Benefit Cost Models to Support Pavement Management Decisions

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for the
Ohio Department of Transportation
Office of Research and Development

and the
U.S. Department of Transportation
Federal Highway Administration

State Job Number 134363

June 2012

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2012/10		

4. Title and subtitle	5. Report Date
Benefit Cost Models to Support Pavement Management Decisions	**June 2012**
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Eddie Y. Chou & Shuo Wang	10. Work Unit No. (TRAIS)
9. Performing Organization Name and Address **The University of Toledo** **2801 W. Bancroft Street** **Toledo, OH 43606**	11. Contract or Grant No. **State Job No. 134363**
	13. Type of Report and Period Covered **Final Report**
12. Sponsoring Agency Name and Address **Ohio Department of Transportation** **1980 West Broad Street** **Columbus, Ohio 43223**	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A critical role of pavement management is to provide decision makers with estimates of the required budget level to achieve specific steady-state network conditions, and to recommend the best allocation of available budget among competing needs for maintenance, rehabilitation, and repair (MR&R) projects or among different networks such as among Districts.

This research study developed a model/procedure that uses the current state of the network and a specified future target state, condition deterioration trends (based on the MR&R treatments received) expressed as Markov condition transition matrices, and the unit cost of treatments, to determine the minimum total cost required and the corresponding treatment policy to achieve the desired target state of the network.

The model can also determine the best network condition state achievable (and the corresponding treatment policy) with a given budget. The corresponding optimization problems with the objective of either minimizing total cost or maximizing overall network condition are formulated as linear programming problems, so that they can be solved very efficiently.

The network level optimization model provides a valuable tool to ODOT decision makers to determine the required network budget and optimal budget allocations.

17. Key Words	18. Distribution Statement
Pavement, Network, Rehabilitation, Optimization, Management, Markov	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**126**	

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

Benefit Cost Models to Support Pavement Management Decisions

Final Report

State Job No. 134363

Principal Investigator: Eddie Y. Chou

The University of Toledo

Prepared in Cooperation with

The Ohio Department of Transportation

and

The U. S. Department of Transportation

Federal Highway Administration

June 2012

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ACKNOWLEDGMENTS

Prepared in cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

The researcher team would like to thank the Ohio Department of Transportation and the Federal Highway Administration for funding this research project.

The assistance and guidance provided by the technical liaisons of this project, Mr. Andrew Williams and Mr. Roger Green, are greatly appreciated.

The following current or former graduate research assistants at the University of Toledo participated in the research efforts during different stages of the research project: Shuo Wang, Lijun Gao, Jun Zhang, and Debargha Datta. Without their assistance, this study could not have been completed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

The Ohio Department of Transportation

Office of Statewide Planning and Research
Research Section

Executive Summary Report

Benefit Cost Models to Support Pavement Management Decisions

Start Date: February 1, 2008

Duration: 54 months

Completion Date: August 31, 2012

Report Date: June 2012

State Job Number: 134363
Report Number: FHWA/OH-2012/10

Funding: $380,883.80

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or call 614-644-8173.

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Problem

A critical role of pavement management is to provide decision makers with estimates of the required budget level to achieve specific steady-state network conditions, and to recommend the best allocation of available budget among competing needs for maintenance, rehabilitation, and repair (MR&R) projects or among different networks such as among Districts.

The Ohio Department of Transportation (ODOT) has developed a comprehensive Pavement Management Information System (PMIS), which provides a collection of tools to support pavement management activities. These tools include reporting of current condition and deficiency, predicting future pavement condition, and estimating remaining service life (RSL). Predicted future pavement condition and estimated RSL allow decision makers to perform "what-if" analysis of the financial impact and level of service provided by a multiyear MR&R work plan. However, given the size of the pavement network and the number of competing project candidates, the number of feasible alternative work plans can be very large. A procedure that can quickly narrow down the alternatives is highly desirable.

Objectives

1. To develop and incorporate cost benefit models and optimization procedures to support pavement management decisions;

2. To investigate and quantify the mid- to long-term financial impact of selecting alternative projects;
3. To define and determine the “near optimal” multi-year work plans according to specified criteria such as maximizing state wide pavement network condition, subject to budgetary and other constraints;
4. To determine the required multi-year budget, by treatment category, to preserve the existing system at specified steady-state condition.
5. To improve the existing PMIS in terms of its capacity, functionality, and stability.
6. To implement the new rehabilitation treatment decision logic for each pavement priority category in all affected PMIS tools.

