ASSESSING AND INTERPRETING THE BENEFITS DERIVED FROM IMPLEMENTING AND USING ASSET MANAGEMENT SYSTEMS

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16. Abstract

Interest in asset management has grown over the last two decades but agencies continue to be concerned about the cost to develop and implement asset management processes. While originally introduced as a tool for policy analysis, HERS-ST is free software that delivers several asset management functions. This report uses a generic methodology to document a strategy to assess the benefits to be gained using tools such as HERS-ST. The impact of decisions made using HERS-ST (referred to as "with HERS-ST") are compared with decisions made using a naïve worst first strategy (referred to as "without HERS-ST") using common performance measures, net present value and benefit cost ratios. The methodology is applied to three different data sets. The data from New Mexico are used to explore strategies for communicating the results using charts, graphs and tables. Data from Kentucky and Delaware are used to develop more in-depth case studies. All three data sets demonstrate that significant benefits can be realized using HERS-ST. A Step-by-Step Guide for implementing the methodology and a training module are also developed.

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1 Introduction

Asset management in the United States has been evolving since the 1970's. The Federal Highway Administration's (FHWA) *Asset Management Primer* (FHWA, 1999) provides several definitions of asset management and the characteristics of asset management systems (AMS). The definitions used in this research are shown here. While asset management is much more than the systems or tools that support strategic thinking and decision making, such systems play an important role in advancing the state of the science and state of the practice of asset management.

> **Transportation Asset Management** is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives.
> *AASHTO Subcommittee on Asset Management*

> **Asset management systems** (AMS) are tools to support the systematic process of maintaining, upgrading, and operating physical assets cost-effectively. Such systems include asset inventory, condition assessment and performance modeling, alternative selection and evaluation of maintenance and rehabilitation, methods for evaluating the effectiveness of each strategy, project implementation, and performance monitoring.
> *Mizusawa. 2007*

These systems first emerged as pavement and bridge management systems. Their importance as tools to support better management of our physical assets was recognized in the Intermodal Surface Transportation Efficiency Act of 1991 and later the Government Accounting Standards Board guidelines for asset reporting. In addition the continued degradation of physical assets in the U.S and ever tightening budget for maintenance and renewal of physical infrastructure has increased awareness of the role of such systems in asset management.

However, there are no comprehensive asset management systems (AMS) in place at present and it is generally recognized that asset management is as much as philosophy as a specific tool or system. Agencies use a variety of tools and systems to support asset management. In many instances, agencies have developed systems or tailored existing systems for specific types of infrastructure assets. Pavement management systems as well as bridge management systems are commonly used as part of the asset management process. Another tool is the Highway Economic Requirement System – State Version (HERS-ST). HERS-ST is a highway investment performance computer model that determines the impact of alternative highway investment levels and program structures on highway conditions, performance, and agency, user, and external costs. While HERS-ST does not capture all possible roadway and pavement options, it provides a more comprehensive tool to explore alternative decisions. Most importantly, HERS-ST includes estimates of user costs. A peer exchange focused on asset management in operations and planning identified six barriers to the implementation of AMS in agencies (Hendren 2005). These are:

- lack of integration using more sophisticated analytic tools to evaluate and prioritize maintenance and rehabilitation projects;
- database issues;
- lack of adequate communication tools and methods for different audiences;
- jurisdictional issues; institutional issues; and
- implementation and development costs.

These barriers can potentially prevent agencies from successfully implementing AMS. In particular, cost is a critical issue and barrier. Without showing that the benefits of AMS implementation exceed the costs for AMS implementation and operation, implementation may not occur. In particular, upper-level managers are interested in benefits that can be translated into monetary values, because they need to justify their investment in AMS. Also, agencies that have already implemented AMS may require justification of past and continued investment in AMS.

This report documents the results of research that builds on past studies and a recent PhD dissertation (Mizusawa 2007) to develop three areas related to assessing the benefits of asset management implementation:

1. Communicating the benefits of asset management
2. Developing a strategy for using HERS-ST to estimate benefits and
3. Applying the tools and techniques to additional case studies.

This research uses HERS-ST for much of the analysis. As well as recognizing agency, user and external costs, HERS-ST develops an economically optimal investment program based on benefit-cost analysis (BCA). HERS-ST attempts to balance investments in safety, capacity and pavement improvements recognizing the impact on air quality, user costs, crashes and pavement roughness. The strength of HERS-ST is not in assembling a portfolio of projects but as a network analysis tool to help set budgets, and explore the impact of strategies on overall network performance. HERS-ST was developed by Federal Highway Administration (FHWA) and is available at no cost. While some practitioners and researchers do not consider HERS-ST to be an asset management system but rather an engineering/economic analysis tool, consistent with the definition presented here, this research (1) interprets AMS to include all **tools** that support asset management and (2) recognizes HERS-ST as an AMS. It is also important to note, that in the context of this research, implementation of an asset management systems in general, and HERS-ST in particular refers to the use of the system or tool.

HERS-ST provides three general evaluation scenarios as follows (FHWA 2006):

- What level of spending is required to achieve an economically optimal program structure that implements all projects identified as economically worthwhile by HERS-ST[1]?
- What user cost/condition/performance level will result from a given spending level?
- What level of spending is required to achieve a certain level of user cost?

[1] It is important to note that HERS-ST does not consider all options and is intended to provide network not project level investment guidance. For example, pavement preservation is not explicitly part of HERS-ST.

Using the scenarios, transportation agencies can conduct long range planning, what-if analysis, congestion management, and so on (FHWA 2003).

This research develops a methodology for analyzing the benefits derived from HERS-ST implementation and applies the methodology to three data sets. Assuming that future savings, in terms of agency, user, and external costs, are possible if agencies follow the optimal program recommended by HERS-ST, the value of these savings is also estimated. Also, the research assesses whether the benefits outweigh the HERS-ST implementation costs to justify HERS-ST implementation.

This research:

- provides a methodology that will help others think about how to evaluate the benefits of system implementation,
- provides a HERS-ST specific methodology for evaluations, and
- explores the magnitude of these benefits recognizing the limitations of HERS-ST.

1.1 Background

Recent research developed a generic methodology for quantifying benefits derived from implementation of AMS (Mizusawa, 2007). The research also recognized the importance of evaluating the benefits of asset management in terms of the 3E's – efficacy, effectiveness and efficiency.

The framework involves three analysis methods: descriptive analysis using before and after (with and without asset management) data, regression analysis, and benefit-cost analysis (BCA). Depending on the implementation of AMS and the availability of time series data related to asset inventory, asset performance, and maintenance and rehabilitation (M&R) treatments, the evaluation design is as follows:

- For an agency that has implemented AMS and has available time series data, use before and after data based on an *ex post facto* evaluation using a comparison between actual performances before and after AMS implementation, or use with and without data based on an *ex post facto* evaluation using a comparison between predicted performance if AMS had not been implemented as quasi performance before AMS implementation and actual performance after AMS implementation.
- For an agency that implemented AMS but has no available time series data and an agency that has not implemented AMS and has no available time series data, use with and without data based on an *ex ante* evaluation using a comparison between predicted performances with and without AMS implementation.

Using this framework, two case studies (Vermont Transportation Agency and HERS-ST) were completed (Mizusawa 2007). However, due to data availability issues, the case studies applies the *ex ante* evaluation only. The results show the applicability of the framework to quantify the benefits of AMS implementation in light of the 3Es. Although the justification of investment in AMS implementation is not conducted using the BCA in the framework due to a lack of available AMS implementation and operating costs, the BCA shows its capability of justifying the investment. Also, the results identify improvements in performance such as pavement conditions and the benefits of AMS implementation consisting of agency, user, and external benefits. For example, it is expected that PMS, one AMS element used by the State of Vermont, increases pavement condition by 10.1 points in 0-100 point scale. Similarly, a case study using HERS-ST identifies $359 million of the benefits of HERS-ST implementation over 10 years. The benefits consist of $1.5 million agency benefits, $323 million user benefits, and $34.5 million external benefits. The case studies suggest that AMS implementation contributes to an improvement in agencies' performance and costs for M&R; and the benefits derived from AMS implementation exceed costs for AMS implementation and operation. Furthermore, the approach is rational and grounded in widely accepted practices.

1.2 Objectives

The objectives of this research are twofold:

- To demonstrate that the implementation of Asset Management Systems (AMS) improves asset performance
- To show that the benefits of using AMS outweigh the costs for AMS implementation and operation.

1.3 Project Overview

This project has three parts:

- Part 1) Methodology
- Part 2) Communication
- Part 3) Case Studies

The first part focuses on the methodology for computing the benefits of implementing HERS-ST. The outcomes of the previous HERS-ST case studies showed the potential of HERS-ST's functions to quantify the benefits of not only HERS-ST per se but also other AMS and tools as an analysis tool because HERS-ST calculates detailed benefits based on elaborate functions derived from numerous past studies. However, there are three issues to be addressed to further investigate HERS-ST implementation as follows:

1. Previous research (Mizusawa 2007) identified some limitations of HERS-ST. Specifically, these limitations are (1) the automatic selection of treatments when trying to simulate a "worst first' strategy, and (2) the ability to analyze benefits by year rather than funding period. The first issue has been addressed in the most recent release of the HERS-ST. However, the second issue was found to be beyond the scope of this project.

2. A step-by-step analysis procedure is also required so others can realize the power of HERS-ST in computing the benefits of implementation. Furthermore recent releases of HERS-ST provide more flexibility. The methodology developed:
    - Addresses the assignment of treatments in HERS-ST under the worst first strategy including the automatic assignment of treatment and the nature of the treatments.
    - Explores opportunities for computing disaggregated benefits per funding period.
    - Develops a step-by-step analysis procedure for estimating the benefits using HERS-ST and develop a guide.
    - Develops a training module for the existing HERS-ST Training Course that walks the user through the procedures for benefit analysis.
3. A user's manual documenting step-by-step analysis procedures using HERS-ST is included in Appendix A. A set of PowerPoint slides and notes that can be used for training are included in Appendix B.

The second part of the project explores communication strategies using graphs and tables. Data from New Mexico are used to illustrate the concepts.

The third part of the project uses HERS-ST to demonstrate the application of the results of the first two parts to additional case studies. Kentucky and Delaware are used as the case studies. The Kentucky case study was completed first and as a result the methodology was modified, as reflected in the Delaware case study and the manual.

1.4 Outline of the Report

This report consists of six chapters, references and three appendices covering the following topics:

Chapter 2 provides an overview of the methodology for evaluating the costs and benefits of using an asset management system.

Chapter 3 explores communication strategies.

Chapters 4 and 5 document the case studies for Kentucky and Delaware

Chapter 6 presents a summary and conclusions.

Appendix A provides a User's Manual for the Step-by-Step Guide for assessing the benefits.

Appendix B includes training materials for a training module on using HERS-ST for assessing the benefits of using asset management.

Appendix C includes a more detailed comparison of improvement strategies in the Kentucky case study.

2 Overview of the Methodology

2.1 Evaluation Concepts

There are two types of evaluation design: an *ex post facto* and *ex ante*. An *ex post facto* or retrospective evaluation is applied to agencies that have already implemented HERS-ST. On the other hand, an *ex ante* or prospective evaluation is applied to agencies that are going to implement HERS-ST. Since we need to quantify the benefits of HERS-ST implementation for agencies that manage a whole network, we focus on performances at network level.

Figure 1 shows the concepts of an *ex post facto* evaluation, which includes two types: a comparison of actual average network conditions, such as pavement condition, before and after HERS-ST implementation (left hand side); and a comparison between predicted average network condition if HERS-ST had not been implemented and actual average network condition after HERS-ST implementation (right hand side). Similar to the analyses of Hudson et al. (2001) and Cowe Falls and Tighe (2004), the first type observes trends in pavement condition using time series data to make a comparison between before and after HERS-ST implementation. The second type needs time series data of the actual pavement condition both before and after HERS-ST implementation as well. The actual pavement condition before HERS-ST implementation is used to predict pavement condition without HERS-ST after the year of HERS-ST implementation based on a strategy before HERS-ST implementation (e.g., a worst first) and to compare this to the actual pavement condition with HERS-ST after HERS-ST implementation. This type includes the analysis by Smadi (2004). Since the actual pavement conditions across the network after HERS-ST implementation are based on a HERS-ST optimization strategy, the actual pavement conditions after HERS-ST implementation are expected to be better than the actual pavement conditions before HERS-ST implementation and the predicted pavement conditions without HERS-ST after the year of HERS-ST implementation. The improvement in the pavement conditions 'before' and 'after' HERS-ST implementation (left hand side) and 'with' and 'without' HERS-ST implementation (right hand side) in the comparisons represents the benefits of HERS-ST implementation in terms of asset performance.

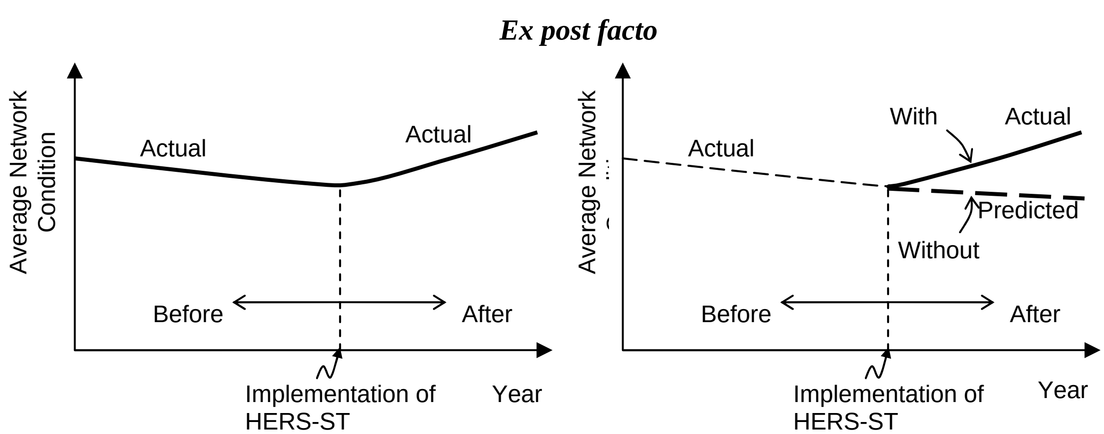

Figure 1. Concepts of *ex post facto* evaluation

Since the time series data required for *ex post facto* evaluation are rarely available in transportation agencies, we need an alternative evaluation method. That is the *ex ante* evaluation depicted in Figure 2. Using current performance data, two different future performances are simulated based on strategies: ‘without HERS-ST’ (e.g., a worst first strategy) and ‘with HERS-ST’ (i.e., a HERS-ST optimization strategy). The predicted condition without HERS-ST can simulate the past actual pavement condition before HERS-ST implementation, while the predicted condition with HERS-ST can simulate the past actual condition after HERS-ST implementation. In addition, since future pavement conditions can be simulated based on the strategies, the *ex ante* evaluation can analyze the benefits of HERS-ST implementation even though an agency had not implemented HERS-ST. Although the predicted conditions do not represent real pavement condition, they can show the difference in pavement condition between ‘with HERS-ST’ and ‘without HERS-ST’, that is, the benefits of HERS-ST implementation. As demonstrated, the *ex ante* evaluation is similar to the *ex post facto* evaluation (right hand side in Figure 1) that compares predicted conditions without HERS-ST implementation to actual conditions after HERS-ST implementation. This is a quasi evaluation design to recognize benefits in pavement conditions between ‘with HERS-ST’ and ‘without HERS-ST.’ A “with HERS-ST” and “without HERS-ST” analysis is conducted in this report to demonstrate the concepts and explore the benefits.

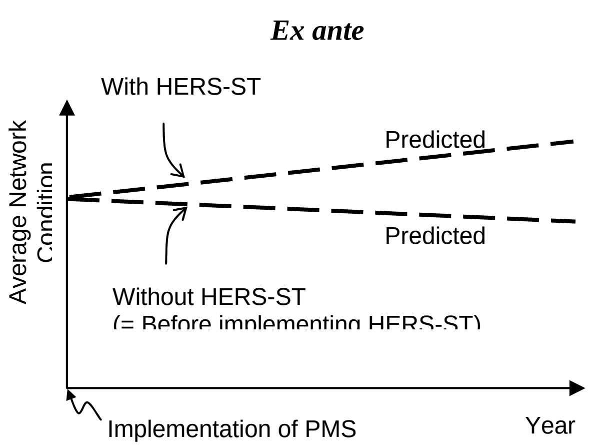

Figure 2. Concept of *ex ante* evaluation

In the analysis, HERS-ST recommends more frequent and preservation treatments and minor rehabilitations while taking into account future pavement conditions. These are relatively small-scale works compared to the worst first strategy’s reactive treatments that are less frequent and more significant than many HERS-ST treatments. Thus, the HERS-ST treatments are less expensive than the worst first strategy’s treatments over a long period, to keep the pavement above a minimum acceptable across the network. Furthermore, the budget saved by the treatments can be used for further treatments. Hence, it is expected that the pavement conditions with HERS-ST is improving more than that without HERS-ST as time goes by because of the efficiency of treatments.

2.2 Using HERS-ST to Assess the Benefits of Asset Management

HERS-ST is designed to provide guidance to Congress in setting budgets and policies related to highways. However, as a rigorous tool for assessing the impacts of alternative highway investment strategies, HERS-ST offers a unique opportunity to assess the net benefits of asset management.

As HERS-ST was not designed for this purpose, this section outlines the process used to assess the costs and benefits of using asset management (in the form of decisions recommended by HERS-ST) versus a worst first strategy.

The overall flow of the analysis is shown in Figure 3.

This analysis method compares:

- Performance measures for 'With' and 'Without' cases
    - Average Present Serviceability Rating (PSR)
    - Average speed and delay
    - Maintenance costs
    - User costs
    - Emission costs
- Benefits and costs, as shown in Table 1, for 'With' and 'Without' cases
    - Net Present Value
    - Benefit-Cost Ratio

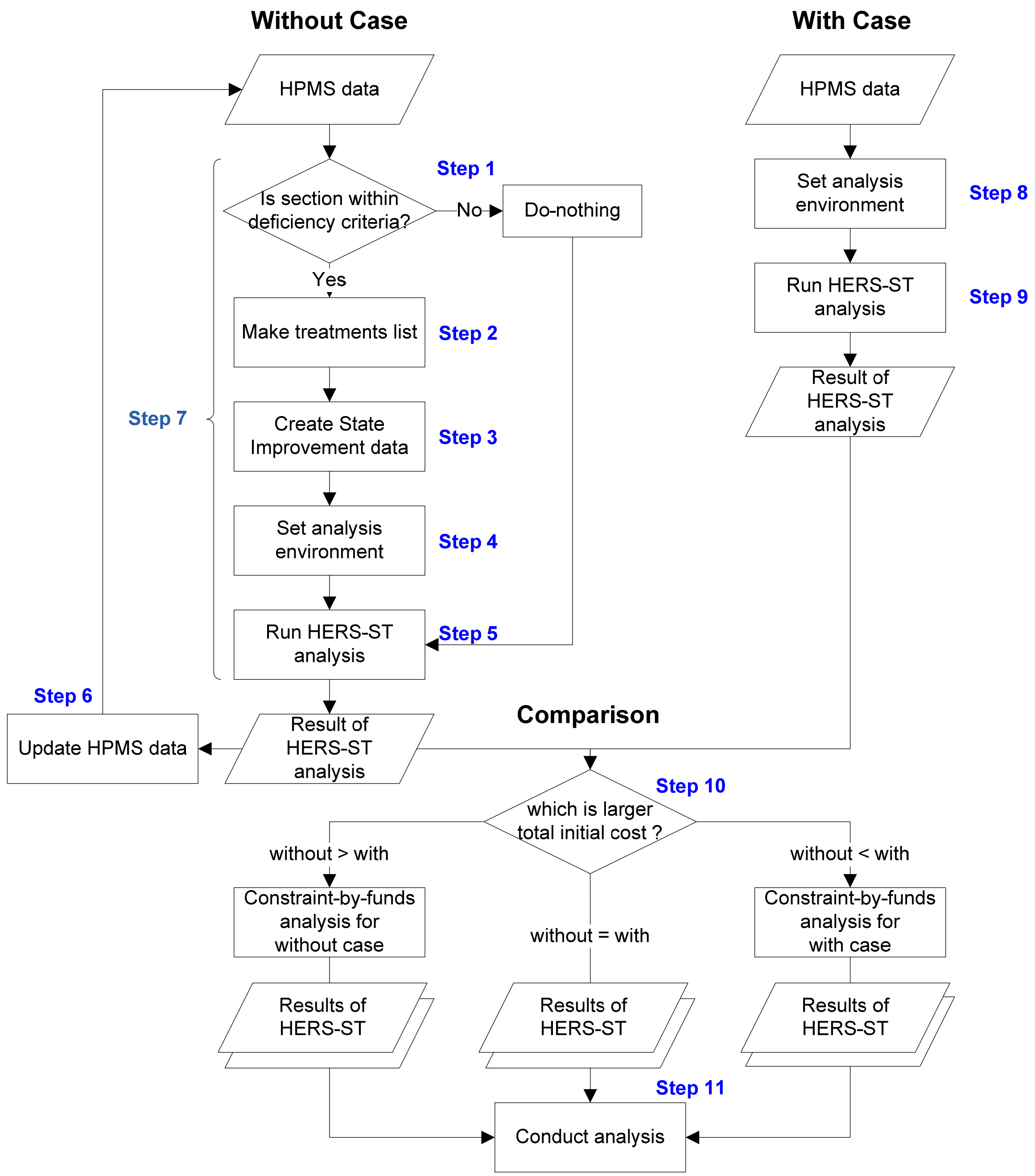

Figure 3. Analysis Flow

Table 1 Benefits and Costs Included in the Analysis

Category		Description
Benefits	Agency	Reduction in maintenance costs
	User	Savings in user costs (travel time cost, vehicle operating cost, safety cost)
	External	Reduction in environmental costs
Costs	Agency	Initial costs for maintenance

- Investment in HERS-ST implementation
  - Net Present Value – For the investment in asset management to be feasible requires the Total Net Benefits with HERS-ST minus the Total Net Benefits without HERS-ST minus HERS-ST Implementation Costs to be greater than zero.
  - Benefit-Cost Ratio - For the investment in asset management to be feasible requires the ratio of the difference in Total Net Benefits with HERS-ST and the Total Net Benefits without HERS-ST to HERS-ST Implementation Costs to be greater than one.

2.3 3Es

Three concepts, efficacy, effectiveness and efficiency, are used to help communicate the results of the analysis. These concepts are defined as follows:

- Efficacy
  - Whether HERS-ST works or not
  - Difference in performance between 'With' and 'Without'
- Effectiveness
  - Degree to which HERS-ST achieves goals
  - Comparison of the difference in degree to the goals between 'With' and 'Without'
- Efficiency
  - Optimal use of resources using the ratio of benefits to costs (or output/outcome to input) of asset management
  - Comparison of the ratios of benefits to costs between 'With' and 'Without'

Figure 4 illustrates how these concepts can be used to graphically communicate the results.

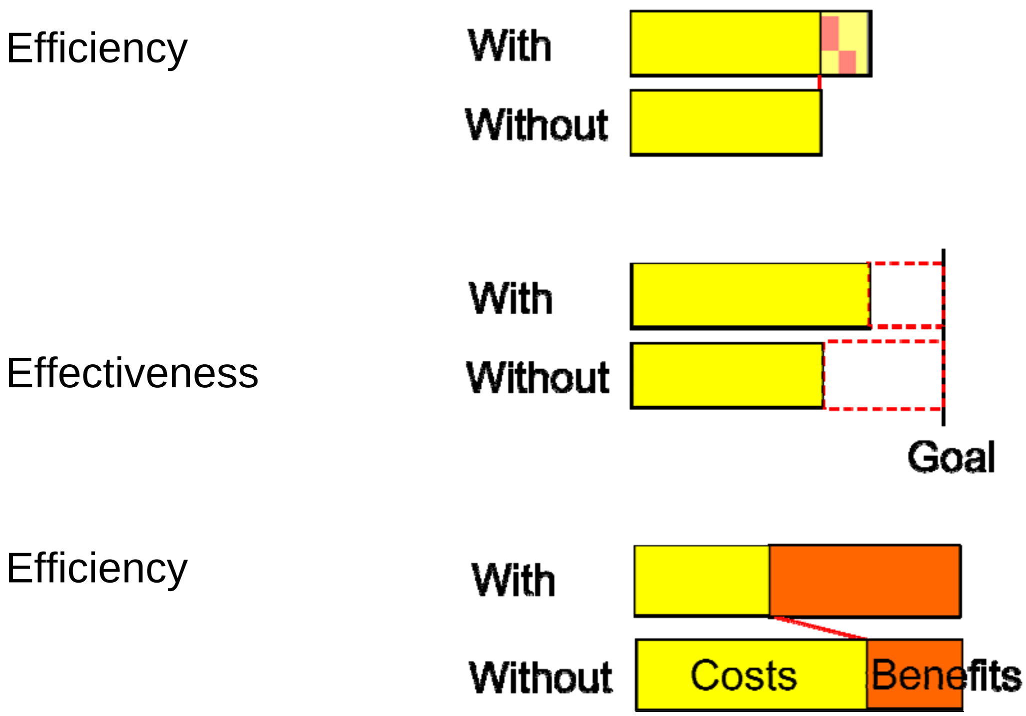

Figure 4. Concepts of Efficacy/ Effectiveness/ Efficiency

2.4 Implementing the Process

Implementing the process requires some modification of the HERS-ST inputs. The process is documented in a user's manual included in the Appendix A. PowerPoint slides and notes for use in training are included in Appendix B.

