

## **APPENDIX C**

# **USER'S GUIDE FOR THE OPTIMAL PREVENTIVE MAINTENANCE TIMING ANALYTICAL TOOL (OPTime)**

## INTRODUCTION

Preventive maintenance is defined as a planned strategy of cost-effective treatments applied to an existing roadway system that preserves the system, retards future deterioration, and maintains and improves the functional condition of the system (without substantially increasing structural capacity) (1). Although many agencies have implemented preventive maintenance programs, there is still very little available guidance on determining the optimal timing of such treatments. The analysis tool developed for this project is intended to bridge that gap by implementing a methodology for calculating optimal timing. Although the analysis tool does not use a true optimization strategy (i.e., all possible treatment application times are not analyzed), it does provide a simple method for choosing the most effective treatment timing from a set of performance and cost data reflecting the application of a preventive maintenance treatment applied at different pavement ages.

This User's Guide is a hands-on introduction to using the macro-driven Microsoft® Excel-based analysis tool (OPTime) that was developed under National Cooperative Highway Research Program (NCHRP) project 14-14, "*Guide for Optimal Timing of Pavement Preventive Maintenance Treatment Applications*." It is not intended to answer all questions about the underlying analysis approach, as the analysis approach is described in much greater detail in chapter 3 of the main report. However, it does provide detailed information organized into the following five areas:

- Analysis tool capabilities—This section describes the capabilities and intended use of the OPTime analysis tool.
- Key concepts of the methodology—For quick reference, this section summarizes many of the important terms that are encountered during the setup and conduct of an analysis session.

- Getting started—General system requirements and step-by-step procedures for getting started using the tool.
- Setting up and conducting an analysis session—This section starts with a discussion of the types of data needed to successfully define all required outputs in the analysis methodology. The second part of this section walks a user through the analysis tool’s user interface and the step-by-step procedure for setting up and conducting an analysis session.
- Input/Output workbooks—Explanation of the produced output workbook that stores a summary of all defined inputs and the analysis output results.

## **ANALYSIS TOOL CAPABILITIES**

The primary purpose of this analysis tool is to enable pavement preservation engineers to analyze historical preventive maintenance-related performance and cost data in order to determine the optimal timing of a given preventive maintenance treatment. However, it is recognized that agencies are in different stages of developing pavement preservation strategies with many still in the early stages of collecting preventive maintenance-related performance data. Therefore, flexibility is built into the tool with the inclusion of two parallel analysis methods (simply referred to as *Detailed* and *Simple* methods) used to compare preventive maintenance timing scenarios. Both analysis types are briefly described below.

- *Detailed Analysis*—The main purpose of the *Detailed* method is to analyze actual (or estimated) data obtained from monitoring preventive maintenance treatment performance in the field over time. Because actual field data is expected for this analysis method, expected condition versus age relationships (before and after preventive maintenance treatment applications) must be defined by either selecting an equation type and entering

known equation coefficients, or by fitting a regression equation through entered condition versus age data points.

- *Simple Analysis*—When actual performance data are not available, the *Simple* method is used to create and compare “what if” timing scenarios. The user interface of the *Simple* method allows the estimation of performance relationships required by the analysis. Performance relationships are more easily defined by choosing a starting condition level, one condition versus age point for the curve to pass through, and the expected extension of life at the governing benefit cutoff value. Essentially, condition indicator relationships are defined visually rather than through the definition of specific mathematical relationships.

As previously indicated, this analysis tool allows a user to define performance relationships associated with different application timings of a given preventive maintenance treatment. Based on those defined performance relationships, the effectiveness of a treatment applied at a particular pavement age is determined as a function of computations of benefit and cost associated with each defined timing scenario. *Benefit* is computed as a function of condition and time (i.e., area under the condition versus age curve for decreasing equations), while included *costs* are compiled as an equivalent uniform annual cost (EUAC) of all included treatment, rehabilitation, work zone user delay, and additional routine maintenance costs. To facilitate timing scenario comparisons, benefit-to-cost (B/C) ratios computed for each timing scenario are then normalized into an *Effectiveness Index* in which the largest B/C ratio is equivalent to an Effectiveness Index of 100. The timing scenario with the largest B/C ratio (i.e., an Effectiveness Index of 100) is identified as the best, most cost-effective, treatment timing of all of those investigated.

It should be noted that the computation of benefit is not limited to the inclusion of only one condition indicator in the analysis methodology. The individual benefits associated with up to nine hot-mix asphalt- (HMA) related condition indicators (seven standard and two user defined fields) or up to eight portland cement concrete- (PCC) related condition indicators (six standard and two user defined fields) may be included in the overall analysis. Benefit values associated with each included condition indicator are then combined into an overall *Total Benefit* using user defined weight values (benefit weighting factors). The detailed procedures for computing individual condition indicator benefits, total overall benefit, costs, and Effectiveness Indices are all described in chapter 3 of the main report.

The output of any analysis session includes the following:

- Benefit Summary—Summary of both individual benefits (benefit values associated with each included condition indicator) and total benefit computed for each timing scenario. The timing scenario with the largest associated B/C ratio is highlighted.
- Cost Summary—Summary of all included treatment, rehabilitation, work zone user delay, and additional routine maintenance costs expressed in present worth dollars. All computed present worth dollars are then compiled into an EUAC so that timing scenarios resulting in different analysis periods may be compared directly (the user has the option to include or exclude any of these cost types from the analysis).
- Effectiveness Summary—The B/C ratios are normalized and reported in terms of Effectiveness Indices. That timing scenario with an Effectiveness Index of 100 (that scenario with the largest B/C ratio) is then highlighted in the output tables. Also included as part of the *Effectiveness Summary* table is the expected life of the pavement resulting from the preventive maintenance treatment application and the associated expected

extension of life (computed as the difference between the expected age at the end of the treatment life minus the predetermined expected do-nothing pavement life).

## **KEY CONCEPTS OF THE METHODOLOGY**

The final analysis methodology used within the analysis tool is built on a number of key concepts that must be understood when setting up and conducting an analysis session. This section provides a quick reference summary of these concepts. A more detailed explanation of most of these analysis method concepts is presented in chapter 3 of the main report.

### **Benefit**

Benefit is defined as the observed influence (usually positive, but it could also be negative) on any one or more included condition indicators resulting from the application of a preventive maintenance treatment. Using this definition, there could be many different types of benefit associated with a given application of a preventive maintenance treatment (e.g., applying a chip seal could result in benefits in the form of improved friction, retarded oxidation, reduced rutting, and so on). Specifically, benefit for a given condition indicator is determined by comparing the area associated with the condition indicator curve without the application of preventive maintenance (i.e., the do-nothing curve) to the area associated with the condition indicator curve that is altered by the application of preventive maintenance. For condition indicators that decrease over time (e.g., serviceability, friction, or a typical composite index) it is the area under the curve that defines benefit. For condition indicators that increase over time (e.g., roughness, cracking, rutting, faulting, and spalling) it is the area above the curve that defines benefit. The condition (y-axis) boundaries used for the area computations are defined by the upper and lower benefit cutoff values (both of which are described in more detail below). The age (x-axis) boundaries used for the area computations are year zero, and the year at which the respective

performance curve crosses the condition trigger level. A more detailed discussion of the benefit computations is included in chapter 3 of the main report.

### **Condition Indicators**

A condition indicator is defined as any measure of condition used to define pavement performance. One or more condition indicators may be selected for a given analysis session. Each selected condition indicator should reflect the benefit of applying preventive maintenance and should be one for which monitoring data are available. This is very important as all of the selected condition indicators will be used to collectively determine the benefit associated with the application of the treatment.

### **Do-Nothing Performance Curve**

The do-nothing performance curve is the condition indicator versus age relationship that is expected in the absence of conducting any preventive maintenance activities on the pavement. Note: the do-nothing curve by default does include the effects of routine maintenance. Do-nothing performance curves must be defined for each condition indicator included in an analysis.

### **Upper Benefit Cutoff Value**

The upper benefit cutoff value is the user-chosen *upper* limit to the benefit area computation (i.e., no area above the upper benefit cutoff level is included in the benefit computation). The upper benefit cutoff value is also the assumed preventive maintenance treatment failure trigger level for a condition indicator relationship that is assumed to *increase* over time (e.g., IRI).

### **Lower Benefit Cutoff Value**

The lower benefit cutoff value is the user-chosen *lower* limit to the benefit area computation (i.e., no area below the lower benefit cutoff level is included in the benefit computation). The lower benefit cutoff value is also the assumed preventive maintenance treatment failure trigger

level for a condition indicator relationship that is assumed to *decrease* over time (e.g., friction number).

### **Analysis Period**

The analysis period for a given timing scenario is the earliest age at which one of the individual condition indicator treatment performance relationships reaches its associated governing benefit cutoff value. To determine the analysis period for a given timing scenario, all condition indicator relationships are first looked at individually to determine the ages at which each curve reaches its respective preventive maintenance treatment failure level.

### **Expected Service Life of the Do-Nothing Condition**

The expected service life for the do-nothing condition is the earliest age at which one of the included condition indicator relationships reaches its individual governing benefit cutoff value (i.e., the upper benefit cutoff value for increasing relationships and the lower benefit cutoff value for decreasing relationships). For an example that includes rutting, cracking, and smoothness, where each performance curve reaches its governing benefit cutoff value at 15, 14, and 17 years, respectively, the overall do-nothing curve expected service life for the analysis session is 14 years (since that is the youngest age of all of the triggering conditions). Note that this expected do-nothing service life, therefore, is the upper boundary condition in the x-direction (i.e., for this example, areas would only be computed for the x-range between 0 and 14 years).

### **Expected Service Life of the Post-Preventive Maintenance Condition**

The expected service life for the post-preventive maintenance condition is the earliest age at which one of the post-preventive maintenance condition indicator relationships reaches its individual governing benefit cutoff value. Continuing the previous example, assume that for a particular timing scenario the rutting, cracking, and smoothness post-preventive maintenance

curves reach their governing benefit cutoff values at 20, 22, and 24 years, respectively. For this timing scenario, the expected service life (and corresponding analysis period) is, therefore, 20 years, since that is the youngest age of all of the triggering conditions. Just as with the do-nothing condition, this expected post-preventive maintenance service life is the upper boundary condition in the x-direction (i.e., areas are only computed for the x-range between 0 and 20 years).

### **Benefit Weighting Factors**

When more than one condition indicator is chosen to represent pavement performance in a given analysis, a method is required for combining the computed individual benefit values associated with each condition indicator. Benefit weighting factors are user-chosen integer values between 0 and 100 that are defined to accomplish this task. These values are *weighting factors* in that all defined benefit weighting factors must add to 100. The contribution to overall benefit associated with a given condition indicator is determined by multiplying the proportional weighting factor (i.e., the entered weighting factor divided by 100) by the computed individual benefit value (i.e., the computed percent in individual benefit area associated with the given condition indicator). In a sense, benefit weighting factors allow the user to define a custom composite index in that the weighting factors determine how much impact each condition indicator's benefit has on the total benefit used in the analysis. While the approach is simple, it is very important for a user (or agency) to conduct many analysis trials in an effort to gain a good understanding of how expected individual benefit areas should be weighted.

## **GETTING STARTED**

### **System Requirements and Recommendations**

To effectively use this analysis tool, an IBM-compatible industry-standard personal computer with the following minimum characteristics is required:

- Intel Pentium Pro, Pentium, or 486 PC.
- Microsoft® Windows 98, Windows 95, Windows NT 4.0, or newer operating system.
- Minimum of 32 Mb of RAM.
- Pointing device.
- CD-ROM drive.
- Super video graphics adapter with at least 800 x 600 resolution with 256 colors (Note: for best viewing, set the display resolution to 1024 x 768 with High [16 bit] color selected).
- Microsoft® Excel. Note: this analysis tool was developed under the Microsoft® Excel 2002.

### **Copying the Analytical Tool to Your Computer**

To use this analysis tool, first copy the *OPTime.xls* Excel workbook to your computer's hard drive. Note: you must have administrative privileges on your computer to accomplish this task.

To copy the file, complete the following steps:

1. Use *Windows Explorer* to create a new working directory on the computer's hard drive that will store the analysis tool workbook.
2. Copy the *OPTime.xls* file from the enclosed CD-ROM to the newly created directory.

To effectively use this analysis tool, continued administrative privileges are needed for the created directory, so that files can be saved to that directory as necessary.

### **Preparing the Microsoft® Excel Environment**

The OPTime analysis tool is a Visual Basic Application (VBA) driven Microsoft® Excel workbook. To facilitate the entry of data, a user-friendly dialog-box driven user interface has been incorporated to give the feel of a stand-alone software program. However, this tool differs from stand-alone software in that it must be opened within Microsoft® Excel. Because this

analysis tool is driven by many macros (a series of commands and functions stored in a Microsoft® Visual Basic code module), Microsoft® Excel must be set up to allow these macros to run. To set security to an acceptable level, complete one of the following sets of steps:

*From the “Tools” menu:*

1. Under the **Tools** menu, click **Macro**.
2. Click **Security** from the **Macro** submenu.
3. Under the **Security Level** tab, set the macro security level to **Medium**.
4. Click **OK** to close the **Security** dialog box.

*From the “Options” menu:*

1. On the **Tools** menu, click **Options**.
2. Click the **Security** tab.
3. Click on the **Macro Security** button.
4. Click the **Security Level** tab, and then set the macro security level to **Medium**.
5. Click **OK** to close the **Security** dialog box.
6. Click **OK** to close the **Options** dialog box.

If these instructions do not appear to be valid for Excel, click on the “Help” menu and conduct a search for “macro security.” Follow the subsequent instructions to set the macro security to “medium.”

### **Starting the Analysis Tool**

To start the analysis tool, simply open the *OPTime.xls* file like any other Microsoft® Excel workbook. Specifically, this file may be opened by either double clicking on the file name after using *Windows Explorer* to locate the file, or by opening the file using the File => Open menu commands within Microsoft® Excel.

Upon opening the file, the standard Excel pop-up dialog box should appear that contains the following warning about macros:

*Macros may contain viruses. It is always safe to disable macros, but if the macros are legitimate, you might lose some functionality.*

Click the **Enable Macros** button to allow Excel to run the macros and open the analysis tool.

Upon opening the *OPTime.xls* file, the macro-driven user interface will automatically present the *Introduction* dialog box.

## **SETTING UP AND CONDUCTING AN ANALYSIS SESSION**

### **Introduction**

This section provides the user with all of the information that is required to set up and conduct a typical analysis session. It begins with an introduction to the types of data required for a typical analysis, and follows with a detailed step-by-step guide to using the analysis tool. This section will help in making input-related decisions while completing the analysis setup process.

### **Required Data Types**

Conducting a meaningful analysis requires the collection and representation of four primary types of data, including do-nothing curve relationships, post-preventive maintenance performance relationships, upper and lower benefit cutoff values, and cost information. As previously stated, the results of the analysis session are only as good as the quality of the defined inputs.

#### *Do-Nothing Curve Relationships*

Before the influence of a preventive maintenance application can be analyzed, the analysis requires a baseline performance curve (or curves) from which the changes due to the application of preventive maintenance are measured. The baseline performance curve of interest for a

particular condition indicator is that performance curve (condition indicator versus time) expected if only routine maintenance were conducted on the pavement. Such curves are referred to as do-nothing performance curves. The methodology requires that the user define a do-nothing performance curve for each condition indicator that is included in the analysis. A good source for this information is an existing pavement management system, although users without access to such curves can easily be walked through a process of approximation.

#### *Post-Preventive Maintenance Performance Relationships*

In addition to defining do-nothing performance relationships, the user must define relationships that describe how the pavement is expected to perform after a preventive maintenance treatment has been placed. More specifically, a separate performance relationship (condition versus age) needs to be defined for each unique combination of condition indicator and treatment application age. For example, if an analysis includes three condition indicators and five application ages, 15 (3 x 5) different performance relationships must be defined.

When using the *Simple* analysis approach, the definition of post-preventive maintenance performance is facilitated by allowing the user to define the starting condition, ending condition, and expected extension of life (in relation to the do-nothing curve). However, when using the detailed approach, the user must define all do-nothing and post-preventive maintenance performance relationships by selecting an equation type and entering equation coefficients directly, or by entering data points and fitting a regression equation through those points.

#### *Benefit Cutoff Values*

Benefit cutoff values are user-defined condition indicator levels that define the upper and lower limits of the calculated benefit areas. That is, no benefit area above the upper benefit

cutoff value or below the lower benefit cutoff value is included in the total benefit area used in the analysis.

The upper and lower benefit cutoff values have different meanings depending on whether the condition indicator curve is increasing or decreasing in nature. The cutoff value on the upper end of the quality scale (i.e., the upper benefit cutoff value for a decreasing curve, and the lower benefit cutoff value for an increasing curve) provides a cap or benefit ceiling on the quality that is credited to the treatment application. Conversely, on the lower end of the quality scale, the benefit cutoff value often referred to as the *governing* benefit cutoff value typically represents the condition level at which the treatment is considered *failed* and requires either an additional preventive maintenance treatment or rehabilitation activity. In contrast to the benefit cutoff value on the upper end of the quality scale, the *governing* benefit cutoff value is the lower benefit cutoff value for a decreasing curve and the upper benefit cutoff value for an increasing curve.

For any analysis, it is recommended that agencies select benefit cutoff values that most closely reflect their current maintenance and rehabilitation policies. For example, if an agency typically only applies one preventive maintenance treatment in the life of a pavement, then the governing benefit cutoff value should be equal to the pavement failure level, as a major rehabilitation is most likely be the next pavement treatment. In contrast, if an agency typically applies a second preventive maintenance treatment after the first application reaches a known condition failure level, it is recommended that the governing benefit cutoff value be set equal to that treatment failure level.