Description

This research study developed a model/procedure to determine the minimum total cost required and the corresponding treatment policy to achieve the desired target state of the network. The model uses the current state of the network and a specified future target state, condition deterioration trends (based on the MR&R treatments received) expressed as Markov condition transition matrices, and the unit cost of treatments.

The developed model can also determine the best network condition state achievable (and the corresponding treatment policy) with a given budget. The corresponding optimization problems with the objective of either minimizing total cost or maximizing overall network condition are formulated as linear programming problems, so that they can be solved very efficiently.

Three subsequent addendums to the original study addressed the PMIS database capacity issue, updated the PMIS code, streamlined and improved the user interface, implemented the new ODOT rehabilitation decision trees, and developed a separate tool for generation of Markov condition transition matrices to support ODOT’s enterprise pavement management system.

Findings

The network level optimization model provides a valuable tool to ODOT decision makers to determine the required network budget and optimal budget allocations. The network optimization model can be used by decision makers to assess the impact of different condition targets and treatment polices on the required network level budget. It can also be used to determine the optimal allocation of available budget among MR&R treatment categories and among Districts or between the Priority and General systems.

Conclusions & Recommendations

As a result of this study, ODOT can determine the budget level required to achieve a specific target of network condition state. Vice versa, future network condition states resulting from a given funding levels can be estimated and optimal treatment policy determined. Multiyear network level work plans based on the determined optimal treatment policy can then be generated. It is recommended that ODOT uses the result of this study to establish future budget needs, funding allocations, and treatment policy, in order to demonstrate best possible use of available budget.

Implementation Potential

The network level optimization models developed in this study can be readily implemented as part of a comprehensive Pavement Management System.

INTRODUCTION

Most transportation agencies in the United States are encountering the difficult task of preserving the aging transportation facilities with ever tightening budget, while maintaining the level of service to the traveling public. Given the current economic condition, the legislatures and the public are increasingly demanding accountability and transparency; therefore, the ability to demonstrate optimal use of the maintenance, rehabilitation, and repair (MR&R) budget has become essential.

The Ohio Department of Transportation (ODOT) manages a pavement network of approximately 49,000 lane miles and spends hundreds of millions of dollar each year on MR&R to keep this vast highway network in a state of good repair.

Pavement management is the process of overseeing the MR&R activities of a pavement network. A critical function of pavement management is to provide decision makers with estimates of the required budget level to achieve specific steady-state network conditions, and to recommend the best allocation of available budget among competing needs for MR&R projects.

ODOT has developed a Pavement Management Information System (PMIS) to support pavement management activities. PMIS consists of a collection of tools that enable reporting of existing pavement inventories, conditions, and deficiencies, forecasting of future pavement conditions, and estimating remaining service life (RSL). Predicted pavement conditions and estimated RSL allow decision makers to perform "what-if" analysis of the financial and level of service impact of network MR&R plans. However, given the size of the pavement network and the number of competing project candidates, the number of feasible alternative work plans can be very large. A procedure that can quickly narrow down the alternatives to the top few candidates for decision makers to choose from is highly desirable.

This research study was initiated to develop a network-level optimization tool to generate the best maintenance and rehabilitation strategies for the entire pavement network. The following report documents the work performed and the findings of the study.

OBJECTIVES OF THE RESEARCH

The objectives of the original study are:

1. To develop and incorporate cost benefit models and optimization procedures to support pavement management decision making;
2. To investigate and quantify the mid to long term financial impact of selecting alternative projects;
3. To define and determine the “near optimal” multi-year work plans according to ODOT specified criteria such as maximizing state wide pavement network condition, subject to budgetary and other constraints;
4. To determine the required multi-year budget, by treatment category, to preserve the existing system at specified steady-state condition;

The first addendum to the original study adds the following objectives:

5. To improve the delivery of the ODOT-PMIS program so that it will be accessible to all ODOT users through Intranet.
6. To upgrade the pavement management database so that it will accommodate the increasing size of pavement data.
7. To integrate the Network Level Optimization module with ODOT-PMIS so that the results could be used more easily by ODOT to support decision-making.

