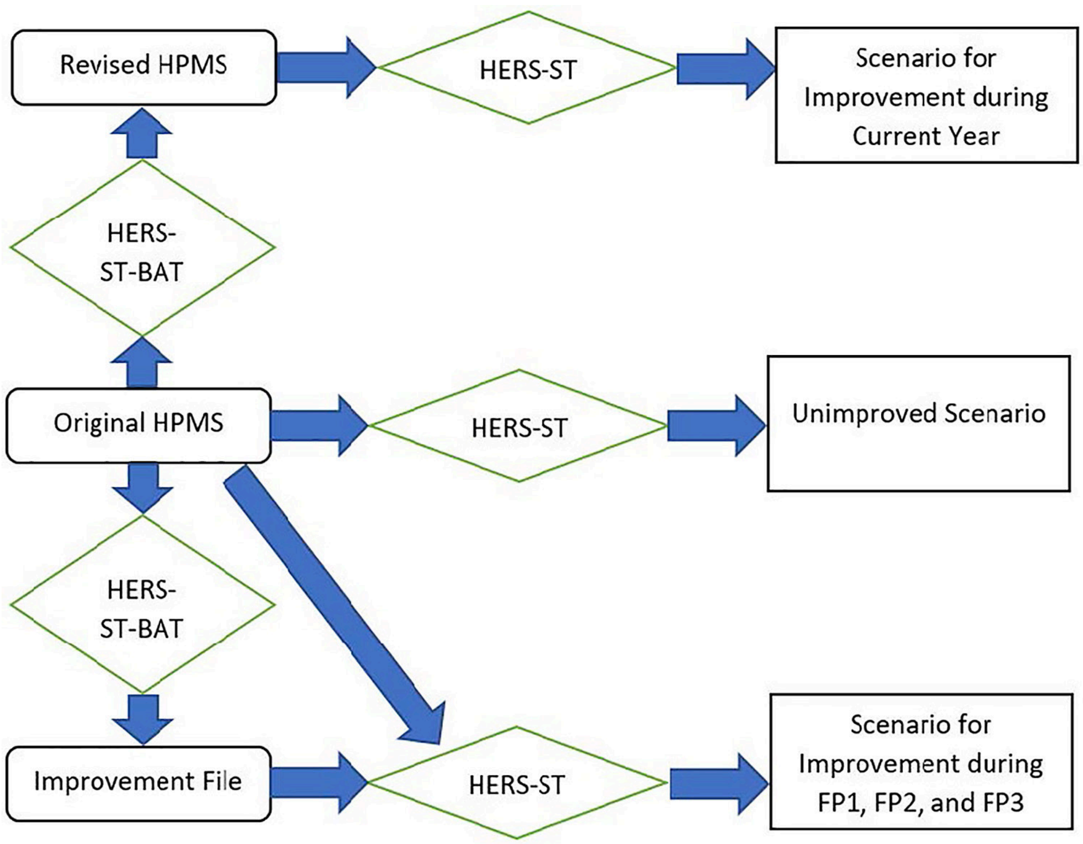
Improved Methodology for Benefit Estimation of Preservation Projects

WA-RD 877.1

Eric L. Jessup
You Zhou
Eric Lang

April 2018



Roles of Three Files in the Simulation Process

Washington State Department of Transportation
Office of Research & Library Services

WSDOT Research Report

18-04-0192

Research Report
Agreement T1462, Task10

Improved Methodology for Benefit Estimation of Preservation Projects

by

Dr. Eric L. Jessup
Associate Professor, School of Economic Sciences

You Zhou
Eric Lang
Research Assistants

Freight Policy Transportation Institute
PO Box 646210
Washington State University
Pullman, WA 99164-6210

Washington State Transportation Center (TRAC)
Washington State University
101 Sloan Hall, PO Box 642910
Pullman, Washington 99163-2910

Washington State Department of Transportation
Technical Research Monitors
Wenjuan Zhao
Doug Brodin
(360) 705-7972

Prepared for

The State of Washington
Department of Transportation
Roger Millar, Secretary

April 17, 2018

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
WA-RD 877.1		

4. Title and Subtitle	5. Report Date
IMPROVED METHODOLOGY FOR BENEFIT ESTIMATION OF PRESERVATION PROJECTS	April 17, 2018
	6. Performing Organization Code
7. Author(s) Eric L. Jessup, Associate Professor, Washington State University You Zhou, Research Assistant, Washington State University Eric Lang, Research Assistant, Washington State University	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Freight Policy Transportation Institute (FPTI) School of Economic Sciences Washington State University PO Box 646210 Pullman, WA 99164-6210	**10. Work Unit No.** **11. Contract or Grant Number** **GCB1462** **T1462-10** **14A-3025-5355**
12. Sponsoring Agency Name and Address Research Office Washington State Department of Transportation Mailstop 47372 Olympia, Washington 98504-7372 Project Manager: Doug Brodin, 360-705-7972	**13. Type of Report and Period Covered** Research Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This research report presents an improved process for evaluating the benefits and economic tradeoffs associated with a variety of highway preservation projects. It includes a summary of results from a comprehensive phone survey concerning the use and application of the software developed by the Federal Highway Administration (FHWA), known as the Highway Economic Requirement System (HERS-ST). This national survey revealed that only a few states utilize this software in evaluating highway preservation projects and revealed an existing need to bridge pavement management and economic impact analyses in the evaluation of highway preservation projects. This research project developed a supplemental software application tool within Excel to improve the HERS-ST software and enhance the capabilities of evaluating highway preservation project analyses. This software application, the HERS-ST Benefit Application Tool (HERS-ST-BAT), has been developed to enhance and improve upon the project evaluation process. By combining HERS-ST-BAT and HERS-ST, the analyst is able to provide estimates for a variety of regional-level agency and user costs associated with preservation programs and more effectively consider different investment alternatives. Three separate preservation project case studies are selected to apply the HERS-ST-BAT and detailed results presented.

17. Key Words	18. Distribution Statement
Highway preservation, economic analysis, user benefits	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	98	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Disclaimer

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

CONTENTS

EXECUTIVE SUMMARY VIII

I: BACKGROUND / PROBLEM STATEMENT 1

II: RESEARCH OBJECTIVE 4

III: LITERATURE REVIEW 6

IV: SURVEY OF STATE DEPARTMENT OF TRANSPORTATION PRESERVATION PROGRAMS 11

V: EVALUATION OF WSDOT BENEFIT ESTIMATION PROCESS 20

VI: HERS-ST BENEFIT APPLICATION TOOL 23

VII: HERS-ST BENEFIT APPLICATION TOOL: CASE STUDY APPLICATIONS 34

VIII: CONCLUSIONS AND RECOMMENDATIONS 59

REFERENCES 63

APPENDIX A: HERS-ST-BAT INSTRUCTION MANUAL 66

APPENDIX B: STATE DEPARTMENT OF TRANSPORTATION SURVEY 86

LIST OF FIGURES

Figure 1: WSDOT Process for Estimating Project Benefits and Economic Impacts 1
Figure 2: General Relationship between Rehabilitation and Pavement Deterioration 3
Figure 3: Flow Chart for the Entire Process 24
Figure 4: Roles of Three Files in the Simulation Process.. 27
Figure 5: Location of I-5 Northbound Project 37
Figure 6: Trends of Baseline and Improvement in YR0 for I-5 NB Project..................... 39
Figure 7: Trends of Baseline and Improvement across Timings for I-5 NB Project........ 41
Figure 8: Location of I-5 Southbound Project 46
Figure 9: Trends of Baseline and Improvement in YR0 for I-5 SB Project 47
Figure 10: Trends of Baseline and Improvement across Timings for I-5 SB Project....... 49
Figure 11: Location of I-90 Westbound Project 53
Figure 12: Trends of Baseline and Improvement in YR0 for I-90 W Project 54
Figure 13: Trends of Baseline and Improvement across Timings for I-90W Project....... 56

LIST OF TABLES

Table 1: Regional Pavement Preservation Partnerships 11
Table 2: Situations of Pavement Preservation Program in State DOTs............................ 13
Table 3: Parameters of Vehicle Operating and Travel Time In HERS-ST....................... 25
Table 4: Change of Cumulative Present Values of Costs from Baseline to Improvement Strategies on I-5 NB.. 44
Table 5: Change of Cumulative Present Values of Costs from Baseline to Improvement Strategies on I-5 SB 51
Table 6: Change of Cumulative Present Values of Costs from Baseline to Improvement Strategies on I-90 W 58

Executive Summary

The Washington State Department of Transportation (WSDOT) currently incorporates the investment cost associated with highway project improvements, in addition to those user and maintenance costs derived from the Highway Economic Requirements System - State Version (HERS-ST), into the REMI-TranSight model to quantify the regional economic benefits associated with transportation investment projects. The focus for the WSDOT is primarily on projects such as new road construction but can also include highway preservation and maintenance. There is a need for a systematic method to estimate the transportation benefits of highway improvement projects. This would provide necessary data inputs for an economic impact analysis process in order to accurately quantify the long-term economic benefits of highway improvement projects.

This research project evaluates and analyzes the current process for calculating pavement improvement benefits and then develops an improved approach for measuring the benefits of these highway preservation projects. In order to better understand how other state transportation departments evaluate different improvement alternatives and to gauge to what extent they utilize the HERS-ST software, a comprehensive national survey of state DOTs was conducted. The results enhanced the understanding of current practices of pavement program analysis across the country as to whether and how HERS-ST is being utilized by state transportation agencies. The survey results revealed that few states still utilize the HERS-ST software and vary widely on how they evaluate pavement projects. Increased utilization of HERS-ST and the application tool developed here has the potential to increase consistency across states and improve the benefit calculation method.

Based on the survey results, the Excel-based HERS-ST Benefit Application Tool (HERS-ST-BAT) was developed. This was created to supplement HERS-ST for benefit and cost estimation processes. It improves the existing process in three primary aspects:

1. Greater control of data inputs used by HERS-ST for simulations;
2. Ability to compare unimproved and improved scenarios at different time periods;
3. Modification of regional input parameters instead of utilizing national averages.

Combining this developed tool, HERS-ST-BAT, with HERS-ST, a transportation agency is better equipped to estimate the changes of agency and user costs from a proposed pavement project with accuracy and flexibility.

The HERS-ST-BAT is applied to three past highway projects from WSDOT and the results reported in the case studies within this report. The measurable user costs and maintenance costs are estimated and used in different scenarios. Compared with the scenario without any improvement, the scenarios with improvements at the appropriate time can reduce total costs by 0.25% to 1.09% at the county level. In addition, Hot Mix Asphalt (HMA) projects can save total costs by $6 to $35 million dollars more than Portland Cement Concrete (PCC) projects. The more specific improvements are delayed, the less total cost savings are realized.

The national survey revealed that individual states evaluate pavement projects differently and do not always utilize consistent approaches. The tool developed here, in conjunction with the HERS-ST software provides an improved method for consistent and systematic pavement project evaluation. The findings generally confirmed that early pavement improvements could significantly extend pavement life and save total costs.

The overall results in this report indicate that the improved method is applicable to various pavement improvement projects. Regional transportation agencies, especially for those without a statewide travel demand model, can incorporate this method for evaluating highway improvement decisions.

I: Background / Problem Statement

The Washington State Department of Transportation (WSDOT) currently utilizes the Federal Highway Administration (FHWA)-developed Highway Economic Requirements System, State Version (HERS-ST) model to quantify the benefits associated with new construction projects, as well as existing road preservation and maintenance projects. The benefits from improvements associated with projects (reduced travel times, lower vehicle operating costs, fewer automobile accidents, reduced emissions, etc.) are then incorporated into the Computable General Equilibrium modeling system developed by REMI-TranSight to quantify broader regional economic impacts in state and local economies. Figure 1 illustrates this procedure.

The existing research on estimating highway projects' economic benefits is not explicitly focused on estimating the benefits of pavement improvement projects; yet such projects do extend the use and longevity of existing infrastructure. This translates into tangible benefits

Figure 1: WSDOT Process for Estimating Project Benefits and Economic Impacts

associated with long-run infrastructure cost savings, like reductions in vehicle operating costs. Since many small-scale pavement improvement projects fail to yield measurable reductions in travel time or other benefits, they are often prioritized below new infrastructure construction, thus placing pavement-related improvements at a disadvantage and ultimately resulting in dilapidated highway and bridge infrastructure. This further illustrates the need to have tools available to WSDOT for communicating why investment in maintenance and rehabilitation should be a priority in today's fiscally-constrained environment.

Traditional methods for estimating the benefits of transportation projects, such as HERS-ST, input-output, or computable general equilibrium models, rely on an expected change in travel time (generally a reduction) that can be estimated or modeled. Pavement improvement projects, such as placing new concrete or asphalt pavement, are critical to maintaining roadway infrastructure, especially for the movement of freight and other heavy vehicles. However, these types of projects often do not provide significant travel time reduction, as the most efficient improvement occurs at a point long before roads become completely unusable and even before there is an appreciable decline in performance. As a result, they are often not prioritized according to the traditional benefit-cost comparison. Figure 2 depicts this general relationship and illustrates how infrastructure performance and longevity are extended through timely rehabilitation. Pavement maintenance often significantly extends capital asset longevity (highways and bridges) and can dramatically reduce future budget expenditures by addressing infrastructure needs early on, prior to the time horizon when the rate of declining deterioration is accelerated due to the absence of maintenance. This limitation in economic benefit calculation of roadway pavement

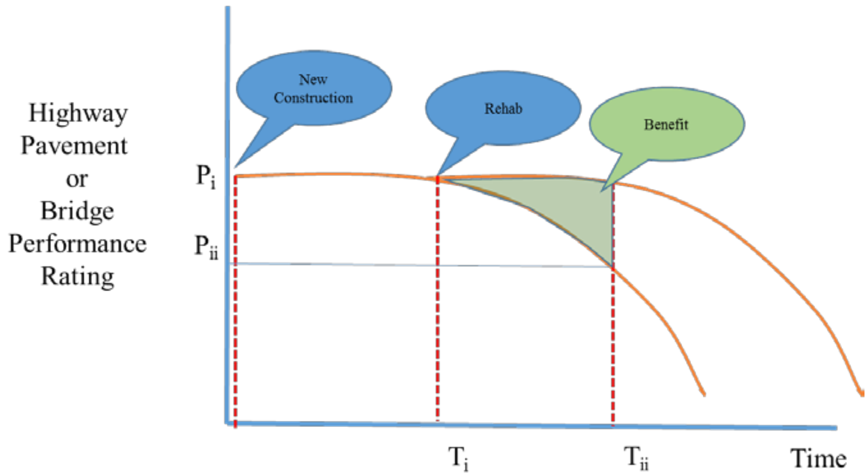


Figure 2: General Relationship between Rehabilitation and Pavement Deterioration

improvement projects makes it both difficult to estimate and communicate the economic benefit of these types of investments.

The results of this research will provide WSDOT with several benefits, including:

1. Develop and deliver an improved process for evaluating the transportation benefits of pavement improvement projects,

2. Provide improved model inputs for WSDOT economic impact analysis work to assess the broader economic impacts of highway improvement, and

3. Create a tool for WSDOT to easily update HERS-ST model parameters and customize the model to Washington-specific data.

II: Research Objective

There are two major objectives of this research project: (1) to evaluate and analyze the current process for calculating highway improvement project costs and benefits, and (2) to develop an improved method for measuring the costs and benefits of such projects. This research and the subsequently developed benefit application tool is applicable to infrastructure supporting both passenger and freight vehicles.

The first objective is accomplished through a comprehensive literature review and national survey of all 50 state department of transportation (DOT) agencies in the United States. The literature review provides details and background on major pavement types and treatments and available evaluation methods. This review builds the foundation with which to assess the procedure that WSDOT currently utilizes in practice and compare it to the developed method.

The national survey compares different approaches and tools employed by each state DOT and aids in compiling a detailed assessment of the strengths, weaknesses, and limitations of the current processes. Particular interest is focused on whether or not and how state DOT departments are using the HERS-ST model. Such information is important for developing improved tools and overcoming current weaknesses to improve states' utilization and the applicability of the HERS-ST modeling software.

Based on the analyses of both the literature and the national survey, the research team developed an improved method for measuring the costs and benefits of highway pavement projects. This supplemental tool to the HERS-ST model features an improved estimation procedure for WSDOT's current method of project evaluation. The added flexibility in terms of input variables is the major improvement made within the HERS-ST supplement, as it allows for different scenarios of project timing or treatment types to be evaluated. This supplemented method of using HERS-ST is both consistent and systematic so that other state DOTs can adopt it with ease.

The HERS-ST-BAT developed in this study is applied here to three past pavement projects from WSDOT as case studies. The application results illustrate the improved estimation capability with the supplemental tool and allow more rigorous, flexible comparisons across different investment alternatives.

III: Literature Review

Once highway pavement is constructed, it starts to deteriorate over time, mainly due to traffic and environmental factors. If some appropriate strategies are implemented at the right time, however, they can slow down the deterioration and extend the pavement service life. In this section, several major strategies, as well as current methods of project evaluation, are discussed.

Pavement Type Selection

The 18,500 lane-mile mainline pavement in Washington can be basically categorized into two types: flexible and rigid (WSDOT, 2007). Flexible pavement is surfaced with either Bituminous Surface Treatment (also called chip seal) or Hot Mix Asphalt (HMA). Chip seal only lasts 6 to 8 years and usually applies to low traffic volume roadways with less than 5000 vehicles per day. HMA is a high-quality pavement type and more durable than chip seal. On average, HMA pavement in western Washington has a 17-year life (WSDOT, 2016a). However, the pavement life decreases to 12 years in eastern Washington. The rigid pavement type only refers to Portland Cement Concrete (PCC) at WSDOT, which is typically designed to last 30 to 50 years. The average unit price of PCC is two times higher than HMA (WSDOT, 2016c). In this report, the pavement type is selected between HMA and PCC.

Washington highways are mainly paved with asphalt. It accounts for 55% of total lane miles and 66% of total vehicle miles traveled (VMT), while the percentages for concrete are only 13% and 28%, respectively (WSDOT, 2016b). The performance of this pavement is monitored by the Washington State Pavement Management System (WSPMS).

Typically, the data required by the WSPMS is gathered by performing a pavement condition survey, which would evaluate roughness, rutting, faulting, and other distress (Uhlmeyer, Luhr, and Rydholm, 2016).

The International Roughness Index (IRI) was developed to measure the roadway smoothness. It ranges from 0 to 999, in the unit of inches per mile (FHWA, 2005). A lower number indicates smoother pavement. In WSDOT's IRI categories, a value below 170 suggests a roadway in good condition and a value above 220 represents a roadway in poor condition (WSDOT, 2016d). Overall, 91% of Washington's highways are in good condition. WSDOT has used IRI to either ensure the quality of construction or determine a need for rehabilitation. This report measures pavement condition with IRI.

Treatment Type Selection

Various treatments can generally be classified into three groups: preservation, rehabilitation, and reconstruction (White, 2012). The preservation design aims to improve or sustain the pavement condition but does not add capacity or structural value. If a preservation program applies the right treatment to the right place at the right time, it can delay the need for rehabilitation and reconstruction, for which the unit costs are substantially higher (Sims, 2005). When pavement performance has been poor, preservation is less cost-effective and the other two strategies are required to restore roads.

Pavement rehabilitation uses the existing pavement structure. It extends pavement service life and/or increases roadway capacity by adding or replacing pavement materials. Overlay is a common rehabilitation method, which lays either HMA or PCC over the remaining structure of the existing pavement (WSDOT, 2015). In contrast, the reconstruction method completely removes and replaces the existing pavement structure with the new one. Given that it is a complete replacement, the unit construction cost of reconstruction for asphalt pavement is high and typically three times more than that of rehabilitation (Luhr and Rydholm, 2015). In this report, the analysis focuses on overlay and reconstruction treatments.

Current Methods of Pavement Project Evaluation

There are several methods for pavement project evaluation. Life-Cycle Cost Analysis (LCCA) is commonly used in this context. LCCA for highway assets is a process that evaluates the total economic value of the initial treatment cost in addition to the discounted future costs of maintenance and rehabilitation associated with the assets (Li, 2006). The three life-cycle cost components are defined as agency costs, user costs, and external costs (Wilde et al., 1999).

Agency costs include all costs incurred directly by the agency over the life of the project, which includes expenditures for preliminary engineering; contract administration; construction (including construction supervision); and all future maintenance, resurfacing, and rehabilitation (Hicks, 1999).

User costs include those costs incurred by highway users during the period of the project. These costs include vehicle operating costs, user delay costs, travel time costs, and accident unit cost. Hall (2003) brings out a key issue while adopting rehabilitation strategies; vehicle operating and user delay costs in relation to lane drop time and length play a significant role in analysis when comparing the life-cycle cost of a preservation treatment with rehabilitation. External costs are focused on the unit effect of vehicle operation on the environment, such as vehicle air emission unit costs. These costs are typically estimated either by way of damage costs or control costs.

Once all costs and their expenditure period have been determined, the future costs will be discounted back to the start year and then added to the initial investment. LCCA results should be subjected to sensitivity analysis to determine the influence of major input variables (Hicks, 1999).

Given the uncertainty of future costs, some research may need to incorporate a probabilistic approach to analysis. Setunge et al. (2002) developed a methodology for all LCCA of alternative rehabilitation treatments for bridge structures. This methodology utilized a Monte Carlo simulation to combine a number of probability distributions in order to establish the distribution of whole life-cycle cost for a bridge structure.

There are many agency benefits that accrue from pavement projects. Starting maintenance earlier can create a domino effect of benefits (AASHTO, 2003). From a financial perspective, early maintenance extends the life of the pavement and reduces the life-cycle cost. The extension in service life and the projected cost savings gained from pavement projects arises in a number of highway agency reports. The Michigan DOT (MDOT) has saved $700 million over a five-year period and California's experience proved that pavement improvements would delay the future need for a costly restoration (Smith, Hoerner, & Peshkin, 2008).

Road condition improvements also result in user benefits, which include higher customer satisfaction, user cost reduction, and increased safety. Most preventive maintenance treatments are less time-consuming. These faster repairs could result in less congestion and lower travelers' costs. Both nationwide surveys of customer satisfaction with the highway system, as well as many state-sponsored surveys (e.g. Washington, California, and Arizona), show that the public is interested in pavement conditions and in seeing those conditions improved (Coopers and Lybrand, 1996; Dye Management Group, 1996; Survey Research Center, 1999; Dye Management Group, 1998).

Li (2006) discussed the calculation of user benefits by identifying consumer surplus: provided with a demand curve, the consumer surplus is the difference between what road users in the aggregate would have been willing to pay and what they are actually asked to pay. The difference may be interpreted as the user benefit associated with the project.

In addition to LCCA, pavement performance modeling is also critical to pavement management. The objective of monitoring pavement performance is to objectively determine the current condition of pavements and then use historical trends to develop a management plan (Lytton, 1987). Pavement performance prediction influences the quality of other components of pavement management such as rehabilitation years, types of treatment, and the selection of cost-effective maintenance alternatives (Li, Xie, and Haas, 1996).

IV: Survey of State Department of Transportation Preservation Programs

Survey Design

In order to more fully understand those approaches and techniques that other state DOTs are currently utilizing to evaluate the benefits and costs of highway and bridge preservation projects, all 50 state DOTs within the United States were surveyed.

For simplicity and standardization purposes, the 50 states below are divided into 4 regions according to the National Center for Pavement Preservation (NCPP) regional pavement preservation partnerships. Table 1 shows these regions.

The WSU research team developed a questionnaire (see Appendix B) directed to all the related engineers and economists. The results of this questionnaire provided detailed information regarding their current practice for pavement preservation and rehabilitation.

Table 1: Regional Pavement Preservation Partnerships

Midwestern	*South-eastern*		*Rocky Mountain West*		*North-eastern*
Illinois	Alabama	Virginia	Alaska	Wyoming	Connecticut
Indiana	Arkansas	West Virginia	Arizona		Delaware
Iowa	Florida		California		Maine
Kansas	Georgia		Colorado		Massachusetts
Michigan	Kentucky		Hawaii		Maryland
Minnesota	Louisiana		Idaho		New Hampshire
Missouri	Mississippi		Montana		New Jersey
Nebraska	North Carolina		Nevada		New York
North Dakota	Oklahoma		New Mexico		Pennsylvania
Ohio	South Carolina		Oregon		Rhode Island
South Dakota	Tennessee		Utah		Vermont
Wisconsin	Texas		Washington		

Source: National Center for Pavement Preservation

The survey was divided into two parts. The first part included general questions about the pavement preservation program in each state. Some of the basic information obtained included the existence of the program, the age of the program, and how each state evaluates preservation versus new construction projects.

Although FHWA formally divides pavement preservation into three main categories; routine maintenance, minor rehabilitation, and preventive maintenance, each state DOT indicated that they have their own definition of the term “pavement preservation” according to the responses from our survey. To ensure that every state was compared on the same basis, the term was clarified before each state DOT responded to the survey.

The survey also requested each respondent provide a description of the current pavement preservation estimation process. Respondents were asked to provide the methods they used for deciding when and how to apply preservation to existing pavement, the method for quantifying benefits and costs, and the software used.

The second part of the survey mainly focused on the HERS-ST software and its utilization. This included a set of questions regarding whether the state was currently utilizing this system, if it was used on its own or in conjunction with other software systems, the ease of use for the current users of the software, and (if applicable) the reason for not utilizing it.

These survey questions were reviewed by the technical advisory committee at WSDOT before they were delivered to other state DOTs. The survey was completed by respondents from state DOTs with various backgrounds and technical specialties including pavement engineers, design/civil construction engineers, and economists.

Survey Results

This section presents a detailed analysis of different DOTs' current state of practice in the U.S. The survey response rate was 100%, meaning all 50 state DOTs responded.

General Information

Based on the survey results, most state DOTs (94%) claim to have a pavement preservation program in place. Only three state DOTs (Arkansas, Ohio, and West Virginia) mentioned that there is no such program in existence for their state.

The upper panel of Table 2 summarizes the results of pavement preservation programs' existence. According to the previously identified regions, all states from the Rocky Mountain West and Northeast regions have a program in place. Two states from the Southeast region (Arkansas and West Virginia) and Ohio from the Midwest region claim

Table 2: Situations of Pavement Preservation Program in State DOTs

	Midwest	Rocky Mountain West	Southeast	Northeast
Program Existence				
Yes	IN,MN,MI, MO,KS,ND, NE,IA,IL,SD, WI	AK,AZ,CO,NM,ID, NV,MT,UT,CA,OR, WY,WA	AL,FL,GA,KY,LA, MS,NC,OK,SC,TN, TX,VA	CT,DE,MA,MD ,NH,NJ,NY,PA, RI,ME,DC
No	OH	-	AR, WV	-
Program Age				
1-10 years	IL,MO,MN, ID,ND,SD,WI	AK,NV,WY	AL,MS,VA,GA,TX, OK	MD,PA,NY,DE, MA,NH,CT
10-20 years	IN,NE	AZ,CO,MT,OR,ID	KY,NC,SC,TN	NJ,RI
>20 years	KS,MI	CA,UT,NM, WA	FL,LA	ME,DC

they don't have a formal program for pavement preservation. These results coincide with the information obtained from the FHWA technical appraisal system, that all Western region states have a pavement preservation program in place, while around two-thirds of state DOTs from the Rocky Mountain and Midwest regions have a formal program. The Southeast and Northeast regions have the fewest number of states with a formal pavement preservation program in place.

All respondents were also asked how long their pavement preservation program has been in effect. Of the states that have a pavement preservation program in place, Kansas, Maine, and Michigan have the longest standing programs, all claiming that their pavement preservation program has been in place for more than 30 years. Alabama reported the shortest existence of such program, responding that theirs has only been in effect for 5 years. As the lower panel of Table 2 shows, of the 46 states that have a pavement preservation program, 50% of states report that their pavement program age is between 1 to 10 years, 28% for 10 to 20 years, and 22% for more than 20 years.

Estimation Methods

According to the FHWA, there are four criteria that form the basis of how benefits of pavement preservation are quantified: an extension in pavement life, the pavement's performance, costs involved in applying preventive maintenance treatments, and cost-effectiveness.

According to the survey results, the majority of state DOTs do not track or quantify the benefits of pavement preservation. The most common factors in pavement preservation are the available budget and existing pavement condition. In some cases, Life-Cycle Cost

Analysis (LCCA) was adopted by the DOTs. States such as Michigan and Minnesota from the Midwest, Colorado and New Mexico from the Rocky Mountain region, Maryland and Pennsylvania from Northeast, and Florida and Virginia from Southeast all claimed usage of LCCA. According to the FHWA, "LCCA is an engineering economic analysis tool that allows transportation officials to quantify the differential costs of alternative investment options for a given project" (FHWA, 2005). LCCA is used not only to analyze the economic viability of new construction projects, but also to examine preservation strategies for current projects. A brief summary of the methods to quantify benefits is listed below:

1. Highway Health Index: An index ranging from 0 to 100, with 0 indicating the worst condition for the pavement and 100 the best. Louisiana utilizes this index to decide whether and how to apply pavement preservation activities.

2. Annualized Cost method: Uniform Equivalent Annual Costs represent the annual equivalence of all costs converted to either present or future value, which is used to compare investment in pavement preservation versus rehabilitation options. New Mexico and Florida mentioned the application of this method.

3. Forecasting system: Michigan uses a Road Quality Forecasting System (RQFS) to calculate the benefit of pavement preservation activities.

4. Asset Management software: Maine, Arkansas, and Indiana use dTIMS software to calculate the benefit of improved pavement conditions. Arizona utilizes FHES for a similar purpose. Delaware uses the AgileAssets module for benefit-cost analysis of all maintenance and rehabilitation work. California uses a Pavement Management System Database called "PaveM."