## *Cost Data Types*

Up to four different cost types may be considered in any analysis session, including preventive maintenance treatment costs, the cost of a rehabilitation activity applied at the end of the estimated service life, work zone user delay costs, and routine maintenance costs.

- Preventive maintenance treatment cost—The treatment cost is the agency cost of applying the chosen preventive maintenance treatment. This cost includes all design, mobilization, material, construction, and traffic control costs associated with the treatment application.
- Rehabilitation cost—The rehabilitation cost is the agency cost of a rehabilitation procedure that would be expected to be conducted when the applied preventive maintenance treatment is considered to be failed (i.e., when the defined post-preventive maintenance treatment relationship crosses the governing [upper or lower] benefit cutoff value). Note that the timing of this rehabilitation cost is very much dependent on the selected governing benefit cutoff value.
- Work zone user delay costs—The methodology limits user costs to those associated with work zone delays (i.e., the cumulative delay cost recognized by all users who travel through the preventive maintenance treatment work zone). To compute user costs, the main types of data that are required are information about expected traffic levels, as well as work zone related information (e.g., expected work zone duration and typical delay times encountered in the work zone).
- Routine maintenance costs—To be completely thorough in the representation of costs in this analysis, the user has the option of including the costs associated with a defined routine maintenance schedule. Examples of routine maintenance activities that fall under this cost type include pothole patching and crack sealing costs (if the timing of first crack sealing is not the focus of the investigation).

## Analysis Setup

The user interface of the analysis tool is a series of sequential steps that must be completed to conduct the analysis. Two parallel paths through the interface are provided based on whether the *Simple* or *Detailed* analysis type is selected. An overall flow chart showing the general structure of the user interface is presented in figure C-1. Each step of the setup process is discussed in more detail in separate sections below.

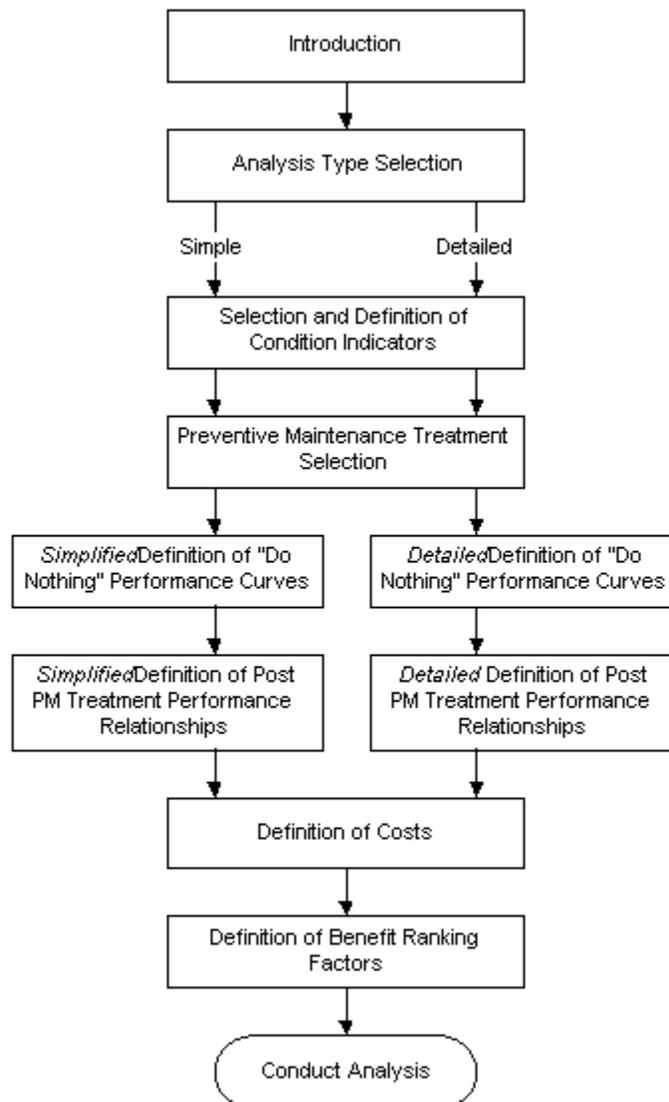


Figure C-1. General structure of the analysis tool's user interface.

### Step 1: Introduction Dialog Box

Once the analysis tool starts, the first dialog box is the *Introduction* dialog box shown in figure C-2. The remainder of this section briefly describes the controls on this dialog box.

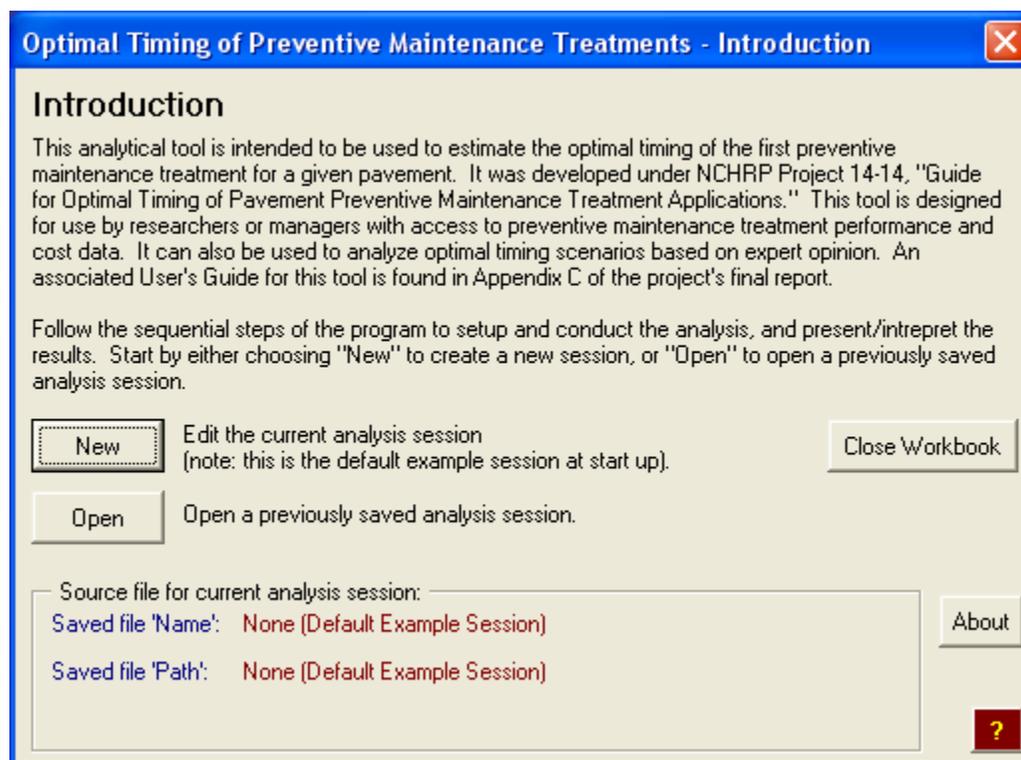
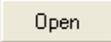
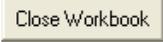


Figure C-2. *Introduction* dialog box.

**New Button.** Click the  button to create a blank analysis session.

**Open Button.** Data files used by the analysis tool are stored as separate Microsoft® Excel workbooks. Click the  button to open an existing (previously saved) analysis session and then select the named Excel workbook that houses the analysis session. For reference, the specific name and path of a file that has been opened will be displayed at the bottom of this dialog. After opening an existing session, use the provided input interface controls to make appropriate changes to the session.

**Close Workbook Button.** Click on the  button to exit and close the analysis tool workbook. Clicking this button will bring up the *Closing the Analysis Workbook* dialog box shown in figure C-3. The  and  buttons provided on this dialog box are described below.

- The  button closes the analysis tool workbook (i.e., *OPTime.xls*) without saving any changes made to the current session. Inputs are only saved as part of the new workbook that is created as a result of conducting an analysis session.
- The  button returns the user to the user interface. The analysis tool workbook (i.e., *OPTime.xls*) will not be closed, and therefore any input changes will not be lost.

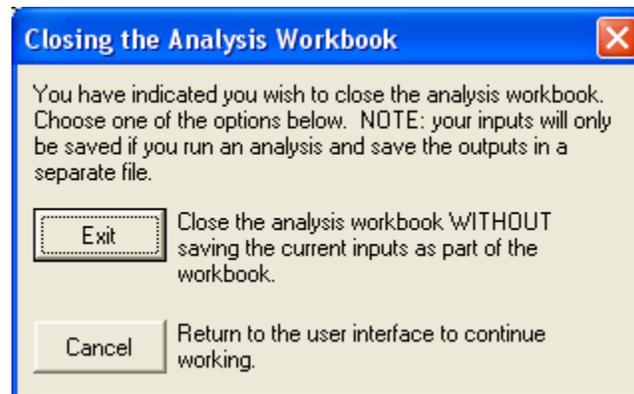


Figure C-3. *Closing the Analysis Workbook* dialog box.

You may also exit the workbook by clicking close window box (i.e., ) in the upper right corner of most dialog boxes. However, recall that exiting the workbook via the close window box will close the workbook without saving any changes made to the inputs.

**About Button.** Click on the  button to view general information about the analysis tool. Such information includes acknowledgements and contact information.

**Help Button.** If at any point during the setup of the analysis session more detailed information associated with a dialog box's purpose, controls, or inputs is needed, click on the provided  button to view specific help text.

### *Step 2: Analysis Type Selection*

As mentioned previously, preventive maintenance timing scenarios may be compared using either a *Simple* or *Detailed* analysis type. The *Detailed* approach is intended for those users that want to analyze actual condition data. The *Simple* approach is intended for those users who would like to become familiar with the analysis concepts but do not have a lot of collected data that they can analyze.

The major difference between the two approaches is the complexity of how both do-nothing and post-preventive maintenance performance curves are defined. The *Simple* approach allows the user to define the do-nothing relationship in terms of a starting condition, the age at which the curve is expected to intersect the governing benefit cutoff value, and the coordinates of one point which the curve is to pass through. Post-preventive maintenance performance relationships are defined in terms of an initial condition value, expected extension of life (in relation to the do-nothing curve), and the coordinates of one pass-through point. In contrast, when using the *Detailed* approach, the user must define all do-nothing and post-preventive maintenance performance relationships by either entering the type of equation and its coefficients, or by entering data points and fitting a regression equation through those points. Use the controls on the *Analysis Type Selection* dialog box (shown in figure C-4) to choose the appropriate analysis type that best suits the available data and analysis purpose.

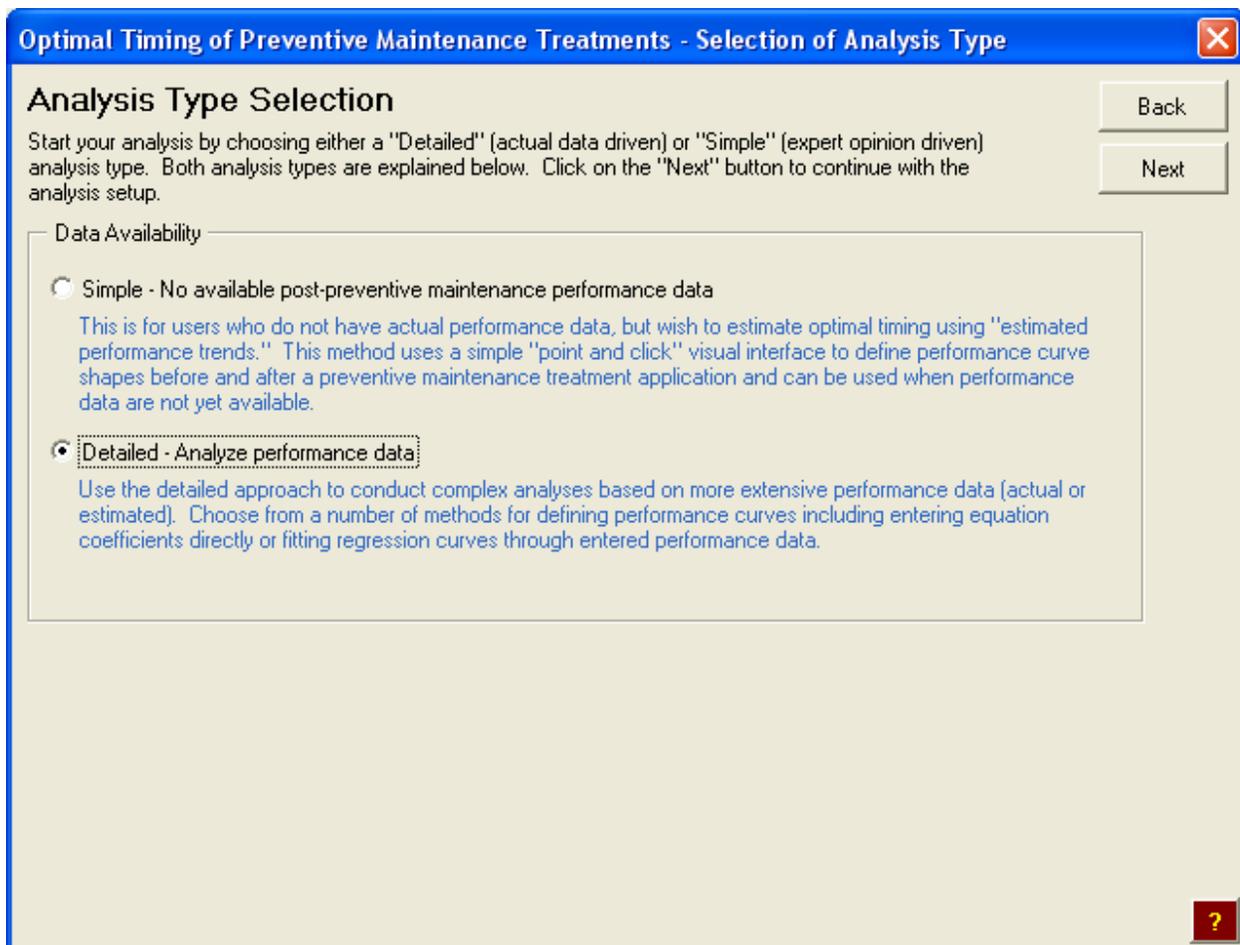


Figure C-4. *Analysis Type Selection* dialog box.

### *Step 3: Selection and Definition of Condition Indicators*

The *Selection of Condition Indicators* tab (shown in figure C-5) provides controls that are used to define the condition indicators that define pavement performance. The selected condition indicators should be those pavement characteristics that are measurable (able to be tracked over time), are indicative of pavement performance (mostly functional performance), and are specifically influenced by the application of the selected preventive maintenance treatment.

**Surface Type.** The first input on this dialog box is the selection of the surface type that best represents the pavement of interest. *HMA-Surfaced* pavements include pavement types such as full-depth asphalt and HMA-overlaid PCC pavements. PCC-surfaced pavements include

**Optimal Timing of Preventive Maintenance Treatments - Selection of Condition Indicators**

### Selection and Definition of Condition Indicators

After selecting a pavement type, select the condition indicators you want to use to define benefit. Next, set the condition indicator units, equation trends (curve shapes), and lower and upper benefit cutoff values.

Surface Type  
 HMA-Surfaced     PCC-Surfaced

HMA-Surfaced Condition Indicators

Condition Indicators	Units	Trend Over Time	Lower Benefit Cutoff Value	Upper Benefit Cutoff Value
<input checked="" type="checkbox"/> Composite index	0 to 100 scale	Decreasing	50	100
<input type="checkbox"/> Nonload-related cracking	Length of cracking, ft	Increasing		
<input type="checkbox"/> Load-related cracking	Length of cracking, ft	Increasing		
<input type="checkbox"/> Oxidation/raveling	Subjective scale (0 to 5)	Decreasing		
<input type="checkbox"/> Rutting	Avg rut depth, in	Increasing		
<input checked="" type="checkbox"/> Roughness/smoothness	IRI, in/mi	Increasing	0	140
<input type="checkbox"/> Friction	Friction number	Decreasing		
<b>User Defined Condition Indicators</b>				
<input type="checkbox"/> User defined 1	Index	Decreasing		
<input type="checkbox"/> User defined 2	Index	Decreasing		

Figure C-5. *Selection of Condition Indicators* dialog box (showing controls associated with an HMA-surfaced pavement).

pavement types such as conventional PCC pavements, PCC pavements with PCC overlays, and whitetopped HMA pavements. The remainder of the controls in this dialog box change to reflect the selected surface type.

**Selection of Condition Indicators.** The choice of surface type determines what condition indicators are available to define performance. Table C-1 summarizes brief descriptions of the default condition indicators and their typical units. In addition to these default choices, two user-definable condition indicator fields are provided so that a user can define custom condition indicators that better measure the effectiveness of a particular preventive maintenance treatment.

Table C-1. Summary of default condition indicators included in the analysis tool.