The process shown in Figure 3 follows these steps:

1. Assemble required HPMS data, and define the beginning year, programming period and funding period.
2. Run HERS-ST for the "Without HERS" scenario
    a. Load HPMS network data
    b. Prepare an improvement list based on current conditions (from HPMS) and standard thresholds.
    c. Assemble data into an Excel file and import into HERS-ST
    d. Set the control data as "Full Engineering Needs Analysis" for the first funding period.
    e. Run HERS-ST for the first funding period
    f. Update the HPMS data, identify deficiencies and repeat the above steps for remaining funding periods.
3. Run HERS-ST for the "With HERS" scenario
    a. Load HPMS network data

b. Run HERS-ST for all funding periods with the objective "All improvements with minimum BCR=1". Compare the initial cost for the "with" scenario to the "without scenario".
   i. If the initial cost of the "with" scenario is more than the "without" scenario then change the objective of the "with" scenario to "maximized benefit as constrained by funds."If the initial cost of the "without" scenario is more than the "with" scenario then an iterative process is used to eliminate treatments from the "without scenario.

The results from the "with" and "without" scenarios can be compared.

3 Communication

Reporting the average pavement condition measure or an aggregate user cost savings is meaningless for many decision makers. These results need to be translated into measures and graphics that communicate the benefits of asset management and are easily understood by the general public and decision makers. Drawing from past experiences (Wittwer et al 2004, Meyer et al, 2007) two strategies were explored:

- Linking the results of the quantitative case studies with past qualitative assessments, and translate results into value per vehicle or per user.
- Developing graphics to communicate the benefits of asset management similar to those used by Ohio Department of Transportation (Meyer et al, 2007).

To illustrate these communication strategies the results from the application of HERS-ST using data from New Mexico was used. This is the default data that comes with HERS-ST. It is not a case study as there was no opportunity to get feedback on actual practices.

3.1 Case Study to Illustrate Communication Concepts

Sample HPMS (Highway Performance Monitoring System) data from the state of New Mexico from 2001, which is included in the HERS-ST package, was used to demonstrate the analysis of the benefits of using HERS-ST. The data consists of 283 sections of road consisting of rural principal arterials, rural minor arterials, and urban principal arterials. The condition of these sections by functional class is shown in Figure 5.

The results of the analysis with HER-ST and without HERS-ST (adopting a worst-first strategy) are reported in terms of costs and performance measures as shown in Figure 6 through Figure 14. Figure 6 shows initiation costs, Figure 7 shows average speed, Figure 8 shows delay, Figure 9 shows PSR, Figure 10 shows vehicle miles of travel, Figure 11 shows maintenance costs, Figure 12 shows user costs, Figure 13 shows emissions costs and Figure 14 shows total costs. The results are also summarized in Table 2.

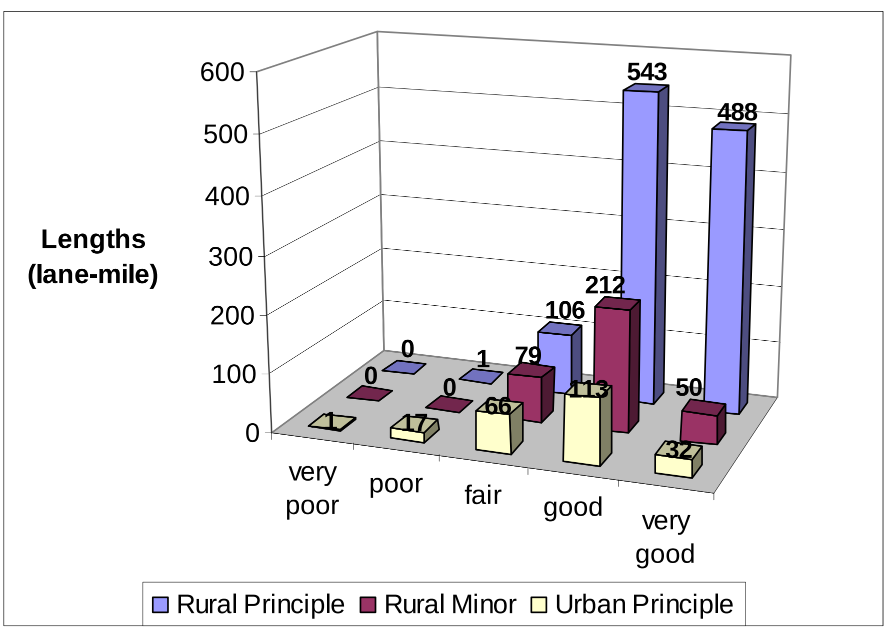

Figure 5. Condition of segments by functional class

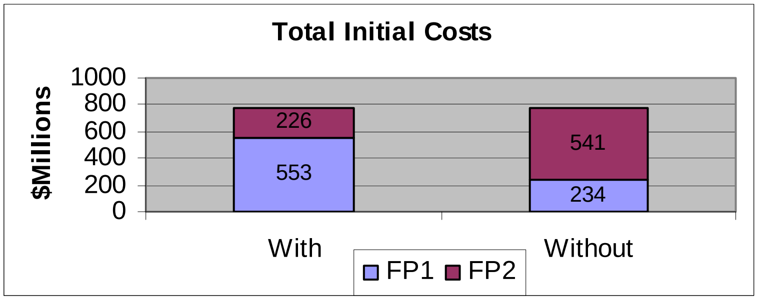

Figure 6. Total Initial Costs - 0.6% (about $4 million) difference b/w the cases

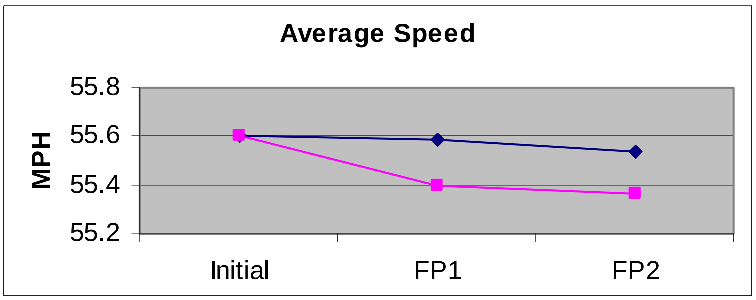

Figure 7. Average Speed - 0.17mph higher in 2010

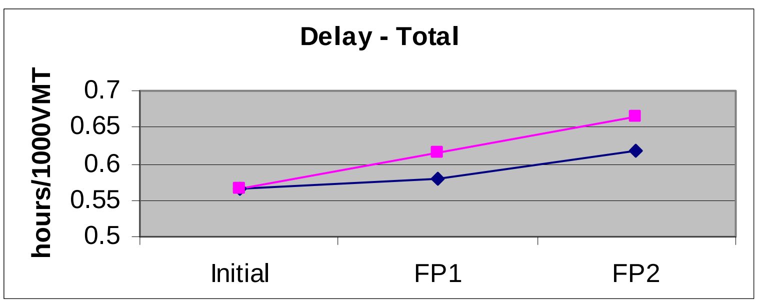

Figure 8. Delay Total -0.045 hours/1000VMT lower in 2010 (2.7 min / 1000 VMT)

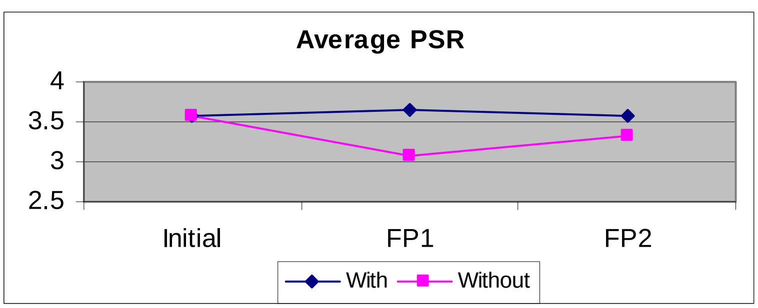

Figure 9. Average PSR - 0.26 points higher over 10 years

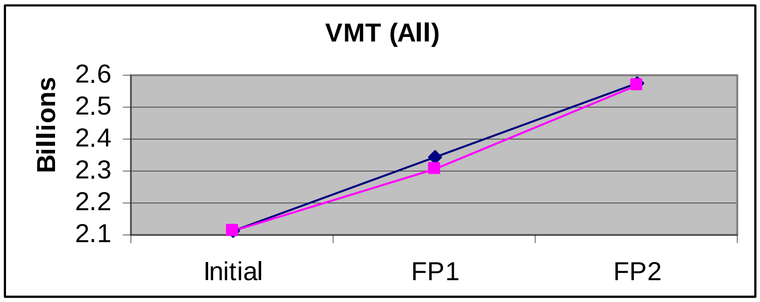

Figure 10. VMT -8million higher in 2010

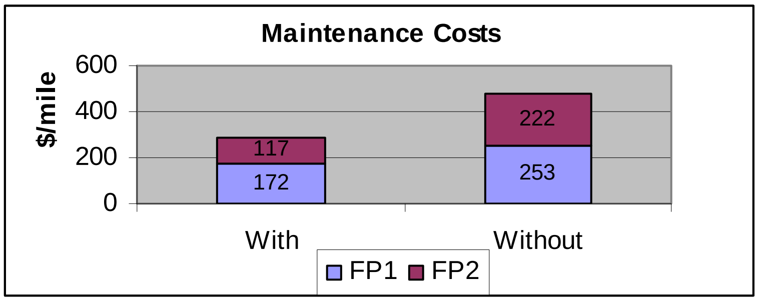

Figure 11. Maintenance Costs -$185/mile difference b/w the cases

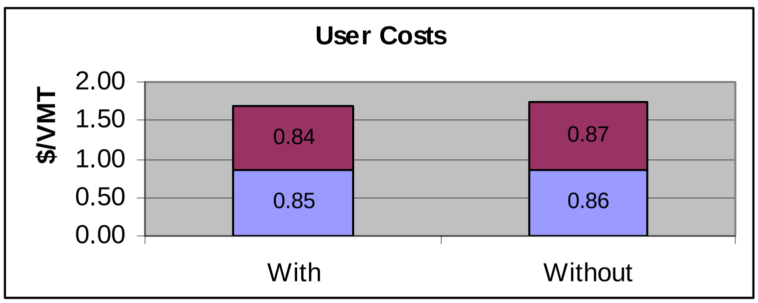

Figure 12. User Costs -$0.04/VMT difference b/w the cases

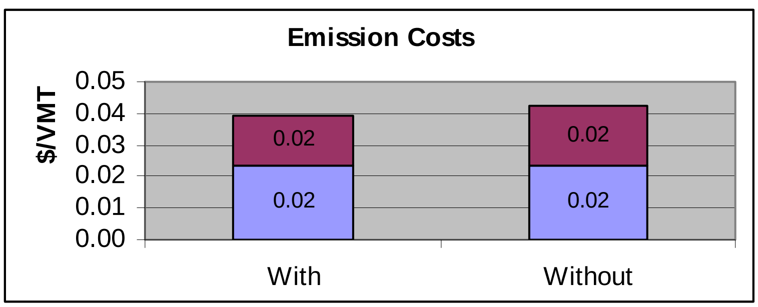

Figure 13. Emissions Costs - $0.003/VMT difference b/w the cases

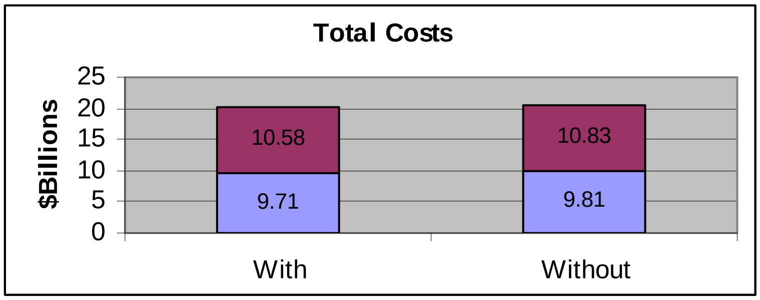

Figure 14. Total Costs - $359 million difference b/w the cases

Table 2. Performance Measures for New Mexico Case Study

Measure	**Difference ("with" versus "without" HERS-ST) in 2010**
Initial Costs	0.6% higher ($4 million)
Average Speed	0.17 mph higher
Delay	0.045hrs/1000 VMT less (2.7 min/ 1000 VMT)
PSR	0.26 points (on a scale of 1-5) higher over 10 years
Vehicles Miles of Travel (VMT)	8 million vehicle miles of travel more
Maintenance Costs	$185/mile less
User Costs	$0.04/ VMT less
Emissions Costs	$0.003/VMT less
Total Costs	$359 million less

Using total Initial Costs and Average BCR in the Improvement Statistics outputs for the with and without cases, the possible benefits of using HERS-ST are $ 2.0 billion over the BCA period as shown in Figure 15.

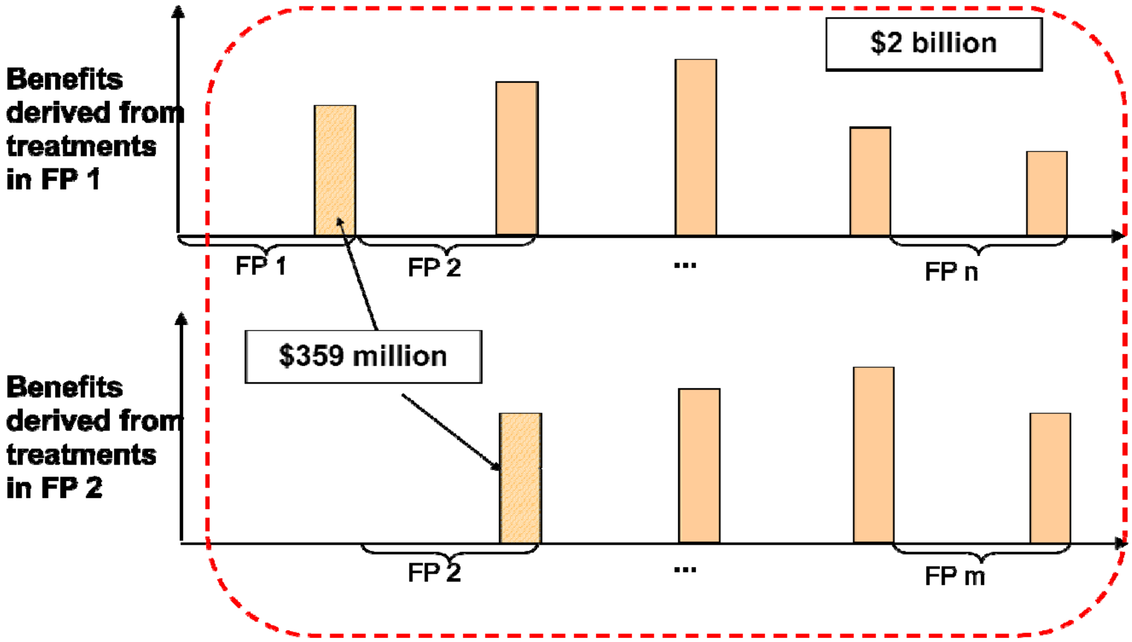

Figure 15. Estimated Benefits

3.2 Discussion

The results presented in the preceding section focus on the differences in the performance measures with and without HERS-ST. Using HERS-ST the predicted performance is always better. The following observations can be made:

- Benefits are derived from different treatments:
    - Forty six percent more sections receive treatment in the 'with' case compared to the 'without' case as shown in Figure 16, and
    - Appropriate timing and application of preservation treatments (Figure 17)
- The case study demonstrates the benefits of using HERS-ST's asset management and the method to assess the benefits using HERS-ST.
- Efficacy, effectiveness, and efficiency are observed.
- The investment in the HERS-ST implementation can be justified if costs are available.

The 'without' case has 60 sections or 180 lane-miles of reconstruction, while the 'with' case has 16 sections or 17 lane-miles. On the other hand, the 'with' case has 104 sections or 617 lane-miles of resurfacing with shoulder improvement, while the 'without' case has 15 sections or 122 lane-miles (these are automatically assigned by HERS-ST, although the 'without' case does not consider the treatment). It is assumed that the 'with' case considers the resurfacing with shoulder improvement as an appropriate treatment type, but not the reconstruction used in the 'without' case. Since the unit cost of resurfacing with shoulder improvement is less expensive than that of reconstruction (e.g., 60-70% less expensive in urban principal), the 'with' case can treat much more pavements than the 'without' case (1.12 times in number of sections; 1.19 times in lane-miles). The 'with' case uses less expensive treatments than the 'without' case, and allows investment in further treatments.

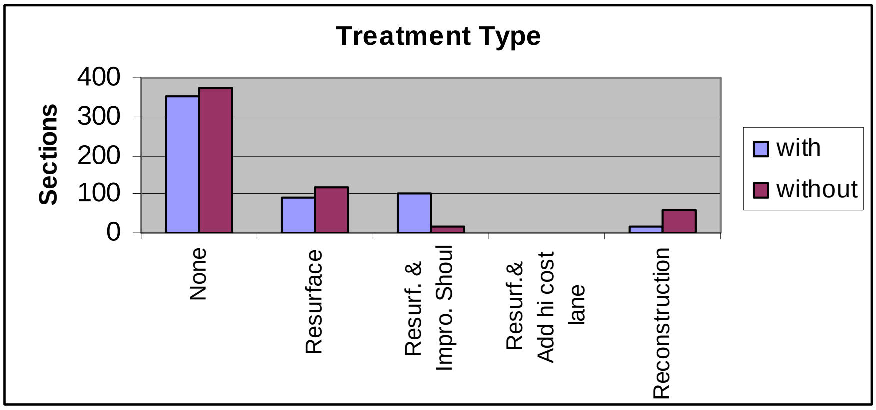

Figure 16. Segments Receiving Treatment

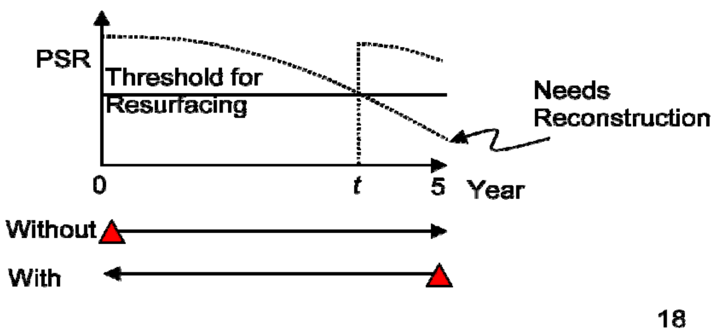

Figure 17. Appropriate Application of Preservation Treatments

In the 'with' case, the preservation treatments are applied to about 30% of the sections.

This can link to the previous situation (i.e., the number of sections with reconstruction of the without case is higher than that of the with case).

4 Kentucky Case Study

To demonstrate the application of the methodology and the communication strategies, a case study is developed using data for Kentucky. This case study evaluates the implementation of HERS-ST using the HPMS data. This chapter documents the case study. The chapter begins by describing the data, and then presents the evaluation design and procedure. The following sections describe the analysis procedure and results, and the chapter concludes with a discussion of the results.

4.1 Data

HPMS data for the years 2003 to 2006 was provided by the Kentucky Transportation Cabinet. Although the HPMS data include 15,263 highway sections, this analysis uses sample data including 2,033 sections, about 13.3% of all sections.

Table 3, Table 4, and Table 5 show the number of highway sections, length of highway in miles, and length of highway in lane-miles, respectively. Although the number of sections of the rural area is lower than that of the urban area, the length of highway of the rural area in terms of miles and lane-miles is higher than that of the urban area. Sections in the rural area have relatively long length.

Table 6 and Table 7 show the percent mileage deficiencies in rural and urban areas in year 2003, based on the PSR, in terms of pavement deficient level (i.e., reconstruction and deficient) and road functional class, which are derived from HERS-ST analysis outputs. The percent mileages are extracted based on the default deficiency criteria used in HERS-ST (Table 8 and Table 9). If pavement condition in a section reaches the criteria for deficient in Table 8, agencies consider applying treatments such as resurfacing. If the condition becomes worse and reaches the criteria for reconstruction in Table 9, agencies need to implement reconstruction.

Table 3. Sections of Highway in 2003

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	113	-	285	116	168	682
Urban	86	27	482	421	335	1,351
Overall	199	27	767	537	503	2,033

Table 4. Length of Highway in 2003 (miles)

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	551.1	-	2,309.8	1,739.9	6,132.7	10,733.5
Urban	209.9	65.4	772.8	1,031.7	1,008.0	3,087.8
Overall	761.0	65.4	3,082.6	2,771.6	7,140.7	13,821.3

Table 5. Length of Highway in 2003 (lane-miles)

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	2,398.6	-	7,287.8	3,523.1	12,295.7	25,505.2
Urban	1,135.8	255.2	2,701.2	2,411.5	2,071.2	8,574.9
Overall	3,534.4	255.2	9,989.0	5,934.6	14,366.9	34,080.1

Table 6. Percent Mileage Deficiencies in Rural Area

Rural	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector
Reconstruction	0	0.024	0	0	0.005
Deficient	15.68	11.192	1.897	0.311	32.011

Table 7. Percent Mileage Deficiencies in Urban Area

Urban	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Reconstruction	0.741	0	6.803	0.967	0	2.076
Deficient	32.011	22.899	36.18	9.032	3.107	15.748

Table 8. Criteria for Deficiency

Rural (1)	Interstate (1)	Principal Arterial (2)		Minor Arterial (6)	Major Collector (7)	
		ADT>6000	ADT<6000		ADT>400	ADT<400
	3.2	3.2	3	2.6	2.4	2.2
Urban (2, 3, or 4)	Interstate (11)	Expressways (12)		Principal Arterial (14)	Minor Arterial (16)	Collectors (17)
	3.4	3.2		3	2.6	2.4

Note: numbers in the parentheses are codes in HPMS data.

Table 9. Criteria for Reconstruction

Rural (1)	Interstate (1)	Principal Arterial (2)		Minor Arterial (6)	Major Collector (7)
	2.3	2.3		2	1.5
Urban (2, 3, or 4)	Interstate (11)	Expressways (12)	Principal Arterial (14)	Minor Arterial (16)	Collectors (17)
	2.3	2.3	2.3	2	1.5

Note: numbers in the parentheses are codes in HPMS data.

As we can see, the interstate and the principal arterial highways in rural and urban areas have high percent mileages that are deficient compared to other functional classes. This is because of higher Annual Average Daily Traffic (AADT) in those classes as Table 10 indicates. The principal arterial highway in urban area has the highest percent mileages needing reconstruction and highest AADT. Interestingly, the expressway in the urban area shows high percent mileages in deficient, although its AADT is relatively low.

Table 10. AADT in 2003

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	3,639,420	-	2,683,109	608,770	595,911	7,527,210
Urban	6,358,862	819,806	9,380,143	4,144,351	1,660,175	22,363,337
Overall	9,998,282	819,806	12,063,252	4,753,121	2,256,086	29,890,547

4.2 Evaluation Design

This case study employs an *ex ante* evaluation to estimate future benefits of HERS-ST implementation using 2003 HPMS data. Actual HPMS data from 2004 to 2006 are used to compare to future average network conditions predicted by HERS-ST and observe how the actual condition lies between the 'with' and 'without' cases.

The *ex ante* evaluation predicts future average network conditions using two different strategies: 'without HERS-ST' (i.e., a worst first strategy) and 'with HERS-ST' (i.e., a HERS-ST optimization strategy). Theoretically, network conditions with HERS-ST are superior to those without. The difference between the average network conditions for the two different strategies represents the benefits of HERS-ST implementation, as Figure 18 demonstrates. In order to predict the two conditions, this research utilizes the functionality of HERS-ST per se.

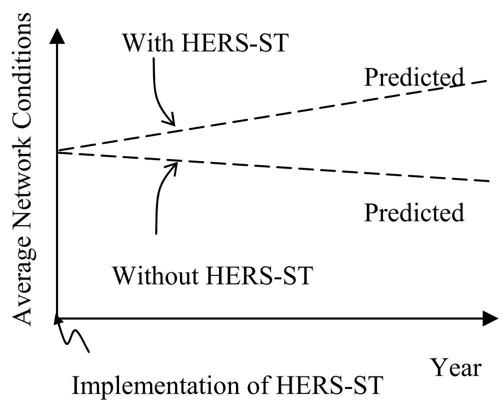

Figure 18. *Ex Ante* Evaluation

4.3 Analysis Procedure

Figure 19 depicts the flow diagram of HERS-SR analysis. This figure is a modified version of Figure 3 reflecting the need to update the data. The prospective evaluation employs twelve steps. Building the "without HERS-ST" case involves steps 1 through 7. Building the "with HERS-ST" case involves steps 8 through 10. Steps 11 and 12 are a comparison of the results.