Utilization of HERS-ST

The majority of state DOTs are not using the HERS-ST software. The survey showed that half of these states are either unaware of this software or do not have the necessary resources to manage it. In addition, other issues such as necessary data inaccessibility and time-consuming simulation processes are also hurdles for the utilization of HERS-ST.

Some states did report previously using HERS-ST, but they no longer utilize it. For example, Indiana Department of Transportation (INDOT) pioneered the use of HERS for state-level planning starting in 1998 for needs assessment, project prioritization, and system performance analysis in the production of the state's long-range transportation and 10-year construction plans. HERS-IN was used in conjunction with the Indiana Statewide Travel Demand Model (ISTDM), which was used to forecast future traffic growth and identify any capacity needs. However, INDOT shifted away from project-specific planning, and subsequently, an executive decision was made to not run HERS-IN. The output was deemed unnecessary to reach appropriate decisions relative to the department's construction program because of this shift away from project-specific planning, which made it difficult to justify the resources being diverted to maintain the model and led to the database becoming outdated.

The survey results indicate that only four states (Washington, Oregon, Kentucky, and Iowa) are currently active users of the HERS-ST software.

WSDOT is a new HERS-ST user. WSDOT started its implementation of pavement management in the late 1960s. In 2015, it purchased the REMI-TranSight model to conduct its economic impact analysis for a variety of transportation investment projects, such as mobility and preservation projects. Since a statewide travel demand model is unavailable to WSDOT, the HERS-ST model was adopted as a complement to the TranSight model. In particular, WSDOT uses HERS-ST to simulate an improvement to a certain highway section and obtain changes to travel time and operating costs. These changes are then incorporated into the TranSight model to quantify the economic impact of the highway project on the state and local economy.

The Oregon Department of Transportation (ODOT) has been the most active HERS-ST user since 1999. Initially, they concentrated on investigating congestion issues and user costs. As they became more familiar with the software, ODOT was able to customize HERS-ST to fit many different levels of analysis, from statewide corridor planning to local road bottleneck identification. Currently, ODOT's research related to safety evaluation, operations analysis, and reliability analysis is conducted with HERS-ST. Given the substantial benefits from HERS-ST in previous projects, ODOT has expressed its continued interest in this software.

The Kentucky Transportation Cabinet (KYTC) is also currently utilizing HERS-ST for estimating the value of pavement preservation activities. However, they only use the software as a supplement and do not believe the HERS-ST software does an adequate job for a number of reasons. First, there are some limitations in the input data; it is only available at a county/state level whereas they would prefer some data at a zip code level. Second, KYTC does not fully trust the outcome of this system as the software operates as a black box, so it does not allow the user to fully monitor the estimation process. Third, the simulation is time-consuming. The KYTC reported more than ten thousand projects statewide and HERS-ST was not fast enough to complete estimations for all potential projects. Lastly, they do not have the necessary resources to manage this software. The use of the data requires a person with both sufficient economics skills and pavement management knowledge, and they do not have the time or funds to hire individuals with this background. Either the pavement management engineers do not quite understand the economics, or the economist does not adequately understand pavement management.

The Iowa Department of Transportation (IDOT) is another active user of the HERS-ST system. The office of Systems Planning reported currently applying the software's analysis to various long-range transportation planning projects, such as the IDOT State Long Range Transportation Plan known as Iowa-In-Motion. Their long-term goal is to also use HERS-ST as an input to support updating the Iowa Road Use Tax Fund (RUTF) Study to determine roadway needs. The RUTF Study is mandated by Iowa statute to be updated every five years and was recently updated in December 2016. Similar to WSDOT, the IDOT does have licenses of the PL+ and TranSight models from REMI and has used them to perform a macro-level economic analysis to determine the cost and benefit impacts of travel demand associated with significant statewide projects in Iowa.

Survey Implications

The survey results imply that there is a need to develop a more systematic and consistent method to quantify the benefits of preservation projects. Though not widely used in pavement projects, the findings indicate that HERS-ST has the potential for such application. In addition, for those states without statewide travel demand models, HERS-ST is a free software to develop transportation benefits.

It is problematic to make the improvement decision based solely on budget availability or pavement condition since the optimal timing could be easily missed. For most transportation agencies quantifying preservation benefits, the decision of implementing such a treatment depends solely on agency cost. To minimize such cost is usually the objective of pavement management. However, this does not fully capture other benefits, such as the benefit of travel time and accident reductions. While some might argue that the immediate reduction of travel time from a pavement improvement project should be negligible, it is limited to focus only on the contemporaneous effect.

V: Evaluation of WSDOT Benefit Estimation Process

Two separate groups within WSDOT, the pavement management group and the economic analysis group, have need to estimate pavement project benefits. Both groups have their own methods which allow them to develop results which meet their particular needs.

The pavement management analysis group's benefit evaluation method concentrates on LCCA. It calculates the agency cost, excluding some unneglectable cost types such as travel time costs, vehicle operating costs, accident costs, and emissions costs. The only user cost included in the pavement management analysis is the user delay cost during the construction period. The pavement group has performed LCCA for all large projects like reconstruction, but not necessarily a small-scale preservation or rehabilitation project. In addition, such analysis focuses only on the improved highway segment and does not show regional estimates for state and local planners.

The WSDOT economic analysis team currently incorporates the estimated change in benefits from improvements run in HERS-ST into the REMI-TranSight model. This is the process to quantify the regional economic benefits associated with a variety of transportation projects, like new road construction and preservation projects. This analysis also covers more comprehensive types of benefits from transportation investments. The survey results indicate that this process has the potential to be developed as a systematic and consistent method for preservation project benefit estimation. Currently, the WSDOT economic analysis team is focused on completing this process for the Connecting Washington capital projects.

There are several ways that these processes could be improved upon to aid in future estimation techniques. First, pavement and treatment type selections, which are integral components in the analysis of pavement management, are completely absent in the economic analysis process. These two selections largely determine the pavement condition after implementing a pavement project and omitting either can result in less accurate estimates. Since there is no such functionality within HERS-ST to address pavement and treatment types for estimations in the first year of analysis, necessary inputs incorporating pavement and treatment type selections have to be prepared before loading the data into HERS-ST.

Second, any user cost improvements might not be measurable immediately after an improvement or project is completed. In this case, it is meaningful to compare the improved and unimproved scenarios over a longer period of time. If roadway deteriorations are not remedied, the difference of user costs between improved and unimproved scenarios could be much larger as time goes on, which is not taken into account in the current HERS-ST software. In addition, due to budget constraints, the necessary funding for a pavement project might not be available during the initial or current period. Therefore, it would be desirable to broaden the analysis to account for timing variations for project improvements. While HERS-ST does offer this flexibility for its users, additional data files are required, which presents a usage barrier for those who are not intimately familiar with the software.

Third, the HERS-ST system utilizes nationally-averaged parameters for estimation. Given that many pavement improvement projects are only for less than ten-mile roadway sections, having the ability to modify parameters to the local, state, or regional level can greatly benefit the accuracy of cost estimates from HERS-ST. This would be done for both the base case and improvement scenarios.

Fourth, economic impact analysis requires inputs such as changes in transportation costs due to transportation investments in order to produce accurate results on regional economic indicators like changes in employment and income. The HERS-ST software could provide some simple summaries on cost changes to feed into economic impact analysis. An in-depth cost analysis and comparison with data summaries such as tables and graphs would be more insightful and aid in the interpretation of estimation results.

All of the above needs became the focus for the improved benefit application tool.

VI: HERS-ST Benefit Application Tool

This research project improves upon the HERS-ST software system to estimate various costs and benefits of potential overlay and reconstruction projects. In order to run the HERS-ST model, the Highway Performance Monitoring System (HPMS) dataset is required as an input. With the highway information contained in the HPMS dataset, HERS-ST can perform the cost analysis and provide an estimate of various agency and user costs for each section of highway. However, the HERS-ST users might encounter difficulties in preparing the necessary data inputs (HPMS file with project information) since they must locate the highway section to be improved in the dataset, know what data must be modified, and how to make the modifications. In addition, the nationally averaged parameters that HERS-ST adopts are often insufficiently accurate for a region-specific project. To solve these issues, an Excel module, called as the HERS-ST Benefit Application Tool (HERS-ST-BAT) was created to supplement HERS-ST for benefit estimation processes. It allows for greater control and modification of input variables to run HERS-ST for a variety of roadway improvement scenarios and compares/contrasts simulation outputs from the HERS-ST estimation.

The general flow process for the HERS-ST-BAT is provided below in Figure 3. The user first imports the original HPMS data into HERS-ST-BAT. Once the user has provided the additional detailed information, the HERS-ST-BAT prepares necessary input data for a highway project and exports that into HERS-ST. The HERS-ST system can then run simulations and export the results. Ultimately, the user must review and summarize results

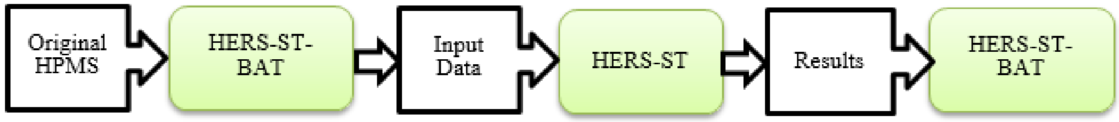


Figure 3: Flow Chart for the Entire Process

in HERS-ST-BAT. Appendix A provides the step-by-step instruction manual in order to utilize this tool.

There are three functional sections in HERS-ST-BAT: (1) economic parameter adjustment, (2) HERS-ST input preparation, and (3) HERS-ST output summary.

Economic Parameter Adjustment

Once the user has access to the relevant economic parameters and the highway performance information, HERS-ST can estimate various user costs such as travel time costs, vehicle operating costs, safety costs, and emission costs. The HERS-ST uses national averages for most parameters. However, in order to obtain more accurate estimates, state or area specific parameters are recommended. Table 3 provides an example to illustrate how these parameters can be adjusted; it includes the parameters of vehicle operating and travel time costs, by vehicle types. The parameters are modified to reflect the situation in Washington State in 2015 as accurately as possible.

The Washington State Department of Revenue provides historical data for motor vehicle fuel tax rates (WADOR, 2017). Currently, Washington State has the same tax rates for gasoline and diesel. In August 2015, the state increased its state fuel tax rate from \$0.375/gallon to \$0.445/gallon. The value shown in each column of the first row of Table

Table 3: Parameters of Vehicle Operating and Travel Time In HERS-ST

Costs	Small Auto	Large Auto	Pickup/ Vans	6-Tire Trucks	3-Axle SU Truck	3-Axle CB Truck	5-Axle CB Truck
Vehicle Operating							
State Fuel Tax ($/gal)	0.410	0.410	0.410	0.410	0.410	0.410	0.410
Fuel ($/gal)	2.222	2.222	2.222	2.222	2.161	2.161	2.161
Business Travel							
Value per Person ($/hr)	20	20	20	20	20	33.93	33.93
Personal Travel							
Value per Person ($/hr)	15	15	15	15	26	N/A	N/A

3 is the average of these two rates. This tax rate isn't the current rate (2018), but that was applicable for FY 2016. Meanwhile, the federal fuel tax has been kept at $0.184/gallon for gasoline and $0.244/gallon for diesel during the entire year.

There are two values for fuel price in the second row of Table 3: one for gasoline and one for diesel. Both are in terms of dollars per gallon and have excluded federal and state fuel taxes. The value for gasoline price was derived by subtracting total fuel tax from the average retail gasoline price ($2.816/gallon) in Seattle in 2015. It applies to small and large automobiles, pickup/vans, and 6-tire trucks. Similarly, the diesel price value was obtained from the difference between total fuel tax and the average diesel retail price ($2.755/gallon) on the western coast (excluding California) in 2015 and applies to 3-axle single unit trucks and 3/5-axle combination trucks. Both gasoline and diesel retail price data were obtained from the U.S. Energy Information Administration (EIA, 2017). The fuel prices and taxes were used to estimate vehicle operating costs.

The HERS-ST software distinguishes between highway travel for business and personal purposes. The recommended values of travel time for these purposes can be found in the WSDOT Pavement Policy (2015). The unit is dollars per hour. HERS-ST assumes that no combination trucks can be operated for personal travel, so there are no figures in the last two columns of the last row in Table 3. These values of travel time were used to estimate travel time costs.

Table 3 is just an example illustrating the parameters that are directly related to vehicle operating and travel time costs. A complete list of editable parameters can be found in the HERS-ST Technical Report. Moreover, only those parameters whose data is immediately available are selected and updated in this example. If the resources of time, labor, and data are available, all parameters could be updated for the most accurate estimation results.

HERS-ST Input Preparation

The analysis for various scenarios requires three types of files: original HPMS file, revised HPMS file, and improvement file. The unimproved scenario only needs the original HPMS file. The revised HPMS file works for the scenario that an improvement occurs during the first year of the analysis. For those scenarios where the improvement is implemented after the first year, both the original HPMS file and improvement file are needed. The role of each file in the process of input preparation and simulating different scenarios is depicted in Figure 4. The discussion below details the functionalities of these files.

Original HPMS File

The original HPMS file is the HPMS data file directly obtained from WSDOT. It reflects the current-year highway conditions calibrated for the HERS model run. Throughout this report,

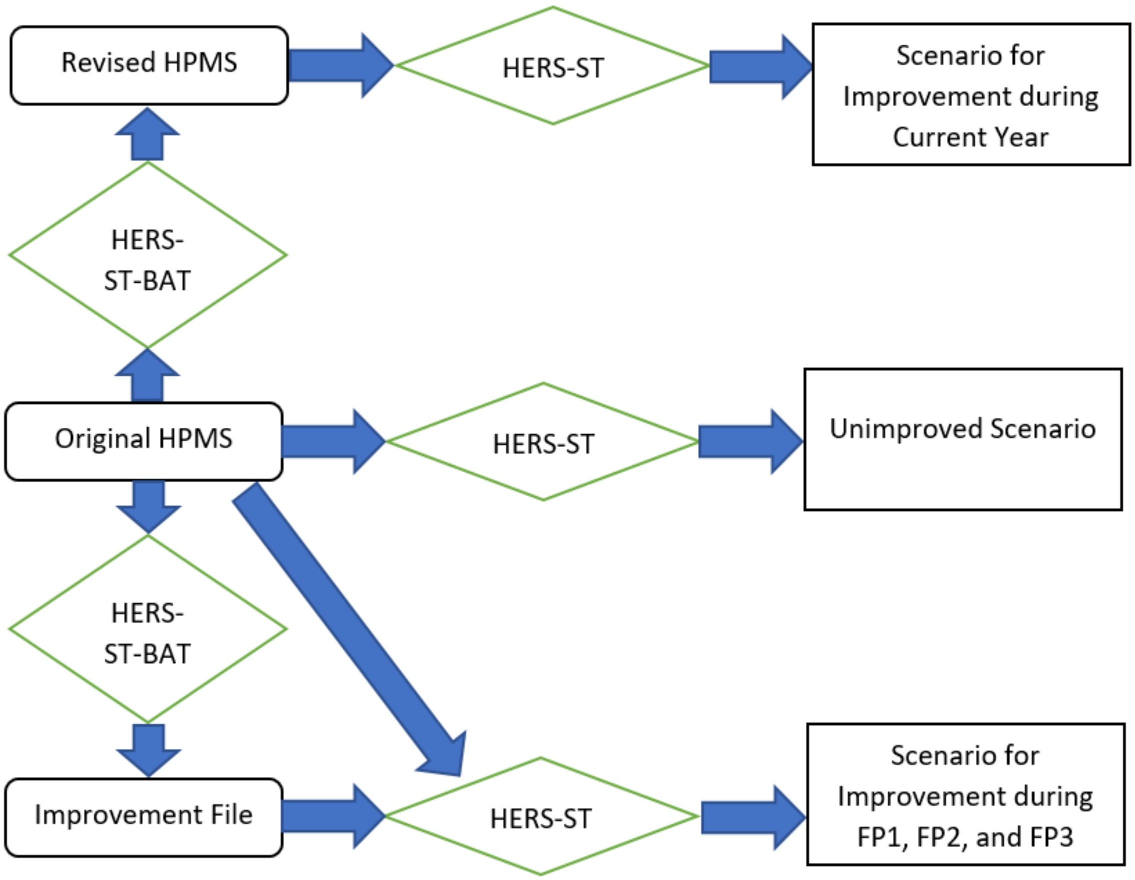


Figure 4: Roles of Three Files in the Simulation Process

the current year (YR0) refers to the year that analysis starts and is in accordance with the value shown under the "Year_Record" column of the HPMS file. The original HPMS file is used for the unimproved scenario in which no improvement can be implemented and roads will deteriorate over time during the entire analysis period.

Revised HPMS File

HERS-ST provides the current-year cost estimates solely based on the information in the loaded HPMS file. If estimates are needed for any improvement implemented and completed during the YR0, however, a user must modify the original HPMS file with some project-specific information before the file is loaded to HERS-ST. As mentioned before, the user might find it difficult to provide the revised HPMS file with the incorporated information from a proposed project. One of the main functions of HERS-ST-BAT is to help facilitate this process.

In the HERS-ST-BAT, the user is only required to enter the necessary project-specific information once: the project location, treatment type, pavement type, post-improvement pavement condition (optional), and project timing. The HERS-ST-BAT then processes all of this information and automatically modifies the original HPMS file for running HERS-ST.

The project location is key in identifying the highway sections that are to be improved in the HPMS file. The required location information includes the state Federal Information Processing Standards (FIPS) code, county code, route ID, beginning milepost, and ending milepost of the project. Since there may be discrepancies in the beginning and ending mileposts between the user input and the HPMS file, HERS-ST-BAT uses the smallest HPMS beginning point that is greater than or equal to the user-specified beginning milepost and the largest HPMS end point that is less than or equal to the user-specified ending milepost. By collecting this information, HERS-ST-BAT can accurately focus on the specific highway section being analyzed and improved.

The pavement condition, measured by IRI, is the main variable that affects user costs. Treatment type choices determine the IRI immediately after improvement. Therefore, it is an essential variable to specify in comparing improvement scenarios. The HERS-ST-BAT provides two main choices for treatment types: Overlay and Reconstruction. By selecting either, the values of pavement conditions within the improved highway segment will be modified in the HPMS file by HERS-ST-BAT correspondingly. If the “Overlay” option is selected, the post-improvement IRI value will be set as 60; if the “Reconstruction” option is selected, the value will be set as 45. Both numbers are provided by WSDOT’s pavement group and indicate the pavement condition as “very good” as defined by the WSDOT IRI categories. It is possible that a user would have a more accurate value of the new IRI than the one provided above. HERS-ST-BAT allows the user the flexibility to specify an IRI value to override the default one.

Pavement type selection is another critical pavement design procedure. HERS-ST-BAT users choose between HMA and PCC, which determines the material applied to a pavement project. The surface type code in the HPMS file will be modified accordingly. For example, if a user chooses the “HMA” option in the pavement type section and “Overlay” option in the treatment type section, the project will lay HMA over an existing pavement structure. If the existing pavement type is joined concrete pavement, the surface type code will be 6, which indicates an asphalt concrete overlay over existing jointed concrete pavement. For more information about the surface type code in HPMS, refer to the 2016 HPMS Field Manual on the FHWA website.

Improvement File

An agency could be more interested in the appropriate timing of the improvement and weighing alternative investment choices now or at different times in the future. For instance, a tight budget today but sufficient funding later might postpone the improvement until the next funding period. In HERS-ST-BAT, a user can choose for the improvement to be undertaken during the first, second, or third funding period, while YR0 is always chosen to compare with the unimproved baseline scenario. Before any improvement takes place, HERS-ST uses its built-in model to simulate the deterioration of pavement condition over years. In accordance with the HERS-ST default setting, there are four funding periods after YR0 and each funding period lasts five years. That is, if YR0 represents 2015, then the first funding period (FP1) spans from 2016 to 2020; the second funding period (FP2) from 2021 to 2025; the third funding period (FP3) from 2026 to 2030; the fourth funding period (FP4) from 2031 to 2035. In total, this represents a 20-year analysis period. The simulation is always completed for the current year and all four funding periods in order to evaluate the impact of improvements over the 20-year period for all the scenarios. The differences in the scenarios is the timing for making such improvements. HERS-ST-BAT users can choose to make project improvements in the current year, first funding period, second funding period, and third funding period. The scenario of improvement during the fourth funding period is intentionally left out of the option. This project investigates the impact of an improvement on various costs over time. Since the fourth funding period is the last funding period, there are no future costs for this scenario. Thus, the timing options is only provided with YR0, FP1, FP2, and FP3. Regardless of which funding period was chosen for making project improvements, the model computes impacts over 20-year period from the current year to the end of fourth funding period.

By applying this option, HERS-ST-BAT can produce a so-called “improvement file,” which is compatible with HERS-ST. HERS-ST uses this “improvement file” and the original HPMS file for scenarios where any improvement is postponed until the first, second, or third funding period. One drawback to applying this particular functionality is that the “improvement file” can only contain information about treatment type, not pavement type. It assumes that an overlay treatment is always performed with flexible pavements and a reconstruction treatment always applies the pavement type that the existing roads have. As a consequence, the results would be the same if the project uses different pavement types but the same treatment type and is implemented after YR0. In contrast, the analysis for the current-year improvement scenario has no such limitation because the surface type value can be directly modified in the HPMS file before it is loaded into HERS-ST.

Again, HERS-ST-BAT is not a substitute for HERS-ST but rather a supplement. Therefore, it is necessary to have access to HERS-ST and to understand how to run it. With the input files from HERS-ST-BAT, the user can obtain HERS-ST simulation results and export them back to HERS-ST-BAT for further analysis.

HERS-ST Output Analysis

Another primary function of HERS-ST-BAT is to analyze outputs from HERS-ST. Although HERS-ST outputs contain more information, the analysis in this report concentrates on outputs related to agency and user costs. HERS-ST only provides the cost estimates in the last year of each funding period. For example, the current year is set as 2015 and each of four funding periods lasts five years based on the default setting. A user can obtain cost estimates in 2015, 2020, 2025, 2030, and 2035 for YR0, FP1, FP2, FP3, and FP4, respectively. A cumulative present value can be calculated by first converting these five single-year values into present values with an appropriate discount rate and then summing them up. This cumulative present value is used to compare different scenarios.

HERS-ST provides two types of results: system conditions and section conditions. Section conditions represent each highway section's characteristics. System conditions are summarized at a regional level to better inform the respective agencies and other stakeholders. Since there can be no additional benefit using section-condition results in this project, the analysis in this report is based on the outputs from the system conditions for simplicity.

Several highway improvement scenarios can be compared with the baseline case, which allows the roads to deteriorate over time in accordance with no improvement projects. For each scenario, there are six types of costs shown in the summary statistics. In order, these costs include travel time cost (TTC), vehicle operating cost (VOC), crash cost, total user cost, maintenance cost, and emission cost. All these costs are in terms of dollars per 1000 VMT, except maintenance cost whose unit is dollars per mile. Moreover, HERS-ST has utilized several price indices to convert all values to constant dollars, whose base year is 2004.

HERS-ST-BAT converts per-unit costs to dollars. For each cost category other than maintenance costs, the values of total costs can be derived from multiplying per-1000-VMT costs by total VMT (in the unit of 1000 VMT). Maintenance costs are calculated by multiplying per-mile maintenance costs by total miles.

TTC and VOC are broken down into two sub-categories: 4-tire vehicles and trucks. The total TTC and VOC is obtained by adding these two sub-categories. The total user costs are the sum of total TTC, total VOC, and crash costs. The estimated pavement maintenance costs are based on the difference between a constant pavement condition, which is defined by HERS-ST, and an actual pavement condition, which is estimated by the HERS-ST built-in pavement deterioration model.

In addition to each funding period's total costs, HERS-ST-BAT can also show the percentage change in each cost category between no-improvement and improvement scenarios for the entire county, in order to more clearly see the potential benefits of undertaking the improvement project. To visualize the results, HERS-ST-BAT includes a graph for each cost trend along with the summary statistics.

VII: HERS-ST Benefit Application Tool: Case Study Applications

In order to test the validity of HERS-ST-BAT and the improved method, three past projects from WSDOT were selected by the project committee as case studies. The selection criteria was primarily based on recent highway projects that the pavement group and the planning group had evaluated and for which necessary data inputs were available. These included: (1) a concrete pavement rehabilitation project on I-5 northbound, (2) a concrete pavement rehabilitation project on I-5 southbound**,** and (3) a replace/rehabilitation concrete project on I-90 westbound. WSDOT's pavement group conducted the original life-cycle cost analysis for pavement type selection. Based on the LCCA revenue and expenditure stream form in each of these project documents, the analysis starting year is 2015 for all of the projects. Therefore, 2015 HPMS files are used for consistency.

The original LCCA focused solely on agency costs and only user costs associated with user delay during construction periods were estimated. All costs have been converted to constant dollar values. For project (3), the base year for this conversion was 2013, which was also the year that the original LCCA was conducted. To keep consistency with project (3), the year that the original LCCA was conducted is assumed to be the conversion base year: 2015 for project (1) and 2013 for project (2).

The costs in the original analysis were constrained to the improved highway segments. It might have been more insightful to investigate the regional costs for government agencies. In WSDOT's economic analysis group, the percentage change of county-level costs is always calculated and fed into REMI-TranSight Model for economic forecasting. This section revisits these three projects and provides estimates for user and maintenance costs at the county level. Although results are shown at the county level, other projects in this county during the same period are not considered in the analysis. If those projects were incorporated, it would be impossible to focus on the effects of the project being studied. In other words, it was assumed that the project being studied was the only project within the county during the analysis period.

Since HERS-ST assumes no construction time, the research team was unable to estimate any user costs during the construction period with the methods proposed in this report. Further, the effects of pavement improvement can be observed immediately, so there were no time delays that needed to be considered for the comparison. For present value calculation, a 4% discount rate was selected in accordance with WSDOT Pavement Policy. It should be noted that this section is not challenging the accuracy of agency and user costs that these projects have estimated. Rather, it aims to offer a more comprehensive view of those projects by supplementing the original cost estimations with the county-level user and maintenance costs.

The general analysis procedure in this case study section follows the steps below:

1. Obtain the original 2015 county-level HPMS file;
2. Import the original file into HERS-ST-BAT and input the project information to create the revised HPMS file and improvement files;
3. Import these three types of files into HERS-ST to run simulations for unimproved scenario and improvements during YR0, FP1, FP2, and FP3;
4. Retrieve the results from HERS-ST system conditions and convert units from dollars per 1000 VMT or per mile to million dollar increments;

5. Incorporate initial construction costs and associated user costs during construction into various costs from step 4 to see how total costs evolve over time under unimproved scenario and each pavement improvement strategy;
6. Calculate the cumulative present value of each cost type for each scenario of each pavement improvement strategy for comparison.

Step 5 creates figures so that the cost trends can be visualized. Step 6 produces tables so that different scenarios and strategies can be compared. The above procedure applies to all three projects and following are details for each project.

Case Study 1: I-5 Northbound Project

As shown in Figure 5, this project is located on the northbound lanes of Interstate 5, between S 260th St and the Duwamish River Bridge (MP 147.64 to MP 156.51) in King County. The actual construction occurred in 2017. The WSDOT pavement group conducted the original LCCA in 2015 to compare between PCC pavement reconstruction and HMA pavement overlay (Cook, 2015). The original analysis only evaluated one part of the full-length construction (4.03 out of 8.87 miles) for 50 years. It was estimated that the present value of agency cost from a deterministic model for PCC reconstruction and HMA overlay were $23,405,000 and $18,203,000, respectively. The agency costs include initial construction costs, subsequent maintenance, and rehabilitation costs. The user costs (user delay costs during initial construction, maintenance, and rehabilitation periods) were estimated to be $107,195,000 and $9,855,000 for PCC reconstruction and HMA overlay, respectively. All costs here are constant dollar values and the analysis year (2015) was the assumed base year. Given the original LCCA, WSDOT pavement selection committee chose HMA pavement overlay as the rehabilitation strategy.