Surface Type	Condition Indicator	Description
HMA	Composite index	Many agencies use composite indices to track pavement performance over time. Examples include a general cracking index or pavement condition index (PCI). Many of these decrease over time and are measured on scales such as a 0 to 100, 0 to 10, or 0 to 5.
	Nonload-related cracking	The sealing or rejuvenating nature of many surface treatments can reduce the development of environmental- or moisture-related cracking. This nonload-related cracking measure reflects that benefit, and would likely be measured in terms of the amount of cracking.
	Load-related cracking	Preventive maintenance treatments such as crack sealing and thin surface seals are effective at keeping the pavement structure free from moisture infiltration, thereby reducing load-related cracking associated with the weakening of the pavement structure. Therefore, the user may want to track the development of load-related cracking over time as a measure of the effectiveness of a particular preventive maintenance treatment. As with non-load-related cracking, load-related cracking would most likely be measured in terms of the amount of cracking.
	Oxidation/Raveling	The sealing or rejuvenating nature of many surface treatments can significantly reduce the occurrence of oxidation and raveling. Raveling is often reported as an area and severity level. Although there is not currently a widely accepted measure of oxidation, the user may want to consider the development of a subjective rating scale (e.g., a scale of 0 to 5).
	Rutting	Several preventive maintenance treatments may be used to correct rutting problems, so rutting may be used as a performance measure. Rutting is typically measured in terms of an average rut depth, which is expected to increase over time.
	Roughness/ Smoothness	<i>Roughness</i> typically increases over time and is often measured in terms of International Roughness Index (IRI). Some agencies prefer to characterize the measurement of surface characteristics in terms of <i>smoothness</i> instead of roughness. A smoothness measurement is typically expected to decrease over time (e.g., present serviceability index [PSI] is a subjective measurement on a 0 to 5 scale, where 5 represents a perfectly smooth pavement).
	Friction	Maintaining adequate surface friction is an important safety concern. Therefore, the effectiveness of a preventive maintenance treatment may be tracked in terms of its influence on friction. Friction is commonly measured in terms of a friction index or skid number (a characteristic that typically decreases over time).
PCC	Composite index	See the <i>Composite index</i> explanation in the HMA-surface section above.
	Cracking (deterioration)	The prompt sealing of cracks on PCC pavements can reduce the deterioration of those cracks over time. Therefore, some users may wish to track the typical deterioration (severity level) of cracks over time. This crack deterioration would most likely be measured in terms of a length of cracking of a particular severity level over time.
	Faulting	As crack and joint sealing are effective at reducing the amount of water that infiltrates the PCC pavement structure, these treatments can have a significant influence on the development of transverse joint faulting. Therefore, faulting may be used as a performance measure. Transverse joint faulting is typically measured in terms of average faulting, which is expected to increase over time.
	Joint Spalling	Effective joint and crack sealing reduces the infiltration of water and incompressible material into joints and cracks, thereby reducing the development of joint spalling (or joint deterioration). Joint spalling is commonly measured in terms of the amount of spalling (number of joints or percentage of total joints) of a particular severity level.
	Roughness/ Smoothness	See the <i>Roughness/Smoothness</i> explanation in the HMA-surface section above.
	Friction	See the <i>Friction</i> explanation in the HMA-surface section above.

To include a particular condition indicator in the analysis, click on the condition indicator name or its associated check box to enable it. To disable a previously selected condition indicator, click again on the condition indicator name or check box. To include one of the user definable fields, first click the name to enable the condition indicator, and then enter a descriptive condition indicator name in the text box directly to the right of the associated check box.

Each selected condition indicator should reflect the benefit of applying preventive maintenance and should be one for which monitoring data are available. This is very important, as all of the selected condition indicators are used collectively to determine the benefit associated with the application of the treatment. It is also important to remember that do-nothing performance curves must be defined for each condition indicator included in the analysis.

**Condition Indicator Units.** For each condition indicator, select the appropriate measurement units from the provided list. If the default list does not contain the desired units, select the "...Edit Unit List" option to add additional unit definitions. When editing the current unit list, the *Unit Management* pop-up dialog box will appear (figure C-6 illustrates an example of the altering of the unit list associated with the *Composite Index*). To add new units to the unit list, type the appropriate descriptive text in the text box at the bottom of the dialog and click the  button to add the text to the unit list. To delete an item from the unit list, click on the item of interest in the unit list and click the  button. Once any unit list editing is completed, click the  button to close the *Unit Management* dialog box.

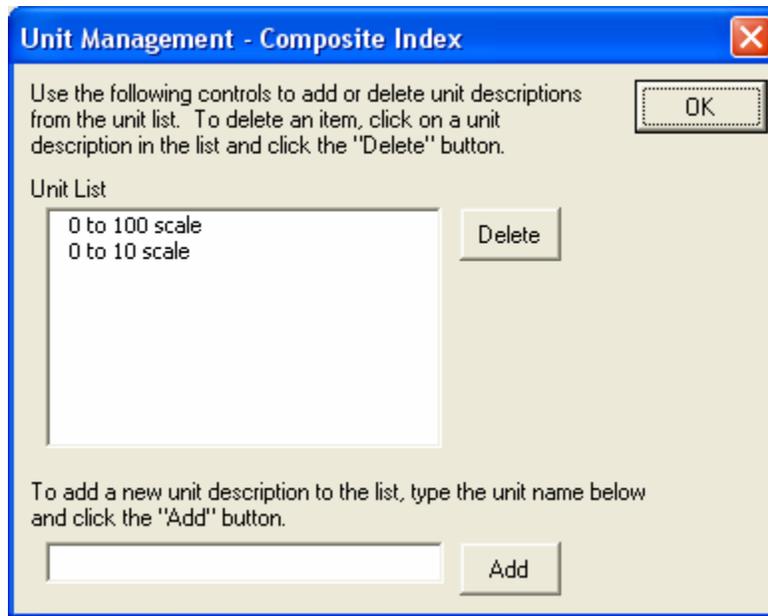


Figure C-6. Example of the *Unit Management* dialog box.

**Trend Over Time.** The *Trend Over Time* field is an indication of the expected performance relationship trend over time. For a given condition indicator, select *Increasing* or *Decreasing* to coincide with the specific chosen units. For example, if “Cracking” were chosen as a condition indicator and the associated units are set to “Length of Cracking, ft,” the “Trend Over Time” input would be set to “Increasing” as the total observed length of cracking is expected to increase with time. In contrast, if PCI were chosen as a composite index, the “Trend Over Time” would be set to “Decreasing,” as PCI is measured on a 0 to 100 index in which 100 represents a pavement with no distress. The underlying analysis engine requires this input to correctly compute benefit. As mentioned previously, benefit is a function of the area *under* a curve when the condition indicator relationship is decreasing, and the area *above* the curve when the relationship is increasing. A more detailed explanation of the benefit computation is included in chapter 3 of the main report.

**Lower and Upper Benefit Cutoff Values.** The lower and upper benefit cutoff values define the condition range that is used in the associated benefit calculations for a given condition

indicator. Since the analysis approach defines benefit as the area *under* a performance curve for a decreasing trend (or the area *above* a performance curve for an increasing trend [e.g., roughness]), these entered benefit cutoff values define the vertical boundary conditions in the area computations. These entered values are expressed in terms of the respective condition indicator units. In the OPTime tool, the upper benefit cutoff value is always entered as the larger of the two benefit cutoff values (i.e., upper benefit cutoff value is always greater than the lower benefit cutoff value). The following sections provide more detailed explanations of the benefit cutoff values as they pertain to decreasing or increasing relationships.

Defining Benefit Cutoff Values for Decreasing Relationships. For relationships that decrease over time, the lower benefit cutoff value represents a condition level indicative of a failure condition level for both the do-nothing and treatment performance curves (some may interpret this failure level as a rehabilitation trigger level). For a single condition indicator, the pavement age at which the do-nothing curve intersects this lower benefit cutoff value is the upper age boundary (in the x-direction) used in the computation of the do-nothing benefit area. Likewise, the pavement age at which the post-preventive maintenance relationship intersects the lower benefit cutoff value is the upper age boundary used in the computation of the post-preventive maintenance benefit area associated with a chosen timing scenario. When more than one condition indicator is used within an analysis session, all individual condition indicator upper age boundaries are compared, and the earliest age is set as the upper age boundary for all condition indicators. That is, as soon as one condition indicator reaches a failed condition, benefit is no longer computed.

For decreasing relationships, using an upper benefit cutoff value is a way to “cap” the benefit area. That is, the user may decide that even though conditions rise above a certain

defined level (e.g. greater skid resistance) the additional benefit may not be necessary and thus should not be credited in the benefit calculations.

Defining Benefit Cutoff Values for Increasing Relationships. When a relationship increases over time, the upper benefit cutoff value is assumed to represent a failure condition level for both the do-nothing curve and the treatment performance curves. For a single condition indicator, the pavement age at which the do-nothing curve intersects this upper benefit cutoff value is the upper age boundary (in the x-direction) used in the computation of the do-nothing benefit area. Likewise, the pavement age at which the post-preventive maintenance relationship intersects the upper benefit cutoff value is the upper age boundary used in the computation of the post-preventive maintenance benefit area associated with a chosen timing scenario.

For increasing relationships, the lower benefit cutoff value represents a way to “cap” the benefit area. That is, the user may decide that even though conditions are observed to fall below a certain defined level (e.g. smoother roads [reduced IRI]) the additional benefit may not be necessary and thus should not be credited in the benefit calculations.

#### *Step 4: Preventive Maintenance Treatment Selection*

The *Preventive Maintenance Treatment Selection* dialog box (shown in figure C-7) provides controls used to choose the preventive maintenance treatment being analyzed and define the timing of any additional routine maintenance to be included in the cost analysis. The dialog box is divided into the *PM (Preventive Maintenance) Treatment Selection* and *Routine/Reactive Maintenance Program Definition* areas.

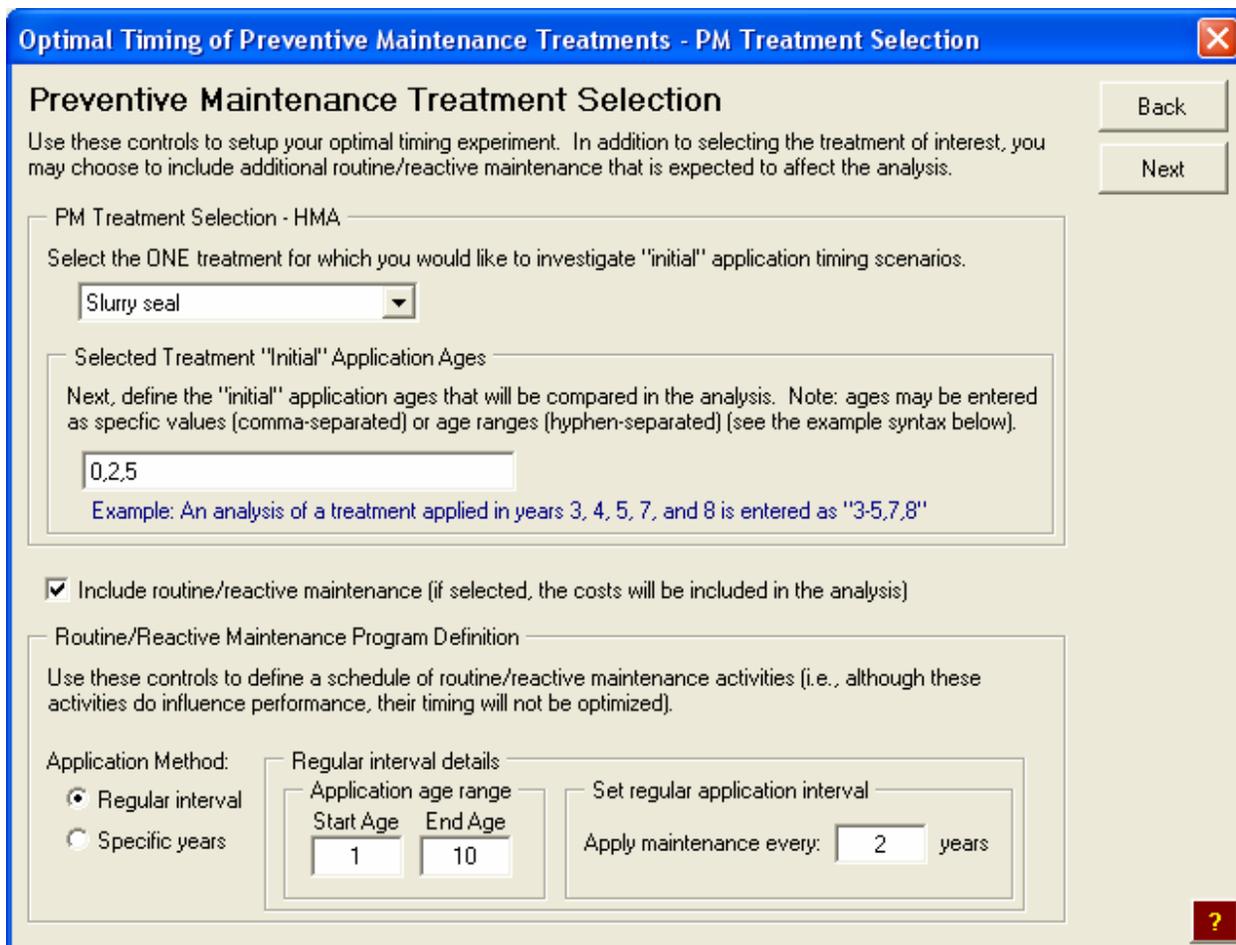


Figure C-7. *Preventive Maintenance Treatment Selection* tab.

**Treatment Selection.** This dialog box is used to select the one preventive maintenance treatment to be investigated within the analysis. A default list of preventive maintenance treatments that reflects the chosen surface type (HMA or PCC) is provided within the *PM Treatment Selection* area of the dialog box. See table C-2 for a summary of all of the default preventive maintenance treatments for each pavement type.

To add custom treatments to the treatment list, select the “...Edit Treatment List” option in the provided treatment list. Selecting this option will open the *Treatment List Management* pop-up dialog box shown in figure C-8. To add a new treatment to the list, type the appropriate descriptive text in the text box at the bottom of the dialog and click the  button.

Table C-2. Default preventive maintenance treatment types.

HMA-Surfaced Pavements	PCC-Surfaced Pavements
Crack filling/crack sealing	Crack sealing
Fog seal	Joint resealing
Slurry seal	Diamond grinding
Scrub seal	
Microsurfacing	
Chip seal	
Thin overlay	
Ultrathin friction course	

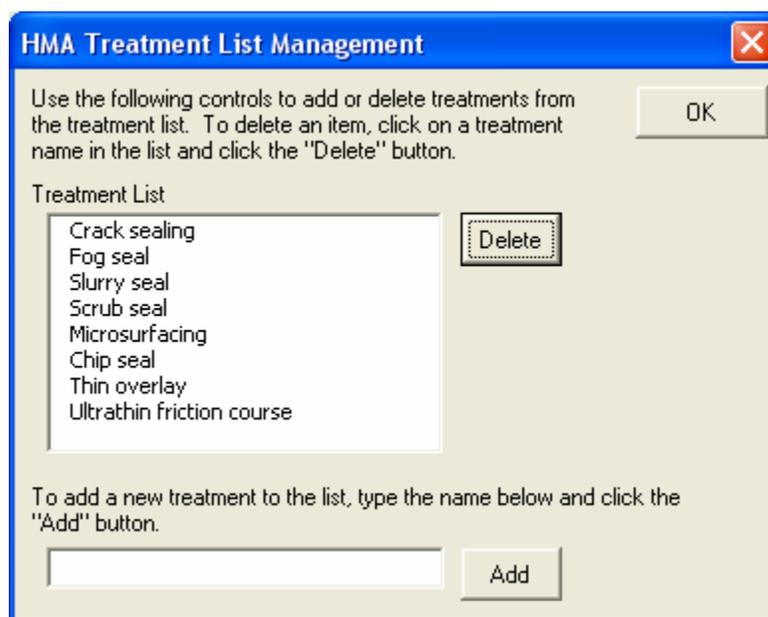


Figure C-8. Example of the *Treatment List Management* dialog box with the default HMA treatment list displayed.

To delete a treatment from list, click on the item of interest and click the  button. Once the list is altered, click the  button to close the dialog box.

**Selection of Treatment Application Ages.** After selecting the treatment to investigate, the next step in the definition of the analysis session is to define the treatment application ages to compare. Input one or more comma-separated application ages or hyphen-separated age ranges in the input box provided in the *Selected Treatment "Initial" Application Ages* area of the dialog

box. For example, entering “1,3,5,7-10” will investigate the effectiveness of the chosen treatment applied in years 1, 3, 5, 7, 8, 9, and 10. Each of these timing scenarios is in terms of the age since the start of the do-nothing curve.

**Routine/Reactive Maintenance Program Definition.** To provide more flexibility in the analysis method, the user may specify the timing and cost of maintenance activities that are assumed to be more routine or reactive in nature. An example of such an activity is pothole patching. While the patching potholes does influence long-term performance, it does not fit the typical preventive maintenance model as it cannot be conducted until after the distress appears (i.e., its timing cannot be truly optimized). To include such activities in the analysis, the specific maintenance timings (years of application) and costs are required to be defined by the user.

To estimate and enter a detailed routine maintenance schedule, click the check box that says “Include routine/reactive maintenance (if selected, the costs will be included in the analysis).” After making that selection, either define the additional maintenance timing schedule in terms of a “Regular interval” or “Specific years.” An example of a regular interval would be “every 2 years starting at year 1 and ending at year 9” (i.e., maintenance applied in years 1, 3, 5, 7, 9). Use the provided input boxes to define such an interval. Defining specific years is similar to entering treatment application ages. All specific years are either entered as comma-separated individual ages or hyphen-separated age ranges. For example, entering “1-3,4,6,8,10” schedules additional maintenance in years 1, 2, 3, 4, 6, 8, and 10. The user is asked to define the expected costs associated with each of the defined years in a later step of the analysis session setup process.