The objectives of the second addendum are:

8. To implement the Network Level Optimization module based on the new rehabilitation decision logic.
9. To improve the PMIS administrative functions to ensure results reported by the ODOT-PMIS are accurate and consistent.

The objectives of the third addendum are:

10. To implement a separate Pavement Distresses and Condition Rating Prediction Tool using Markov transition and/or linear regression as the prediction models
11. To generate the Markov transition matrices and/or linear regression coefficients with easy to use user interface for both input and output
12. Generation of the predicted condition file by roadway section for the entire network.

GENERAL DESCRIPTION OF RESEARCH

The original research project consists of the following tasks:

- *Task 1 Literature Review and Survey of Existing Cost Benefit, Budget Allocation and Optimization Models*
- *Task 2 Review ODOT's PMIS to Determine Data Availability*
- *Task 3 Compare Available Models and Recommend the Most Suitable Procedures for Use by ODOT*
- *Task 4 Incorporation of the Procedures into PMIS*
- *Task 5 Validation of the Results*
- *Task 6 Preparation and Submission of Final Report*

Three subsequent addendums add the following tasks to this project:

Addendum 1 (2009)

- *Task 7 Upgrade the PMIS Database and Converting PMIS from VB to VB.NET*
- *Task 8 Make PMIS Accessible by Intranet*
- *Task 9 Improve the Network Level Optimization Function User Interface and Reporting Capabilities*
- *Task 10 Preparing and Conducting Training for the Developed PMIS Tools including the Network Level Optimization Function*

Addendum 2 (2010)

- *Task 11 Implement the network level optimization function based on the new rehabilitation decision logic*
- *Task 12 Revise and improve the administrative functions of the ODOT-PMIS*

Addendum 3 (2011)

- *Task 13 Specifications of the User Interface and Output Requirements for the Markov Transition Matrices Application*

- *Task 14 Confirm data outputs to be used as inputs into the enterprise pavement management system*
- *Task 15 Implementation of the Software Tool*
- *Task 16 Review and Revision of the Developed Tool*

The above tasks are further described in the following paragraphs.

Task 1 Literature Review and Survey of Existing Cost Benefit, Budget Allocation, and Optimization Models

A literature was conducted and found that most developed benefit cost/optimization models have two essential components: (1) pavement condition prediction models and (2) optimization algorithms (de la Garza et al. 2010).

Pavement Performance Prediction Models

An accurate and reliable pavement condition prediction model is essential for a pavement optimization model (Akyildiz 2008). There are two main types of prediction models, namely deterministic models and probabilistic models.

De la Garza et al. (2010) developed a regression prediction model by deterministically computing pavement deterioration rates based on historical data. However, the pavement deterioration rates are often "uncertain" (Butt et al. 1994). Therefore, the probabilistic model based on the Markov process is the most frequently used approach (Bako et al. 1995; Chen et al. 1996; Golabi et al. 1982; Abaza 2007). A critical component of this model is the Markov transition probability matrix. Most developed models use two transition matrices for each repair treatment: one for condition improvements in the first year the treatment is conducted, and the other for the deterioration trend after the treatment (Chen et al. 1996). Generally, the elements of the transition probability matrices are calculated based on historical pavement condition data, or are assumed when historical data are insufficient or not available (Bako et al. 1995).

In this study, future pavement condition is predicted based on historical data using a Markov transition probability model. Such transition probabilities are updated each year when new condition data become available. The Markov prediction model is then integrated within a linear programming optimization model.

Previously Developed Pavement Network Optimization Models

Two optimization models utilizing the linear programming algorithm and the Markov prediction model are Arizona's model developed by Golabi et al. (1982), and Oklahoma's model developed by Chen et al. (1996).

The first modern network-level pavement management system was developed by Golabi et al. (1982) for Arizona Department of Transportation (ADOT) (Ferreira et al. 2002). In Golabi et al.'s optimization model, a total of 120 pavement conditions states were defined by the variables including present amount of cracking, change in amount of cracking during the previous year, the present roughness, and index to the first crack. The statewide pavement network was divided into nine road categories (sub-networks) based on traffic volume and a regional environmental factor. The maintenance actions were grouped into 17 types ranging from routine maintenance to substantial corrective measures.