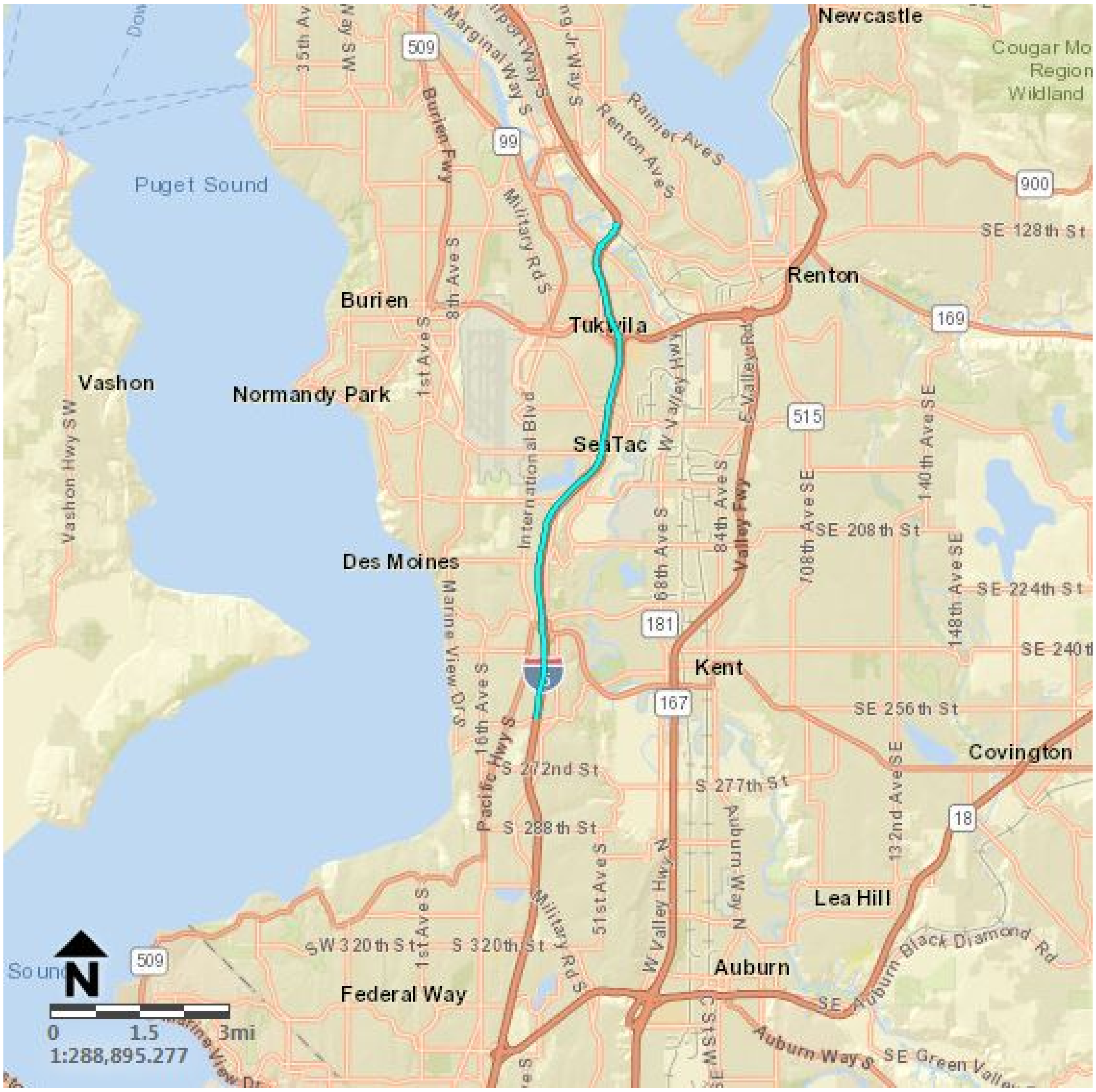


Figure 5: Location of I-5 Northbound Project

To supplement the above analysis, the research team used the 2015 King County HPMS file, which contains information for the 407 miles of national and state highways within the county. Importing it into the HERS-ST-BAT allowed supplemental evaluation and analysis and illustrated the application of the tool. As mentioned before, the costs were collected from HERS-ST system conditions and converted to million dollar increments. Based on these system condition outputs, the estimated values of various cost types in the current year or last year of each baseline funding period and each pavement strategy can be summarized. By combining the summary values, the total costs in the current or last year of each baseline funding period and each pavement strategy can be calculated by summing up total travel time costs, total vehicle operating costs, crash costs, HERS-ST-defined maintenance costs, emission costs, initial construction costs, and user delay costs in the original LCCA.

There are two points that need to be clarified before proceeding. First, HERS-ST outputs are constant dollar values based on 2004, while original LCCA costs are based on 2015. To convert the LCCA costs to be based on 2004, the original initial construction costs ($17,342,800 for PCC reconstruction and $15,198,550 for HMA overlay) were deflated using the FHWA National Highway Construction Cost Index (NHCCI), which was 1.6984 in 2015 and 1.1098 in 2004. After conversion, the initial construction costs were $11,332,200 for PCC reconstruction and $9,931,090 for HMA overlay. The user costs during the initial construction ($66,054,160 for PCC reconstruction and $9,854,880 for HMA overlay) were converted with the Consumer Price Index (CPI) for the West region, which was 193 in 2004 and 243.015 in 2015. In the end, the converted user costs during the initial construction were $52,459,530 for PCC reconstruction and $7,826,640 for HMA overlay.

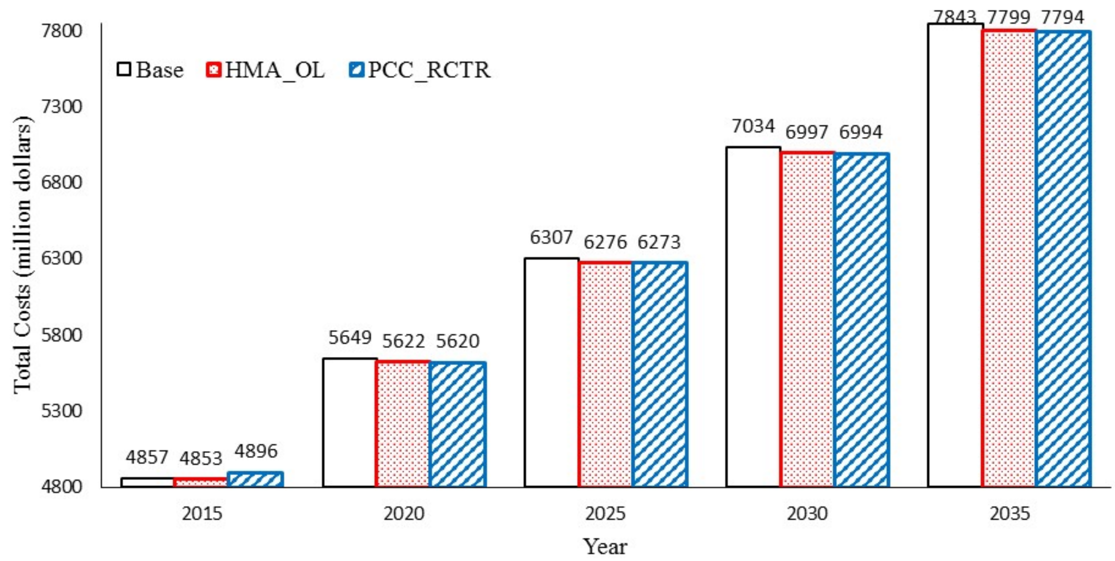


Figure 6: Trends of Baseline and YR0 Improvements for I-5 NB Project in King County

Second, any subsequent maintenance and rehabilitation costs provided in the original LCCA were not included in the calculation of total costs in this analysis. The future NHCCI and CPI do not exist, so it is difficult to convert these costs. Moreover, the HERS-ST annual maintenance costs, which are estimated costs to maintain roads in a good condition, has been added to the total costs. The exclusion of similar costs from the original analysis avoids potential double-counting.

Figure 6 presents how total costs will change over time for the baseline, HMA overlay implemented in initial year 2015, and PCC reconstruction implemented in 2015. The total costs of all scenarios will keep increasing. Due to initial construction costs and associated user delay costs, the reductions in total user costs and maintenance costs are ultimately made up. For the YR0 PCC reconstruction scenario, the total costs in 2015 were even higher than the baseline costs. In contrast, the 2015 total costs of the YR0 HMA overlay scenario were still lower than baseline costs. After 2015, the total costs of both strategies will be lower than the baseline. Moreover, PCC reconstruction values are always the lowest, even though the differences are small.

The benefit of an improvement strategy can be defined by cost savings, which are the cost differences between the baseline and improvement strategies. The cost savings show that the HMA overlay improvement made in 2015 has saved total costs by $143 million (the sum of $4 million in 2015, $27 million in 2020, $31 million in 2025, $37 million in 2030, $44 million in 2035) from the baseline while PCC reconstruction has saved $113 million (the sum of $-39 million in 2015, $29 million in 2020, $34 million in 2025, $40 million in 2030, and $49 million in 2035). Due to the high initial construction costs and associated user delay costs, the total costs of PCC reconstruction in 2015 is $4.896 billion dollars which is higher than 2015 baseline total costs ($4.857 billion dollars). Therefore, the cost saving of PCC reconstruction from the baseline costs in 2015 is negative ($4.857 - $4.896 billion = $-39 million).

If the improvement for some reason can not be implemented during YR0, HERS-ST-BAT allows for the scenario that the improvement is postponed until FP1, FP2, or FP3. Figure 7 compares these three scenarios. Again, the figure consistently shows an increase in total costs. Before an improvement implementation, costs are the same as the baseline. This is because it was assumed that there were no other ongoing projects in the county during the analysis period. Similar to Figure 6, in the last year of the funding period that PCC reconstruction was implemented, the total costs of PCC reconstruction strategies were the

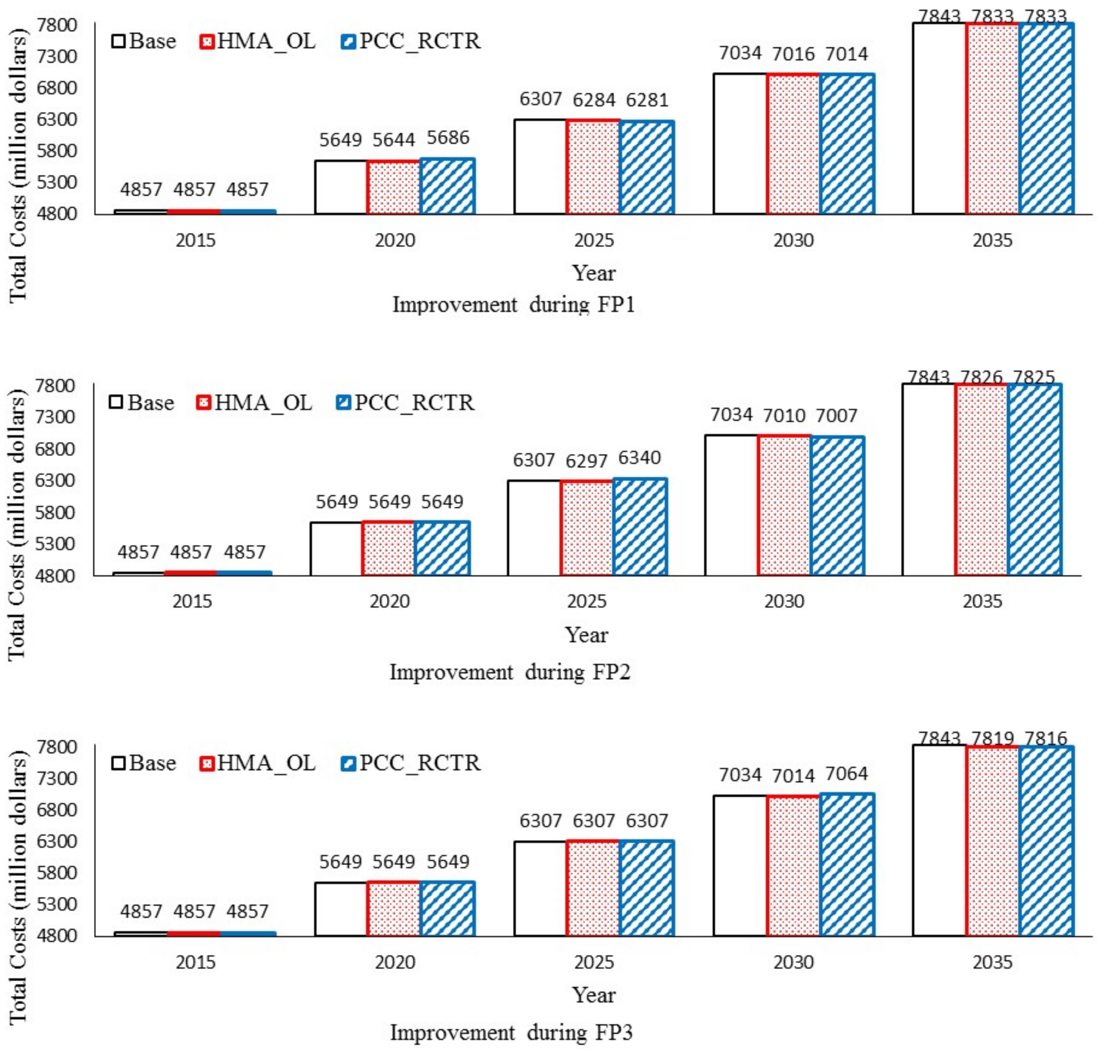


Figure 7: Scenario Analysis Results of Implementing Pavement Improvements across Different Funding Periods for I-5 NB Project in King County

highest but then became the lowest after that. The total costs of HMA overlay strategies are always lower than the baseline.

Also, the longer the project is delayed, the fewer benefits there are within a certain number of funding periods. For example, compare the strategies of implementing HMA overlay during FP2 or FP3: the total cost savings of FP2 HMA overlay are $51 million (the sum of

$10 million in 2025, $24 million in 2030, and $17 million in 2035), while the total cost savings of FP3 HMA overlay are $44 million (the sum of $20 million in 2030 and $24 million in 2035).

Based on the HERS-ST system condition results for this I-5 NB project, the present cost values in the current year and the last year of each funding period for different scenarios can be calculated with the 4% discount rate. Except for initial construction costs and associated user delay costs, there are five single-year values (2015, 2020, 2025, 2030, and 2035) for each cost type in each scenario. The cumulative present value of each cost type for each scenario is obtained by adding these five values. That is, the results related to the cumulative present value is the sum of the five-year total for each scenario. The cumulative present value of total costs was calculated by adding the present values of total travel time costs, total vehicle operating costs, crash costs, HERS-ST-defined maintenance costs, emission costs, initial construction costs, and user delay costs during the construction from the original LCCA. For example, the cumulative present value of total costs would be $21,158,000 if the HMA overlay was implemented in YR0.

With the cumulative present value each cost type for each scenario, its percentage change between the baseline and each improvement strategy can be calculated. Table 4 provides a summary. The total user costs are the sum of total TTC, total VOC, and crash costs. Either HMA overlay or PCC reconstruction can lower the total user costs whenever they are implemented. Both strategies also largely reduce maintenance costs. However, the later implementation occurs, the less savings in total user costs and maintenance costs. The total user cost and maintenance cost savings from PCC reconstruction are higher than those from

HMA overlay, no matter the timing. For both HMA overlay and PCC reconstruction, the best time is the current year. It reduces total costs by 0.414% for HMA overlay and 0.247% for PCC reconstruction. The third funding period is the worst time. It reduces total costs by 0.047% for HMA overlay and increases costs by 0.153% for PCC reconstruction. The total costs are higher because the savings from total user costs and maintenance costs can not completely offset the high initial construction costs and associated user delay costs for PCC reconstruction. Therefore, this analysis confirms HMA overlay as the better choice.

Table 4: Change of Cumulative Present Values of Costs from Baseline to Improvement Strategies on I-5 NB

	TTC_ 4Tire	TTC_ Trucks	TTC_ Total	VOC_ 4Tire	VOC_ Trucks	VOC_ Total	Crash	Total User	Maint.	Emis.	Total Costs
HMA_OL_YR0	-.0119%	-.0901%	-.0152%	-1.2416%	-1.0525%	-1.2004%	-.0001%	-.5011%	-4.4780%	-.0032%	-.4138%
HMA_OL_FP1	.3556%	.3627%	.3592%	-1.0352%	-.8495%	-1.0010%	.0893%	-.2341%	-4.2157%	.1203%	-.1482%
HMA_OL_FP2	.2694%	.3204%	.2680%	-.8041%	-.6041%	-.7804%	.0513%	-.1908%	-3.4200%	.0660%	-.1056%
HMA_OL_FP3	.1674%	.1615%	.1673%	-.5269%	-.4359%	-.5126%	.0217%	-.1315%	-2.4267%	.0351%	-.0469%
PCC_RCTR_YR0	-.0152%	-.0948%	-.0250%	-1.3564%	-1.1451%	-1.3157%	-.0025%	-.5512%	-4.8321%	-.0044%	-.2468%
PCC_RCTR_FP1	.4112%	.4055%	.4189%	-1.1788%	-.9912%	-1.1392%	.0840%	-.2640%	-4.6906%	.1383%	.0390%
PCC_RCTR_FP2	.3104%	.3560%	.3169%	-.9163%	-.7170%	-.8874%	.0689%	-.2098%	-3.8033%	.0772%	.0923%
PCC_RCTR_FP3	.2037%	.1922%	.2017%	-.6159%	-.5200%	-.6006%	.0323%	-.1486%	-2.7418%	.0424%	.1528%

Note: 1. Baseline is the unimproved scenario; "HMA_OL_YR0" or "PCC_RCTR_YR0" indicates the strategy that the HMA Overlay or PCC Reconstruction is implemented during the current year; "HMA_OL_FPx" or "PCC_RCTR_FPx" indicates the strategy that the HMA Overlay or PCC Reconstruction is implemented during the x funding period.

2. "TTC" and "VOC" denote travel time costs and vehicle operating costs, respectively; total user costs are the sum of TTC, VOC, and Crash costs; "Maint." is the annual maintenance costs from HERS-ST; "Emis." is the emission costs; "Constr." And "User Delay" are initial construction costs and user delay costs during the construction from WSDOT; total costs are the total of all costs.

3. Each value in the table is the percentage change of cumulative present value of corresponding cost type for corresponding improvement strategies. The cumulative present value is the sum of 5 single-year present values. Each of these 5 values represents the costs in the last year of each funding period.

Case Study 2: I-5 Southbound Project

The second highway project selected was also on I-5 but on the southbound lanes. This project length was slightly longer than the first project. As presented in Figure 8, it is also in King County and located between S 320th St and the Duwamish River Bridge (MP 143.85 to MP 156.5). The actual construction occurred in 2016. The WSDOT pavement group conducted the original LCCA in 2013 to compare the PCC pavement reconstruction and HMA pavement overlay improvements (Cook, 2013). The original report analyzed a 2.66-mile sample of the 12.65-mile full-length construction road for 50 years. It was estimated that the present values of agency cost from a deterministic life cycle cost model for PCC reconstruction and HMA overlay were $23,288,000 and $13,399,000, respectively. These include initial construction costs and subsequent maintenance and rehabilitation costs. The user costs (user delay costs during the initial construction, maintenance, and rehabilitation periods) were estimated to be $56,891,000 and $7,178,000 for PCC reconstruction and HMA overlay, respectively. All costs here are constant dollar values and the analysis conducting year (2013) was assumed as the base year. The WSDOT pavement selection committee chose the HMA pavement overlay project as the selected rehabilitation strategy.

2015 was used as the starting year for project analysis for consistency purpose. Therefore, again, the research team used 2015 King County HPMS file to supplement analysis. After unit conversion, various estimated costs in the current year or last year of each funding period of baseline and each pavement strategy has been calculated.

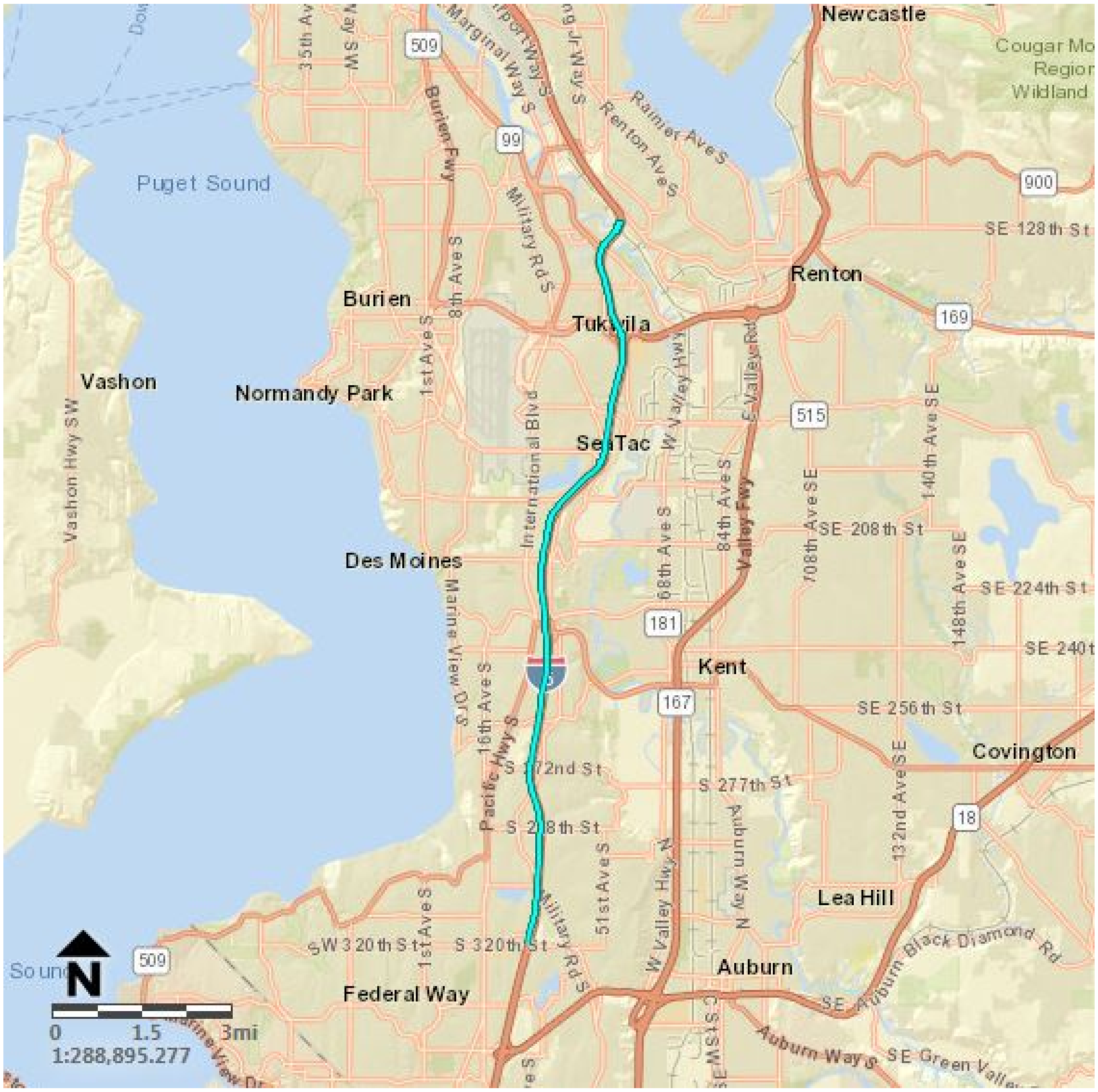


Figure 8: Location of I-5 Southbound Project

For this I-5 SB project, HERS-ST outputs were constant dollar values based on 2004, but the costs in the original LCCA were based on 2013. To convert them to be based on 2004, the original initial construction costs ($17,601,850 for PCC reconstruction and $11,191,140 for HMA overlay) were deflated with FHWA's National Highway Construction Cost Index (NHCCI) which was 1.6131 in 2013 and 1.1098 in 2004. After conversion, the initial construction costs were $12,110,040 for PCC Reconstruction and $7,699,480 for HMA Overlay. The user costs during the initial construction ($36,591,950 for PCC reconstruction and $6,965,060 for HMA overlay) were converted with the Consumer Price Index (CPI) in the West region, which was 193 in 2004 and 235.824 in 2013. In the end, the converted user costs during the initial construction were $29,947,110 for PCC reconstruction and $5,700,250 for HMA overlay.

With the same method to calculate total costs, Figure 9 shows how they evolve from 2015 to 2035 for the baseline and the strategies implemented in initial year. The results are like those from the first project: total costs increase over time. With the initial construction costs and associated user delay costs, the total costs for PCC reconstruction in 2015 are the highest while those for HMA overlay are the lowest. After 2015, the total costs of both

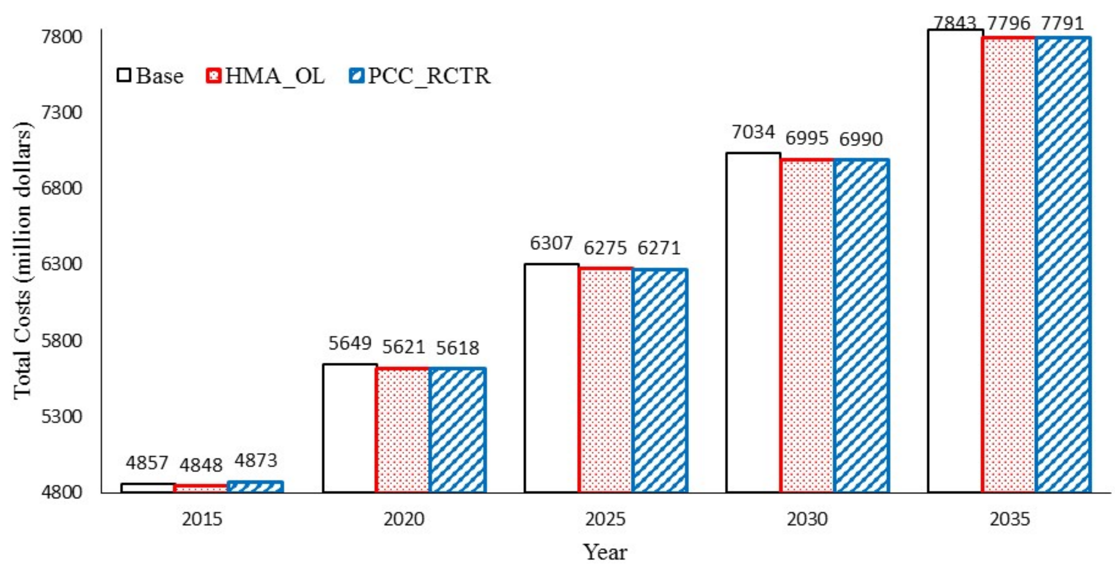


Figure 9: Trends of Baseline and YR0 Improvements for I-5 SB Project in King County

strategies will be lower than the baseline. Moreover, the costs of PCC reconstruction are always slightly lower than HMA overlay.

In total, the HMA overlay in YR0 saves total costs by $155 million (the sum of $9 million in 2015, $28 million in 2020, $32 million in 2025, $39 million in 2030, and $47 million in 2035) from the baseline while the PCC reconstruction in YR0 saves $147 million (the sum of $-16 million in 2015, $31 million in 2020, $36 million in 2025, $44 million in 2030, and $52 million in 2035). Due to the high initial construction costs and associated user delay costs, the total costs of PCC reconstruction in 2015 is 4.873 billion dollars which is higher than 2015 baseline total costs ($4.857 billion dollars). Therefore, the cost saving of PCC reconstruction from the baseline total costs in 2015 is negative ($4.873 – $4.857 billion = -$16 million).

Figure 10 displays the improvement scenarios with variation in project timing after 2015. In general, the figure is consistent with Figure 8. The HMA overlay and PCC reconstruction trends are also similar. Total costs for both are the same as the baseline before improvements and lower after improvements. In the last year of the funding period when an improvement occurs, total costs of PCC reconstruction are the highest and total costs of HMA overlay are the lowest. In addition, the longer the project is delayed, the fewer the benefits within a certain number of funding periods. For example, compare the strategies of PCC reconstruction during FP2 and FP3: the total cost savings of FP2 PCC reconstruction are $48 million (the sum of $-6 million in 2025, $32 million in 2030, and $22 million in 2035), while the total cost savings of FP3 PCC reconstruction are $31 million (the sum of $-1 million in 2030 and $32 million in 2035).

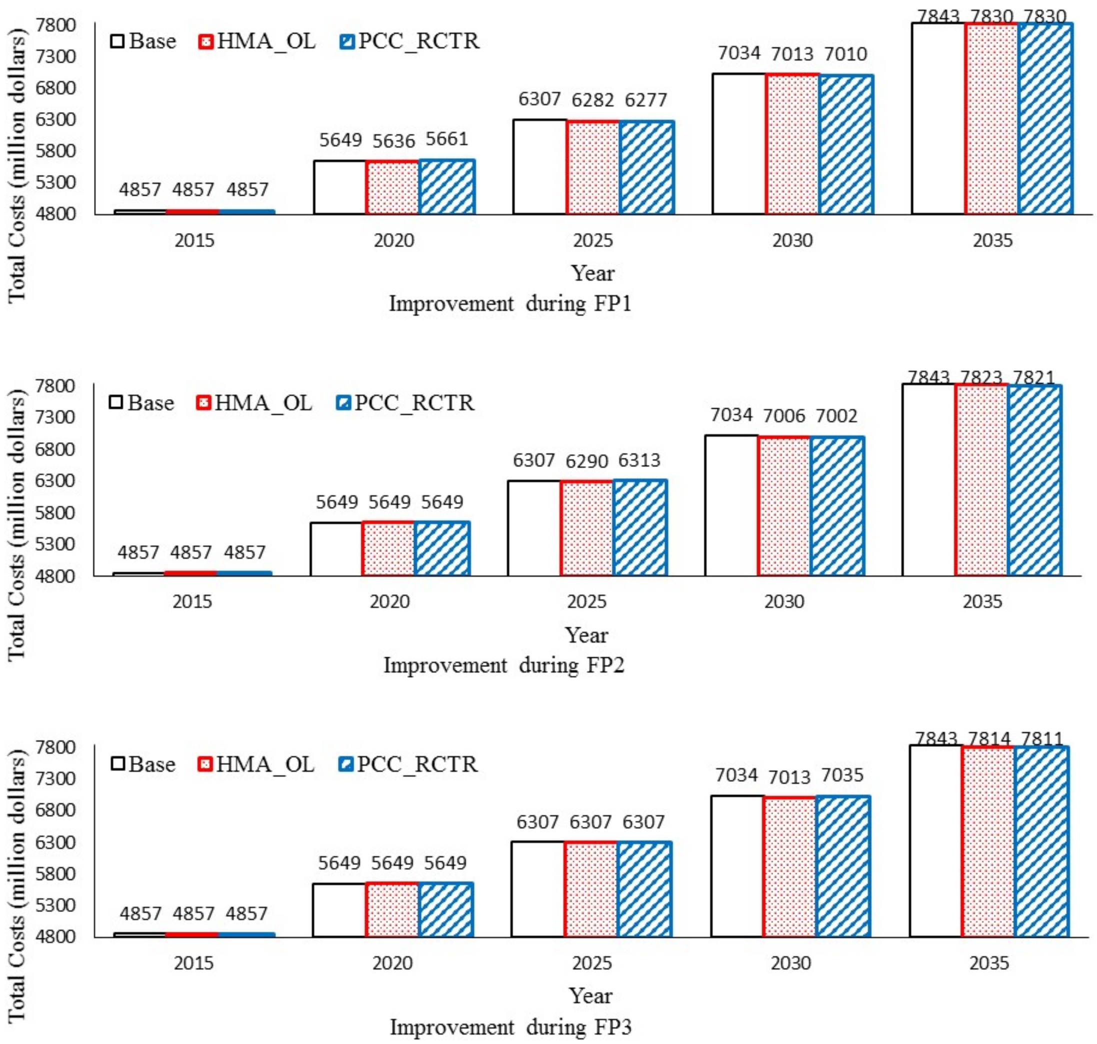


Figure 10: Scenario Analysis Results of Implementing Pavement Improvements across Different Funding Periods for I-5 SB Project in King County

Based on HERS-ST system condition outputs for this I-5 SB project, each cost type's cumulative present value for each scenario is obtained using the same method from the last project. Table 5 summarizes the percentage change of each cost type's cumulative present value between the baseline and each improvement strategy. Overall, either HMA overlay or PCC reconstruction can lower the total user costs and maintenance costs whenever they are implemented. The percentage savings of maintenance costs are much larger than the total user costs. Again, the later the implementation, the less total user costs can be saved. In contrast, for maintenance costs of PCC reconstruction, the improvement during FP1 saves the most. The savings of total user costs and maintenance costs from PCC reconstruction are always higher than those from HMA overlay for all periods. For both HMA overlay and PCC reconstruction, the best period is the current year. It reduces total costs by 0.455% for HMA overlay and 0.385% for PCC reconstruction. The third funding period is the worst time. It reduces total costs by 0.089% for HMA overlay and increases costs by 0.023% for PCC reconstruction. Therefore, this analysis confirms HMA overlay as the better choice.