### *Step 5: Definition of Do-Nothing Performance Relationships*

In this step, all of the do-nothing performance curves associated with the selected condition indicators are defined. A do-nothing curve represents the typical performance expected on this type of pavement if no preventive maintenance treatment were applied. A performance relationship must be defined on each visible tab before proceeding to the next step.

The dialog box used to define do-nothing performance relationships changes depending on the type of analysis session. The interfaces for the *Simple* and *Detailed* analysis methods are described separately below.

*Defining Do-Nothing Relationships Under the “Simple” Analysis Method.* The controls used to define do-nothing relationships in a *Simple* analysis are shown in figure C-9. On this dialog box, a separate tab is displayed for each condition indicator included in the analysis session. The same controls used to define the do-nothing performance relationship are provided on each tab.

For this *Simple* analysis method, do-nothing curves are created by defining three points on the curve: a starting point, an ending point, and a pass-through point. To facilitate the definition of these three points, the expected equation trend (i.e., the user-defined *trend over time* associated with the current condition indicator) is displayed in the lower left corner of each condition indicator tab. Specific details on defining each of these three points are provided separately below.

Defining a Starting Point. The starting point for a given do-nothing curve is defined by entering an expected time zero condition level in the ‘*Initial*’ *condition level* input box. For convenience, the specific condition indicator units associated with the entered condition level are displayed directly above this ‘*Initial*’ *condition level* input box.

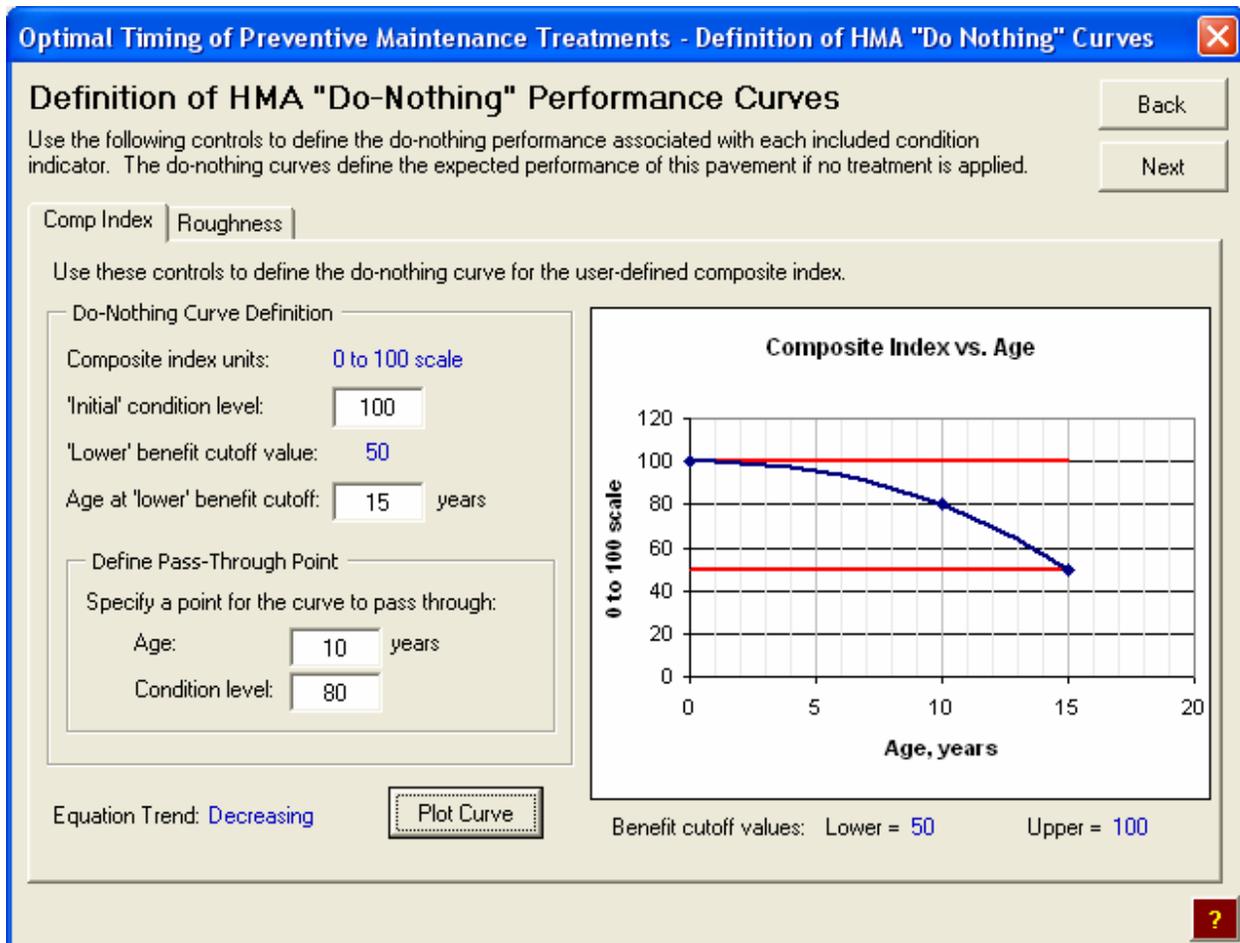


Figure C-9. Example of the *Definition of Do-Nothing Curves* dialog box—*Simple Analysis*.

Defining an Ending Point. The ending point for a given do-nothing curve is defined as the time at which the do-nothing curve is expected to intersect the governing benefit cutoff value level. Recall that the upper benefit cutoff value is the governing condition for *increasing* relationships, while the lower benefit cutoff value is the governing condition for *decreasing* relationships.

To define the curve's ending point, enter the expected age (in years) at which the curve is to intersect the governing upper or lower benefit cutoff value. For convenience, the governing benefit cutoff value is displayed directly above this input box used to enter the *Age at ('upper' or 'lower') benefit cutoff value*.

Defining the Pass-Through Point. The final step in defining the do-nothing curve is to define a third point for the curve to pass-through. This point should have an *age* that is between time zero and the ending point age, and a condition that is between the starting point and ending point conditions. Enter the specific pass-through point age and condition in the appropriate input boxes within the *Define Pass-Through Point* area of the dialog box.

Do-Nothing Curve Chart. The defined do-nothing performance relationship is plotted along with the defined benefit cutoff values on the condition indicator chart on the right side of each tab. For reference, the actual defined lower and upper benefit cutoff values are displayed below the chart. To update the chart after making changes to any of the inputs, click the  button. It is important to note that the shape of a do-nothing curve is determined automatically by the analysis tool. Specifically, an *increasing* do-nothing equation is plotted by fitting a *second-order polynomial* curve through the defined points. In contrast, a *decreasing* do-nothing equation is plotted by fitting a *power model* curve through the defined points. The typical shapes of these curves, as well as the equation form, are discussed in more detail in the next section.

*Defining Do-Nothing Relationships Under the Detailed Analysis Method.* The dialog box used to define do-nothing relationships in the *Detailed* analysis is shown in figure C-10. In this dialog box, a separate tab is displayed for each selected condition indicator included in the analysis session. The same controls used to define the do-nothing performance relationship are provided on each tab.

Selecting a Data Entry Method. The first step is to choose the method used to define the do-nothing performance relationship. As previously indicated, there are two options to define performance curves in the *Detailed* analysis method: selecting an equation type and entering

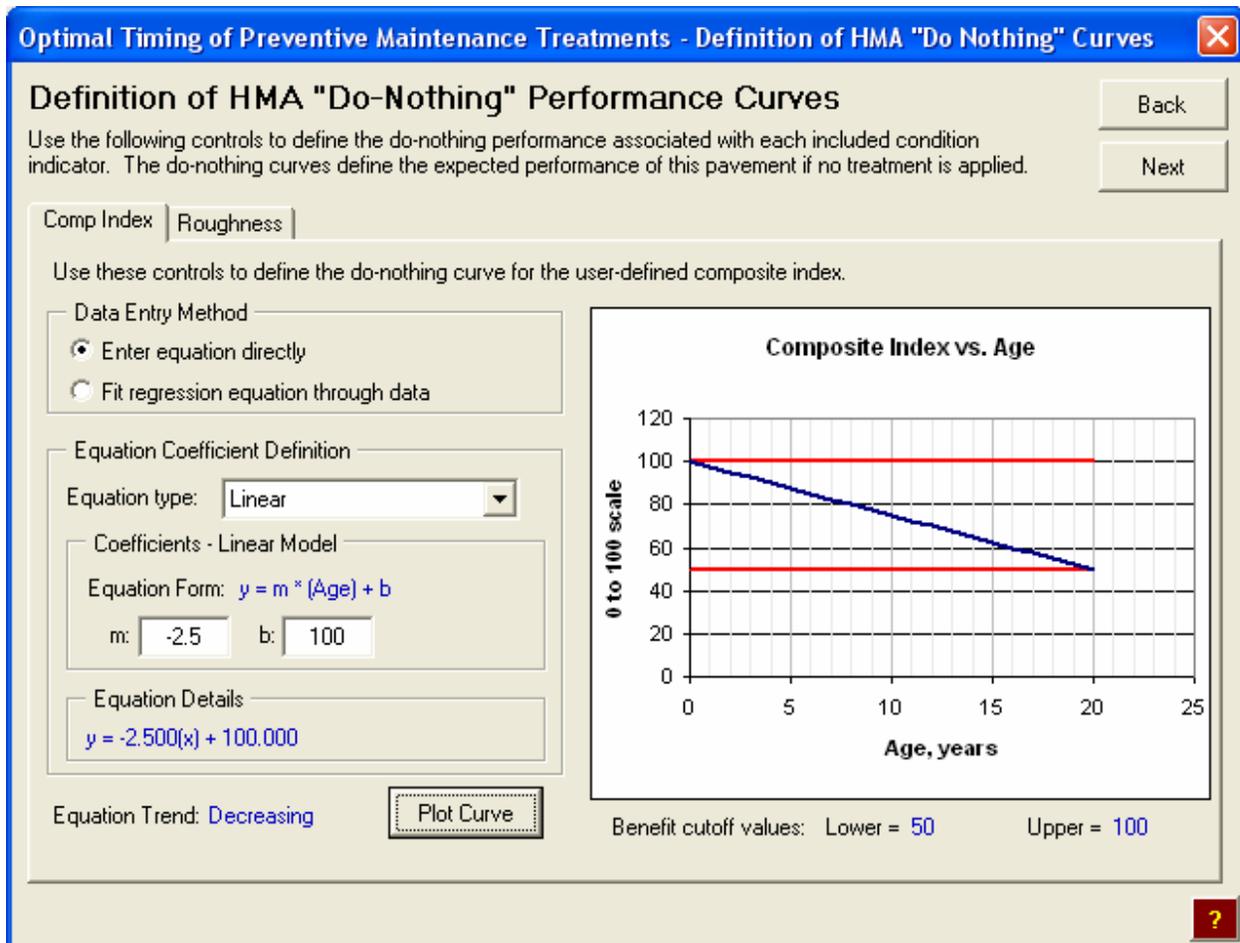


Figure C-10. Example of the *Definition of Do-Nothing Curves* dialog box in the—*Detailed Analysis* (with the *Equation Coefficient Definition* area displayed).

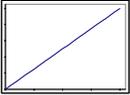
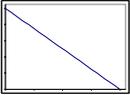
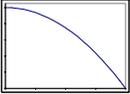
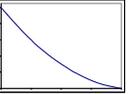
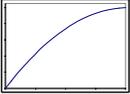
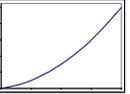
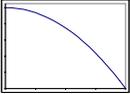
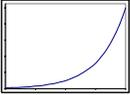
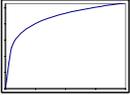
known equation coefficients, or fitting a regression equation though entered condition versus age data points. Choosing the *Enter equation directly* data entry method displays the *Equation Coefficient Definition* area. Additional options include choosing an equation type and defining the associated equation coefficients. Choosing the *Fit regression equation through data* choice displays the *Regression Equation Details* area; this then requires the entry of actual performance data points and the selection of the type of model.

Method 1: Entering Equations Directly. The *Equation Coefficient Definition* area is displayed when the user chooses the *Enter equation directly* data entry method (see figure C-10). Required inputs include the selection of an equation type and definition of associated

equation coefficients. More specific details on the selection of an equation type and the definition of equation coefficients are included below.

- *Equation Type*—Use the equation type list box to select an equation type for the current do-nothing curve. The five available equation types are as follows: linear, power model, second-order polynomial, exponential, and logarithmic. Table C-3 presents detailed descriptions of each available equation type, including the model form, required coefficients, the applicability of the model based on expected trends over time, and some visual feedback demonstrating the typical curve shapes that are associated with the chosen model type.

Table C-3. Details of the equation types available for use in the analysis tool.

Equation Type	Equation Form	Required Coefficients	Applicable Equation Direction	Example Curve Shape(s)
Linear	$y = m * (\text{Age}) + b$	m, b	Increasing	
			Decreasing	
Power Model	$y = C - m * (\text{Age})^p$	C, m, P	Decreasing	 
Second-Order Polynomial	$y = A * (\text{Age})^2 + B * (\text{Age}) + C$	A, B, C	Increasing	 
			Decreasing	 
Exponential	$y = A * e^{B * (\text{Age})}$	A, B	Increasing	
Logarithmic	$y = A * \text{Ln}(\text{Age}) + B$	A, B	Increasing	

- To facilitate the selection of an appropriate equation type, the expected equation trend (i.e., the user-defined *trend over time* associated with the current condition indicator) is displayed in the lower left corner of each condition indicator tab. A warning is displayed if the defined equation does not match this expected equation trend.
- *Equation Coefficients*—After selecting an appropriate equation type, the *Coefficients* area will display input boxes for the required coefficients. Define required coefficients by entering values in the provided input boxes. See table C-3 for a summary of the required equation coefficients associated with each available model type.
  - *Compiled Performance Relationship*—When the equation is defined, the compiled performance equation is displayed in the *Equation Details* area of the current tab. After making changes to the equation coefficients, click the  button to update the equation details displayed in this area.
  - *Do-Nothing Curve Chart*—The defined do-nothing performance relationship is plotted along with the defined benefit cutoff values on the condition indicator chart on the right side of each tab. For reference, the actual defined lower and upper benefit cutoff values are displayed below the chart. To update the chart after making changes to the equation coefficients, click the  button.

Method 2: Fitting a Regression Equation Through Entered Data. The second method used to define a do-nothing performance relationship is the fitting of a regression equation through entered data points. The *Regression Equation Details* area is displayed when the user chooses the *Fit regression equation through data* choice (see figure C-11). This area of the dialog box displays the current regression equation type and the specific computed regression

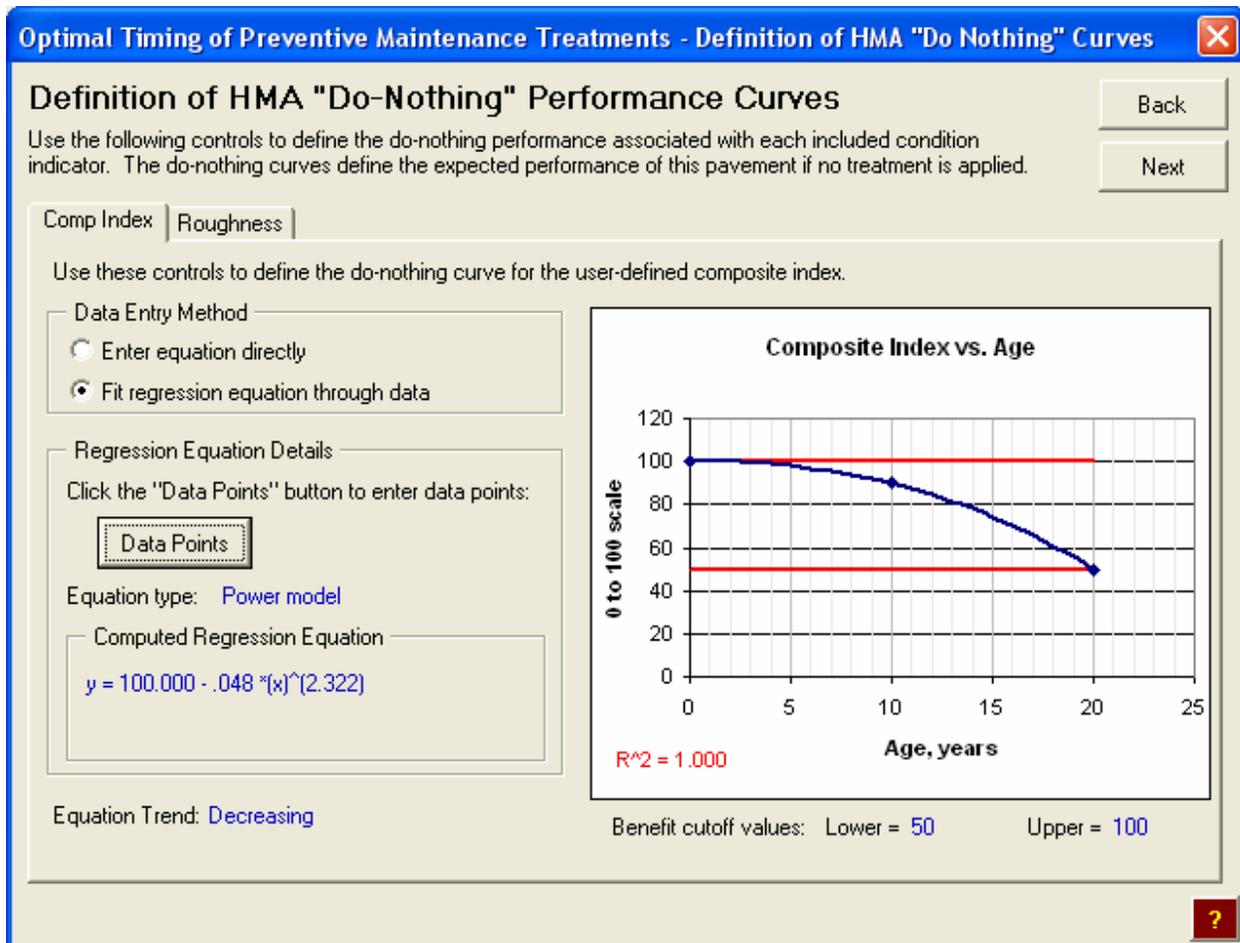


Figure C-11. Example of the *Definition of Do-Nothing Curves* dialog box—*Detailed Analysis* (with the *Regression Equation Details* area displayed).

equation. More specific details on how to define the specific data points and regression equation type are included below.