Golabi et al. (1982) developed a Markov transition probability prediction model using historical pavement condition data to address the probabilistic aspect of pavement deterioration. A single Markov transition probability matrix was used to estimate the deterioration trend of pavements receiving routine maintenance, which was equivalent to "Do Nothing" in other researcher's models, no matter what repair action they receive before the routine maintenance (Chen et al. 1996). As a result, pavements with different repair treatments, such as reconstruction or thin overlay, were assumed to deteriorate at the same rate after the treatments were conducted, which is considered by Chen et al. (1996) as one of the major limitations of Golabi et al.'s model.

The network-level optimization model for Arizona was consisted of a long-term model and a short-term model. The objective functions of the two models were to minimize the total expected cost. The long-term model calculated a maintenance policy that minimizes the expected long-term average cost to keep the pavement network condition at a desired level. The short-term model then sought a maintenance policy over an analysis period T that minimizes the total expected cost to achieve the long-term standard within the first T years. The outcome of this optimization model included the optimized maintenance policy, the expected minimum budget required, and the predicted pavement condition (Golabi et al. 1982).

Another network-level optimization model was established by Chen et al. (1996) for the Oklahoma Department of Transportation with the application of linear programming and the Markov decision process. Pavement conditions were divided into five states, namely excellent, good, fair, poor, and bad, in terms of the overall pavement condition index. Nine treatments were defined: thin, medium, thick overlay on both asphalt and concrete pavements, medium and thick asphalt reconstruction, and concrete reconstruction. Chen et al. (1996) used a global optimization model which seeks the optimal solution for the entire network, although the network is divided into six pavement groups by traffic volume and pavement types.

The main improvement of the Oklahoma optimization model is that it used two Markov transition matrices for each repair treatment. One is for the immediate impact of the treatment on the pavement condition improvement when it is conducted in the first year. The other is for the deterioration trend after the treatment, which is also known as a “Do Nothing” matrix. In other words, the deterioration trends for different repair treatments were estimated separately. Therefore, this prediction model is more realistic and accurate than previous ones in that pavements with different last treatments tend to deteriorate at different rates (Chen et al. 1996).

Both cost minimization and benefit maximization approaches are implemented in Chen et al.’s optimization model. Two methods for estimating the benefits of pavement maintenance and rehabilitation are developed for the benefit maximization model. One method is to convert pavement conditions into benefit indexes. The benefit index is determined subjectively by engineering judgment considering traffic volume and pavement condition (Chen et al. 1996). The other method is to estimate benefits on the basis of the area under the performance curve after a treatment is applied.

Other methodologies such as integer programming and deterministic prediction models, have also been utilized previously by other researchers. Li et al. (1998) presented an integer programming optimization model for pavement network maintenance and rehabilitation. A time-related Markov probabilistic model is established for pavement condition prediction considering both the immediate treatment effects and the potential impact on the rate of future condition deterioration, which is similar to the prediction model developed by Chen et al. (1996). The major difference between the two Markov models is that Li et al.'s model predicts the exact pavement condition state (PCS) score, such as pavement condition index (PCI) or pavement serviceability index (PSI), rather than the pavement condition category, such as excellent or poor. This approach facilitates the establishment of the cost-effectiveness-based integer programming optimization model, as the predicted PCS score can be used directly to estimate the benefit of a treatment.

The model developed by Li et al. uses a multiyear integer programming model on a year-by-year basis. The objective of the model is to maximize the total value of cost-effectiveness in each analysis year, given the available budget constraints and other applicable constraints. The main output of this program consists of the optimal maintenance and rehabilitation treatment strategy and the predicted condition state for each pavement section in each analysis year (Li et al. 1998). Li et al. (1998) showed an example problem of a network with only five pavement sections. However, integer programming models are much more difficult to solve than linear programming models, especially when the problem size is large or the constraints are complicated (Hillier and Lieberman 2010). Since ODOT's pavement network contains tens of thousands of sections, the computational requirements would be extremely high. Therefore, integer programming is not appropriate for pavement maintenance and rehabilitation optimization at the network-level for ODOT.