Table 5: Change of Cumulative Present Values of Costs from Baseline to Improvement Strategies on I-5 SB

	TTC_ 4Tire	TTC_ Trucks	TTC_ Total	VOC_ 4Tire	VOC_ Trucks	VOC_ Total	Crash	Total User	Maint.	Emis.	Total Costs
HMA_OL_YR0	-.0119%	-.0882%	-.0152%	-1.2937%	-1.0934%	-1.2561%	-.0001%	-.5218%	-4.7065%	-.0032%	-.4548%
HMA_OL_FP1	.3864%	.3769%	.3907%	-1.1551%	-.9613%	-1.1162%	.0797%	-.2659%	-4.7004%	.1364%	-.2002%
HMA_OL_FP2	.2968%	.3324%	.2995%	-.9148%	-.7098%	-.8815%	.0689%	-.2154%	-3.8394%	.0820%	-.1054%
HMA_OL_FP3	.1900%	.1757%	.1887%	-.6115%	-.5145%	-.5925%	.0323%	-.1530%	-2.7445%	.0459%	-.0886%
PCC_RCTR_YR0	-.0152%	-.0948%	-.0192%	-1.4518%	-1.2303%	-1.4088%	-.0001%	-.5876%	-5.1983%	-.0032%	-.3853%
PCC_RCTR_FP1	.4490%	.4646%	.4537%	-1.3255%	-1.1039%	-1.2853%	.1047%	-.3051%	-5.2947%	.1580%	-.1040%
PCC_RCTR_FP2	.3438%	.3722%	.3508%	-1.0505%	-.8440%	-1.0139%	.0854%	-.2471%	-4.3173%	.0936%	-.0469%
PCC_RCTR_FP3	.2260%	.2064%	.2259%	-.7178%	-.6153%	-.6962%	.0423%	-.1769%	-3.1163%	.0528%	.0225%

Note: 1. Baseline is the unimproved scenario; “HMA_OL_YR0” or “PCC_RCTR_YR0” indicates the strategy that the HMA Overlay or PCC Reconstruction is implemented during the current year; “HMA_OL_FPx” or “PCC_RCTR_FPx” indicates the strategy that the HMA Overlay or PCC Reconstruction is implemented during the x funding period.

2. “TTC” and “VOC” denote travel time costs and vehicle operating costs, respectively; total user costs are the sum of TTC, VOC, and Crash costs; “Maint.” is the annual maintenance costs from HERS-ST; “Emis.” is the emission costs; “Constr.” And “User Delay” are initial construction costs and user delay costs during the construction from WSDOT; total costs are the total of all costs.

3. Each value in the table is the percentage change of cumulative present value of corresponding cost type for corresponding improvement strategies. The cumulative present value is the sum of 5 single-year present values. Each of these 5 values represents the costs in the last year of each funding period.

Case Study 3: I-90 Westbound Project

The last project evaluated was on the westbound lanes of Interstate 90 near Cle Elum as shown in Figure 11, from MP 84.21 to MP 93.30 in Kittitas County. The actual construction occurred in 2016. The WSDOT pavement group conducted the original LCCA in 2013 to analyze the alternative rehabilitation strategies between PCC pavement overlay and HMA pavement overlay (Byrd and Barrett, 2013). The original analysis covered the full length of the proposed improvement project for 50 years. It was estimated that the present values of agency cost from a deterministic life cycle cost model for PCC overlay and HMA overlay would be $29,446,000 and $27,041,000, respectively. The user costs (user delay costs during the construction, maintenance, and rehabilitation periods) were estimated to be $954,000 and $1,081,000, respectively. All costs here are constant dollar values based on 2013. The committee selected HMA pavement overlay as the chosen rehabilitation strategy.

2015 was used as the starting year for project analysis for consistency purpose. Therefore, the research team supplemented the analysis with the 2015 Kittitas County HPMS file, which includes information for 183 miles of national and state highways. After unit conversion, various estimated costs in the current or last year of each baseline funding period and each pavement strategy can be obtained. Since Kittitas County has substantially more rural areas than King County, all kinds of costs in Kittitas County are much less than King County's.

For this I-90 W project, HERS-ST outputs were still constant dollar values based on 2004, but the costs in the original LCCA were based on 2013. To convert them to be based on

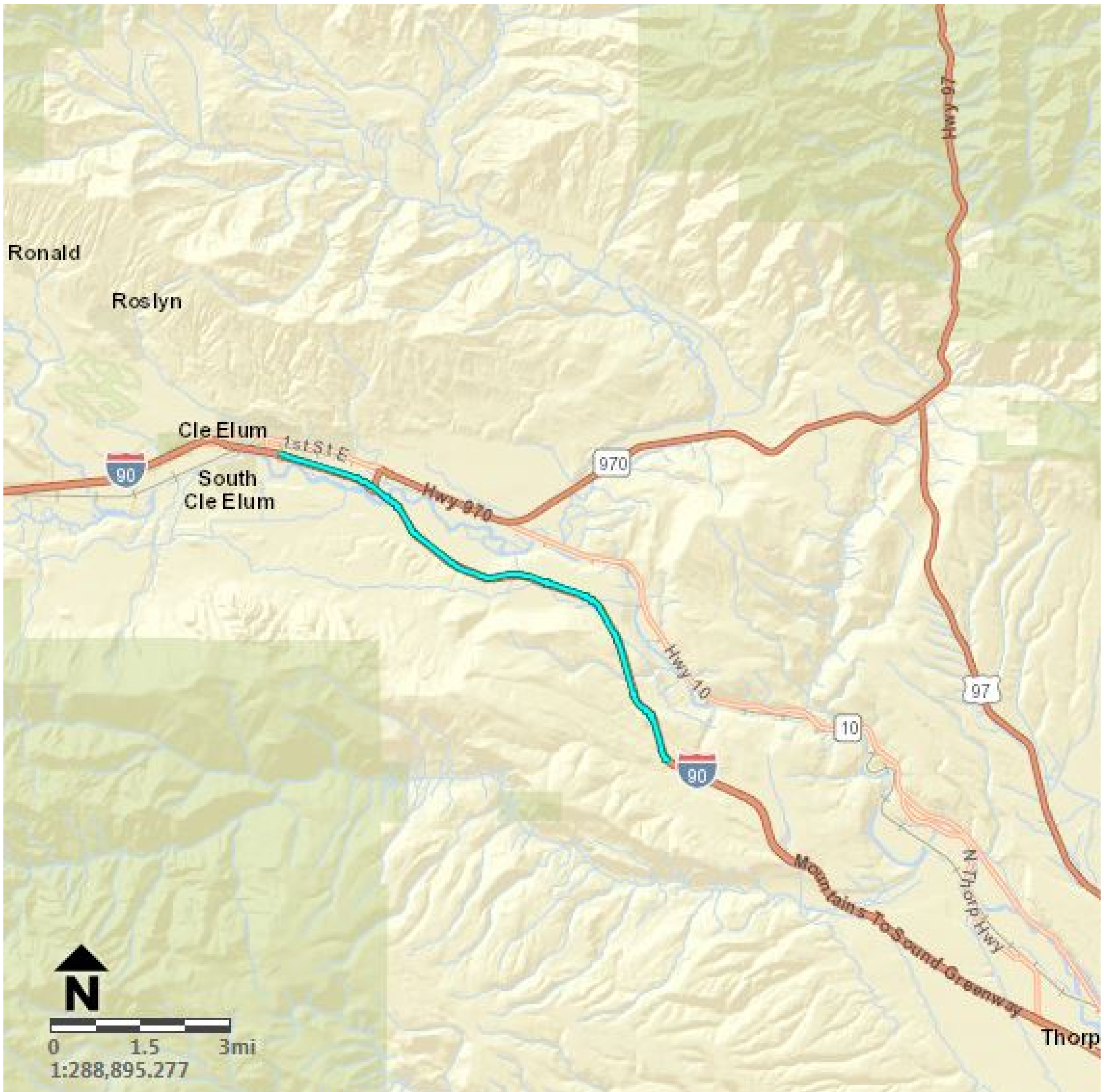


Figure 11: Location of I-90 Westbound Project

2004, the original initial construction costs ($27,993,000 for PCC overlay and $21,036,000 for HMA overlay) were deflated with FHWA's National Highway Construction Cost Index (NHCCI), which was 1.6131 in 2013 and 1.1098 in 2004. After conversion, the initial construction costs were $19,259,120 for PCC overlay and $14,472,724 for HMA overlay. The user costs during the initial construction ($794,060 for PCC overlay and $212,810 for

HMA overlay) were converted with the Consumer Price Index (CPI) in the West region, which was 193 in 2004 and 235.824 in 2013. The converted user costs during the initial construction were $649,864 for PCC overlay and $174,165 for HMA overlay.

The total costs changing over time for the baseline, HMA overlay implemented in initial year, and PCC overlay implemented in initial year are presented in Figure 12. In general, the figure still shows that total costs increase over time. Unlike the I-5 projects, the 2015 total costs of both strategies were higher than the baseline and later became lower. The cost difference between these two strategies was tiny after 2015. This is mainly due to the calculation method of post-improvement IRI WSDOT provided. Based on this method, the post-improvement IRI is assumed to be the same regardless of the treatment types. That is, pavement type will not affect post-improvement IRI. Given that total user costs and

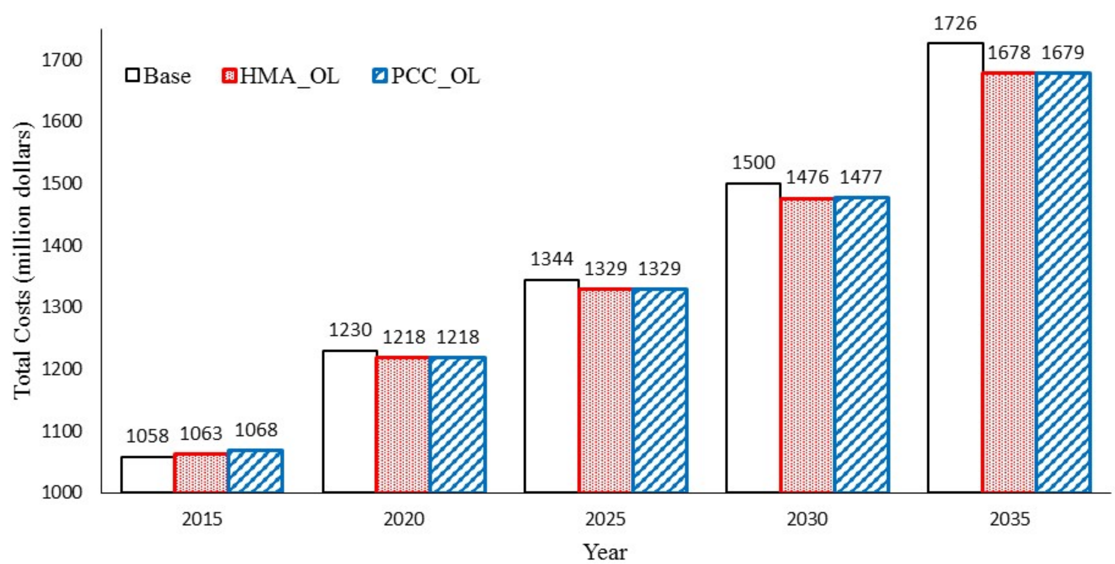


Figure 12: Trends of Baseline and YR0 Improvements for I-90 W Project in Kittitas County

maintenance costs are mainly affected by pavement condition, the difference in pavement type plays only a minor role in determining total cost difference.

The savings for HMA overlay in YR0 are $94 million (the sum of $-5 million in 2015, $12 million in 2020, $15 million in 2025, $24 million in 2030, and $48 million in 2035) while they are $87 million (the sum of $-10 million in 2015, $12 million in 2020, $15 million in 2025, $23 million in 2030, and $47 million in 2035) for PCC overlay in YR0. Due to the high initial construction costs and associated user delay costs, the total costs of HMA overlay and PCC reconstruction in 2015 are $1.063 and $1.068 billion dollars, respectively. Both are higher than 2015 baseline total costs ($1.058 billion dollars). Therefore, the cost savings of both HMA overlay and PCC reconstruction from the baseline in 2015 are negative ($1.058 billion – $1.063 billion = $-5 million and $1.068 billion - $1.058 billion = $-10 million).

Figure 13 compares the timing of only HMA overlay strategies. The results for any improvement after YR0 was obtained from HERS-ST with the improvement file. As mentioned before, the improvement file always assumes that an overlay is conducted with flexible pavement. Thus, this method can only analyze HMA overlay after YR0 but not PCC overlay. As shown in the figure, except for HMA overlay during the FP1 in 2020, total costs are always equal to or lower than the baseline. Still, the more improvement is delayed, the less total cost savings. Figure 13 shows that HMA overlay's total cost savings during FP1, FP2, and FP3 are $85 million (the sum of $-2 million in 2020, $16 million in 2025, $24 million in 2030, and $47 million in 2035), $72 million (the sum of $1 million in

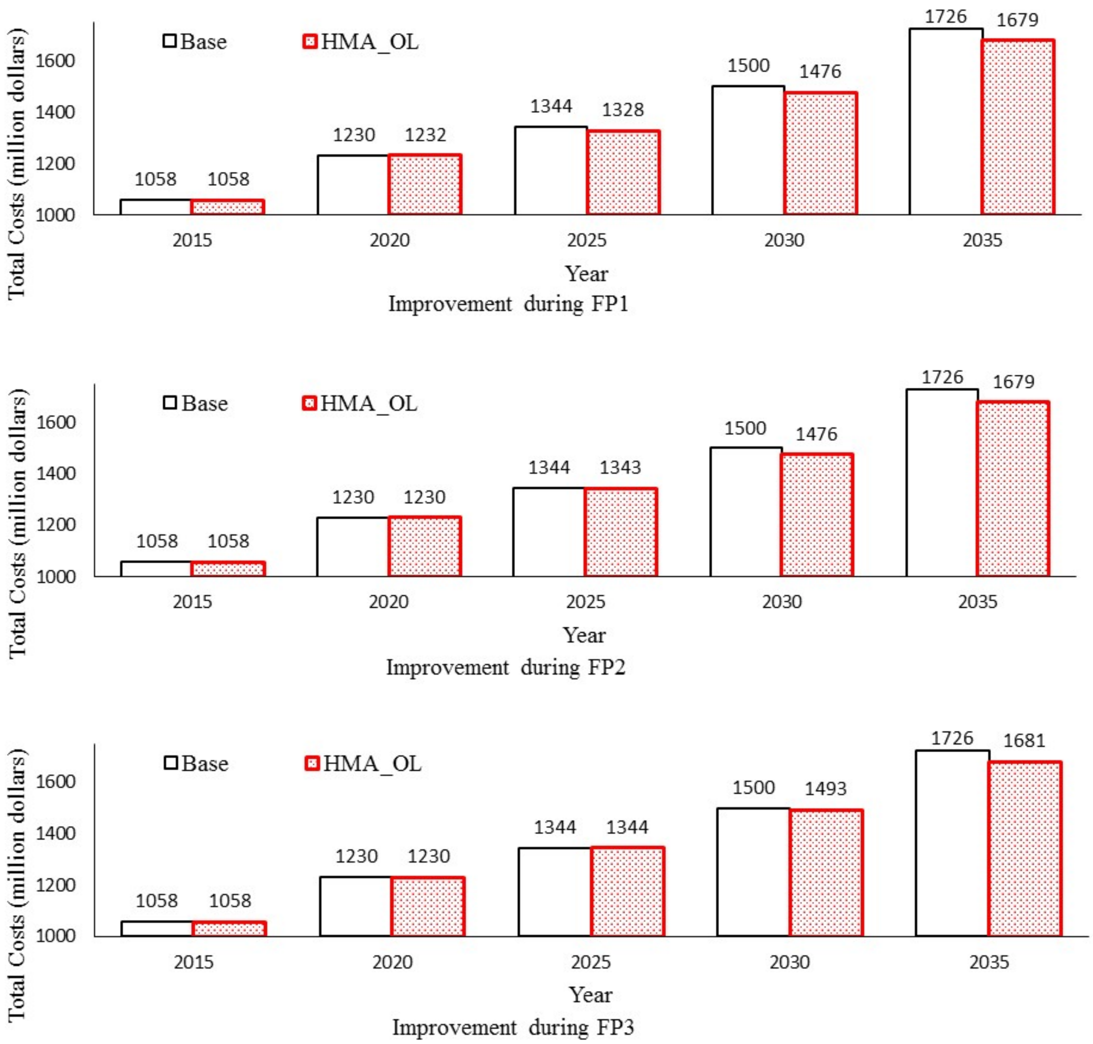


Figure 13: Scenario Analysis Results of Implementing Pavement Improvements across Different Funding Periods for I-90 W Project in Kittitas County

2025, $24 million in 2030, and $47 million in 2035), and $52 million (the sum of $7 million in 2030, and $45 million in 2035), respectively.

Based on HERS-ST system outputs for this I-90 W project and following the same procedure as the last two projects, the research team calculates each cost type's cumulative present value for each scenario. Table 6 summarizes the percentage change of each cost type's cumulative present value between baseline and each improvement strategy. The difference in total user costs and maintenance costs between HMA overlay in YR0 and PCC overlay in YR0 are small. Due to the improvement file's limitation in HERS-ST, the costs of PCC overlay after YR0 can not be estimated and are missing from the table. For the HMA Overlay, the best time is the current year. It reduces total costs by 1.094% for HMA overlay. The third funding period is the worst time. It reduces total costs by 0.394% for HMA overlay. The PCC overlay during YR0 decreases total costs by 0.964%. Therefore, this analysis confirms HMA overlay's selection.

Table 6: Change of Cumulative Present Values of Costs from Baseline to Improvement Strategies on I-90 W

	TTC_ 4Tire	TTC_ Trucks	TTC_ Total	VOC_ 4Tire	VOC_ Trucks	VOC_ Total	Crash	Total User	Maint.	Emis.	Total Costs
HMA_OL_YR0	-1.0431%	-1.8669%	-1.2890%	-1.9456%	-1.5664%	-1.7597%	.0561%	-1.4304%	-16.2071%	-.1276%	-1.0944%
HMA_OL_FP1	-.9855%	-1.7568%	-1.2439%	-1.6053%	-1.2477%	-1.4723%	.0946%	-1.2540%	-14.5297%	-.1164%	-0.9205%
HMA_OL_FP2	-1.0258%	-1.7797%	-1.2388%	-1.0823%	-.9528%	-.9872%	.0681%	-.9999%	-11.8518%	-.1272%	-0.6702%
HMA_OL_FP3	-.9479%	-1.5654%	-1.1288%	-.5270%	-.6143%	-.5373%	.0505%	-.7202%	-8.1874%	-.1142%	-0.394%
PCC_RCTR_YR0	-1.0606%	-1.8669%	-1.2890%	-1.9309%	-1.5388%	-1.7285%	.0561%	-1.4138%	-15.7246%	-.1276%	-0.9635%

Note: 1. Baseline is the unimproved scenario; "HMA_OL_YR0" or "PCC_RCTR_YR0" indicates the strategy that the HMA Overlay or PCC Reconstruction is implemented during the current year; "HMA_OL_FPx" or "PCC_RCTR_FPx" indicates the strategy that the HMA Overlay or PCC Reconstruction is implemented during the x funding period.

2. "TTC" and "VOC" denote travel time costs and vehicle operating costs, respectively; total user costs are the sum of TTC, VOC, and Crash costs; "Maint." is the annual maintenance costs from HERS-ST; "Emis." is the emission costs; "Constr." And "User Delay" are initial construction costs and user delay costs during the construction from WSDOT; total costs are the total of all costs.

3. Each value in the table is the percentage change of cumulative present value of corresponding cost type for corresponding improvement strategies. The cumulative present value is the sum of 5 single-year present values. Each of these 5 values represents the costs in the last year of each funding period.

VIII: Conclusions and Recommendations

This research report summarizes the results of a national survey to determine the extent to which other states utilize the HERS-ST software in evaluating highway improvement benefits. This comprehensive phone survey revealed that only four states currently utilize the software and each does so in different capacities. The survey results also indicated significant inconsistencies across states in how highway projects are evaluated. Most state DOTs make improvement decisions based solely on pavement conditions or budget availability.

The WSDOT began utilizing this software in conjunction with the REMI-TranSight Model to evaluate the benefits of different highway improvement projects. Within WSDOT, there are also differences in how pavement projects are evaluated by the pavement management and economic analysis groups. In general, the economic analysis of highway projects concentrates on larger construction and preservation projects over longer time horizons for planning purposes. The evaluation of pavement projects within the pavement management framework utilizes the life-cycle cost analysis approach and typically does not consider some measurable user costs, such as travel time costs and vehicle operating costs.

In order to mitigate some existing challenges and limitations of using the HERS-ST software, an Excel module, called the HERS-ST Benefit Application Tool (HERS-ST-BAT), was developed and applied to three preservation projects. This supplemental tool was created to advance HERS-ST and to improve the benefit and cost estimation process. It improves the existing process in three primary aspects.

First, the pavement and treatment type selections represent an integral component of the pavement program evaluation process. As two main choices in pavement projects, Hot Mix Asphalt (HMA) and Portland Cement Concrete (PCC) comparisons are possible in the application tool. In addition, reconstruction and overlay are included in the treatment type selection. By selecting any combination of pavement and treatment types, the value of surface type and pavement condition of the improved highway section will be modified by HERS-ST-BAT accordingly.

Second, the user cost change may not be measurable immediately following the improvement, which makes comparisons over a longer period of time extremely valuable in order to capture possible growth or decline of respective costs and benefits. This flexibility is added in the developed software, HERS-ST-BAT, to compare the unimproved scenario with various improvement strategies over 20 years. Moreover, it allows the user to postpone the project implementation until the first, second, or third funding period.

Third, the original HERS-ST system utilizes nationally-averaged parameters for estimation. In order to obtain a more accurate result that is applicable to the individual state or region, several parameters can be adjusted to the state or regional level in HERS-ST-BAT. Using the State of Washington as an example, these parameters are:

(1) Gasoline price in Washington
(2) Diesel price in the Western region, less California
(3) Washington State fuel tax
(4) Values of personal and business travel time in Washington

Note that the research team is not adopting Washington-specific diesel price in this project. For future analysis, Washington state diesel price is available to WSDOT and should be used in the BAT model. Diesel Combining this developed tool, HERS-ST-BAT, with

HERS-ST, a transportation agency is better equipped to estimate the changes of agency and user costs from a proposed pavement project with additional accuracy and flexibility.

The HERS-ST-BAT is applied to these three case studies and the results provided. The findings indicate that this proposed method has the potential to be more broadly utilized at other state DOTs and offers a more robust evaluation of pavement improvement projects with local attribute data. It should be noted that four funding periods, or 20 years in total, are the default setting in HERS-ST and have therefore been used in these case studies. It would be beneficial in the future to extend this time horizon, regardless of the increased simulation time in HERS-ST. This would allow better comparison of projects that recoup benefits over longer time horizons.

The case studies also reveal the main limitation of this method when applying the improvement file for timing analysis. If a scenario that an improvement is implemented during the first, second, or third funding period is studied, it is impossible to apply this method to the strategies of PCC overlay and reconstruction with the new pavement type that differs from the one used by the existing roads. In addition, HERS-ST is not a network model. Although some large infrastructure projects might have a spillover effect, it cannot be captured by the framework described in this report.

In conclusion, the improved method in this project provides a solution by showing a comprehensive benefit-cost picture for a variety of pavement improvement scenarios. This improved method can better inform decision makers and avoid unnecessary investments or loss from poor preservation project timing. Consequently, the method is recommended to those state DOTs where a sophisticated evaluation method for pavement improvement project is missing.

Some basic resources are necessary to apply this method. First, the HERS-ST software has to be accessible to the user, which also means that the user needs to know how to use HERS-ST. Second, applying and utilizing the HERS-ST-BAT requires a moderate-level computer knowledge in order to prepare the necessary input files. Since it stores all input and output data and enables Excel macros, low-level configurations may result in estimation being a time-consuming process with this tool. Finally, a regional HPMS file is key to running HERS-ST. For more accurate estimates, it is strongly recommended to contain the complete information in the HPMS file for several crucial variables, including AADT, IRI, and highway capacity.

References

AASHTO. (2003). *User Benefit Analysis for Highways*. Washington,D.C.: American Association of State Highway and Transportation Officials.

Byrd, A. & Barrett, G. (2013). *I-90/Oaks Ave Vic to Elk Heights Rd Vic WB-Replace/Rehab Concrete Pavement Type Selection.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Cook, G. (2013). *I-5 SB S 320th St to Duwamish River Bridge-Concrete Pavement Rehab MP 143.85 to MP 156.50 Pavement Type Selection.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Cook, G. (2015). *I-5 NB S 260th St to Duwamish River Bridge-Concrete Pavement Rehab MP 147.64 to MP 156.51 Pavement Type Selection.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Coopers & Lybrand, L.L.P. (1996). *National Highway User Survey.* Washington, DC: Federal Highway Administration, U.S. Department of transportation.

Dye Management Group. (1996). *Maintenance Management and Administration Evaluation.* Seattle, WA: Washington State Department of Transportation.

Dye Management Group. (1998). *Public Perceptions Report.* Phoenix, AZ: Arizona Department of Transportation.

Energy Information Administration (EIA). (2017). *Weekly Retail Gasoline and Diesel Prices*. Retrieved from https://www.eia.gov/dnav/pet/pet_pri_gnd_a_epm0_pte_dpgal_w.htm

Federal Highway Administration (FHWA). (2005). *HERS-ST Highway Economic Requirements System - State Version: Technical Report*. Washington, D.C.: Federal Highway Administration, U.S. Department of transportation.

Hall, K. C. (2003). Guidelines for Life-Cycle Cost Analysis of Pavement Rehabilitation Strategies. *82nd TRB Annual Meeting.* Washington, D.C.

Hicks, R. A. (1999). *Life Cycle Cost Analysis of Asphalt-Rubber Paving Materials.* Tempe, AZ: Final Report Volumes I and II to Rubber Pavement Association.

Li, N. X.-C. (1996). *Reliability-Based Processing of Markov Chains for Modeling Pavement Network Deterioration.* Transportation Research Record.

Li, Z. (2006). *Optimal Investment Decision-Making for Highway Transportation Asset Management under Risk and Uncertainty*. Chicago, IL: MRUTC.

Luhr, D. R., & Rydholm, T. (2015). *Economic Evaluation of Pavement Management Decisions.* Proceedings of the International Conference on Managing Pavement Assets 9, Alexandria, VA.

Lytton, R. (1987). Concepts of Pavement Performance Prediction and Modeling. *Second North American Conferennce on Managing Pavements*, (pp. 2.3-2.19).

Setunge, S., Kumar, A., Nezameian, A., De Silva, S., Lokuge, W., Carse, A.,… Pham, L. (2002). Whole of Life Cycle Cost Analysis in Bridge Rehabilitation. CRS Construction Innovation, 2002-005-C-03.

Sims, T. (2005). *Texas Pavement Preservation Program*. Retrieved from http://www.utexas.edu/research/tppc/pubs/sims.pdf

Smith, K. H. (2008). *Concrete Pavement Reference Manual.* Ames, IA: National Concrete Pavement Technology Center, Iowa State Unveristy.

Survey Research Center. 1999. *Survey of Licensed California Drivers Regarding Highway Maintenance Activities, Executive Summary*. University Research Foundation, California State University, Chico, CA.

Uhlmeyer, J. S., Luhr, D. R., & Rydholm, T. (2016). Pavement Asset Management. Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2007). *2007-2026 Highway System Plan (Chapter 1)*. Olympic, WA: Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2013). *WSDOT Strategies Regarding Preservation of the State Road Network – A Report to the State Legislature in Response to SB 6381.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2015). *WSDOT Pavement Policy*. Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2016a). *Average Pavement Life in Washington State.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2016b). *State Highway Surface Type Breakdown: 2014.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2016c). *WSDOT Highway Construction Costs.* Olympic, WA: Construction Office, Washington State Department of Transportation.

