitation Options Used in LCCA.

When reconstruction alternatives are considered, more agencies (30) use a fixed analysis period. The lengths of the analysis periods were listed as ranging from 1 to 50 years for reconstruction. Fourteen (14) agencies stated that two or more rehabilitation alternatives were considered in the analysis and six (6) stated that only one was considered. Fewer agencies reported defining additional life in terms of a trigger value (8) or failure point (9). This is reflected in figure 4-12.

A question pertaining to the calculation of salvage values, if used, was also posed to the states. This question asked whether salvage values were determined through one of the following methods:

- Set as a fixed amount.
- Calculated as a percentage of some value.
- Determined in terms of remaining life.

Responders were also given the option of identifying some other way of calculating salvage value.

A total of fourteen (14) agencies indicated that they do not consider salvage value in their analysis. Of the agencies that do use salvage value, the responses were fairly evenly split between each of the calculation methods. Six (6) agencies stated that it was determined

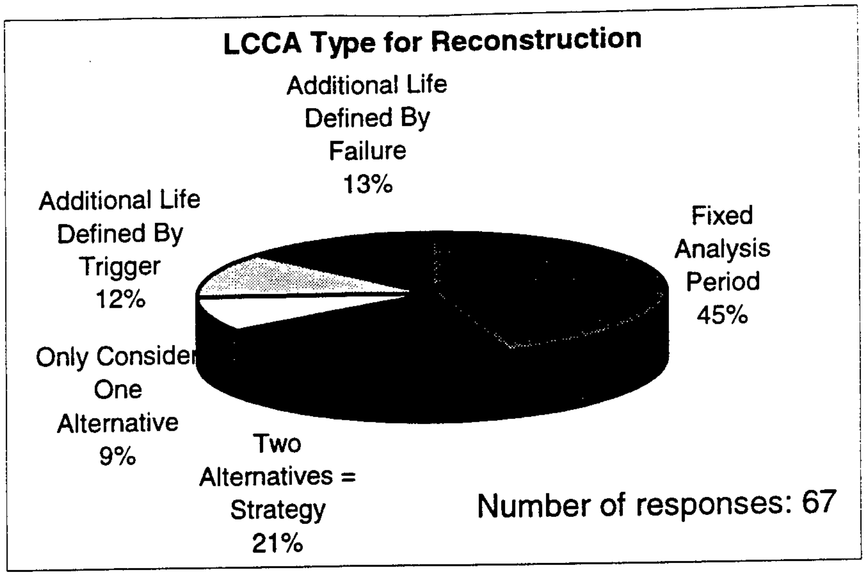

Figure 4-12. Reconstruction Options Used in LCCA.

as a fixed cost, five (5) stated it was determined as a function of initial rehabilitation cost, and six (6) indicated that salvage value was determined in terms of remaining life. Six (6) agencies used another method of determining salvage values. These included family curves, setting all salvage values at equal amounts, determining the value of the material in place, or dividing the remaining life by the design life and multiplying it by the total cost. The responses to this question are summarized in figure 4-13.

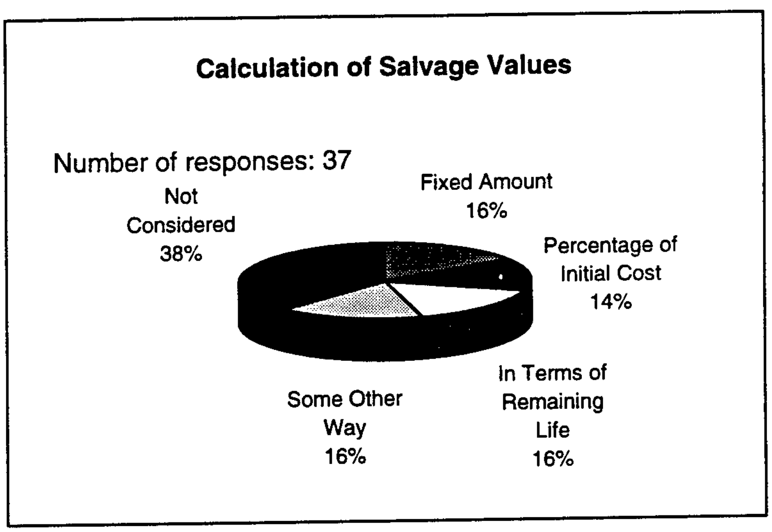

Figure 4-13. Calculation of Salvage Value in LCCA.

The final question prompted agencies to indicate whether the results of their LCCA were compared to any other type of analysis result. Thirty-two (32) agencies indicated that the results were not compared to any other type of analysis. Six (6) agencies stated that they did compare the results and listed the delay analyses, risk analyses, benefit/cost, congestion costs, and other features as the types of analyses used. The responses to this question are summarized in figure 4-14.

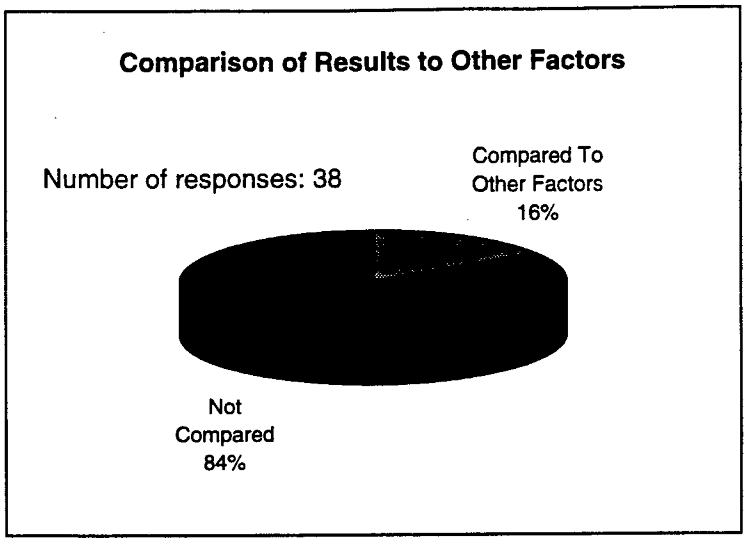

Figure 4-14. Comparison of LCCA Results to Other Analysis Types.

4.2 Economic Factors Used in the Analysis

Agencies using economic factors in their LCCA were also asked to provide values used for discount rate, interest rate, inflation rate, and the life of the alternatives. In some cases, rather than providing values, the source of the information was provided. The responses provided are summarized below.

4.2.1 Discount Rate

A number of different factors were listed as important in determining a discount rate. Several states listed the discount rate as the difference of the interest rate minus the inflation rate. Other states look at current bond rates, or other economic factors, to determine the value to use. Two states mentioned their use of the AASHTO guidelines and one referred to TRB Synthesis 122 as a reference.

Of the agencies that provided values, most responses fell within the 3-5% range. Other values provided included 2.71%, 6%, 8%, and a range of 0 to 10%. A summary of the responses is provided in figure 4-15.

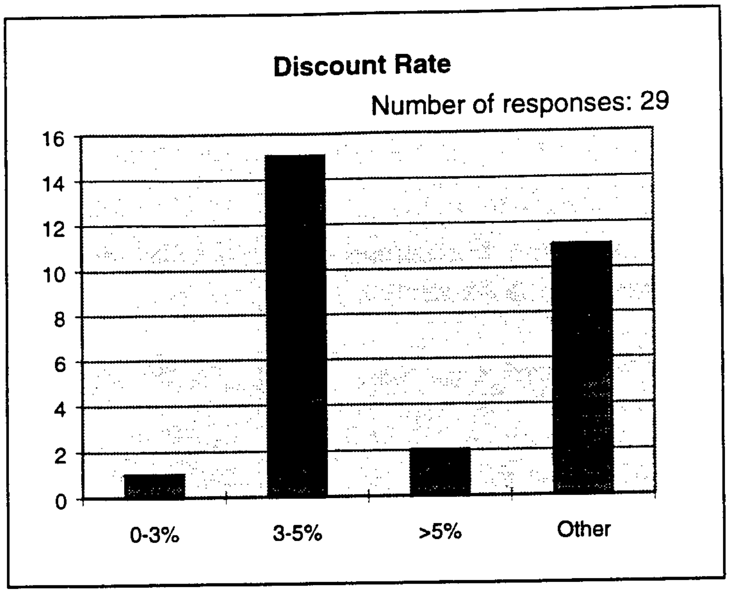

Figure 4-15. Use of Discount Rate.

4.2.2 Interest Rate

It appears that there are not a lot of states using interest rate in their LCCA. Only 12 states indicated that it was currently included. Most agencies indicated that the interest rate is tied to information provided at a local revenue conference, the interest rate currently being earned by the state, the bond rate, or a rate set by the controller. Only a few values were provided, including values of 6%, 7%, and 8% and ranges of 0 to 10% and 5 to 8%. One agency indicated that they would use an interest rate based on the prime interest rate in the future.

4.2.3 Inflation Rate

Again, there was a great deal of variety in the responses regarding the calculation of the inflation rate. Several agencies indicated that they use the consumer price index (CPI) as a source for determining the inflation rate; other sources that were listed included a revenue conference, the controller, the FHWA, or economic estimates. Nine (9) states provided values typically used for the inflation rate. One listed a range of 3 to 4%, another listed a range of 1 to 3%. Two (2) agencies stated that they use a value of 3%, three (3) stated that they use 4%, one uses 5%, and another uses 5.2%.

4.2.4 Alternative Life

Few agencies chose to respond to this question. In most cases, agencies indicated that the life of the alternative was set by the PMS, or by the Design or Materials/Research Divisions based on historical performance. Only one agency responded to this question in terms of setting a value, stating that they use a life of 50 years.

4.3 Summary of State Responses

The responses to this questionnaire demonstrate that a LCCA is an important tool in the pavement design activities performed by state highway agencies. Most of the responding agencies indicated that a LCCA is used in pavement design, but relatively few agencies are using these concepts in their PMS activities. Although a number of different factors are considered in the states' LCCA, initial costs and economic factors such as interest, inflation, and discount rates are most common.

A smaller number of states consider maintenance costs and salvage values in their LCCA. Follow-up questions indicate that although these factors are considered, states have less confidence in estimating these numbers than the more commonly considered factors. In fact, thirty-one (31) out of thirty-seven (37) respondees stated that their level of confidence in maintenance cost estimates was either fair or poor. This is in sharp contrast to the thirty-three (33) respondees (out of forty [40]) who reported that their level of confidence in their initial cost estimates was good.

Because of the lack of confidence in the quality of the maintenance cost estimates, many state agencies reported that they did not estimate separate costs for each rehabilitation or reconstruction alternative considered; although many states indicated that they intended to add this capability in the near future. At the present time, most maintenance cost estimates are developed through the preparation of historical or departmental estimates.

There were three primary approaches used to estimate salvage values: using a fixed amount, determining a percentage of the initial cost of the project, or developing an estimate in terms of the remaining life of the pavement. Fourteen agencies (14) indicated that they do not consider salvage value in any form in their LCCA.

Variations in LCCA approaches occur for rehabilitation and reconstruction alternatives. Agencies more commonly use a fixed analysis period when considering reconstruction alternatives than with rehabilitation alternatives. The length of the fixed analysis period normally ranges from 10 to 50 years.

Once the LCCA is completed, there are relatively few agencies that indicated that they compare the results to other studies such as user delay studies. An overwhelming majority of agencies, thirty-two (32) out of thirty-eight (38) respondees, indicated that there is no comparison conducted.

4.4 Evaluating Economic Strategies and Maintenance Costs Forecasts

In order to evaluate the various approaches used to conduct LCCA within state highway agencies, the third task of the research project involved the development of criteria that could be used to evaluate each of the components of the analysis. Preliminary criteria were developed by the contractor and reviewed by the Technical Panel for the project. Based on the discussions, a final set of criteria were developed and used to evaluate some of the components of the LCCA. The criteria and the evaluation of each component are summarized in tables 4-1 through 4-12. This information, plus the information in the next few chapters, is used as the basis for the recommendations made in chapter 9 of this report. Table 4-1 presents a summary of the network approaches used for prioritizing projects in a pavement management system. The approach used by the SDDOT, incremental benefit/cost, is one of the most common approaches used today. It requires the use of LCC data to calculate an Equivalent Uniform Annual Cost (EUAC) to determine the most cost-effective rehabilitation treatment and timing for a given project section.

Table 4-2 focuses on the pavement type selection approaches most common today. The present worth approach, currently being used by the SDDOT, is well accepted and recommended by the FHWA.

Table 4-3 presents the approaches being used by state agencies to incorporate inflation, interest, and discount rates into a LCCA. These values are usually based on historical trends which may be obtained from published material. The incorporation of these values into the LCCA permit the agency to take the change in costs over time into account in the analysis.

Table 4-4 summarizes the length of the analysis period used by various agencies in their LCCA. An analysis period of 35 to 40 years is common.

In most agencies, estimates of initial costs are based on historical records or departmental estimates of costs based on previous projects, as summarized in table 4-5. Estimates of maintenance costs are more varied and agencies typically have little faith in the numbers produced. The approaches used to develop maintenance costs are presented in table 4-6. Other future costs must also be taken into account in the analysis, as presented in table 4-7. These costs most commonly include future rehabilitation activities.

One of the most controversial aspects of LCCA is the use of user costs in the analysis. Although few agencies currently incorporate user costs into their analysis calculation, there are some agencies that are considering user costs in more subjective ways. The use of user costs in the LCCA is presented in table 4-8.

The use of a salvage value in a LCCA is also somewhat controversial. A number of different approaches may be used to consider the value of the pavement facility at the end of the analysis period, as shown in table 4-9. An estimate of the residual value based on the remaining service life of the pavement is most common.

Tables 4-10 through 4-12 present other aspects of the LCCA. Tables 4-10 and 4-11 summarize the development of costs and service lives for various pavement activities and the variations states use to consider regional differences. Table 4-12 introduces some approaches that may be considered to incorporate the consideration of risk and uncertainty into the analysis. The FHWA supports the use of a probabilistic approach as part of the LCCA.

Table 4-1. Network Analysis Approach (PMS).

Approach	Description	Assumptions	Technical Viability	Complexity	Inputs	Changes Required to Implement	Concerns Addressed by Approach	Other States Using Approach	Does It Address FHWA Requirements
Existing SDDOT - dTIMS	Incremental B/C, Benefit determined as area under performance curve Costs approximate LCC using EUAC.	1. Area under curve is representative of benefit. 2. LCC are representative of actual costs. 3. Second treatment is performed. 4. Analysis periods are equal.	Good	Moderate. The software determines the benefit from models in the program. LCC are fairly simplistic at this point.	1. Performance models 2. LCC data 3. Feasible treatments 4. Rules for applying treatments 5. Second strategies	None	1. Overall network effectiveness analysis	Indiana Utah Mississippi Vermont And Others	Yes
Cost-effectiveness	Same as incremental B/C	1. Area under curve is representative of benefit. 2. LCC are representative of actual costs.	Good	Same as IBC	1. Performance models 2. LCC data 3. Feasible treatments 4. Rules for applying treatments	None	Overall network effectiveness analysis	Minnesota Oregon	Yes
Least Initial Cost	Determine lowest initial cost strategy	1. LCC do not greatly impact the selection of a strategy. 2. Initial costs are representative of actual costs 3. No difference in effectiveness between treatments is considered	Less sophisticated than current approach	Simple	Initial costs for each feasible treatment.	Software could probably accommodate this approach with minor changes	None	Unknown	No
Least LCC	Determine lowest LCC strategy	1. LCC are representative of actual costs. 2. No difference in effectiveness between treatments is considered.	Less sophisticated than current approach	Fairly simple	LCC values for each viable treatment	Some simple modifications to the software would be required to eliminate consideration of benefit.	LCC is addressed at a network level	Unknown	Not for multi-year programming objectives

Table 4-2. Pavement Selection Process Approach.

Approach	Description	Assumptions	Technical Viability	Complexity	Inputs	Changes Required to Implement	Concerns Addressed by Approach	Other States Using Approach	Does It Address FHWA Guidelines
Present Worth	Present and future costs are discounted back to a point in time	Economic factors can be forecasted, periodic costs are known.	Good	Moderate	Initial, periodic, and annual costs. Economic factors. Analysis period.	Economic factors will need to be added.	Present value of future expenditures.	Washington Ohio North Carolina Pennsylvania	Yes
Annualized Approach	Costs expended over various points in time are converted to an equivalent uniform annual cost	Same as present worth	Good	Moderate	Same as present worth	Economic factors need to be added, new equation needs to be used	Present value of future expenditures, differing performance periods of alternatives	Indiana (network level)	Yes

<u>**Additional Criteria**</u>

When is the analysis used?

The use of these approaches varies depending on the agency. For example, Florida uses a LCCA for new construction and rehabilitation projects with base or subbase work. Pennsylvania uses LCCA in its pavement selection process for Interstate projects if they are over $1 million and on projects over $5 million dollars for other non-exempt projects. North Carolina bases its decisions on the Structural Number (SN) of its projects. The NHS Designation Act of 1995 requires a LCCA on NHS projects where the cost of a usable project segment equals or exceeds $25 million.

Table 4-3. Economic Factors - Inflation, Interest, and Discount Rate.

Approach	Use in Analysis	Method Used to Determine Value	Technical Viability	Availability of Information Needed	Update Requirements	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach
Inflation rate	Represents the increase in future prices due to inflation.	History ENR Construction Cost Index (Current Index/1972 Index)	Better if estimated as a constant compound rate. Not supported by FHWA.	Primarily based on estimates. Could use consumer price index (CPI).	Annual check of value being used.	Good	Takes into account the change in costs over time.	Arizona Pennsylvania Indiana
Interest rate	Represents the earning power of money if invested in other ways.	History	Not generally used by public agencies. Not supported by FHWA.	Primarily based on estimates of past interest rates and projects of future rates.	Annual check.	Easily incorporated but not generally used.	Considers the alternative uses of funds.	Pennsylvania
Discount rate	Another way to represent the increase in future prices due to inflation.	History	Generally accepted. Supported by FHWA	OMB publishes a real discount rate summary each year.	Annual check.	Already used in South Dakota Pavement Management System	Takes into account the change in costs over time.	Arizona Florida North Carolina Ohio Oregon South Dakota (PMS)

Table 4-4. Analysis Period.

Length of Analysis Period	Does Length Vary for Rehabilitation versus Reconstruction?	Basis for Determining Length of Analysis Period	Technical Viability	Availability of Information Needed	Update Requirements	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach	Does It Address FHWA Guidelines
35 years	No, unless temporary designs are used for rehabilitation.	Serviceable life estimate. Must be long enough to show long-term differences between rehabilitation alternatives.	Good	Good	Periodic reviews	Excellent	Shorter period than is used by either the PMS (50) or the pavement selection process (40).	Arizona Washington Ohio	Yes – FHWA recommends at least 35 years.
40 years	Used on reconstruction or new construction.	Design period.	Good	Good	Periodic reviews	Excellent	This period is currently used in the pavement selection process. If PMS used this length, both would have a common basis for analysis.	South Dakota Florida	Yes – greater than 35 years.
30 years	No	Serviceable life estimate.	Poor	Good	Periodic reviews	Possible, but not recommended	None	Kansas, North Carolina, Oregon	No – less than 35 years
Other analysis periods	Varies, but generally one analysis period is selected to compare strategies.	Serviceable life estimate.	Fair	Good	Periodic reviews	Good	None. It is recommended that one length be adopted.	Pennsylvania Indiana	It does if length is greater than 35 years.

Table 4.5 Initial Costs.

Costs Considered	Method for Obtaining Costs	Technical Viability	Are Historical Trends Used?	Resource Reqrmts	Variation in Costs for Design Strategies	Availability of Cost Information	Difficulty of Obtaining Info	Update Reqrmts	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach	Does It Address FHWA Guidelines?
All costs associated with design and construction.	Historical bid documents, inhouse staff estimates.	Good.	Yes	Moderate	Yes depending on design approach used.	Good. Frequently obtained from bid documents.	Could be difficult for a new design approach.	Periodic checks.	Used in current practices.	None	Most states using LCCA	Yes

Table 4-6. Maintenance Costs.

Costs Considered	Method for Obtaining Costs	Technical Viability	Are Historical Trends Used?	Assumptions Made	Level of Confidence in Values	Resource Reqrmts	Variation in Costs for Design Strategies	Availability of Cost Information	Difficulty of Obtaining Info
Cumulative annual costs	Historical estimates	Fair	Yes, if available.	Annual maintenance will be performed and historical cost estimates are representative of costs. Also assumes costs fixed by surface type.	Generally fair or poor.	Cost tracking systems required.	Primarily vary by surface type and/or reinforcement type (pavement type).	Often difficult to track by project segment. Maintenance cost files may be available for general cost summaries.	Difficult to obtain estimates any more specific than costs by surface type. Some agencies may estimate by design type.
No maintenance costs	None	Poor	No	All maintenance costs are equal regardless of design selected.	Fair or poor.	None	None	N/A	N/A

Update Reqrmts	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach	Does It Address FHWA Guidelines?
Periodic reviews	Good	Could be used to standardize estimates used in PMS and pavement type selection.	Arizona California Montana Nebraska New York Tennessee Virginia	Yes
None	Could be done but is not recommended.	None.	Kansas Mississippi Washington	No

Table 4-7. Other Future Costs.

Costs Considered	Method for Obtaining Costs	Technical Viability	Are Historical Trends Used?	Assumptions Made	Level of Confidence in Values	Resource Reqrmts	Variation in Costs for Design Strategies	Availability of Cost Information	Difficulty of Obtaining Info
Periodic rehabilitation costs	Historical figures, inhouse estimates	Good	Yes	Timing of application, cost of treatment, life of treatment.	Good	Must have data on the life and cost of each treatment, must have strategies outlined for consistency.	Yes	Generally good – use past bid documents	Differentiating between life estimates for different designs may be difficult.

Update Reqrmts	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach	Does It Address FHWA Guidelines?
Periodic checks on all assumptions.	Good.	Currently being used in both PMS and pavement design strategy.	Indiana Illinois Montana	Yes

Table 4-8. User Costs.

Costs Considered	Method for Obtaining Costs	Technical Viability	Are Historical Trends Used?	Assumptions Made	Level of Confidence in Values	Resource Reqrmts	Variation in Costs for Design Strategies	Availability of Cost Information	Difficulty of Obtaining Info
User delay cost	Research – estimates of $0.06 per vehicle per mile or $6.25 per hour	Good	Yes -- averages are found	Same delay costs are applicable for reconstruction, rehabilitation, and maintenance.	Fair to good	Must determine ADT levels, length of project, number of days of delay	Delay defined for each approach. Generally not used for new construction.	Varies by state	Difficult to determine cost per mile or hour.
No user costs	N/A	Poor	No	There are no differences between user costs for each treatment.	Low	None	None	N/A	N/A
Differential delay due to detours and adverse traffic caused by an alternate.	Estimates of delay time for each approach	Fair	Yes	Differences exist in delay between treatments.	Fair	Number of days of delay	Varies based on closure, etc.	Varies by agency	Estimating number of delay days per rehabilitation type.
Number of vehicles affected.	Estimate cost of delay per vehicle type.	Fair	Yes	Rate of delay cost per vehicle, length of delay for treatments	Fair	Hourly cost per vehicle, traffic counts, delay lengths	Length of delay varies	May be difficult to obtain without research	Determining a reasonable value per vehicle and estimating traffic affected.

Update Reqrmts	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach	Does It Address FHWA Guidelines?
Traffic and costs periodically	Could be done	Incorporates use of user costs into analysis	Arizona Washington	Yes
None	Currently being done in PMS	None	Florida	No
Delay estimates for construction	Good	Incorporates one aspect of user costs into analysis	Indiana	Somewhat
Traffic and costs periodically	Could be done	Incorporates use of user costs into analysis	Pennsylvania	Yes

Table 4-9. Salvage Value.

Use in Analysis	Method Used to Determine Value	Technical Viability	Availability of Information	Update Requirements	Level of Confidence	Feasibility of Incorporation into Existing Practices	Improvements Made to Existing Practices	Other States Using this Approach
To determine residual value at end of analysis period.	Percent of Initial Cost, taking into account values such as removal, recycle potential, etc.	Good	Factors would have to be developed for each material.	Regular updates of recycle factors, costs, % of rebuilding required	Fair – these values approximate 1/3 of initial costs, which the DOT feels is reasonable.	Fair	Takes salvage value into account	Arizona
Not used in analysis	None	Poor	N/A	None	N/A	Same as existing practice	None	Florida
Estimate residual value based on remaining service life	Salvage Value = Cost of last rehab * (RSL/DSL) where RSL = remaining service life and DSL = design service life.	Good	Good	Minimal – DSL values will need to be checked regularly	Good	Good	Takes salvage value into account	Indiana Washington Oregon

Table 4.10. Costs and Service Lives of Pavement Activities.

LCCA Component	Approach Used	Method Used to Obtain Information	Are Different Values Used For Districts or Regions?
Initial Cost	Current cost approach	Departmental Estimates from Historical Data	If supported in the database
	Current cost approach	Bid Summaries	Generally localized
Maintenance Costs	Not used	N/A	N/A
	Current cost approach	Departmental Estimates from Historical Data	Generally not detailed at this level
Rehabilitation Costs	Estimate future cost	Inflate current bid prices to future costs	If supported in the database
	Current cost approach	Departmental Estimates from Historical Data	If supported in the database
Service Lives	Remaining Service Life (RSL) approach	Number of years until an anticipated failure point is reached.	Only if performance data show marked differences. Most often separated by functional classification or traffic levels.
	Fixed projections	Each treatment has a fixed life based on departmental estimates	Generally not
	Performance models from PMS	Pavement performance models in PMS	Only if performance data show marked differences. Most often separated by functional classification or traffic levels.

Table 4-11. Timing and Costs of Other Future Activities.

Approach	Use of Future Costs in LCCA	Determination of Timing of Future Costs	Default Values for Costs and Service Life Information	Variation in Values Among Districts and Regions	Trigger Values Used to Determine Future Costs and Timing (traffic volume, % trucks, etc.)
Fixed Policy	Identification of future rehabilitation treatments	Policies are established for each treatment that specifies the repair intervals and maintenance activities to include in the analysis.	Current cost values used Service life assumed in the cycle	Generally not, but may be varied if the database supports it.	Generally specified based on number of years since last rehab.
PMS Network Analysis Approach	Subsequent treatments are used to prioritize rehabilitation needs at the network level	Estimated by the incremental benefit cost approach based on performance models, trigger values, and budget levels available	Input into system based on historical information	Variation may be included in performance models and/or costs	Trigger values used to identify feasible treatments, traffic volumes used to estimate benefit from treatments.
Case By Case Basis	A set of treatments is designed for each project based on in-situ conditions	Timing based on historical estimates of similar projects. Costs generally based on historical estimates.	No	Since each case is considered separately, there would be variation in districts and regions	May be used informally

Table 4-12. Risk and Uncertainty.

Approach	Consideration of Uncertainty	Consideration of Risk and Vulnerability of Pavement Activities	Consideration of Obsolescence	Incorporation of Effect of New Materials or Construction Techniques	Method for Incorporating Risk and Uncertainty Factors	Use of Probabilistic Model to Consider Risk and Uncertainty	Availability of Historical Data to Develop Probabilistic Risk Models
Margin of Error	Cost within a specific range are considered equal (10-15%)	N/A	N/A	Estimates developed based on expert opinion	Informal realization that costs within a range of 10-15% are equal	N/A	N/A
FHWA Probabilistic Approach	Considers uncertainty of estimates and assumptions	Considers variation in pavement performance	Considers other factors that affect the results of the analysis	Provides a way of estimating the likelihood of performance estimates for new treatments or materials	Use of risk analysis software such as "@Risk" and "Crystal Ball" (add-in functions to Excel) Users estimate the probable variation of input values	A number of variability functions are used to describe the variation, including triangular distributions, normal distributions, log normal distributions, and so on	Initially based on agency estimates of variation that may be supported by historical data

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5.0 Use of LCCA in the South Dakota Department of Transportation

A LCCA is used in two ways within the SDDOT: as part of the pavement management system and as part of the pavement selection process. The pavement management system uses LCCA as part of its incremental benefit/cost analysis for prioritizing pavement preservation needs. At the project level, LCCA is used in the pavement selection process to identify specific treatments for individual pavement sections.

The two applications of LCCA within the SDDOT have each developed independently over the years, as new tools became available. The pavement management system, for example, has only been used for a few years. At the time of its implementation, some of the program capabilities in terms of life-cycle costing were utilized to enhance the analysis process. A discount rate was incorporated into the analysis and pavement performance models were developed to estimate the serviceable lives of pavements.