De la Garza et al. (2010) developed a network-level linear programming optimization model, in which a deterministic prediction model is utilized for pavement condition deterioration. Five pavement condition states are defined based on the Combined Condition Index (CCI) values. Nine maintenance and rehabilitation treatments, ranging from ordinary maintenance to reconstruction, are identified. Each treatment is allowed to be conducted on only one pavement condition category. De la Garza et al.'s model assumes that the deterioration rates are fixed for each pavement condition state and that pavements only deteriorate from an upstream condition to the next downstream condition. The pavement deterioration rates are calculated deterministically from historical data. The model is subject to several sets of constraints such as performance targets and budget limitation.

The optimization model developed by de la Garza et al. (2010) can be used as a powerful decision support tool in pavement management at the network-level. The objective function can be modified to solve different problems. However, there are two limitations in the deterioration model: (1) the same deterioration rates are used for all pavements no matter whether the last treatment is reconstruction or thin overlay (Chen et al. 1996); (2) the deterministic prediction model cannot consider the uncertain aspect of pavement deterioration (Butt et al. 1994).

Based on the above literature review, the research team of this study decided to utilize the probabilistic Markov deterioration process and the linear programming model to develop a network level optimization tool. That is, the benefit cost model for pavement management is be expressed as an optimization model that minimize the cost to achieve a desired level of pavement network condition or maximize the benefits for a given amount of budget.

The only cost that is being considered in this study is the "agency cost," which includes cost of maintenance, rehabilitation and reconstruction. The other cost is the user cost, which includes congestion delay, vehicle operating, and MR&R delay costs. In this study, the reduced user costs due to the pavement network being in the state of good repair, is inherently considered as the benefits of MR&R activities. Therefore, the benefit is expressed as the reduced amount of deficient pavements within the network.

Other definitions of cost or benefit can be adopted and used in the network optimization model developed in this study, without affecting its validity.

Task 2 Review ODOT's PMIS to Determine Data Availability

The data available in the existing ODOT pavement database were reviewed. It was found that the pavement condition and project history data along with the roadway inventory data are sufficient to support the development of the network level optimization model. The updated average cost data for various MR&R treatment were provided by ODOT staff based on recently completed projects.

Task 3 Compare Available Models and Recommend the Most Suitable Procedures for Use by ODOT

Based on the results of literature review (Task 1) and the data available in the database (Task 2), a network level optimization model based on the probabilistic Markov deterioration process and the linear programming model was deemed most suitable for ODOT, and therefore recommended by the researchers. This was concurred by ODOT staff.

Task 4 Incorporation of the Procedures into PMIS

The existing ODOT PMIS was modified to incorporate the optimization model and procedure into the existing PMIS. A linear programming solver was embedded within the PMIS to solve the formulated optimization problem. A user friendly interface and tools were incorporated to allow decision maker to test the models with various scenarios and perform 'what-if' analysis. Graphical reports including the optimized cost, treatment policy, and the corresponding network condition states, all forecasted to a user specified future year can be generated. Several examples are shown in the Findings section. Further details of the Optimization tool within the PMIS can be found in Appendix B.

Task 5 Validation of the Results

The developed optimization model is validated by comparing its result with other non-optimal treatment policies. The costs required to maintain the General System at various condition state levels are used as an example for validation purpose. The results show that the minimum cost solution generated by the optimization model is lower than all the solutions. More details of the validation are shown in Section II of the Findings chapter.

Task 6 Preparation and Submission of Draft Final Report

A draft final report documenting all the tasks performed and the findings of the study has been prepared and submitted for review.

Task 7 Upgrade the PMIS Database and Converting PMIS from VB to VB.NET

The existing PMIS database has been split into multiple Microsoft Access databases, so that the overall storage capacity is now not limited by the 2 gigabyte maximum size of a single Access database. The original plan also calls, as an alternative, for the PMIS to be upgraded to the more powerful Microsoft SQL Server Express, which has a maximum capacity of 4 gigabyte. However, after much effort to convert the Access database to the SQL Server Express database, it was found the performance of the PMIS actually decreased. After investigation, it was determined that due to the way that PMIS calls the database, it is not taking advantage of the faster speed of the SQL Server Express engine. Since the database capacity issue has been addressed by finding a way to link multiple Access databases, additional efforts to address the SQL Server Express performance issue is beyond the scope of this study.