Washington State Department of Transportation (WSDOT). (2016d). *WSDOT Pavement Roughness (IRI) Report: 2014.* Olympic, WA: Materials Laboratory, Washington State Department of Transportation.

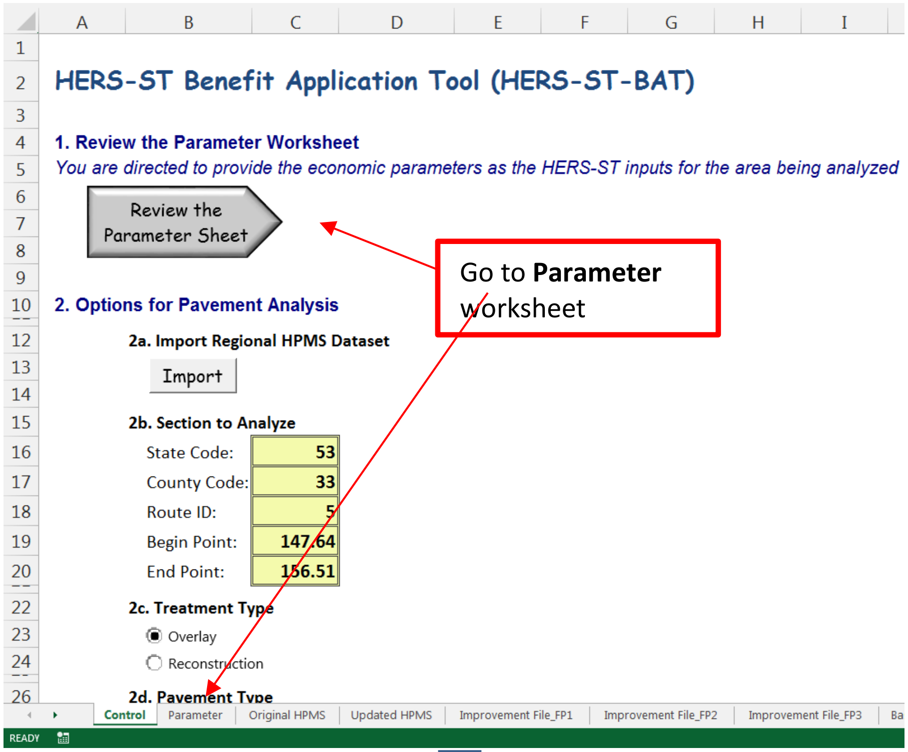
Washington State Department of Revenue (WADOR). (2017). *Motor Vehicle Fuel Tax Rates*. Retrieved from http://dor.wa.gov/Content/FindTaxesAndRates/OtherTaxes/tax_MVfuel.aspx

White, G. (2012). *WSDOT Pavement Preservation Guide for Local Agencies*. WSDOT Research Report, WA-RD 800.1.

Wilde, J. S. (1999). *Life Cycle Cost Analysis of Portland Cement Concrete Pavements.* Austin, TX: The University of Texas at Austin.

Appendix A: HERS-ST-BAT Instruction Manual

1. Review the Parameter Worksheet



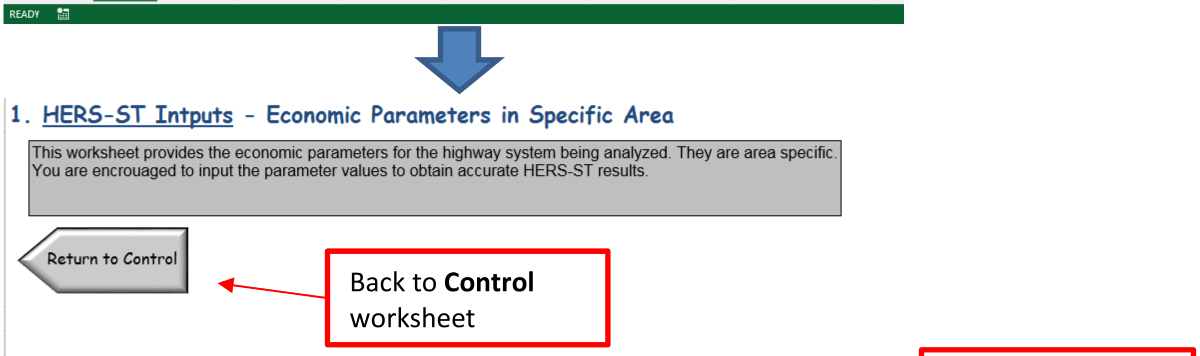
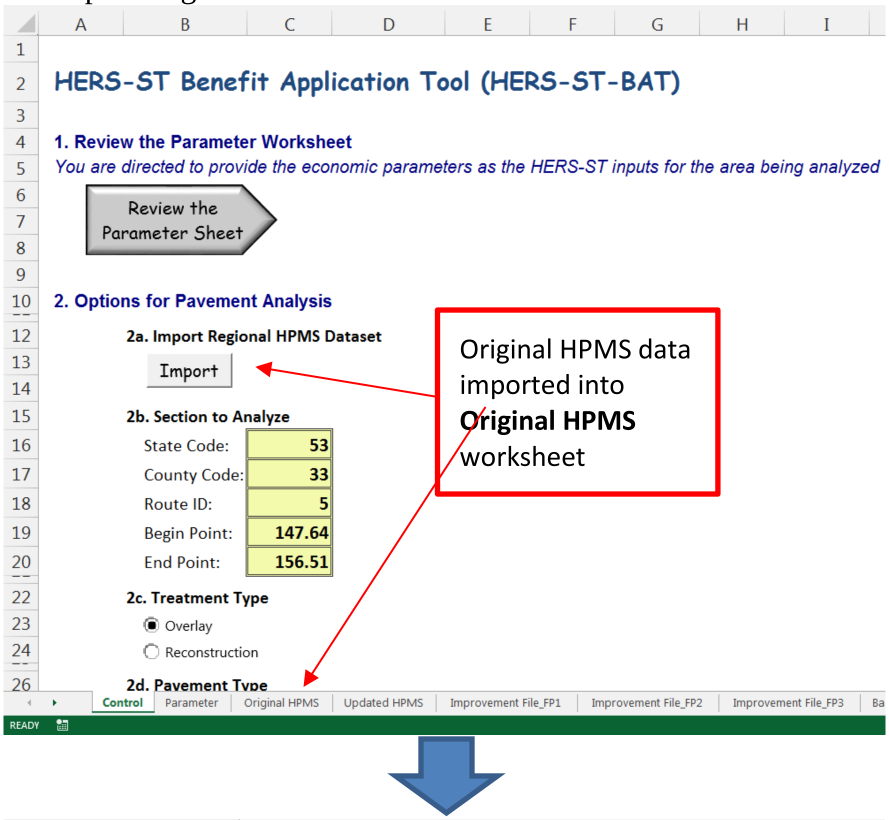


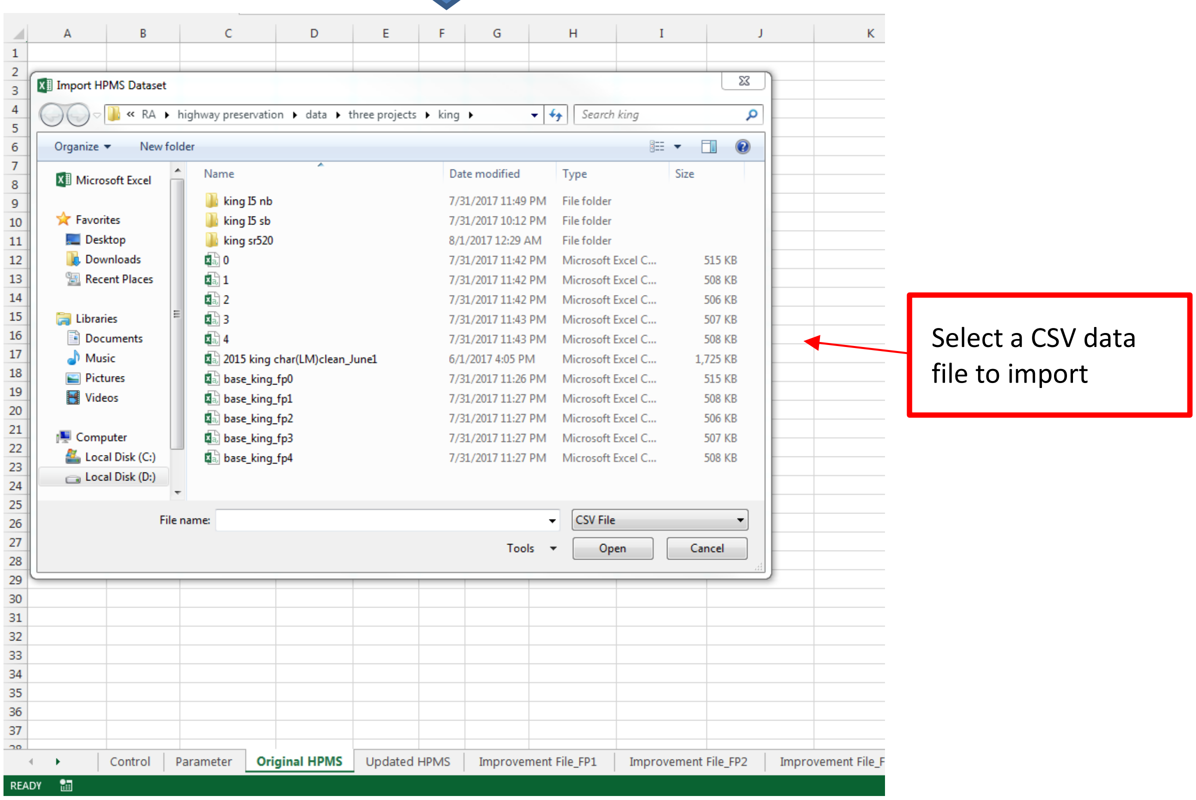
Table 1. Parameters of Vehicle Operating Costs and Travel Time Costs-Improved Version

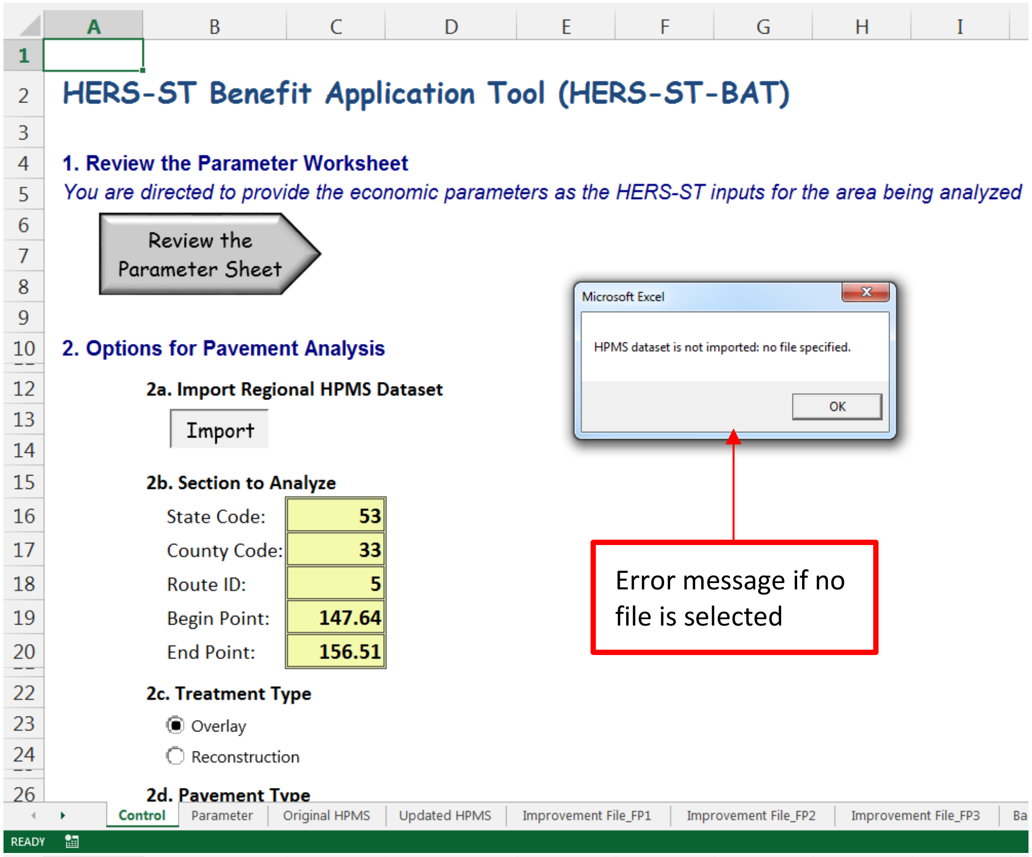
Costs	small auto	large auto	pickup/Vans	6-tire trucks	3-axle SU Truck	3-AxleCB Truck	5-Axle CB Truck
Vehicle Operating							
Fuel	2.816	2.816	2.816	2.816	2.755	2.755	2.755
Federal Tax	0.184	0.184	0.184	0.184	0.244	0.244	0.244
State Tax	0.494	0.494	0.494	0.494	0.494	0.494	0.494
Oil	3.479	3.479	3.479	1.391	1.391	1.391	1.391
Tires	45.8	72.4	79.8	192.6	476.9	476.9	476.9
Maintenance	79.6	96.6	122.8	229.8	325	336.6	336.6
Depreciation Value	16322	19251	20746	31000	68200	79000	85900
Business Travel							
Value per Person	20	20	20	20	30	33.93	33.93
Avg. Occupancy	1.04	1.04	1.04	1.01	1.01	1.02	1.02
Vehicle	2.79	3.42	4.41	6.22	8.97	8.05	7.33
Inventory	0	0	0	0	0	0.77	0.77
Personal Travel							
Value per Person	15	15	15	15	26	0	0
Avg. Occupancy	1.38	1.38	1.61	1.61	20.2	0	0
Percent Personal	0.952	0.952	0.943	0	0.111	0	0

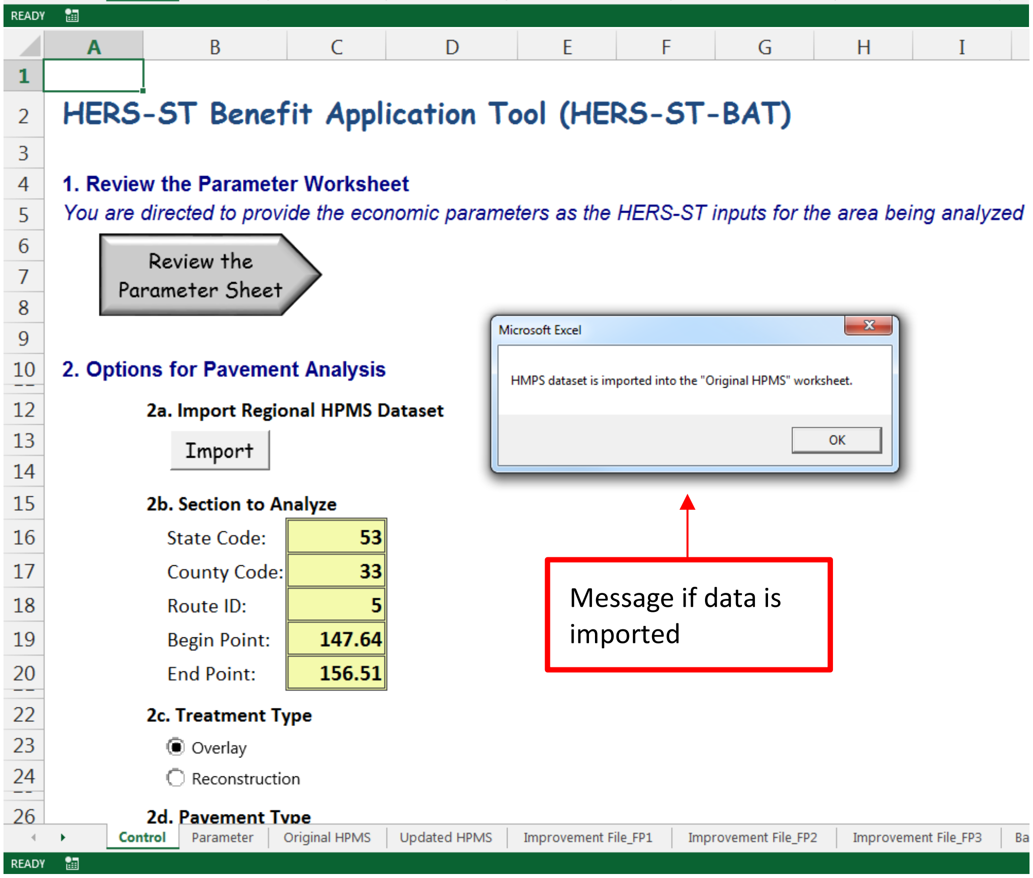
2. Options for Pavement Analysis

2a. Import Regional HPMS Dataset

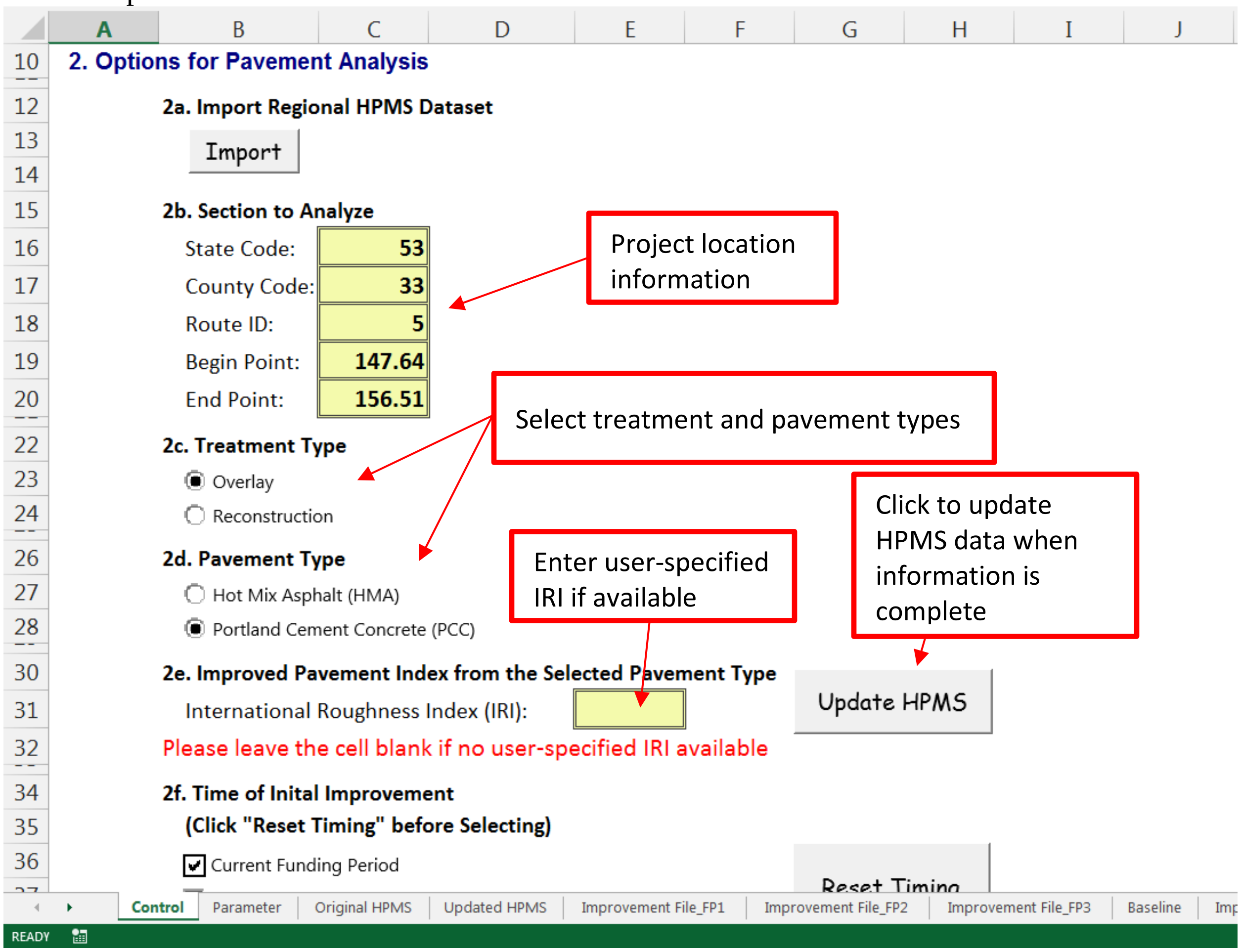




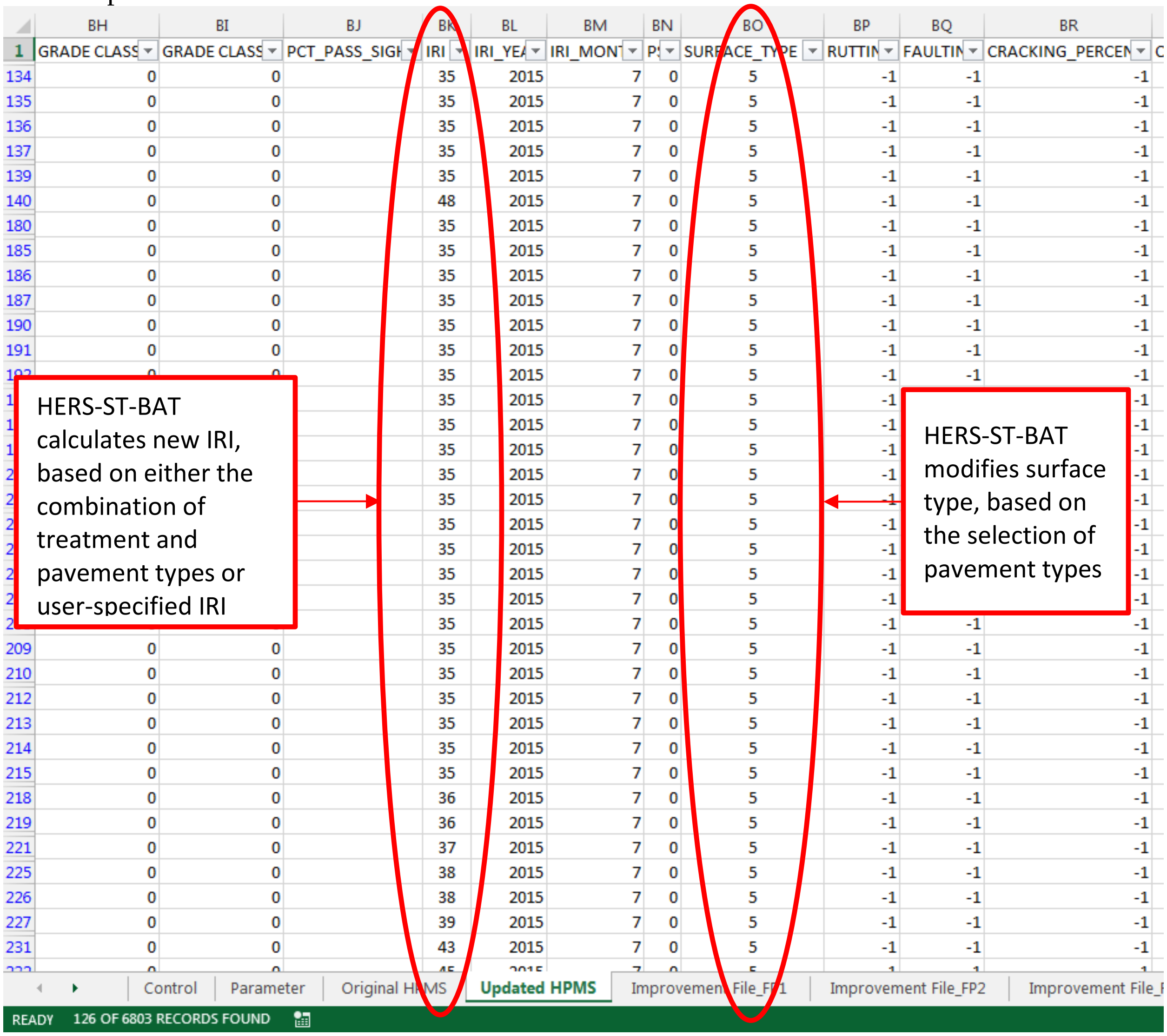

HERS-ST Benefit Application Tool (HERS-ST-BAT)
1. Review the Parameter Worksheet
You are directed to provide the economic parameters as the HERS-ST inputs for the area being analyzed
Review the Parameter Sheet
2. Options for Pavement Analysis
2a. Import Regional HPMS Dataset
Import
2b. Section to Analyze
State Code: 53
County Code: 33
Route ID: 5
Begin Point: 147.64
End Point: 156.51
2c. Treatment Type
Overlay
Reconstruction
2d. Pavement Type
Microsoft Excel
HPMS dataset is not imported: no file specified.
OK
Error message if no file is selected
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
READY

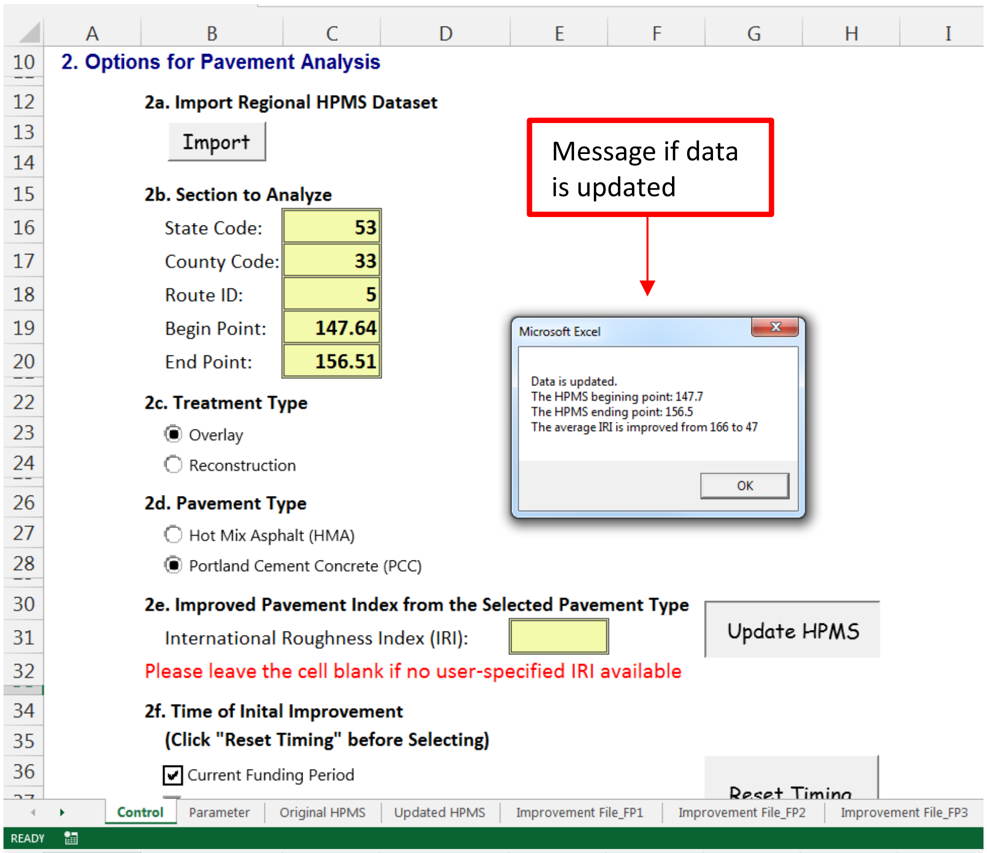

HERS-ST Benefit Application Tool (HERS-ST-BAT)
1. Review the Parameter Worksheet
You are directed to provide the economic parameters as the HERS-ST inputs for the area being analyzed
Review the Parameter Sheet
2. Options for Pavement Analysis
2a. Import Regional HPMS Dataset
Import
2b. Section to Analyze
State Code: 53
County Code: 33
Route ID: 5
Begin Point: 147.64
End Point: 156.51
2c. Treatment Type
Overlay
Reconstruction
2d. Pavement Type
Microsoft Excel
HMPS dataset is imported into the "Original HPMS" worksheet.
OK
Message if data is imported
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
READY