In addition to differences in performing the LCCA at the network- and the project-levels, other situations have caused problems in the development of reliable life-cycle cost estimates. An example of this type of situation is the incorporation of maintenance costs in the analysis. At the time this project was initiated, maintenance costs and activities were reported for an entire length of a highway within a Maintenance Unit. Costs were not differentiated by activity, preventing the SDDOT from tracking the costs of maintenance activities on pavement sections with different conditions. Another problem caused by this approach was that by averaging costs across an entire length of pavement, the SDDOT could not identify where the majority of their costs went.

In order to improve the accuracy of maintenance cost estimates in the LCCA, several changes were made to the tracking and reporting of maintenance activities. One change involved the reporting of maintenance activities on more homogeneous segments than was done in the past. This change allows the Department to begin tracking maintenance costs by design type. Another change involved the addition of function numbers to the maintenance activity reporting so that shoulder work and mainline work could be differentiated.

This chapter focuses on the factors currently being used within the SDDOT for their LCCA at both the network and project levels. The recommendations provided in chapter 9 would modify the activities discussed in this chapter.

5.1 Network-Level LCCA

At the network level, the LCCA is used to prioritize pavement rehabilitation needs for given funding levels. The pavement management system conducts an incremental benefit cost analysis that estimates the benefit (additional service life times traffic levels) and the cost (life cycle cost) for each feasible rehabilitation strategy to identify a benefit/cost ratio. Based on the funding levels available, the best combination of projects, treatments, and timing are selected using the benefit/cost ratios.

The implementation of the pavement management system required that the Department define certain analysis elements. These elements include pavement performance models to reflect the deterioration patterns of the State's pavement network, feasible rehabilitation treatments to consider in the analysis, trigger points to identify when each treatment is considered feasible, costs for each feasible treatment, and economic factors that influence the analysis.

The scope of this project does not include an evaluation of the treatments, performance models, and trigger values associated with a LCCA. Instead, it focuses attention on the economic factors and maintenance costs used in the analysis. For that reason, this section of the report focuses only on these components of the network-level LCCA.

5.1.1 Approach

As discussed above, the network-level PMS incorporates the use of a LCCA as part of its incremental benefit cost analysis. The program calculates an Equivalent Uniform Annual Benefit (EUAB) and Equivalent Uniform Annual Cost (EUAC) associated with each of the treatment strategies.

5.1.2 Interest, Inflation, and Discount Rates

The calculation of EUACs is based on a discount rate of 3%. No information was provided to the research team concerning the selection of a rate to use in the analysis, although it is assumed the rate was set as part of the pavement management implementation. No interest or inflation rates are used.

5.1.3 Analysis Period

The network-level analysis considers an analysis period of 50 years.

5.1.4 Costs

The analysis uses present costs to analyze future expenditures. Costs are estimated from an initial cost for both an initial treatment and a subsequent treatment (which together comprise a rehabilitation strategy) and an average per mile cost for maintenance activities such as crack sealing and chip seals. The initial costs are estimated from historical records and maintenance costs are determined by design type using a 3-year average from the Maintenance Department.

User costs and salvage values are not considered in the pavement management system analysis.

5.1.5 Service Lives

As part of the pavement management system, performance models were developed for each of the treatments considered in the analysis. The pavement management system uses the performance models to estimate the deterioration patterns of a treatment strategy, which may be a combination of one or two treatments that last approximately 20 years. Treatments are usually set 3-5 years in advance of construction.

5.1.6 Risk and Uncertainty

Risk and uncertainty are not incorporated into the analysis at the network level.

5.2 Project-Level LCCA

At the project level, the LCCA is used to identify the most appropriate treatment for each individual project being designed based on insitu conditions.

5.2.1 Approach

At the present time, LCCA is only used as part of the pavement selection process for new graded projects. In the future, the Department would like to consider the use of a LCCA on other types of projects.

5.2.2 Interest, Inflation, and Discount Rates

During meetings with the SDDOT, it was reported that no interest, inflation, and discount rates were being used in the pavement type selection process. However, in examples provided by Planning and Programming, an interest rate of 7%, construction inflation rate of 5%, and maintenance inflation rate of 4% are shown.

5.2.3 Analysis Period

The pavement type selection process uses an analysis period of 40 years for new construction.

5.2.4 Costs

The analysis uses present costs to analyze initial costs and future improvements. These costs are estimated from historical records and bid documents from similar jobs. Maintenance costs are based on an average per mile cost by surface type, although improvements to the tracking of these costs may improve these estimates.

User costs and salvage values are not considered in the pavement selection process, but an example of a calculation of delay costs for a project was provided.

5.2.5 Service Lives

The type of pavement being considered typically establishes the costs and service lives of various pavement activities considered in the LCCA. The costs are typically estimated 3 years in advance of construction.

5.2.6 Risk and Uncertainty

Risk and uncertainty are not incorporated, nor recommended, in the project – level economic analysis at this time.

5.3 Summary

Based on the discussions of the LCCA at the network- and project-levels, it is evident that a great deal of variation exists in the treatment of economic and other factors in the analysis. The use of these factors in the pavement management system and the pavement type selection process are summarized in table 5.1.

Table 5-1 Summary of Current SDDOT LCCA Factors.

	Pavement Management	**Pavement Type Selection**
Approach	EUAC as part of an incremental benefit cost analysis. Analysis conducted on all pavement sections hitting trigger values.	Currently used only on new graded projects. Considering use on major rehabilitation projects.
Interest, Inflation, or Discount Rate	Discount rate of 3% used.	Reportedly not used but examples show interest and inflation rates.
Analysis Period	50 years	40 years
Initial Costs	Present costs	Present costs
Maintenance Costs	3-year average cost from Maintenance by design type.	Average costs by surface type.
User Costs	Not used.	Not used, but example of delay cost calculation provided.
Salvage Value	Not used.	Not used.
Costs and Service Lives of Pavement Activities	20-years for selecting strategies.	Set by treatment type.
Timing and Costs of Other Future Activities	Prepared 3-5 years in advance of construction.	Prepared 3 years in advance of construction.
Risk and Uncertainty	Not considered.	Not considered.

At a minimum, the recommendations for this project should address the lack of consistency in LCCA factors used in the pavement management system and pavement type selection process. For example, the pavement type selection process reportedly does not use interest, inflation, and discount rates in its analysis, although an example was provided that incorporated interest and inflation rates (with different inflation rates for construction and maintenance). The pavement management system uses a discount rate of 3% for its analysis.

Another example of a lack of consistency in the two analyses is the analysis period. The pavement management system considers a treatment strategy that covers about 20 years of a 50 year analysis period. The pavement type selection process, on the other hand, uses a 40 year analysis period and all anticipated treatments that will be applied during that period are identified. Although the difference in treatments considered at the network- and project-level might be appropriate, the differences in the length of the analysis period is probably not appropriate.

The difference in the LCCA approaches used by Materials and Surfacing and Planning and Programming does not have to be addressed by the Department at this time. Both approaches use a present worth analysis as the basis of the life cycle cost considerations, however the pavement management system used by Planning and Programming converts the present worth to an EUAC for the optimization analysis. Since a change from the use of the EUAC would require programming changes to the pavement management software, and both approaches are a form of present worth analysis, no recommendations were made to convert the Department to one approach.

The chapter on recommendations addresses the inconsistencies discussed earlier while also identifying any changes to the existing procedures that will enhance the LCCA process allowing it to better approximate future conditions.

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6.0 Improving the Forecasting of Future Economic Factors and Maintenance Costs in LCCA

The primary focus of this project involves an investigation into current practice in the area of LCCA and methods that would enable the SDDOT to improve the use of economic factors and maintenance costs in LCCA. The objective of this chapter is to discuss the results of the tasks that dealt with improving the reliability of LCCA results through improved maintenance and economic factors.

6.1 Improving Economic Factors in LCCA

Economic factors are one of the most important components of the LCCA at the network or project level. The economic factors have a large impact on the results of the analysis and are possibly the most difficult aspect of the project to estimate. For that reason, a portion of the project involved an investigation to determine whether techniques were available to improve the forecasting of the economic factors used in the analysis. The results of that investigation are presented in the following sections.

6.1.1 Discount Rate

As discussed in an earlier chapter, there is some disagreement in the use of interest, inflation, and discount rates in a LCCA. However, in recent years the trend appears to be toward the use of real discount rates that are established as the rate over and above the general economy inflation rate. The FHWA and several authors on LCCA (Kirk and Dell'Isola 1995, Kleskovic 1990) support the use of the discount rate.

Agencies differ in the selection of a discount rate for LCCA. A cursory review of the use of discount rates in various agencies shows a range of values are used. Typical rates used by various organizations are shown in table 6-1. These values were obtained through a survey of various agencies.

A review of recent historical trends in discount rates can be found in the Office of Management Budget (OMB) Circular A-95. The trends for the past five years are shown in table 6-2. It is immediately obvious that regardless of the analysis period used, the average discount rate has been between 3.0 and 3.8. There is, however, a fair amount of variation between years, especially between the years 1993, 1994, and 1995.

Based on this information, it is reasonable to assume a discount rate equal to the 5-year average of historical discount rates from OMB for an analysis period of at least 30 years. This rate can easily be reviewed each year and updated according to historical trends. Using this approach, the 1997 discount rate for the analysis would be 3.8%. For simplicity sake, the number could be rounded to 4.0%.

Table 6-1. Use of Discount Rates in Various Organizations.

Organization	Discount Rate (%)
AASHTO	4.0-5.0
U.S. Department of Agriculture	4.0
U.S. Department of Energy	7.0
Federal Aviation Administration	10.0
Minnesota DOT	4.5
Arizona DOT, Tennessee DOT, Michigan DOT, New Jersey DOT, New York DOT, South Carolina DOT, Virginia DOT, Washington DOT	4.0
Illinois DOT, Louisiana DOT	3.0
Connecticut DOT	3-5
Nebraska DOT	2.71
Rhode Island DOT	8.0
Wisconsin DOT	5.0
Pennsylvania DOT	6.0

Table 6-2. Recent Trends in Real Discount Rates (%) (OMB Circular A-95 March 1997).

Analysis Period (years)	92	93	94	95	96	Average	Std Deviation
3	2.7	3.1	2.1	4.2	2.7	**3.0**	0.7
5	3.1	3.6	2.3	4.5	2.7	**3.2**	0.8
7	3.3	4.0	2.5	4.6	2.8	**3.4**	0.8
10	3.6	4.3	2.7	4.8	2.8	**3.6**	0.8
30	3.8	4.5	2.8	4.9	3.0	**3.8**	0.8

6.1.2 Construction Price Estimating

In order to conduct a LCCA, it is important that an agency estimate the type, cost, and timing of rehabilitation actions that must be applied over the analysis period. Using the approaches discussed earlier in this report, present value costs are used to represent the costs of future activities and discount rates are used to establish the present worth of these costs. One of the concerns within the SDDOT is whether there are fluctuations in construction prices that may not be adequately represented by discount rates.

This issue was investigated by comparing the construction price indices over the past 10 years to the change in consumer price index (CPI) which measures the average price of goods consumed by urban wage earners. The CPI is a weighted average, in which the weights reflect the spending of urban wage earners, giving more weight to products that are most important to consumers. The change in the CPI is representative of the rate of inflation.

The variation in the CPI and the Highway Construction Price Indices for excavation, resurfacing, structures, and the overall composite index are presented in table 6-2. This table compares the difference in values when compared to a base year of 1994. For example, in 1987, the CPI was 34.3 percent lower than the 1994 value. For the same year, excavation costs were 11.7% lower and resurfacing costs were 18.2 % lower. Similarly, in 1996, the CPI was 8.9% higher than in 1994 while the excavation cost and resurfacing costs were 6.5% and 5.5% higher, respectively. These values indicate that although the cost of living (inflation) was 8.9% higher than in 1994, the construction costs increased at a slightly lower rate. Comparing all the values in the table indicates that this trend is not always true. Even the costs of resurfacing, perhaps the item most relevant to this study, shows a variation in the costs over the years.

Table 6-2. Comparison of Changes in CPI and Highway Construction Price Indices (Bureau of Labor Statistics and FHWA Highway Statistics 1994)

	CPI	Excavation	Resurfacing	Structures	Composite
1987	-34.3	-11.7	-18.2	-8.3	-13.1
1988	-29.2	-0.9	-18.4	1.8	-7.4
1989	-23.6	-12.5	-18.7	8.6	-6.4
1990	-15.9	-13.3	-16.4	8.1	-5.7
1991	-11.8	-15.6	-12.9	3.2	-6.6
1992	-7.8	-19.9	-12.6	-0.5	-8.7
1993	-3.9	-8.8	-7.2	-3.4	-5.9
1994	0	0	0	0	0
1995	3.8	3.2	2.7	3.7	3.8
1996	8.9	6.5	5.5	7.3	7.5
1997	9.9	9.7	8.2	11	11.3

In order to improve the estimating of construction costs, trends would need to be evident in the data that would allow an agency to forecast changes in costs that are much higher or lower than the general rate of inflation (which is addressed through the use of a discount rate). The values from table 6-2 were plotted to identify any trends that could be used to help establish such a pattern. A review of the resulting plot, shown in figure 6-1, illustrates that no simple trends in forecasting future construction costs appears to be evident. However, the years 1995 through 1997 seem to show closer trends than in previous years. This would tend to support the theory that in recent years, construction prices are following the CPI fairly closely.

6.2 Improving Maintenance Cost Reporting

One of the greatest concerns regarding the SDDOT's LCCA procedures is the accuracy and appropriateness of the current maintenance cost estimating techniques. As discussed in the previous chapter, the SDDOT currently uses two average maintenance costs: one for asphalt pavements and one for concrete pavements. No distinctions are made in costs for pavement design, functional class, and geographic location. This situation resulted in large part from the lack of historical maintenance cost data since maintenance costs were being reported over large non-homogenous sections. Cost for all types of in-house maintenance were reported together and mainline and shoulder costs were also mixed.

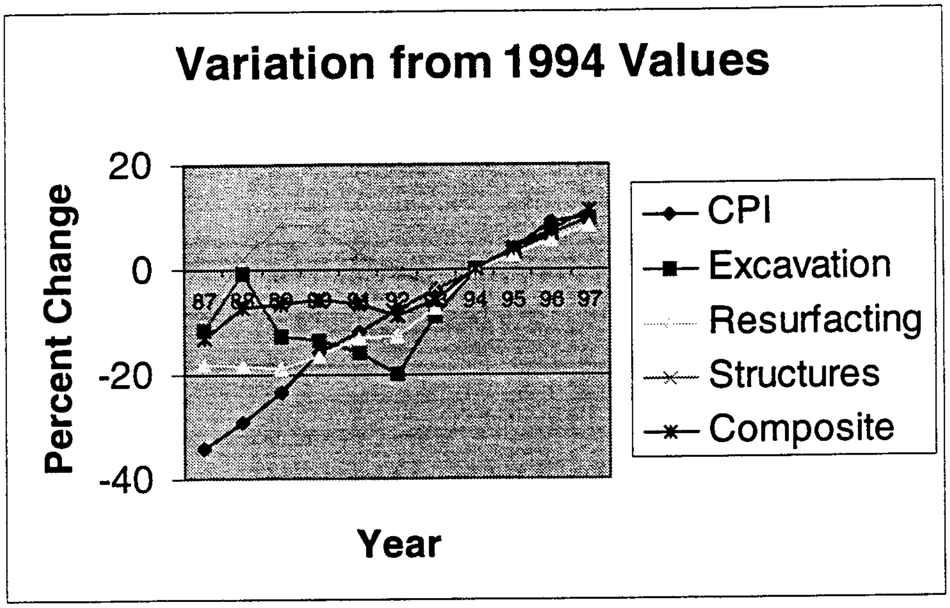

Figure 6-1. Variations in CPI and Construction Price Indices

Immediately prior to the start of this research project, changes have been made within the Department to improve the reporting of maintenance cost data. These changes included modifications to the reporting procedures that allowed for individual maintenance activities to be reported on homogenous segments rather than along an entire length of a highway maintenance unit. In addition, changes were made to differentiate between mainline and shoulder work.

The SDDOT's historical maintenance cost data, reported in the *Highway Needs Analysis and Project Analysis Report*, reflects both formal and informal maintenance activities. The data also reflect costs spent on activities that affect pavement performance, such as crack sealing, and activities that do not impact performance, such as snow removal and mowing. Formal maintenance activities, such as chip seals and rout and seal, can typically be separated out. Informal maintenance may be separated out, but it is generally included in the average per mile maintenance cost for a surface type. If necessary, contract maintenance could be pulled out of the average mile maintenance costs, however the average cost still reflects materials, time, wages, equipment, and miscellaneous costs (such as freight). Indirect costs are not normally charged to a project.

The historical maintenance data also contains some discrepancies in the reporting of maintenance activities if both state maintenance and contract maintenance forces do them. An example of this type of activity includes chip seals. Other activities, such as rout and seal, are traditionally done by contract maintenance so this discrepancy is not universal.

As a result of the historical practices, there have been no reasonable options for estimating the cost of maintenance activities in any more detail than asphalt and concrete pavements. For that reason, maintenance cost variations by region and performance differences that may affect the timing of maintenance have been ignored. Instead, costs of $700 per mile to $1200 per mile have been used to reflect the cost of maintenance on asphalt pavements and a range of $350 to $1800 per mile have been used for continuously reinforced concrete pavements. Generally, maintenance costs less than $1000 per mile are used for asphalt pavements and greater than $1000 per mile are used for concrete pavements.

In order to develop recommendations to improve the forecasting of maintenance costs, a number of factors must be addressed. First, the treatments that are included in the LCCA must be addressed to see if they are reasonable. Second, since historical maintenance cost data are not available, the current costs can be compared to values used in other agencies to see if they are comparable. Finally, before recommendations are made to improve the processes, the information should be evaluated as part of a sensitivity analysis to determine its impact on the overall results of the analysis. This final step is included in the next chapter. This chapter focuses on the maintenance information included in the existing LCCA procedures.

6.2.1 Treatments and Costs

Information regarding the types of maintenance activities included in the pavement management system and the pavement type selection process was provided by representatives of the SDDOT. The following activities and costs are shown as maintenance activities in the pavement management system.

<u>Asphalt Treatments</u>

- Rout and Seal Cracks - $1200 per lane mile, $500 mobilization, $100 traffic control, 0.5% preliminary engineering (P.E.), and 10% cost escalation (all costs per 2-lane mile)
- Chip Seal - $4800 per lane mile, $500 mobilization, $500 traffic control, 0.5% P.E., and 10% construction engineering (all costs per 2-lane mile)
- Routine Asphalt Maintenance – Varies based on years since rehabilitation and inflated at a rate of 4% (initial year is set at $500)

<u>Concrete Treatments</u>

- Saw and Seal Joints – $15,280 per lane mile, $500 mobilization, $500 traffic control, 0.5% P.E., and 10% cost escalation (all costs per 2-lane mile)

- Pavement Repair – Varies based on years since rehabilitation and inflated at a rate of 4% (initial year is set at $500)

The timing and selection of these treatments is dependent on the pavement performance models for each surface type, the budget levels available, and the other needs within the agency. The trigger limits for maintenance improvements in the pavement management system are shown in table 6-3.

Table 6-3. Trigger Limits for Maintenance Improvements

Surface Type	Treatment	Conditions
Rigid Pavements	Saw and Seal Joints	Joint Spalling Index Between 3.7 and 4.5 Joint Seal Index Between 2.0 and 4.3
	Routine Maintenance	Age Since Last Rehabilitation Greater Than 1.0
Flexible Pavements	Chip Seal	Transverse Cracking Index Greater Than or Equal (GTE) to 3.5 Fatigue Cracking Index GTE to 3.3 Patching Index GTE to 2.3 Block Cracking Index GTE 3.4 Roughness Index GTE 4.0 Rut Depth Index GTE 4.0
	Chip Seal	Rehab = C Age Since Periodic Rehab Equals 1 Transverse Cracking Index Greater Than 4.0 Fatigue Cracking Index GTE 3.3 Patching Index GTE 2.3 Block Cracking Index GTE 3.4 Roughness Index GTE 4.0 Rut Depth Index GTE 4.0
	Chip Seal	Rehab = S Age Since Periodic Rehab Equals 6 Transverse Cracking Index Greater Than 4.0 Fatigue Cracking Index GTE 3.3 Patching Index GTE 2.3 Block Cracking Index GTE 3.4 Roughness Index GTE 4.0 Rut Depth Index GTE 4.0
	Rout and Seal	Rehab = O Age Since Rehab = 2
	Routine Asphalt Maintenance	Age Since Rehab GTE 1

After reviewing the trigger values for rigid and flexible maintenance activities, it is evident that many of the treatments are triggered by condition levels, as defined by the various distress indices. However, there are several treatments, such as routine asphalt maintenance that are triggered only by the age since the last rehabilitation treatment.

The pavement type selection process uses a different set of recommendations for its maintenance cost estimating. The maintenance treatments considered at this level are listed below.

Rigid Pavement Options

- Concrete Pavement Restoration (CPR) at year 15 and year 30
- Year 15 CPR costs $20,000 per mile
- Year 30 CPR costs $80,000 per mile

Flexible Pavement Options

- Crack Seal in years 2, 18, and 34
- Chip Seal in years 3, 19, 35
- Crack seal costs are $1,306 per mile
- Chip seal costs are $6,584 per mile

Immediately, one can note the substantial differences in costs and timing of maintenance activities specified at the network and project level. For instance, the pavement type selection process uses costs for CPR at year 15 and 30. The pavement management system, on the other hand, has specific maintenance activities such as saw and seal joints and pavement repair listed. It is not clear whether the difference in terminology represents the same activities. Further, the pavement management system assumes an annual maintenance cost while the pavement type selection process does not. Other differences, such as the costs used in the analysis and the types of treatments considered, are also evident.

The current treatment recommendations can be compared to treatments used by other transportation agencies to compare the reasonableness of the recommendations. In 1996, an NCHRP Synthesis titled *Cost-Effective Preventive Pavement Maintenance* summarized the preventive maintenance activities being used in state transportation agencies (Geoffroy 1996). The report tabulates the results of a survey sent to the state highway agencies to address the types of treatments being used, the frequency of their application, and the types of costs incurred. The summary also presents the increase in pavement life (in years) gained by the application of the treatment and the source of the information. The following preventive maintenance activities are summarized in Appendix D of the synthesis.

Portland Cement Concrete Surfaces

- Joint Spall Repair
- Joint Sealer Replacement

Asphalt Concrete Surfaces

- Crack Filling
- Single Application Chip Seal
- Multiple Application Chip Seal
- Slurry Seal
- Micro-Surfacing
- Thin Hot Mix Asphalt (HMA) Overlay

Asphalt Overlaid Concrete Pavement

- Fill Sawed and Sealed Joint in AC over old joints in concrete
- Crack Filling
- Single Application Chip Seal
- Multiple Application Chip Seal
- Slurry Seal
- Micro-Surfacing
- Thin HMA Overlay

The results of the survey of state practices are summarized in tables 6-4 through 6-7. These tables summarize the values reported by the responding states for the treatments most common to those used by the SDDOT: joint spall repair, joint sealer replacement, crack filling for asphalt pavements, and single chip seal. The following options were provided as sources of information for each maintenance activity.

1. Pavement Management System
2. Maintenance Management System
3. Research project conducted to determine benefits of preventive maintenance
4. Estimate based on the observational experience of the agency's maintenance, materials, and pavement engineers.

A quick comparison of the treatment timings and costs used by the SDDOT pavement type selection process and the practices reported by other states show some differences. On rigid pavements, the SDDOT includes CPR in years 15 and 30 at a cost of $20,000 and $80,000 per lane mile, respectively. Although the activities included in SDDOT's CPR are not specifically mentioned, joint spall repair and joint seal repair could be expected to be included. Tables 6-4 and 6-5 indicate that most state agencies apply both joint spall repair and joint seal repair more often than the SDDOT and usually perform the first application prior to year 15. The costs are difficult to compare since additional activities could be included in the per lane mile costs reported by the SDDOT.

A comparison of crack filling and single application chip seals on flexible pavements show similar results. The SDDOT pavement type selection activities are reported to include crack sealing beginning in year 2 with an application every 16 years at a cost of

$1,306 per lane mile. In year 3, a chip seal is applied. This treatment is repeated every 16 years at a cost of $6,584 per lane mile.

The crack seal activities are compared to those reported in table 6-6. The first application of crack sealing in year 2 seems reasonable in comparison to the information reported by other states. The frequency of application, however, is much longer than the applications reported by any other states. Most states reported a frequency between 2 and 6 years. The crack seal costs seem reasonable compared to other states.

One of the differences in the frequency of SDDOT's crack sealing program is the immediate application of a chip seal in the year following the crack seal program. The SDDOT's application frequency of 6-7 years is reasonable, with most frequencies being in the 5-8 year range. The early application of a chip seal in year 3 is much earlier than other states are applying this treatment, with typical ages of 5-10 years being reported.

6.3 Summary

The work summarized in this chapter focuses on methods to improve the LCCA procedures in the SDDOT through improvements to the economic and maintenance forecasting tools being used. There appears to be some basis for better estimating the discount rate used in the analysis based on historical trends. Each year, a 5-year average of the reported discount rate could be used for the State's LCCA. This would provide the State with a foundation for better estimating the present worth of various treatments.

Another component of the economic analysis is the determination of costs that are used for maintenance, rehabilitation, and reconstruction activities. There does not appear to be a method of forecasting future construction cost activities from indexes such as the construction price index.

This chapter also focused on improving maintenance cost reporting so that the anticipated costs associated with the application of maintenance activities could be improved. Based on per lane mile costs reported by other states for maintenance activities, South Dakota's current costs do not appear to be out of line. There does not exist any historical information that would improve these costs to incorporate variation in pavement performance or to better estimate costs by surface type. As maintenance information is collected using the new reporting techniques, this information may be available in the future.

Finally, the timing of maintenance activities used in the pavement type selection process were compared to practices in other states. Rigid pavement maintenance activities are applied later than in most states and the frequency of application in South Dakota is longer than other states practice. Crack sealing performed on flexible pavements is started at times similar to other stages, and the 6-7 year frequency is in line with other states. The chip seal application in South Dakota is started earlier than in other states, but its frequency is longer than other states use.

Table 6-4. Joint Spall Repair For PCC Pavements (Geoffroy 1996).

State	Age at First Application	Frequency of Application (years)	Cost Per Lane Mile ($)	Observed Increase in Pavement Life (years)	Source of Information (see footer to table)
AL	>20	7-8	50,000-74,999	7-8	4
AR	As needed		1,500-1,999	5-6	4
CA	All ages	5-6	Unknown	2-4	4
GA	10-11		2,000-3,999	7-8	2,4
ID	9-10	7-8	7,000-9,999	Unknown	4
IN	9-10	9-10	25,000-49,000	7-8	1,4
IA	9-10	Varies	7,000-9,999	7-8	4
KS	9-10		10,000-14,999	5-6	4
LA	7-8	Varies	1,000-1,499	2-4	4
ME	As needed		<1,000	Unknown	4
MD	9-10	5-6	$132/sy	5-6	1,2,4
MN	12		10,000-14,999	7-8	4
MO	9-10	2-4	5,000-6,999	7-8	4
NE	As needed	Varies	<1,000	N/A	2
NV	5-6	2-4	10,000-14,999	2-4	1,2,4
NM	9-10	5-6	1,000-1,499	5-6	4
NY	9-10	9-10	5,000-6,999	Unknown	1,4
NC	9-10		7,000-9,999	9-10	4
OH	>10	Varies	$128/cy	2-4	4
RI	7-8	2-4	1,500-1,999	5-6	4
SC	2-4	9-10	Unknown	9-10	4
TN	9-10	Varies		2-4	4
TX	10+		$100/sy	5-6	4
WI	7-8	5-6	1,500-1,999	5-6	1,2
SD	**15**	**15**	**$20,000 to $80,000 for CPR (per 2-lane mile)**		**4**

1. Pavement Management System
2. Maintenance Management System
3. Research project conducted to determine benefits of preventive maintenance
4. Estimate based on the observational experience of the agency's maintenance, materials, and pavement engineers

Table 6-5. Joint Sealer Replacement for PCC Pavements (Geoffroy 1996).