Building the Without Case

Step 1: Select highway sections in the HPMS data based on pavement condition in year 2003, with respect to the default deficiency criteria in Table 8 and Table 9, in order to create user-specified maintenance treatments data (i.e., State Improvement data) as of 2003.

Step 2: List two treatments (i.e., resurfacing and reconstruction) for the selected sections in Step 1 based on a worst first strategy focusing on sections that have deficiencies from 2003 to 2006 in the first funding period. The worst first strategy prioritizes highway sections based on ascending order with Pavement Serviceability Rating (PSR) and descending order with Annual Average Daily Traffic (AADT). The two treatments are assigned for the selected sections from 2004 and 2006 and the treatments are equally distributed from 2004 to 2006 in terms of lane-miles[2].

Figure 20 depicts the concept of funding periods from year 2003 to 2009. Given that the HPMS data is for 2003, highway condition in year 2006 in the first funding period is predicted using HERS-ST analysis function. The condition is compared with the actual condition documented in the HPMS data.

[2] HERS-ST assumes that treatments are implemented in the middle of the funding period to calculate benefits and costs in its output. Hence, the distribution of the treatments over the period is not critical (FHWA 2005).

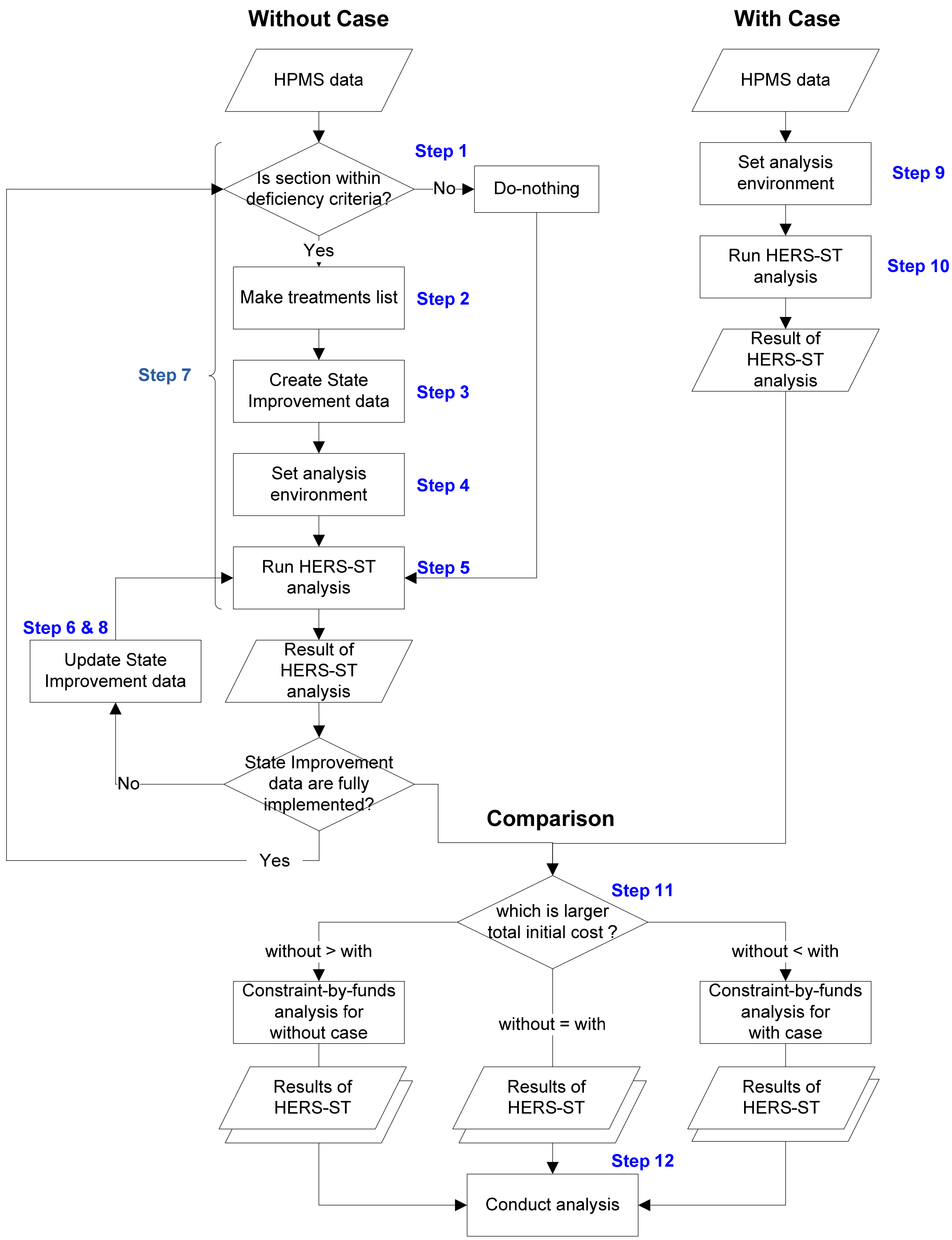

Figure 19. Flow Diagram

Also, the second funding period is obtained from Step 7 addresses future highway conditions.

$$\underbrace{\begin{array}{cccc} 2003 & 2004 & 2005 & 2006 \\ \text{(Initial)} & \text{(Yr 1)} & \text{(Yr 2)} & \text{(Yr 3)} \end{array}}_{\text{FP1}}$$

$$\underbrace{\begin{array}{cccc} 2006 & 2007 & 2008 & 2009 \\ \text{(Initial)} & \text{(Yr 1)} & \text{(Yr 2)} & \text{(Yr 3)} \end{array}}_{\text{FP2}}$$

Figure 20. Concept of Funding Periods

Step 3: Create the set of State Improvement data using the list of treatments based on the worst first strategy in Step 2.

Step 4: Set the analysis environment for the first 3-year funding period, including price reference year (2004), interest rate (4%), length of funding period (3 years), number of funding periods (2), and run objective for the 'without' case (a full engineering needs analysis).

The full engineering needs analysis addresses the following questions (FHWA 2006):

- How much will it cost to correct all highway deficiencies over a funding period?
- What will the system's condition and performance be?

Step 5: Run HERS-ST analysis to analyze the 'without' case by overriding the State Improvement data created in Step 3 using the analysis environment in Step 4.

Step 6: Observe the analysis output and update the State Improvement data if the treatments listed in the data are not fully implemented. There are two cases. One is that HERS-ST assigned treatments in sections where no treatments are assigned in the State Improvement data in Step 3. That is, HERS-ST selected treatments in sections whose conditions do no reach the deficiency criteria. In this case, select 'none' for the sections to delete the HERS-ST recommended treatments in the State Improvement data by assigning a do-nothing treatment as follows:

- Year: 2003
- Improvement type: 0
- Override flag: Yes

Also, there are sections where HERS-ST selected treatments overwrote user specified treatments in the analysis output. In this case, HERS-ST considers that the HERS-ST selected treatments are more aggressive (i.e., efficient in terms of benefits and costs) than user specified treatments. These treatments are kept as they exist.

Once updating is accomplished, run HERS-ST analysis again and iterate the process above until when user-specified treatments are fully implemented.

Step 7: Conduct HERS-ST analysis for the second funding period (i.e., from 2006 to 2009), using Step 1 through Step 5 excluding Step 4 (since the analysis environment is already set in Step 4, it is not necessary to set up the environment again).

Given the result of the first funding period, the treatments in the second funding period are added in the State Improvement data with respect to the deficiency criteria. Then, the HERS-ST analysis will be conducted again over two funding periods.

Step 8: Similarly, it is necessary to confirm if there are HERS-ST recommended treatments in a section where no treatments are assigned in an analysis output. If so, the followings are inputted:

- Year: 2006
- Improvement type: 0
- Override flag: Yes

Building the With Case

Step 9: Set the analysis environment for two 3-year funding periods, including price reference year (2004), interest rate (4%), length of funding period (3 years), number of funding periods (2), and run objective for the 'with' case (a minimum benefit-cost ratio analysis (benefit-cost ratio (BCR)>1)).

The minimum BCR analysis addresses the following questions (FHWA 2006):

- Which treatments exceed a specified minimum BCR?
- What level of investment would meet this BCR threshold?
- What will the condition and performance of the highway system be after investing at this level?

Step 10: Run HERS-ST analysis to analyze the 'with' case by running HERS-ST analysis.

Comparison

Step 11: Compare the total initial costs for the two funding periods addressed in the HERS-ST analysis output between the 'with' and 'without' cases. The objective of this comparison is to adjust the difference in the initial costs between the two cases, because the equal amounts of initial costs are required to observe the difference in highway performances. There are three responses with respect to three conditions as Table 11 shows.

Table 11. Responses in Comparison of Initial Costs

Condition	Response
If 'without' case > 'with' case	For the 'without' case, use a constraint-by-funds analysis with the same amount of funds as the initial cost for 'with' case.
If 'without' case = 'with' case	Compare 'with' and 'without' cases.
If 'without' case < 'with' case	For the 'with' case, use a constraint-by-funds analysis with the same amount of funds as the initial cost for 'without' case.

The comparison in this case study shows that the initial cost of the 'with' case is larger than that of the 'without' case. Because the initial costs in the first and second 3-year funding periods exceed the initial costs of the 'with' case in the same periods, the initial costs of the 'with' case is adjusted by a constraint-by-funds analysis. After conducting the constraint-by-funds analysis, the total initial costs of the 'with' case became \$2,222,000 or 0.05% less than that of the 'without' case. The two cases have almost the same amount of the total initial costs, \$4.8 billion, as Figure 21 shows.

Due to the constraint, the output of HERS-ST analysis indicates a different treatment selection (i.e., resurfacing and reconstruction) from Step 10.

Step 12: Conduct an analysis based on the methods in the following section.

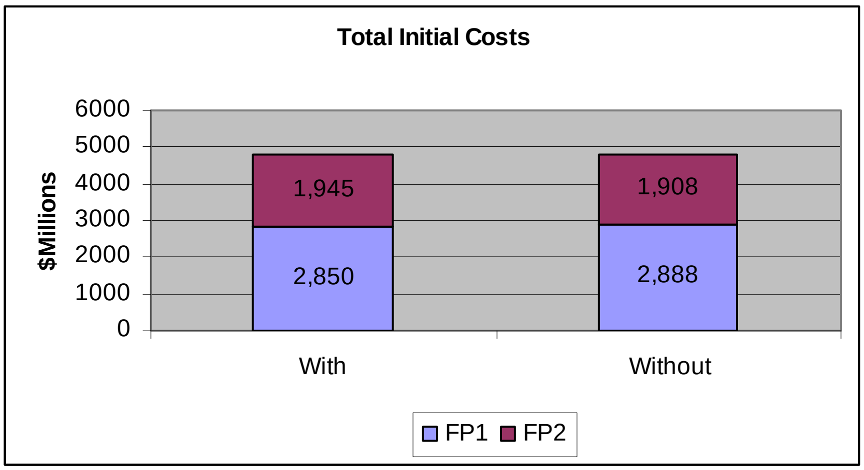

Figure 21. Total Initial Costs for With and Without Cases

4.4 Analysis Methods

Two different types of analysis methods considered prior to conducting the analysis of the results as follows:

Type 1: Apply highway improvements for the 'without' case, with respect to the default deficiency criteria used by HERS-ST based on pavement condition.

This type uses the same method as the HERS-ST case study used in the previous research (Mizusawa and McNeil 2008), which applied two treatment types, resurfacing and reconstruction. However, this type of analysis cannot be completely executed because HERS-ST recommends more aggressive (i.e., cost-effective) treatments instead of the user specified treatments. Also, using only two treatments is not practical.

Type 2: Apply the highway improvements as same as those for the 'with' case for the 'without' case.

This type utilizes the 'with' case. Given the HERS-ST recommended treatments, HERS-ST applies the treatments to the 'without' case if a section reaches the default deficiency criteria. This type of the analysis is supposed to observe only the timing effect[3] based on

[3] The timing effect is also addressed in the *Discussion* section.

the comparison between the ‘with’ and ‘without’ cases. However, it cannot be completely executed because HERS-ST does not propose treatments for all sections whose conditions are below the criteria.

Based on the consideration above, this research uses HERS-ST recommended treatments for the sections whose conditions are below the deficiency criteria for the ‘without’ case. If HERS-ST does not recommend any treatments for the sections, resurfacing and reconstruction are applied to them. It is noted that this research cannot distinguish the timing effect and the treatment type effect in the benefits of using HERS-ST.

Using the results of HERS-ST analyses of the ‘with’ and ‘without’ cases, various performance measures can be compared between the cases over 6 years or 2 funding periods to quantify the benefits of using HERS-ST. The performance measures are:

- Average PSR – pavement condition
- Average speed and delay – traffic flow
- VMT (vehicle miles traveled) – traffic volume in terms of driving distance and time
- Maintenance Costs – agency costs
- Total User Costs
- Emission Costs – external cost
- Total Costs, including agency, user, and external costs

To assess the benefits of using HERS-ST in monetary terms, BCA employs the net present value method or the BCR method using the benefits and costs listed in Table 12, which are available from the results of the HERS-ST analysis.

Table 12. Benefits and Costs in Benefit-Cost Analysis

Category		Description
Benefits	Agency	Reduction in maintenance cost
	User	Savings in user costs, including travel time cost, vehicle operating cost, safety cost
	External (non-user)	Reduction in environmental costs, which are subjected to non-user.
Costs	Agency	Initial costs for maintenance treatments

The results of the BCA can be used to justify investment in implementing HERS-ST. Since there are no available data related to HERS-ST implementation costs, we provide information for a discussion of whether the benefits outweigh HERS-ST implementation costs using the total net benefits produced by HERS-ST implementation (i.e., the difference in the net benefits summing up all benefits and costs listed in Table 12 between ‘with’ and ‘without’ cases) based on the following expressions for net present value (equation 1) and benefit cost ratio (equation 2):

$$\text{((Net Benefits with HERS-ST) – (Net Benefits without HERS-ST))} \\ \text{– (HERS Implementation Costs)} \geq 0 \quad \ldots\ldots (1)$$

or

$$\frac{\left((Net\_Benefits\_withHERS) - (Net\_Benefits\_withoutHERS)\right)}{(HERS\_implementation\_Costs)} \geq 1.0 \;\ldots\ldots (2)$$

4.5 Analysis Results

The results for the 'with' and 'without' cases are obtained from HERS-ST outputs and are presented in Table 13 and Table 14. Table 13 shows the improvement statistics that provide a summary of data about the improvements selected during each funding period. Also, it shows data expressing the effects of the selected improvements on the improved sections during the last year of the funding period. For example, items from number 1 to 9 provide statistical information during each funding period, while items from 10 to 20 provide annual costs and benefits in the last year of each funding period that are derived from implementing all improvements in the middle of the period (FHWA 2006).

Table 14 addresses the initial system conditions and the condition after each funding period.

Benefit Quantification

Consistent with the communications strategy presented in Chapter 3, Figure 22 through Figure 29 compare the performance measures for the "with" and "without" as available in the System Conditions HERS-ST outputs.

Figure 22 draws the average pavement conditions in terms of PSR over the analysis period for the 'with' and 'without' cases. The condition of the 'with' case steadily increases, while that of the 'without' case fluctuates. This is because the numbers or lane-miles of implemented treatments are different between the 'with' and 'without' cases. The 'with' case implements 243 treatments for 2,755 lane-miles in the first funding period and 286 treatments for 2,831 lane-miles in the second funding period. On the other hand, the 'without' case implements 384 treatments for 3,959 lane-miles in the first funding period and 129 treatments for 963 lane-miles in the second funding period. These numbers will be discussed in the *Discussion* section later. At the end of the analysis period (i.e., 2009), the 'with' case has higher PSR than the 'without' case by 0.07 points on a scale of zero to 5.

Table 13. Improvement Statistics

No.	Performance Measure	With HERS-ST		Without HERS-ST	
		FP 1	FP 2	FP 1	FP 2
1	Total Initial Cost ($ thousands)	2,849,559	1,944,797	2,888,344	1,908,234
2	Lane-Miles Improved	3,320	3,108	3,587	1,111
3	Average BCR	7.17	4.176	3.163	2.176
4	Miles Improved	792	1,093	10,385	1,067
5	Lane-Miles Added	555	271	131	149
6	Capital Requirements by IBCR Range [a]	2,849,559	1,944,797	1,152,117	415,089
7	Sample Sections by IBCR Range [a]	243	286	252	82
8	Miles Improved by IBCR Range [a]	792	1,093	740	213
9	Travel-Time Benefits by IBCR Range [a]	133.1	99.7	-15.6	71.7
10	Total Benefits ($thousand) [a] Excluding pollution damage savings	1,697,183	701,034	634,376	545,079
11	Maintenance Cost Savings ($thousand) [a]	194,563	153,273	148,701	81,430
12	User Benefits ($thousand) [a]	1,502,620	547,761	485,675	463,648
13	Travel-Time Savings ($thousand) [a]	1,166,076	319,520	5,657	347,287
14	Operating Cost Savings ($thousand) [a]	300,504	207,755	484,501	107,805
15	Safety Benefits ($thousand) [a]	36,039	20,484	-4,483	8,555
16	Crashes Avoided ($thousand) [a]	-1,038	-655	-968	-243
17	Injuries Avoided [a]	-385	-236	-402	-117
18	Lives Saved [a]	-1	-1	-3	0
19	VMT of Improved Sections [a]	8,642	6,502	8,103	2,750
20	Pollution Damage Savings ($thousand) [a]	-18,384	-25,196	-4,893	-8,686

Notes: 1) Costs are based on 2004 dollars.
2) FP: Funding Period
3) [a] These represent values in the last year of funding periods.
4) IBCR: Incremental Benefit Cost Ratio

Table 14. System Conditions

System Condition	Initial	With		Without	
		FP 1	FP 2	FP 1	FP 2
Mile	13,821.3	13,821.3	13,821.3	13,821.3	13,821.3
Lane-Miles	34,086	34,641.9	34,913.6	34,216.4	34,366.6
Average PSR	3.424	3.467	3.494	3.464	3.427
Average IRI	97.4	95.5	93	95.2	97.8
Average Speed – Overall (MPH)	45.428	46.782	47.016	45.011	45.22
Delay – Zero Volume (hours/1000VMT)	1.062	1.036	1.007	1.032	1.014
Delay – Incident (hours/1000VMT)	0.461	0.316	0.341	0.618	0.629
Delay – Other (hours/1000VMT)	1.723	1.405	1.417	1.938	1.918
Delay – Total (hours/1000VMT)	3.246	2.757	2.765	3.588	3.561
VMT – 4 Tire Vehicle (millions)	34,562	38,312	41,890	39,008	41,228
VMT – Single Unit Trucks (millions)	1,534	1,710	1,879	1,743	1,849
VMT – Combination Trucks (millions)	2,903	3,296	3,678	3,376	3,619
VMT – All (millions)	39,001	43,318	47,447	44,129	46,696
VHT – 4 Tire (millions)	777	836	910	885	931
VHT – Single Unit Trucks (millions)	32	35	38	37	39
VHT – Combination Trucks (millions)	48	54	60	57	62
VHT – All (millions)	858	952	1,009	980	1,032
Travel Time Costs – 4 Tire Vehicles ($/1000VMT)	454	438	437	461	459
Travel Time Costs – Trucks ($/1000VMT)	600	582	582	616	617
Travel Time Costs – All ($/1000VMT)	471	455	454	479	478
Operating Costs – 4-Tire Vehicles ($/1000VMT)	276	276	276	274	275
Operating Costs – Trucks ($/1000VMT)	658	657	658	649	648
Operating Costs – All ($/1000VMT)	320	320	321	318	319

System Condition	Initial	With		Without	
		FP 1	FP 2	FP 1	FP 2
Crash Costs ($/1000VMT)	134	133	132	134	134
Total User Costs ($/1000VMT)	926	910	908	932	931
Crash Rate (/100 million VMT)	255.2	252.4	249.7	253.8	251.9
Injury Rate (/100 million VMT)	114.4	113.1	112.1	114	113.3
Fatality Rate (/100 million VMT)	1.58	1.57	1.56	1.59	1.59
Maintenance Costs ($/1000 mile)	147,432	95,792	101,997	100,974	110,460
Emissions Costs ($/1000VMT)	23.861	18.574	14.447	16.927	14.304
BCR of Last Improvement		2.541	2.397	0	0

Notes: 1) Costs are based on 2004 dollars. 2) FP: Funding Period 3) VHT: Vehicle hours of travel-time

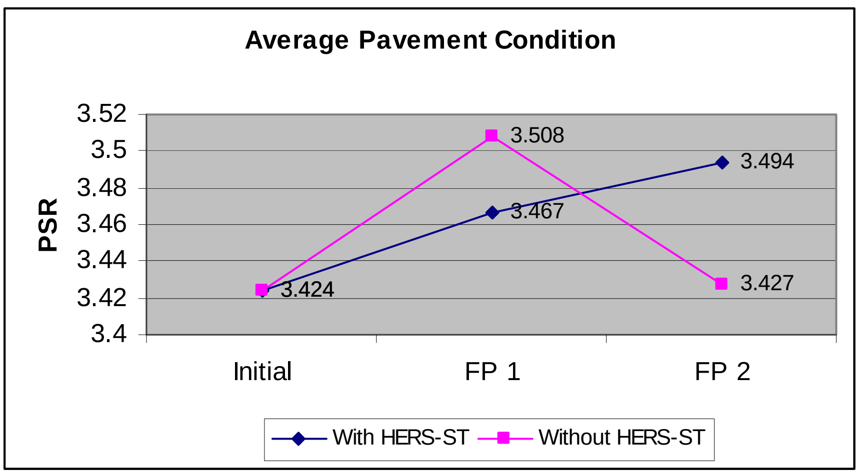

Figure 22. Average Pavement Condition

Figure 23 shows the overall average speed for the 'with' and 'without' cases. The 'with' case has a 1.8 mph higher average speed than the 'without' case in 2009. Because the 'with' case implements 894 lane-miles more treatments dealing with capacity expansion (i.e., improving shoulders, widening lanes, and adding lanes) than the 'without' case, the average speed of the 'with' case is higher than that of the 'without' case.

Figure 24 depicts the total average delay, including zero traffic volume, incidents and other, for the two cases. Because of the number of the capacity expansion treatments implemented, the 'with' case has a 0.8 hours per 1000 VMT lower delay than the 'without' case in 2009.

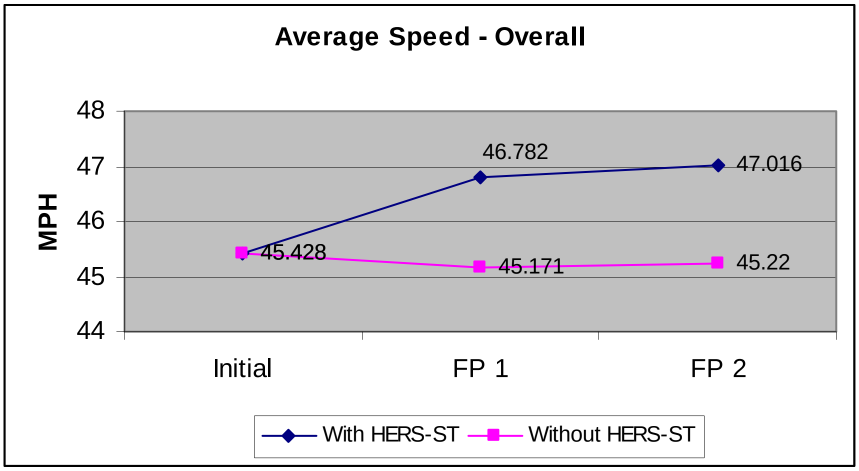

Figure 23. Average Speed

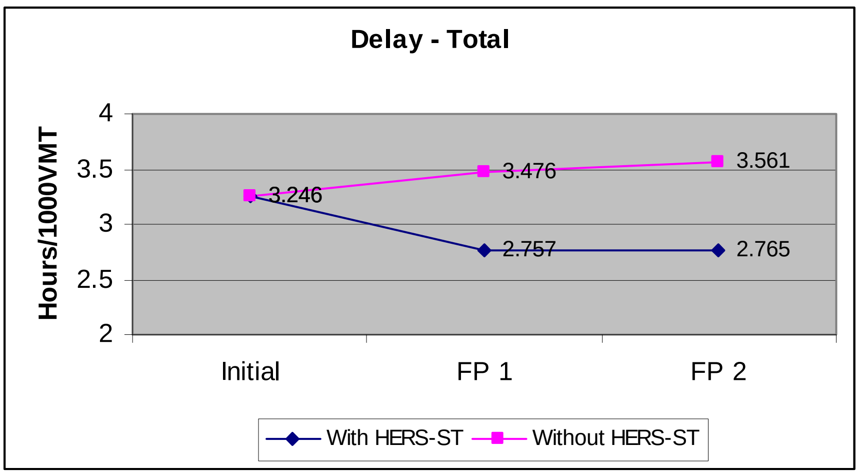

Figure 24. Delay

Figure 25 shows VMT for the two cases. Similarly, due to the number of capacity expansion treatments, the 'with' case has a 0.8 billion higher VMT than the 'without' case.