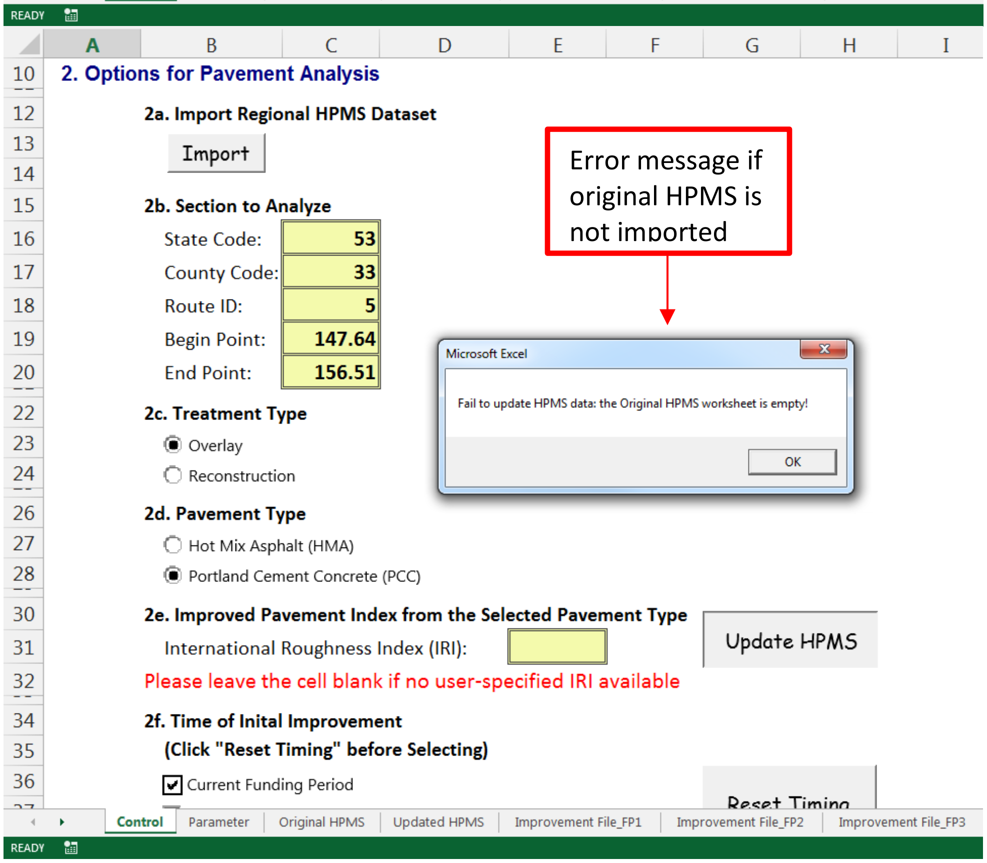
2b-2e. Improvement Information

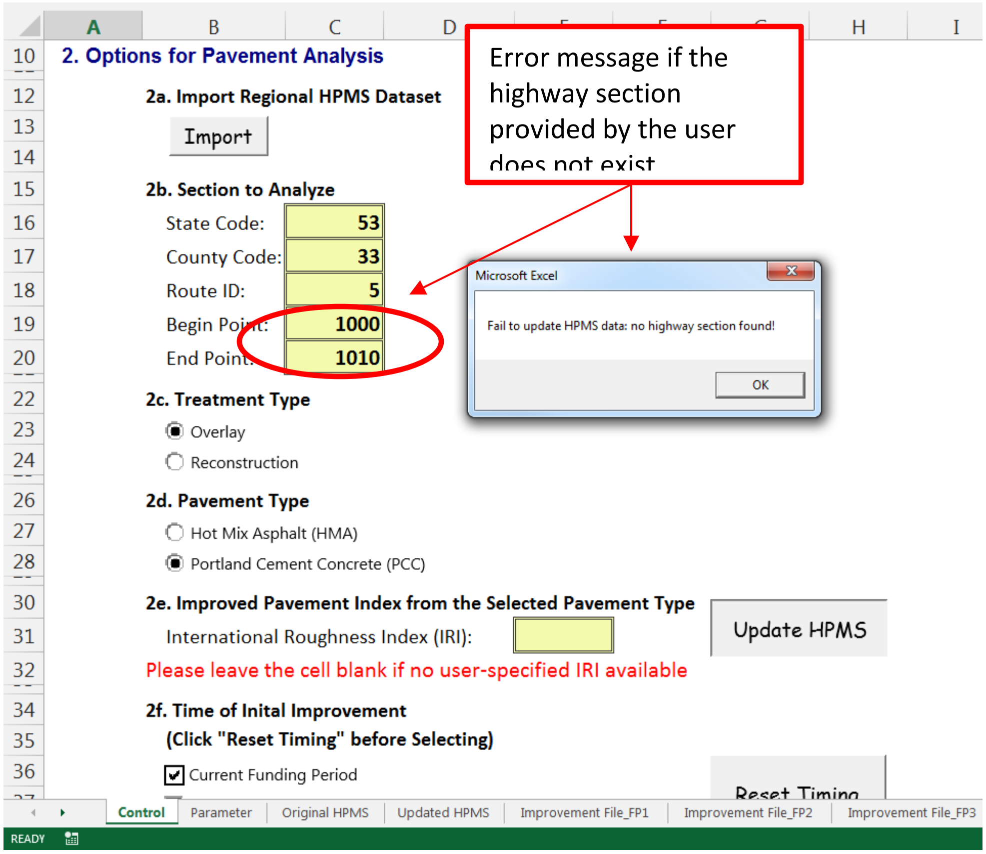


2b-2e. Update HPMS Data

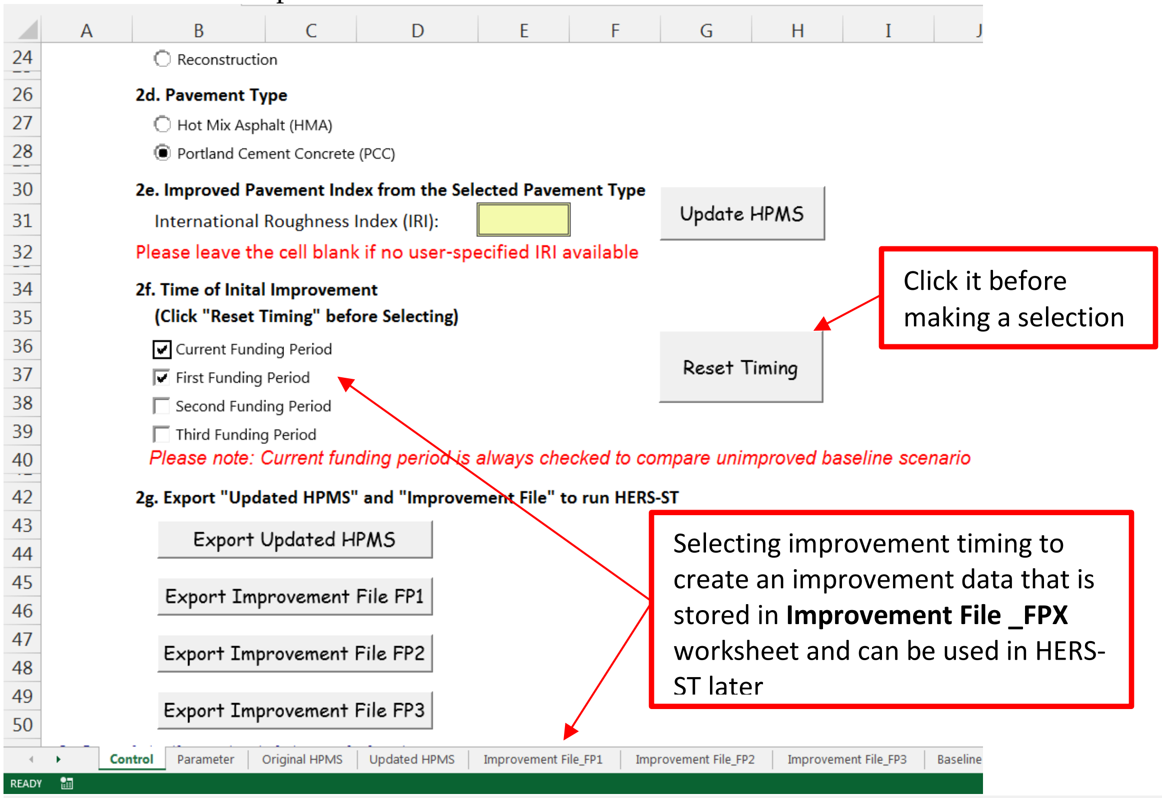


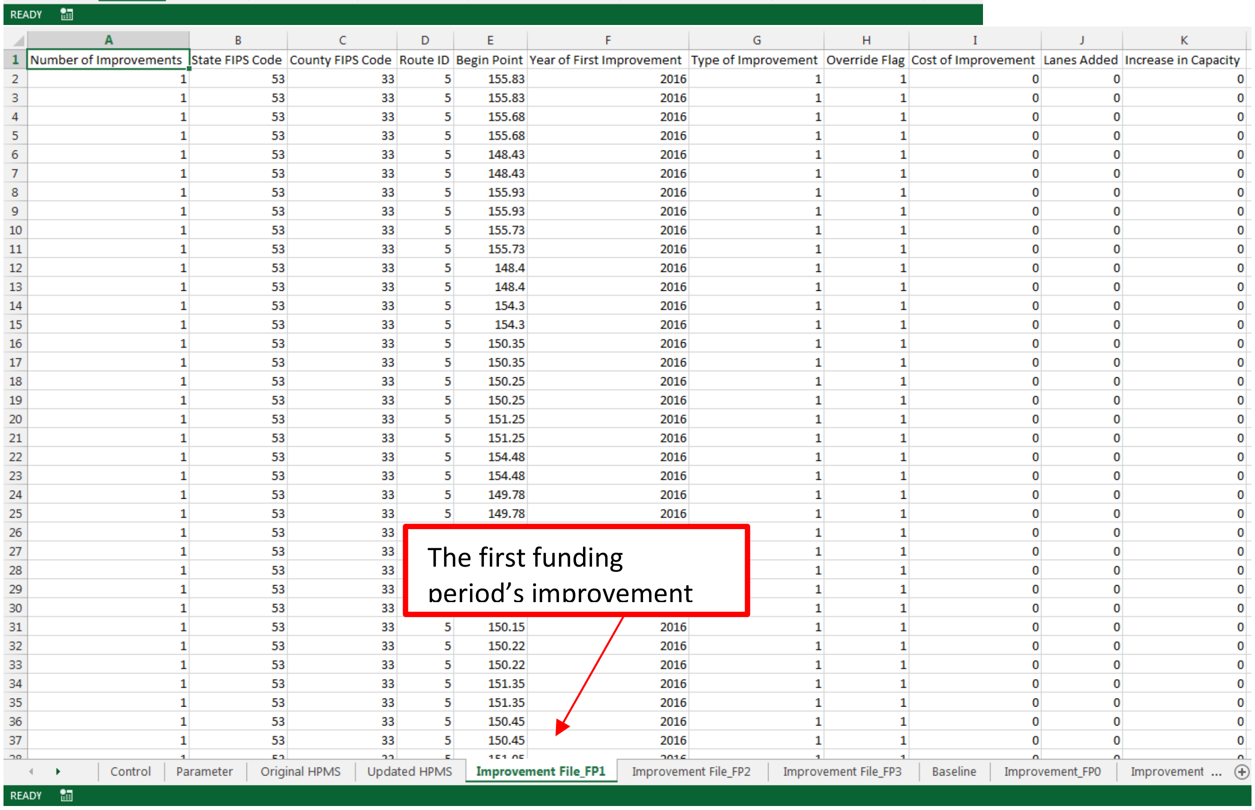

2. Options for Pavement Analysis
2a. Import Regional HPMS Dataset
Import
2b. Section to Analyze
State Code: 53
County Code: 33
Route ID: 5
Begin Point: 147.64
End Point: 156.51
2c. Treatment Type
Overlay
Reconstruction
2d. Pavement Type
Hot Mix Asphalt (HMA)
Portland Cement Concrete (PCC)
2e. Improved Pavement Index from the Selected Pavement Type
International Roughness Index (IRI):
Update HPMS
Please leave the cell blank if no user-specified IRI available
2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
Message if data is updated
Microsoft Excel
Data is updated.
The HPMS begining point: 147.7
The HPMS ending point: 156.5
The average IRI is improved from 166 to 47
OK
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
READY


2. Options for Pavement Analysis
2a. Import Regional HPMS Dataset
Import
2b. Section to Analyze
State Code: 53
County Code: 33
Route ID: 5
Begin Point: 147.64
End Point: 156.51
2c. Treatment Type
Overlay
Reconstruction
2d. Pavement Type
Hot Mix Asphalt (HMA)
Portland Cement Concrete (PCC)
2e. Improved Pavement Index from the Selected Pavement Type
International Roughness Index (IRI):
Update HPMS
Please leave the cell blank if no user-specified IRI available
2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
Error message if original HPMS is not imported
Microsoft Excel
Fail to update HPMS data: the Original HPMS worksheet is empty!
OK
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
READY

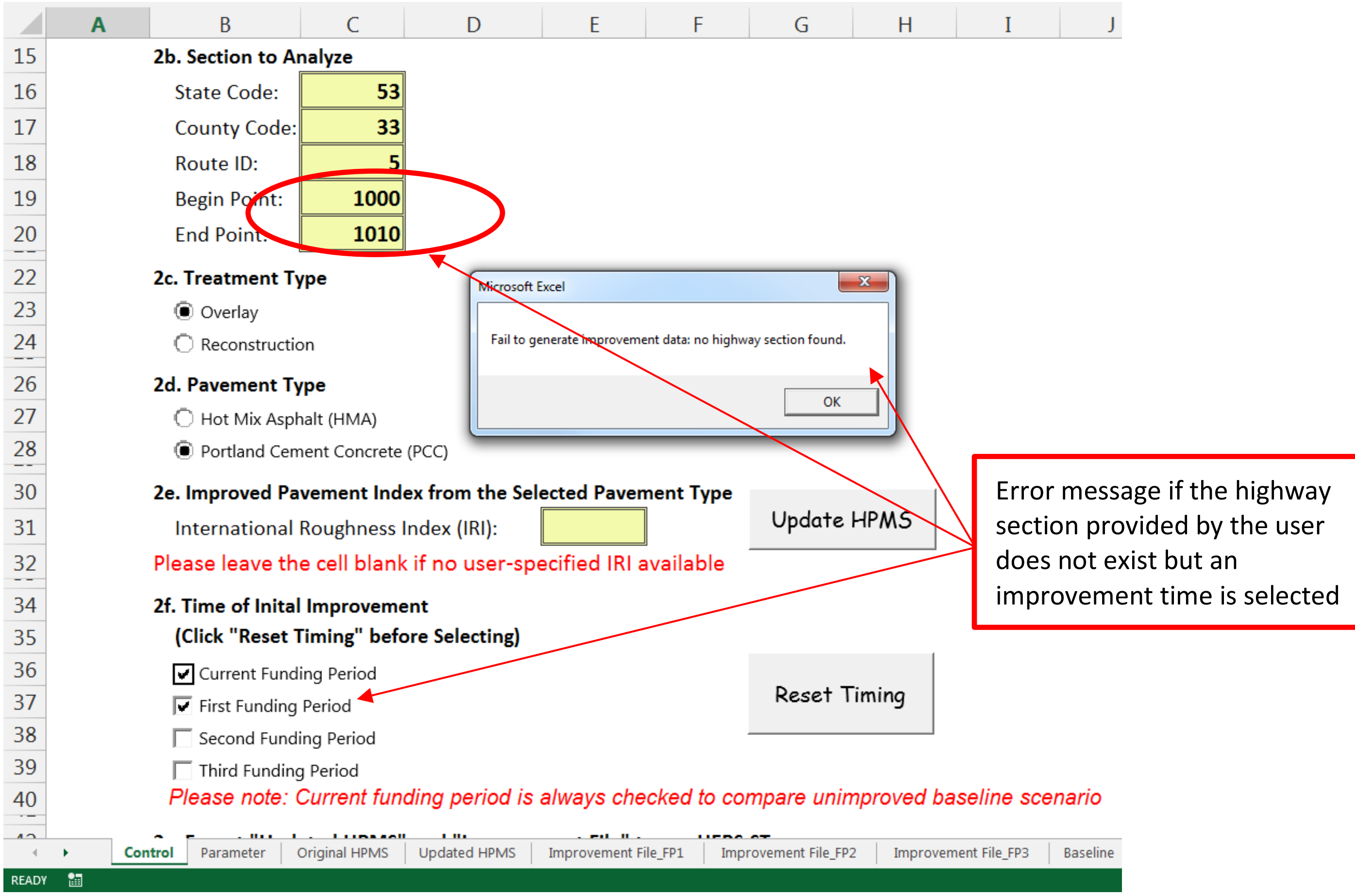

Error message if the highway section provided by the user does not exist
2. Options for Pavement Analysis
2a. Import Regional HPMS Dataset
Import
2b. Section to Analyze
State Code: 53
County Code: 33
Route ID: 5
Begin Point: 1000
End Point: 1010
Microsoft Excel
Fail to update HPMS data: no highway section found!
OK
2c. Treatment Type
Overlay
Reconstruction
2d. Pavement Type
Hot Mix Asphalt (HMA)
Portland Cement Concrete (PCC)
2e. Improved Pavement Index from the Selected Pavement Type
International Roughness Index (IRI):
Update HPMS
Please leave the cell blank if no user-specified IRI available
2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
READY

2f. Time of Initial Improvement

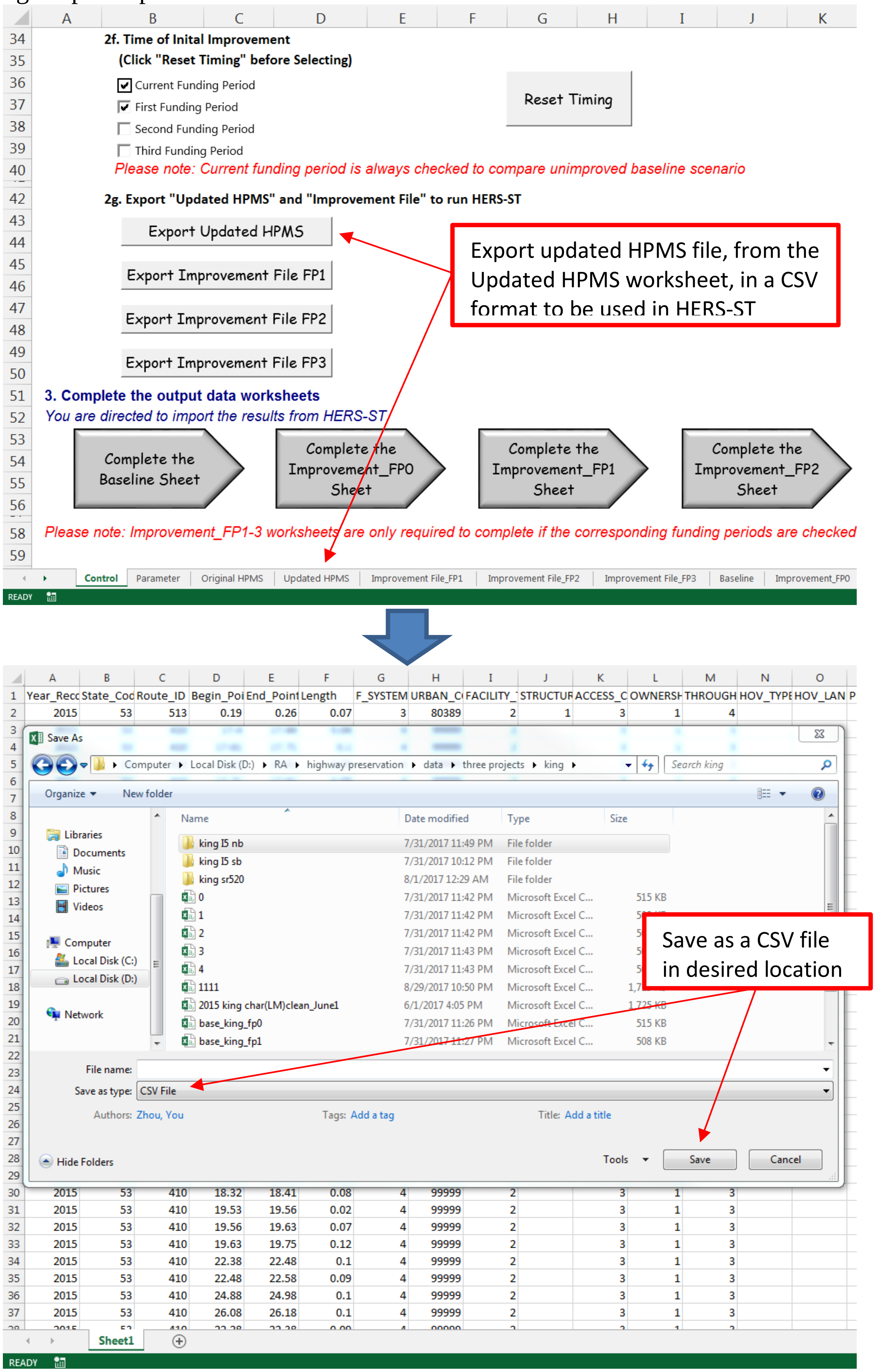


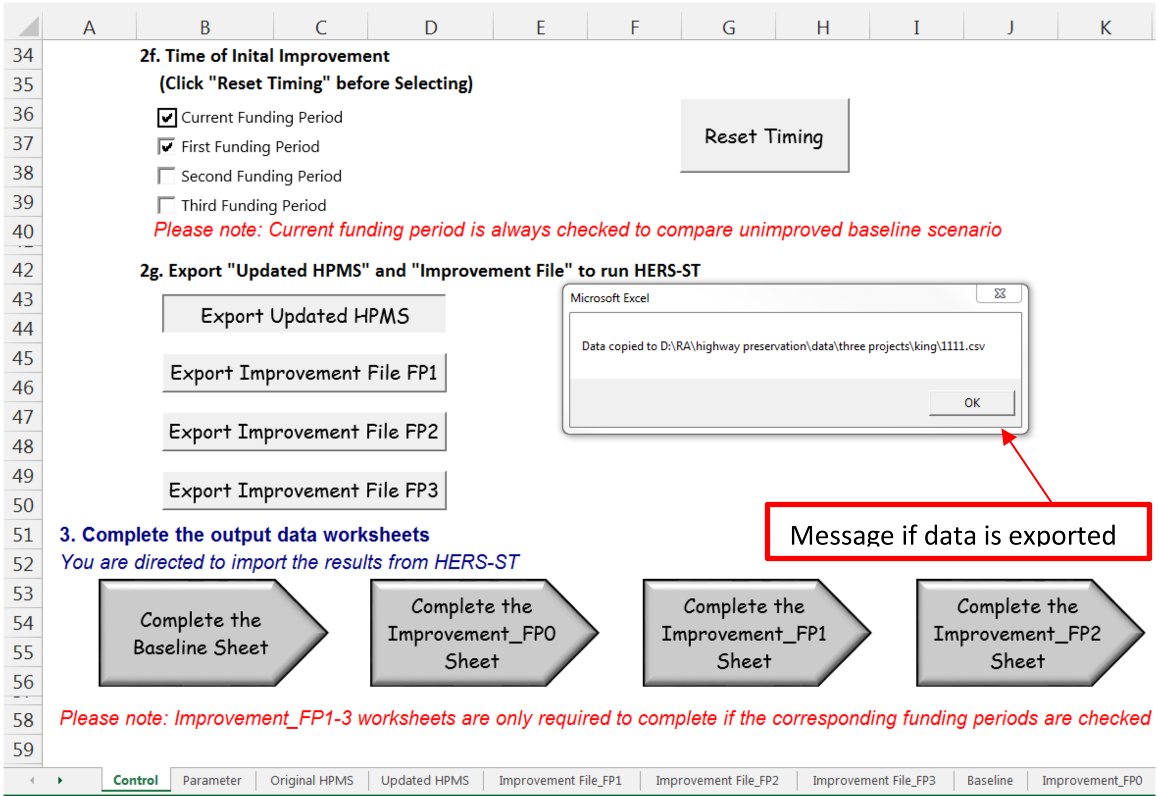


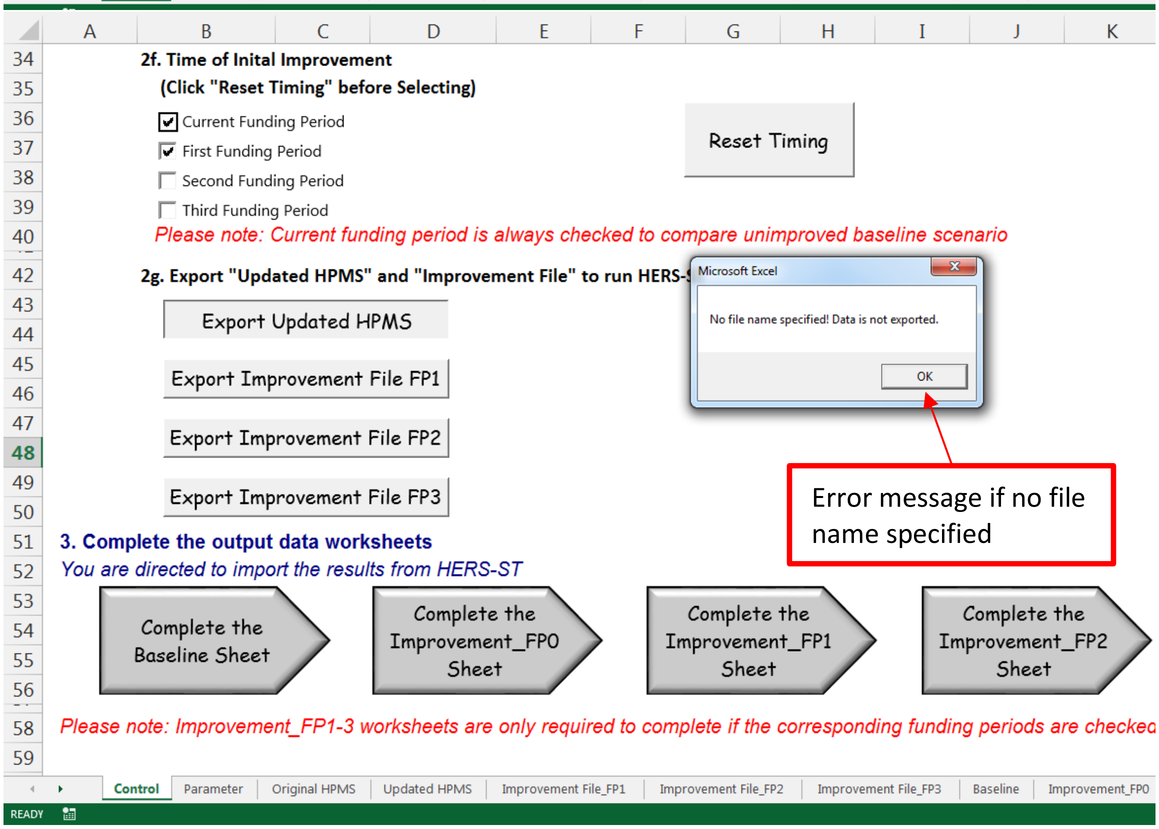
	Number of Improvements	State FIPS Code	County FIPS Code	Route ID	Begin Point	Year of First Improvement	Type of Improvement	Override Flag	Cost of Improvement	Lanes Added	Increase in Capacity
2	1	53	33	5	155.83	2016	1	1	0	0	0
3	1	53	33	5	155.83	2016	1	1	0	0	0
4	1	53	33	5	155.68	2016	1	1	0	0	0
5	1	53	33	5	155.68	2016	1	1	0	0	0
6	1	53	33	5	148.43	2016	1	1	0	0	0
7	1	53	33	5	148.43	2016	1	1	0	0	0
8	1	53	33	5	155.93	2016	1	1	0	0	0
9	1	53	33	5	155.93	2016	1	1	0	0	0
10	1	53	33	5	155.73	2016	1	1	0	0	0
11	1	53	33	5	155.73	2016	1	1	0	0	0
12	1	53	33	5	148.4	2016	1	1	0	0	0
13	1	53	33	5	148.4	2016	1	1	0	0	0
14	1	53	33	5	154.3	2016	1	1	0	0	0
15	1	53	33	5	154.3	2016	1	1	0	0	0
16	1	53	33	5	150.35	2016	1	1	0	0	0
17	1	53	33	5	150.35	2016	1	1	0	0	0
18	1	53	33	5	150.25	2016	1	1	0	0	0
19	1	53	33	5	150.25	2016	1	1	0	0	0
20	1	53	33	5	151.25	2016	1	1	0	0	0
21	1	53	33	5	151.25	2016	1	1	0	0	0
22	1	53	33	5	154.48	2016	1	1	0	0	0
23	1	53	33	5	154.48	2016	1	1	0	0	0
24	1	53	33	5	149.78	2016	1	1	0	0	0
25	1	53	33	5	149.78	2016	1	1	0	0	0
26	1	53	33				1	1	0	0	0
27	1	53	33				1	1	0	0	0
28	1	53	33				1	1	0	0	0
29	1	53	33				1	1	0	0	0
30	1	53	33				1	1	0	0	0
31	1	53	33	5	150.15	2016	1	1	0	0	0
32	1	53	33	5	150.22	2016	1	1	0	0	0
33	1	53	33	5	150.22	2016	1	1	0	0	0
34	1	53	33	5	151.35	2016	1	1	0	0	0
35	1	53	33	5	151.35	2016	1	1	0	0	0
36	1	53	33	5	150.45	2016	1	1	0	0	0
37	1	53	33	5	150.45	2016	1	1	0	0	0