State	Age at First Application	Frequency of Application (years)	Cost Per Lane Mile ($)	Observed Increase in Pavement Life (years)	Source of Information (see footer to table 6-4)
AL	>20	7-8	25,000-49,999	7-8	4
AZ	9-10	9-10	15,000-24,999	5-6	4
AR	9-10	5-6	1,500-1,999	5-6	4
CA	All ages	5-6	Unknown	2-4	4
CT	9-10	7-8	5,000-6,999	7-8	4
ID	9-10	7-8	10,000-14,999	Unknown	4
IN	9-10	9-10	In spall repair	7-8	1,4
IA	2-4	7-8	5,000-6,999	Unknown	4
ME	As needed		<1,000	Unknown	4
MD	5-6	2-4	10,000-14,999	9-10	2,4
MI	10-15		15,000-24,999	9-10	4
MN	12		5,000-6,999	7-8	4
MO	9-10	2-4	1,500-1,900	5-6	4
NV	5-6	2-4	15,000-24,999	2-4	2,4
NM	20	9-10	2,000-3,999	9-10	4
NY	7-8	7-8	5,000-6,999	Unknown	1,4
NC	7-8	7-8	5,000-6,999	9-10	4
PA	5-6	5-6	$9.20/gal	Unknown	1,2,4
SC	9-10	12-15	7,000-9,999	9-10	4
TN	7-8	7-8	10,000-14,999	Unknown	4
TX	10+		50,000-74,999	5-6	4
VA	9-10	7-8	4,000-4,999	5-6	4
WA	5-6	5-6	<1,000	5-6	4
SD	**15**	**15**	**$20,000 to $80,000 for CPR (per 2-lane mile)**		**4**

Table 6-6. Crack Filling for AC Pavements (Geoffroy 1996).

State	Age at First Application	Frequency of Application (years)	Cost Per Lane Mile ($)	Observed Increase in Pavement Life (years)	Source of Information (see footer for table 6-4)
AL	9-10	7-8	10,000-14,999	2-4	4
AK	<2	5-6	2,000-3,999	2-4	1,4
AZ	5-6	2-4	1,000-1,499	2-4	1,2,4
AR	5-6	2-4	1,000-1,499	2-4	4
CA	All ages	5-6	2,000-3,999	2-4	4
CT	7-8	5-6	15,000-24,999	5-6	1,2,4
GA	7-8		<1,000	2-4	2,4
ID	5-6	2-4	$1/lf of crack	7-8	4
IN	2-4	2-4	<1,000	2-4	2,4
IA	2-4	5-6	1,500-1,999	Unknown	4
KS	9-10	3-5	1,000-1,499	2-4	4
LA	5-6	2-4	1,500-1,999	2-4	1
ME	2-4		2,000-3,999	Unknown	1
MD	7-8	2-4	5,000-6,999	5-6	1,2,4
MI	2-4		Varies	5-6	4
MN	2-4		1,500-1,999	<2	4
MS	7-8	2-4		2-4	4
MO	2-4	<2		7-8	4
NV	2-4	<2	15,000-24,999	2-4	1,2,4
NH	5-6	5-7			
NM	7-8	5-6	5,000-6,999	5-6	1
NY	2-4	2-4	1,500-1,999	Unknown	1,4
NC	5-6	7-8	2,000-3,999	7-8	4
OH	5-6		1,000-1,499	2-4	4
PA	2-4	2-4	$7.40/gal	2-4	1,2,4
RI	7-8		2,000-3,999	7-8	4
SC	10-20	5-6	Varies	5-6	4
TN	Varies	Varies	2,000-3,999	2-4	4
TX	9-10	2-4	1,500-1,999	2-4	4
VT	2-4		1,000-1,499	5-6	2,4
WA	5-6	5-6	1,000-1,499	5-6	4
WI	2-4	5-6	1,000-1,499	2-4	1,3,4
SD	**2**	**6-7**	**$1306 (per 2-lane mile)**		**4**

Table 6-7 Single Application Chip Seal for AC Pavements (Geoffroy 1996).

State	Age at First Application	Frequency of Application (years)	Cost Per Lane Mile ($)	Observed Increase in Pavement Life (years)	Source of Information (see footer for table 6-4)
AL	7-8	7-8	5,000-6,999	2-4	4
AK	>15		15,000	2-4	1,4
AZ	7-8	7-8	7,000-9,999	7-8	1,2,4
AR	Varies		2,000-3,999	2-4	4
CA	5-6	5-6	7,000-9,999	2-4	4
CT	11-15	2-4	15,000-24,999	7-8	1,2,4
GA	11-12		2,000-3,999	4-5	2,4
ID	<2	7-8	5,000-6,999		4
IN	7-8	5-6	2,000-3,999	5-6	2,4
IA	15-20	5-6	5,000-6,999	5-6	4
KS	9-20	3-5	2,000-3,999	2-4	4
LA	9-10	7-8	4,000-6,999	5-6	4
MD	9-10	5-6	4,000-4,999	5-6	4
MI	>10		5,000-6,999	5-6	4
MN	2-5	Varies	7,000-9,999	Unknown	3,4
MS	7-8	5-6	4,000-4,999	5-6	4
MO	12-14	9-10	4,000-4,999	2-4	4
NV	5-6	5-6	10,000-14,999	5-6	1,2,4
NM	9-10	5-6	1,000-1,499	5-6	1
NY	7-8	2-4	7,000-9,999	2-4	3,4
NC	7-8	5-6	5,000-6,999	5-6	4
PA	5-6	5-6	4,000-4,999	5-6	1,2,4
SC	15-20	5-6	5,000-6,999	2-4	4
TN	>10	Varies	10,000-14,999	2-4	4
TX	9-10	7-10+	7,000-9,999	7-8	2,4
WA	7-8	7-8	7,000-9,999	7-8	4
WI	5-6	5-6	5,000-6,999	5-6	4
SD	**3**	**6-7**	**$6,584 (per 2-lane mile)**		**4**

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7.0 Sensitivity Analysis

In order to make specific recommendations to the SDDOT that will help improve the consistency and reliability of the results of their LCCA, it is important that the recommendations match the capabilities of the Department personnel and that reasonable efforts are made to address the factors that most significantly influence the results of the analysis. In order to determine which variables have the greatest influence on the State's LCCA, a sensitivity analysis was conducted. The results of the sensitivity analysis are presented in this chapter. The information obtained through this portion of the project had a substantial influence on the recommendations made to the Department in chapter 9.0.

7.1 Sensitivity Analysis Framework

The sensitivity analysis was designed to evaluate the effect that changing one input variable would have on the resulting LCCA results used by the SDDOT. The analysis was conducted by varying one or more input variables, such as discount rate and initial cost, to determine the importance of the variable on the resulting net present value. This type of analysis provides an agency with the ability to determine the variables that have the largest impact on the results of the LCCA. Armed with this information, the SDDOT can focus on improving those variables that have the most significant effect on the results of the analysis.

The analysis used a present worth analysis to evaluate the sensitivity of each input variable. As part of the sensitivity analysis, the following variables were considered independently.

- Discount rate
- Analysis period
- Initial costs
- Periodic costs (including amount and timing)
- Annual costs (including amount and timing)
- Salvage value

Nominal values for each variable were established as the baseline for the analysis. The following costs were used in the analysis as default values when that particular variable was not being analyzed in the sensitivity analysis.

- Discount rate = 4 percent
- Analysis period = 30 years
- Initial cost = $500,000
- Periodic cost = $200,000 at year 15
- Annual cost = $4,000 from years 2 to 30
- Salvage value = $150,000 (30 percent of initial costs)

Each variable was considered independently and the results were plotted so the effects could be easily assessed. In many instances, the plots depict a change in one variable for various other values of a second variable. For instance, the effect of discount rate was evaluated for different analysis periods, salvage values, and initial costs. These plots provide an opportunity to evaluate two variables at a time.

The results of the sensitivity analysis are presented in Appendix E. A summary of the findings is presented in the following section.

7.2 *Summary of the Sensitivity Analysis Results*

Before deciding what improvements should be made to any individual component of a LCCA, it is important to understand which variables have the most impact on the analysis results. In some cases, choosing not to include a cost factor, because either the costs are difficult to obtain or the uncertainty of the accuracy of the costs is so high, may be a prudent decision. This is especially true if the impact of the particular cost factor on the LCCA results is only marginal.

This section summarizes the findings from the sensitivity analysis. It presents each of the variables considered and the impact on the analysis results. The supporting documentation for each of these points was presented in the previous section.

7.3.1. Discount Rate

- Higher discount rates reduce the present worth of a single cost (negative cost for salvage value).
- Changes in the discount rate are more significant at lower discount rates (i.e., an increase from 1 to 2 percent has more effect than an increase from 3 to 4 percent).
- The discount rate has more impact on costs incurred later in the analysis period. The initial cost is not affected by the discount rate, whereas the salvage value is greatly affected by the discount rate.

7.3.2 Analysis Period

- Assuming the amount of periodic cost remains unchanged, the analysis period does not have a significant effect on present worth.
- The effect becomes more significant as the salvage value, which occurs at the end of the analysis period, increases.
- Longer analysis periods usually entail more periodic costs (major maintenance or rehabilitation), that significantly affect the present worth. In other words, more maintenance and rehabilitation treatments (and therefore more costs) are generally incurred during a 40-year period than over a 25-year period. If that assumption is true, comparisons of present worth values for two different analysis periods are not comparable.
- Comparison of alternatives using present worth must have the same analysis periods.

- Using different analysis periods, the lowest present worth does not always translate to the lowest equivalent uniform annual cost.

7.3.3 Initial Costs

- Because initial costs are already in present worth dollars, they have a direct effect on the present worth (i.e., the change in the initial cost is equal to the change in the present worth).
- Initial costs are not affected by discount rate.
- Initial costs must be accurately estimated.

7.3.4 Periodic Costs

- Periodic costs, such as major maintenance or rehabilitation costs, will significantly affect present worth.
- The amount of all periodic costs within the analysis period is critical.
- The timing of a single periodic cost is nearly insignificant (less than 5 percent change from year 10 to year 20).
- The amount and timing of periodic costs become less significant as the discount rate increases.
- The number of periodic costs, assuming the total costs remain constant, has little effect on the present worth.

7.3.5 Annual Costs

- Annual costs do not have a significant impact on the present worth (doubling the annual cost results in less than 10 percent change in present worth).
- The impact is further reduced as the discount rate goes up.
- The timing of annual costs (year costs begin or end) has only a minor effect on present worth.
- An increase in annual costs over the analysis period does not greatly affect present worth.

7.3.6 Salvage Value

- Because salvage value occurs at the end of the analysis period, its effect on present worth is minimized.
- Longer analysis periods and higher discount rates will reduce the effect of salvage value.

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8.0 FHWA Recommendations on Best Practice in LCCA

In 1996, the FHWA initiated a Demonstration Project to investigate techniques being used in LCCA and produce a Technical Bulletin to provide guidance to states for conducting this type of analysis. At the time this report was written, the Draft Technical Bulletin had been prepared and a pilot of the demonstration project had been conducted. The information contained in this chapter summarizes the information published in the January 1997 Draft version of the Technical Bulletin (FHWA 1997).

8.1 Overview

The FHWA Technical Bulletin provides guidance and recommendations on sound practice for conducting a LCCA in pavement design practices. It does not address the use of LCCA techniques at the network level, such as that used in a pavement management system. Many of the recommendations provided in this report, however, can be used at the network level as well as at the project level. In fact, the SDDOT should try as much as possible to be consistent in their practices at these two analyses levels.

The FHWA Technical Bulletin begins with a discussion of the fundamental principles involved in conducting a LCCA. Much of the material discussed in this portion of the Technical Bulletin is presented in chapter 3.0 of this report, *Introduction to a Life-Cycle Cost Analysis*. A large portion of the Technical Bulletin focuses on the individual components of a LCCA, including recommendations for the length of the analysis period, construction cost estimates, and user cost estimates. The Technical Bulletin also introduces the use of probability in a LCCA and provides an example of a net present value analysis that incorporates the use of probabilistic analysis tools.

This chapter attempts to summarize the recommendations included in the Technical Bulletin as best practice. Documentation to support the recommendations made by FHWA is available in the Technical Bulletin.

8.2 FHWA Recommendations for LCCA

The FHWA recommends that highway agencies develop comprehensive procedures that provide them with sufficient levels of information so that a LCCA can be used to capture and evaluate the differences between various pavement design alternatives and supporting rehabilitation strategies. Formalized, objective procedures should be used so that information for the analysis is used consistently throughout the Department.

8.2.1 Analysis Type

The FHWA promotes the use of Net Present Value (NPV) for conducting a LCCA. The NPV of each alternative is computed using the following economic/mathematical formula.

$$\text{NPV} = \text{Initial Cost} + [\text{Future Cost} / (1 + \text{Discount Rate})^n]$$

8.2.2 Costs

Chapter 3.0 of this report presents a discussion on the use of real/constant or nominal dollars in a LCCA. Constant dollars reflect dollars with the same or constant purchasing power over time. Nominal dollars, on the other hand, reflect dollars with fluctuating purchasing power as a function of time. Nominal dollars are generally used to fold in future price rises due to anticipated inflation.

A LCCA can be conducted using either real/constant dollars or nominal dollars, but FHWA suggests that best practice indicates the use of real/constant dollars and real discount rates. This combination of real values for both costs and discount rate eliminates the need to estimate and include an inflation premium for both cost and discount rates.

8.2.3 Discount Rates

As discussed in the previous section, the FHWA recommends the use of real discount rates, especially if real costs are used in the analysis. The FHWA further recommends the use of a reasonable discount rate that reflects historical trends over long periods of time. Based on averages provided in the OMB Circular, FHWA recommends a real discount rate of 3 to 5 percent.

8.2.4 Analysis Period

The primary objective in selecting the length of an analysis period is that it be sufficiently long enough to reflect any long-term cost differences associated with the design strategies being considered. The analysis period should generally be longer than the pavement design period, except in the case of extremely long lived pavements. Shorter periods of time may be used, but generally only when design alternatives are being evaluated to "buy time" until a more permanent rehabilitation activity can be implemented.

The FHWA recommends an analysis period of at least 35 years for all pavement projects, including new construction, rehabilitation, restoration, or resurfacing projects.

8.2.5 Performance Lives and Activity Timing

The estimated performance life of each treatment applied during the analysis period has a substantial impact on the results of the LCCA. The FHWA recommends that performance information for various pavement strategies be established through an analysis of pavement management data and historical experience. The pavement design strategy should state the year in which each treatment should be considered and identify all activities that should be included. An example of PennDOT's pavement design strategy for new concrete, concrete reconstruction, and unbonded concrete overlays is presented in table 8-1.

Table 8.1 PennDOT's Concrete Pavement Design Strategy (FHWA 1997).

Year	Treatment
5	Clean and seal 25% of longitudinal joints. Clean and seal 5% of transverse joints. 0% for neoprene seals. Seal coat shoulders, if Type I paved shoulders.
10	Same as year 5.
15	Clean and seal 25% of longitudinal joints. Clean and seal 10% of transverse joints. 5% for neoprene seals. Seal coat shoulders, if Type I paved shoulders.
20	Concrete patch 5% of pavement area. Spall repair 1% of transverse joints (5 sf/joint). Slab stabilization: minimum 25% of transverse joint. Diamond grind 100% of pavement area. Clean and seal all longitudinal joints, including shoulders. Clean and seal all transverse joints. 7% for neoprene seals. Seal coat shoulders, if Type I paved shoulders. Maintenance and protection of traffic. User delay.
25	Clean and seal 25% of longitudinal joints. Clean and seal 10% of transverse joints, 10% for neoprene seals. Seal coat shoulders, if Type I paved shoulders.
30	Concrete patch 2% of pavement area. Clean and seal all joints with fiberized asphalt membrane. 60 -#/sy leveling course 3.5 in. ID-2 or 4-in. ID-3/ID-2 overlay. Saw and seal joints. Type 7 paved shoulders. Adjust all guide rail and drainage structures. Maintenance and protection of traffic. User delay.
35	Seal coat shoulders.
Note:	The CPR strategy slated for year 20 can be moved to year 15 at the District's discretion. However, when doing this, the overlay at year 30 must be moved to year 25 and another overlay added at year 33.

8.2.6 Construction Quantities/Unit Prices

Since real costs are being used, it is recommended that quantities and unit prices be determined from historical data compiled by the state highway agency, or from previously bid jobs of comparable scale.

8.2.7 Agency Costs

A LCCA is primarily used to distinguish between competing pavement rehabilitation alternatives through an evaluation of cost differences between the alternatives. Costs that are common to both alternatives are generally not considered in the analysis. For that reason, any agency costs that are considered in the analysis should be included only if they are different costs for the different alternatives.

There are a number of different types of costs that could be incurred by the agency. In general, these include preliminary engineering, contract administration, construction supervision and costs, future maintenance and rehabilitation costs, and any administrative costs. These costs can also include operating costs for special activities such as interchange lighting, or tunnel lighting and ventilation. Some agencies also consider salvage value to be an agency cost.

Perhaps the most straightforward portion of the agency costs is the estimation of construction costs based on previous contracts for projects of similar scope. Maintenance costs are more difficult to obtain, as discussed in an earlier chapter. Other costs specific to one of the alternatives being considered should be detailed on a case by case basis, using previous projects as much as possible to establish the cost estimates.

Salvage values are used by some agencies to represent the value of an alternative at the end of the analysis period. There are two components to salvage value: its residual value and its serviceable life. From a pavement perspective, the FHWA considers the residual value of a pavement to be the net value realized from recycling the pavement. The FHWA considers the differential residual value between pavement design strategies to be minimal, especially when discounted back over 35 years.

The second component of salvage value, serviceable life, represents the more significant of the two components. This component represents the serviceable life at the end of the analysis period. It is used to distinguish between the remaining service life of each of the design strategies at the end of the analysis period. For example, if alternative A reaches the end of its serviceable period at the end of the analysis period (say year 35), it has a salvage value of 0. Another alternative, alternative B, may include a 10-year rehabilitation treatment in year 30. This alternative would have a remaining serviceable life of 5 years at the end of the 35-year analysis period. The salvage value of alternative B would be 50% (5 of the 10 years) of the cost of the 10-year treatment. The salvage value is referred to as a negative cost when the segment has some economic value at the end of the analysis period. In other words, rather than being treated as a cost to the agency, it is treated as a benefit to the agency (or the opposite of a cost).

8.2.8 User Costs

Although very controversial, the FHWA supports the use of user costs in the conduct of a LCCA. Very simply, user costs are those cost incurred by users of a highway facility over the life of the project. They are influenced by road conditions as well as delays caused by construction activities. In a LCCA, agencies should concern themselves with the differences in user costs between competing alternatives.

The FHWA discusses three separate cost components as part of its discussion on user costs: vehicle operating costs, accident costs, and user delay costs. The FHWA Technical Bulletin presents a comprehensive summary of the factors that must be taken into account in order to determine the costs associated with these three components. First, the classification of the vehicles using the facility must be determined since different vehicles have different operating characteristics and operating costs. The FHWA recommends converting the 13 vehicle classifications included in the Traffic Monitoring Guide into 3 classes for heavy trucks, single unit trucks, and passenger vehicles. The FHWA further recommends dividing passenger vehicles into commercial and non-commercial categories since the cost of delays vary significantly for these two categories.

User costs must be determined for both normal operating conditions and work zone operations. During normal operating conditions, there should be little difference in accident costs and delay costs due to pavement design decisions. For that reason, FHWA does not promote the comparison of user costs during normal operating conditions as part of the LCCA until research findings are available to better quantify the variation in these costs.

Competing pavement rehabilitation alternatives can vary significantly in the user delay and accident costs associated with initial construction and future maintenance activities. Additional costs caused by the delay of commercial vehicles should also be taken into account in this category. These costs are largely impacted by the amount and operating characteristics of the traffic effected, and the dollar costs assigned to vehicle operating costs and delay time. The FHWA recommends that characteristics such as the frequency of construction and maintenance activities and the number of days the work zone will last be specified for each preservation strategy. Ideally, the development of alternatives should identify the length of the section; the number, duration, and timing of lane closures; posted speeds; and the availability and physical characteristics of alternative routes. The FHWA also points out that user costs associated with routine maintenance activities are generally infrequent, of short duration, and outside periods of peak traffic flow. For this reason, the FHWA recommends focusing on user costs associated with major work zones normally associated with construction activities.

There is an extensive discussion in the draft Technical Bulletin on the calculation of user costs associated with work zone activities. Several examples are also provided to illustrate the concepts that are discussed.

8 .3 Reliability in LCCA

In addition to providing guidance with the components of a LCCA, the FHWA Technical Bulletin also provides information on the reliability of the analysis itself. The discussion starts with a summary of sources of input assumptions normally used in the analysis. For example, the FHWA states that pavement management systems can be a source of much of the information needed to estimate pavement condition and performance and project needs. Much of the information, however, relies on estimates by experienced personnel or assumptions, as listed in table 8-2. Inherent in any of these estimates, projections, or assumptions is a degree of uncertainty that can only be considered if a probabilistic approach is used for the analysis.

Table 8-2. Typical Source of Input Assumptions (FHWA 1997).

Agency Costs	
Preliminary Engr. Constr Mgmt	Estimates
Construction	Estimates
Maintenance	Assumption
User Costs	
Current Traffic	Estimates
Future Traffic	Projections
Hourly Demand	Estimates
Vehicle Distributions	Estimates
Dollar Value of Delay Time	Assumption
Work Zone Configuration	Assumption
Work Zone Hours of Operation	Assumption
Work Zone Duration	Assumption
Work Zone Activity Years	Projections
Accident Rates	Estimates
Accident Cost Rates	Assumption
Timing of Costs	
Pavement Performance	Projected
Discount Rates	Assumption

Because of the amount of uncertainty that can be expected in the analysis, the FHWA is promoting the use of probabilistic rather than deterministic approaches to LCCA. Using traditional means of conducting a LCCA, agencies rely on a sensitivity analysis to understand the effect of changing one or more values on the final results of the analysis. A sensitivity analysis is somewhat limited by the number of input variables that can be changed at one time.

Today, software is available that allows an agency to estimate the likelihood that a particular net present value will be met. This software uses a probabilistic approach of risk analysis techniques that allow a user to input a range of input values and the probability of their occurrence. The outputs from this analysis include probability distributions of the LCCA results. As a result, an agency can more rationally and confidently select the most appropriate alternative.

The probabilistic approach relies on a Monte Carlo simulation, which allows the substitution of variability into equations. The FHWA discusses the use of risk analysis software packages (such as @Risk or Crystal Ball) that work in conjunction with spreadsheet software programs to do the statistical analysis using Monte Carlo simulation. These programs operate as "add-in" functions to spreadsheets that provide an opportunity to input a description of the variation in an input value. The FHWA encourages the use of this type of analysis for input variables such as cost, the year the costs will be incurred, and the discount rate.

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9.0 Guidelines for the use of LCCA in the SDDOT

This research study was initiated in order to provide guidelines and recommendations that improve the reliability and consistency of LCCA procedures in the SDDOT. The guidelines incorporate recommendations for improving the use of economic factors and maintenance costs in the Department's pavement management system and pavement selection process. The recommendations are based on an evaluation of the practices in other states, the guidelines developed by the FHWA, and the constraints affecting the SDDOT. The chapter concludes with recommendations for incorporating the guidelines into the Department's ongoing pavement rehabilitation and reconstruction activities.

9.1 The Use of LCCA in the SDDOT

The identification of pavement preservation activities to improve and maintain the condition of the highways in the State of South Dakota is conducted at two levels; the network- and project-levels. At the network-level, projects are prioritized among the state and feasible rehabilitation activities are identified. At the project-level, individual highway improvements are analyzed in more detail as part of the pavement type selection process. Life-cycle costing is an important component of each of these analysis levels, influencing the types of treatments that are most cost-effective for the Department.

The FHWA's NHS Designation Act of 1995 mandates the use of a LCCA on all NHS projects with a cost of $25 million dollars or more. These guidelines recommend an expanded use of a LCCA, as part of the incremental benefit cost analysis in the pavement management system and as part of the pavement selection process for new construction and rehabilitation projects within the State where alternate designs are considered feasible. In order to be useful to the Department, it is critically important that the two analysis levels utilize consistent economic factors and treatment considerations as much as possible. Further, it is important that a feedback loop is established between the pavement management and design groups so that realistic pavement performance trends can be incorporated into the analysis.

The LCCA should consider all costs associated with the construction, rehabilitation, and maintenance of a facility over an analysis period that should encompass the service life of all alternatives. The results of the LCC analysis are important in selecting the preferred alternative, but other factors, such as budget constraints, constructability, and environmental constraints, should also be taken into consideration in selecting the best alternative for any given project.

9.2 Economic Analysis Approach

The LCCA will be based on a present worth (PW) analysis technique that allows the conversion of all present and future costs to a single point in time or converts the costs to an equivalent uniform annual cost (EUAC). In the PW analysis, the present and future expenses are converted to a base of today's costs and the total present worth costs are then compared to one another. The annualized approach (EUAC) is very similar to the present worth analysis because the cost of a future expenditure must first be converted to its present worth cost before calculating its annualized cost. It is anticipated that the pavement selection process will utilize the PW approach and the pavement management system will use the EUAC analysis. For purposes of these guidelines, both of these analysis techniques are referred to as a PW analysis.

The general form of each equation is presented below.

Present Worth Method

$$PW = F\,[1/(1+i)^n]$$

Where PW = Present worth,
F = The future sum of money at the end of n years,
n = Number of years, and
i = Discount rate.

The factor $[1/(1+i)^n]$ is also known as the Single Payment Present Worth Factor (SPW).

Annualized Method

$$A = PW\,\frac{i\,(1+i)^n}{(1+i)^n-1}$$

Where A = Annual cost,
PW = Present worth,
n = Number of years, and
i = Discount rate.

The factor $\frac{i\,(1+i)^n}{(1+i)^n-1}$ is also known as the Uniform Capital Recovery Factor (UCR)

Research indicates that the majority of states use one or both of these approaches as the basis of their LCCA (WSDOT 1995). These approaches are also recommended in the FHWA Draft Technical Bulletin (FHWA 1997).

9.3 Nominal Versus Real Dollars

As discussed in an earlier chapter, a PW analysis can be conducted using either nominal or real (constant) dollars. Nominal dollars are used to represent costs that have fluctuating purchasing power over time. In most cases, nominal dollars are used to factor in costs associated with inflation.

These guidelines support the use of real dollars in the LCCA, as supported by the FHWA Draft Technical Bulletin (FHWA 1997). Real dollars reflect costs that maintain a constant level of purchasing power over time. The use of real dollars is recommended because it eliminates the need to estimate and include an inflation premium for both costs and discount rates in the analysis. Because an analysis should not mix the use of real dollars with nominal dollars, and the fact that if real costs are used then real discount rates must be used, the use of real discount rates is also recommended.

9.4 Discount Rate

A discount rate is used in a LCCA to compare costs that occur at different points in the analysis period. The discount rate is used to reduce the impact of future costs on the analysis, reflecting the fact that money has a time value (Kleskovic 1990). The discount rate is generally defined as the difference between the market interest rate and inflation, using real dollars.

The selection of an appropriate discount rate is complicated by the fact that the market interest rate and inflation rates fluctuate with time. For that reason, it is difficult to identify a discount rate that will be representative over the entire analysis period. It should also be recognized that the discount rate should not be based on unusual economic conditions that occur for only a short period of time.

The sensitivity analysis conducted as part of this study found that changes in the discount rate are more significant at lower discount rates than at higher discount rates (i.e., an increase from 1 to 2 percent has more effect than an increase from 3 to 4 percent). Further, high discount rates favor alternatives that stretch costs out over a period of time, since the future costs are discounted in relation to the initial costs. A lower discount rate favors alternatives with high initial costs since the future costs are added in almost at face value.

At the present time, the SDDOT does not use a discount rate as part of its pavement selection process. However, a discount rate of 3 percent is used in the pavement management LCCA. A historical review of national discount rates was presented in chapter 6 of this report. This review shows that for an analysis period of 30 years, the 1996 average 5-year discount rate is 3.8 percent. This value falls within the guidelines recommended by the FHWA (3 to 5 percent).

For purposes of developing guidelines, it is recommended that the SDDOT use a 5-year average discount rate rounded to the nearest integer in its LCCA. The OMB as an appendix to OMSB Circular A-95 publishes annual updates of the average discount rates. It is suggested that these annual updates be used each year to determine the average rate to be used in the analysis. For 1997, a discount rate of 4 percent should be used, based on the 1996 5-year average value. This recommendation supports the use of a national discount rate because it is easy to justify to the legislature, industry, and Department staff. It also balances local fluctuations in economic factors with national trends. An average value is important so that yearly fluctuations in economic factors are minimized.

9.5 Analysis Period

The analysis period is the time period over which each of the feasible treatments is compared. The analysis period should be long enough to reflect any long-term cost differences associated with the alternate design strategies by incorporating several maintenance and rehabilitation activities. The FHWA Draft Technical Bulletin (FHWA 1997) suggests an analysis period of at least 35 years. The survey of state practice conducted as part of this study showed a range of analysis periods are being used, although the majority ranged between 20 and 40 years. Finally, the 1993 *AASHTO Guide for the Design of Pavement Structures* provides the following recommendations for different highway conditions.