The following costs are derived from the System Conditions outputs in Table 14. The values of the first funding period were calculated by taking average values between the initial and the first funding period, and the values of the second period were the average between the first funding period and the second funding period for the 'with' and 'without' cases. Hence, the costs are approximated.

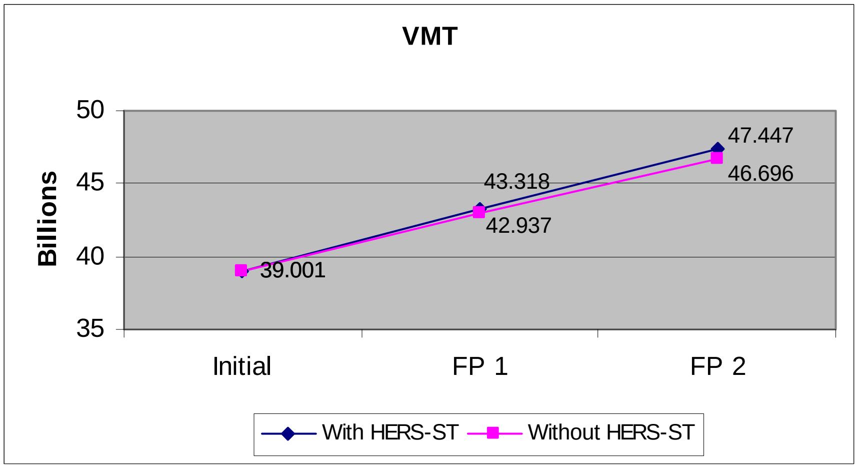

Figure 25. Vehicle Mile Traveled

Figure 26 shows the unit maintenance costs for the 'with' and 'without' cases over the two funding periods. The amount of the 'with' case is $9 per mile less than that of the 'without' case.

Using the initial costs and lane-miles improved in the Improvement Statistics outputs, the detailed unit maintenance costs were analyzed in terms of the initial costs per lane-miles improved to see the reason why the 'without' case has higher unit maintenance costs. It is recognized that the 'resurface and add high-cost lanes' in the second funding period of the 'without' case has the highest unit maintenance costs, $13,039.7 per lane-miles, which occupies 48% of the initial costs for all treatments in the second funding period of the 'without' case. Hence, the unit maintenance costs in the second funding period of the 'without' case are twice as high as those in the first and second periods of the 'with' case and in the first period of the 'without' case. It is assumed that this is one cause of high unit maintenance costs of the 'without' case. The resurface and add high-cost lanes treatment is applied to sections where those conditions are below the deficiency criteria. Although the resurface was originally applied to the sections, HERS-ST recommends implementing the 'resurface and add high-cost lanes' instead. Due to the high unit maintenance costs of the 'without' case, the lane-miles (or sections or miles) improved of the 'without' case became lower than those of the 'with' case, thus leading to the worse conditions explained above.

Figure 27 shows the unit user costs, including travel time costs, vehicle operating costs, and crash costs for the 'with' and 'without' cases. The 'with' case has $0.03 per VMT less unit user costs than the 'without' case.

Figure 28 depicts unit emission costs for the 'with' and 'without' cases. Although the 'with' case previously shows better conditions in terms of the performance measures (e.g., average pavement condition and average speed) and lower maintenance and user costs, it shows the worse conditions in the unit emission costs, $0.004 per VMT higher than the 'without' case. This situation may be caused by the higher average speed as shown in Figure 23.

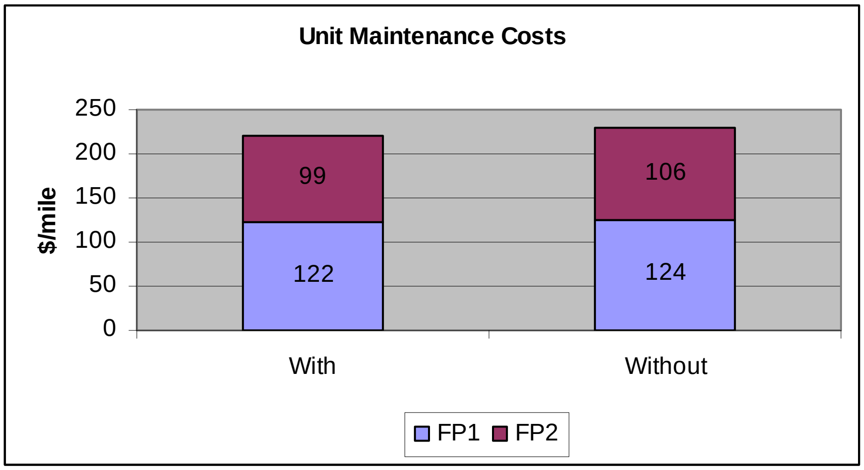

Figure 26. Unit Maintenance Costs

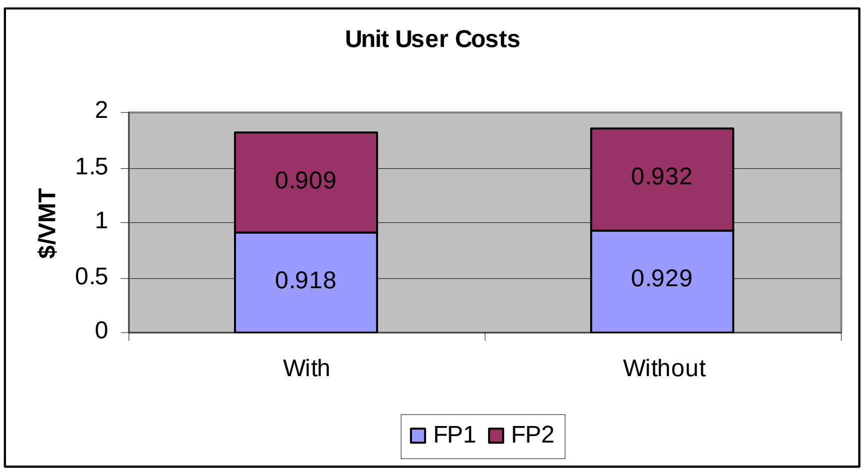

Figure 27. Unit User Costs

Given the unit maintenance, user, and emission costs, we can estimate the total costs by adding all costs that are obtained from multiplying by miles improved for the maintenance costs and VMT for the user and emission costs over the analysis period. The calculations of the total costs based on 2004 dollars, including the calculations of the unit costs and the differences (i.e., savings or benefits), are shown in Table 15.

Figure 29 summarizes the total costs, including maintenance costs, user costs, and emission costs that are addressed above for the 'with' and 'without' cases. The 'with' case has $5.4 billion lower total costs compared to the 'without' case, that is, the benefits of implementing HERS-ST. Especially, the savings in the user costs significantly contribute to the benefits due to the scale. The emission costs have an adverse effect in reducing the benefits.

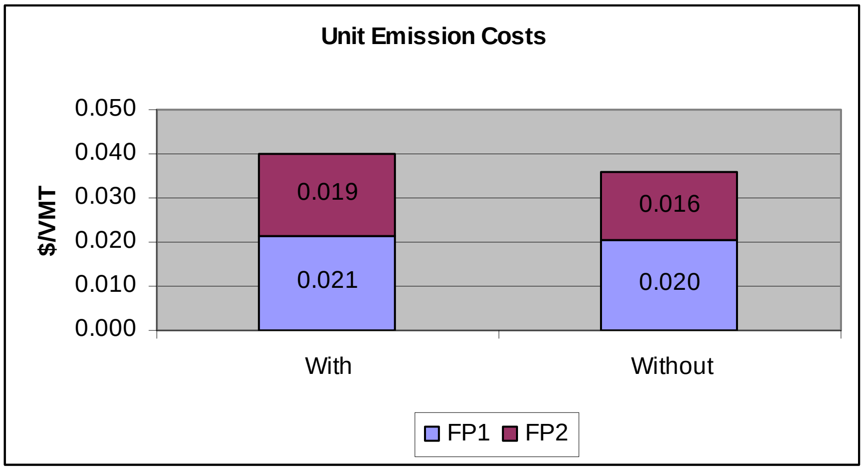

Figure 28. Unit Emission Costs

Table 15. Calculation of Costs and Savings

<u>Maintenance Costs (Agency Costs)</u>		
With case	:	(\$147,432+\$95,792)/2 × 792 × 3/1,000 + (\$95,792+\$101,997)/2 × 1,093 × 3/1,000 = 0.6 (million)
Without case	:	(\$147,432+\$100,974)/2 × 10,385 × 3/1,000 + (\$100,974+\$110,460)/2 × 1,067 × 3/1,000 = 4.2 (million)
		Savings in agency costs = 4.2 – 0.6 = 3.6 million
<u>User Costs</u>		
With case	:	(\$926+\$910)/2 × (39,001mil+43,318mil)/2 × 3/1,000 + (\$910+\$908)/2 × (43,318mil+47,447mil)/2 × 3/1,000 = 237,111.3 (million)
Without case	:	(\$926+\$932)/2 × (39,001mil+44,129mil)/2 × 3/1,000 + (\$932+\$931)/2 × (44,129mil+46,696mil)/2 × 3/1,000 = 242,746.9 (million)
		Savings in user costs = 242,746.9 – 237,111.3 = 5,635.5 million
<u>Emission Costs (External Costs)</u>		
With case	:	(\$23.861+\$18.574)/2 × (39,001mil+43,318mil)/2 × 3/1,000 + (\$18.574+\$14.447)/2 × (43,318mil+47,447mil)/2 × 3/1,000 = 4,867.8 (million)
Without case	:	(\$23.861+\$16.927)/2 × (39,001mil+44,129mil)/2 × 3/1,000 + (\$16.927+\$14.304)/2 × (44,129mil+46,696mil)/2 × 3/1,000 = 4,670.4 (million)
		Savings in external costs = 4,670.4 – 4,867.8 = -197.3 million

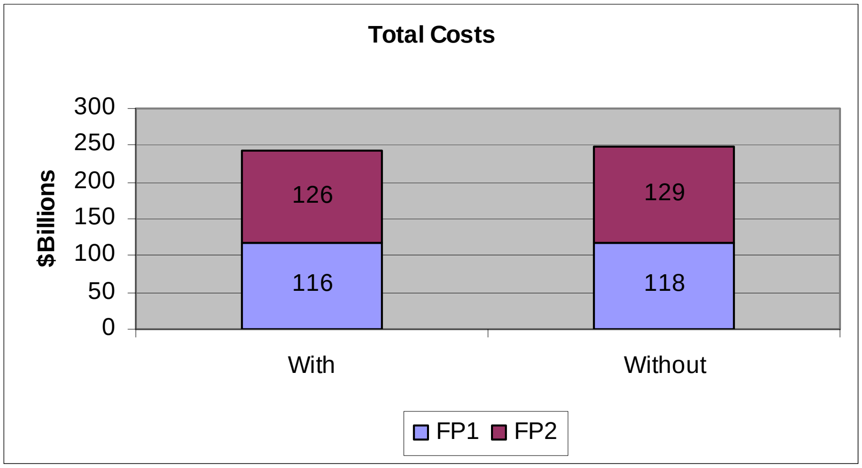

Figure 29. Total Costs

It is noted that the benefits, $5.4 billion, do not include all benefits over the analysis period (i.e., 6 years). Figure 30 depicts the conceptual benefits of HERS-ST implementation derived from the total costs. User and external benefits[4] derived from treatments implemented in the first funding period accrue over the second funding period. However, the benefits do not count the benefits in the second funding period. Hence, the actual benefits would be higher than that amount.

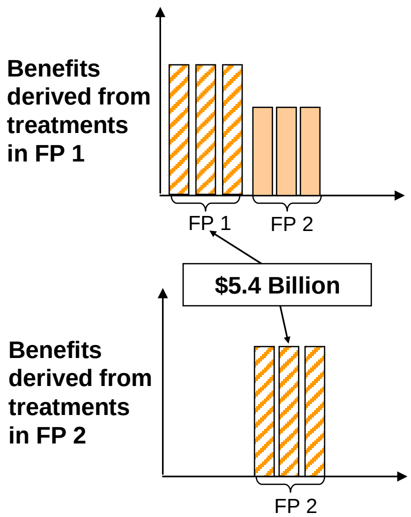

Figure 30. Conceptual Benefits of HERS-ST Implementation Derived from the Total Costs

[4] The external benefits derived from the difference in the emission costs between the 'with' and 'without' cases may be negative (i.e., disbenefits) in the second funding period as well as the first funding period.

Given the total initial costs and average BCRs in the Improvement Statistics outputs listed in Table 13, the benefits for the 'with' and 'without' cases over the BCA period[5] are estimated as Table 16 shows. Next, the net benefits, that is, the differences obtained from the subtraction of the total initial costs from the total benefits for the 'with' and 'without' cases are calculated as follows:

Net Benefits With case : 25,225,694 – 4,794,356 = 20,431,338

Net Benefits Without case : 13,932,410 – 4,796,578 = 9,135,832

Then, the difference in the net benefits between the 'with' and 'without' cases is calculated based on the two members of Eq.(1), that is, (Net Benefits with HERS-ST) – (Net Benefits without HERS-ST). The differences are $11.3 billion (based on 2004 dollar), which are the total benefits of HERS-ST implementation.

Table 16. Costs and Benefits of With and Without Cases

Field			With HERS-ST Total	Without HERS-ST Total	(With HERS-ST) – (Without HERS-ST) Total
FP1	Total Initial Cost	1	*2,849,559*	*2,888,344*	-38,785
	Average BCR	2	*7.170*	*3.163*	n.a.
	Total Benefits	1×2	20,431,338	9,135,832	11,295,506
FP2	Total Initial Cost	3	*1,944,797*	*1,908,234*	36,563
	Average BCR	4	*4.176*	*2.176*	n.a.
	Total Benefits	3×4	8,121,472	4,152,317	3,969,155
Total	Total Initial Cost	1+3	4,794,356	4,796,578	-2,222
	Average BCR	(1×2+3×4)/(1+3)	5.262	2.905	n.a.
	Total Benefits	1×2+3×4	25,225,694	13,932,410	11,293,284

Notes: 1) Monetary values are based on 2004 thousand dollars.

2) *Italics* are derived from HERS-ST analysis outputs.

[5] The BCA period responds to the duration of treatments' lives. For example, a simple resurface treatment takes one or two funding periods as a BCA period. However, in case of significant treatments, the BCA period can extend beyond the end of the overall analysis period (i.e., 25 years) (FHWA 2005).

Figure 31 depicts the conceptual benefits of HERS-ST implementation derived from the total initial cost and average BCR in Table 16 to illustrate the difference from the benefits shown in Figure 30. The upper figure shows the benefits produced by treatments in the first funding period, while the lower figure shows the benefits produced by treatments in the second funding period. Although this case study focuses on the benefits accrued in the first two funding periods (i.e., 6 years), the benefits continue to accrue beyond the end of the second funding period. The sum of the benefits from the first funding period to an *n* th funding period in the upper figure and the benefits from the second funding period to an *m* th funding period in the lower figure responds to $11.3 billion over the BCA period. Meanwhile, the sum of the benefits in the first funding period in the upper figure and the benefits in the second funding period in the lower figure is worth $5.4 billion over 6 years. Although the benefits are estimated, it is difficult to determine the duration of the BCA period and the exact benefits over 6 years using the HERS-ST outputs.

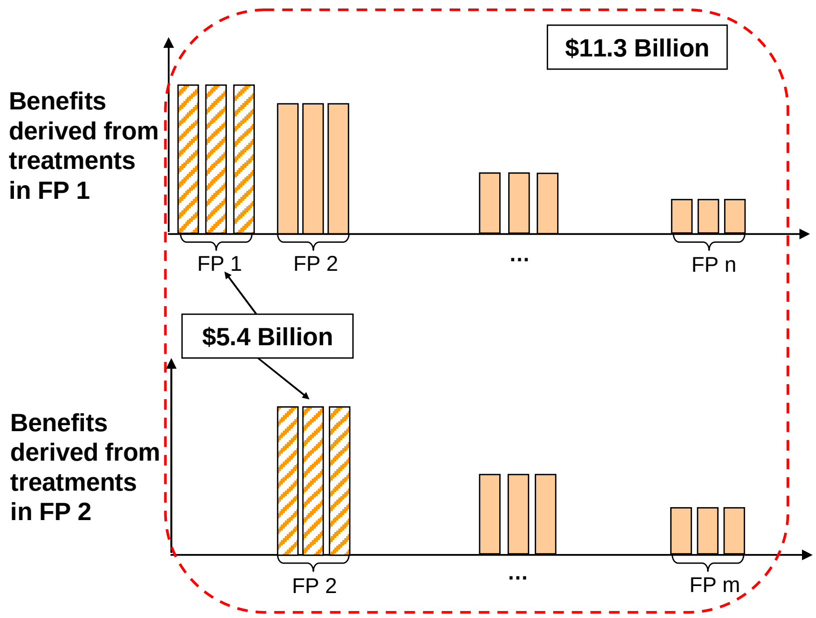

Figure 31. Conceptual Benefits of HERS-ST Implementation Derived from the Total Initial Cost and Average BCR

Investment Justification

Given the quantified discounted benefits of HERS-ST implementation, the comparison of the benefits to HERS-ST implementation costs is conducted to justify investment in HERS-ST implementation. Since there are no available data related to actual implementation costs, this discussion of whether the benefits outweigh HERS-ST implementation costs remains exploratory. Using the quantified total benefits, the following are addressed:

- If an agency spends less than $5.4 billion in implementation costs over 6 years, the agency can justify the investment in HERS-ST implementation, or

- If an agency spends less than $11.3 billion in implementation costs over 25 years, the agency can justify the investment in HERS-ST implementation.

Since the $5.4 billion in benefits does not include the entire benefits over 6 years, the allowable amount of HERS-ST implementation costs would be higher than $5.4 billion. In the second point, a BCA period is specified as 25 years, because significant treatments can extend beyond 20 years (FHWA 2005). Despite the incompleteness of the analysis and assumptions, these can be criteria to justify investments in terms of the positive net present value using Eq.(1) or BCR higher than 1.0 using Eq.(2), if HERS-ST implementation costs are available. It is not expected that HERS-ST implementation costs would approach $5.4 billion over 6 years because HERS-ST is a free application distributed by FHWA and all states already collect the HPMS data required, even when other costs such as labor are considered. To make this discussion more robust, it is necessary to calculate the exact benefits over a specific analysis period and compare them to the actual implementation costs.

4.6 Actual and Predicted Conditions

To compare the results of the theoretical “with” and “without” cases, actual conditions are compared with the predicted condition obtained from HERS-ST outputs for the performance measures addressed in the preceding *Analysis Results* section. To obtain the actual condition, each year’s HPMS data are used to calculate the initial condition that represents the actual condition over three years. For example, 2004 HPMS data are used to obtain the initial condition, that is, the condition in 2004. The comparisons articulate current highway conditions and relationships with predicted conditions for the ‘with’ and ‘without’ cases.

Figure 32 shows average pavement condition in terms of PSR. The actual condition keeps PSR about 3.43, good condition, over three years. According to the Kentucky Long-Range Statewide Transportation Plan (KYTC 2008), pavements in the state of Kentucky are deteriorating due to insufficient funding levels to maintain the pavements. Since the average pavement is maintained in good condition despite the funding problem, it is implied that the pavement management in Kentucky has efficiently contributed to the pavement condition. However, it is necessary to investigate how much funds have been used for the pavement management and what treatments have been applied over the years to conclude definitively the pavement management is responsible for more efficient management of pavements.

Figure 33 and Figure 34 show the average speed and delay, respectively. The actual condition is in between the ‘with’ and ‘without’ cases in 2006. The speed and delay related to traffic flow are affected by the treatments enhancing capacity. Because the actual implemented treatments are unknown, it is necessary to obtain the information of what types of treatments had been implemented in Kentucky for the three years. Since the average pavement condition is stable over the years, it is assumed that transportation agencies in Kentucky focused on capacity enhancing treatments to alleviate congestion rather than maintenance and rehabilitation treatments to maintain good surface condition, thus improving average speed and delay.

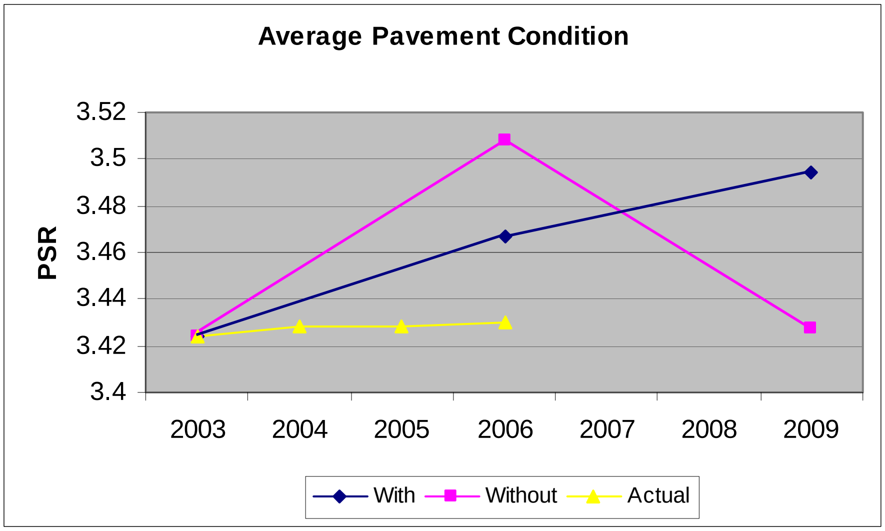

Figure 32. Average Pavement Condition

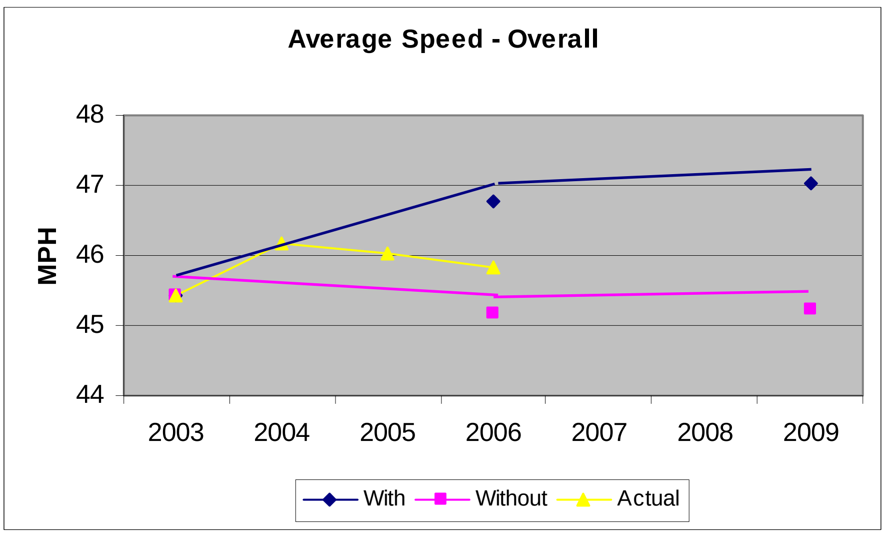

Figure 33. Average Speed

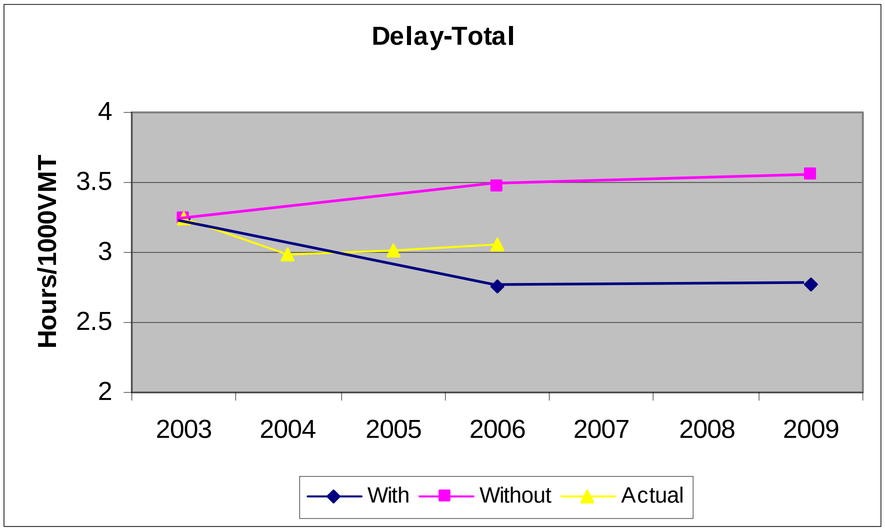

Figure 34. Delay

As Figure 35 depicts, the VMT of the actual is over 3 billion less than that of the 'with' case and that of the 'without' case. This difference between the actual and the HERS-ST outputs, including the 'with' and 'without' cases, may be caused by the overestimation of the future AADTs in the HPMS data. According to the Kentucky Long-Range Statewide Transportation Plan (KYTC 2008), VMT increased 18.26 percent from 1993 to 2003. Hence, the HPMS data rely on the past traffic growth to predict the future AADTs. However, the actual traffic growth from 2003 to 2006 is 1.9 percent, thus accounting for the difference. The difference may affect the average speed and delay as well as the benefits (i.e., $5.4 billion over 6 years and $11.3 billion over 25 years) in the *Analysis Results* section. To obtain more accurate results, it is recommended to update the HERS-ST input date using the actual AADTs.