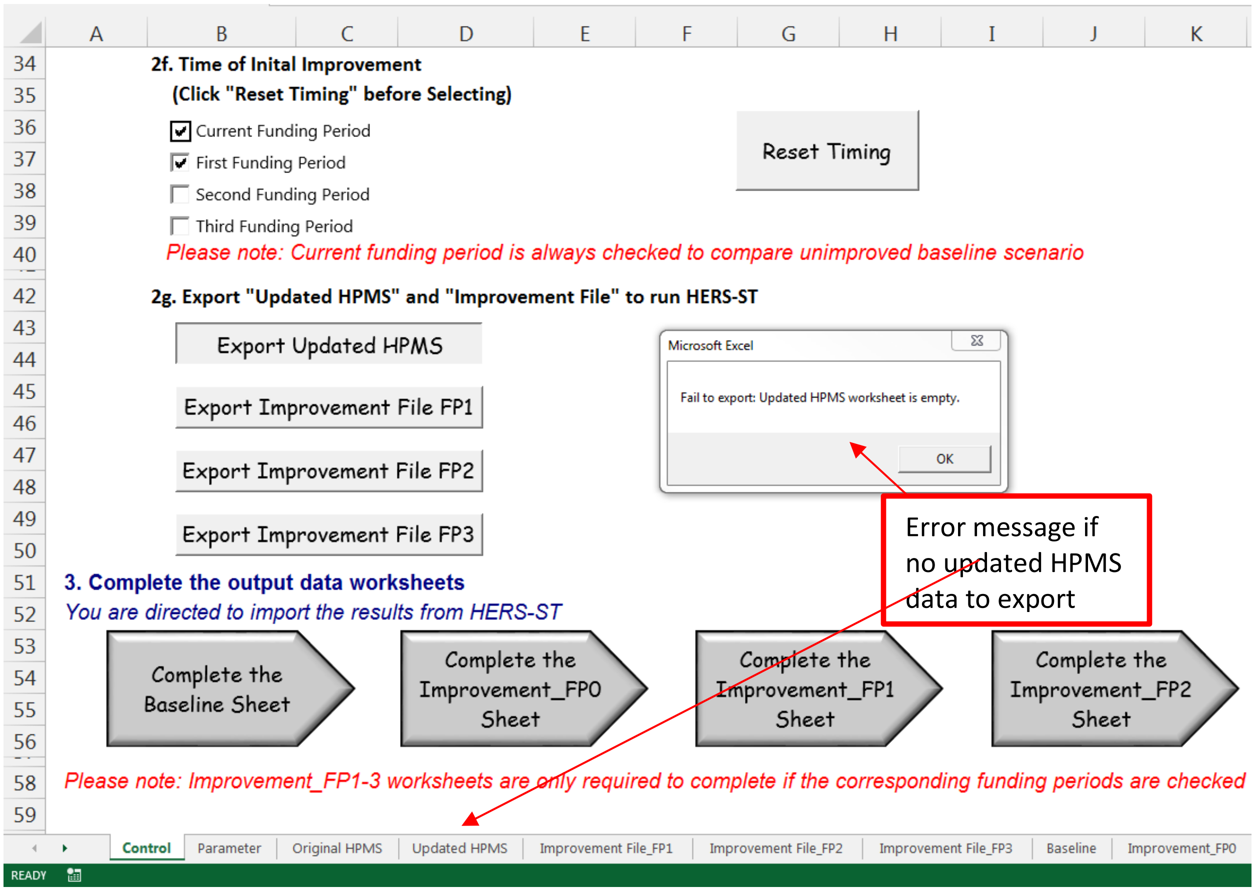

2b. Section to Analyze
State Code: 53
County Code: 33
Route ID: 5
Begin Point: 1000
End Point: 1010
2c. Treatment Type
Overlay
Reconstruction
2d. Pavement Type
Hot Mix Asphalt (HMA)
Portland Cement Concrete (PCC)
2e. Improved Pavement Index from the Selected Pavement Type
International Roughness Index (IRI):
Please leave the cell blank if no user-specified IRI available
2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Please note: Current funding period is always checked to compare unimproved baseline scenario
Update HPMS
Reset Timing
Microsoft Excel
Fail to generate improvement data: no highway section found.
OK
Error message if the highway section provided by the user does not exist but an improvement time is selected
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
READY

2g. Export Updated HPMS Data

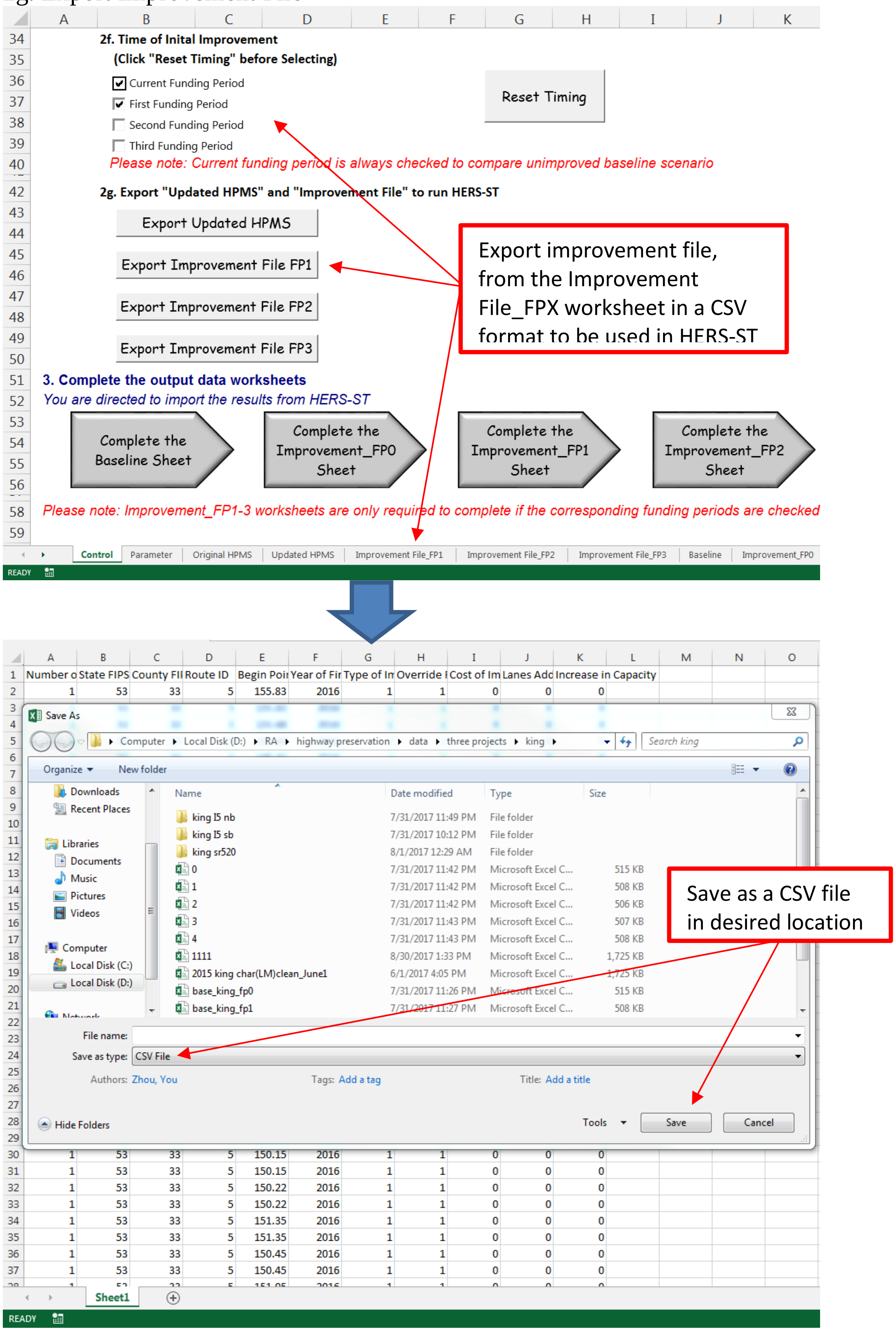


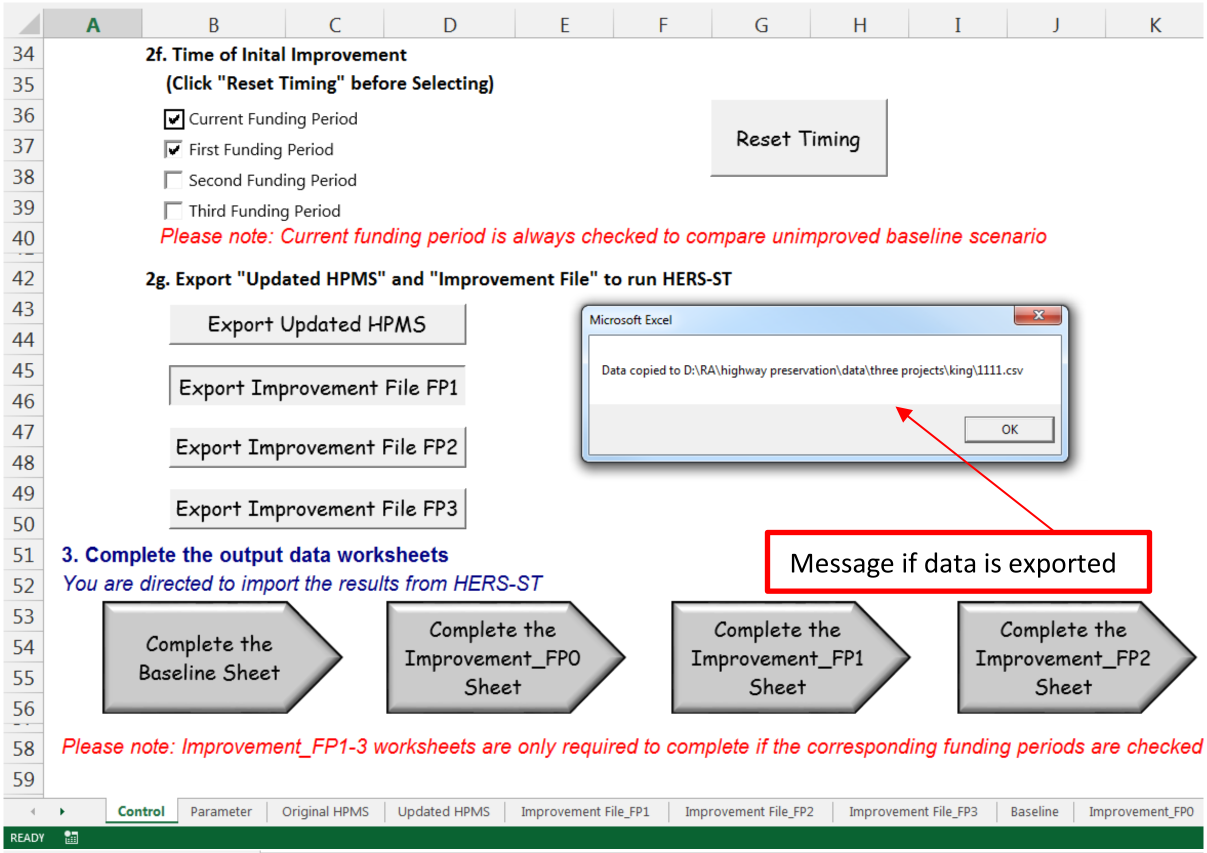

2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Reset Timing
Please note: Current funding period is always checked to compare unimproved baseline scenario
2g. Export "Updated HPMS" and "Improvement File" to run HERS-ST
Export Updated HPMS
Export Improvement File FP1
Export Improvement File FP2
Export Improvement File FP3
Microsoft Excel
Data copied to D:\RA\highway preservation\data\three projects\king\1111.csv
OK
Message if data is exported
3. Complete the output data worksheets
You are directed to import the results from HERS-ST
Complete the Baseline Sheet
Complete the Improvement_FP0 Sheet
Complete the Improvement_FP1 Sheet
Complete the Improvement_FP2 Sheet
Please note: Improvement_FP1-3 worksheets are only required to complete if the corresponding funding periods are checked
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0

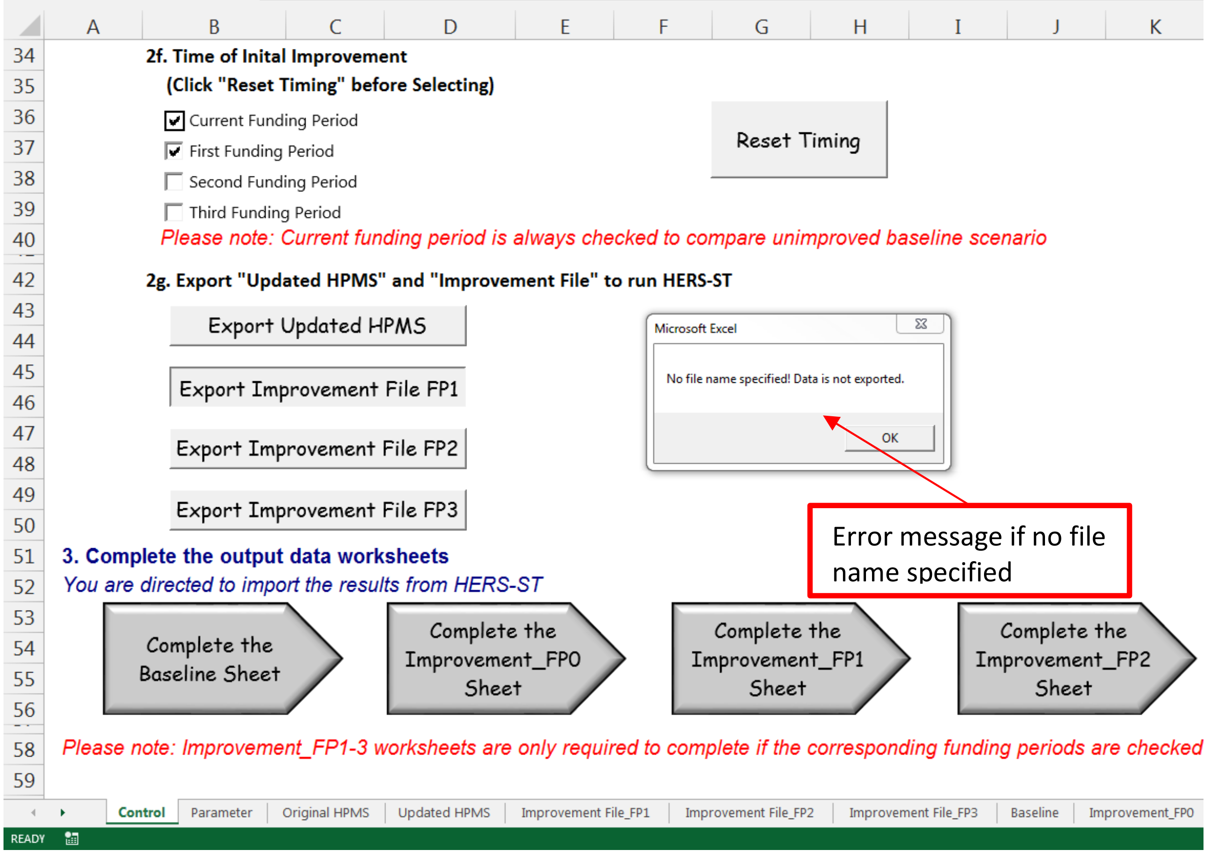

2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Reset Timing
Please note: Current funding period is always checked to compare unimproved baseline scenario
2g. Export "Updated HPMS" and "Improvement File" to run HERS-
Export Updated HPMS
Export Improvement File FP1
Export Improvement File FP2
Export Improvement File FP3
Microsoft Excel
No file name specified! Data is not exported.
OK
Error message if no file name specified
3. Complete the output data worksheets
You are directed to import the results from HERS-ST
Complete the Baseline Sheet
Complete the Improvement_FP0 Sheet
Complete the Improvement_FP1 Sheet
Complete the Improvement_FP2 Sheet
Please note: Improvement_FP1-3 worksheets are only required to complete if the corresponding funding periods are checked
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0
READY

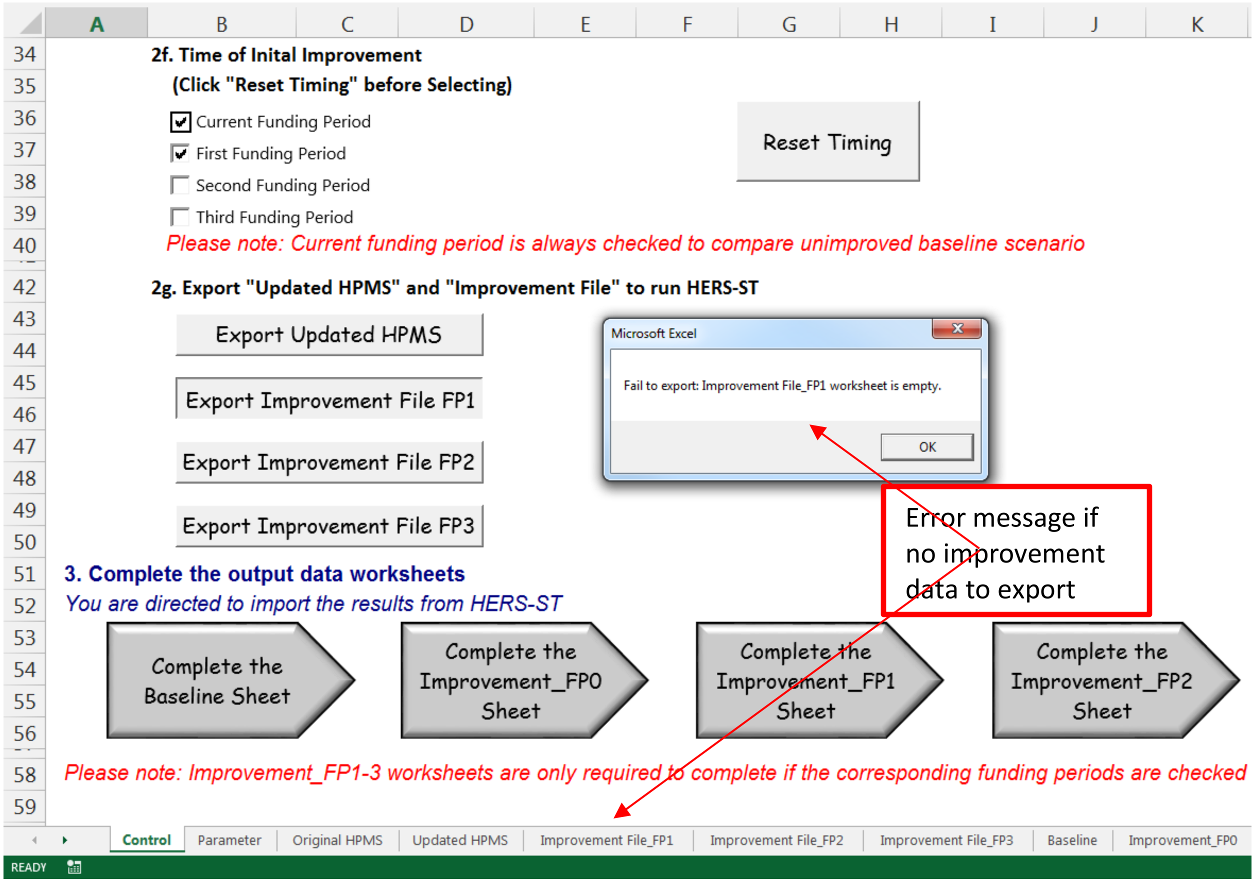

2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Reset Timing
Please note: Current funding period is always checked to compare unimproved baseline scenario
2g. Export "Updated HPMS" and "Improvement File" to run HERS-ST
Export Updated HPMS
Export Improvement File FP1
Export Improvement File FP2
Export Improvement File FP3
Microsoft Excel
Fail to export: Updated HPMS worksheet is empty.
OK
Error message if no updated HPMS data to export
3. Complete the output data worksheets
You are directed to import the results from HERS-ST
Complete the Baseline Sheet
Complete the Improvement_FP0 Sheet
Complete the Improvement_FP1 Sheet
Complete the Improvement_FP2 Sheet
Please note: Improvement_FP1-3 worksheets are only required to complete if the corresponding funding periods are checked
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0
READY

2g. Export Improvement File



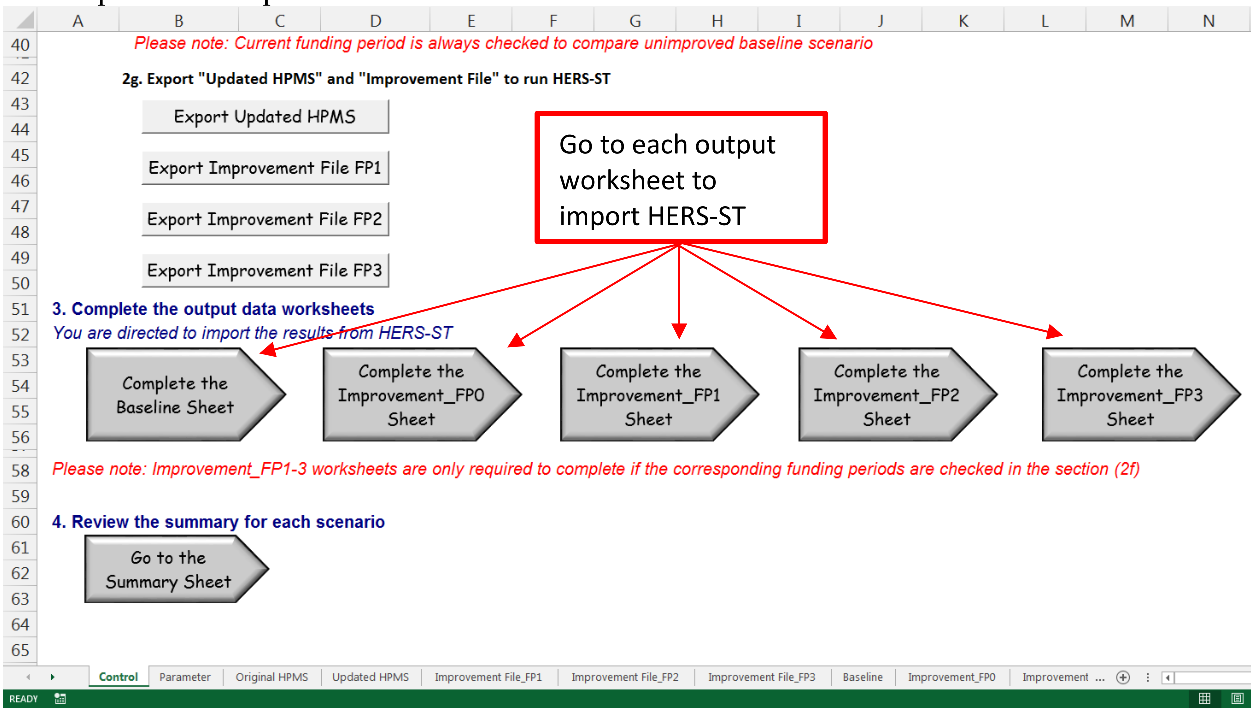

2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Reset Timing
Please note: Current funding period is always checked to compare unimproved baseline scenario
2g. Export "Updated HPMS" and "Improvement File" to run HERS-ST
Export Updated HPMS
Export Improvement File FP1
Export Improvement File FP2
Export Improvement File FP3
Microsoft Excel
Data copied to D:\RA\highway preservation\data\three projects\king\1111.csv
OK
Message if data is exported
3. Complete the output data worksheets
You are directed to import the results from HERS-ST
Complete the Baseline Sheet
Complete the Improvement_FP0 Sheet
Complete the Improvement_FP1 Sheet
Complete the Improvement_FP2 Sheet
Please note: Improvement_FP1-3 worksheets are only required to complete if the corresponding funding periods are checked
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0
READY

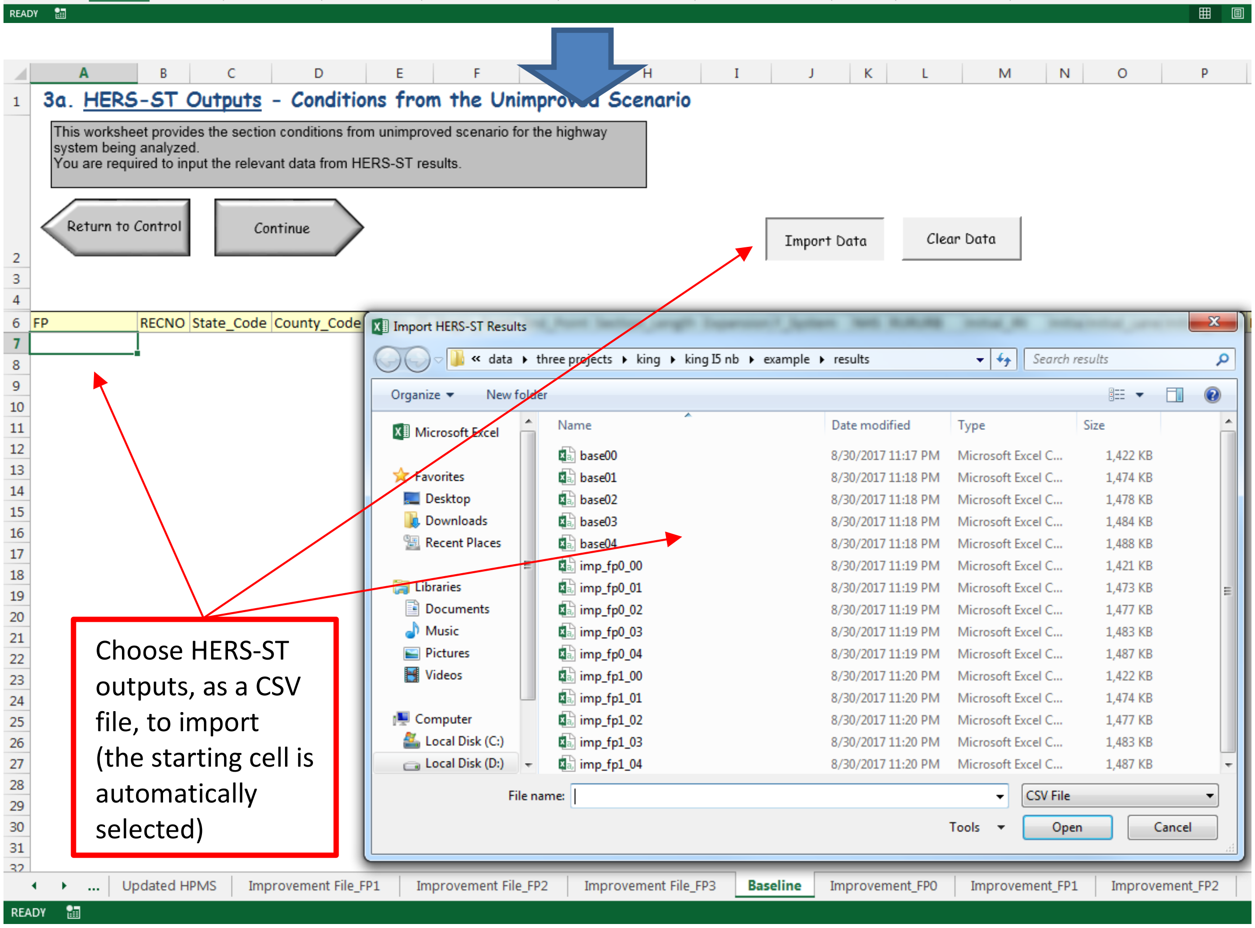

2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Reset Timing
Please note: Current funding period is always checked to compare unimproved baseline scenario
2g. Export "Updated HPMS" and "Improvement File" to run HERS-ST
Export Updated HPMS
Export Improvement File FP1
Export Improvement File FP2
Export Improvement File FP3
Microsoft Excel
No file name specified! Data is not exported.
OK
Error message if no file name specified
3. Complete the output data worksheets
You are directed to import the results from HERS-ST
Complete the Baseline Sheet
Complete the Improvement_FP0 Sheet
Complete the Improvement_FP1 Sheet
Complete the Improvement_FP2 Sheet
Please note: Improvement_FP1-3 worksheets are only required to complete if the corresponding funding periods are checked
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0
READY

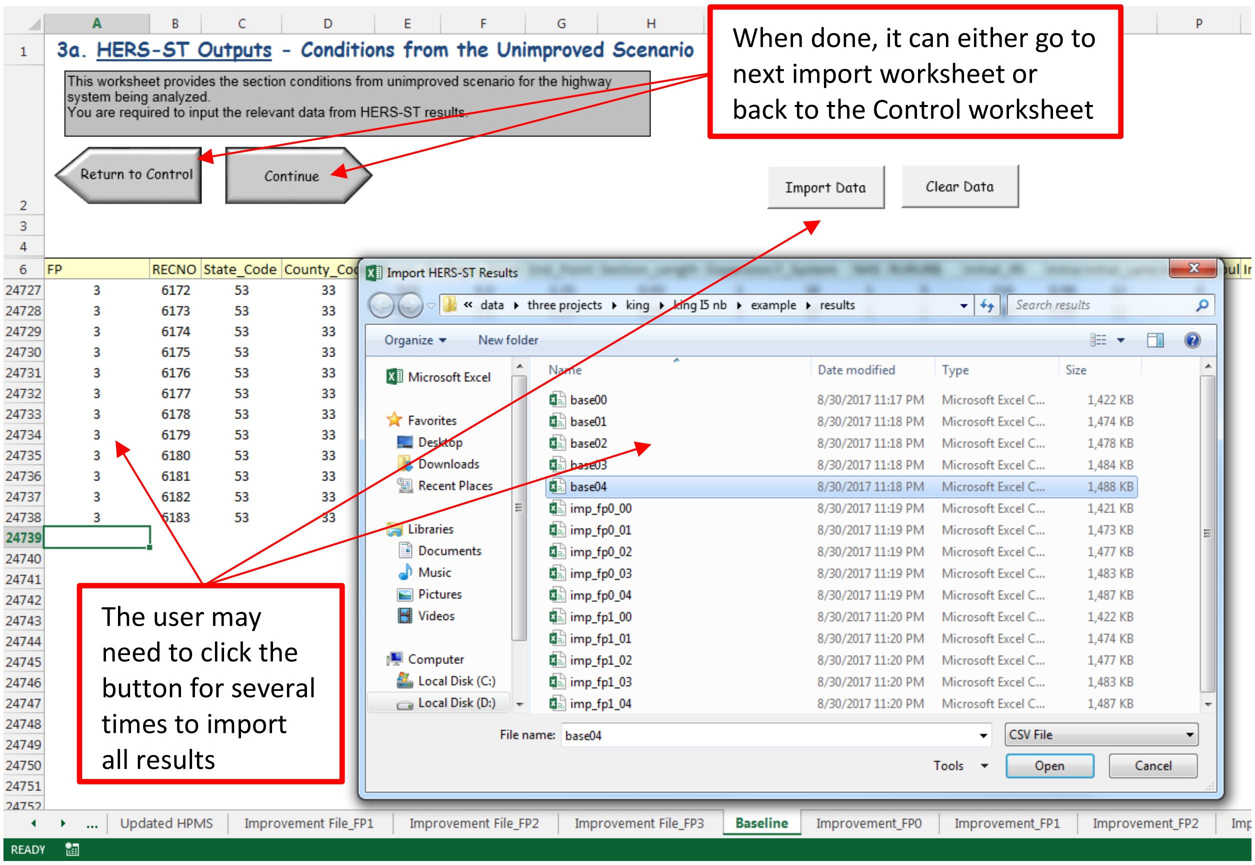


2f. Time of Inital Improvement
(Click "Reset Timing" before Selecting)
Current Funding Period
First Funding Period
Second Funding Period
Third Funding Period
Reset Timing
Please note: Current funding period is always checked to compare unimproved baseline scenario
2g. Export "Updated HPMS" and "Improvement File" to run HERS-ST
Export Updated HPMS
Export Improvement File FP1
Export Improvement File FP2
Export Improvement File FP3
Microsoft Excel
Fail to export: Improvement File_FP1 worksheet is empty.
OK
Error message if no improvement data to export
3. Complete the output data worksheets
You are directed to import the results from HERS-ST
Complete the Baseline Sheet
Complete the Improvement_FP0 Sheet
Complete the Improvement_FP1 Sheet
Complete the Improvement_FP2 Sheet
Please note: Improvement_FP1-3 worksheets are only required to complete if the corresponding funding periods are checked
Control
Parameter
Original HPMS
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0
READY