- *Entering Regression Data*—To enter specific data points and select the regression equation type to be used, click the Data Points button. This opens the *Regression Equation Data Entry* dialog box shown in figure C-12. To define the current do-nothing curve, enter data points (year and value) in the provided tabular input boxes on the left side of the dialog. Up to 20 data points may be used to define the equation. The data may be entered in any age order, as they will be sorted in ascending order upon leaving this dialog box.



Based on the selected equation type, the resulting do-nothing curve is displayed in the chart area on the right side of the dialog box. The upper and lower benefit cutoff levels are also plotted as red lines on this same chart. To update the chart after making changes to the entered data points, click the  button.

- *Do-Nothing Curve Chart.* As with the first method, the regressed do-nothing performance relationship is displayed along with the defined benefit cutoff values on the condition indicator chart on the right side of each tab. For reference, the actual defined lower and upper benefit cutoff values are displayed below the chart. To change any details of the displayed regression curve, click on the  button to re-open the *Regression Equation Data Entry* dialog box.

In order to compare different regression equation types, the  $R^2$  value is displayed on the chart. The  $R^2$  value is a statistical characteristic that gives an indication of the goodness of fit of an equation through a particular data set.  $R^2$  values range from 0 to 1.0 with an  $R^2$  value of 1.0 indicating a perfect fit (i.e., all data points fall on the regression curve).

#### *Step 6: Definition of Post-Preventive Maintenance Performance Relationships*

The next step in the setup of the analysis session is to define all of the post-preventive maintenance performance relationships associated with the chosen treatment application ages. The *Treatment Performance Relationship Summary List* dialog box displays a list of all of the post-preventive maintenance performance relationships that must be defined before conducting the analysis session. Each row in the displayed list is associated with each unique combination of chosen condition indicator and treatment application age. For example, if three condition indicators and five application ages are selected, there will be 15 rows (3 x 5) in the summary list

box. The specific information displayed in the summary list is dependent on the selected analysis method.

**Contents of the *Simple Analysis Summary List*.** When conducting a *Simple* analysis, the summary list (see figure C-13) displays detailed information about each defined performance relationship. Specifically, the columns of this displayed list present the following data:

- *Index*—A generic list index that shows the total number of relationships that need to be defined.
- *Condition Indicator*—The condition indicator associated with the current post-preventive maintenance relationship.
- *Condition Indicator Units*—The user-selected units associated with the condition indicator of the current relationship.
- *Application Year*—The application age for which the current performance relationship is applicable.
- *Condition Values*—The user-defined initial condition and governing benefit cutoff values are presented here as feedback.
- *Extension of Life*—This column is the user-defined extension of life (in comparison to the associated do-nothing curve) expected as a result of the preventive maintenance treatment application.
- *Pass-Through Point*—The last two columns in the list defines the user-defined pass-through point used to determine the post-preventive maintenance equation.

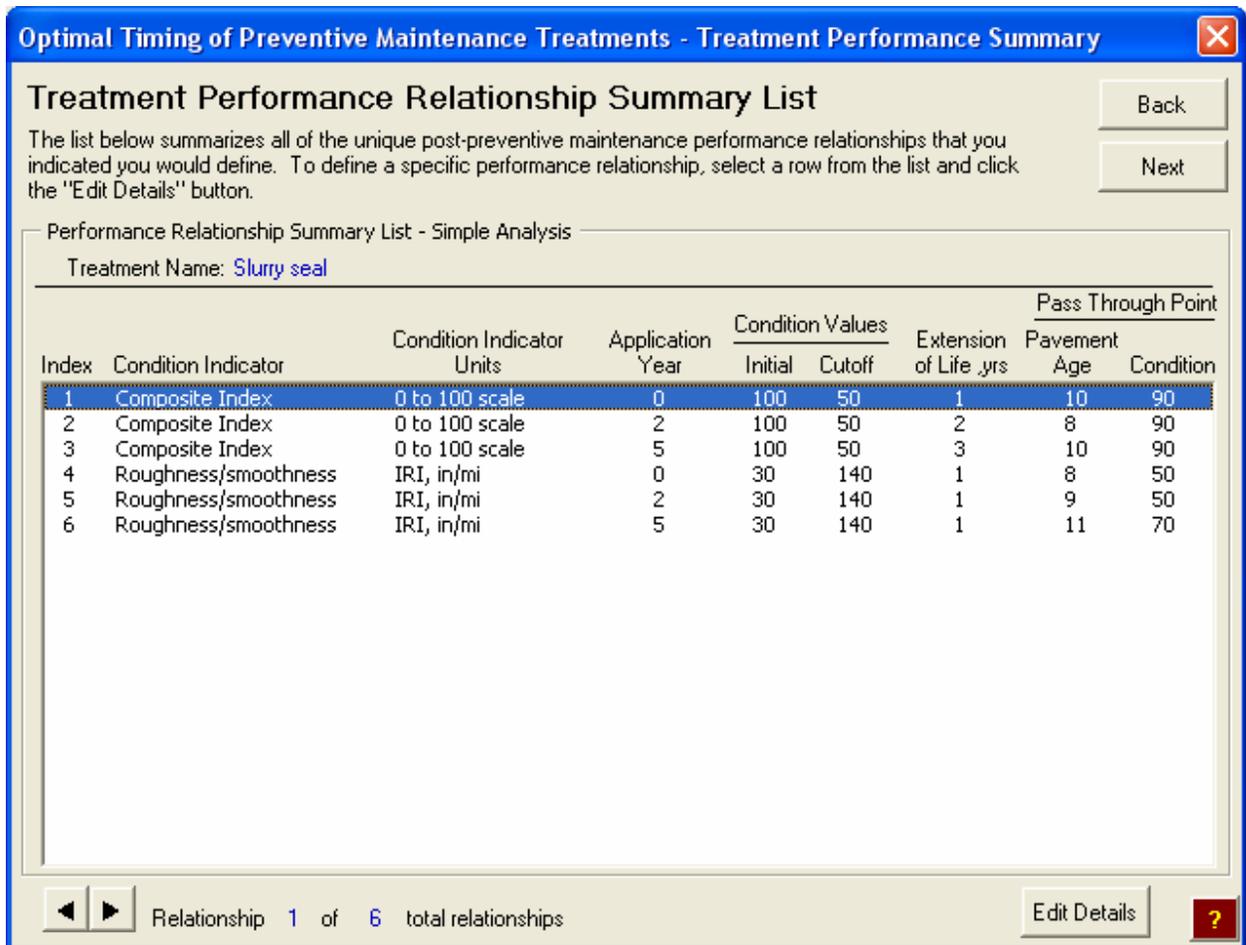


Figure C-13. Example of the *Treatment Performance Relationship Summary List* associated with a *Simple* analysis.

To define the specifics of a particular post-preventive maintenance relationship, first click on that row in list and then click the  button. This opens the *Treatment Performance Relationship Details* dialog box (see figure C-14). Use the controls on this box to define the details of the current post-preventive maintenance relationship. The dialog box is primarily divided into two different areas: the feedback area (at the top of the dialog box) and the *Performance Relationship* details area.

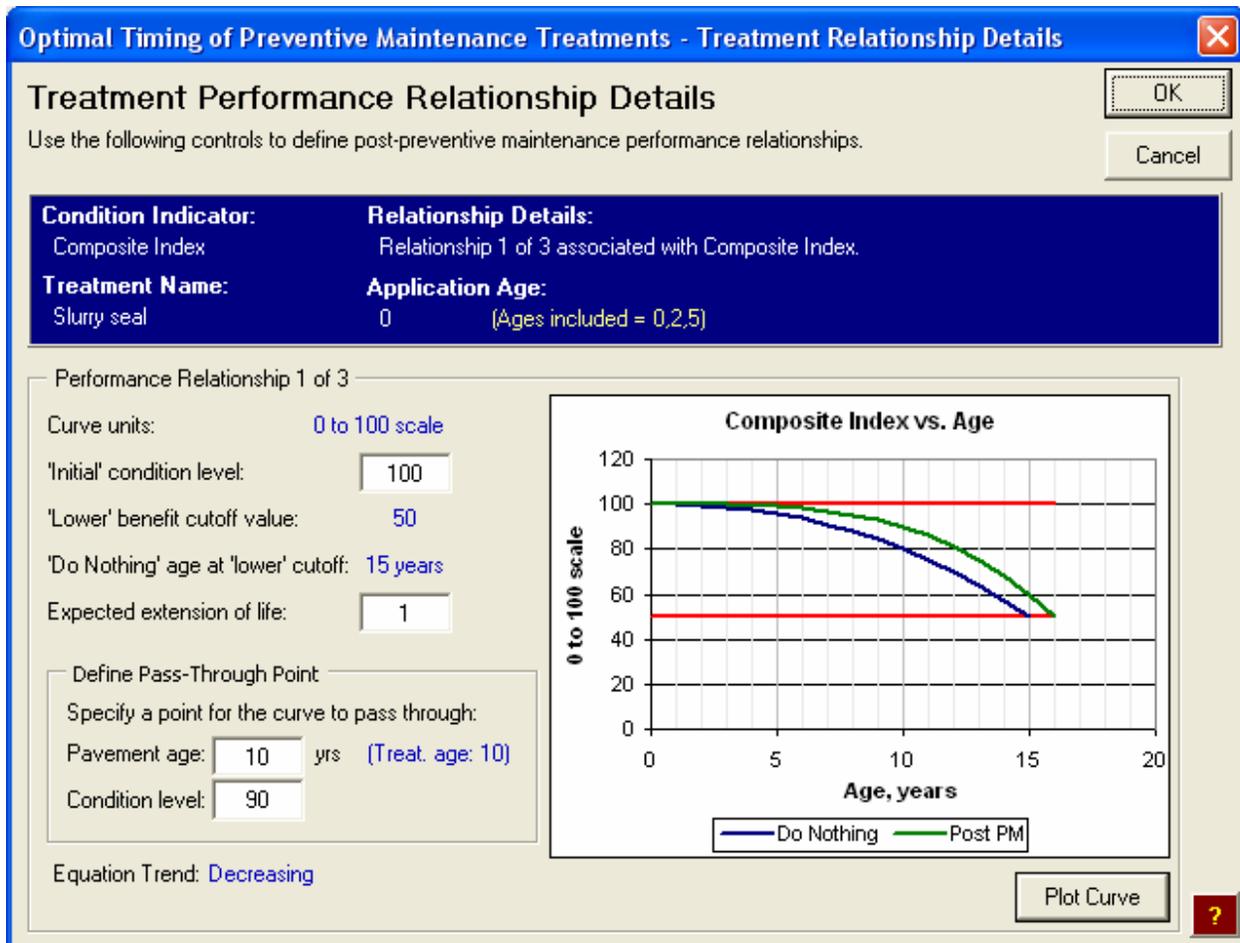


Figure C-14. Example of the *Treatment Performance Relationship Details* dialog associated with a *Simple* analysis.

Feedback Area. In the feedback area of the dialog box, pertinent information is provided about the current performance relationship for which the details need to be defined. This information includes the condition indicator name, treatment name, relationship details, and the current application age.

Performance Relationship Area. The details of the current post-preventive maintenance relationship are defined using the controls in the lower left area of the dialog box. As with the definition of do-nothing curves under the *Simple* analysis method, three points on a curve define post-preventive maintenance relationships: a starting point, an ending point, and a pass-through point. To help in the definition of these three points, the expected equation

trend (i.e., the user-defined *trend over time* associated with the current condition indicator) is displayed in the lower left corner of each condition indicator tab.

- *Defining a Starting Point*—The starting point for a given do-nothing curve is defined by the condition level that is expected as a result of the treatment application (i.e., the condition immediately after treatment application). This value is entered in the *'Initial' condition level* input box. For convenience, the specific condition indicator units associated with the entered condition level are displayed directly above this *'Initial' condition level* input box.
- *Defining an Ending Point*—The ending point for a given post-preventive maintenance curve is the time at which the post-preventive maintenance curve is expected to intersect the governing benefit cutoff value level. Recall that the upper benefit cutoff value is the governing condition for *increasing* relationships, while the lower benefit cutoff value is the triggering condition for *decreasing* relationships. The values reflecting the associated do-nothing curve ending point (i.e., the governing benefit cutoff level and the age at which the associated do-nothing curve intersects that cutoff level) are provided as reference points for the post-preventive maintenance relationship.

In the *Simple* analysis method, the curve's ending point is defined by entering an extension of life (in years) that is expected as a result of the preventive maintenance treatment application. This extension of life is the expected difference (in years) between the ages when the post-preventive maintenance and do-nothing curves cross the governing benefit cutoff condition. For example, if the post-preventive maintenance and do-nothing curves are expected to intersect the governing benefit

cutoff value at years 18 and 16, respectively, enter a “2” (years) in the *Expected extension of life* input box (i.e., the extension of life is  $18 - 16 = 2$  years).

- *Defining the Pass-Through Point*—The final step in defining the post-preventive maintenance curve is to define a third point for the curve to pass through. This point is necessary as it defines the shape of the performance curve. As the name indicates, the value entered in the *Pavement Age* input box represents the *pavement* age rather than the *treatment* age (i.e., the entered age is NOT the age since treatment application, but rather it is the time since the start of the do-nothing curve). However, for reference, the associated age since treatment application (i.e., treatment age) is displayed in parentheses next to the *Pavement Age* input box. The *Pavement Age* must fall between the age at treatment application and the ending point age.

The pass-through point condition is entered in the *Condition Level* input box in the *Define Pass-Through Point* area. The entered condition level must fall between the starting point and ending point conditions.

Post-Preventive Maintenance Curve Chart. The current post-preventive maintenance relationship is plotted along side its corresponding do-nothing curve on the condition indicator chart on the right side of the dialog box. Also included on the chart are the defined upper and lower benefit cutoff levels (for reference, the actual defined lower and upper benefit cutoff values are displayed below the chart). To update the chart after making changes to any of the inputs, click the  button.

**Contents of the *Detailed Analysis Summary List.*** In a *Detailed* analysis, the summary list (see figure C-15) displays detailed information about each defined performance relationship. Specifically, the columns of this displayed list present the following data:

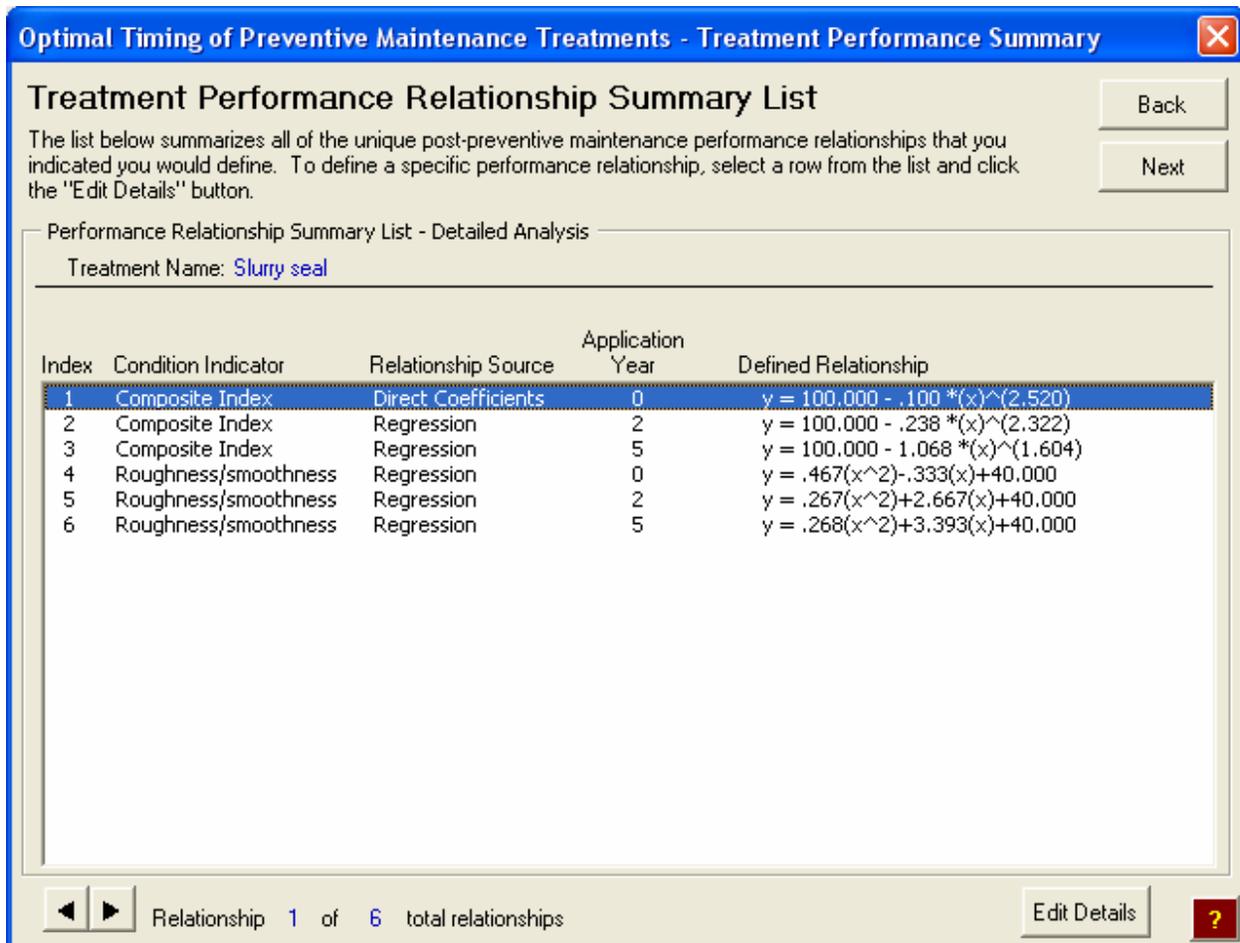


Figure C-15. Example of the *Treatment Performance Relationship Summary List* associated with a *Detailed* analysis.