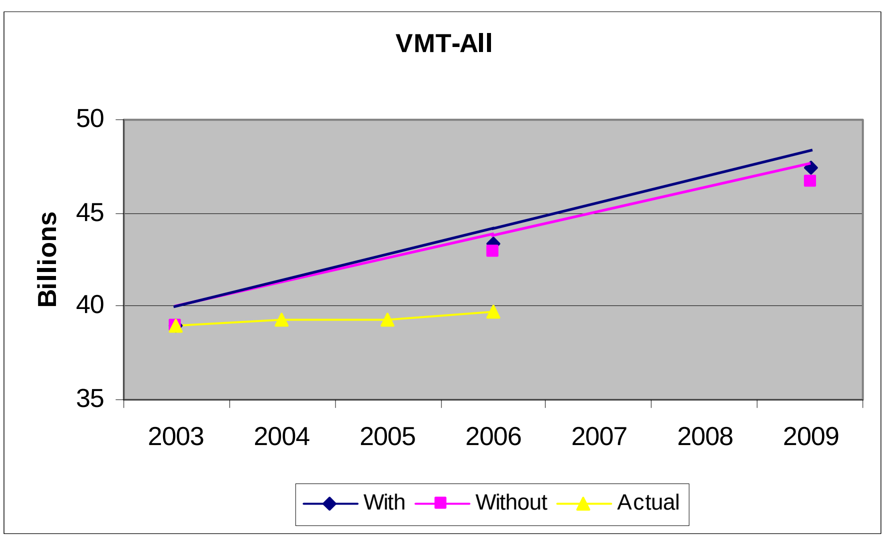

Figure 35. Vehicle Miles of Travel (VMT) by Year

4.7 Discussion

The results of the case study showed the benefits in pavement and traffic conditions between the 'with' and 'without' cases. These benefits are due to the fact that different treatments were applied to 18.8% of the sections in the 'with' case compared to the 'without' case over 6 years. There are two effects to produce the benefits between the two cases in the different treatment implementation.

One is the timing of treatment implementation. Since the 'with' case determines the timing of treatments based on the predicted pavement conditions at the end of a funding period (FHWA 2005), the preservation treatments are applied to 9.0% of the treatments implemented in the 'with' case. Meanwhile, the 'without' case focuses on the initial pavement conditions of the funding period and thus assumes that treatments are not required, even though the conditions go below an acceptable level at the end of the funding period. Hence, the 'without' case needs to employ a more aggressive treatment (i.e., reconstruction) than the 'with' case in order to keep the pavement in good condition (see Figure 36 and Figure 37, and more detailed information in Appendix C). Also, as Table 17[6] addresses, the unit cost of reconstruction is four times high than that of resurface. Hence, the aggressive treatment overextends the budget for treatments.

The other is the difference between an economic modeling in the 'with' case and an engineering modeling in the 'without' case. Since the treatments of the 'with' case are determined by a HERS-ST optimization strategy using a minimum BCR analysis (BCR>1), the 'with' case addresses treatments that have high benefits, including agency, user, and external, and low total initial costs. On the other hand, the treatments of the 'without' case are assigned in the sections whose conditions are within the deficiency criteria, regardless of taking into account the total initial costs. Hence, the unit treatment costs of the 'without' cases tend to be higher than those of the 'with' case as Table 17 draws. The higher unit treatment costs overextend the budget for treatments as well.

(It seems that the 'with' case based on the HERS-ST's economic modeling gives us better decision makings to implement treatments for keeping better pavement and traffic conditions with the cost-effective manner. To maximize the agency, user, and external benefits while considering the total initial costs, HERS-ST looks at future conditions and determines appropriate treatment sets. However, it is important to note that the economic modeling may overlook the risk of highway deficiency because the economic modeling prioritizes sections that have higher traffic volume to maximize the user benefits, which occupy almost whole total benefits as Table 15 indicates. If there are sections that have high risk of deficiency with low traffic volume, the economic model may not select the sections for treatment application, especially under the budget constraint. It is important to consider the risk in the decision making for treatment implementation in practice.)

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[6] The numbers are derived from HERS-ST output (Improvement Statistics: Total Initial Costs and Lane-Miles Improved). It is noted that these numbers are different from the numbers in Figure 37, which are obtained from the products of section lengths, numbers of peak lane, and expansion factors in the original HPMS data.

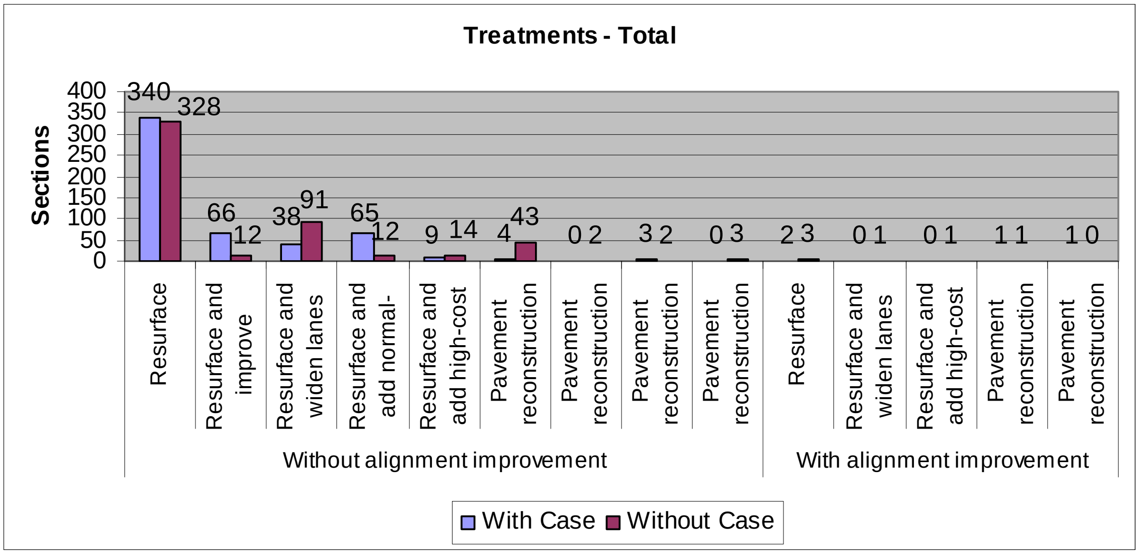

Figure 36. Treatments for With and Without Cases (Number of Sections)

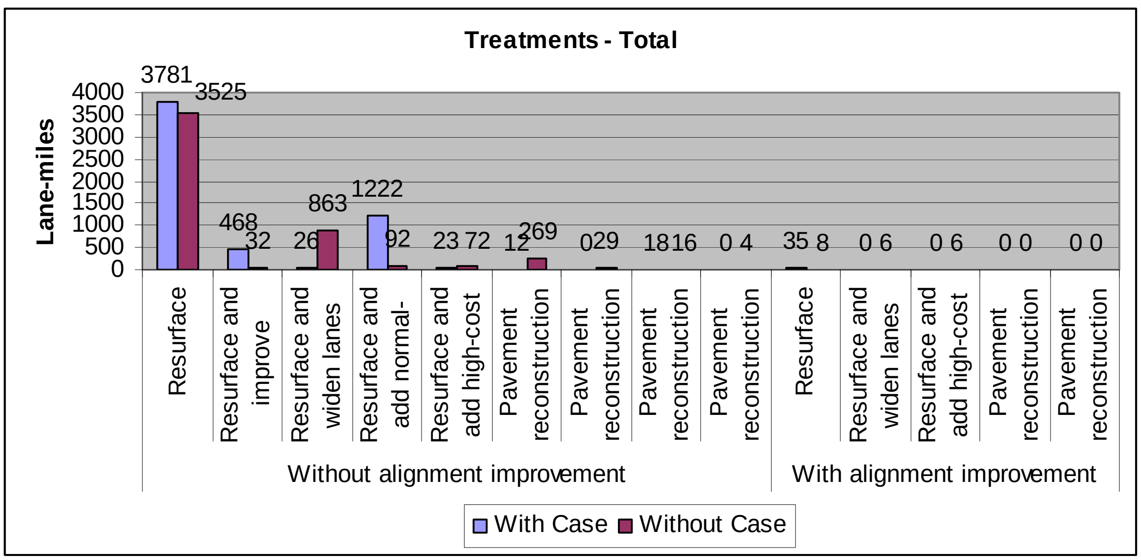

Figure 37. Treatments for With and Without Cases (Lane-miles)

Table 17. Sample Comparison of Treatment Costs between With and Without Cases

Treatment	With Case			Without Case		
	Lane-miles	Unit cost ($1000/lane-mile)	Cost ($1000)	Lane-miles	Unit cost ($1000/lane-mile)	Cost ($1000)
Resurface	3 860	307	11 83300	3 289	349	11 46868
Resurface and improve shoulders	4 67	361	16 8,762	3 0	458	13 ,734
Resurface and widen lanes	2 5	661	16 ,514	6 87	1,5 61	1, 072,566
Resurface and add normal-cost lanes	1, 985	1,6 35	3, 244,866	2 18	2,3 29	50 7,723
Pavement reconstruction	1 1	1,3 49	14 ,836	1 84	1,8 05	33 2,092

4.8 Summary

This case study assessed the benefits of HERS-ST derived from two different scenarios simulating performances with HERS-ST and without HERS-ST. The predicted performances are based on analysis functions in HERS-ST per se. Given the analysis results, the following observations are made:

- HERS-ST implementation improves the PSR by 0.07 points on a scale of zero to 5 over six years.
- HERS-ST implementation creates better driving environment in terms of average speed and delay. Due to the better environment created by the HERS-ST implementation, VMT would be increased.
- These benefits are derived from the HERS-ST's optimization strategy deploying the economic modeling that allows implementing preservation and low-unit cost treatments.
- HERS-ST estimated the benefits of 'with' and 'without' cases. The differences, $5.4 billion over 6 years and $11.3 billion over 25 years, are the approximate benefits of HERS-ST implementation consisting of savings in agency, user, and external costs.
- To justify the investment in HERS-ST implementation, the costs for HERS-ST implementation and operation are needed. However, it is not expected that HERS-ST implementation costs would approach $5.4 billion over 6 years.
- The benefits addressed above are based on the predicted AADTs. Hence, it is necessary to use the actual AADTs for obtaining more accurate benefits.

Given the results above, this research recognized that HERS-ST implementation may produce benefits. It is possible to observe whether the investment in HERS-ST implementation can be justified by comparing the total net benefits to the costs of implementation if HERS-ST implementation costs are available.

5 Delaware Case Study

The second case study uses HPMS form Delaware Department of Transportation (DelDOT). Like the case study for Kentucky, this case study evaluates the implementation of HERS-ST using the HPMS data. Where possible, this case study uses the same structure as the Kentucky case study. As the methodology is the same, only the data overview and analysis results are presented. The chapter begins with an overview of the data and then presents the results. The results are then compared with actual data. The chapter concludes with a discussion of the results.

5.1 Data

HPMS data for the years 2003 to 2006 was provided by Delaware Department of Transportation. Although the HPMS data includes 5120 highway sections, only 643 sections were complete samples. We used sections with complete data in this case study, which is about 12.5% of all sections. Table 18, Table 19 and

Table 20 show the number of highway sections, length of highway in miles, and length of highway in lane-miles, respectively in our sample database. Although the number of sections of the rural area is half of the urban area, the length of highway of the rural area in terms of miles and lane-miles is higher the urban area. Sections in the rural area have relatively long length.

Table 21 and Table 22 show the percent mileage deficiencies in rural and urban areas in year 2003, in terms of pavement deficient level (i.e., reconstruction and deficient) and road functional class, which are derived from HERS-ST analysis outputs. The percent mileages are extracted based on the default deficiency criteria used in HERS-ST (Table 8

and Table 9). As for the Kentucky case study, if pavement condition (PSR) for a section reaches the criteria for deficient in Table 8, it is assumed that DelDOT considers applying treatments such as resurfacing. If the condition becomes worse and reaches the criteria for reconstruction in Table 9, agencies need to implement reconstruction.

Table 18. Sections of Highway in 2003

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	0	-	85	56	76	217
Urban	35	18	97	133	143	426
Overall	35	18	182	189	219	643

Table 19. Length of Highway in 2003 (miles)

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	0	-	214.1	121.9	554	890
Urban	40.6	13.8	134.5	159.6	219.2	567.7
Overall	40.6	13.8	348.6	281.5	773.2	1457.7

Table 20. Length of Highway in 2003 (lane-miles)

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	0	-	789.4	310.7	1132.9	2233
Urban	241.5	55.2	496	423.9	472.9	1689.5
Overall	241.7	55.2	1285.4	734.6	1605.8	3922.5

Table 21. Percent Mileage Deficiencies in Rural Area

Rural	Interstate	Principal Arterial	Minor Arterial	Major Collector	Overall
Reconstruction	0	0.419	0	0.814	0.608
Deficient	0	14.318	3.733	0.814	4.462

Table 22. Percent Mileage Deficiencies in Urban Area

Urban	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Reconstruction	1.597	12.608	3.348	0	0	1.214
Deficient	8.448	18.55	24.798	3.849	3.949	9.536

As we can see, the interstate and the principal arterial highways in rural and urban areas have high percent mileages in deficient compared to other functional classes. This is because of higher Annual Average Daily Traffic (AADT) in those classes as Table 23 indicates. The principal arterial highway in urban area has the highest percent mileages in reconstruction and AADT. Interestingly, the expressway in the urban area shows high percent mileages in both deficient and reconstruction, although its AADT is relatively low.

Table 23. AADT in 2003

	Interstate	Expressway	Principal Arterial	Minor Arterial	Major Collector	Overall
Rural	0	-	1,867,645	633,226	342,086	2,842,957
Urban	3,509,456	686,404	2,883,199	2,105,542	797,480	9,982,081
Overall	3,509,456	686,404	4,750,844	2,738,768	1,139,566	12,825,038

5.2 Analysis Results

The results for the ‘with’ and ‘without’ cases are obtained from HERS-ST outputs and are presented in Table 24 and Table 25. Table 24 shows the improvement statistics that provide a summary of data about the improvements selected during each funding period. Also, it shows data expressing the effects of the selected improvements on the improved sections during the last year of the funding period. For example, items from number 1 to 9 provide statistical information during each funding period, while items from 10 to 20 provide annual costs and benefits in the last year of each funding period that are derived from implementing all improvements in the middle of the period (FHWA 2006). Table 25 shows the initial system conditions and the condition after each funding period.

Table 24. Improvement Statistics

No.	Performance Measure	With HERS-ST		Without HERS-ST	
		FP 1	FP 2	FP 1	FP 2
1	Total Initial Cost ($ thousands)	447953	294827	448440	295941
2	Lane-Miles Improved	784	641	1166	984
3	Average BCR	10.04	10.06	8.08	9.64
4	Miles Improved	197	178	391	332
5	Lane-Miles Added	64	42	0	0
6	Capital Requirements by IBCR Range [a]	447953	294827	401699	278978
7	Sample Sections by IBCR Range [a]	100	78	146	118
8	Miles Improved by IBCR Range [a]	197	178	297	323
9	Travel-Time Benefits by IBCR Range [a]	64.5	52.9	-12.2	-6.4
10	Total Benefits ($ thousands) [a] Excluding pollution damage savings	393645	225439	309451	257630
11	Maintenance Cost Savings ($ thousands) [a]	162156	107965	147355	145092
12	User Benefits ($thousand) [a]	231488	117474	162095	112538
13	Travel-Time Savings ($ thousands) [a]	88130	31728	-12060	-4569
14	Operating Cost Savings ($ thousands) [a]	133808	85560	175269	118080
15	Safety Benefits ($ thousands) [a]	9549	185	-1113	-972
16	Crashes Avoided ($ thousands) [a]	-141	-143	-249	-199
17	Injuries Avoided [a]	-46	-59	-105	-81
18	Lives Saved [a]	0	0	0	0
19	VMT for Improved Sections [a]	2531	1582	3148	2273
20	Pollution Damage Savings ($ thousands) [a]	-1864	-2671	-1013	-1601

Notes: 1) Costs are based on 2004 dollars.
2) FP: Funding Period
3) [a] These represent values in the last year of funding periods.
4) IBCR: Incremental Benefit Cost Ratio

Table 25. System Conditions

System Condition	Initial	With		Without	
		FP 1	FP 2	FP 1	FP 2
Mile	1,457.8	1,457.8	1,457.8	1,457.8	1,457.8
Lane-Miles	3,922.5	3,987.4	4,030.4	3,922.5	3,922.5
Average PSR	3.64	3.65	3.64	3.78	3.82
Average IRI	77	75.6	75.2	66.5	62.4
Average Speed – Overall (MPH)	43.729	44.599	44.898	43.793	43.723
Delay – Zero Volume (hours/1000VMT)	1.299	1.289	1.277	1.293	1.283
Delay – Incident (hours/1000VMT)	0.598	0.425	0.434	0.62	0.677
Delay – Other (hours/1000VMT)	1.816	1.599	1.505	1.798	1.828
Delay – Total (hours/1000VMT)	3.714	3.314	3.216	3.71	3.788
VMT – 4 Tire Vehicle (millions)	6,546	6,766	6,964	6747	6937
VMT – Single Unit Trucks (millions)	371	384	395	382	393
VMT – Combination Trucks (millions)	391	407	421	405	418
VMT – All (millions)	7310	7557	7782	7535	7749
VHT – 4 Tire (millions)	150	152	156	154	159
VHT – Single Unit Trucks (millions)	8	8	8	8	8
VHT – Combination Trucks (millions)	8	8	8	8	8
VHT – All (millions)	167	169	173	172	177
Travel Time Costs – 4 Tire Vehicles ($/1000VMT)	467	455	453	467	469
Travel Time Costs – Trucks ($/1000VMT)	691	669	665	691	696
Travel Time Costs – All ($/1000VMT)	491	478	475	491	493
Operating Costs – 4-Tire Vehicles ($/1000VMT)	260	259	259	254	252
Operating Costs – Trucks ($/1000VMT)	564	566	566	554	550
Operating Costs – All ($/1000VMT)	292	291	291	286	283
Crash Costs ($/1000VMT)	142	140	140	142	142
Total User Costs ($/1000VMT)	925	910	907	919	919
Crash Rate (/100 million VMT)	297	295.5	294.3	297.8	297.4

System Condition	Initial	With		Without	
		FP 1	FP 2	FP 1	FP 2
Injury Rate (/100 million VMT)	128.8	128.0	127.7	129.2	129.1
Fatality Rate (/100 million VMT)	1.49	1.47	1.47	1.49	1.49
Maintenance Costs ($/1000 mile)	186387	135469	117688	145622	112496
Emissions Costs ($/1000VMT)	19.329	15.249	12.06	15.181	11.984
BCR of Last Improvement		4.60	2.29	-	-

Notes: 1) Costs are based on 2004 dollars.
2) FP: Funding Period
3) VHT: Vehicle hours of travel-time

Benefit Quantification

The following figures depict the impacts of HERS-ST implementation on performance measures available in the System Conditions HERS-ST outputs. Figure 38 draws the average pavement conditions in terms of PSR over the analysis period for the 'with' and 'without' cases. The condition of the 'with' case keeps PSR in the current condition, while that of the 'without' case increases. This is because in 'without' case the only goal is increasing the pavement condition and the only criteria to do a treatment for a section is its PSR but for 'with' case other benefits are considered too. At the end of analysis period PSR for 'without' case is more than 'with' case.

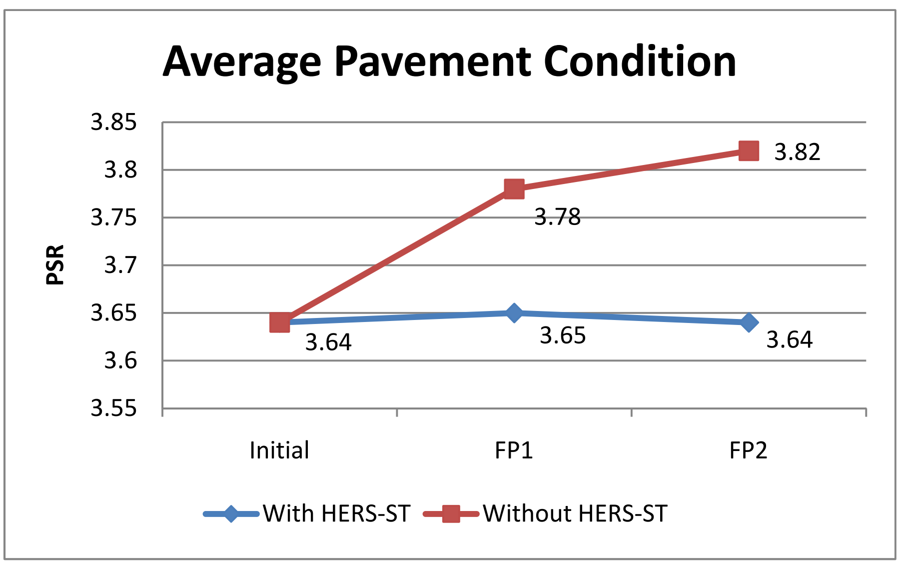

Figure 38. Average Pavement Condition

Figure 39 shows the overall average speed for the 'with' and 'without' cases. The 'with' case has a 1.1 mph higher average speed than the 'without' case in 2009. Because the 'with' case implements 400 lane-miles more treatments dealing with capacity expansion (i.e., improving shoulders, widening lanes, and adding lanes) than the 'without' case, the average speed of the 'with' case is higher than that of the 'without' case.

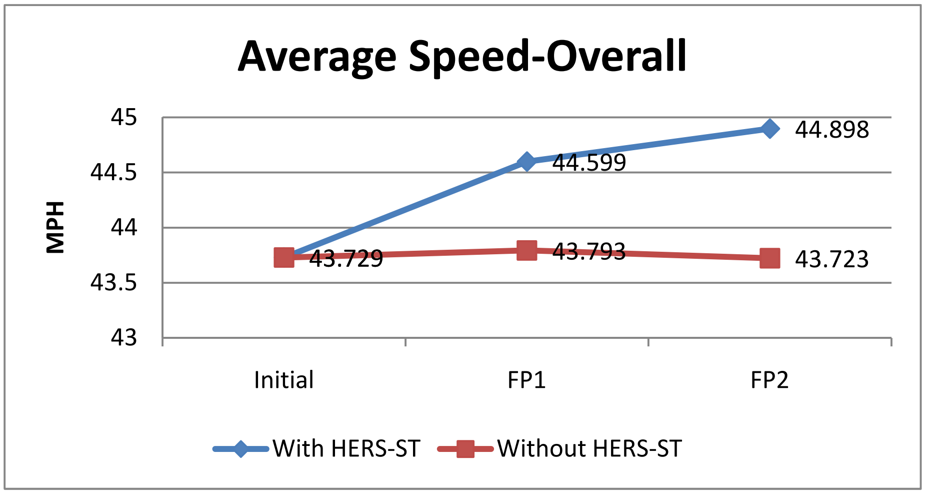

Figure 39. Average Speed

Figure 40 depicts the total average delay, including zero traffic volume, incidents and other, for the two cases. Because of the number of the capacity expansion treatments implemented, the 'with' case has a 0.57 hours per 1000 VMT lower delay than the 'without' case in 2009.

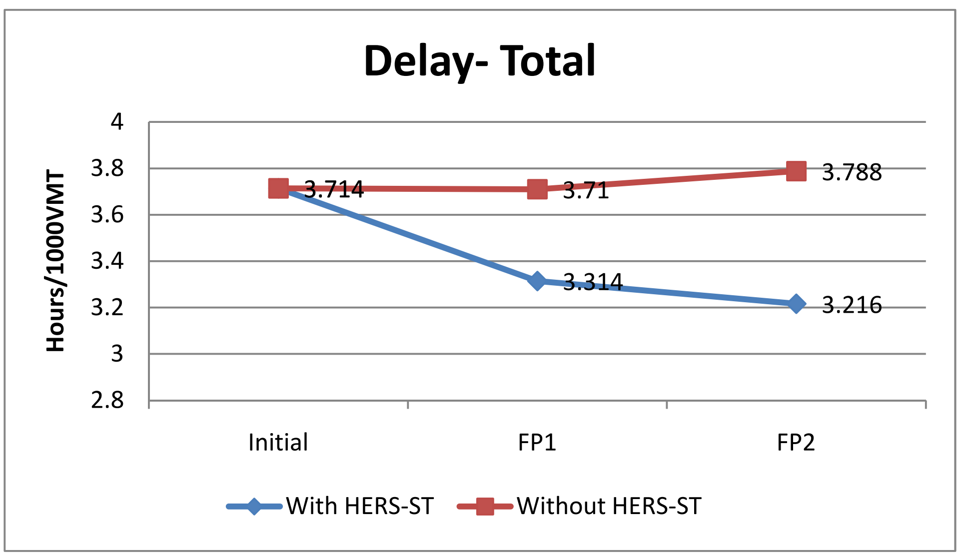

Figure 40. Delay

Figure 41 shows VMT for the two cases. Similarly, due to the number of capacity expansion treatments, the 'with' case has a 33 million higher VMT than the 'without' case.