Additionally, the PMIS codes were converted from Microsoft Visual Basic 6.0 to the newer Microsoft Visual Basic .NET 2008. This allows the PMIS to be integrated with the optimization tools as the external optimization engine (IBM ILOG CPLEX 12.1) can be called directly by the newer VB.NET, but not by VB 6. Substantial recoding and testing of the revised program were performed due to the redesigned PMIS database and the syntax differences between VB 6 and VB.NET.

Task 8 Make PMIS Accessible by Intranet

It was proposed that an updated version of the PMIS program would be made available to all ODOT users through Intranet. The PMIS was to be installed on an ODOT server according to the proposal. However, during a meeting with ODOT Information Technology staff, the researchers were told that ODOT IT would be responsible for executing this task through its existing internal process, once the PMIS is completed and approved for deployment. Therefore, this task was bypassed by the research team.

Task 9 Improve the Network Level Optimization Function User Interface and Reporting Capabilities

The Network Optimization Function has been integrated into the ODOT-PMIS and the desired tools for reporting of results have been enhanced according to needs expressed by ODOT staff. With the new user interface, users can define pavement condition classification based on the PCR scores; determine the year from which historical condition data are used to generate the Markov transition matrices; enter the unit costs of the treatments; choose the appropriate objective function; select allowable treatments for pavements in different conditions; set other constraints, such as the network condition target and the maximum available budget. This function provides the capability to generate the charts and tables showing the projected pavement condition distribution, the optimized recommended treatment policy, and the corresponding budget allocation for an analysis period of up to 30 years.

Task 10 Preparing and Conducting Training for the Developed PMIS Tools including the Network Level Optimization Function

A complete user manual for the updated PMIS, including all the existing tools and the newly developed network optimization function, is included in Appendix B of this report. The researchers can conduct a training session at the ODOT Central Office, if necessary.

Task 11 Implement the network level optimization function based on the new rehabilitation decision logic

The new rehabilitation decision logics (trees) for the Priority, General and Urban systems were implemented in the PMIS. As a result, a list of rehabilitation candidates based on these decision logics can be generated for each pavement network. The rehabilitation list can be separated by District, County, or Pavement type. Further details about this rehabilitation candidates function can be found in Appendix B.

Task 12 Revise and improve the administrative functions of the ODOT-PMIS

Several administrative functions to update and validate PMIS data and to generate rehabilitation candidates were reviewed and improved to ensure accurate and credible results. The format specifications of the three critical input tables (PCR table, project history table and road inventory table) were revised according the current PMIS function needs. The procedures of processing the raw data for further analysis were streamlined by combining several functions in an earlier version of the PMIS. The rehabilitation candidates function was modified and improved based on the new rehabilitation decision logic. Pavement condition prediction functions were also reviewed, verified, and modified. A new function, Average Conditions at Rehabilitation, was developed to generate a report showing the average pavement condition when the selected treatment activities were conducted. Appendix B includes detailed descriptions of each of the revised functions.

Task 13 Specifications of the User Interface and Output Requirements for the Markov Transition Matrices Application

Several meetings with ODOT Offices of Pavement Engineering and Technical Services staff were held to determine the detailed specifications of the user interface and input/output requirements for the Markov Transition Matrices Application.

Task 14 Confirm data outputs to be used as inputs into the enterprise pavement management system

The required contents and format of the output data were confirmed through meetings and communications with ODOT staff. The outputs of the application are to be used as inputs for ODOT's Enterprise Pavement Management System currently under development. Sample matrices were provided for review and confirmation.

Task 15 Implementation of the Software Tool

The software tool was implemented using VB.NET according to the specifications and requirements provided by ODOT staff during Task 13. The three critical tables (PCR table, project history table and road inventory table) can be imported via a built-in function, Import New Data. The function, Generate Base Tables, can combine the raw data with one click. This tool provides the capability for users to select appropriate prediction methods and to edit default deterioration slopes for each pavement group. QA/QC checks can be performed by using the function Plot Prediction vs. Data. The Markov transition matrices, regression coefficients and default deterioration slopes can be viewed and exported to an Excel spreadsheet.

Task 16 Review and Revision of the Developed Tool

The Markov transition matrices generation tool was tested by ODOT staff and revisions were made based on comments received.