- *Index*—A generic list index that gives an indication of the total number of relationships that need to be defined.
- *Condition Indicator*—The condition indicator associated with the current post-preventive maintenance relationship.
- *Relationship Source*—The method used to define the presented relationship. The two methods available include *Direct Coefficients* (i.e., choosing an equation type and defining the appropriate equation coefficients) or *Regression* (i.e., defining data points and fitting a regression equation through those points).

- *Application Year*—The application age for which the current performance relationship is applicable.
- *Defined Relationship*—The defined post-preventive maintenance relationship associated with a given combination of condition indicator and treatment application age. *Not Defined* is displayed in this data field for those post-preventive maintenance relationships that have not yet been defined.

To define a particular post-preventive maintenance relationship equation, first click on that row in the list and then click the  button.

Clicking the  button opens the *Treatment Performance Relationship Details* dialog box (see figure C-16). Use the controls on this box to define the details of the current post-preventive maintenance relationship. The dialog box is divided into two different areas: a feedback area (at the top of the dialog box) and the *Performance Relationship* details area.

The feedback area of the dialog box provides pertinent information about the current performance relationship for which the details need to be defined. This information includes the condition indicator name, treatment name, relationship details, and the current application age. For the *Detailed* analysis method, the process used to define the post-preventive maintenance performance curves is identical to the process used to define the do-nothing curves. The first step is to choose the method for defining the do-nothing performance relationship. As with the definition of do-nothing curves, either an equation type and known equation coefficients may be entered directly or a regression equation may be fitted though entered data points.

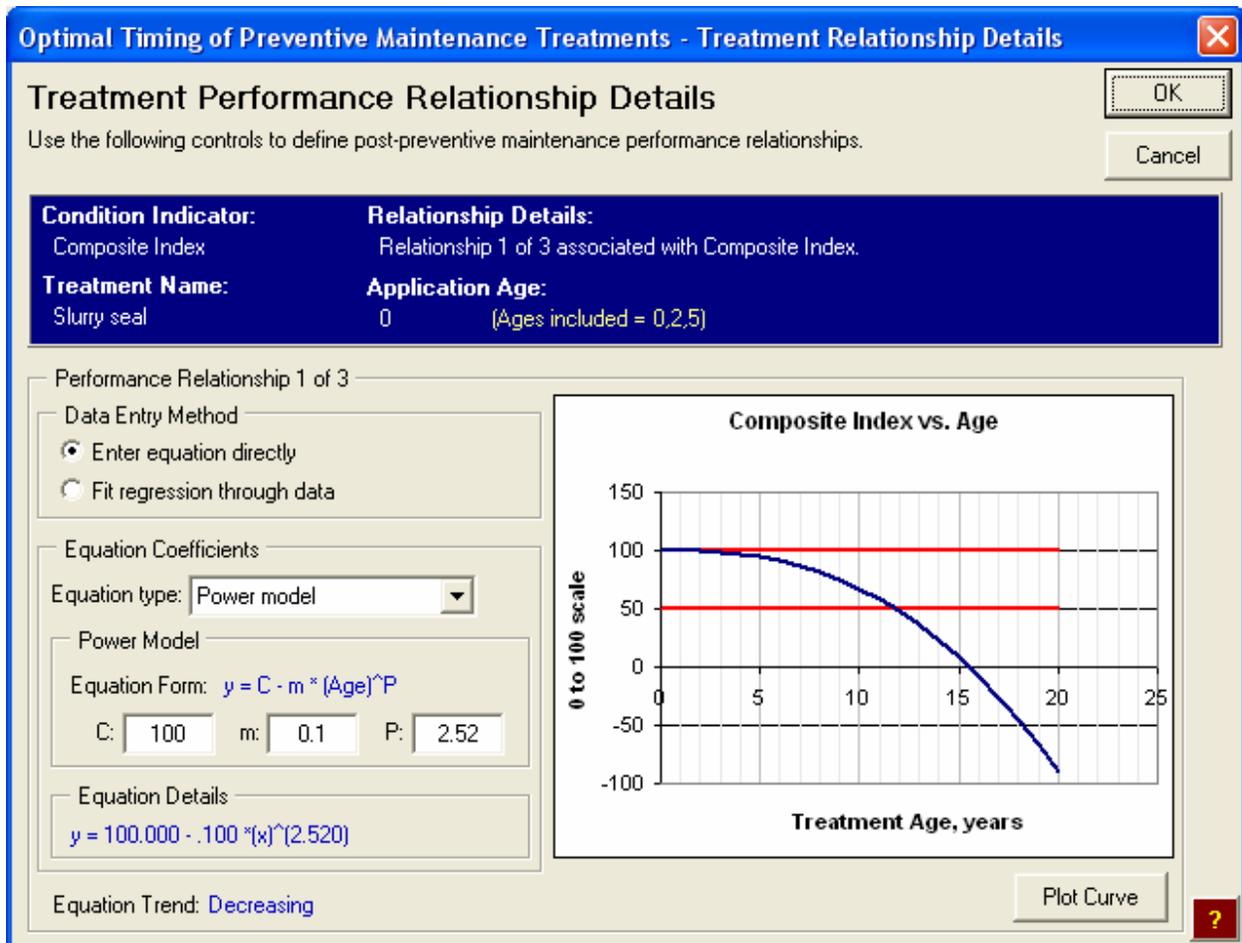


Figure C-16. Example of the *Treatment Performance Relationship Details* dialog box associated with a *Detailed* analysis.

Method 1: Entering Equations Directly. The *Equation Coefficient Definition* area is displayed when the user chooses the *Enter equation directly* data entry method (see figure C-16). Within this area of the dialog box, the user is asked to select an equation type and define associated equation coefficients (table C-3 summarizes the required equation coefficients associated with each available model type.)

The defined post-preventive maintenance performance relationship is plotted along with the defined benefit cutoff values on the condition indicator chart on the right side of each tab. Note that the x-axis of this chart represents the *treatment age* rather than the overall

*pavement* age. To update the chart after making changes to the equation coefficients, click the  button.

Method 2: Fitting a Regression Equation Through Entered Data. The second method that may be used to define a post-preventive maintenance performance relationship is to fit a regression equation through entered data points. The *Regression Equation Details* area is displayed when the user chooses the *Fit regression equation through data* choice. This area of the dialog box provides feedback to the user as the current regression equation type and the specific computed regression equation are presented.

To define the specific data points and regression equation type to be used, click the  button. Clicking this button opens the *Regression Equation Data Entry* dialog box shown in figure C-17. To define the current post-preventive maintenance curve, enter data points (year and value) in the table on the left side of the dialog box (note that the entered year is in terms of the age since treatment application). Up to 20 data points may be used to define the equation, and the data may be entered in any age order as they will be sorted in ascending order upon exiting this dialog box.

Next, select an appropriate regression equation type from the *Equation Type* list box. See table C-3 for more details regarding the specifics of each equation type and for guidance on what model is best suited to the expected curve shape. The  $R^2$  value is displayed on the chart to help the user determine which equation type is a best fit for the given data set.

Based on the chosen equation type, the resulting post-preventive maintenance curve is displayed in the chart area on the right side of the dialog box. The upper and lower benefit



**Optimal Timing of Preventive Maintenance Treatments - Definition of Costs**

**Definition of Costs**

Use the following controls to define the costs to be included in the analysis. Use the available controls to define specific cost types and their details.

**Selection of Cost Types**

- Treatment application costs
- Rehabilitation costs
- User delay costs (associated with work zone)

**General Inputs**

**Project Area (or Length):** 1 mi.

**Discount Rate:** 4.0 %

PM Treatments | Rehabilitation | User Delay | Cost Summary

Enter treatment unit costs and estimated routine maintenance costs (if applicable) to be used in the analysis.

**PM Treatment Costs**

**Treatment Name:**  
Slurry seal

**Treatment Unit Cost:**  
18000 per mi.

**Total Computed Treatment Cost:**  
\$18,000

**Routine Maintenance Costs at Indicated Years**  
Select a year from the list and enter the associated cost.

Year	Total Routine Maint. Cost, \$
1	\$1,000
3	\$2,000
5	\$3,000
7	\$3,500
9	\$4,000

**Yearly Maintenance Cost Details**

**Year:**  
Year 9

**Total Routine Maintenance Cost at Year #:**  
4000

Figure C-18. Example of the *Definition of Costs* dialog box with the *PM (Preventive Maintenance) Treatments* tab visible.

**Selection of Cost Types.** The first step on this dialog box is to use the controls in the *Selection of Cost Types* area to select the cost types to be included in the analysis. In addition to any routine/reactive costs defined previously, the following three different cost types are available:

- *Treatment application costs*—Treatment costs are agency costs associated with the construction of the preventive maintenance treatment.
- *Rehabilitation costs*—As it is widely held that preventive maintenance treatments delay the timing of more costly rehabilitation activities, to include that potential long term life-cycle cost impact, the analysis tool allows the inclusion of a rehabilitation cost. When

rehabilitation costs are included, a rehabilitation activity is assumed to be applied at the end of the preventive maintenance treatment's service life. Recall that the end of the preventive maintenance treatment service life is the earliest age at which one of the post-preventive maintenance performance curves (associated with one of the included condition indicators) reaches its governing benefit cutoff value.

- *User delay costs*—The methodology limits user costs to those associated with work zone delays (i.e., the cumulative delay cost recognized by all users subjected to the preventive maintenance treatment work zone). Other common types of condition-sensitive user costs (e.g., vehicle operating, discomfort, and crash costs) are not included because the range in condition is assumed to be relatively small for pavements that are candidates for preventive maintenance. This cumulative delay cost is computed as a function of the average number of vehicles per day (AADT), work zone duration, average vehicle delay time, and cost per delay time per vehicle.

Use the *Selection of Cost Types* check boxes to select the cost types to include in an analysis. Clicking on an already enabled cost type disables it. Enabling a cost type causes its associated details tab (at the bottom of the dialog box) to become enabled. While all three cost types are optional in that each can be disabled, at least one of the cost types must be enabled (the cost of preventive maintenance treatments is recommended) before the analysis can continue.

**General Inputs.** Two general cost-related inputs—the project size and discount rate—greatly affect the calculated life-cycle costs.

- *Project Area (or Length)*—Select a unit type from the list box and enter an appropriate project size-related value (as an integer) in the input box. These entered values allow the computation of total costs that feed into the life-cycle cost analysis. In many cases, the use of a standard unit length, such as 1 mile, is appropriate.

- *Discount Rate*—The discount rate is used to translate post-construction costs into equivalent present worth and future worth costs. It is defined as the difference between the interest and inflation rates over a period of time, and represents the real value (or cost) of money. The interest rate is the nominal cost of money, while the inflation rate represents the changing purchasing power of money. Historically, discount rates have ranged from 3 to 5 percent. Therefore, the default value is set at 4.0 percent in the OPTime tool.

***Preventive Maintenance Treatment Cost Details.*** The *PM Treatments* cost details tab (see figure C-18) includes all of the controls required to define the preventive maintenance treatment costs, as well as any costs associated with additional maintenance.

- *Preventive Maintenance Treatment Costs*—The treatment unit cost is entered in the *Treatment Unit Cost* input box. The assigned area (or length) units match those defined in the *General Inputs* area. The computed total treatment cost is then displayed directly below as the *Total Computed Treatment Cost*. In the life-cycle cost analysis, this total computed treatment cost is applied at the treatment application age associated with a given timing scenario.
- *Routine Maintenance Costs at Indicated Years*—If the costs of routine/reactive maintenance are included in step 4 of the analysis setup, the user also defines the associated cost details in the *Routine Maintenance Costs at Indicated Years* area of this dialog box. The provided list displays all of the years for which maintenance costs are identified. To enter the costs associated with each year, click on a row in the table and enter the associated cost in the *Total Routine Maintenance Cost at Year #* input box. Undefined costs are interpreted as \$0 costs in the analysis.

**Rehabilitation Cost Details.** If rehabilitation costs are included in this analysis, the *Rehabilitation* tab (displayed in figure C-19) is enabled. Two different input box values are entered on this tab. First, enter a descriptive name of the scheduled rehabilitation activity in the *Rehabilitation Activity Name* input box. Next, enter a unit cost for the activity in the *Rehabilitation UNIT Cost* input box (the unit cost is entered in terms of the dimensional units defined in the *General Inputs* area). The computed total rehabilitation cost is then displayed directly below the input box as the *TOTAL Computed Rehabilitation Cost*.

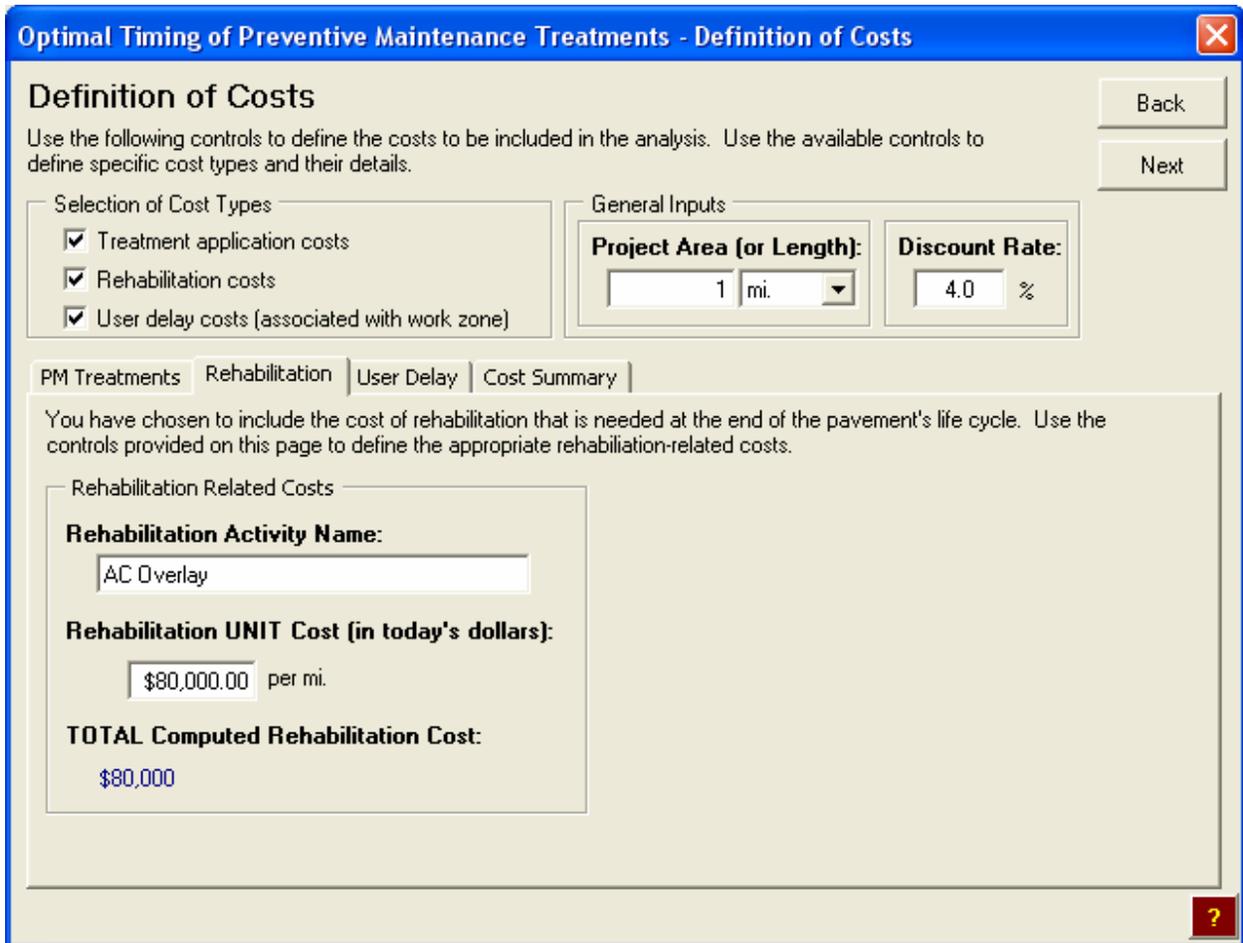


Figure C-19. Example of the *Definition of Costs* dialog box with the *Rehabilitation* tab visible.