Highway Conditions	Analysis Period (years)
High Volume Urban	30 to 50
High Volume Rural	20 to 50
Low Volume Paved	15 to 25
Low Volume Aggregate Surface	10 to 20

At the present time, the SDDOT uses an analysis period of 40 years in its pavement selection process and 50 years in its pavement management system. The sensitivity analysis found that the length of the analysis period does not have a significant impact on the results of the analysis.

It is recommended that the SDDOT adopt the use of a single analysis period for each of its LCCA levels that is long enough to reflect the cost differences in various alternatives, without being too long to adequately represent the future economic factors and pavement performance characteristics. For these reasons, an analysis period of 40 years is recommended.

9.6 Cost Factors

In general, all costs associated with the maintenance, construction, and rehabilitation of a facility during the analysis period should be considered in a LCCA. For purposes of conducting the analysis, however, only the differences in costs associated with each alternative are included in the analysis. Equal costs that are incurred at the same time for each alternative will have an equal impact on the present worth, so need not be considered.

The following costs may be considered in the analysis.

9.6.1 Design Costs

Design costs are generally not included in a LCCA because they are assumed to be equal for each design being considered. If, however, the cost of one design is significantly different, than the cost of the others being considered, then these costs should be considered in the analysis. The difference in design costs should be estimated as a percentage of the total initial construction cost.

9.6.2 Construction Costs

Construction costs are frequently referred to as the initial costs associated with each of the design alternatives being considered. Based on the results of the survey of state practice that was conducted as part of this study, most agencies rely on departmental or historical estimates to prepare these costs using previous contracts as the basis for these estimates.

The results of the sensitivity analysis conducted as part of this project illustrate that the results of the present worth analysis are very dependent on the values used to estimate the initial costs of a project. For that reason, the estimates should be as current as possible and should reflect geographical or regional differences, as much as possible.

The SDDOT should use the historical information from previous bids on projects to develop an initial cost rate sheet that can be used in both the pavement selection process and the pavement management system. The document should be incorporated into the final LCC guidelines developed for the state to ensure consistency in the use of these values. The cost rate sheet should be evaluated annually and updated as necessary to reflect the existing pricing trends.

9.6.3 Maintenance Costs

Maintenance costs reflect those costs associated with maintaining a pavement above a predetermined condition level using both corrective and preventive maintenance activities. Historically, maintenance costs have been very difficult for the SDDOT to estimate due to its maintenance cost reporting practices. In recent years, efforts were initiated to improve the effectiveness of maintenance cost reporting to reduce the state's reliance on one maintenance cost for asphalt pavements and one cost for concrete pavements.

The survey of state practice in LCCA clearly illustrates that maintenance cost reporting is one of the most difficult aspects of the analysis for most states. Fortunately, because of the relatively low cost of maintenance, and the discounting of these costs over time, the results of the present worth analysis are not largely impacted by the accuracy of maintenance costs in the analysis. In fact, doubling the annual maintenance costs, or altering the years in which they are applied, did not have a significant effect on the results of the analysis.

It is recommended that the SDDOT develop a consistent maintenance policy for each of its design treatments that can be used by both the pavement management system and the pavement selection process. The policy should specify the types and timing of maintenance treatments that should be applied following the application of either a reconstruction or rehabilitation treatment. The costs associated with these treatments should also be specified.

As much as possible, the maintenance cost estimates used in the maintenance policy should be reflective of the costs recorded by the maintenance records for each pavement design. However, because of the relatively low significance of the maintenance costs on the results of the analysis, these estimates do not need to be much more specific than those currently being used. As these estimates improve over time, they should be updated.

9.6.4 Rehabilitation Costs

One of the reasons for using an analysis period over 35 years is to consider the costs of future rehabilitation in the analysis. Rehabilitation costs represent periodic costs that must be applied at some future date in order to restore the pavement to an acceptable performance level. The results of the present worth analysis are influenced by the timing of the rehabilitation treatment, the costs associated with the treatment, and the expected performance of the treatment after it has been applied. This emphasizes the importance of good pavement performance data to estimate the appropriate timing for applying the treatment and the expected life of the treatment after its application. Data from the pavement management system should be used to prepare these pavement performance estimates.

It is recommended that the pavement management system be used to verify the timing and expected performance of the rehabilitation activities being used in the pavement selection process. This would improve the consistency in the recommendations being used at each analysis level. Costs should be based on bid documents as much as possible, with regional or geographical differences being reflected. The costs should be reviewed at least annually and the treatment timings and performance should be updated each time the pavement management performance models are updated.

9.7 Salvage Value

The salvage value represents the value of the pavement at the end of the analysis period. The analysis period is made up of a residual value, which is generally considered to be negligible, and the serviceable life, which accounts for the difference in remaining pavement life between alternatives. If an alternative has reached its full life cycle at the end of the analysis period, it is generally considered to have no remaining serviceable salvage value. If it has not completed its life cycle, the salvage value is calculated as the percentage of the expected serviceable life remaining multiplied by the cost of the last resurfacing or reconstruction activity. This analysis allows treatments with different serviceable lives to be considered fairly over the analysis period.

The second component of salvage value, the residual value, is representative of the net value of the pavement from activities such as recycling the pavement. In general, the differential residual value between pavement design strategies is not very large. When these values are discounted over an analysis period of 35 to 40 years, they tend to have little impact on the analysis results. For that reason, the residual value of salvage value was not considered further in this study.

The calculation of the serviceable life component of salvage value can be determined using the equation shown below.

Salvage Value = (CC) [ERL/TEL] (WSDOT 1995)

Where CC = Last construction or rehabilitation cost
ERL = Expected remaining life
TEL = Total expected life

The remaining service life of each treatment should be determined using the pavement performance models in the pavement management system, as described in the previous section on rehabilitation costs.

9.8 User Costs

In general, user costs are those costs that are incurred by a highway user over the life of each of the design alternatives. User costs can be made up of three different cost components: vehicle operating costs (such as tires, gas, and oil), accident costs, and user delay costs (such as costs associated with slow downs due to construction and maintenance activities or the inability to use the facility).

The results of the state survey conducted as part of this study indicate that few agencies currently consider user costs as part of their LCCA. Those agencies that do incorporate user costs tend to use the closure period due to construction as the primary consideration in estimating these costs. This is most likely due to the difficulty in estimating the operating costs of each vehicle and the passenger costs of the individuals being delayed.

In order to consider user costs in the analysis, it is recommended that the SDDOT incorporate an estimate of the number of times a facility will be under construction and the number of days each work period will last as part of its analysis. This approach does not address all possible user costs, but provides a means for beginning to incorporate user costs into the analysis. This information is recommended as a supplement to the LCCA rather than a part of the calculation of present worth of each alternative. The number of days of closure is determined independently of the present worth calculation and should only be considered as an additional factor to take into account with factors already being considered in selecting an alternative.

9.9 LCCA Spreadsheet

An Excel spreadsheet has been provided to assist the SDDOT in conducting its LCCA. This spreadsheet, which is presented in the form of a worksheet, allows three different alternatives to be compared over a stated analysis period. For each of the alternatives being considered, initial costs, periodic costs, and annual costs can be entered. A salvage value can also be input in order to determine the final present worth value. A copy of the worksheet is included as figure 9-1.

The spreadsheet also provides the SDDOT with the opportunity to conduct a sensitivity analysis. The tools for conducting the sensitivity analysis are being presented as part of the training class being conducted at the conclusion of the project.

9.10 Impact of Recommendations

The impact of the recommendations made to the SDDOT were evaluated by comparing the results of the LCCA using the recommended economic values to the results provided from an analysis conducted previously by the Department. The framework of the analysis, and the results from both approaches are provided in Appendix F.

9.11 Implementation of the Recommendations

The recommendations provided in this chapter can be implemented immediately upon approval by the SDDOT. The recommendations that are provided do not substantially change the approach being used to conduct the LCCA in the SDDOT. Rather, they improve the economic models currently being used by providing guidelines that can be used consistently by the pavement management system and the pavement selection process in conformance with federal guidelines and state of the practice.

The recommendations require that the existing pavement performance models from the pavement management system be used to update the pavement rehabilitation treatment timings that are considered in the pavement selection process and estimate the serviceable life of each alternative. The SDDOT is in the process of updating their performance models, so this activity could be postponed until the completion of the ongoing study in this area. However, the Department has a reasonable amount of confidence in its existing expert-based performance models, so this activity could begin immediately.

Finally, the SDDOT needs to standardize its policies for maintenance and rehabilitation activities included in the LCCA. This activity will serve to improve the reliability of the analysis results and again improve the consistency of the state's analysis techniques.

9.12 Risk Analysis

The FHWA is currently promoting the use of a probabilistic approach in LCCA so that the risk associated with each of the analysis inputs can be taken into account in the analysis. Instead of using each of the inputs as a single value, a probabilistic approach considers each estimate, projection, and assumption as a range of values and the probability distribution associated with the possible values. The results present the likelihood that a particular present worth will occur.

LIFE-CYCLE COST ESTIMATING WORKSHEET

Enter Initial Analysis Year 1997
Enter Analysis Period 40
Enter Annual Discount Rate, % 2

Project Identification NH 0083(44) 153, Sully county
US83 from Onida N to the Potter County Line
13.0 miles, grading and surfacing AC Alternative

				Alternative 1		Alternative 2		Alternative 3	
				Project Description:		Project Description:		Project Description:	
Initial Costs Item No.	Item Description	Analysis Year	Calendar Year	Estimated Cost	Present Worth	Estimated Cost	Present Worth	Estimated Cost	Present Worth
1	Grade & Interim Surface	0	1997	$345,000	$345,000	$0	$0	$0	$0
2	4" AC Surface	0	1997	$270,000	$270,000	$0	$0	$0	$0
3		0	1997			$0	$0		
4									
5									
6									
7									
8									
Total Present Worth of Initial Costs				$615,000	$615,000	$0	$0	$0	$0

Periodic Costs Item No.	Item Description	Analysis Year	Calendar Year	Estimated Cost	Present Worth	Estimated Cost	Present Worth	Estimated Cost	Present Worth
1	Rout & Seal	2	1999	$1,410	$1,355			$0	$0
2	Chip Seal	3	2000	$7,900	$7,444			$0	$0
3	Chip Seal	10	2007	$7,900	$6,481	$0	$0		
4	Mill 1" with 2.5" AC Overlay	16	2013	$122,000	$88,870	$0	$0	$0	$0
5	Rout & Seal	18	2015	$1,410	$987				
6	Chip Seal	19	2016	$7,900	$5,423				
7	Mill 1" with 2.5" AC Overlay	30	2027	$122,000	$67,353				
8	Rout & Seal	32	2029	$1,410	$748				
Total Present Worth of Periodic Costs					$178,662		$0		$0

Annual Costs Item No.	Item Description	First Yr. of Ann. Costs Analysis Yr.	First Yr. of Ann. Costs Cal Yr	Last Yr. of Ann. Costs Analysis Yr	Last Yr. of Ann. Costs Cal Yr	Estimated Annual Cost	Present Worth	Estimated Annual Cost	Present Worth	Estimated Annual Cost	Present Worth
1	Maint Activity 1	1	1998	5	2002	$500	$2,357				
2	Maint Activity 2	6	2003	7	2004	$1,000	$1,759				
3	Maint Activity 3	8	2005	9	2006	$1,500	$2,535	$0	$0	$0	$0
4	Maint Activity 4	10	2007	11	2008	$1,000	$1,625	$0	$0	$0	$0
5	Maint Activity	12	2009	13	2010	$1,500	$2,342				
6	Maint Activity	14	2011	15	2012	$2,000	$3,002				
7	Maint Activity	16	2013	21	2018	$1,000	$4,162				
8	Maint Activity	22	2019	40	2037	$2,000	$20,689				
Total Present Worth of Annual Costs							$38,470		$0		$0

Replacement/Salvage Value Item No.	Item Description	Analysis Year	Calendar Year	Estimated Value	Present Worth	Estimated Value	Present Worth	Estimated Value	Present Worth
1		40	2037	$0	$0				
2		40	2037			$0	$0	$0	$0
3									
4									
Total Present Worth of Replacement/Salvage Value					$0		$0		$0

TOTAL LCC	Alternative 1	Alternative 2	Alternative 3
Present Worth LCC	$832,131	$0	$0
Equivalent Uniform Annual LCC	$30,419	$0	$0

Lowest LCC Alternative			
PW Cost Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE
% Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE

Figure 9-1. Life Cycle Cost Estimating Worksheet.

The use of probability shows tremendous promise in the area of LCCA, however the use of these techniques is not yet well understood. The SDDOT is encouraged to participate in the FHWA's demonstration project on this topic and incorporate the use of probabilistic techniques in its LCCA as soon as possible.

10. Findings and Conclusions

This report documents the findings and recommendations provided as a result of a study on the use of economic factors and maintenance costs in the SDDOT's LCCA. The study sought to address two issues affecting the Department's conduct of LCCA at the pavement management and pavement selection levels. First, the study investigated the use of more reliable economic factors in the analysis itself. The results are presented in the form of guidelines for the use of economic factors in LCCA. These guidelines include the following recommendations.

- The use of a present worth analysis (which includes equivalent uniform annual cost).
- The use of real dollars and a real discount rate.
- The use of the 5-year OMB average value for discount rate (4.0 for 1997).
- The use of a 40-year analysis period.
- The standardization of construction, maintenance, and rehabilitation treatment consideration through the development of polices that are reviewed annually.
- The use of a salvage value to represent the remaining serviceable life of a treatment at the end of the analysis period.
- The use of the number of closure days associated with each rehabilitation strategy as a supplement to the results of the present worth calculation.

Secondly, the study investigated the importance of various factors on the results of a LCCA. Most importantly, the impact of improved maintenance costs was evaluated because of the expressed concern by the SDDOT on their unreliable maintenance cost estimates. The study found that maintenance costs did not have a significant impact on the results of a LCCA and that the SDDOT did not currently have the historical records available to improve the current maintenance estimates. The Department has implemented improved maintenance cost reporting activities that should refine the existing maintenance estimates in future years.

Most importantly, there should be more consistency between the LCCA conducted as part of the pavement management system and the pavement selection process. Although some differences in the analyses are inherent because of the different levels of analysis, the two approaches should use consistent inputs as much as possible. The pavement performance information from the pavement management system should also be used to improve the rehabilitation timing and service life estimates considered in the pavement selection process.

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Appendix A: Sample Present Worth Tables

Table A-1. Present worth factors for future costs at year n.

Time Period, n	Discount Rate, i									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
2	0.9803	0.9612	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264
3	0.9706	0.9423	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513
4	0.9610	0.9238	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830
5	0.9515	0.9057	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209
6	0.9420	0.8880	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5963	0.5645
7	0.9327	0.8706	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5470	0.5132
8	0.9235	0.8535	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.5019	0.4665
9	0.9143	0.8368	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4604	0.4241
10	0.9053	0.8203	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.4224	0.3855
11	0.8963	0.8043	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3875	0.3505
12	0.8874	0.7885	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3555	0.3186
13	0.8787	0.7730	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.3262	0.2897
14	0.8700	0.7579	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2992	0.2633
15	0.8613	0.7430	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2745	0.2394
16	0.8528	0.7284	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2519	0.2176
17	0.8444	0.7142	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.2311	0.1978
18	0.8360	0.7002	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.2120	0.1799
19	0.8277	0.6864	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1945	0.1635
20	0.8195	0.6730	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1784	0.1486
21	0.8114	0.6598	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1637	0.1351
22	0.8034	0.6468	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1502	0.1228
23	0.7954	0.6342	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1378	0.1117
24	0.7876	0.6217	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1264	0.1015
25	0.7798	0.6095	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.1160	0.0923
26	0.7720	0.5976	0.4637	0.3607	0.2812	0.2198	0.1722	0.1352	0.1064	0.0839
27	0.7644	0.5859	0.4502	0.3468	0.2678	0.2074	0.1609	0.1252	0.0976	0.0763
28	0.7568	0.5744	0.4371	0.3335	0.2551	0.1956	0.1504	0.1159	0.0895	0.0693
29	0.7493	0.5631	0.4243	0.3207	0.2429	0.1846	0.1406	0.1073	0.0822	0.0630
30	0.7419	0.5521	0.4120	0.3083	0.2314	0.1741	0.1314	0.0994	0.0754	0.0573
35	0.7059	0.5000	0.3554	0.2534	0.1813	0.1301	0.0937	0.0676	0.0490	0.0356
40	0.6717	0.4529	0.3066	0.2083	0.1420	0.0972	0.0668	0.0460	0.0318	0.0221
45	0.6391	0.4102	0.2644	0.1712	0.1113	0.0727	0.0476	0.0313	0.0207	0.0137
50	0.6080	0.3715	0.2281	0.1407	0.0872	0.0543	0.0339	0.0213	0.0134	0.0085
60	0.5504	0.3048	0.1697	0.0951	0.0535	0.0303	0.0173	0.0099	0.0057	0.0033

Formula $PW = \frac{1}{(1+i)^n}$

Table A-2. Present worth factors for annual costs over n years.

Time Period, n	Discount Rate, i									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
2	1.9704	1.9416	1.9135	1.8861	1.8594	1.8334	1.8080	1.7833	1.7591	1.7355
3	2.9410	2.8839	2.8286	2.7751	2.7232	2.6730	2.6243	2.5771	2.5313	2.4869
4	3.9020	3.8077	3.7171	3.6299	3.5460	3.4651	3.3872	3.3121	3.2397	3.1699
5	4.8534	4.7135	4.5797	4.4518	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908
6	5.7955	5.6014	5.4172	5.2421	5.0757	4.9173	4.7665	4.6229	4.4859	4.3553
7	6.7282	6.4720	6.2303	6.0021	5.7864	5.5824	5.3893	5.2064	5.0330	4.8684
8	7.6517	7.3255	7.0197	6.7327	6.4632	6.2098	5.9713	5.7466	5.5348	5.3349
9	8.5660	8.1622	7.7861	7.4353	7.1078	6.8017	6.5152	6.2469	5.9952	5.7590
10	9.4713	8.9826	8.5302	8.1109	7.7217	7.3601	7.0236	6.7101	6.4177	6.1446
11	10.3676	9.7868	9.2526	8.7605	8.3064	7.8869	7.4987	7.1390	6.8052	6.4951
12	11.2551	10.5753	9.9540	9.3851	8.8633	8.3838	7.9427	7.5361	7.1607	6.8137
13	12.1337	11.3484	10.6350	9.9856	9.3936	8.8527	8.3577	7.9038	7.4869	7.1034
14	13.0037	12.1062	11.2961	10.5631	9.8986	9.2950	8.7455	8.2442	7.7862	7.3667
15	13.8651	12.8493	11.9379	11.1184	10.3797	9.7122	9.1079	8.5595	8.0607	7.6061
16	14.7179	13.5777	12.5611	11.6523	10.8378	10.1059	9.4466	8.8514	8.3126	7.8237
17	15.5623	14.2919	13.1661	12.1657	11.2741	10.4773	9.7632	9.1216	8.5436	8.0216
18	16.3983	14.9920	13.7535	12.6593	11.6896	10.8276	10.0591	9.3719	8.7556	8.2014
19	17.2260	15.6785	14.3238	13.1339	12.0853	11.1581	10.3356	9.6036	8.9501	8.3649
20	18.0456	16.3514	14.8775	13.5903	12.4622	11.4699	10.5940	9.8181	9.1285	8.5136
21	18.8570	17.0112	15.4150	14.0292	12.8212	11.7641	10.8355	10.0168	9.2922	8.6487
22	19.6604	17.6580	15.9369	14.4511	13.1630	12.0416	11.0612	10.2007	9.4424	8.7715
23	20.4558	18.2922	16.4436	14.8568	13.4886	12.3034	11.2722	10.3711	9.5802	8.8832
24	21.2434	18.9139	16.9355	15.2470	13.7986	12.5504	11.4693	10.5288	9.7066	8.9847
25	22.0232	19.5235	17.4131	15.6221	14.0939	12.7834	11.6536	10.6748	9.8226	9.0770
26	22.7952	20.1210	17.8768	15.9828	14.3752	13.0032	11.8258	10.8100	9.9290	9.1609
27	23.5596	20.7069	18.3270	16.3296	14.6430	13.2105	11.9867	10.9352	10.0266	9.2372
28	24.3164	21.2813	18.7641	16.6631	14.8981	13.4062	12.1371	11.0511	10.1161	9.3066
29	25.0658	21.8444	19.1885	16.9837	15.1411	13.5907	12.2777	11.1584	10.1983	9.3696
30	25.8077	22.3965	19.6004	17.2920	15.3725	13.7648	12.4090	11.2578	10.2737	9.4269
35	29.4086	24.9986	21.4872	18.6646	16.3742	14.4982	12.9477	11.6546	10.5668	9.6442
40	32.8347	27.3555	23.1148	19.7928	17.1591	15.0463	13.3317	11.9246	10.7574	9.7791
45	36.0945	29.4902	24.5187	20.7200	17.7741	15.4558	13.6055	12.1084	10.8812	9.8628
50	39.1961	31.4236	25.7298	21.4822	18.2559	15.7619	13.8007	12.2335	10.9617	9.9148
60	44.9550	34.7609	27.6756	22.6235	18.9293	16.1614	14.0392	12.3766	11.0480	9.9672

Formula: $$PW = \frac{(1+i)^n - 1}{i(1+i)^n}$$

Appendix B: Literature Search

South Dakota Life-Cycle Cost Analysis (LCCA)
Literature Search

Sikow, Catharina, Kimmo Tikka, and Juha Aijo, Impact Analysis of Road Keeping: Case Study of Lapland District in Finland, Transportation Research Record 1455, National Academy Press, Washington, D.C., 1994.

Due to a slowing economy, the Finnish Road Administration (FinnRA) proposed budget cuts for the maintenance and rehabilitation of the road network in the Lapland district, the northernmost district of Finland. In order to understand the implications of the proposed budget cuts, the district initiated an analysis of the impacts of alternative strategies on the road network condition, agency and user costs, maintenance level of service, and the regional economy.

The analysis consists of a network-level (HIPS) and project-level (PMS91) analysis. The objective of the HIPS model is to find the optimal condition level of roads by minimizing total costs to the society, that is, the sum of both road maintenance and rehabilitation costs and road user costs. User costs are analyzed for each budget level considered so that the impacts can be assessed quickly. In the Lapland analysis, rehabilitation budgets over 150 million marks show diminishing marginal returns on user costs.

Road users were divided into four functional classes: commerce/distribution, local inhabitants, industry, and tourism. District management and operation staff decided that the most important classes were industry and tourism, so those classes were given more weight. The weighting implied that maintenance actions on the subnetworks service these two user groups were valued more than actions on other subnetworks irrespective of, for example, total traffic volumes.

A preliminary comparison of user cost savings from highway investments and pavement management rehabilitation showed that the allocation of funds between these two subcomponents was not straightforward. When indirect economic impacts are taken into account and depending on traffic volumes and the composition of traffic, the total net benefits from the construction of new roads in urban areas seemed to exceed those of pavement maintenance of rural gravel roads.

From this, the authors presume that rehabilitation and investments are, mathematically speaking, nonseparable. For this reason, they feel it is necessary to simultaneously optimize the two subcomponents to maximize the welfare of Lapland. They also feel it is important not to separate maintenance from rehabilitation or investments. As a result, they feel that the allocation of funds must be done centrally and simultaneously.

Riley, Mike J., Christopher R. Bennett, David R. Saunders, and Andy Kim, Optimizing Design Standards for New Pavements Using Highway Design and Maintenance Standards Model (HDM-III), Transportation Research Record 1449, National Academy Press, Washington, D.C., 1994.

This paper documents a new set of pavement design standards which use a life-cycle costing approach that was developed for the highways in Thailand. The analysis was conducted with the World Bank's Highway Design and Maintenance Standards Model (HDM-III) which performs economic appraisals of a pavement under different design and maintenance standards. The program predicts the pavement deterioration and vehicle operating costs over the analysis period, so it can be used to determine the optimal design standard on the basis of economic principles.

The paper presents little information regarding the life-cycle analysis that was conducted, focusing more on the engineering aspects of the pavement designs considered. Figure 2 of the paper does present the total transport costs associated with each of the pavement design thicknesses and various levels of maintenance. The costs are presented in terms of million Baht.

Novak, Edwin C. Jr., Wen-Hou Kuo, Life-Cycle Cost Versus Network Analysis, Transportation Research Record 1344, National Academy Press, Washington, D.C., 1992.

This paper proposes a three-step process for economic analysis: network life-cycle cost analysis, to establish program development constraints that minimize the total cost of preservation; program analysis, to select the combination of projects and treatments that meet policy constraints and maximize program benefits; and engineering analysis, to minimize project cost.

This approach is contrasted to the practices followed by many agencies to first select the lowest LCC treatment for each proposed project and then select the optimal combination of proposed projects to minimize the long-term cost of preservation. The authors contend that this approach may not be appropriate because what is best for each project may not be best for the network as a whole. For this reason, the authors consider the LCC of preserving the network to be the most important activity while the LCC of preserving projects is the third most important issue. Maximizing program benefits is considered to be the second most important issue.

To apply LCC analysis to a network instead of individual projects, two conceptual changes are applied. First, the lane-mile length of alternative MR&R programs is substituted for projects. Secondly, the average design service life (ADSL) of alternative MR&R programs is substituted for MR&R treatments. The objective of the network LCCA is to establish the MR&R program development constraints needed to guide the program development so that long-term network condition and funding goals are met.

Costs of alternative programs are based on lane-mile cost data for projects with different design lives (figure 3) and the following equation:

$$\text{Annual MR\&R program cost} = P/100 \times L \times C_x$$

Where: P = Percent of the network annually preserved
L = Lane-mile length of the network
C_x = Lane-mile cost of the designated design service life category

The annual reactive maintenance cost is computed using the following equation:

$$\$RMC = [P_0 + (P_5 + P)/2]/100 \times L \times C_x$$

Where: P_5 = Percent of the network that annually deteriorates into the zero remaining service life category
C_x = the network's reactive maintenance cost per lane mile

The paper also states that the annual cost per lane mile for reactive maintenance of pavements in unacceptable condition is assumed to be $2500/lane-mile.

The effects of inflation are considered in the network LCCA. When the costs of MR&R treatments are expected to increase with each year of delayed action, treatments with high initial cost and long life tend to provide the lowest network LCC. For project LCCA, where money is discounted, investments in short-life treatments of low initial cost tend to have lower project LCC. Network LCC uses an analysis period of 40 years. Project LCCA uses a discount rate of 4.5% and a 20-year life for each rehabilitation option and 35-year life for each reconstruction option. These options are analyzed over a 40-year analysis period.

U.S. Department of Transportation, Federal Highway Administration, Memorandum, April 19, 1996

The objective of this memorandum is to provide information and guidance to assist in the implementation of the LCCA requirements contained in the National Highway System (NHS) Designation Act of 1995 which requires States to conduct a LCCA of each NHS high cost ($25,000,000 or more) usable project segment. The Act defines LCCA as " a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future cost, such as maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment". The reason for including the LCCA is to "reduce long-term costs and improve quality and performance".

The memorandum states that, as a minimum, the States must produce an indicator of the total economic worth of the usable project segment that is based on analysis of initial as well as discounted future costs over the life of the project segment. It also states that FHWA Division Offices are not to prescribe the forms of LCCA that a State must undertake. They should assure, however, that the State's practices are consistent with fundamental principles of good/best practice. It goes on to say that good/best practices have sufficiently long analysis periods to reflect long-term cost differences associated with reasonable investment alternatives, employ accepted discount rates, and **address the inherent variability in input parameters.**

Campbell, Bruce, Thomas F. Humphrey, Methods of Cost-Effectiveness Analysis for Highway Projects, National Cooperative Highway Research Program, Synthesis of Highway Practice 142, Transportation Research Board, National Research Council, Washington, D.C., 1988.

A cost-effectiveness analysis is one approach used to determine the individual merit of a project or the most appropriate level of investment in a project. This synthesis describes the state-of-the-practice in 1988 among state transportation agencies in using cost-effectiveness analyses. Other economic analysis techniques are summarized. The synthesis lists the following economic analysis methods that have been used as the basis for comparing alternatives:

1. The discounted cashflow analysis methods such as the present worth, annualized, and rate-of-return methods.
2. Benefit/cost ratio.
3. Break-even analysis.
4. Payback period.
5. Capitalized cost.
6. Life-cycle cost analysis.
7. Economic analysis of roadway occupancy for maintenance and rehabilitation (EAROMAR).

The following factors are listed as important considerations in any of the previously listed analysis techniques.

1. Inflation.
2. Discount rates.
3. Analysis period.
4. Interest rates.
5. Risks/uncertainties.
6. Sensitivity analysis.
7. Cost factors, including design, construction, and maintenance.
8. Rehabilitation.
9. User costs.
10. Salvage value.
11. Energy use.

These factors are not discussed in the synthesis.