FINDINGS OF THE RESEARCH EFFORT

The findings of this study are presented in this section. They include:

I. Development of the network level optimization models,

II. Validation of the results of the optimization models,

III. Minimum budget required to achieve a desired condition level,

IV. Effect of allowable treatments on required budget,

V. Optimum budget allocation among treatment types,

VI. Optimum budget allocation among Districts

I. Development of the network level optimization models

In this research, the pavement network is divided into three sub-networks according to the pavement types (1, Concrete; 2, Flexible; 3, Composite). Each sub-network is divided into four groups according to the last repair treatments (1, Preventive Maintenance (PM); 2, Thin Overlay; 3, Minor Rehabilitation; 4, Major Rehabilitation). Each group is further divided into five pavement condition states (1, Excellent; 2, Good; 3, Fair; 4, Poor; 5, Very Poor) based on the PCR score. Each pavement condition class may be recommended for one of the five repair treatments (Do Nothing, Preventive Maintenance, Thin Overlay, and Major Rehabilitation). In the optimization model: N is the number of pavement types, K is the number of repair treatment types, I is the number of pavement condition states and T is the number of analysis years. $Y_{ntk'ik}$ is the decision variable representing the proportion of pavement type n in condition state i with last treatment k' receiving recommended repair treatment k in year t. Two assumptions are: (1) the total mileage of the pavement network remains constant and (2) the pavement types do not change for any pavement section during the analysis period.

Two objective functions are developed. The first one is to minimize the total repair cost of the pavement network to achieve a certain condition level goal (Equation 1):

Minimize

$$\sum_{n=1}^{N}\sum_{t=1}^{T}\sum_{k'=1}^{K}\sum_{i=1}^{I}\sum_{k=0}^{K} Y_{ntk'ik} \cdot C_{ntk'ik} \tag{1}$$

where $C_{ntk'ik}$ is the unit cost of applying treatment k in year t to pavement type n in state i with last treatment k'.

The second objective function is to maximize the proportion of pavements in Excellent, Good, and Fair condition over the analysis period with given budget constraints (Equation 2):

Maximize

$$\sum_{n=1}^{N}\sum_{t=1}^{T}\sum_{k'=1}^{K}\sum_{i=1}^{3}\sum_{k=0}^{K} Y_{ntk'ik} \tag{2}$$

There are four sets of required constraints namely non-negativity constraints, sum-to-one constraints, initial condition constraints, and state transition constraints. The non-negativity constraints (Equation 3) ensure that all variables in the optimization model are non-negative.

$$Y_{ntk'ik} \geq 0 \quad \text{for all } n = 1,\ldots, N;\ t = 1,\ldots, T;\ k' = 1,\ldots, K;\ i = 1,\ldots, I;\ k = 0,\ldots, K \tag{3}$$

The sum-to-one constraints (Equation 4) ensure that the entire pavement network is divided into many proportions and each proportion is represented by a decision variable.

$$\sum_{n=1}^{N}\sum_{k'=1}^{K}\sum_{i=1}^{I}\sum_{k=0}^{K} Y_{ntk'ik} = 1 \quad \text{for all } t = 1,\ldots, T \tag{4}$$

The initial condition constraints (Equation 5) pass the values representing current pavement condition state distribution for each pavement group to the optimization model.

$$\sum_{k=0}^{K} Y_{n1k'ik} = Q_{nk'i} \quad \text{for all } n = 1,\ldots, N;\ k' = 1,\ldots, K;\ i = 1,\ldots, I \tag{5}$$

where $Q_{nk'i}$ is the proportion of pavement type *n* in state *i* with last treatment *k'* in initial year.

The state transition constraints (Equation 6) integrate the Markov transition probability model with the linear programming model. From the second analysis year on, the proportion of pavement type *n* in condition state *j* with last treatment *k'* in year *t* is derived from two parts of pavement in various condition states in year *t-1*: one part with last treatment *k'* receiving no new treatment (Do Nothing) and the other part receiving new treatment *k'*.

$$\sum_{k=0}^{K} Y_{ntk'jk} = \sum_{i=0}^{I}\sum_{k=1}^{K} Y_{n(t-1)kik'} \cdot P_{nk'ij} + \sum_{i=0}^{I} Y_{n(t-1)k'i0} \cdot DN_{nk'ij}$$

for all *n* = 1,…, *N*; *t* = 2,…, *T*; *k'* = 1,…, *K*; *j* = 1,…, *I*; (6)

where $P_{nk'ij}$ is the probability that pavement type *n* receiving new treatment *k* transit from state *i* to state *j* and $DN_{nk'ij}$ is the probability that pavement type *n* with last treatment *k'* receiving no new treatment (Do Nothing) moves from state *i* to state *j*.