**User Delay Cost Details.** The analysis approach allows user costs associated with construction delay to be included. In this analysis, user costs are associated with operating vehicles in a construction zone and specifically include the delay costs due to reduced speed to enter the work zone (perhaps even to come to a complete stop if queuing), reduced speed through the work zone, and use of alternate routes to avoid work zone. The *User Delay* tab (figure C-20) includes all of the controls required to compute the user delay costs.

**Optimal Timing of Preventive Maintenance Treatments - Definition of Costs**

**Definition of Costs**

Use the following controls to define the costs to be included in the analysis. Use the available controls to define specific cost types and their details.

Selection of Cost Types

- Treatment application costs
- Rehabilitation costs
- User delay costs (associated with work zone)

General Inputs

Project Area (or Length): 1 mi.

Discount Rate: 4.0 %

PM Treatments | Rehabilitation | **User Delay** | Cost Summary

Enter design traffic information and costs associated with user delays work zones. The design traffic information is needed to compute the number of vehicles that pass through a work zone for a given year.

Design Traffic

Initial ADT: 10,000 veh/day

ADT growth rate: 2 percent

Growth type: Simple

Percentage ADT by vehicle type

Passenger Cars: 60 %

Single Unit Trucks: 20 %

Combination Trucks: 20 %

Edit Hourly Traffic Distribution

Delay Cost Rate

**Passenger Cars:** 11.50 \$/hr

**Single Unit Trucks:** 18.50 \$/hr

**Combination Trucks:** 22.50 \$/hr

Work Zone Related Information

Treatment name: Slurry seal

Work zone start time: 8:00 a.m.

Work zone duration: 12 hours

Avg. additional delay time, min/veh (by type):

Passenger Cars: 5 min/veh

Single Unit Trucks: 10 min/veh

Combination Trucks: 25 min/veh

Figure C-20. Example of the *Definition of Costs* dialog box with the *User Delay* tab visible.

The inputs in this basic analysis are based on the method outlined in the 1998 FHWA report *Life-Cycle Cost Analysis in Pavement Design* (23). To compute user delay costs, the following inputs are required:

- *Design Traffic Information*—Input general traffic information, such as initial average daily traffic (ADT), the expected annual growth rate in ADT, and the expected ADT growth type (either simple or compound). Additionally, define the percent ADT associated with passenger cars, single unit trucks, and combination trucks. The *Percentage ADT by Vehicle Type* inputs are entered as integer values and all three must sum to 100. To define the specific percent of total day ADT associated with each clock hour of the day, click on the  button. This opens the *Traffic Distribution Details* dialog box displayed in figure C-21. All of these traffic inputs are used to compute the total number of passenger cars, single unit trucks, and combination trucks that will pass through a defined work zone. Note: the default hourly traffic distribution values shown in figure C-21 are the default values used in the MicroBENCOST life-cycle cost software for rural roadways (23).
- *Delay Cost Rate*—Delay cost rates for each vehicle classification must be entered in the appropriate input boxes. The 1998 FHWA *Report* provides typical ranges of \$10 to \$13 for passenger cars, \$17 to \$20 for single unit trucks, and \$21 to \$24 for combination trucks (23). The default values used in the OPTime tool are the average values of each of these ranges. These entered values are used to compute the total delay cost associated with each vehicle passing through the defined work zone.

**Traffic Distribution Details** [X]

**Hourly Traffic Distribution** [OK]

This list shows the percent distribution of average daily traffic (ADT) by hour.

12:00 a.m.	1.8 %	12:00 p.m.	5.7 %
1:00 a.m.	1.5 %	1:00 p.m.	6.4 %
2:00 a.m.	1.3 %	2:00 p.m.	6.8 %
3:00 a.m.	1.3 %	3:00 p.m.	7.3 %
4:00 a.m.	1.5 %	4:00 p.m.	9.3 %
5:00 a.m.	1.8 %	5:00 p.m.	7 %
6:00 a.m.	2.5 %	6:00 p.m.	5.5 %
7:00 a.m.	3.5 %	7:00 p.m.	4.7 %
8:00 a.m.	4.2 %	8:00 p.m.	3.8 %
9:00 a.m.	5 %	9:00 p.m.	3.2 %
10:00 a.m.	5.4 %	10:00 p.m.	2.6 %
11:00 a.m.	5.6 %	11:00 p.m.	2.3 %

24 Hour TOTAL = 100.00 %

(Note: the total hourly % ADT values must total to 100.) [?]

Figure C-21. Example of the *Traffic Distribution Details* dialog box with default percentages shown.

- Work Zone Related Information*—The work zone related information area is used to define the details of the project work zone. The *Work zone start time* is the clock hour when the work zone is assumed to start. The *Work zone duration* is the total number of hours that the work zone is expected to be active on the roadway (i.e., the time from lane closures to time of opening to traffic). These two inputs together are used to determine the number of vehicles that will be passing through the work zone. Finally, the *Average additional delay time* (in minutes/vehicle) for each vehicle type is required to determine the effect of the work zone on each of the three vehicle categories.

**Cost Summary.** The *Cost Summary* tab (figure C-22) summarizes all of the preventive maintenance treatment, rehabilitation, and user delay costs that are selected for the analysis.

Note: the routine/reactive maintenance costs are not summarized on this tab.

**Optimal Timing of Preventive Maintenance Treatments - Definition of Costs**

**Definition of Costs**

Use the following controls to define the costs to be included in the analysis. Use the available controls to define specific cost types and their details.

Selection of Cost Types

- Treatment application costs
- Rehabilitation costs
- User delay costs (associated with work zone)

General Inputs

**Project Area (or Length):** 1 mi.

**Discount Rate:** 4.0 %

PM Treatments | Rehabilitation | User Delay | **Cost Summary**

The following are the different costs that will be used in the analysis (note: all costs are in today's dollars).

**PM Treatment Cost Summary**

**Treatment Name:**  
Slurry seal

**Total Computed Treatment Cost:**  
\$18,000

**Rehabilitation Cost Summary**

**Rehabilitation Activity Name:**  
AC Overlay

**Total Computed Rehabilitation Cost:**  
\$80,000

**User Cost Summary**

Note: all of the user cost numbers presented below are representative of year "0" values only (i.e., both costs and number of vehicles affected will be inflated with time based on your inputs.)

Vehicle Category	No. of Vehicles	Cost per Vehicle, \$	Total Costs by Category, \$
Passenger Cars:	4,374	\$0.96	\$4,192
Single Unit Trucks:	1,458	\$3.08	\$4,496
Combination Trucks:	1,458	\$9.38	\$13,669
<b>Total (All Categories)</b>	<b>7,290</b>		<b>\$22,356</b>

Figure C-22. Example of the *Definition of Costs* dialog box with the *Cost Summary* tab visible.

#### Step 8: Definition of Benefit Weighting Factors

If multiple condition indicators are selected, an individual benefit is calculated for each condition indicator and they are all used to determine optimal treatment timing. Applying a benefit weighting factor is a way of differentially weighting these *individual* benefits associated with the different condition indicators. The *Benefit Weighting Factors* dialog box (figure C-23) contains input boxes associated with each condition indicator. All benefit weighting factors are entered as integers and must total to 100 before proceeding.

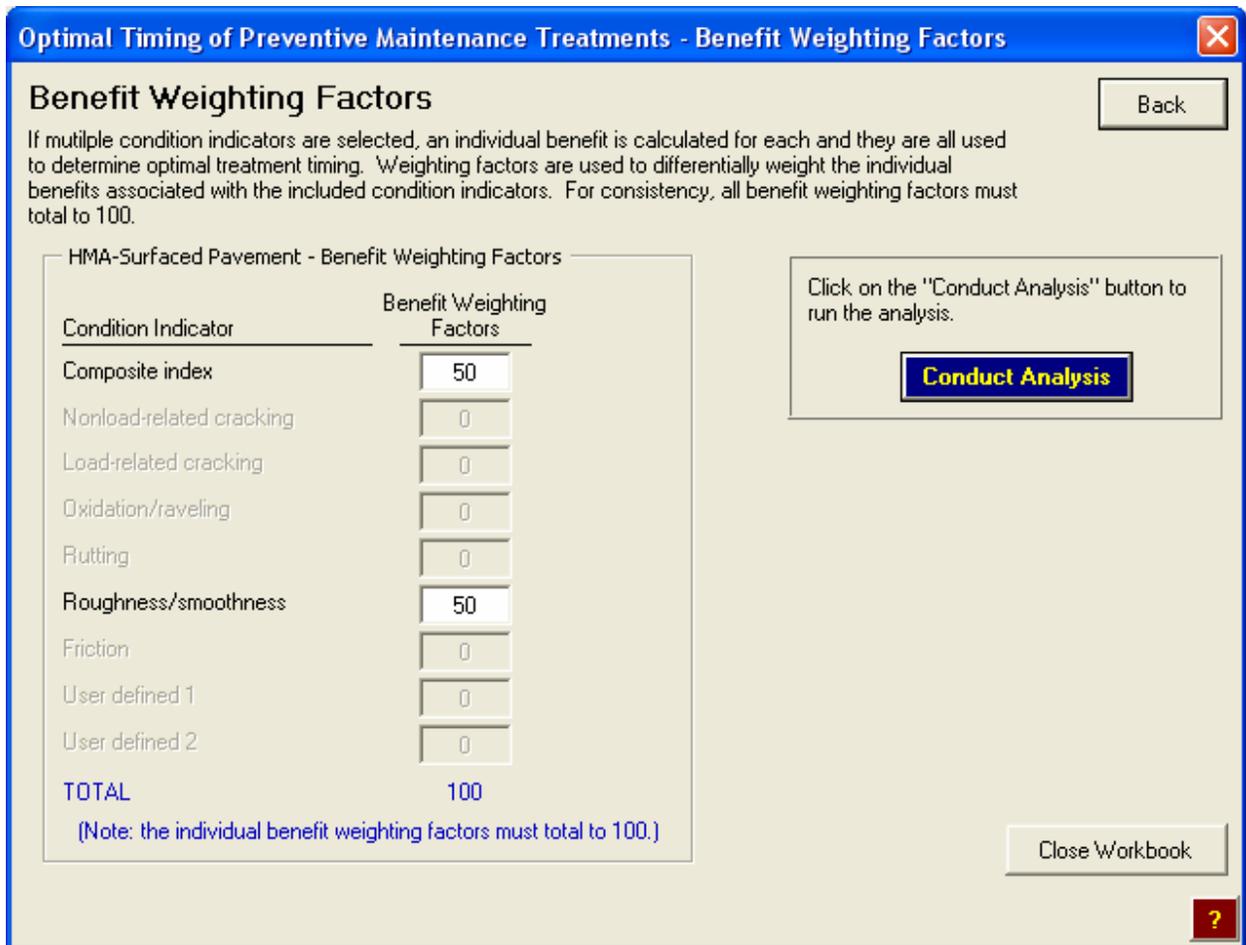


Figure C-23. Example of the *Benefit Weighting Factors* dialog box.

As an example, assume that a particular preventive maintenance treatment timing resulted in individual percent increases in benefit values of 27 percent for rutting, 12 percent for roughness (IRI), and 47 percent for friction. That is, the preventive maintenance treatment application resulted in an increase of 27 percent over the rutting do-nothing benefit area, 12 percent over the IRI do-nothing benefit area, and 47 percent over the friction do-nothing benefit area. The benefit weighting factors are then used to combine these individual increases in benefit area into one overall increase in benefit area. Using respective benefit weighting factors of 60, 30, and 10 (note: these factors all add to 100), overall benefit contributions are determined by multiplying the benefit weighting factor percentages by the individual benefit values (e.g., for rutting 27 percent \* 60/100 = 16.2 percent). The total overall benefit contribution is then the sum of those

values calculated for each individual condition indicator; therefore, in this example, the total overall benefit contribution is 24.5 percent. While by itself this total benefit value is essentially meaningless, total benefit values computed for different timing scenarios can be used to compare the effectiveness of the different timing scenarios. A summary of this example is presented in table C-4.

Table C-4. Example computation of overall benefit.

<b>Condition Indicator</b>	<b>Individual Benefit Values, %</b>	<b>Assigned Benefit Weighting Factor</b>	<b>Benefit Weighting Factor Percentage</b>	<b>Overall Benefit Contribution, %</b>
Rutting	27	60	$60/100 = 0.6$	16.2
Roughness (smoothness)	12	30	$30/100 = 0.3$	3.6
Friction	47	10	$10/100 = 0.1$	4.7
<b>TOTAL</b>	—	<b>100</b>	<b>1.0</b>	<b>24.5</b>

**Selecting Appropriate Benefit Weighting Factors.** Selecting benefit weighting factors that “correctly” weight the different condition indicators is a very difficult task. Because each condition indicator is plotted in different units, a 10 percent increase in area associated with roughness is unlikely to have the same impact on performance as a 10 percent increase in friction area. To choose meaningful benefit weighting factors, it is recommended that many different combinations of benefit factors be evaluated to calibrate the resulting treatment effectiveness with actual expected performance data. This process is not unlike the process used to determine the relative impacts of different distress values when they are incorporated into a composite index.

Extreme caution should be used when selecting benefit factors. In fact, as a first step, it is recommended that each condition indicator be analyzed separately to get a better idea of the individual impacts of different timing scenarios on expected performance.

**Conducting the Analysis.** The last step of the sequential interface (the *Benefit Weighting Factors* dialog box) includes a  button. Clicking this button will cause the analysis to be conducted. During the analysis process, a new workbook is created (in the background) in which all of the inputs and outputs associated with the current session are stored. After the analysis process is complete, a dialog box will appear which asks if the user wants to save the current analysis session results.

## **INPUT/OUTPUT WORKBOOKS**

After an analysis is conducted, all inputs and outputs of that session are compiled into a new Microsoft® Excel workbook that may be named and saved. Then, from the *Introduction* dialog box (the first step of the sequential session definition procedure), any of these saved input/output workbooks can be opened by clicking the  button and selecting a valid workbook. Each input/output workbook is comprised of a worksheet summarizing inputs, a worksheet summarizing outputs, a condition performance relationship chart for each included condition indicator, and a set of charts that summarize the output results.

### ***Input Data Sheet***

The *Input Data* sheet (see figure C-24) is a summary of all the inputs, including cost details, do-nothing curve relationship details, and post-preventive maintenance treatment performance relationship details.

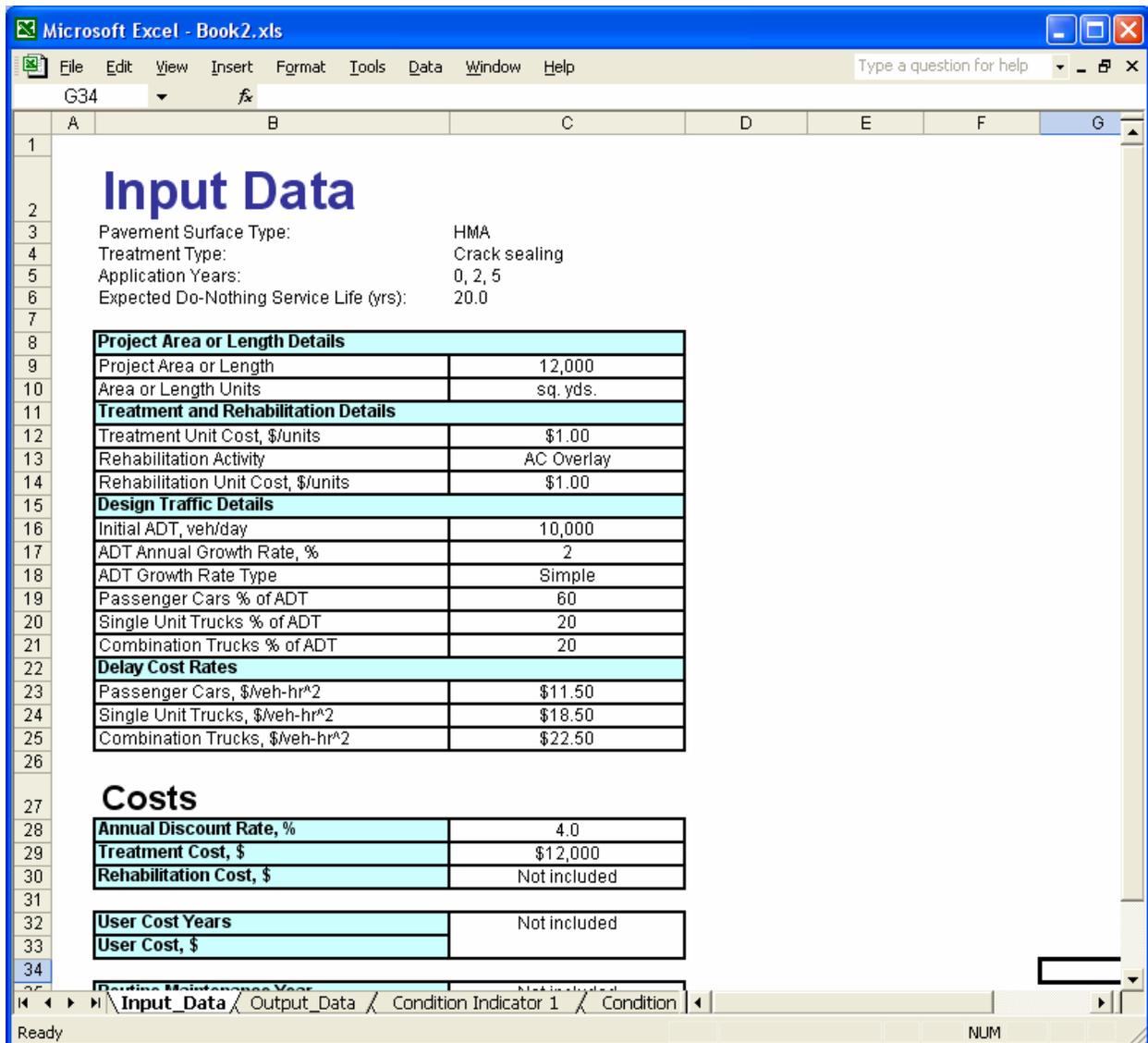


Figure C-24. Example of an *Input Data* sheet included in an input/output workbook.