The most common analyses used in life-cycle costing have been the discounted cashflow analyses, including the present-worth method and the annualized method. The present-worth method involves the conversion of all of the present and future expenses to a base of today's cost. The present worth of some planned future expenditure is equivalent to the amount of money that would need to be invested now at a given compound interest rate for the original investment plus interest to equal the expected cost at the time it is needed. The totals of all present-worth costs are compared and the lowest cost alternative is chosen, providing all other things are equal. For this type of analysis it is important that the following factors be defined: costs, discount rate, analysis period, a methodology for determining salvage value, and the expected life for the various potential rehabilitation alternatives.

The annualized method requires converting all of the present and future expenditures to a uniform annual cost. This is a valuable tool for economic analysis because it reduces each alternative to a common base of a uniform annual cost. For that reason, the quality of the input data is important to ensure accuracy in comparing alternatives. A discount rate is used to convert costs into the uniform annual costs, including initial, recurring, and nonrecurring costs. Future expenditures must be converted to its present worth before its annualized cost can be calculated. A uniform capital recovery factor is used to determine annual costs from initial costs and nonrecurring costs that have been converted to present worth. The alternative that has the smallest total annual cost is considered the best selection, if all other things are equal.

With LCCA, the factors that most influence the analysis results include inflation, discount rate, and analysis period. Some of the components of LCCA are well known, such as the initial construction costs. Other costs are highly uncertain, such as future maintenance activities and cost, so methods that reduce the uncertainty of these factors are used when possible. A sensitivity analysis is used to determine which variables have the most influence on the cost of an alternative.

Peterson, Dale E., Life-Cycle Cost Analysis of Pavements, National Cooperative Highway Research Program, Synthesis of Highway Practice 122, Transportation Research Board, National Research Council, Washington, D.C., 1985.

This synthesis is perhaps the leading reference on state practices in the area of LCCA of pavements. The synthesis states that LCC has been defined as an "economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars". Others define it as an " analysis which considers the construction, operation, and maintenance of a facility during its entire design life".

A four-step process for conducting a LCC study is described. The first step involves selecting the area of study, such as pavement design. The second step is the generation of alternatives and the removal of any item of cost that is common among all alternatives. Once that is completed, the third step involving the evaluation of designs is conducted. This step includes the identification of every cost associated with each alternative which are converted to today's dollars through a discounted cashflow analysis. A sensitivity analysis may be included to determine if any change in values for some of the assumptions might alter the results of the analysis. The last step involves the consideration of any noneconomic factors that are considered important in the selection of the final design.

Several economic factors considered in LCC are discussed in the synthesis. Inflation is described as the general increase in prices throughout the economy. It is important to distinguish this from differential price trends which reflect the difference between the price changes for the item being evaluated and the overall economic price trend. The synthesis emphasizes that it is necessary to choose between the use of "constant" dollars and "current" dollars when performing an economic analysis. Constant dollars are uninflated and represent the price levels prevailing for all elements at the base year for the analysis. Current dollars are inflated and represent price levels that may exist at some future date when the costs are incurred. Because of the uncertainty in predicting future rates for inflation, the constant dollars approach has been generally recommended because only the differential inflation on future costs needs to be identified.

A study by Cady observed the following effects of inflation:

- The element of cashflow most seriously affected by inflation is single future amounts, followed in order by a gradient series and a uniform series.
- Uniform series and gradient series are increasingly affected by inflation with decreasing interest rates (single future amounts are not affected).
- The effects of inflation for all cashflow elements become more pronounced with increasing time.
- The effects of inflation increase for all cashflow elements with increasing inflation rate.

He further states that "failure to account for the effects of inflation in comparing the cashflows of highway construction or maintenance alternatives will significantly understate real costs".

Discount rates are also discussed. The discount rate is used as the means for comparing the alternative uses for funds by reducing the future expected costs to present-day terms. Discount rates are used to reduce various costs or benefits to their present worth or to uniform annual costs so that the economics of the different alternatives can be compared. Both interest and inflation tend to reduce the future value of a fixed amount of money. Some future cost, such as rehabilitating a pavement, that is expected to take place several years after the original pavement construction will cost more than it does today because of inflation. To properly evaluate this, it is necessary to first determine the future cost by using the inflation rate and then determine its present worth by using the interest rate. There is general agreement that the discount rate, also known as the real cost of capital, should be the difference between the market interest rate and inflation using constant dollars. Market interest rates approach the real cost of capital when inflation is zero. Many agencies estimate this difference as being in the range of 4%, however the real discount rate can be calculated using the following equation.

$$i^* = \underline{(1 + i)\ (1 + q)} - 1$$

Appendix C: Questionnaire

Introduction: This survey document is part of a research effort being conducted by the South Dakota Department of Transportation (SDDOT) to develop guidelines for using economic factors and maintenance costs in life-cycle cost analysis at the network and project levels. Your timely response to the questions below is greatly appreciated.

Please check the appropriate responses.

1. Do you use life-cycle costing:

Currently	*Considering in the Future*	
______	______	in your pavement management system for project selection?
______	______	in your pavement design activities?

2. What factors are considered in your life-cycle costing?

Currently	*Considering in the Future*	
______	______	initial construction/rehabilitation costs
______	______	anticipated maintenance costs over the life of the alternative
______	______	discount, interest and/or inflation rates
______	______	salvage value
______	______	user costs (please specify: ____________________)
______	______	other factors (please specify: ____________________)

3. How are initial construction/rehabilitation costs obtained?

Currently	*Considering in the Future*	
______	______	estimates provided by Department personnel
______	______	historical estimates prepared by _________ within the Department (identify office with this responsibility)
______	______	other (please specify: ____________________)

4. How are anticipated maintenance costs estimated?

Currently	*Considering in the Future*	
______	______	estimates provided by Department personnel
______	______	historical estimates prepared by _________ within the Department (identify office with this responsibility)
______	______	other (please specify: ____________________)

5. Are maintenance costs estimated differently for each rehabilitation alternative considered?

Currently	*Considering in the Future*	
______	______	Yes
______	______	No

6. What level of confidence do you currently have in the following cost estimates? (Circle the most appropriate response)

Initial construction/rehabilitation costs:	Good	Fair	Poor
Anticipated maintenance costs:	Good	Fair	Poor

(continued on next page)

7. What values are used for the following? How are they determined?

Currently	*Considering in the Future*	
______	______	Discount rate - Determined by: ____________________
______	______	Interest rate - Determined by: ____________________
______	______	Inflation rate - Determined by: ____________________
______	______	Alternative life - Determined by: ____________________

8. How frequently are the discount, interest, and inflation rates updated?

Currently	*Considering in the Future*	
______	______	At least every 6 months
______	______	At least annually
______	______	Very infrequently
______	______	Never

9. When considering a number of different **rehabilitation** alternatives with various lives associated to them, which of the following statements reflect your life-cycle cost analysis? (Please indicate if one answer applies to your network-level analysis and another to your project-level analysis)

Currently	*Considering in the Future*	
______	______	The analysis period is fixed at _____ years
______	______	A series of two or more rehabilitation alternatives are considered to be one rehabilitation strategy for a potential project over the analysis period.
______	______	Only one rehabilitation alternative is considered to be one rehabilitation strategy over the analysis period, even if its expected life is shorter than the analysis period.
______	______	The additional life provided by the alternative is measured in terms of the length of time until the condition value that triggered the repair is met.
______	______	The additional life provided by the alternative is measured in terms of the length of time until a condition that represents failure is met.

10. When considering a number of different **reconstruction** alternatives with various lives associated to them, which of the following statements reflect your life-cycle cost analysis? (Please indicate if one answer applies to your network-level analysis and another to your project-level analysis)

Currently	*Considering in the Future*	
______	______	The analysis period is fixed at _____ years.
______	______	A series of two or more rehabilitation alternatives are considered to be one rehabilitation strategy for a potential project over the analysis period.
______	______	Only one rehabilitation alternative is considered to be one rehabilitation strategy over the analysis period, even if its expected life is shorter than the analysis period.

(continued on next page)

10. (Continued)

Currently	Considering in the Future	
______	______	The additional life provided by the alternative is measured in terms of the length of time until the condition value that triggered the repair is met.
______	______	The additional life provided by the alternative is measured in terms of the length of time until a condition that represents failure is met.

11. How are salvage values or costs of removal considered?

Currently	Considering in the Future	
______	______	As a fixed dollar amount.
______	______	As a percentage of ________.
______	______	In terms of remaining life.
______	______	In some other way. (Please identify:____________________)
______	______	Not considered.

12. After the life-cycle cost analysis is completed, do you compare the results to any other type of analysis result, such as a user delay study?

Currently	Considering in the Future	
______	______	Yes (Please explain: ____________________________)
______	______	No

13. Who do you feel would be the best person to address any follow-up questions we may have regarding this survey?

Name: ________________________________ Position: ____________________

Phone: ________________ Fax: ________________ E-mail: ____________

Please include copies of any life-cycle cost analysis documentation your agency may have available.

When the survey is completed, please return it to:
Katie Zimmerman, Applied Pavement Technology, Inc.
412 W. Nevada
Urbana, IL 61801
or fax it to:
(217) 384-4385

Call Katie with any questions at: (217) 384-0817

Appendix D: Survey Responses

	Is LCC Used In:		Factors Used in LCC								Initial Costs Obtained From					Maintenance Costs Estimated From					Are Maintenance Costs Estimated For Each Alternative?	
	PMS	Design	Initial	Maintenance	Discount,	Salvage	User	Specify:	Other	Specify:	Dept	Historical	Specify	Other	Specify	Dept	Historical	Specify	Other	Specify		
State			Costs	Costs	Interest, Inflation	Value	Costs		Factors		Estimates	Estimates	By Whom:		How:	Estimates	Estimates	By Whom:		How:	Yes	No
Alabama																						
Alaska	X	Future	X	Future	X		Future	IRI			X					Future					Future	
Arizona		X	X	X	X	X	X	Time Delay				X	Contr/Specs				X	Maint/Mtls			X	
Arkansas																						
California	Future	Future	Future	Future	Future	Future	Future				X	X	Office Engr	X	Contr Cost	X	X	Office Eng	X	Contr Cost	X	
Colorado																						
Connecticut	Future	X	X	X	X	Future	Future				X					X					X	
Delaware	Future		Future	Future	Future	Future	Future				X					X					Future	
District of Columbia																						
Florida	Future	Future	X		X				X	Shld Const $	X	X	Estimates			X	X	Maintenance				
Georgia	X	X	X	X	Future	X	Future				X					X						X
Hawaii	Future	X	Future	Future	Future	Future					Future					Future					Future	
Idaho	X	X	X	X	X	X					X					X						X
Illinois		X	X	X	X				X	AASHTO	X	X	Design			X	X	Design				X
Indiana	X	X	X	Future	X	X			X	Maint of Traffic		X	Contracts				X	Operations			Future	
Iowa	Future	X	X	X	X	X	Future				X	X	Contracts			X	X	Contracts			X	
Kansas	X	X	X	Future	X	X	X	Detour, adv.trvl						X	Bid Summ	Future					Future	
Kentucky																						
Louisiana	X	X	X	X	X	Future	Future					X	P.M.				X	Maintenance			Future	X
Maine	Future	X	X	X		X					X					X						X
Maryland	Future	X	X	Future	X		X	Addl User Cst						X	Bid Summ				X	Part of LCCP		X
Massachusetts																						
Michigan	X	X	X	X	X						X								X	LCC Comm.	X	
Minnesota	X	X	X		X	X			X	Rehab Life	X											X
Mississippi	Future	X	X	Future	X	X	Future				X	X	Constr			Future	Future				Future	
Missouri		X	X	X	X	X	Future				X						Future	Maintenance	X	Equal for all	Future	X
Montana	X	X	X	X	X	X	X	Sep Analysis	X	Admin $		X	PMS				X	Maintenance			X	
Nebraska	Future	X	X	X	X	X						X	PS&E				X	Maintenance				X
Nevada	Future	Future	Future	Future	Future	Future					X	X	Design			X	X	Maintenance				X
New Hampshire																						
New Jersey	Future	X	X	X	X	X	Future	VOC & Delay	Future	Emissions	X	X	Contr Admin			X	X	Maintenance	Future	MMS	Future	X
New Mexico	Future	X	Future	Future	Future									Future	CMS & MMS	X	X	Maintenance	Future	MMS	X	
New York		X	X	X	X	X	Future	Delay Cost				X	Bid Est				X	Maintenance				X
North Carolina	Future	X	X	X	X				X	Constructability, $	X					X	Future	Maintenance			X	
North Dakota	Future	X	X		X	X					X	X	Design									X
Ohio		X	X	X	X		Future		X	Lane Delay	X	X	Pvmts				X	Pvmts			X	
Oklahoma																						
Oregon		X	X	see comments	X	X					X											X
Pennsylvania		X	X	X	X		X	Delay, Stops			X	X	Constr Mngt						X	SpecStrat/Curve	X	
Puerto Rico	Future	Future	X	Future							X	Future				X	Future				X	
Rhode Island	Future	X	X	Future	X	Future	Future		X	Regional Est.	X								X	Reg Est	Future	
South Carolina	X		X	Future	X						X					Future						X
South Dakota	X	X	X	X							X					X						X
Tennessee	Future	X	X	X	X				X	Tral Control, Future $	X						X	Maintenance			X	
Texas																						
Utah	X	X	X	X	X		X	Delay, Operating			X					X						X
Vermont																						
Virginia		X	X	X	X	X			X	Exp, Preference, Maint		X	Contract			X	X	Maintenance			X	
Washington		X	X	Future	X	X	X	Delay				X	Pre-constr			Future					Future	
West Virginia	Future	Future	Future	Future	Future	Future						Future	Programming			Future					Future	
Wisconsin	X	X	X	X	X	X	Future				X					X					X	
Wyoming		X	X	X	X						X	X	Contracts			X					X	
# of Responses:																						
Current	12	33	35	22	32	19	7		10		28	19		3		18	16		6		15	16
Future	19	6	6	15	7	8	14		1		1	2		1		7	4		1		12	0

	Level of Confidence		Values Used in LCCA				Frequency of Updates For Discount, Interest, Inflation Rates				LCCA For Different Rehabilitation Alternatives						
State	Initial Costs	Maintenance Costs	Discount Rate	Interest Rate	Inflation Rate	Alternative Life	Every 6 mo	Annually	Infrequently	Never	Analysis Period Fixed	Length of Analysis Period	Two Alternatives are One Strategy	Only One Alt Considered	Addl Life Defined By Next Trigger	Addl Life Defined By Failure Point	Not Used For Rehabilitation
Alabama																	
Alaska	Good			Future	Future	Future		Future	X		X	4-10 years	X	X	Future		
Arizona	Good	Fair	4%			Hist Records			X		X	35 years (project)	X	X	X	X	
Arkansas																	
California	Good	Good	Future	Future	Future	Future	Future										
Colorado																	
Connecticut	Good	Fair	3-5%								X	30 years	X				
Delaware	Fair	Fair		5%	5%				X								
District of Columbia																	
Florida	Fair	Fair	Rev Conf	Rev Conf	Rev Conf			X			X	40 years					
Georgia	Good	Good	Future	Future	Future					X					X		
Hawaii	Fair	Poor		Future					X		X	10 years			Future		
Idaho	Fair	Fair			4%					X						X	
Illinois	Good	Good	3%						X		X - Project	0 years (new constr)		X - Network			
Indiana	Good	Fair	0-10%	0-10%						X(Sens.Anal	X	Ntwk30, Pro20-40		X - Network	X - Network		
Iowa	Good	Good	Int-Infl	State Earned	CPI			X			X - Project	Depends on alt type		X - Project	X - Project		
Kansas	Good	Poor		7%	5.20%				X		X	30 years	X			X	
Kentucky																	
Louisiana	Good	Poor	3%		4%			Future	X								X
Maine	Good	Fair								X							X
Maryland	Fair	Fair	Int-Infl	8%	4%				X		X	30 years	X				
Massachusetts																	
Michigan	Good	Fair	4%					X			X - Project	20 years	X - Project				
Minnesota	Good	Poor	4.50%							X	X - Project	35 years		X - Network		X - Network	
Mississippi	Good	Fair		5-8%	1-3%		X									X	
Missouri	Good	Fair	4%							X	X	35 years	X				
Montana	Good	Good	Bond Rate		FHWA, USB	PMS	X				X	30 now, future 35	X			X	
Nebraska	Good	Fair	2.71%	Controller	Controller			X							X		
Nevada	Good	Fair	AASHTO	Bond Rate	CPI			X			Future	10 yrs-P, 20yrs-N	Future				
New Hampshire																	
New Jersey	Good	Fair	4%			Varies		Future	X		Future		Future		X		
New Mexico	Good	Poor	PMS	PMS	PMS	PMS			X						Future - Network		
New York	Good	Fair	4%						X		X - Project	30 years	X - Project		X - Project		
North Carolina	Fair	Poor	AASHTO			AASHTO		Future		X	Future	30 years	X				
North Dakota	Good	N/A	Synth122			Matls/Res			Future	X			X				
Ohio	Good	Fair	SensAnal						X		X	35 years					
Oklahoma																	
Oregon	Good	N/A	0-4%, use 4			Designers			X				X		X	X	
Pennsylvania	Good	Fair	6%							X	X	40 years					
Puerto Rico	Good	Fair							X		X	20 years	X			X	
Rhode Island	Good	Poor	8%	6%	3%		Future	X			X	20 years	Future	X			
South Carolina	Good	Poor	4%		3%			Future	X		X - Network	10 years	X - Network	X - Network	X - Network	X - Network	
South Dakota	Good	Fair									X	40					
Tennessee	Good	Fair	4.50%			Design Guidelines			X		X - Project	30 years	X - Project		X - Project		
Texas																	
Utah	Good	Good	Econ Factors	Econ Factors	Econ Est	Mtls/PMS		X			X	20 years	X		X	X	
Vermont																	
Virginia	Fair	Fair	4%							X	X	30 years			X		
Washington	Good	Poor	4%			Hist Performance				X	X	40 years					
West Virginia				Future-Prime				Future			Future	20 years					
Wisconsin	Good	Fair	5%			50 years			X							X	
Wyoming	Good	Fair			3-4%					X	X	30 years					
# of Responses:																	
Current	G-33,F-7,P-0	G-6,F-22,P-9					2	7	17	12	25		16	8	11	11	2
Future							2	6	1	0	4		3	0	3	0	0

	LCCA For Different Rehabilitation Alternatives							Calculation of Salvage Values							Are Results Compared To Any Other Analysis Result?			Notes or Comments
State	Analysis Period Fixed	Length of Analysis Period	Two Alternatives are One Strategy	Only One Alt Considered	Addl Life Defined By Next Trigger	Addl Life Defined By Failure Point	Not Used For Reconstruction	Fixed Amount	Percentage of:		In Terms of Remaining Life	Another Way	Specify:	Not Considered	Yes	Explain:	No	
Alabama																		
Alaska	X	1 year		X					Future	Initial Cost				X			X	
Arizona	X	20 years (project)	X	X	X	X			X	Initial Cost							X	
Arkansas																		
California											Future				Future	Congestion Cost		Study by Consultant Underway
Colorado																		
Connecticut	X	30 years	X		X							Future	Offset from recycle	X			X	
Delaware																		
District of Columbia																		
Florida	X	40 years												X			X	
Georgia					X			X									X	
Hawaii	X	10 years			Future			Future									X	
Idaho						X						X	Family Curves				X	
Illinois				X										X			X	
Indiana												X	(RL/DL)*$		X	User Delay & B/C		
Iowa	X	Depends on Alt		X - Project	X - Project			Removal $				X	Set equal	X if > 50 yrs			X	
Kansas	X	30 years	X			X							Mat'l value				X	
Kentucky																		
Louisiana	X	35 years						Future						X			X	
Maine	X	20 years						X									X	
Maryland	X	30 years	X			Future								X			X	
Massachusetts																		
Michigan	X - Project	35 years	X											X	Future		X	
Minnesota	X - Project	35 years												X			X	
Mississippi	X - Network	25 years							X	Initial Cost							X	
Missouri	X	35 years	X									X	Equal		X	Other features		
Montana	X	30 now, future 35	X			X						X	Depr & Disp $		X	User Delay/Risk Anal		
Nebraska	X	50 years							X	Initial Cost							X	
Nevada	Future	10 yrs-P, 20 yrs-N	Future								X						X	Research project currently underway
New Hampshire																		
New Jersey	Future		Future		X			X			Future						X	
New Mexico					Future - Network									X			X	
New York											X						X	
North Carolina	X	30 years	X											X			X	Only include future O/Ls in LCC, not maintenance
North Dakota	X	40 years	X								X						X	
Ohio	X	35 years												X	X	Lane Delay		
Oklahoma																		
Oregon	X	30 years	X			X					X						X	Compare annual costs and see if maint closes or widens differ
Pennsylvania	X	40 years												X	X	Delay Costs		
Puerto Rico	X	20 years	X			X											X	
Rhode Island	X	20 years	Future	X							Future			X			X	
South Carolina	X	40 years		X	X	X		X									X	
South Dakota	X	40 years												X			X	
Tennessee	X - Project	30 years	X - Project		X - Project							X	All Equal				X	
Texas																		
Utah	X	20 years	X		X	X					X						X	
Vermont																		
Virginia	X	30 years				X			X	Initial Cost							X	
Washington	X	40 years									X				X	User delay		
West Virginia	Future	20 years						Future									Future	
Wisconsin	X	50 years	X						X	Rehab $							X	
Wyoming	X	30 years						X									X	
# of Responses:																		
Current	30		14	6	8	9	0	6	5		6	6		14	6		32	
Future	3		3	0	2	1		3	1		3	1		0	2		1	

Appendix E: Sensitivity Analysis Findings

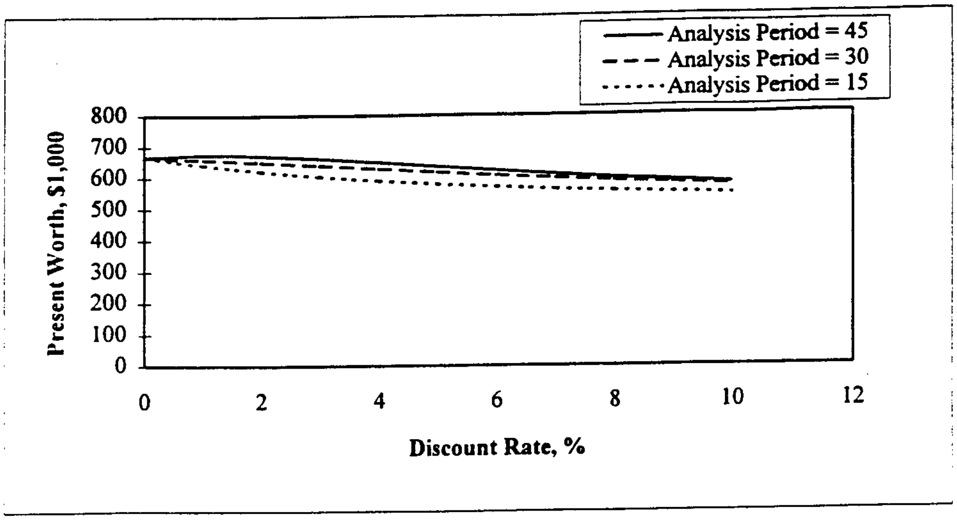

Figure E-1. Effect of Analysis Period Using Nominal Values.

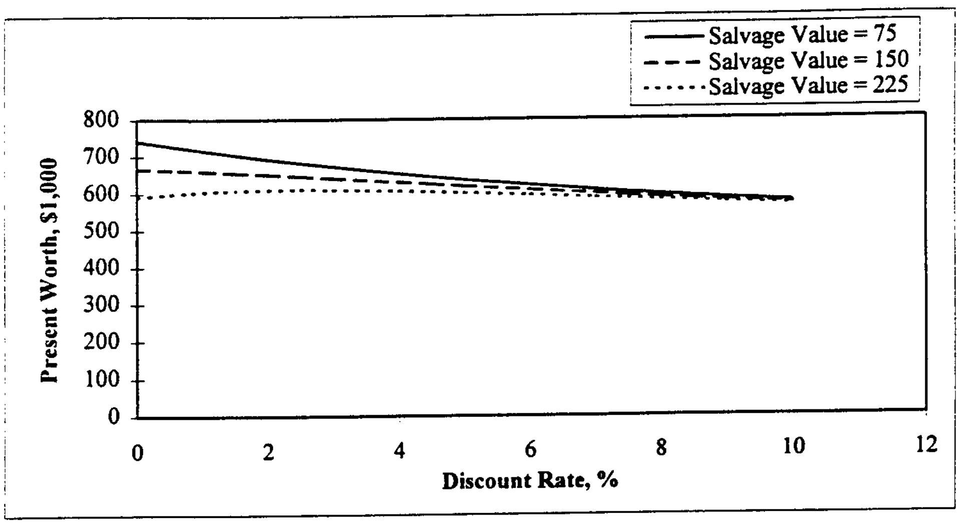

Figure E-2. Effect of Salvage Value Using Nominal Values.

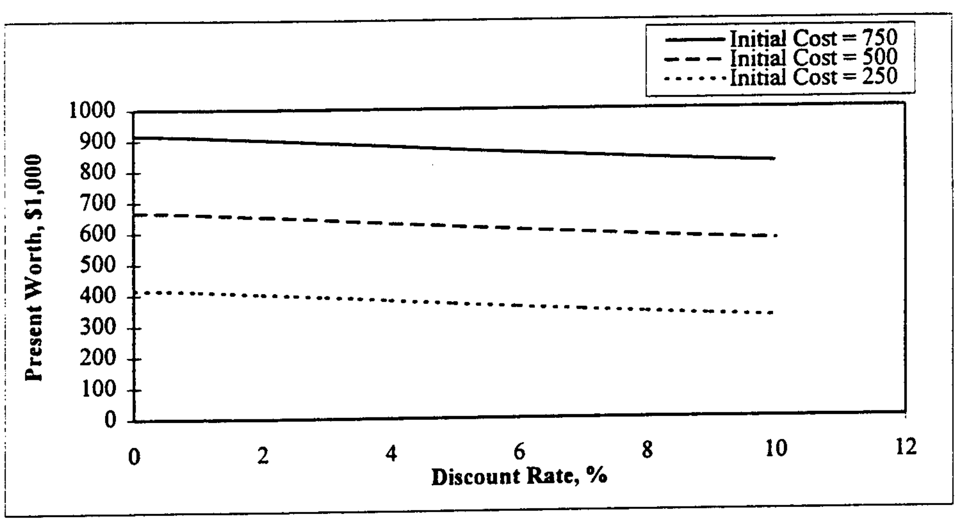

Figure E-3. Effect of Initial Cost Using Nominal Values.

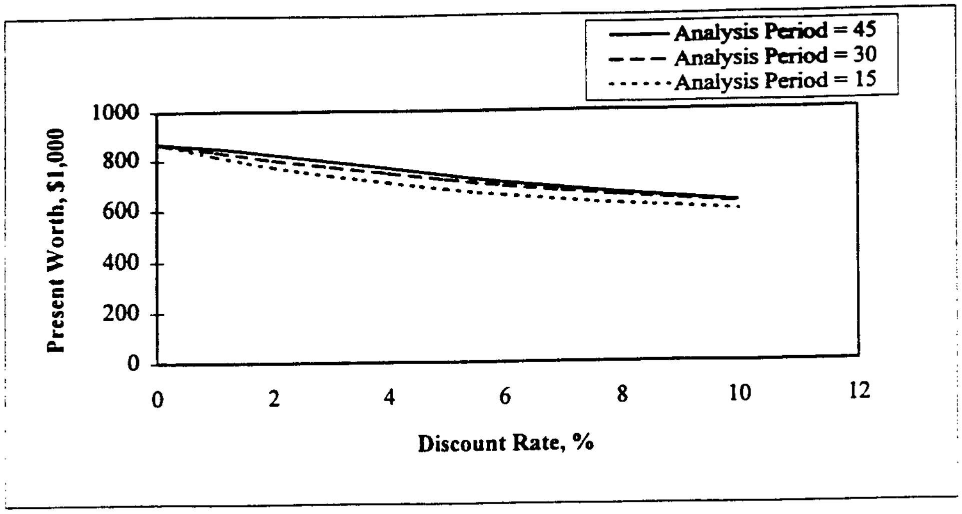

Figure E-4. Effect of Analysis Period (Periodic Cost = $400,000).