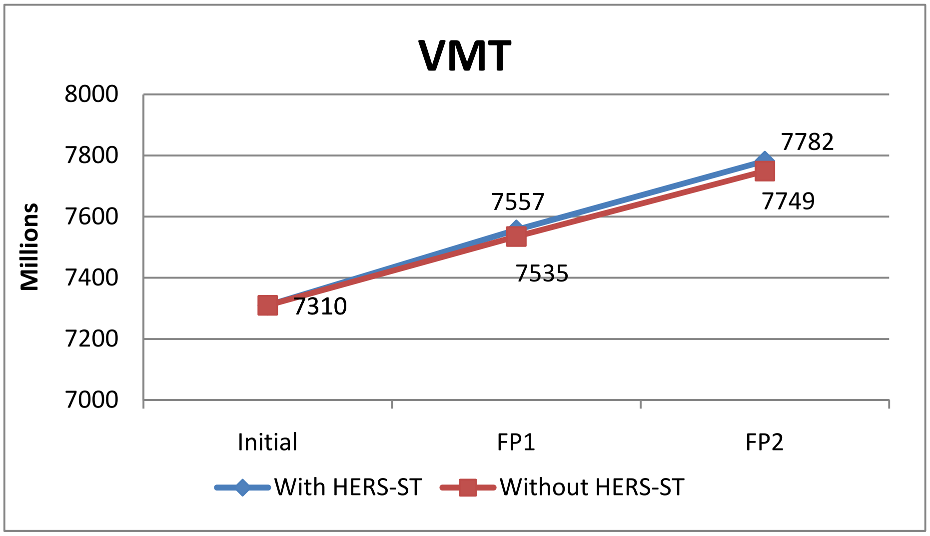

Figure 41. Vehicle Miles Traveled

The following costs are derived from the System Conditions outputs in Table 25. The values of the first funding period were calculated by taking average values between the initial and the first funding period, and the values of the second period were the average between the first funding period and the second funding period for the 'with' and 'without' cases. Hence, the costs are approximated.

Figure 42 shows the unit maintenance costs for the 'with' and 'without' cases over the two funding periods. The amount of the 'with' case is $7 per mile less than that of the 'without' case.

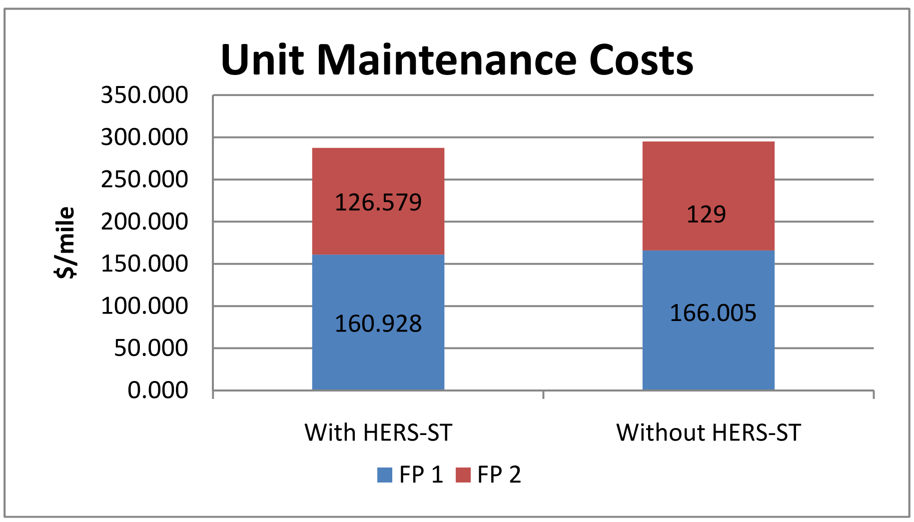

Figure 42. Unit Maintenance Costs

Figure 43 shows the unit user costs, including travel time costs, vehicle operating costs, and crash costs for the 'with' and 'without' cases. The 'with' case has $0.014 per VMT less unit user costs than the 'without' case.

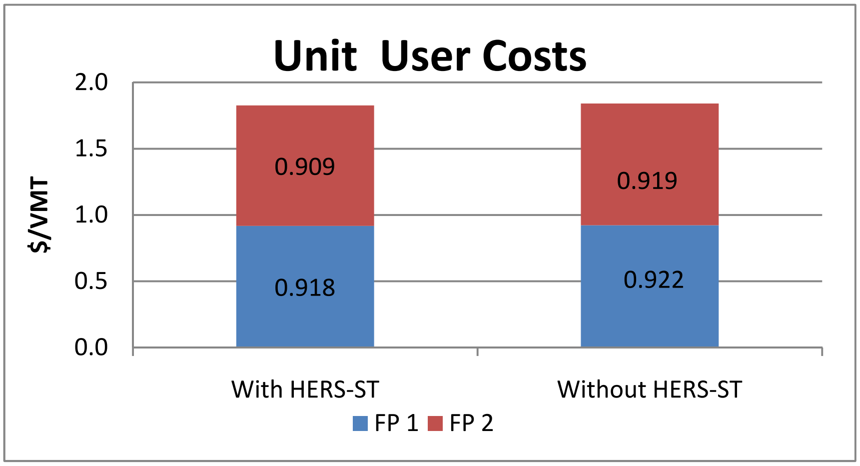

Figure 43. Unit User Costs

Figure 44 depicts unit emission costs for the 'with' and 'without' cases. 'with' case previously shows the worse conditions in the unit emission costs, $0.0001 per VMT higher than the 'without' case. This situation may be caused by the higher average speed and lower performance measure (PSR).

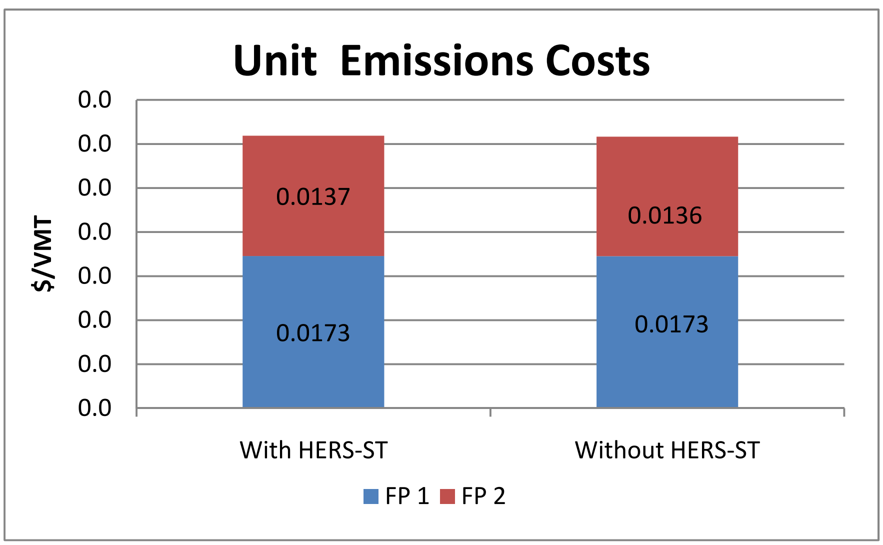

Figure 44. Unit Emissions costs

Given the unit maintenance, user, and emission costs, we can estimate the total costs by adding all costs that are obtained from multiplying by miles improved for the maintenance costs and VMT for the user and emission costs over the analysis period. The calculations of the total costs based on 2004 dollars, including the calculations of the unit costs and the differences (i.e., savings or benefits), are shown in Table 26.

Table 26. Calculation of Costs and Savings

Maintenance Costs (Agency Costs)		
With case	:	($186387+$135469)/2*1457.8*3/1000+($135469+$117688)/2*1457.8*3/1000= 1.26 (million)
Without case	:	($186387+$145622)/2*1457.8*3/1000+($145622+$112496)/2*1457.8*3/1000= 1.29 (million)
		Savings in agency costs = 1.29 – 1.26 = 0.03 million
User Costs		
With case	:	($925+$910)/2*(7310mil+7557mil)*3/1000+($910+$907)/2*(7557mil+7782mil)* 3 /1000= 41363.9 (million)
Without case	:	($925+$919)/2*(7310mil+7535mil)*3/1000+$919*(7535mil+7749mil)*3/1000= 41599.6 (million)
		Savings in user costs = 41599.6 – 41363.9 = 235.7 million
Emission Costs (External Costs)		
With case	:	($19.329+$15.249)/2*(7310mil+7557mil)*3/1000+($15.249+$12.060)/2*(7557mil + 7782 mil)*3/1000=699.7 (million)
Without case	:	($19.329+$15.181)/2*(7310mil+7535mil)*3/1000+($15.181+$11.984)*(7535mil+ 7749mil)*3/1000= 695.6 (million)
		Savings in external costs = 695.6 – 699.7 = -4.1 million

Figure 45 summarizes the total costs, including maintenance costs, user costs, and emission costs that are addressed above for the ‘with’ and ‘without’ cases. The ‘with’ case has $0.23 billion lower total costs compared to the ‘without’ case, that is, the benefits of implementing HERS-ST. Especially, the savings in the user costs significantly contribute to the benefits due to the scale. The emission costs have an adverse effect in reducing the benefits.

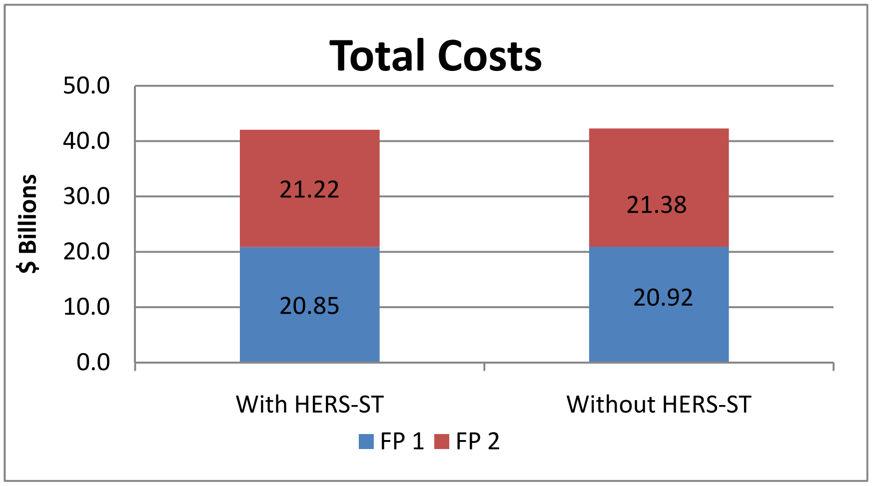

Figure 45. Total Costs

It is noted that the benefits, \$0.23 billion, do not include all benefits over the analysis period (i.e., 6 years). Figure 46 depicts the conceptual benefits of HERS-ST implementation derived from the total costs. User and external benefits[7] derived from treatments implemented in the first funding period accrue over the second funding period. However, the benefits do not count the benefits in the second funding period. Hence, the actual benefits would be higher than that amount.

Given the total initial costs and average BCRs in the Improvement Statistics outputs listed in Table 24, the benefits for the 'with' and 'without' cases over the BCA period[8] are estimated as Table 27 shows. Next, the net benefits, that is, the differences obtained from the subtraction of the total initial costs from the total benefits for the 'with' and 'without' cases are calculated as follows:

Net Benefits With case	:	7,463,408– 742,780= 6,720,620
Net Benefits Without case	:	6,476,266– 744,381= 5,731,885

Then, the difference in the net benefits between the 'with' and 'without' cases is calculated based on the two members of Eq.(1), that is, (Net Benefits with HERS-ST) – (Net Benefits without HERS-ST). The differences are \$.99 billion (based on 2004 dollar), which are the total benefits of HERS-ST implementation.

[7] The external benefits derived from the difference in the emission costs between the 'with' and 'without' cases may be negative (i.e., disbenefits) in the second funding period as well as the first funding period.

[8] The BCA period responds to the duration of treatments' lives. For example, a simple resurface treatment takes one or two funding periods as a BCA period. However, in case of significant treatments, the BCA period can extend beyond the end of the overall analysis period (i.e., 25 years) (FHWA 2005).

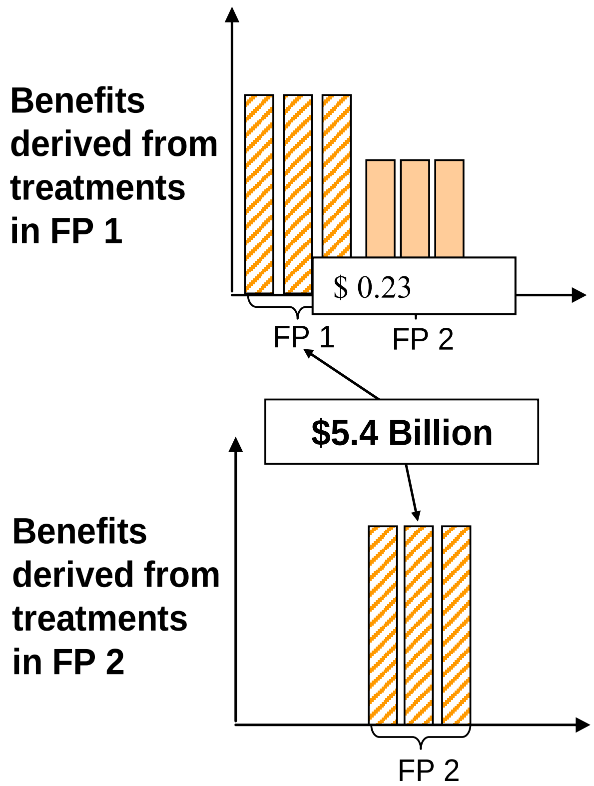

Figure 46. Conceptual Benefits of HERS-ST Implementation Derived from Total Costs

Table 27. Costs and Benefits of With and Without Cases

<table>
<tr><th colspan="3">Field</th><th>With HERS-ST Total</th><th>Without HERS-ST Total</th><th>(With HERS-ST) – (Without HERS-ST) Total</th></tr>
<tr><td rowspan="3">FP1</td><td>Total Initial Cost</td><td>1</td><td>447953</td><td>448440</td><td>-487</td></tr>
<tr><td>Average BCR</td><td>2</td><td>10.04</td><td>8.08</td><td>n.a.</td></tr>
<tr><td>Total Benefits</td><td>1×2</td><td>4,497,448</td><td>3,623,395</td><td>874,053</td></tr>
<tr><td rowspan="3">FP2</td><td>Total Initial Cost</td><td>3</td><td>294827</td><td>295941</td><td>-1,114</td></tr>
<tr><td>Average BCR</td><td>4</td><td>10.06</td><td>9.64</td><td>n.a.</td></tr>
<tr><td>Total Benefits</td><td>3×4</td><td>2,965,960</td><td>2,852,871</td><td>113,088</td></tr>
<tr><td rowspan="3">Total</td><td>Total Initial Cost</td><td>1+3</td><td>742,780</td><td>744,381</td><td>-1,601</td></tr>
<tr><td>Average BCR</td><td>(1×2+3×4)/(1+3)</td><td>10.048</td><td>8.700</td><td>n.a.</td></tr>
<tr><td>Total Benefits</td><td>1×2+3×4</td><td>7,463,408</td><td>6,476,266</td><td>987,141</td></tr>
</table>

Notes: 1) Monetary values are based on 2004 thousand dollars.
2) *Italics* are derived from HERS-ST analysis outputs.

Figure 47 depicts the conceptual benefits of HERS-ST implementation derived from the total initial cost and average BCR in Table 27 to illustrate the difference from the benefits shown in Figure 46. The upper figure shows the benefits produced by treatments in the first funding period, while the lower figure shows the benefits produced by treatments in the second funding period. Although this case study focuses on the two funding periods (i.e., 6 years) the benefits occur beyond the funding periods. The sum of the benefits from the first funding period to an nth funding period in the upper figure and the benefits from the second funding period to an m^{th} funding period in the lower figure responds to $11.3 billion over the BCA period. Meanwhile, the sum of the benefits in the first funding period in the upper figure and the benefits in the second funding period in the lower figure is worth $5.4 billion over 6 years. Although the benefits are estimated, it is difficult to determine the duration of the BCA period and the exact benefits over 6 years using the HERS-ST outputs.

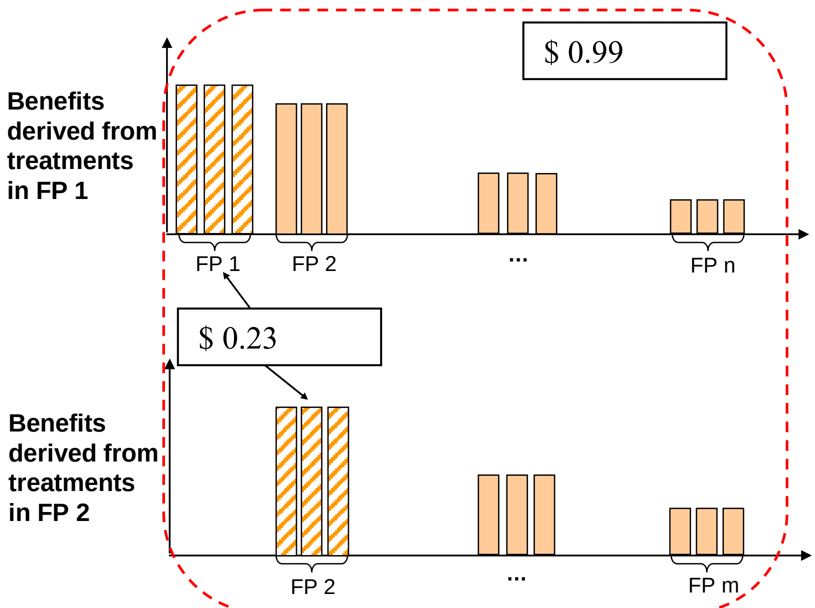

Figure 47. Conceptual Benefits of HERS-ST Implementation Derived from the Total Initial Cost and Average BCR

Investment Justification

Given the quantified discounted benefits of HERS-ST implementation, the comparison of the benefits to HERS-ST implementation costs is conducted to justify investment in HERS-ST implementation. Since there are no available data related to implementation costs, this discussion of whether the benefits outweigh HERS-ST implementation costs remains an exploration. Using the quantified total benefits, the following are addressed:

- If an agency spends less than $5.4 billion in implementation costs over 6 years, the agency can justify the investment in HERS-ST implementation, or
- If an agency spends less than $11.3 billion in implementation costs over 25 years, the agency can justify the investment in HERS-ST implementation.

Since \$5.4 billion in benefits do not include the entire benefits over 6 years, the allowable amount of HERS-ST implementation costs would be higher than \$5.4 billion. In the second point, a BCA period is specified as 25 years, because significant treatments can extend beyond 20 years (FHWA 2005). Despite the incompleteness of the analysis and assumptions, these can be criteria to justify investments in terms of the positive net present value using Eq.(1) or BCR higher than 1.0 using Eq.(2), if HERS-ST implementation costs are available. It is not expected that HERS-ST implementation costs would approach \$5.4 billion over 6 years because HERS-ST is a free application distributed by FHWA and all states already collect the HPMS data required, even when other costs such as labor are considered. To make this discussion more robust, it is necessary to calculate the exact benefits over a specific analysis period and compare them to the actual implementation costs.

5.3 Actual and Predicted Conditions

The following figures depict the comparisons between the actual condition and the predicted condition obtained from HERS-ST outputs for the performance measures addressed in the *Analysis Results* section. To obtain the actual condition, each year's HPMS data are used to calculate the initial condition that represents the actual condition over three years. For example, 2004 HPMS data are used to obtain the initial condition, that is, the condition in 2004. The comparisons articulate current highway conditions and relationships with predicted conditions for the 'with' and 'without' cases.

Figure 48 shows average pavement condition in terms of PSR. In the actual condition PSR decreases over 5 years (2003-2007). The graph shows that lots of maintenance treatment has been done in year 2007 so average PSR is increased for year 2008 comparing to 2007 but the final PSR for 2008(3.5) is still lower than average PSR for 2003 and lower than both 'with' and 'without' case. Ignoring the temporary treatment for just one year, pavements in the state of Delaware are deteriorating so the state may decide to use more efficient asset management plan. However, it is necessary to investigate how much funds have been used for the pavement management and what treatments have been applied over the years to conclude whether the efficient contribution occurred.

Figure 49 and Figure 50 show the average speed and delay, respectively. The actual condition shows big fluctuations comparing to 'without' case which shows constant values and 'with' case which is improving constantly. However the values for year 2008 are better than 2003 and 'without' case. Total delay is even better than 'with' case. The speed and delay related to traffic flow are affected by the treatments enhancing capacity. Because the actual implemented treatments are unknown, it is necessary to obtain the information of what types of treatments had been implemented in Delaware for the six years. Since the average pavement condition is getting worse over these 5 years, it can be assumed that state of Delaware is focused on treatments that increase capacity rather than improving pavement condition.

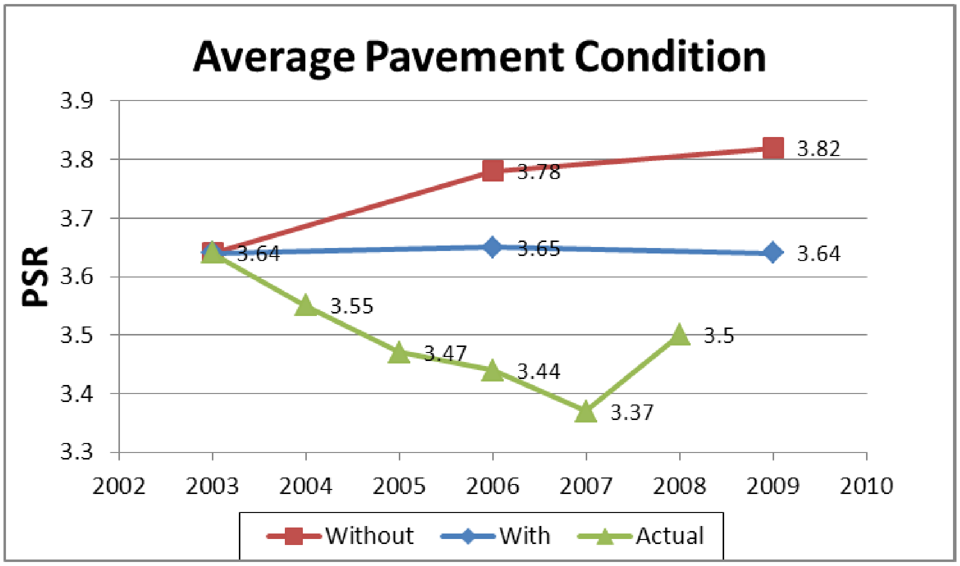

Figure 48. Average Pavement Condition

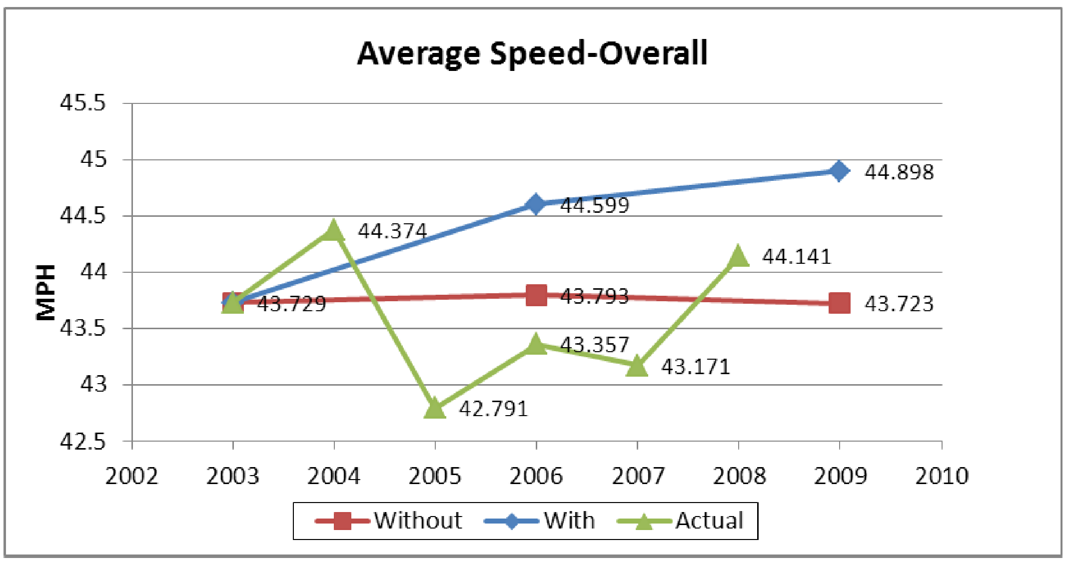

Figure 49. Average Speed

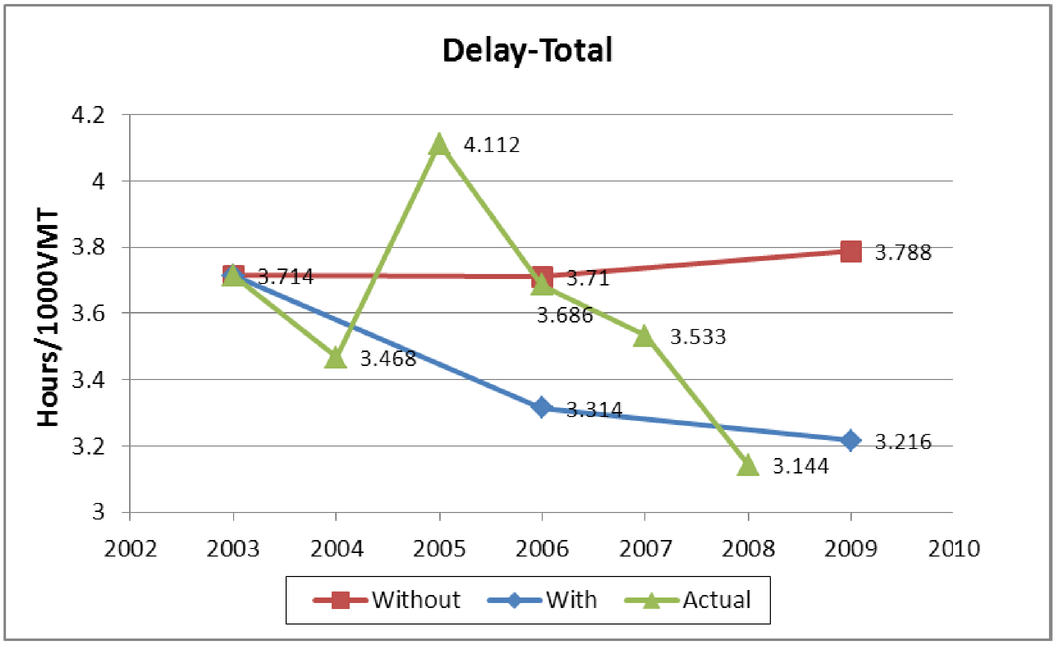

Figure 50. Delay

As Figure 51 depicts, the VMT of the actual is almost 2 billion less than that of the 'with' case and that of the 'without' case. This difference between the actual and the HERS-ST outputs, including the 'with' and 'without' cases, may be caused by the overestimation of the future AADTs in the HPMS data. HPMS data rely on the past traffic growth to predict the future AADTs. The difference may affect the average speed and delay as well as the benefits in the *Analysis Results* section. To obtain more accurate results, it is recommended to update the HERS-ST input date using the actual AADTs.