### ***Output Data Sheet***

The *Output Data* sheet is a summary of all the outputs that were determined during the current analysis session (see figure C-25). In addition to general feedback, such as the pavement surface type, treatment type, treatment application years, and the computed expected do-nothing service life, this data sheet contains a benefit summary, a cost summary, and an effectiveness summary.

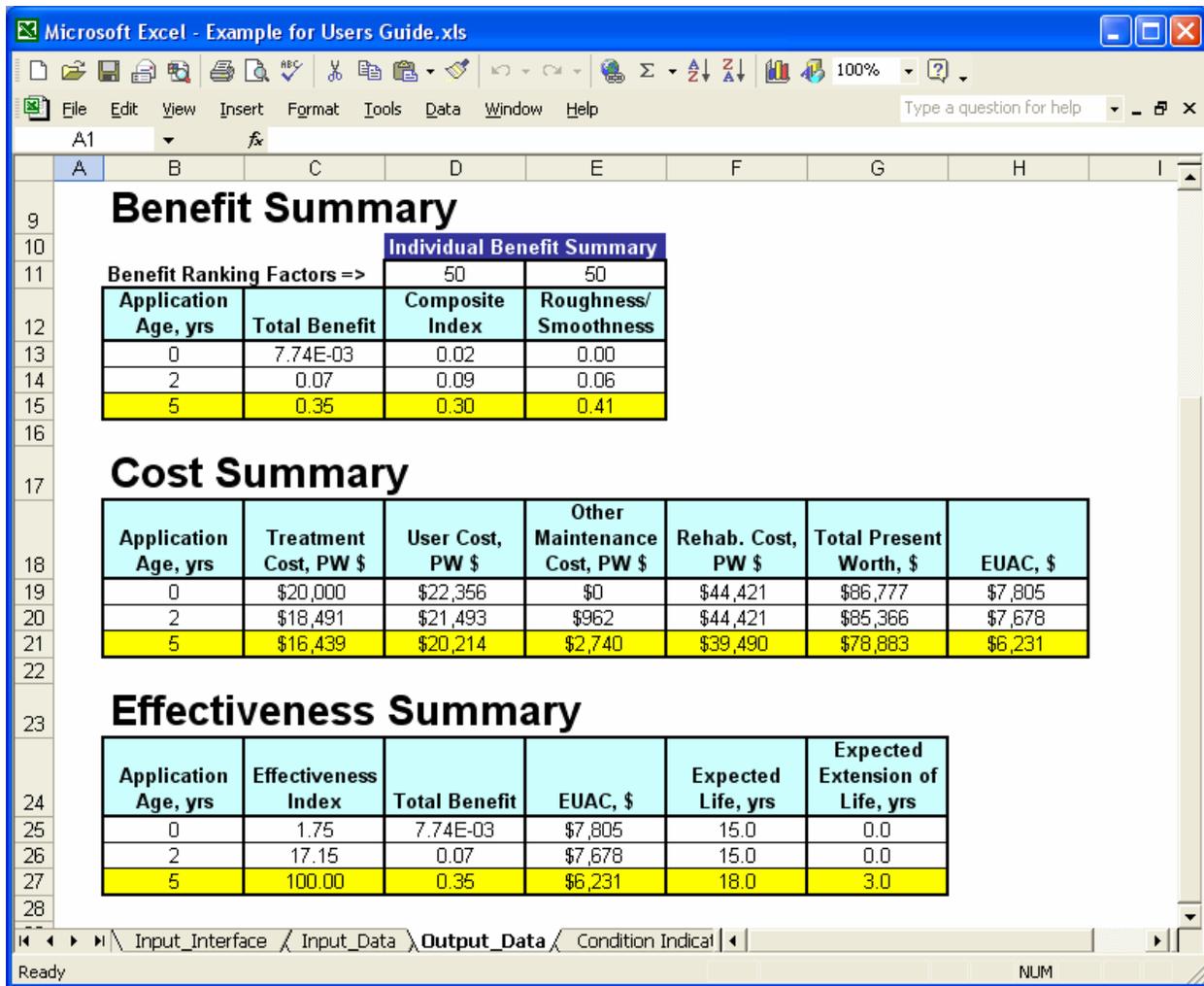


Figure C-25. Example of an *Output Data* sheet included in an input/output workbook.

### *Benefit Summary*

The benefit summary area of the *Output Data* sheet is comprised of individual condition indicator benefit values and a computed total benefit value associated with each application timing scenario. The application age associated with the highest Effectiveness Index is highlighted in yellow in the benefit summary table.

### *Cost Summary*

The cost summary area presents the actual costs included in the analysis session. Those cost types that were not chosen for inclusion in the analysis are presented as *n/a* in this table. The

first column of this table includes the treatment application ages. The next four columns include the costs (in today's dollars) associated with the preventive maintenance treatment, user delay, and other maintenance (routine/reactive maintenance). The *Total Present Worth* column is computed as the sum of all of the present worth values of the individual included costs. Finally, the total present worth cost is translated into a EUAC based on the expected service life associated with each individual timing scenario (application age).

### *Effectiveness Summary*

The final area of the *Output Data* worksheet is a summary of the relative effectiveness of each timing scenario. This table is comprised of six columns that include the treatment application age, computed Effectiveness Index, total benefit and EUAC values (copied from the benefit and cost summary tables above), an expected life, and expected extension of life.

**Effectiveness Index.** Each individual timing scenario is compared based on a normalized B/C ratio referred to as the Effectiveness Index. For each application age, a B/C ratio is computed internally as the ratio of the computed total benefit and EUAC values (presented in columns 3 and 4 of this table). Since the actual computed B/C value has little meaning, the individual computed B/C ratios are normalized to a 0 to 100 scale by comparing all B/C ratios to the maximum individual B/C ratio (i.e., that ratio that is associated with the optimal timing scenario). This normalized value, referred to as the Effectiveness Index, is computed for each timing scenario using equation 1:

$$EI_i = \left[ \frac{(B/C)_i}{(B/C)_{\max}} \right] \times 100 \quad (\text{Eq. 1})$$

where:

$EI_i$ =Effectiveness Index associated with the  $i^{\text{th}}$  timing scenario (dimensionless).

$(B/C)_i$  = Benefit-to-cost ratio associated with the  $i^{\text{th}}$  timing scenario.

$(B/C)_{\text{max}}$  = Maximum of all of the benefit-to-cost ratios associated with the different timing scenarios.

$i$  = Index associated with the current timing scenario.

Table C-5 illustrates this process by showing an example in which the analysis consisted of applying one chip seal in either year 1, 2, 3, 4, 5, or 6 (i.e., six timing scenarios). Using the benefit and cost values assumed in table C-4, timing scenario 3 has the highest B/C ratio, and is thus assigned an Effectiveness Index of 100. An agency that generated these results could conclude that the optimal time to apply this preventive maintenance treatment is in year 4, but notice that the results from an application in year 3 are very similar. Where there are minor differences in the Effectiveness Index, there is more leeway in the timing of these treatments, while larger differences in Effectiveness Index imply that the effects of deferring treatment application are more significant.

Table C-5. Example computation of effective indices for different treatment timing scenarios.

<b>Year of Preventive Maintenance Application</b>	<b>BENEFIT (B) Overall Benefit, %</b>	<b>COST (C) EUAC, \$</b>	<b>Benefit-to-Cost Ratio (B/C), %/\$</b>	<b>Effectiveness Index</b>
1	52.7	\$10,000	0.00527	47
2	65.5	\$9,615	0.00681	61
3	102.4	\$9,246	0.01108	99
4	99.8	\$8,890	(Max) 0.01123	100
5	72.5	\$8,548	0.00848	76
6	65.4	\$8,219	0.00796	71

For clarification, the rows associated with the most effective application age (i.e., the application age with an Effectiveness Index = 100) are highlighted in yellow in all three summary tables. When a computed B/C ratio is negative, that application age is labeled as “Not

Effective” as this indicates that there would be a negative benefit associated with applying the treatment at that particular pavement age.

**Expected Life.** The fifth column of the *Effectiveness Summary* table presents the computed expected life associated with each timing scenario. As indicated previously, the expected service life for the post-preventive maintenance condition is the earliest age at which one of the post-preventive maintenance condition indicator relationships reaches its individual governing benefit cutoff value. In other words, the presented expected life is the age at which one of the condition indicator relationships is assumed to reach a user defined *failure* level (i.e., the governing benefit cutoff value).

**Expected Extension of Life.** The final column of the *Effectiveness Summary* table presents the computed expected extension of life associated with each timing scenario. These values are determined as the difference between the expected post-preventive maintenance treatment life (those values in column 5 of the table) and the expected life of the pavement without a treatment (represented by the original do-nothing curve). This calculated *Expected Do-Nothing Service Life* is that value presented in the general feedback area of the *Output Data* worksheet. The expected extension of life will, therefore, be negative for those timing scenarios where the application of a treatment causes the condition level to reach the governing benefit cutoff value sooner than what would have been achieved without applying the treatment (i.e., the do-nothing condition).

### **Condition Indicator Charts**

A series of charts are included in the input/output workbooks to visually present the expected condition indicator relationships associated with the most effective timing scenario. A separate chart is included for each condition indicator included in the analysis session. The example plot

shown in figure C-26 illustrates a case in which the most effective timing scenario occurs when a preventive maintenance treatment is applied at a pavement age of 5 years.

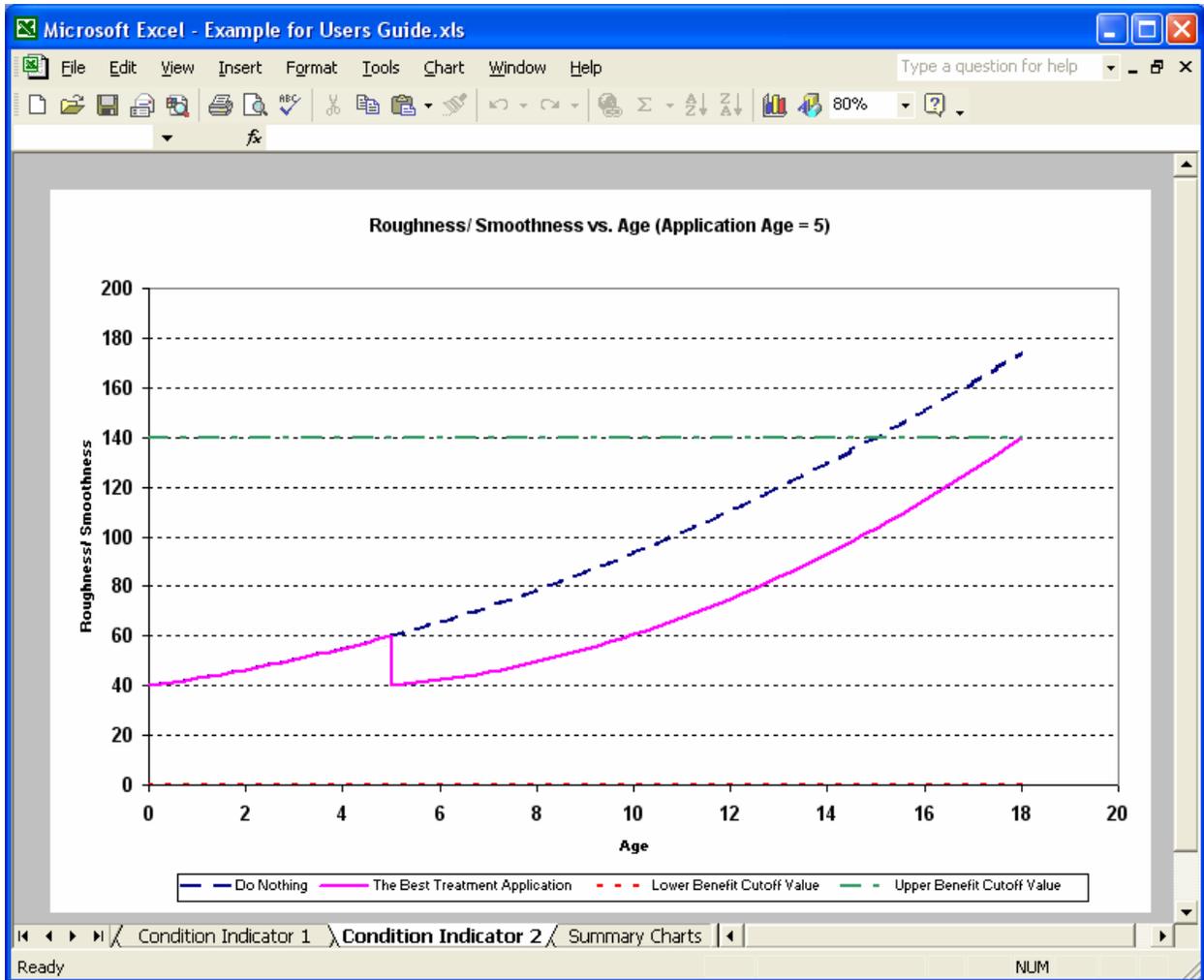


Figure C-26. Example of a *Condition Indicator* sheet included in an input/output workbook.

## Summary Charts Sheet

The final worksheet in each input/output workbook is the *Summary Charts* sheet (see figure C-27). This sheet contains four charts that summarize the data presented in the *Effectiveness Results* table on the *Output Data* worksheet. Specifically, the following four summary plots are included:

- Effectiveness index versus treatment application timing.
- Extension of life versus treatment application timing.
- EUAC versus treatment application timing.
- Total benefit versus treatment application timing.

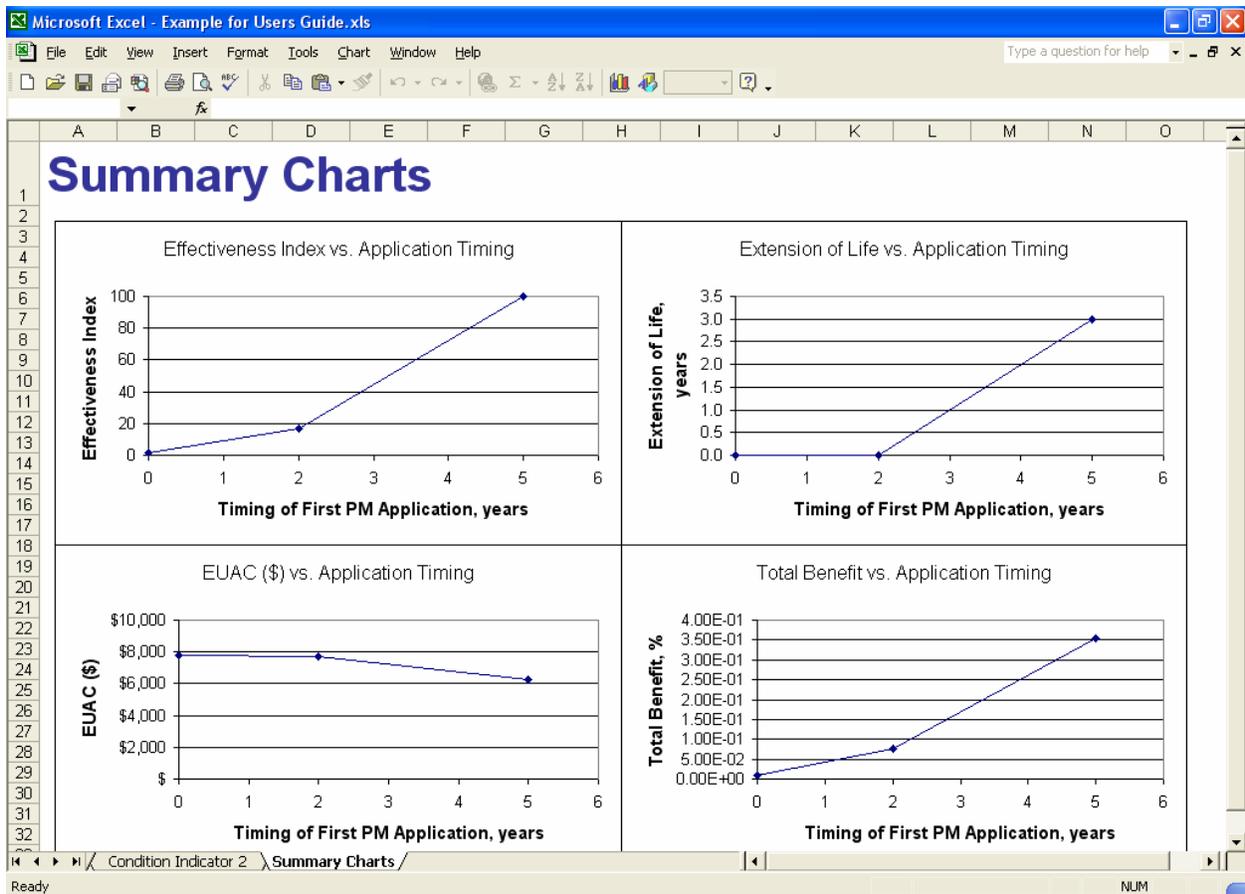


Figure C-27. Example of the *Summary Charts* sheet included in an input/output workbook.