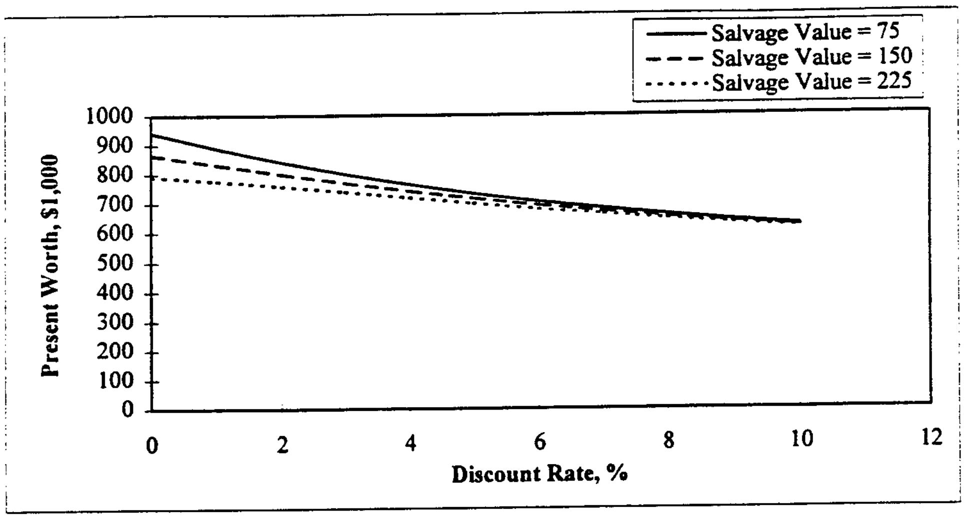

Figure E-5. Effect of Salvage Value (Periodic Cost = $400,000).

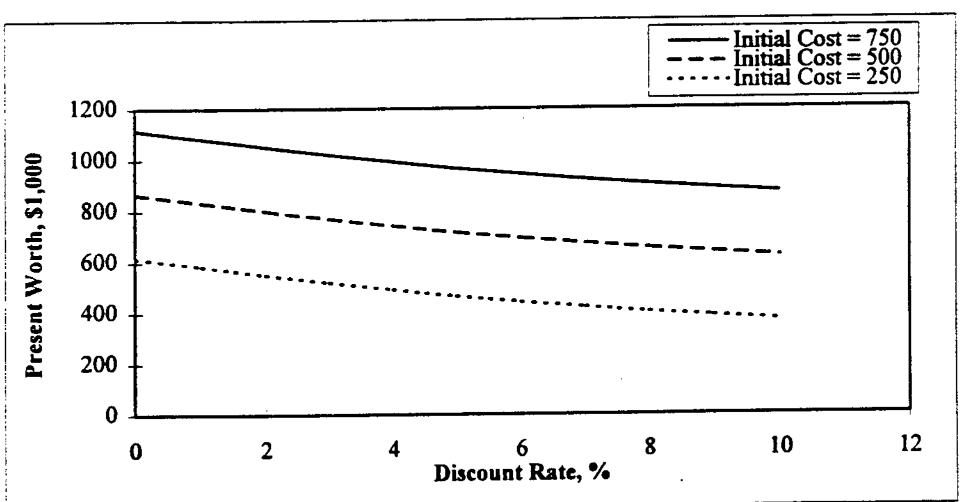

Figure E-6. Effect of Initial Cost (Periodic Cost = $400,000).

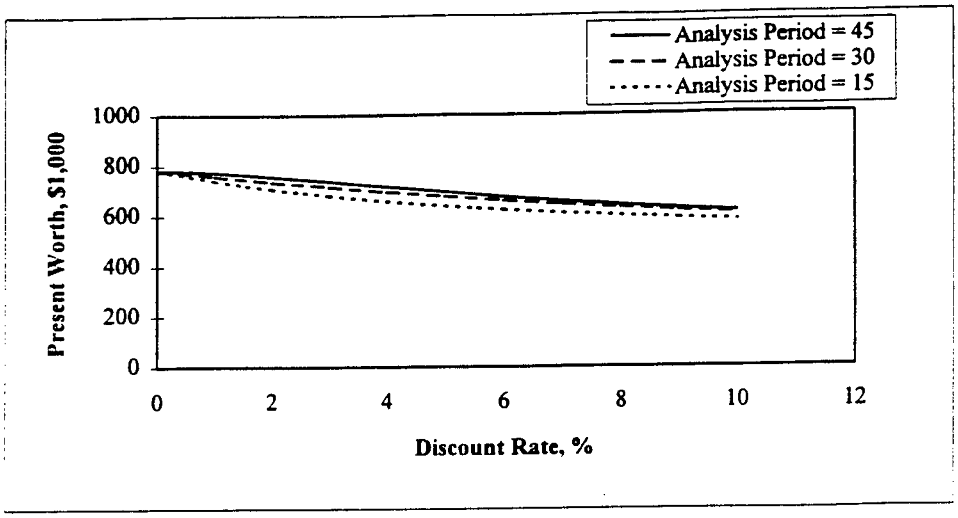

Figure E-7. Effect of Analysis Period (Annual Cost = $8,000).

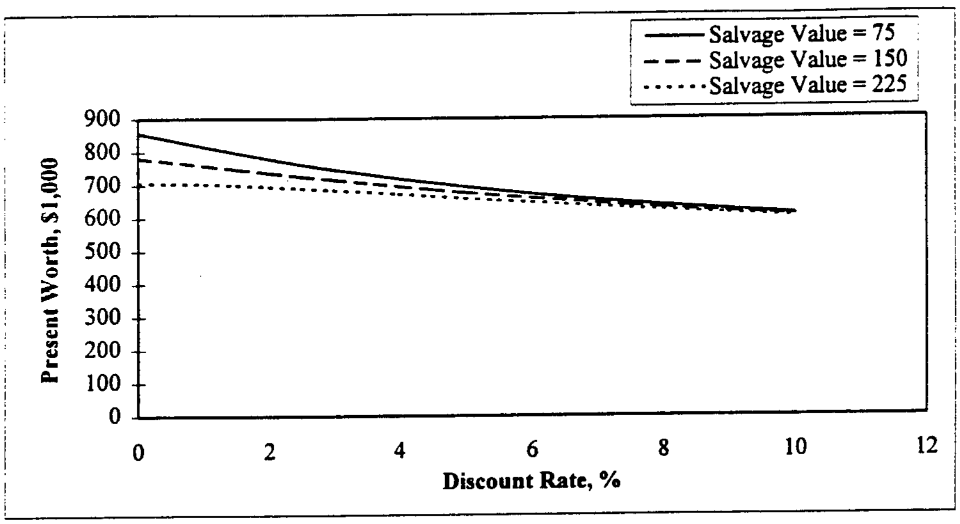

Figure E-8. Effect of Salvage Value (Annual Cost = $8,000).

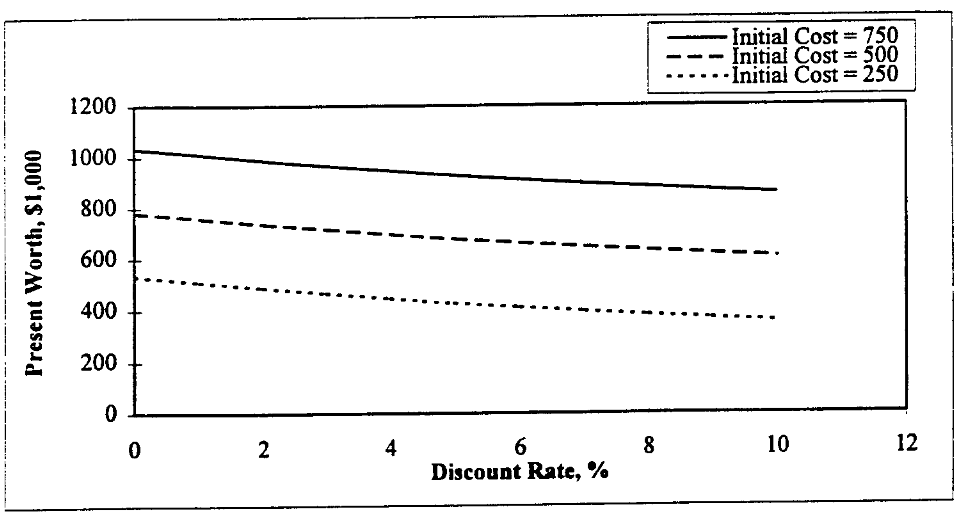

Figure E-9. Effect of Initial Cost ($Annual Cost = $8,000).

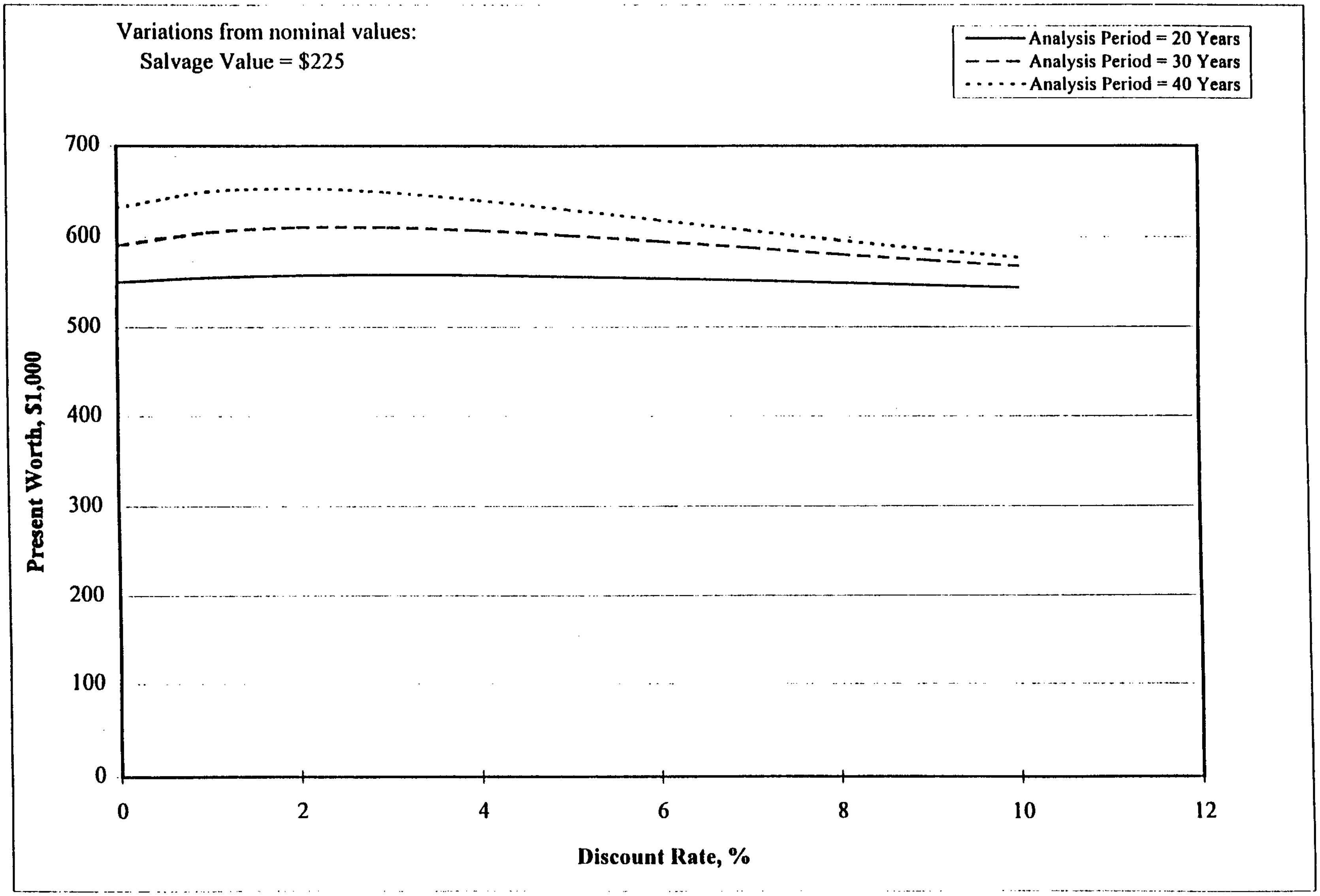

Figure E-10. Impact of a Change in Salvage Value.

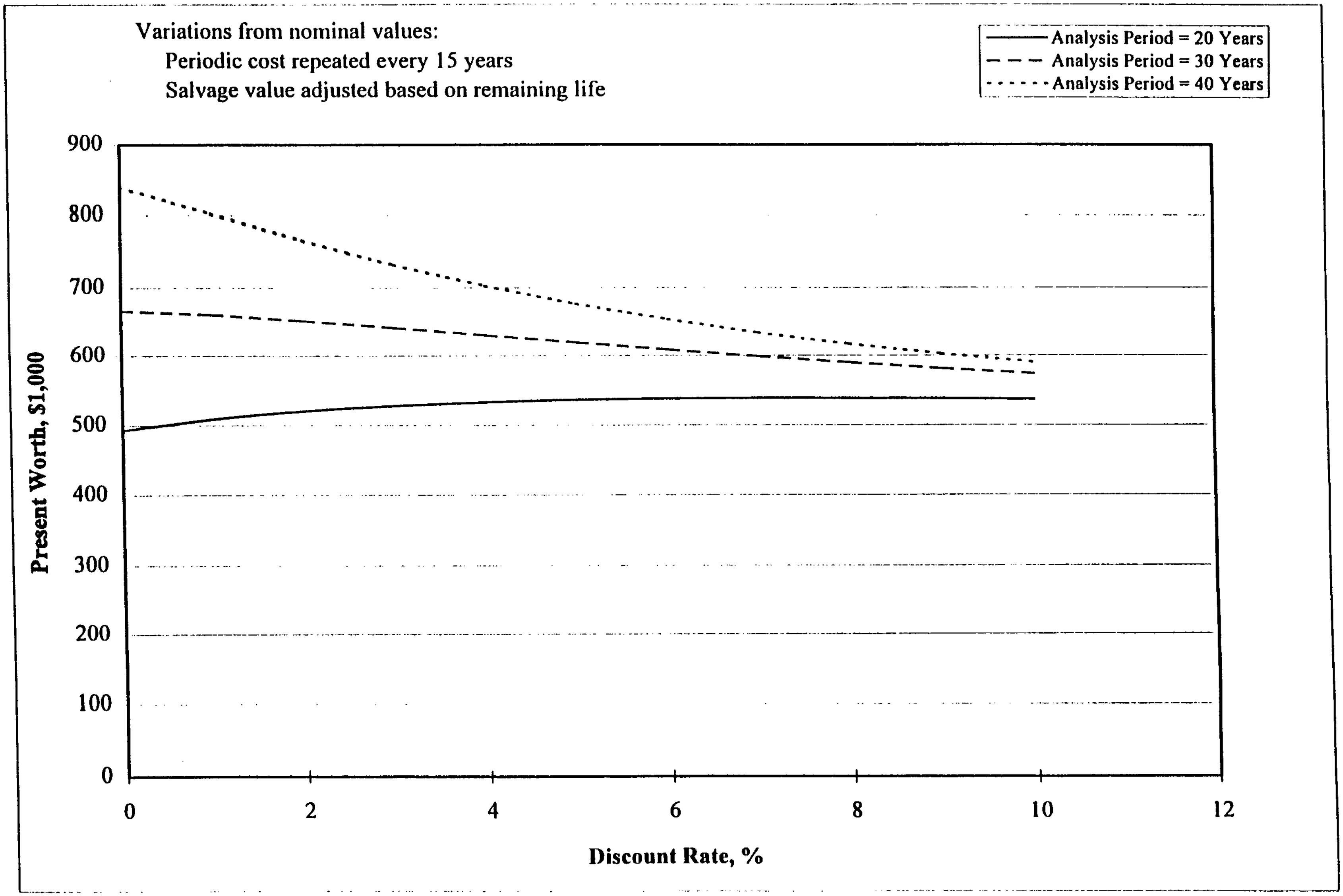

Figure E-11. Impact of Cycling Periodic Cost.

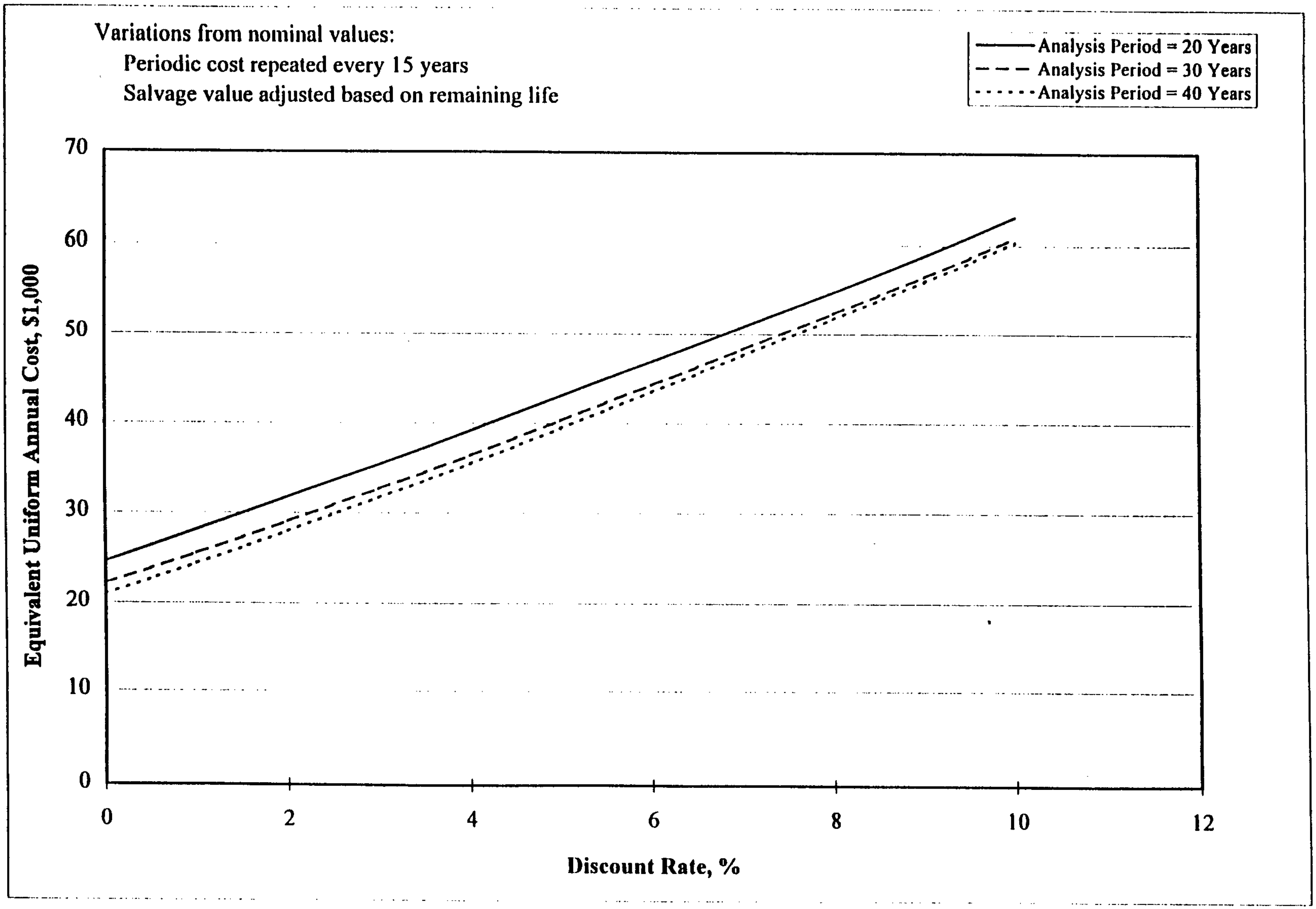

Figure E-12. Impact of Cycling Periodic Cost on EUAC.

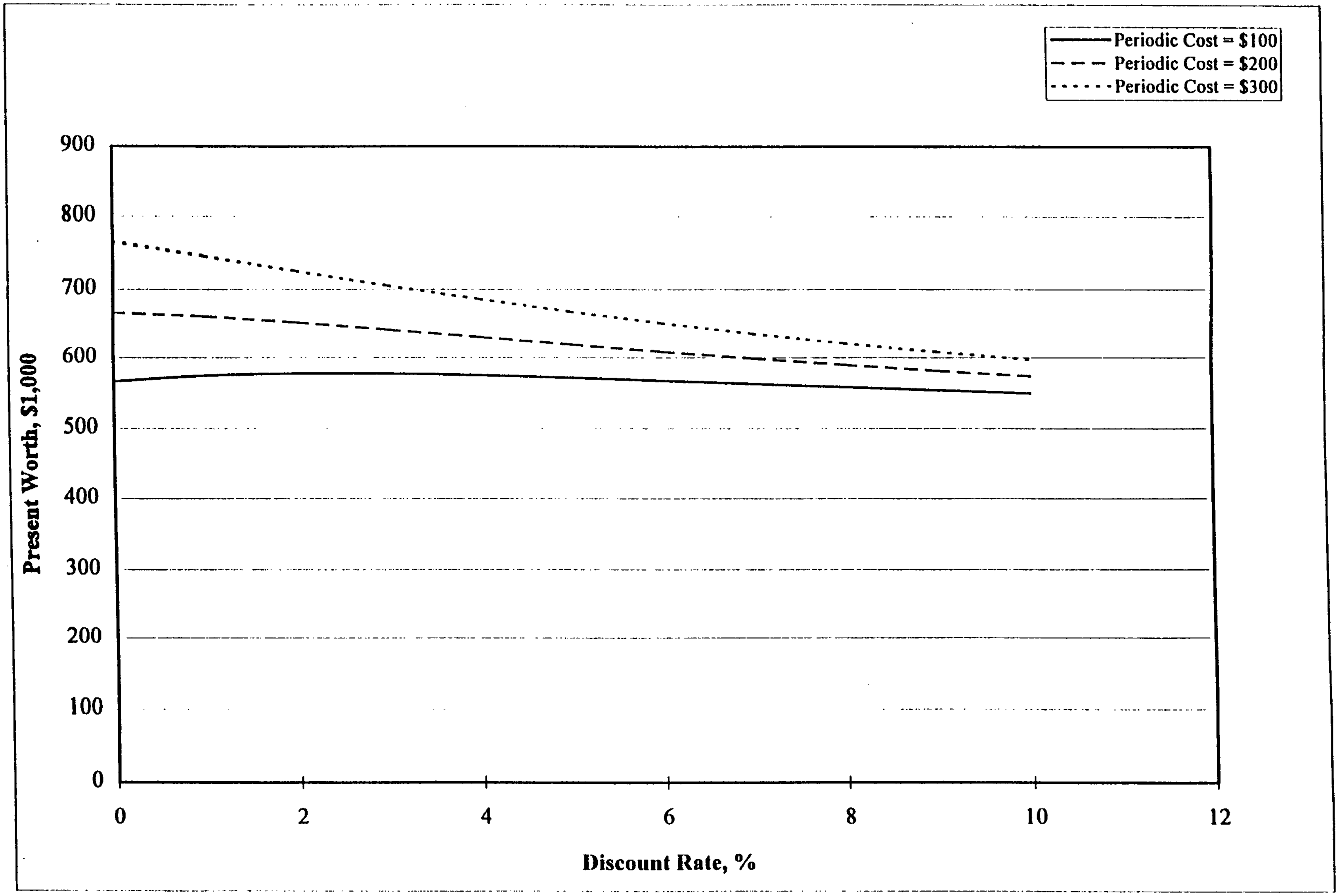

Figure E-13. Impact of a Change in Periodic Cost.

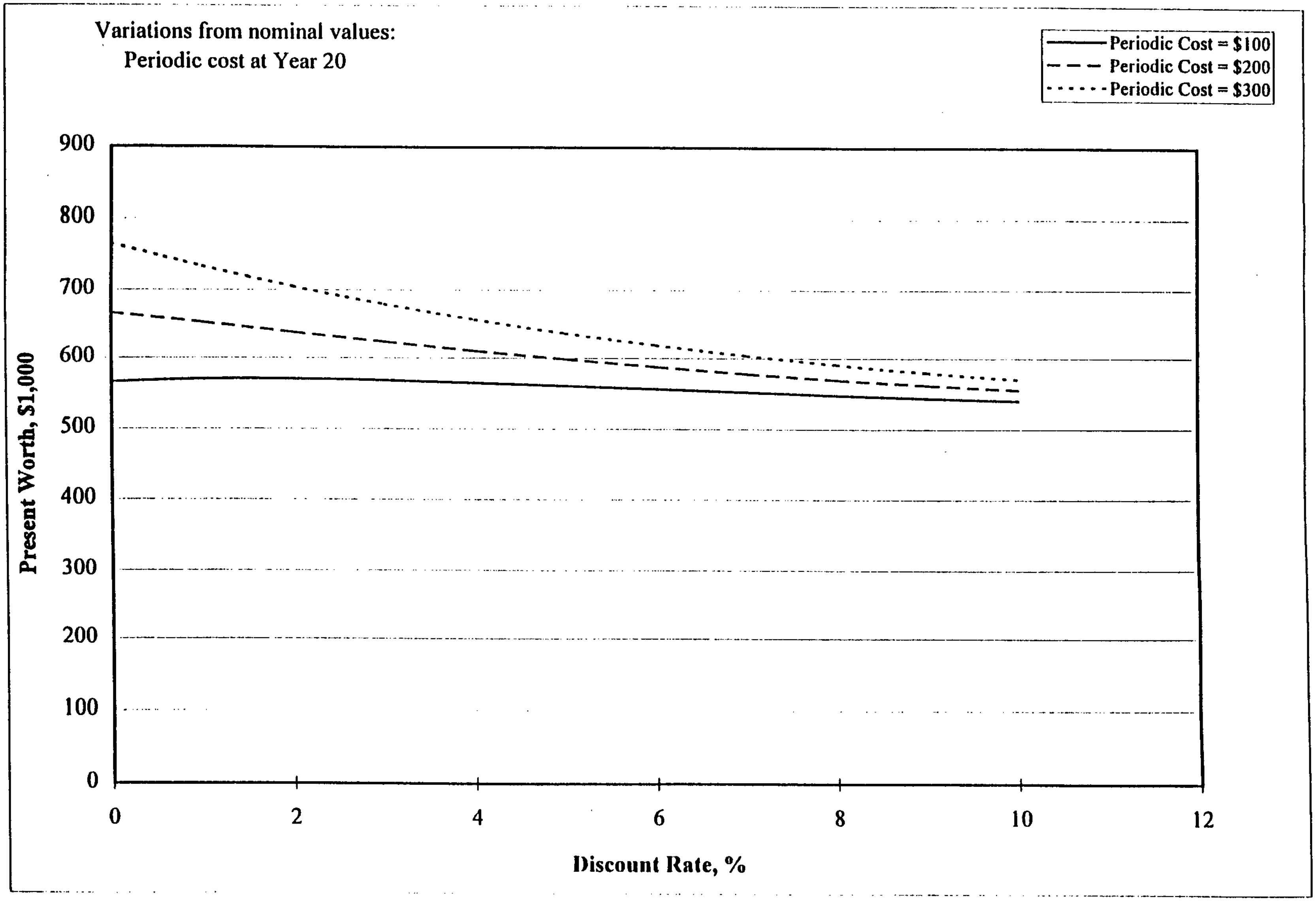

Figure E-14. Impact of a Change in Timing of Periodic Cost.