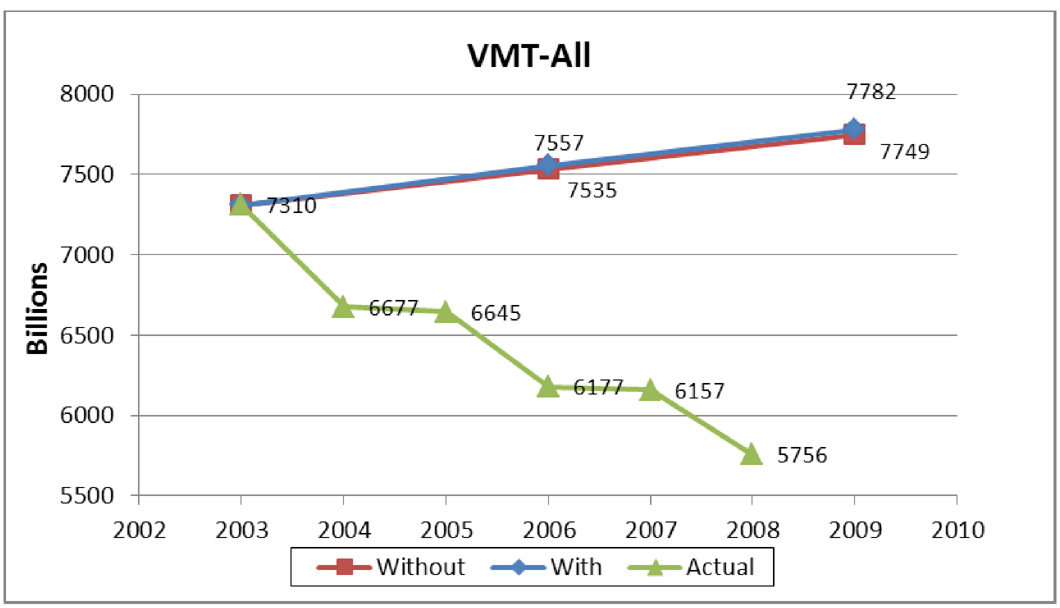

Figure 51. Vehicle Miles of Travel (VMT) by Year

5.4 Discussion

The results of the case study showed the benefits in pavement and traffic conditions between the ‘with’ and ‘without’ cases. The average pavement condition is the only parameter which is better for without case. But the total benefit of applying HERS-St is clearly more than without case. These benefits are due to the fact that different treatments were applied to the highway sections in the ‘with’ case compared to the ‘without’ case over 6 years. There are two effects to produce the benefits between the two cases in the different treatment implementation.

The most important advantage of HERS-St is the economic modeling in the ‘with’ case. Since the treatments of the ‘with’ case are determined by a HERS-ST optimization strategy using a minimum BCR analysis (BCR>1), the ‘with’ case addresses treatments that have high benefits, including agency, user, and external, and low total initial costs. On the other hand, the treatments of the ‘without’ case are assigned in the sections whose conditions are within the deficiency criteria, regardless of taking into account the total initial costs. Hence, the unit treatment costs of the ‘without’ cases tend to be higher than those of the ‘with’ case. The higher unit treatment costs overextend the budget for treatments as well.

(It seems that the ‘with’ case based on the HERS-ST’s economic modeling gives us better decision makings to implement treatments for keeping better pavement and traffic conditions with the cost-effective manner. To maximize the agency, user, and external benefits while considering the total initial costs, HERS-ST looks at future conditions and determines appropriate treatment sets. However, it is important to note that the economic modeling may overlook the risk of highway deficiency because the economic modeling prioritizes sections that have higher traffic volume to maximize the user benefits, which occupy almost whole total benefits as. If there are sections that have high risk of deficiency with low traffic volume, the economic model may not select the sections for treatment application, especially under the budget constraint. It is important to consider the risk in the decision making for treatment implementation in practice.)

6 Summary and Conclusions

This report presents a generic methodology for assessing the benefits of using HERS-ST as an asset management tool and explores strategies for communicating the results. Three data sets are used to demonstrate the application of this material. The first data set from New Mexico, included in the HERS-ST software, is used to provide examples of charts, graphs and tables that can be used to communicate the benefits. The second and third data sets are case studies that apply the methodology to Kentucky and Delaware to demonstrate the application of the methodology and the results. These case studies were also used to refine the methodology and develop a Step-by-Step Guide and a training module that can be used stand alone or in conjunction with the existing HERS-ST training.

The results of the case studies suggest that there are substantial benefits to be gained by using asset management tools to assist in decision making to improve pavement serviceability, safety and reduce congestion.

The project also demonstrates the challenges involved in assessing the benefits derived from using asset management tools. Few tools capture user costs and have robust decision making models that capture the full range of preservation and improvement options.

7 References

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Appendix A. User's Manual

The following user's manual is intended to provide a step by step guide for using HERS-ST to estimate the benefit of using HERS-ST for asset management.

Assessing and Interpreting the Benefits Derived from Implementing and Using Asset Management Systems

Step by Step Manual for Assessing the Benefits of Using HERS_ST as an Asset Management Tool

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Sue McNeil

University of Delaware

January 2011

A) Background

This manual provides step-by-step instructions for using the Highway Economic Requirements Systems – State version (HERS-ST) to assess the benefits of asset management (Federal Highway Administration, 2009). The process, as shown in Figure 52, was developed assuming HERS-ST is used to support data-driven decision making for pavement maintenance. The process builds on the work of Mizusawa (2007). The process compares the performance of the network, assuming decisions are made "with HERS" to the performance of the network assuming decisions are made "without HERS" (based on worst first or other selected strategy). This manual describes how to set up HERS-ST to run these scenarios.

B) Requirements

- HERS-ST v4.4
- Highway Performance Monitoring System (HPMS) data

C) Assembling the Data

1- Set the beginning year, programming period and funding period

The beginning year may be the past year or any other year you can provide HPMS data for. Programming period is the period your scenarios for asset management are designed for. Funding period is time intervals for which the organization sets the budget.

If you choose the beginning year so that the analysis period covers documented conditions, you can compare HERS-ST results with the actual results for the programming period. For example, if you choose year 2003 as

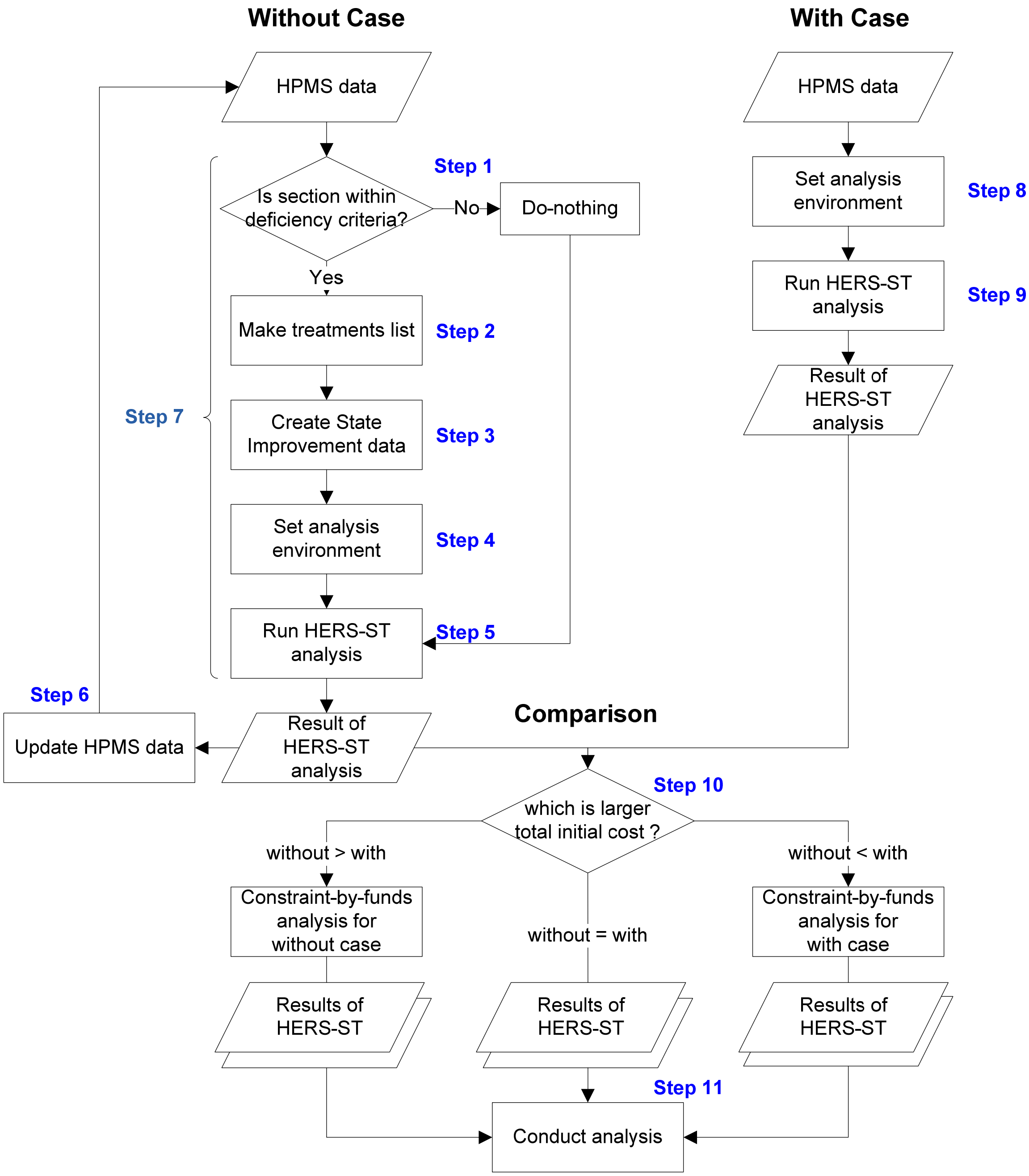


Figure 52 Analysis Process

the beginning year and use a 6-year funding period, which could be separated as two 3-year funding periods, you can compare the scenarios “with HERS-ST“ and “without HERS-ST” with the actual data for years between 2004-2009.

2- Prepare HPMS data for the beginning year (required) and for each year of programming period (optional) for the following variables:

- Average PSR
- Average Speed

- Total Delay
- Total VMT

D) Run HERS-ST

1- Load Network Data:
Import HPMS network data to HERS-ST. Based on previous experiences, 10%-20% of data is enough for the analysis. Try to have the same distribution for the actual data and for the sample data. For example, the mileage percentage of each functional class would be the same for sample and actual data. Use complete samples otherwise, you may have incorrect results.

2- Run “Without HERS” Scenario (Steps 1-7 in Figure 52):

2-1) Prepare the Improvement List (Steps 1 and 2):

In this scenario we use HERS just to implement our selected improvements and see the results. In this scenario a list of selected improvement is imported to HERS. This list should show our chosen strategy with which we want to compare HERS-ST. The selected strategy is worst-first. Although you can get the concept of priority in the worst-first strategy, HERS does not accept a prioritized imported improvement list. So, we just try to find all the deficient sections and make suggestions to improve all of them. To find deficient sections, we need two principle things:

- current condition of the pavement sections
- a standard threshold to define the deficiency.

Current condition of the pavement is available in HPMS data. PSR and IRI show the pavement condition. We used PSR as a measure in this project. The standard for deficiency can be borrowed from HERS-ST defaults. There are two types of pavement deficiency threshold in HERS: 1-Deficiency level 2-Reconstruction level. These two levels can be seen in the HERS_ST parameter data as shown in the screen shot in Figure 53.

We propose resurfacing for sections below the deficiency level and reconstruction for sections below the reconstruction level. An excel worksheet with all the sections in these two categories along with the proposed improvement must be prepared. The important point here is this list is the improvement selected for the first funding period. All these steps should be repeated for the second funding period, as described later.

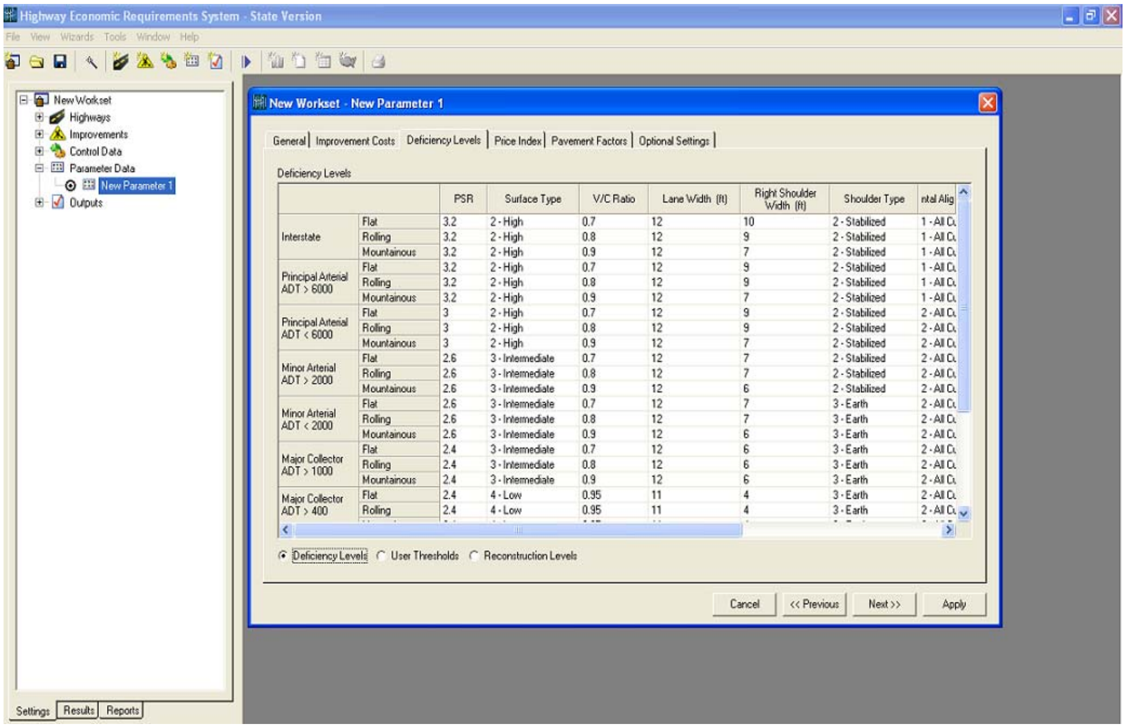


Figure 53. Deficiency Levels

The excel worksheet including deficient sections and proposed improvement should have 10 columns:

- Column 1 is the number of improvements, which is “1” for all sections in this case.
- Column 2, 3 and 4 are state, county and section ID, which can be copied from HPMS data.
- Column 5 is the year you want to do the improvement. HERS-ST considers that treatments are implemented in the middle of funding period when calculating benefits and costs as part of its output. So you can choose any year in the first funding period. In our example the beginning year is 2003 and the funding period is 2004-2006. So, any choice -- 2004, 2005 or 2006 -- is acceptable for the first funding period.
- Column 6 is the type of improvement. It is easy to use Excel formula to assign “Resurfacing” for section with PSR between “deficiency” and “reconstruction” level and “Reconstruction” for section with PSR less than “reconstruction” level. To use the HERS default level for reconstruction and resurfacing, the functional class and AADT of the sections are necessary. This data is available in HPMS dataset. For resurfacing, use “1” in the 6th column. The respective code for reconstruction is “6”. You should use “0” for all other section which are in good condition in the beginning year.

- Column 7 represents that your selected treatment will be override the HERS selected treatments or not. You should use “1”, which means yes to fill out this column. This feature helps you just to use your specified treatments.
- Column 8, 9 and 10 are cost of improvement, number of lanes added and the capacity increase. You can leave them as 0 to use HERS defaults for cost and 0 for lanes added and capacity increase.

Finally save this excel sheet as a CSV file. You can import this CSV file to the HERS-ST.

In summary, the steps to create an improvement list are as follows:

- Extract all sample sections’ state, county and section ID besides PSR, AADT and functional class from HPMS dataset.
- Assign reconstruction, resurfacing or nothing to all the section based on current PSR and HERS_ST default level for deficiency and reconstruction level. It is important to assign nothing to the sections that do not need any treatment to prevent HERS_ST considering software selected treatment for these sections.
- Import the list to the HERS_ST improvement

2-2) Set the control data for without scenario (Steps 3 and 4).

Set the objective as “Full Engineering Needs Analysis”. We use this objective to make sure that all the treatments in the improvement list will be implemented. Make sure to mark “override HERS using State-specific improvements” in the objective window.

The discount rate, length of funding period and number of funding periods are other data that should be entered in the control data part of scenario. Number of funding periods here is 1 because we are planning for the first funding period.

2-3) Run HERS-ST for the first funding period (Step 5).

2-4) Update the HPMS data and identify deficiencies at the end of the funding period (Step 6).

Use the section condition in “Results” to find out the pavement condition (PSR) and AADT at the end of first funding period.

2-5) Repeat these steps for the next funding period (Step 7).

Use new PSR and AADT to prepare an improvement list for the second period.

Update the Excel sheet you prepared for the list of improvements.

Begin by adding one to the numbers in the first column. (As mentioned before, the first column is the number of the improvement.) Add another 6 columns to the pervious list for the new funding period following the procedure for calculating the values in columns 5-10 (step 2-1). This procedure is repeated with the new PSR and AADT data to fill the six new columns. In this case for the second run:

- Change the first column from "1" to "2". In the second run we want to combine funding period one and two so we need to define 2 improvements for each section.
- Keep column 2-10 the same as before and
- Calculate the values for column 11-16 with the same procedure described for column 5-10 respectively.

Update the number of funding periods in control data. In this case change it from 1 to 2

Run HERS-ST with new improvement list and new control data.

Repeat steps 2-4 till 2-8 with if you have more than 2 funding periods.

3- Run the "With HERS_ST" Scenario (Steps 8 and 9)

3-1) Use the same network data developed for the "without HERS-ST" Scenario

3-2) Use a blank list of improvements for this scenario

3-3) In the control data, set objective as "All improvements with minimum BCR=1".

3-4) Set discount rate, length of funding period and number of funding periods the same as the last run of without case.

3-5) Run "with HERS_ST" scenario.

4- Comparing Scenarios (Step 10)
To compare "with" and "without" scenarios, both scenarios should have the same budget level. So, we first compare total initial cost of these two scenarios.

a) If the initial cost for "with" scenario is more than "without" scenario. Change "with" case objective to "maximized benefit as constrained by funds". Then use the reported total initial cost for "without" case as the available fund for with case. This amount of fund should be entered in the funds/goals tab in control data for each funding period. Keep all other parameters the same and run new "with" Scenario.
b) If "without" scenario's total initial cost is more than "with" scenario, the initial cost of "with" scenario will be set as available budget. Then an iterative method should be applied to find the treatments those are in the budget range. "Without" scenario is a worst-first strategy, so you should delete as many sections in the improvement list as the initial cost will be less than or equal to available budget based on the current condition of sections. Therefore, you should start with deleting sections with better

PSR and check the expenses for the new set of treatments until the budget constraint is satisfied.

5- Comparing Results (Step 11)

Now everything is ready to compare improvement and system condition parameters for two scenarios. The most important parameters that should be compared are Average PSR, Average Speed, Total Delay, Total VMT, Users' Benefits and Total Benefit. You may use tables and charts to compare these two scenarios.

6- Comparing Result With Actual Case

To complete your report you can compare the two scenarios' result with actual data you have from HPMS data or any other source for the whole planning period. To compare the actual data with HERS-St outputs, you can import HPMS data for each year to HERS and run HERS with default settings. The initial system condition gives you the parameters with HERS format.

References

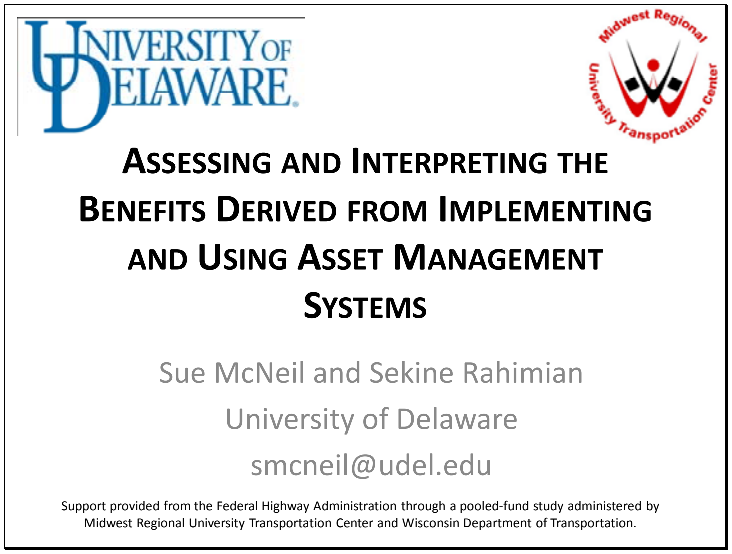
Mizusawa, Daisuke (2007). Strategic Directions for Implementing Asset Management: Quantifying Benefits of Asset Management, Unpublished Ph.D Thesis, Urban Planning and Policy, University of Illinois at Chicago.

Federal Highway Administration. Highway Economic Requirements System – State Version, User's Guide, Software Version 4.4., 2009.

Appendix B. Training Materials

The following PowerPoint slides and notes are intended to serve as a training module for explaining how HERS-ST can be used to estimate the benefits of asset management. The slides should be used in conjunction with the manual included in Appendix C.

Slide 1



This training module has been developed as part of the project "Assessing and Interpreting the Benefits Derived from Implementing and Using Asset Management Systems." Support for this project was provided from the Federal Highway Administration through a pooled-fund study administered by Midwest Regional University Transportation Center at University of Wisconsin, Madison and Wisconsin Department of Transportation.

Slide 2

Outline

- Objectives
- Background
- Overview
- A Step by Step Guide for HERS-ST
- Communicating the Results
- Resources

The training modules covers:

•Study objectives

•Study background

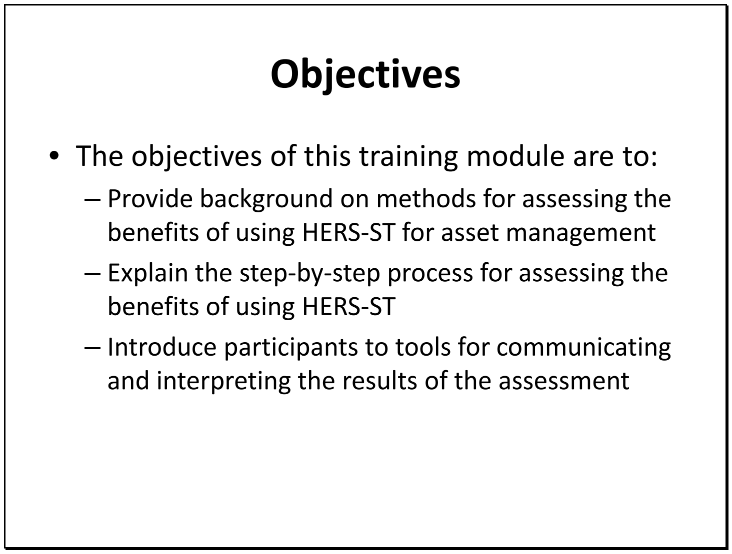
•Study overview

•A step-by-step guide for using HERS-ST to estimate benefits

•Communicating the results

•Project resources

Slide 3



The objectives of this training module are

•To provide background on the methods used for assessing the benefits of using HERS-ST for asset management

•To explain the step-by-step process developed for the assessing those benefits

•To introduce participants to tools for communicating and interpreting the results of the assessment.