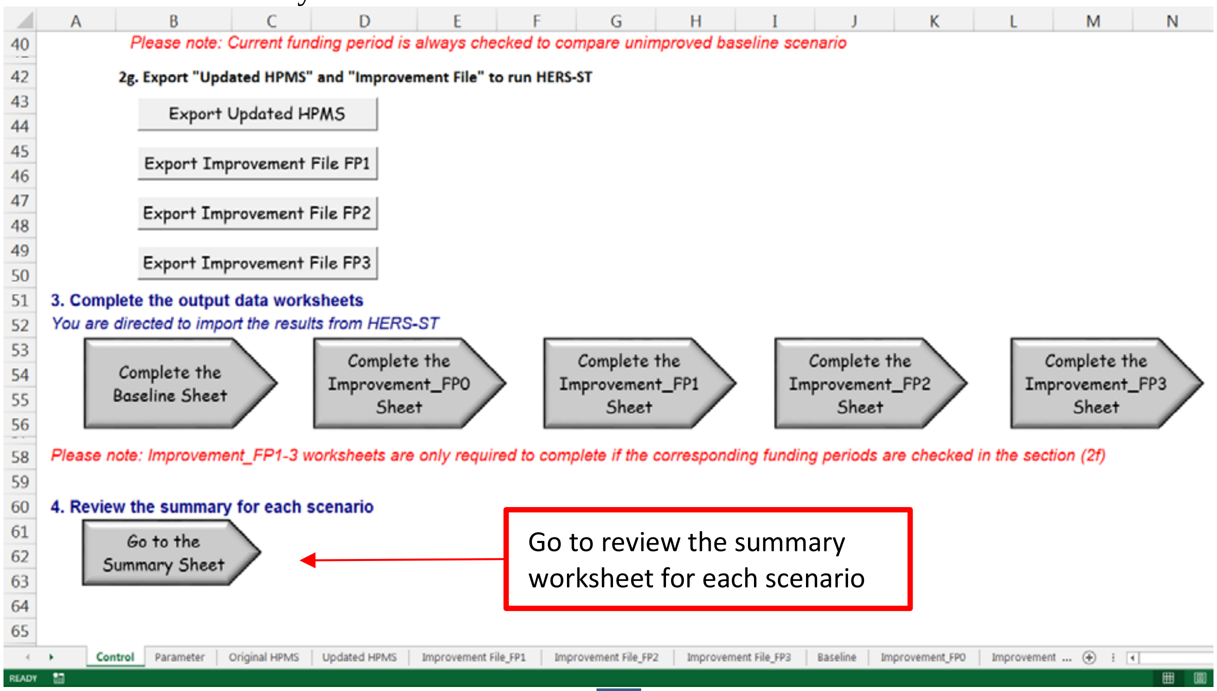
3. Complete the Output Data Worksheets






3a. HERS-ST Outputs - Conditions from the Unimproved Scenario
This worksheet provides the section conditions from unimproved scenario for the highway system being analyzed.
You are required to input the relevant data from HERS-ST results.
Return to Control
Continue
When done, it can either go to next import worksheet or back to the Control worksheet
Import Data
Clear Data
Import HERS-ST Results
The user may need to click the button for several times to import all results
File name: base04
CSV File
Open
Cancel
Updated HPMS
Improvement File_FP1
Improvement File_FP2
Improvement File_FP3
Baseline
Improvement_FP0
Improvement_FP1
Improvement_FP2
READY

4. Review the Summary



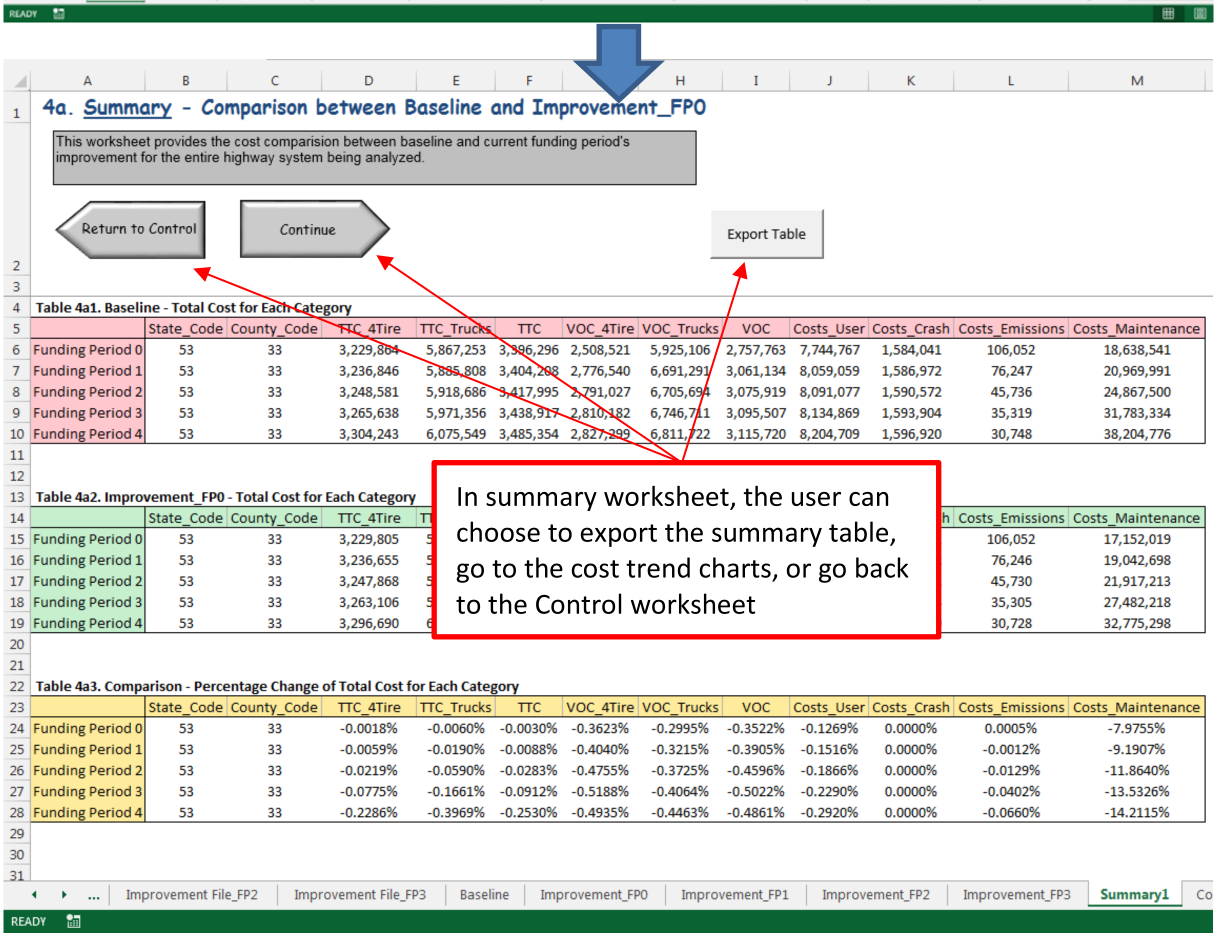


Table 4a1. Baseline - Total Cost for Each Category

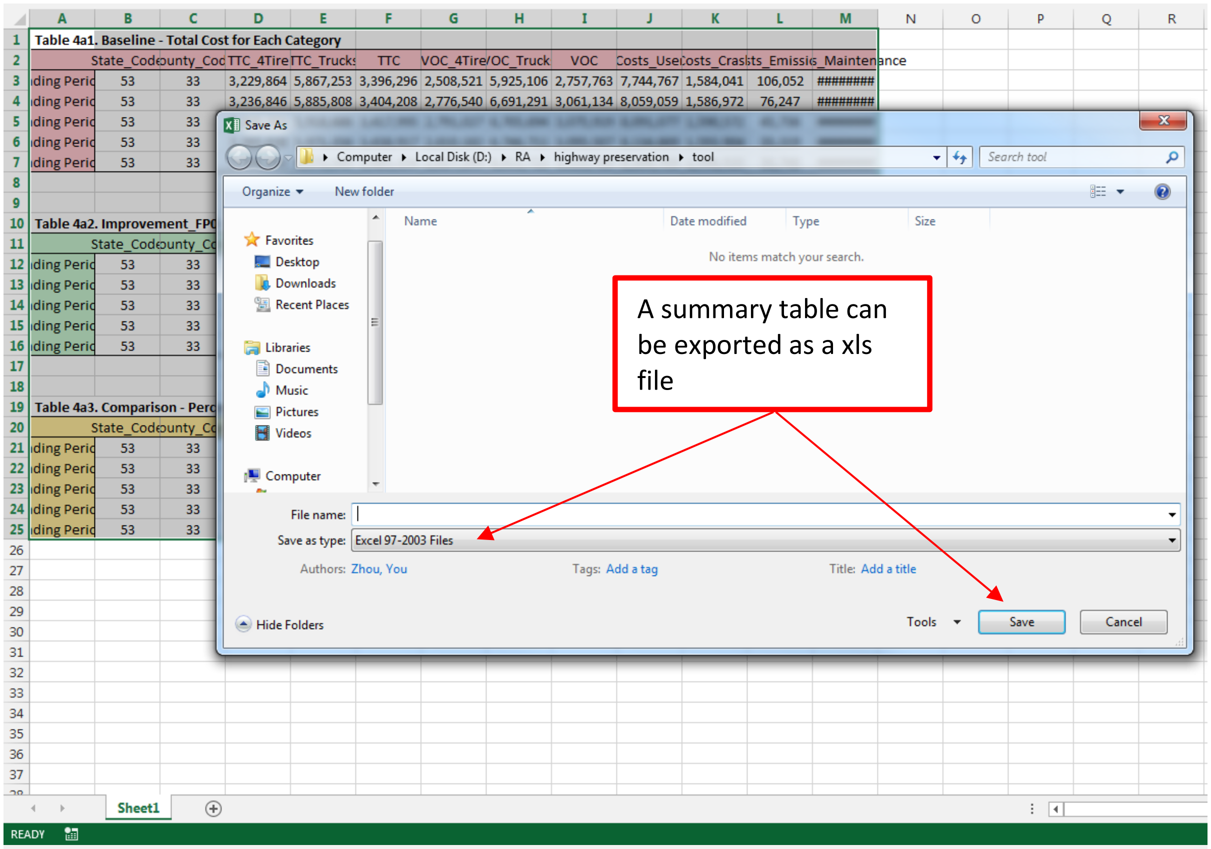
	State_Code	County_Code	TTC_4Tire	TTC_Trucks	TTC	VOC_4Tire	VOC_Trucks	VOC	Costs_User	Costs_Crash	Costs_Emissions	Costs_Maintenance
Funding Period 0	53	33	3,229,864	5,867,253	3,396,296	2,508,521	5,925,106	2,757,763	7,744,767	1,584,041	106,052	18,638,541
Funding Period 1	53	33	3,236,846	5,885,808	3,404,208	2,776,540	6,691,291	3,061,134	8,059,059	1,586,972	76,247	20,969,991
Funding Period 2	53	33	3,248,581	5,918,686	3,417,995	2,791,027	6,705,694	3,075,919	8,091,077	1,590,572	45,736	24,867,500
Funding Period 3	53	33	3,265,638	5,971,356	3,438,917	2,810,182	6,746,711	3,095,507	8,134,869	1,593,904	35,319	31,783,334
Funding Period 4	53	33	3,304,243	6,075,549	3,485,354	2,827,299	6,811,722	3,115,720	8,204,709	1,596,920	30,748	38,204,776

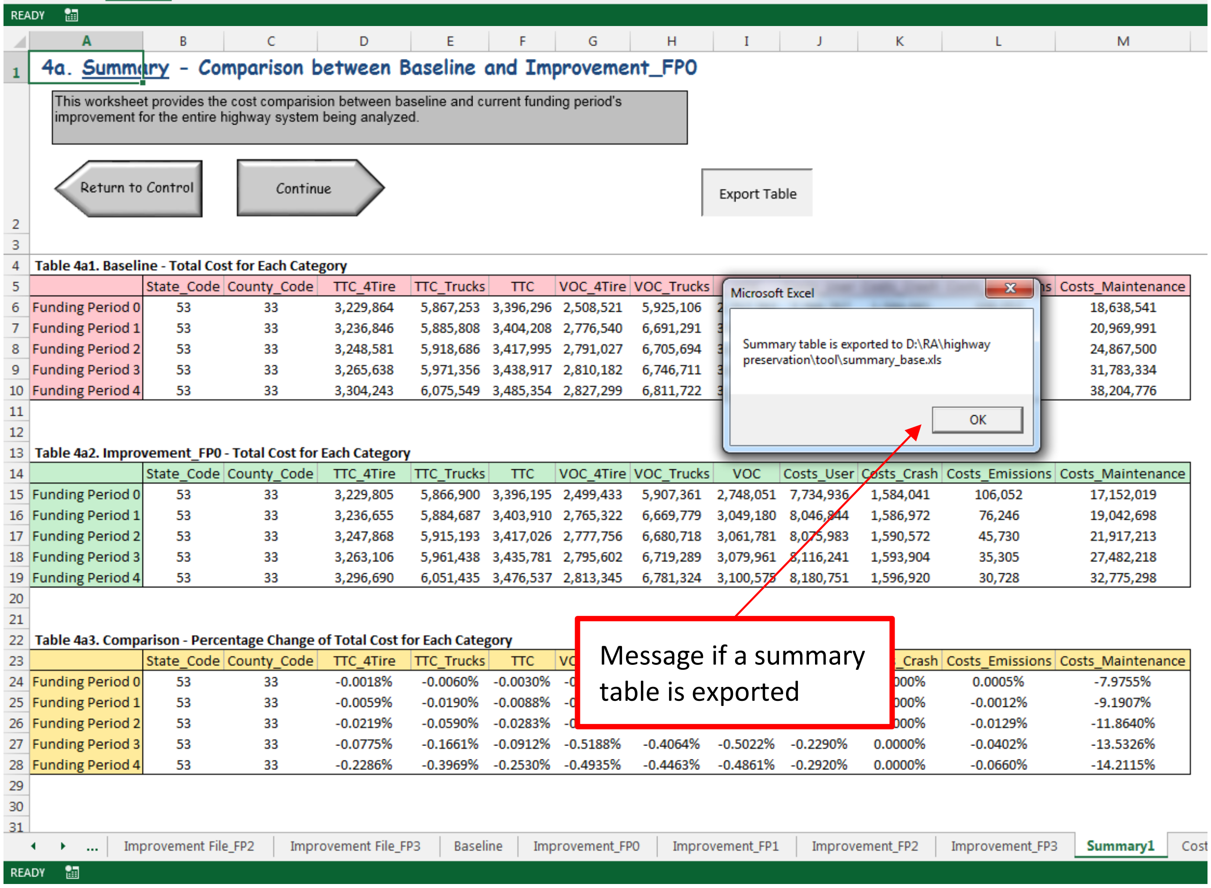
Table 4a2. Improvement_FP0 - Total Cost for Each Category

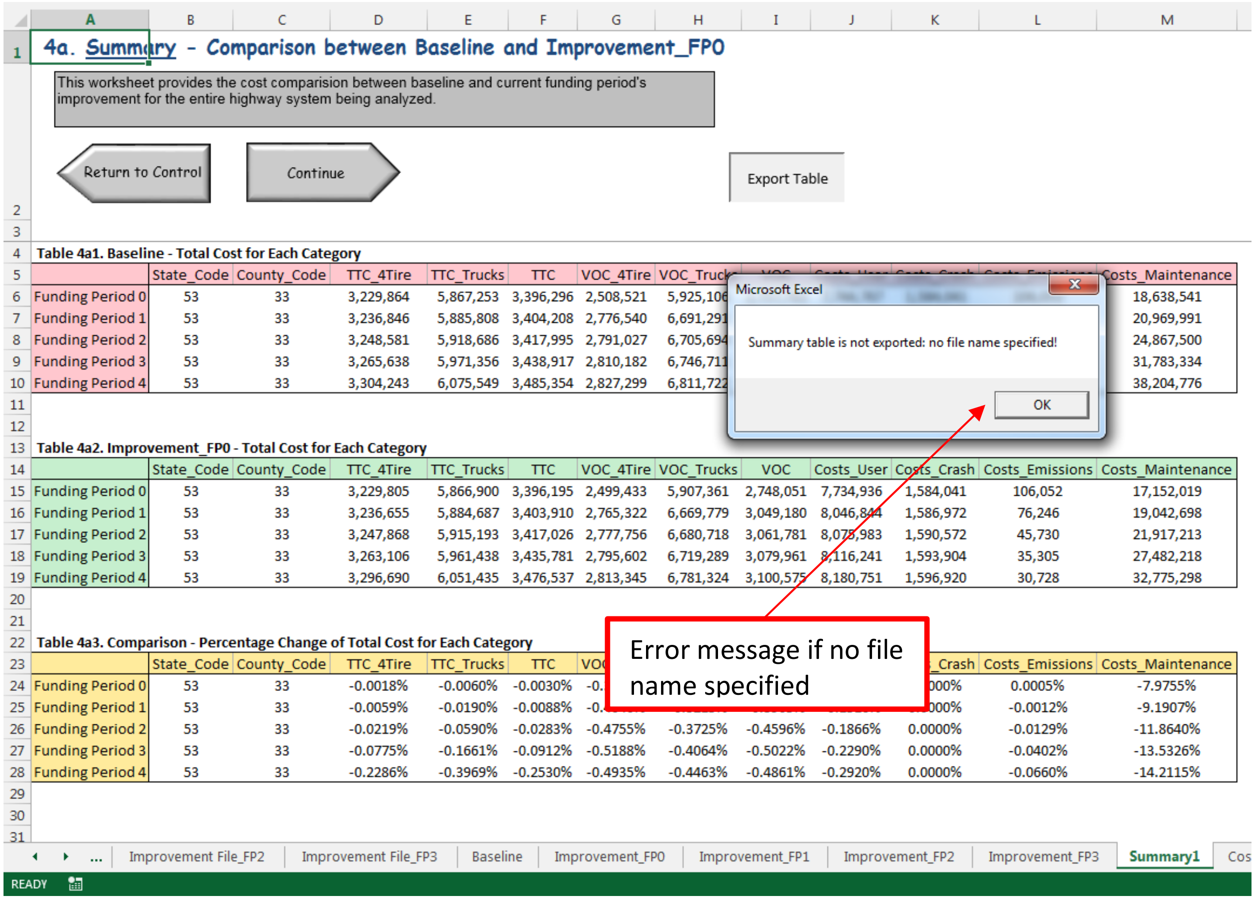
	State_Code	County_Code	TTC_4Tire	Costs_Emissions	Costs_Maintenance
Funding Period 0	53	33	3,229,805	106,052	17,152,019
Funding Period 1	53	33	3,236,655	76,246	19,042,698
Funding Period 2	53	33	3,247,868	45,730	21,917,213
Funding Period 3	53	33	3,263,106	35,305	27,482,218
Funding Period 4	53	33	3,296,690	30,728	32,775,298

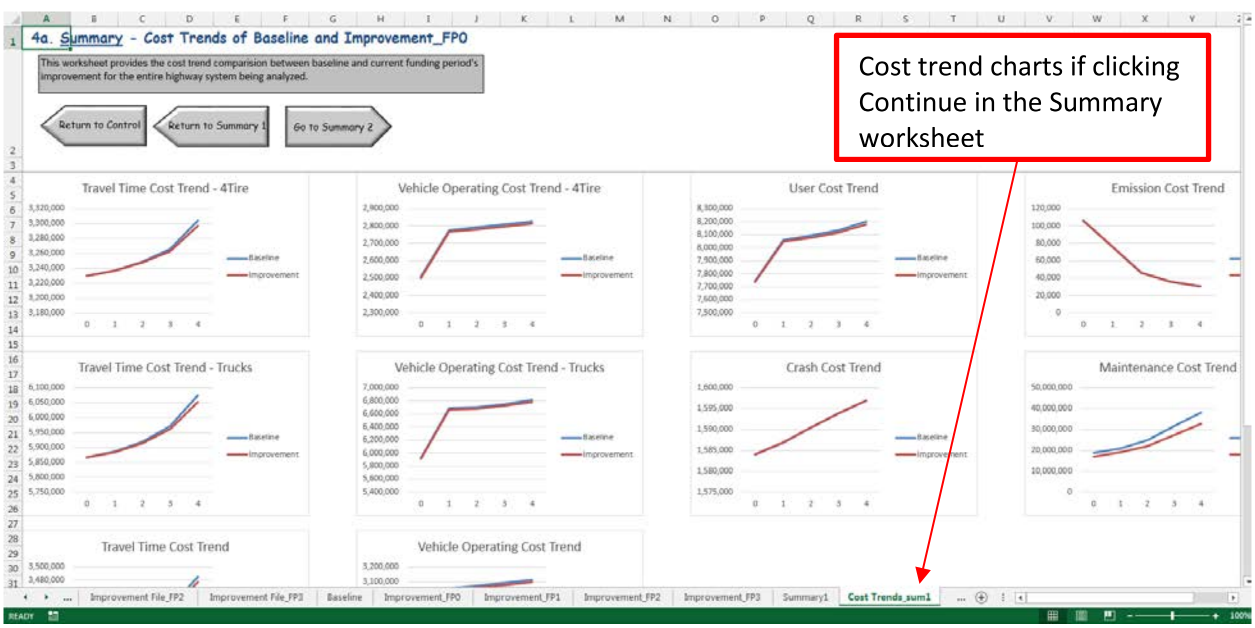
Table 4a3. Comparison - Percentage Change of Total Cost for Each Category

	State_Code	County_Code	TTC_4Tire	TTC_Trucks	TTC	VOC_4Tire	VOC_Trucks	VOC	Costs_User	Costs_Crash	Costs_Emissions	Costs_Maintenance
Funding Period 0	53	33	-0.0018%	-0.0060%	-0.0030%	-0.3623%	-0.2995%	-0.3522%	-0.1269%	0.0000%	0.0005%	-7.9755%
Funding Period 1	53	33	-0.0059%	-0.0190%	-0.0088%	-0.4040%	-0.3215%	-0.3905%	-0.1516%	0.0000%	-0.0012%	-9.1907%
Funding Period 2	53	33	-0.0219%	-0.0590%	-0.0283%	-0.4755%	-0.3725%	-0.4596%	-0.1866%	0.0000%	-0.0129%	-11.8640%
Funding Period 3	53	33	-0.0775%	-0.1661%	-0.0912%	-0.5188%	-0.4064%	-0.5022%	-0.2290%	0.0000%	-0.0402%	-13.5326%
Funding Period 4	53	33	-0.2286%	-0.3969%	-0.2530%	-0.4935%	-0.4463%	-0.4861%	-0.2920%	0.0000%	-0.0660%	-14.2115%


Save As
A summary table can be exported as a xls file
File name:
Save as type: Excel 97-2003 Files
Save
Cancel


4a. Summary - Comparison between Baseline and Improvement_FP0
This worksheet provides the cost comparision between baseline and current funding period's improvement for the entire highway system being analyzed.
Return to Control
Continue
Export Table
Microsoft Excel
Summary table is exported to D:\RA\highway preservation\tool\summary_base.xls
OK
Message if a summary table is exported


4a. Summary - Comparison between Baseline and Improvement_FP0
This worksheet provides the cost comparision between baseline and current funding period's improvement for the entire highway system being analyzed.
Return to Control
Continue
Export Table
Table 4a1. Baseline - Total Cost for Each Category
State_Code County_Code TTC_4Tire TTC_Trucks TTC VOC_4Tire VOC_Trucks ... Costs_Maintenance
Funding Period 0 53 33 3,229,864 5,867,253 3,396,296 2,508,521 5,925,106 ... 18,638,541
Funding Period 1 53 33 3,236,846 5,885,808 3,404,208 2,776,540 6,691,291 ... 20,969,991
Funding Period 2 53 33 3,248,581 5,918,686 3,417,995 2,791,027 6,705,694 ... 24,867,500
Funding Period 3 53 33 3,265,638 5,971,356 3,438,917 2,810,182 6,746,711 ... 31,783,334
Funding Period 4 53 33 3,304,243 6,075,549 3,485,354 2,827,299 6,811,722 ... 38,204,776
Microsoft Excel
Summary table is not exported: no file name specified!
OK
Table 4a2. Improvement_FP0 - Total Cost for Each Category
State_Code County_Code TTC_4Tire TTC_Trucks TTC VOC_4Tire VOC_Trucks VOC Costs_User Costs_Crash Costs_Emissions Costs_Maintenance
Funding Period 0 53 33 3,229,805 5,866,900 3,396,195 2,499,433 5,907,361 2,748,051 7,734,936 1,584,041 106,052 17,152,019
Funding Period 1 53 33 3,236,655 5,884,687 3,403,910 2,765,322 6,669,779 3,049,180 8,046,844 1,586,972 76,246 19,042,698
Funding Period 2 53 33 3,247,868 5,915,193 3,417,026 2,777,756 6,680,718 3,061,781 8,075,983 1,590,572 45,730 21,917,213
Funding Period 3 53 33 3,263,106 5,961,438 3,435,781 2,795,602 6,719,289 3,079,961 8,116,241 1,593,904 35,305 27,482,218
Funding Period 4 53 33 3,296,690 6,051,435 3,476,537 2,813,345 6,781,324 3,100,575 8,180,751 1,596,920 30,728 32,775,298
Table 4a3. Comparison - Percentage Change of Total Cost for Each Category
State_Code County_Code TTC_4Tire TTC_Trucks TTC VO... Crash Costs_Emissions Costs_Maintenance
Funding Period 0 53 33 -0.0018% -0.0060% -0.0030% -0. ... 000% 0.0005% -7.9755%
Funding Period 1 53 33 -0.0059% -0.0190% -0.0088% -0. ... 000% -0.0012% -9.1907%
Funding Period 2 53 33 -0.0219% -0.0590% -0.0283% -0.4755% -0.3725% -0.4596% -0.1866% 0.0000% -0.0129% -11.8640%
Funding Period 3 53 33 -0.0775% -0.1661% -0.0912% -0.5188% -0.4064% -0.5022% -0.2290% 0.0000% -0.0402% -13.5326%
Funding Period 4 53 33 -0.2286% -0.3969% -0.2530% -0.4935% -0.4463% -0.4861% -0.2920% 0.0000% -0.0660% -14.2115%
Error message if no file name specified
Improvement File_FP2 Improvement File_FP3 Baseline Improvement_FP0 Improvement_FP1 Improvement_FP2 Improvement_FP3 Summary1
READY


4a. Summary - Cost Trends of Baseline and Improvement_FP0
This worksheet provides the cost trend comparision between baseline and current funding period's improvement for the entire highway system being analyzed.
Return to Control
Return to Summary 1
Go to Summary 2
Cost trend charts if clicking Continue in the Summary worksheet
Travel Time Cost Trend - 4Tire
Vehicle Operating Cost Trend - 4Tire
User Cost Trend
Emission Cost Trend
Travel Time Cost Trend - Trucks
Vehicle Operating Cost Trend - Trucks
Crash Cost Trend
Maintenance Cost Trend
Travel Time Cost Trend
Vehicle Operating Cost Trend
Baseline
Improvement
Cost Trends_sum1

Appendix B: State Department of Transportation Survey

<u>Highway Preservation Benefits Survey</u>

Questions:
State:

1. Does your state currently have a pavement preservation (may be called maintenance) program?

Yes	No

   a. If Yes, proceed to 2
   b. IF No…….ask if there is any division that is responsible for calculating the benefit of pavement maintenance versus new construction?

2. How many years has this program been in existence? ________________yrs.

3. Is this division responsible for estimating the value ($ benefit) associated with different pavement projects?

Yes	No

4. Is this estimation process applied to both new highway construction projects and maintenance (preservation) of existing infrastructure?

Yes	No

5. Can you describe how that estimation process is calculated?

Steps involved

6. Do you or anyone within the DOT currently utilize the HERS-ST (Highway Economic Requirements System, developed by the FHWA-Federal highway administration) system for estimating the value of these improvements?

Yes (proceed to question 7)	No (go to question 9)

7. Can you provide more detail as to how this system is applied? Is it utilized solely or in conjunction with other software systems (such as IMPLAN)? Please explain.

Steps involved

8. If you are using this system, do you believe it does an adequate job for estimating the economic cost/benefit of alternative projects (new and preservation)?

9. If you are not using this system, what is the reasoning for not utilizing this software system?

a) Access to necessary data inputs
b) Knowledge of using the software system
c) The outcomes aren't credible
d) Takes too long to run simulations
e) Don't have the necessary resources (staff) to manage this

Other reason
(Explain)

Thank you for your time!