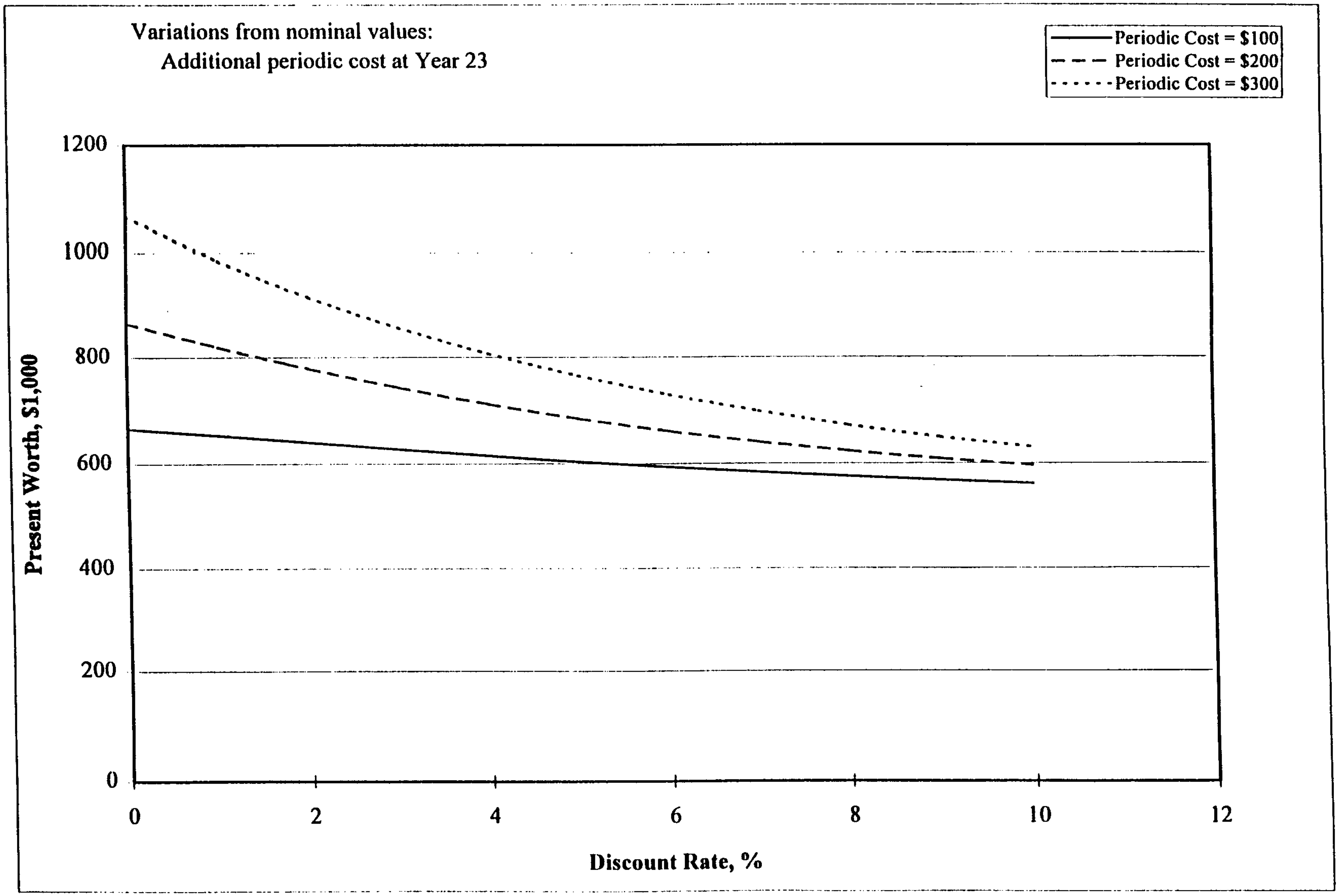

Figure E-15. Impact of an Additional Periodic Cost.

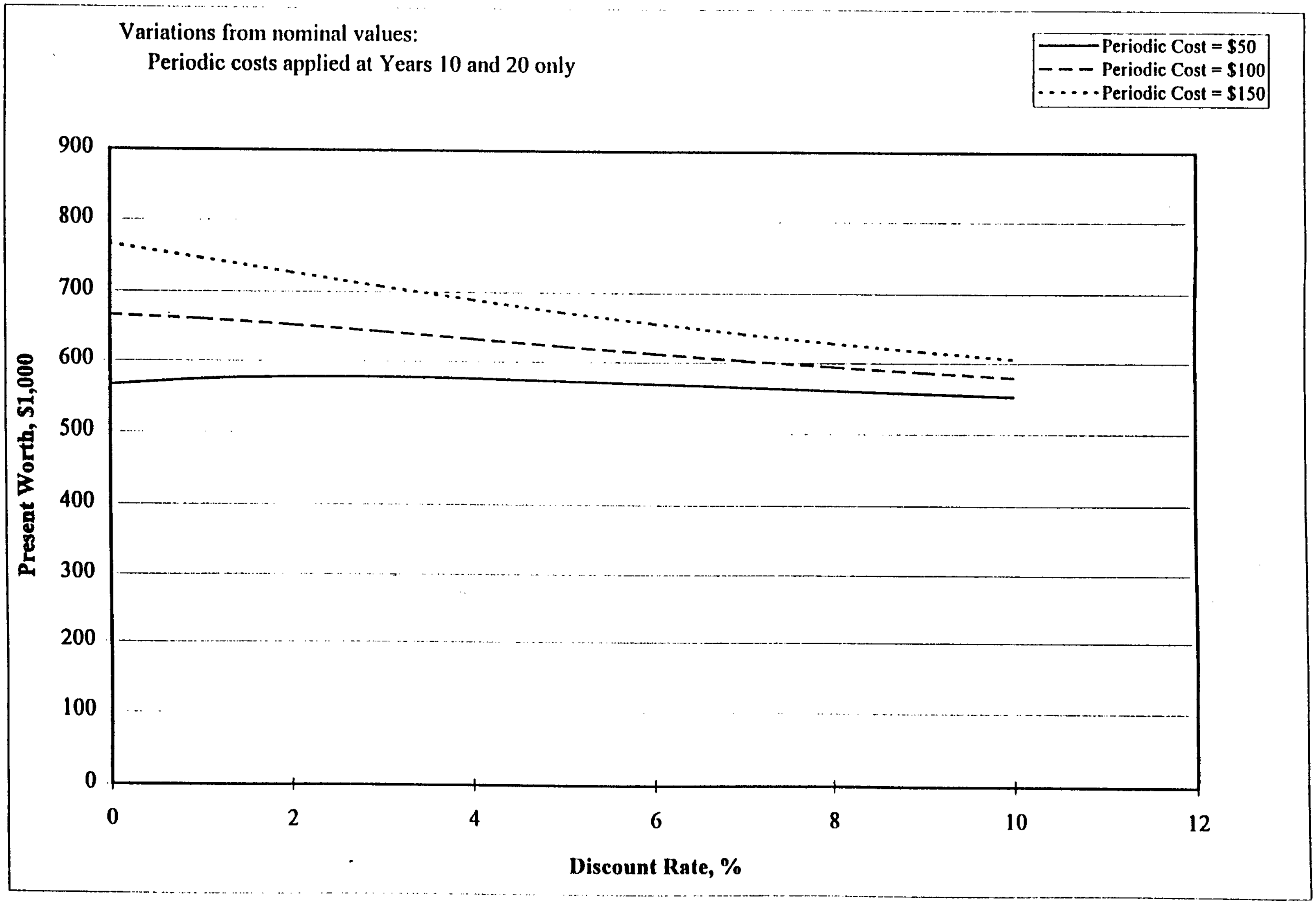

Figure E-16. Impact of a Change in Amount and Timing of Periodic Cost.

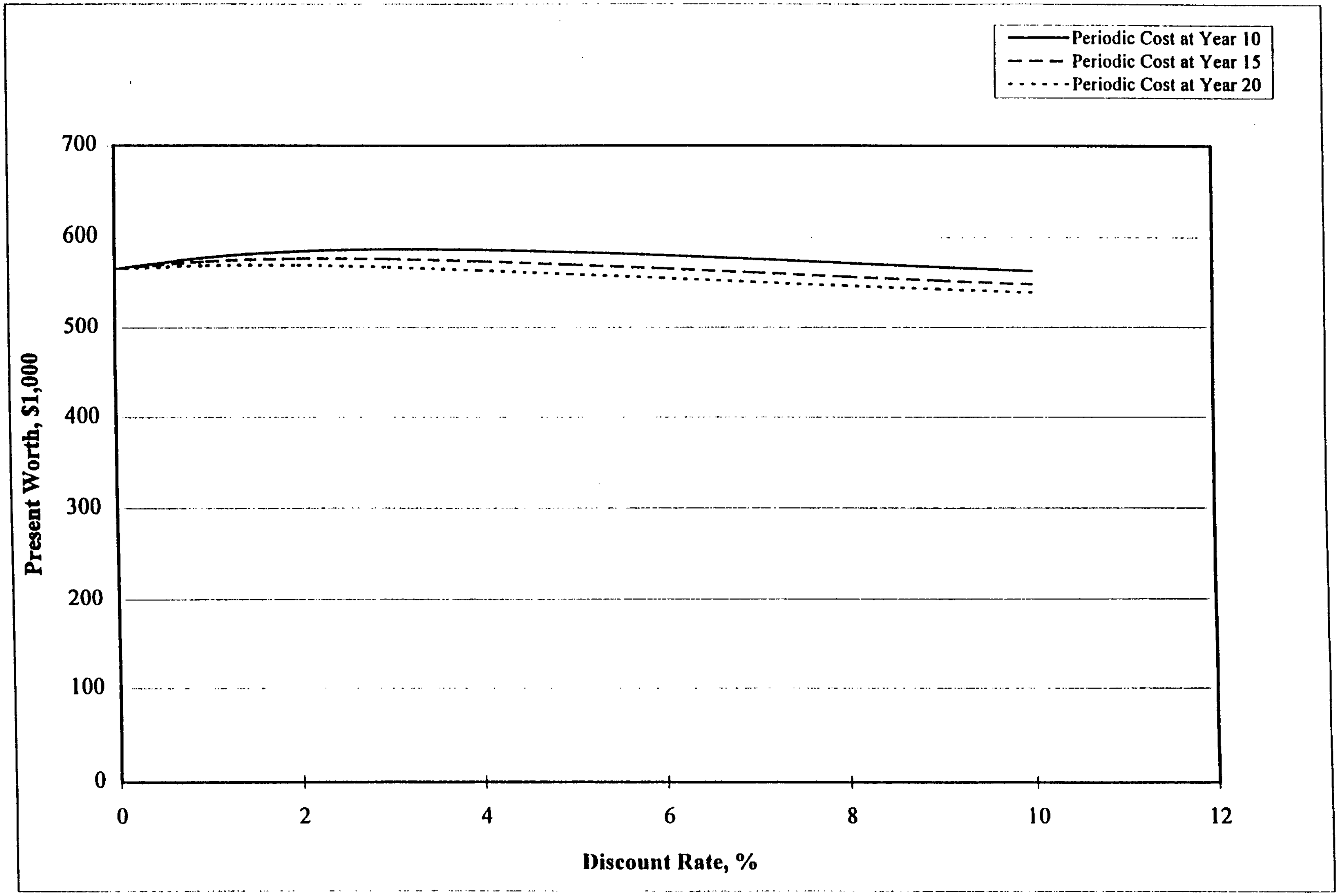

Figure E-17. Impact of a Change in Timing of Periodic Cost.

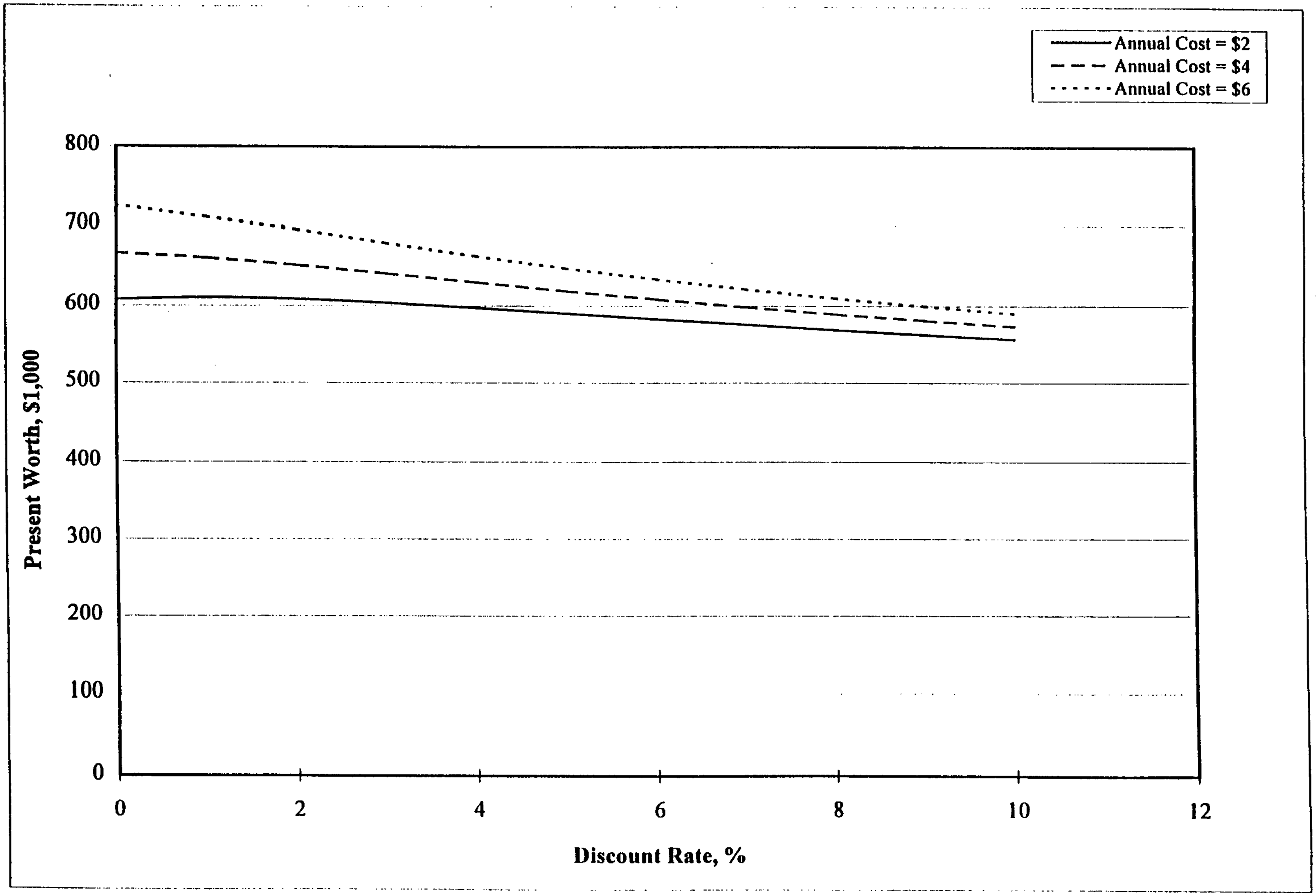

Figure E-18. Impact of a Change in Annual Cost.

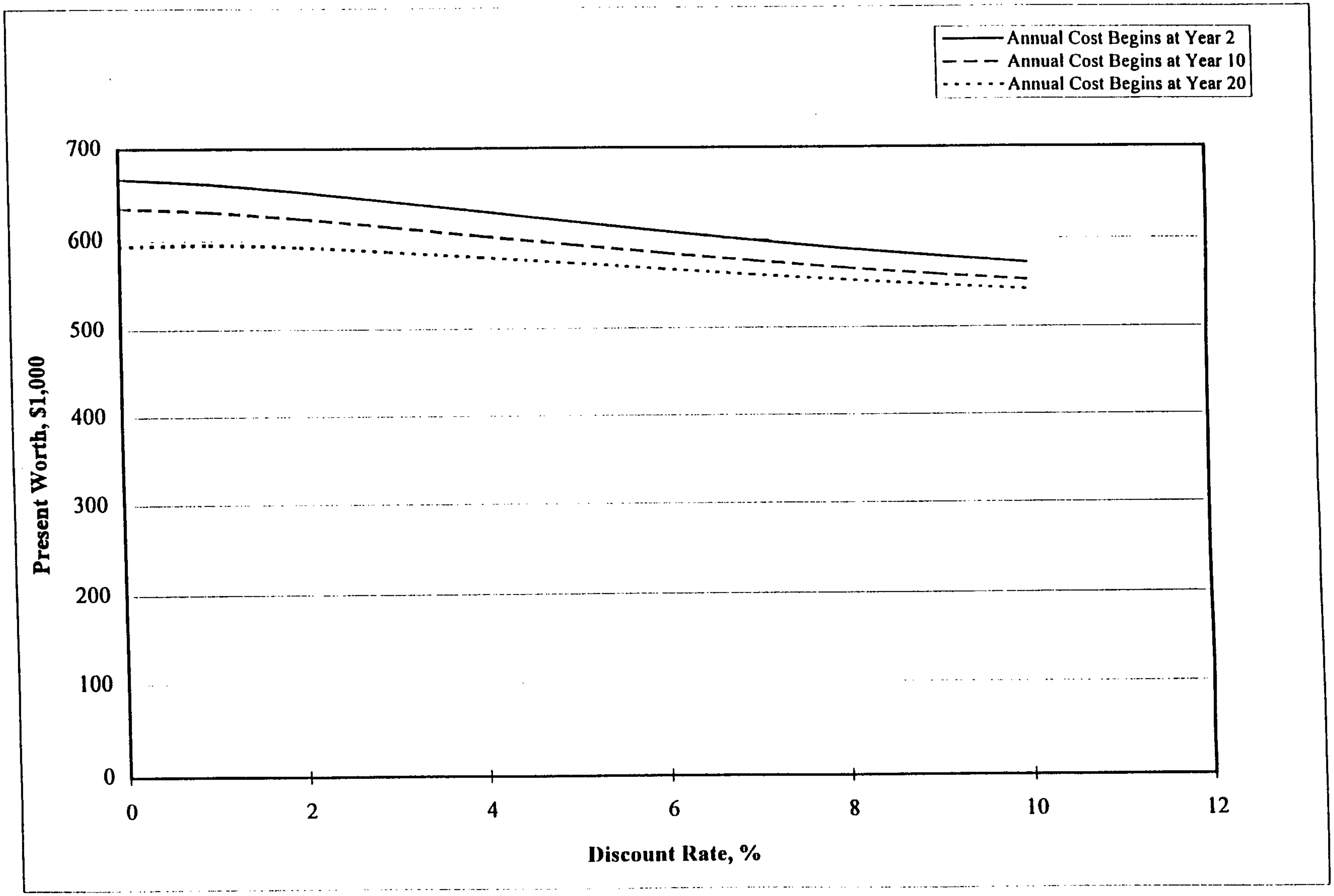

Figure E-19. Impact of a Change in Timing of Annual Cost.

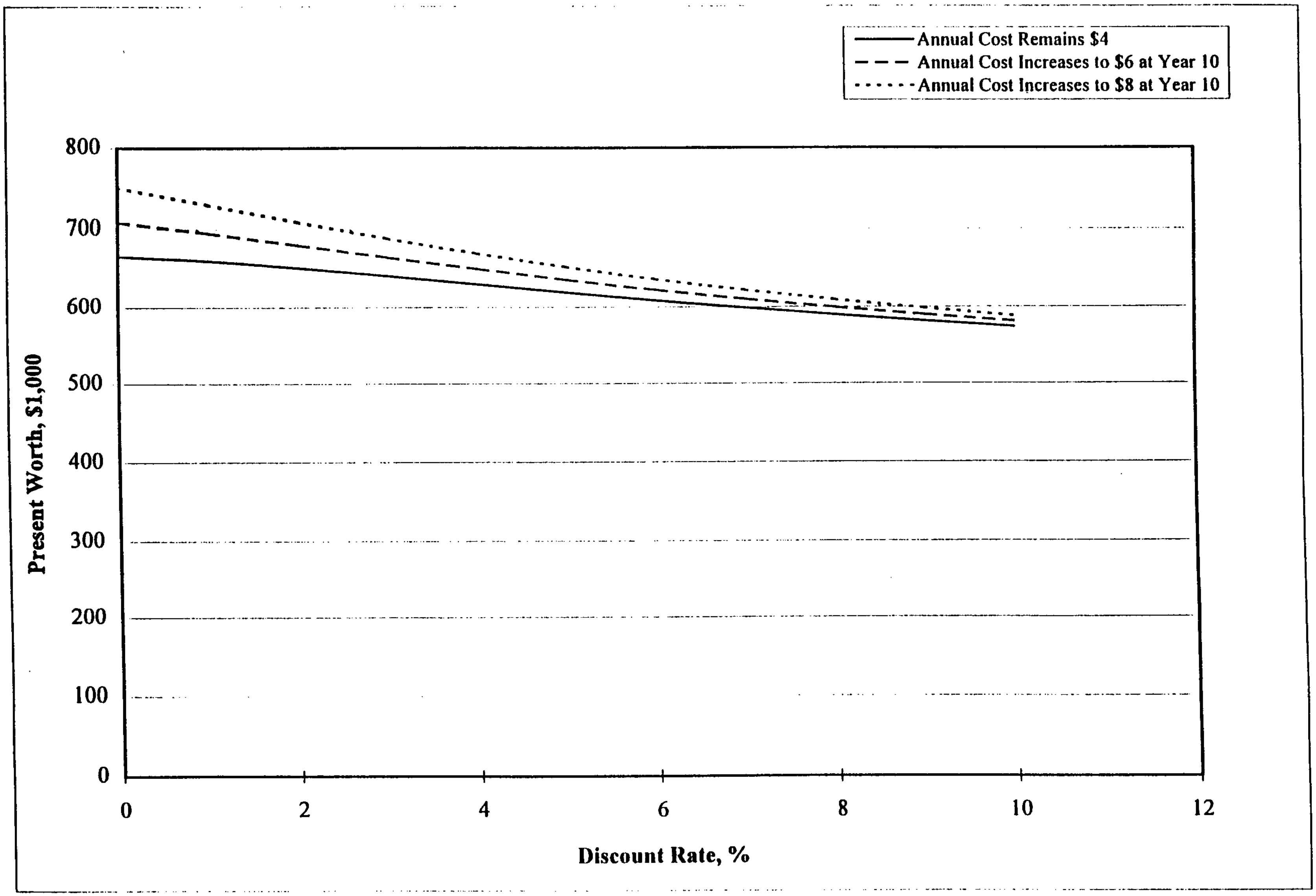

Figure E-20. Impact of a Change in Annual Cost at Specified Time.

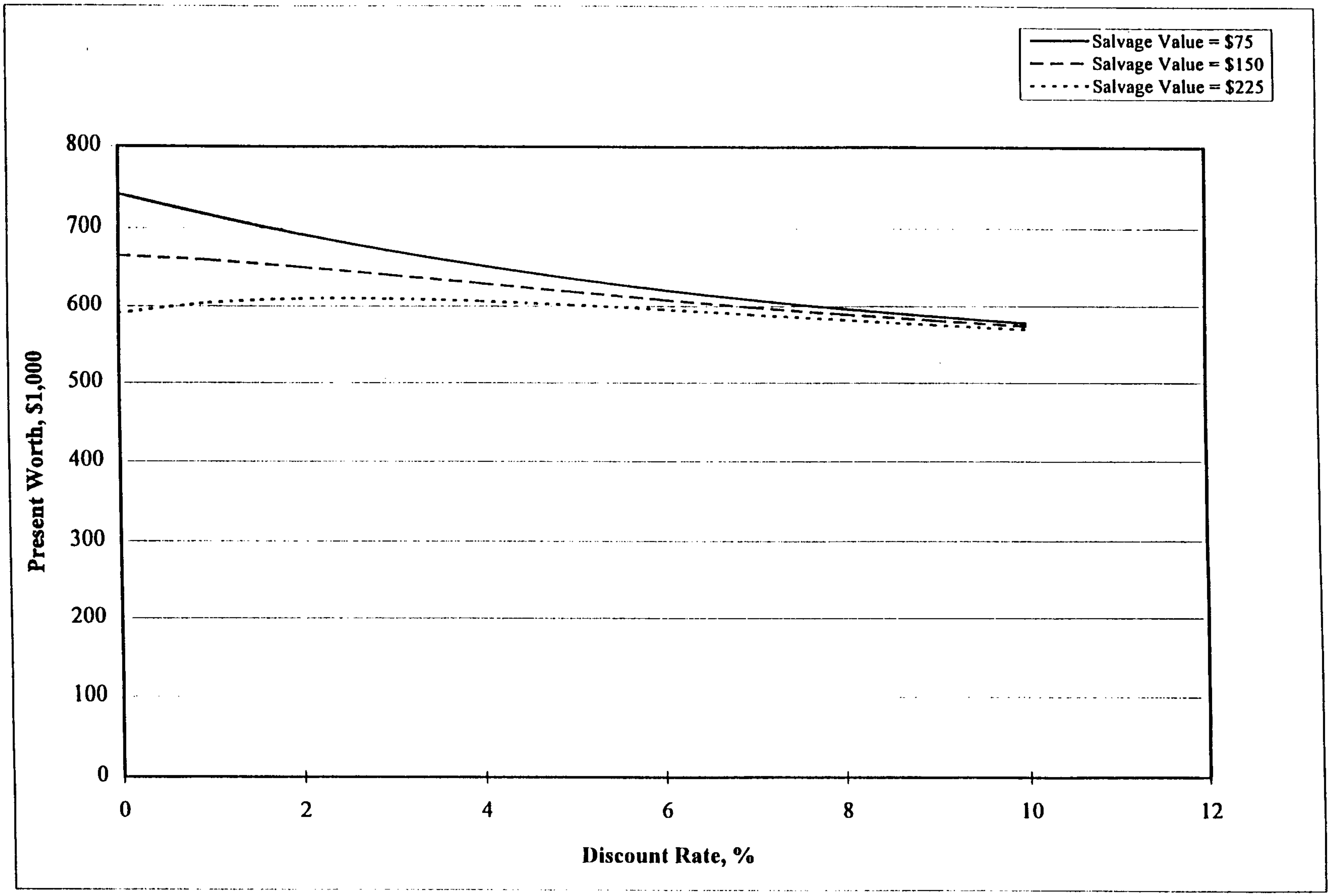

Figure E-21. Impact of a Change in Salvage Value.

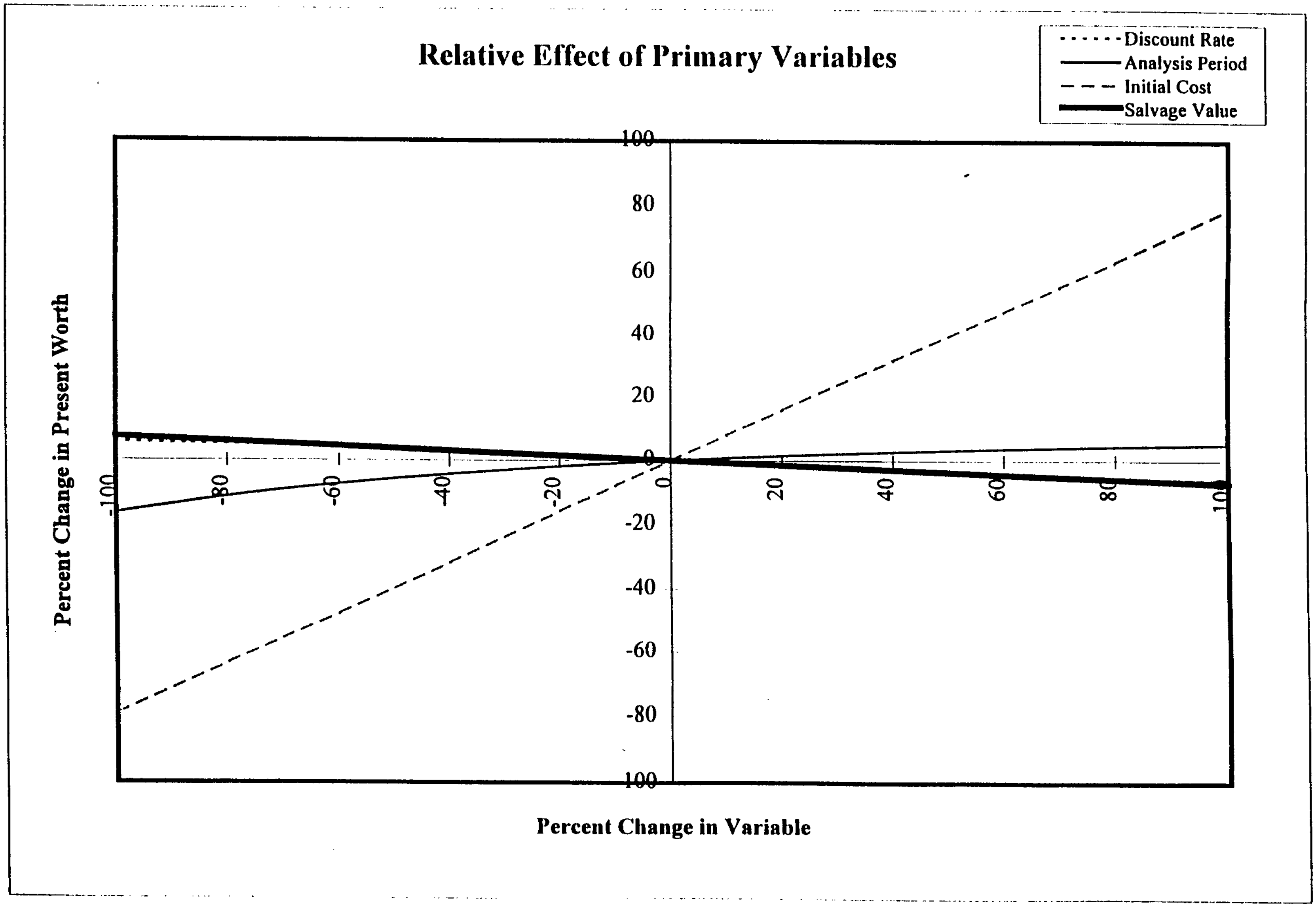

Figure E-22. Relative Effect of Primary Variables.