Slide 4

Background

- Assumptions:
  - Participants are familiar with HERS-ST and the HPMS data.
  - Participants understand asset management concepts including performance measures.
- Resources:
  - HERS-ST – Highway Economic Requirements System / State Version.
    - Tool to identify highway deficiencies, and apply economic criteria to select the most cost-effective mix of improvements.
    - See http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm
    - Software (free) and documentation are available from FHWA
  - HPMS - Highway Performance Monitoring System
    - Data on the extent, condition, performance, use, and operating characteristics of the Nation's highways.
    - See http://www.fhwa.dot.gov/policy/ohpi/hpms/abouthpms.cfm

This module assumes that participants are familiar with HERS-ST, the Highway Economic Requirements System, and the Highway Performance Monitoring System (HPMS) data used an input to HERS-ST. All states are required to collect and report HPMS data every year. The reported data are sample data and data quality varies from state to state. Data includes condition and traffic data. HERS was originally developed as a policy tool to assist congress in setting budgets. The state version was developed recognizing the value of the economic analysis based on engineering data. HERS-ST is free software that can be downloaded. More information is also available on line about HPMS.

Slide 5

Background

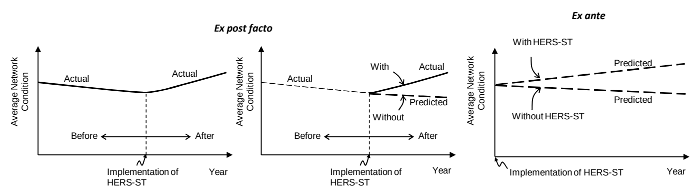
- A barrier to implementing asset management is implementation and development costs.
- A generic methodology was developed to demonstrate the benefits of asset management for comparison with the implementation and development costs.
- Benefits are identified as future savings in agency costs, user costs (crashes, travel time) and external costs (emissions)

One motivation for this project was that a peer exchange identified implementation and development costs as one of the barriers to implementing asset management. Earlier work demonstrated clear benefits could be achieved by implementing asset management and developed a generic methodology to compute these benefits. The benefits include savings in agency costs, user costs and external costs.

Slide 6

Overview

- Types of evaluation
  - *Ex post-facto* - retrospective (after the fact)
  - *Ex ante* – prospective (before the fact)



The generic methodology uses two kinds of evaluation –

•Retrospective evaluation which is used after you have implemented asset management

•Prospective evaluation which is used before you have implemented asset management.

The graphics are intended to illustrate the two methods, which are actually very similar as data must compared over the time same time frames.

Slide 7

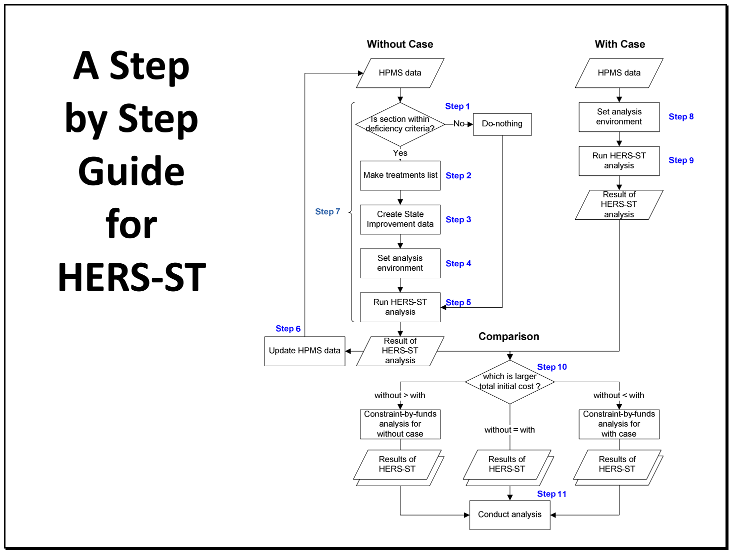
Overview

- Evaluation
  - Is based on a network level analysis
  - Uses Net Present Value and Benefit Cost ratios
  - Uses two scenarios – “With” and “Without” asset management
  - Uses funding periods
- Performance measures are used
  - Average Present Serviceability Rating (PSR)
  - Average speed and delay
  - Maintenance costs
  - User costs
  - Emissions costs

The evaluation is based on a network level analysis (that is actual projects may differ but average network conditions replicated); uses net present value and benefit cost ratios to represent the economic value of improvements; uses two scenarios - “with” and “without” asset management to make the comparison; and uses funding period for implementing improvements.

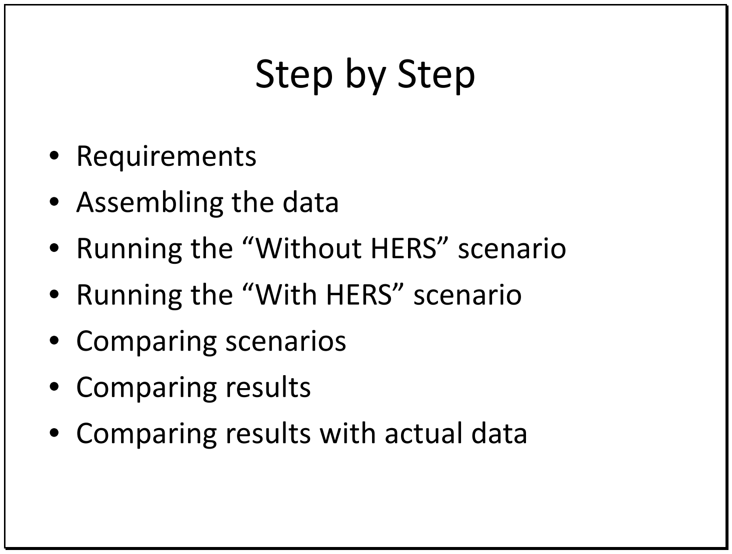
Several performance measures are available in HERS-ST to track how the “with” and “without” strategies are doing.

Slide 8



This flow chart documents the 11 step process for assessing the benefits of using HERS-ST for asset management.

Slide 9



The step by step guide addresses the following elements:

•Requirements – what you need to do the analysis

•Assembling the data – what data you need to complete the analysis

•Running the "Without HERS" scenario – setting up and running the "without" scenario

•Running the "With HERS" scenario – setting up and running the "with" scenario

•Comparing scenarios – making sure you are using the same budgets and how to adjust!

•Comparing results – comparing the performance measures and other metrics

•Comparing results with actual data

Slide 10

Requirements

- HERS-ST Version 4.4
- HPMS data
- Actual performance (optional)

HERS-ST version 4.4 can be download from FHWA's Office of Asset Management's website (see background or resources)

HPMS data can be obtained from FHWA or state DOTs

Actual performance data may be HPMS data or data from the state

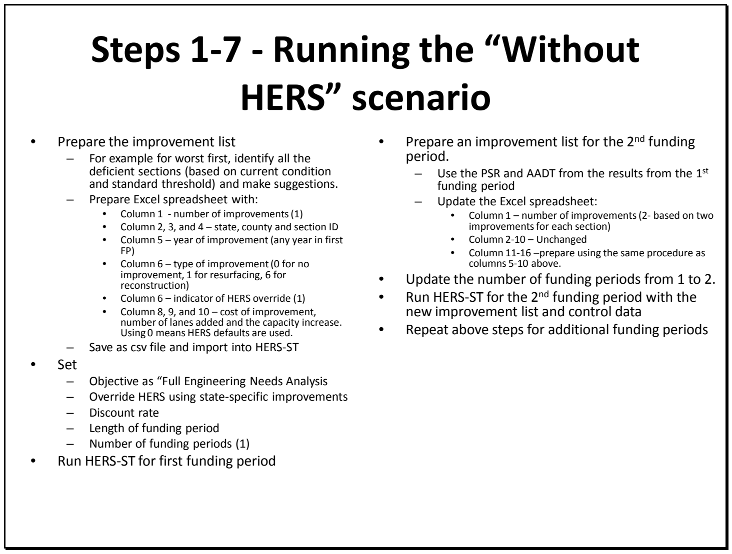
Slide 11

Assembling the data

- Specify
  - Start year
  - Programming period
  - Funding period
- Prepare HPMS data for the start year (required) and each year of the programming period (optional) including:
  - Average PSR
  - Average speed
  - Total delay
  - Total VMT

Specifying the period of analysis requires specifying the start year, programming period and funding periods. The programming period will consist of a number of funding periods (commonly 2). Funding periods are always the same length.

Slide 12



Steps 1-7 cover the "Without" scenario. These are the most involved steps because for every funding period you have to construct an excel file with data. Beginning with funding period 1, the user determines the improvement required under a worst first scenario to address deficiencies based on threshold PSRs that define the need for reconstruction and resurfacing. The initial Excel spreadsheet is structured as follows:

- Column 1 - number of improvements (1)
- Column 2, 3, and 4 – state, county and section ID
- Column 5 – year of improvement (any year in first FP)
- Column 6 – type of improvement (0 for no improvement, 1 for resurfacing, 6 for reconstruction)
- Column 6 – indicator of HERS override (1)
- Column 8, 9, and 10 – cost of improvement, number of lanes added and the capacity increase. Using 0 means HERS defaults are used.

The control variables are set as follows

- Objective as "Full Engineering Needs Analysis
- Override HERS using state-specific improvements
- Discount rate
- Length of funding period

- Number of funding periods (1)

HERS-ST is run for the first funding period.

Improvement for the 2nd funding period are then determined based on the results of the first funding period. The Excel spreadsheet is updated and structures as follows:

- Column 1 – number of improvements (2- based on two improvements for each section)
- Column 2-10 – Unchanged
- Column 11-16 –prepare using the same procedure as columns 5-10 above.

The number of funding periods is updated in the control variables and HERS-ST run.

The analysis is repeated for additional funding periods.

Slide 13

Steps 8-9 -Running the “With HERS” scenario

- Use the same network data as the “Without HERS” scenario
- Use a blank list of improvements
- Set
  - Objective as “All improvements with minimum BCR = 1”
  - Discount rate
  - Length of funding period
  - Number of funding periods (same as last run for “Without HERS”
- Run “With HERS”

The “With” scenario is simple. The same data is used and the objective set to “All improvements with minimum BCR=1”

Slide 14

Step 10 - Comparing scenarios

- Review initial cost for “with” and “without” scenarios.
  - If “with“ scenario is more, then
    - Change objective to “maximized benefit as constrained by funds”
    - Enter the funding from “without” case in control data.
    - Run HERS
  - If “without” scenario is more, then
    - Delete sections in improvement list with better PSR until budget is met.
    - Run HERS

Scenarios are compared to make sure the resources (initial costs) are consistent. If the initial costs differ then they are adjusted iteratively. If “with”scenario is more, then

- Change objective to “maximized benefit as constrained by funds”
- Enter the funding from “without” case in control data.
- Run HERS

If “without” scenario is more, then

- Delete sections in improvement list with better PSR until budget is met.
- Run HERS

Slide 15

Step 11 - Comparing results

- Use tables and charts to compare
  - Average PSR
  - Average Speed
  - Total Delay
  - Total VMT
  - Users' Benefits
  - Total Benefit

Results are compared using the performance measures as well as net present value and benefits.

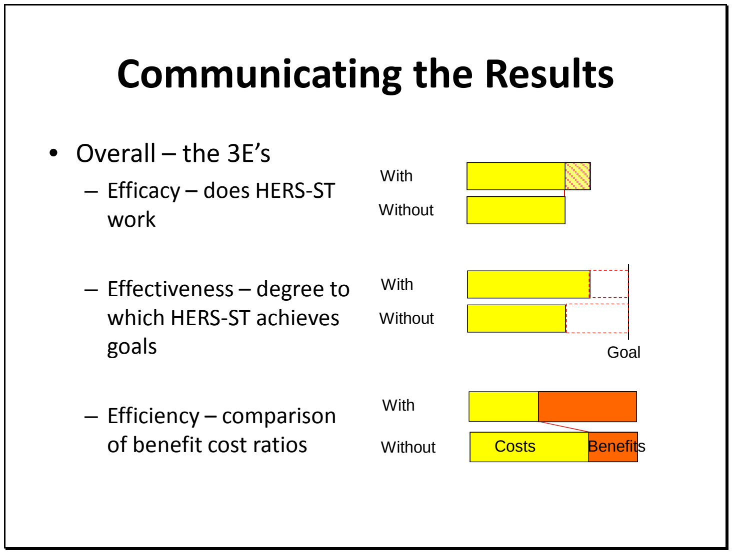
Slide 16

Step 11 - Comparing results with actual data

- Data from HPMS or any other sources can be used to compare with the “With” and “Without” scenarios

Comparisons are also made with actual conditions.

Slide 17



The results must be communicated. One strategy is to use the 3 E's – efficacy, effectiveness and efficiency.
Efficacy simply asks if the value "with" HERS exceeds the value "without"

Effectiveness asks how close each scenario is to meeting a specified goal.

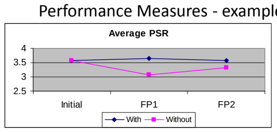
Efficiency explore the relative values of one scenario compared to another.

Slide 18

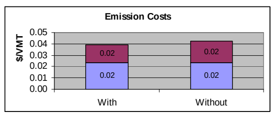
Communicating the Results

Charts and Graphs

Performance Measures - example



Costs - example

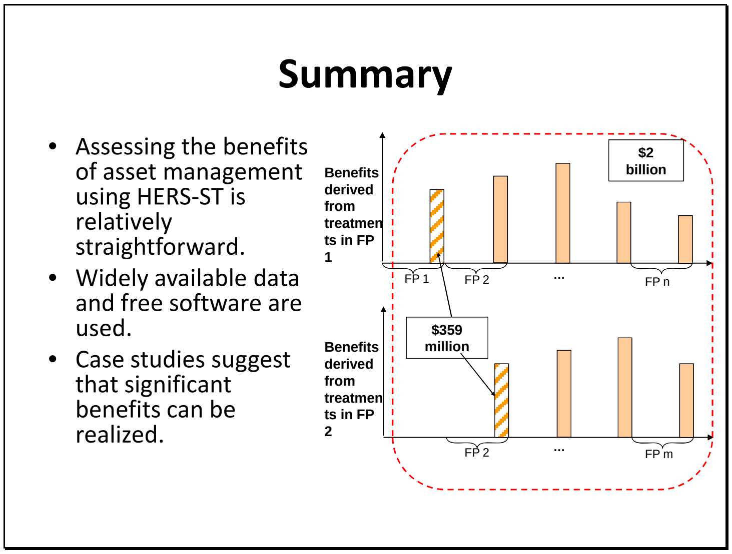


Tables

Measure	**Difference in 2010 (with versus without HERS-ST)**
Initial Costs	0.6% higher ($4million)
Average Speed	0.17 higher
Delay	0.045hrs/1000 VMT less
PSR	0.26 points higher over 10 years
VMT	8 million more
Maintenance Costs	$185/mile less
User Costs	$0.04/ VMT less
Emissions Costs	$0.003/VMT less
Total Costs	$359 million less

A variety of charts, graphs and tables can be used to summarize the results. Here are some examples.

Slide 19



Case studies demonstrate significant benefits can be achieved using asset management. This training module has demonstrated a method for assessing those benefits.

Slide 20

Resources

- HERS-ST – Highway Economic Requirements System / State Version.
  - http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm
- HPMS - Highway Performance Monitoring System
  - http://www.fhwa.dot.gov/policy/ohpi/hpms/abouthpms.cfm
- "Generic Methodology for Evaluating Net Benefit of Asset Management System Implementation," Daisuke Mizusawa and Sue McNeil, J. Infrastructure. Syst. 15, 232 (2009)
- Step by Step Manual Developed for HERS_ST as an Asset Management Tool: Assessing and Interpreting the Benefits Derived from Implementing and Using Asset Management Systems, Sekine Rahimiam and Sue McNeil, University of Delaware, 2011.

The listed resources provide access to data and software, as well as provide background for the project.

Appendix C. Detailed Results from the Kentucky Case Study

This appendix documents implemented treatments in the first and second funding period for the 'with' and 'without' cases for the Kentucky Case Study presented in Chapter 4. The results are part of the HERS-ST analysis. These numbers are disaggregated from those in Figure 36 and Figure 37.

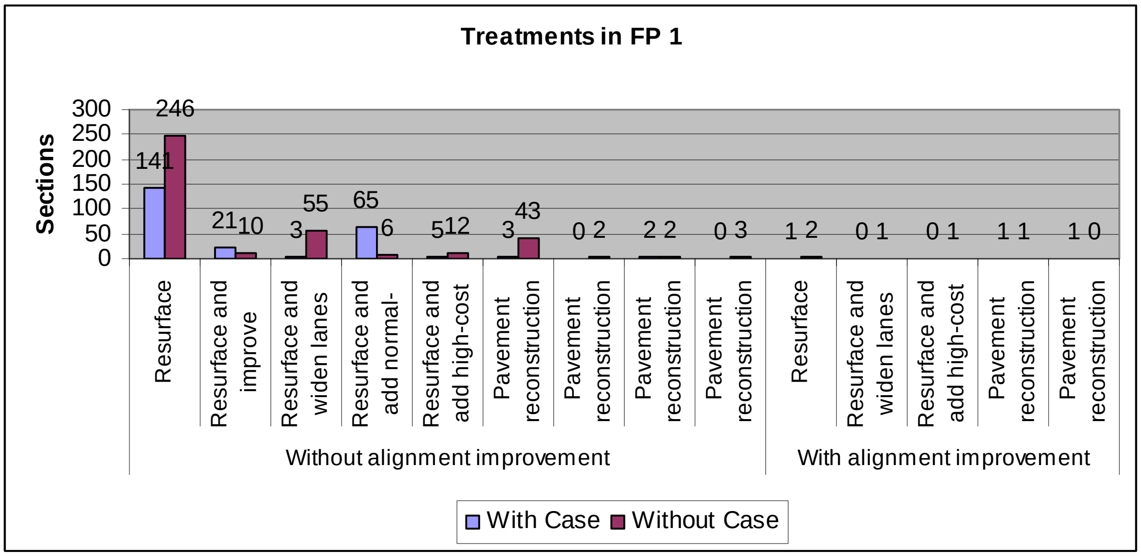


Figure 54. Treatments in First Funding Period for With and Without Cases (Number of Sections)

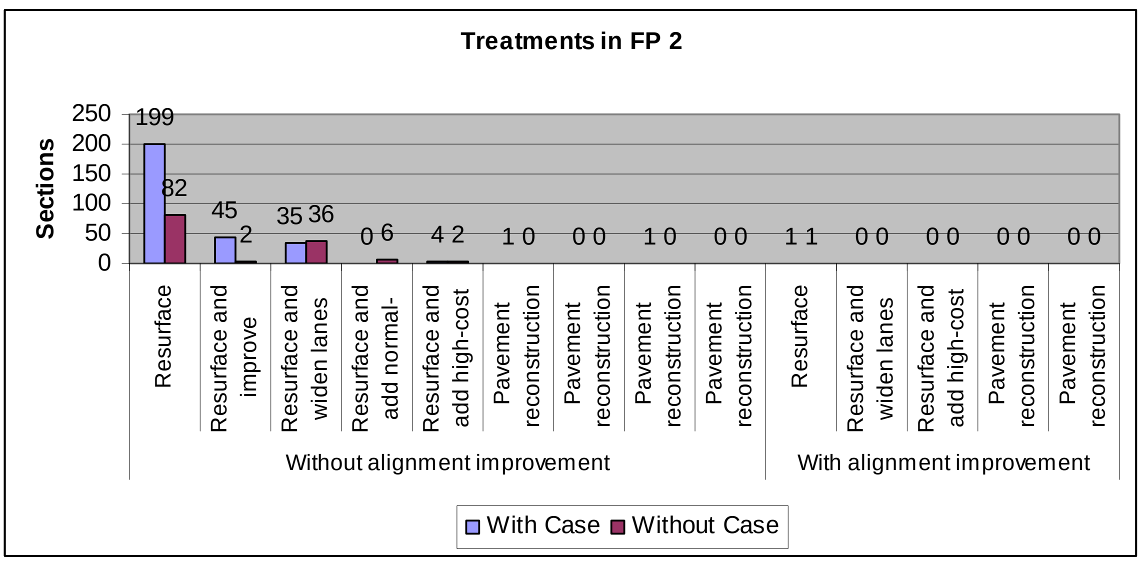


Figure 55. Treatments in Second Funding Period for With and Without Cases (Number of Sections)

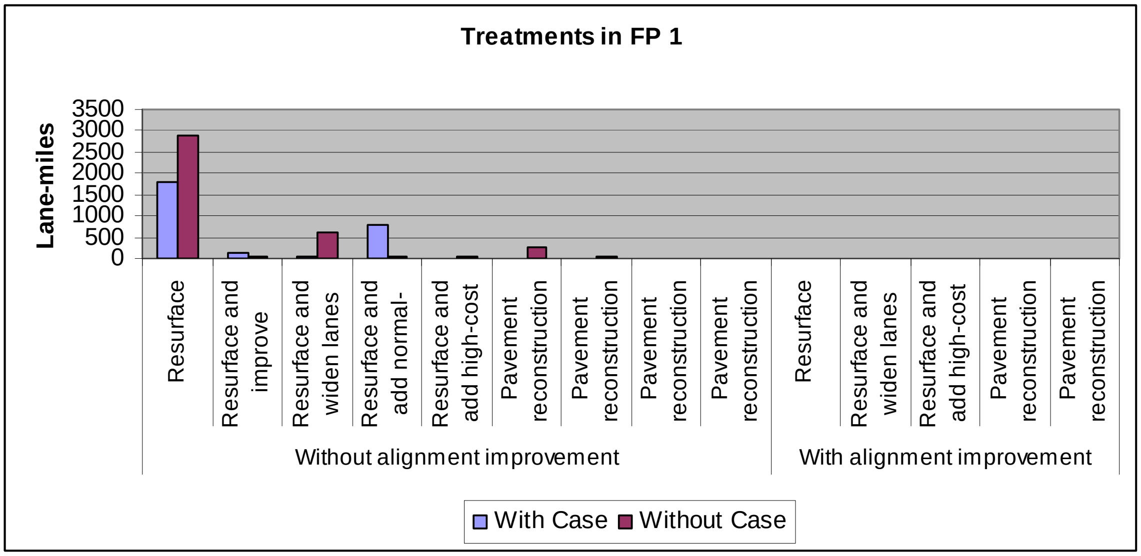


Figure 56. Treatments in First Funding Period for With and Without Cases (Lane-miles)

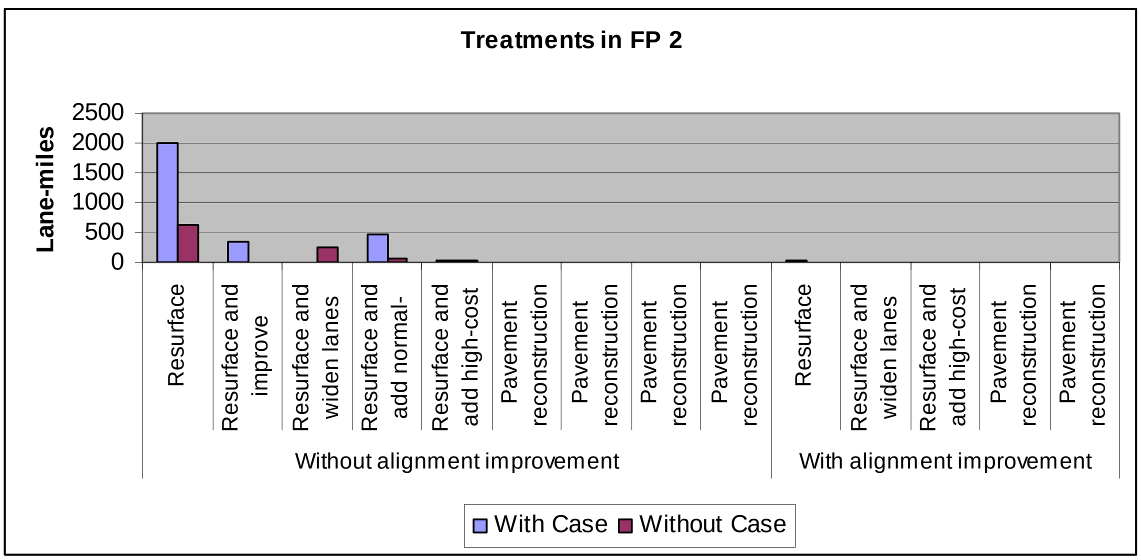


Figure 57. Treatments in Second Funding Period for With and Without Cases (Lane-miles)