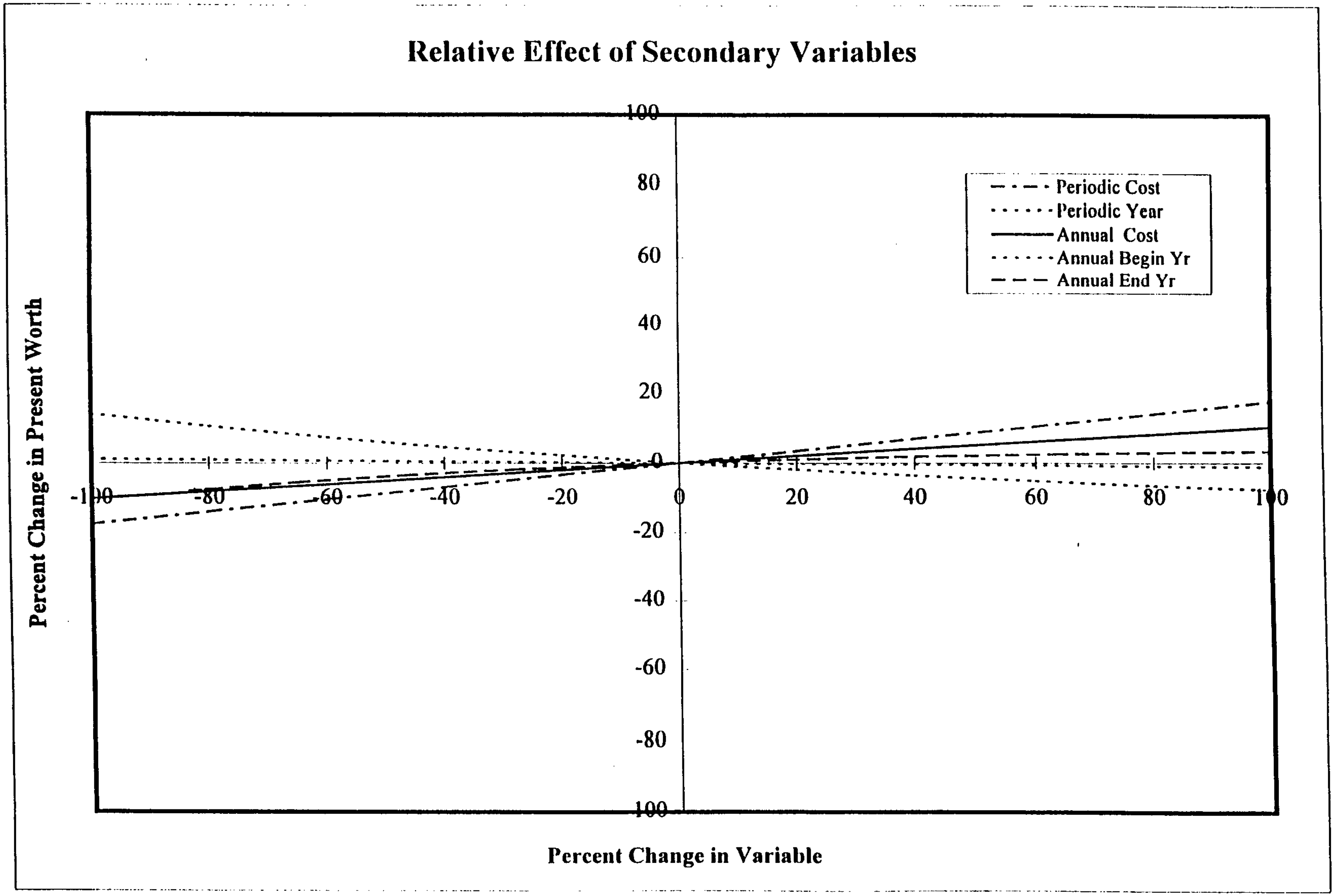

Figure E-23. Relative Effect of Secondary Variables.

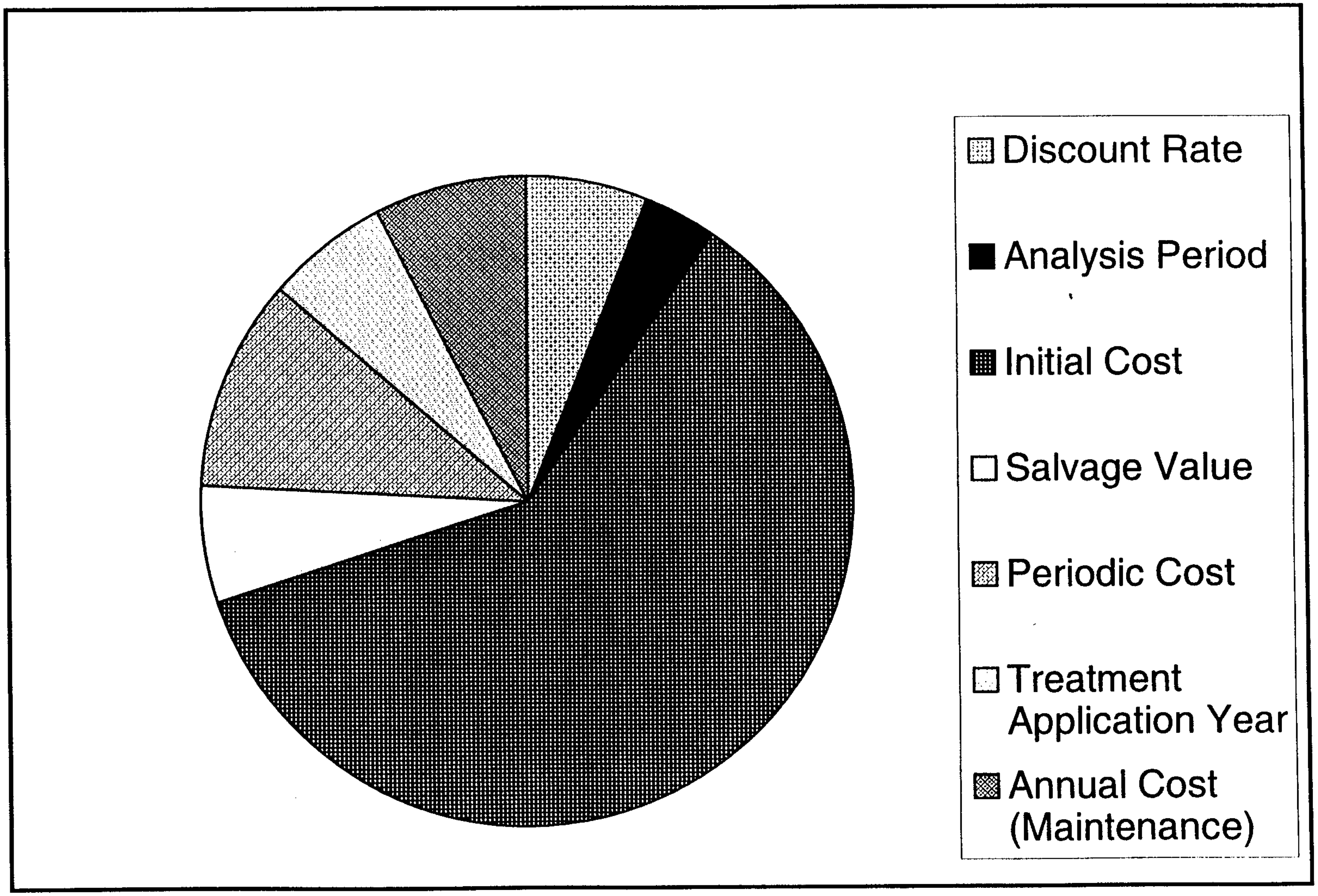

Figure E-24. Relative Impact of Each Variable on Present Worth Calculation.

Appendix F: Comparison of LCCA Calculations Using Recommended Values

Comparison of LCCA Results Using the Recommendations Included in This Report

In order to assess the impacts of the recommendations provided in this report on the current practices of the SDDOT, an analysis was performed on an actual project evaluated as part of the pavement selection process. The feasible alternatives for the project are defined as an asphalt surfacing project and a concrete surfacing project. The project description and the analysis sheets provided by the SDDOT are included. Planning and Programming provided the information used in this example.

The present worth values calculated using the current procedures were entered into a LCCA worksheet developed as part of this project. The present worth values for each alternate are included as figures E-1 and E-2. The values calculated using the worksheet do not exactly match the calculations made by the SDDOT because of the limitations to the number of maintenance entries on the worksheet and the use of interest and inflation rates rather than a discount value.

Calculations were also made using the economic value recommendations presented in this report. The results of this analysis are included in figures E-3 and E-4. Without addressing the timing, type, and costs used for each analysis there was little impact on the results of the analysis using the recommendations from the report. More dramatic impacts are anticipated as a result of changes to the periodic and annual treatments included in each scenario.

PROJECT: 0
ALTERNATE 1:

IMPROV LIFE (YRS)	=	44
INTEREST RATE	=	7.0 %
INFLATION RATES:		
CONSTRUCTION	=	5.0 %
MAINTENANCE	=	4.0 %

TOTAL PRESENT VALUE = $828,008

AVE. ANNUAL COST = $18,818

CONST YEAR	MAINT COST($)	CAPITAL INVESTMENT IMPROVEMENT	COST($)	INFLATED AMOUNT($) IMPROV	INFLATED AMOUNT($) MAINT	PRESENT VALUE($)
-3	$3,000			$0	$3,000	$3,000
-2	$3,000			$0	$3,120	$2,916
-1	$0	Grade & Interim Surfacing	$345,000	$380,363	$0	$332,223
0	$0	PCCP Surfacing	$430,000	$497,779	$0	$406,336
1	$500			$0	$585	$446
2	$500			$0	$608	$434
3	$500			$0	$633	$422
4	$500			$0	$658	$410
5	$500			$0	$684	$398
6	$500			$0	$712	$387
7	$1,000			$0	$1,480	$752
8	$1,000			$0	$1,539	$731
9	$1,000			$0	$1,601	$711
10	$1,000			$0	$1,665	$691
11	$1,000			$0	$1,732	$672
12	$1,000			$0	$1,801	$653
13	$1,500			$0	$2,809	$952
14	$1,500			$0	$2,922	$925
15	$1,500			$0	$3,039	$899
16	$1,500			$0	$3,160	$874
17	$2,500			$0	$5,478	$1,416
18	$1,000	Pavement Restoration	$20,000	$55,719	$2,279	$14,007
19	$1,000			$0	$2,370	$535
20	$1,000			$0	$2,465	$520
21	$1,000			$0	$2,563	$505
22	$1,000			$0	$2,666	$491
23	$1,500			$0	$4,159	$716
24	$1,500			$0	$4,325	$696
25	$1,500			$0	$4,498	$677
26	$1,500			$0	$4,678	$658
27	$2,000			$0	$6,487	$852
28	$2,000			$0	$6,746	$828
29	$2,500			$0	$8,770	$1,006
30	$1,500	Pavement Restoration	$80,000	$400,255	$5,473	$43,508
31	$1,500			$0	$5,691	$570
32	$1,500			$0	$5,919	$554
33	$1,500			$0	$6,156	$539
34	$2,000			$0	$8,536	$698
35	$2,000			$0	$8,878	$679
36	$2,000			$0	$9,233	$660
37	$2,000			$0	$9,602	$641
38	$2,500			$0	$12,483	$779
39	$2,500			$0	$12,982	$757
40	$3,000			$0	$16,201	$883

PROJECT:
ALTERNATE 1:

IMPROV LIFE (YRS)	=	44		
INTEREST RATE	=	7.0 %	TOTAL PRESENT VALUE =	$799,079
INFLATION RATES:				
CONSTRUCTION	=	5.0 %	AVE. ANNUAL COST =	$18,161
MAINTENANCE	=	4.0 %		

CONST	MAINT	CAPITAL INVESTMENT		INFLATED AMOUNT(S)		PRESENT
YEAR	COST(S)	IMPROVEMENT	COST(S)	IMPROV	MAINT	VALUE(S)
-3	$3,000			$0	$3,000	$3,000
-2	$3,000			$0	$3,120	$2,916
-1	$0	Grade & Interim Surfacing	$345,000	$380,353	$0	$332,223
0	$0	4" AC Surfacing	$270,000	$312,559	$0	$255,141
1	$500			$0	$585	$446
2	$500	Rout & Seal	$1,410	$1,300	$608	$1,717
3	$500	Chip Seal	$7,900	$10,587	$633	$7,478
4	$500			$0	$658	$410
5	$500			$0	$684	$398
6	$1,000			$0	$1,423	$774
7	$1,000			$0	$1,480	$752
8	$1,500			$0	$2,309	$1,097
9	$1,500			$0	$2,402	$1,066
10	$1,000	Chip Seal	$7,900	$14,897	$1,665	$6,873
11	$1,000			$0	$1,732	$672
12	$1,500			$0	$2,701	$979
13	$1,500			$0	$2,809	$952
14	$2,000			$0	$3,896	$1,233
15	$2,000			$0	$4,052	$1,199
16	$1,000	Mill 1" with 2.5" AC Overlay	$122,000	$308,288	$2,107	$85,827
17	$1,000			$0	$2,191	$566
18	$1,000	Rout & Seal	$1,410	$3,928	$2,279	$1,499
19	$1,000	Chip Seal	$7,900	$23,110	$2,370	$5,751
20	$1,000			$0	$2,465	$520
21	$1,000			$0	$2,563	$505
22	$1,500			$0	$3,999	$737
23	$1,500			$0	$4,159	$716
24	$2,000			$0	$5,767	$928
25	$2,000			$0	$5,997	$902
26	$2,500			$0	$7,797	$1,096
27	$2,500			$0	$8,108	$1,065
28	$3,000			$0	$10,119	$1,242
29	$3,000			$0	$10,524	$1,208
30	$1,500	Mill 1.5" with 2.5" AC Overlay	$122,000	$610,389	$5,473	$66,042
31	$1,500			$0	$5,691	$570
32	$1,500	Rout & Seal	$1,410	$7,778	$5,919	$1,283
33	$1,500	Chip Seal	$7,900	$45,755	$6,156	$4,544
34	$1,500			$0	$6,402	$524
35	$1,500			$0	$6,658	$509
36	$2,000			$0	$9,233	$660
37	$2,000			$0	$9,602	$641
38	$2,500			$0	$12,483	$779
39	$2,500			$0	$12,982	$757
40	$3,000			$0	$16,201	$883

LIFE-CYCLE COST ESTIMATING WORKSHEET

Enter Initial Analysis Year: 1997
Enter Analysis Period: 40
Enter Annual Discount Rate, %: 2

Project Identification: NH 0083(44) 153, Sully county
US83 from Onida N to the Potter County Line
13.0 miles, grading and surfacing AC Alternative

	Alternative 1	Alternative 2	Alternative 3
	Project Description:	Project Description:	Project Description:

Initial Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Cost	Alt. 1 Present Worth	Alt. 2 Estimated Cost	Alt. 2 Present Worth	Alt. 3 Estimated Cost	Alt. 3 Present Worth
1	Grade & Interim Surface	0	1997	$345,000	$345,000	$0	$0	$0	$0
2	4" AC Surface	0	1997	$270,000	$270,000	$0	$0	$0	$0
3		0	1997			$0	$0		
4									
5									
6									
7									
8									
Total Present Worth of Initial Costs				$615,000	$615,000	$0	$0	$0	$0

Periodic Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Cost	Alt. 1 Present Worth	Alt. 2 Estimated Cost	Alt. 2 Present Worth	Alt. 3 Estimated Cost	Alt. 3 Present Worth
1	Rout & Seal	2	1999	$1,410	$1,355			$0	$0
2	Chip Seal	3	2000	$7,900	$7,444			$0	$0
3	Chip Seal	10	2007	$7,900	$6,481	$0	$0		
4	Mill 1" with 2.5" AC Overlay	16	2013	$122,000	$88,870	$0	$0	$0	$0
5	Rout & Seal	18	2015	$1,410	$987				
6	Chip Seal	19	2016	$7,900	$5,423				
7	Mill 1" with 2.5" AC Overlay	30	2027	$122,000	$67,353				
8	Rout & Seal	32	2029	$1,410	$748				
Total Present Worth of Periodic Costs					$178,662		$0		$0

Annual Costs Item No.	Item Description	First Yr. of Ann. Costs Analysis Yr.	First Yr. Cal Yr	Last Yr. of Ann. Costs Analysis Yr	Last Yr. Cal Yr	Alt. 1 Estimated Annual Cost	Alt. 1 Present Worth	Alt. 2 Estimated Annual Cost	Alt. 2 Present Worth	Alt. 3 Estimated Annual Cost	Alt. 3 Present Worth
1	Maint Activity 1	1	1998	5	2002	$500	$2,357				
2	Maint Activity 2	6	2003	7	2004	$1,000	$1,759	$0	$0	$0	$0
3	Maint Activity 3	8	2005	9	2006	$1,500	$2,535	$0	$0	$0	$0
4	Maint Activity 4	10	2007	11	2008	$1,000	$1,625				
5	Maint Activity	12	2009	13	2010	$1,500	$2,342				
6	Maint Activity	14	2011	15	2012	$2,000	$3,002				
7	Maint Activity	16	2013	21	2018	$1,000	$4,162				
8	Maint Activity	22	2019	40	2037	$2,000	$20,689				
Total Present Worth of Annual Costs							$38,470		$0		$0

Replacement/Salvage Value Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Value	Alt. 1 Present Worth	Alt. 2 Estimated Value	Alt. 2 Present Worth	Alt. 3 Estimated Value	Alt. 3 Present Worth
1		40	2037	$0	$0	$0	$0	$0	$0
2		40	2037						
3									
4									
Total Present Worth of Replacement/Salvage Value					$0		$0		$0

TOTAL LCC	Alternative 1	Alternative 2	Alternative 3
Present Worth LCC	$832,131	$0	$0
Equivalent Uniform Annual LCC	$30,419	$0	$0

Lowest LCC Alternative			
PW Cost Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE
% Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE

Figure F-1. Present Worth of AC Alternative Using Current Procedure.

LIFE-CYCLE COST ESTIMATING WORKSHEET

Enter Initial Analysis Year: 1997
Enter Analysis Period: 40
Enter Annual Discount Rate, %: 2

Project Identification: NH 0083(44) 153, Sully county
US83 from Onida N to the Potter County Line
13.0 miles, grading and surfacing PCC Alternative

	Alternative 1	Alternative 2	Alternative 3
	Project Description:	Project Description:	Project Description:

Initial Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Cost	Alt. 1 Present Worth	Alt. 2 Estimated Cost	Alt. 2 Present Worth	Alt. 3 Estimated Cost	Alt. 3 Present Worth
1	Grade & Interim Surface	0	1997	$345,000	$345,000	$0	$0	$0	$0
2	PCCP Surfacing	0	1997	$430,000	$430,000	$0	$0	$0	$0
3		0	1997			$0	$0		
4									
5									
6									
7									
8									
Total Present Worth of Initial Costs				$775,000	$775,000	$0	$0	$0	$0

Periodic Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Cost	Alt. 1 Present Worth	Alt. 2 Estimated Cost	Alt. 2 Present Worth	Alt. 3 Estimated Cost	Alt. 3 Present Worth
1	Pavement Restoration	18	2015	$20,000	$14,003			$0	$0
2	Pavement Restoration	30	2027	$80,000	$44,166			$0	$0
3		0	1997	$0	$0	$0	$0		
4		0	1997	$0	$0	$0	$0		
5		0	1997	$0	$0			$0	$0
6		0	1997	$0	$0				
7		0	1997	$0	$0				
8		0	1997	$0	$0				
Total Present Worth of Periodic Costs					$58,169		$0		$0

Annual Costs Item No.	Item Description	First Yr. of Ann. Costs Analysis Yr.	First Yr. of Ann. Costs Cal Yr	Last Yr. of Ann. Costs Analysis Yr	Last Yr. of Ann. Costs Cal Yr	Alt. 1 Estimated Annual Cost	Alt. 1 Present Worth	Alt. 2 Estimated Annual Cost	Alt. 2 Present Worth	Alt. 3 Estimated Annual Cost	Alt. 3 Present Worth
1	Maint Activity 1	1	1998	6	2003	$500	$2,801				
2	Maint Activity 2	7	2004	12	2009	$1,000	$4,974				
3	Maint Activity 3	13	2010	16	2013	$1,500	$4,504	$0	$0	$0	$0
4	Maint Activity 4	17	2014	17	2014	$2,500	$1,785	$0	$0	$0	$0
5	Maint Activity	18	2015	22	2019	$1,000	$3,366				
6	Maint Activity	23	2020	26	2023	$1,500	$3,694				
7	Maint Activity	27	2024	28	2025	$2,000	$2,320				
8	Maint Activity	30	2027	40	2037	$2,500	$13,778				
Total Present Worth of Annual Costs							$37,222		$0		$0

Replacement/Salvage Value Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Value	Alt. 1 Present Worth	Alt. 2 Estimated Value	Alt. 2 Present Worth	Alt. 3 Estimated Value	Alt. 3 Present Worth
1		40	2037	$0	$0				
2		40	2037			$0	$0	$0	$0
3									
4									
Total Present Worth of Replacement/Salvage Value					$0		$0		$0

TOTAL LCC	Alternative 1	Alternative 2	Alternative 3
Present Worth LCC	$870,391	$0	$0
Equivalent Uniform Annual LCC	$31,818	$0	$0

	Alternative 1	Alternative 2	Alternative 3
Lowest LCC Alternative			
PW Cost Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE
% Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE

Figure F-2. Present Worth of PCC Alternative Using Current Procedure.

LIFE-CYCLE COST ESTIMATING WORKSHEET

Enter Initial Analysis Year: 1997
Enter Analysis Period: 40
Enter Annual Discount Rate, %: 4

Project Identification: NH 0083(44) 153, Sully county
US83 from Onida N to the Potter County Line
13.0 miles, grading and surfacing   AC Alternative

	Alternative 1	Alternative 2	Alternative 3
	Project Description:	Project Description:	Project Description:

Initial Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Cost	Alt. 1 Present Worth	Alt. 2 Estimated Cost	Alt. 2 Present Worth	Alt. 3 Estimated Cost	Alt. 3 Present Worth
1	Grade & Interim Surface	0	1997	$345,000	$345,000	$0	$0	$0	$0
2	4" AC Surface	0	1997	$270,000	$270,000	$0	$0	$0	$0
3		0	1997			$0	$0		
4									
5									
6									
7									
8									
Total Present Worth of Initial Costs				$615,000	$615,000	$0	$0	$0	$0

Periodic Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Cost	Alt. 1 Present Worth	Alt. 2 Estimated Cost	Alt. 2 Present Worth	Alt. 3 Estimated Cost	Alt. 3 Present Worth
1	Rout & Seal	2	1999	$1,410	$1,304			$0	$0
2	Chip Seal	3	2000	$7,900	$7,023			$0	$0
3	Chip Seal	10	2007	$7,900	$5,337	$0	$0		
4	Mill 1" with 2.5" AC Overlay	16	2013	$122,000	$65,137	$0	$0		
5	Rout & Seal	18	2015	$1,410	$696			$0	$0
6	Chip Seal	19	2016	$7,900	$3,750				
7	Mill 1" with 2.5" AC Overlay	30	2027	$122,000	$37,615				
8	Rout & Seal	32	2029	$1,410	$402				
Total Present Worth of Periodic Costs					$121,263		$0		$0

Annual Costs Item No.	Item Description	First Yr. of Ann. Costs Analysis Yr.	First Yr. of Ann. Costs Cal Yr	Last Yr. of Ann. Costs Analysis Yr	Last Yr. of Ann. Costs Cal Yr	Alt. 1 Estimated Annual Cost	Alt. 1 Present Worth	Alt. 2 Estimated Annual Cost	Alt. 2 Present Worth	Alt. 3 Estimated Annual Cost	Alt. 3 Present Worth
1	Maint Activity 1	1	1998	5	2002	$500	$2,226				
2	Maint Activity 2	6	2003	7	2004	$1,000	$1,550				
3	Maint Activity 3	8	2005	9	2006	$1,500	$2,150	$0	$0	$0	$0
4	Maint Activity 4	10	2007	11	2008	$1,000	$1,325	$0	$0	$0	$0
5	Maint Activity	12	2009	13	2010	$1,500	$1,838				
6	Maint Activity	14	2011	15	2012	$2,000	$2,265				
7	Maint Activity	16	2013	21	2018	$1,000	$2,911				
8	Maint Activity	22	2019	40	2037	$2,000	$11,527				
Total Present Worth of Annual Costs							$25,792		$0		$0

Replacement/Salvage Value Item No.	Item Description	Analysis Year	Calendar Year	Alt. 1 Estimated Value	Alt. 1 Present Worth	Alt. 2 Estimated Value	Alt. 2 Present Worth	Alt. 3 Estimated Value	Alt. 3 Present Worth
1	4 Years of Remaining Life	40	2037	$30,500	$6,353				
2		40	2037			$0	$0	$0	$0
3									
4									
Total Present Worth of Replacement/Salvage Value					$6,353		$0		$0

TOTAL LCC	Alternative 1	Alternative 2	Alternative 3
Present Worth LCC	$755,703	$0	$0
Equivalent Uniform Annual LCC	$38,181	$0	$0

Lowest LCC Alternative			
PW Cost Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE
% Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE

Figure F-3. Present Worth of AC Alternative Using the Economic Value Recommendations.

LIFE-CYCLE COST ESTIMATING WORKSHEET

Enter Initial Analysis Year	1997	Project Identification	NH 0083(44) 153, Sully county
Enter Analysis Period	40		US83 from Onida N to the Potter County Line
Enter Annual Discount Rate, %	4		13.0 miles, grading and surfacing PCC Alternative

	Alternative 1	Alternative 2	Alternative 3
	Project Description:	Project Description:	Project Description:

Initial Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt 1 Estimated Cost	Alt 1 Present Worth	Alt 2 Estimated Cost	Alt 2 Present Worth	Alt 3 Estimated Cost	Alt 3 Present Worth
1	Grade & Interim Surface	0	1997	$345,000	$345,000	$0	$0	$0	$0
2	PCCP Surfacing	0	1997	$430,000	$430,000	$0	$0	$0	$0
3		0	1997			$0	$0		
4									
5									
6									
7									
8									
Total Present Worth of Initial Costs				$775,000	$775,000	$0	$0	$0	$0

Periodic Costs Item No.	Item Description	Analysis Year	Calendar Year	Alt 1 Estimated Cost	Alt 1 Present Worth	Alt 2 Estimated Cost	Alt 2 Present Worth	Alt 3 Estimated Cost	Alt 3 Present Worth
1	Pavement Restoration	18	2015	$20,000	$9,873			$0	$0
2	Pavement Restoration	30	2027	$80,000	$24,665			$0	$0
3		0	1997	$0	$0	$0	$0		
4		0	1997	$0	$0	$0	$0		
5		0	1997	$0	$0			$0	$0
6		0	1997	$0	$0				
7		0	1997	$0	$0				
8		0	1997	$0	$0				
Total Present Worth of Periodic Costs					$34,538		$0		$0

Annual Costs Item No.	Item Description	First Yr. of Ann. Costs Analysis Yr.	First Yr. of Ann. Costs Cal Yr	Last Yr. of Ann. Costs Analysis Yr	Last Yr. of Ann. Costs Cal Yr	Alt 1 Estimated Annual Cost	Alt 1 Present Worth	Alt 2 Estimated Annual Cost	Alt 2 Present Worth	Alt 3 Estimated Annual Cost	Alt 3 Present Worth
1	Maint Activity 1	1	1998	6	2003	$500	$2,621				
2	Maint Activity 2	7	2004	12	2009	$1,000	$4,143				
3	Maint Activity 3	13	2010	16	2013	$1,500	$3,401	$0	$0	$0	$0
4	Maint Activity 4	17	2014	17	2014	$2,500	$1,283	$0	$0	$0	$0
5	Maint Activity	18	2015	22	2019	$1,000	$2,285				
6	Maint Activity	23	2020	26	2023	$1,500	$2,297				
7	Maint Activity	27	2024	28	2025	$2,000	$1,361				
8	Maint Activity	30	2027	40	2037	$2,500	$7,023				
Total Present Worth of Annual Costs							$24,414		$0		$0

Replacement/Salvage Value Item No.	Item Description	Analysis Year	Calendar Year	Alt 1 Estimated Value	Alt 1 Present Worth	Alt 2 Estimated Value	Alt 2 Present Worth	Alt 3 Estimated Value	Alt 3 Present Worth
1	2 Years Remaining Life	40	2037	$13,400	$2,791				
2		40	2037			$0	$0	$0	$0
3									
4									
Total Present Worth of Replacement/Salvage Value					$2,791		$0		$0

TOTAL LCC	Alternative 1	Alternative 2	Alternative 3
Present Worth LCC	$831,161	$0	$0
Equivalent Uniform Annual LCC	$41,993	$0	$0

Lowest LCC Alternative			
PW Cost Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE
% Difference From Lowest LCC Alternative	FALSE	FALSE	FALSE

Figure F-4. Present Worth of PCC Alternative Using the Economic Value Recommendations.

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