In order to make the optimization model more practical, several sets of optional constraints are also introduced. The condition constraints (Equation 7 and Equation 8) ensure that the proportion of pavement in certain condition states is in a prescribed range.

$$\sum_{n=1}^{N}\sum_{k'=1}^{K}\sum_{k=0}^{K} Y_{ntk'ik} \le \varepsilon_{it} \quad \text{for all } t = 2,\dots, T\text{; selected } i \tag{7}$$

$$\sum_{n=1}^{N}\sum_{k'=1}^{K}\sum_{k=0}^{K} Y_{ntk'ik} \ge \xi_{it} \quad \text{for all } t = 2,\dots, T\text{; selected } i \tag{8}$$

where ε_{it} is the upper limit of proportion of pavement in condition *i* in year *t* and ξ_{it} is the lower limit of proportion of pavement in condition *i* in year *t*.

For instance, pavements in Poor and Very Poor condition are considered as deficient. It may be desirable to limit the total amount of deficient pavements (or deficiency level) to a given percentage, say, 5%, of the entire network. If the desirable deficiency level is much lower than the existing deficiency level, a significant amount of rehabilitation would be required to achieve the desired condition target immediately. Therefore, it is more reasonable to allow the condition target (in term of desired deficiency level) to be achieved gradually by linearly reducing the proportion of deficient pavements using Equation 9:

$$\varepsilon_{it} = \begin{cases} \varepsilon_{i1} - \dfrac{\varepsilon_{i1} - \varepsilon_i}{t'-1}(t-1) & 2 \le t \le t' \\ \varepsilon_i & t' < t \le T \end{cases} \tag{9}$$

where ε_i is the desired proportion of condition state *i*; ε_{it} is the upper limit of proportion of pavement in condition *i* in year *t*; *t'* is the year to achieve condition target specified by the user and *T* is the number of analysis years.

The allowable treatment constraints (Equation 10) ensure that certain treatments can only be applied to pavements in certain condition states or with certain last treatments.

$$Y_{ntk'ik} = 0 \text{ for all } t = 1,\ldots, T\text{; selected } n, k', i, k \tag{10}$$

Experience reveals that some treatments are cost effective only when pavements are in certain condition states and with appropriate last treatments. For example, preventive maintenance (PM) is only cost effective on pavements in Good condition as shown in Table 1, so the corresponding decision variables are set to zero to disallow PM on pavements in other condition states.

Table 1. Example of Allowable Treatments for Priority System Pavements

Condition	Do Nothing	PM	Thin Overlay	Minor Rehab	Major Rehab
Excellent	Yes				
Good	Yes	Yes			
Fair	Yes			Yes	
Poor	Yes			Yes	Yes
Very Poor	Yes				Yes

The effectiveness of some treatments is also associated with the last treatment. For instance, if PM is conducted on pavements with last treatments of PM, the underlying distress of the pavement can only be "masked" for a short period of time and the distress may resurface quickly within a few years after treatment. However, PM is a lower cost treatment, which may cause the optimized solution to recommend PM treatments to be applied repeatedly. Therefore, it is necessary to add a set of constraints to disallow PM treatment on pavements with last treatment of PM.

The budget constraints (Equation 11) ensure that the required budgets recommended by the optimized solution do not exceed the maximum available budget for each year.

$$\sum_{n=1}^{N}\sum_{t=1}^{T}\sum_{k'=1}^{K}\sum_{i=1}^{I}\sum_{k=0}^{K} Y_{ntk'ik} \cdot C_{ntk'ik} \cdot L \le B_t \quad \text{for all } t = 1, \ldots, T \tag{11}$$

where L is the total length of entire pavement network and B_t is the maximum available budget in year *t*.

It is possible that the optimized repair policy obtained from the mathematical model would recommend a large number of pavements to be repaired in the first couple of years in order to minimize the total cost over the analysis period. However, the recommended budget may be far beyond the maximum available budget of the highway agency, which makes the optimized repair strategy unsuitable for practical use. For that reason, the budget constraints are included in the model.

On the basis of the above objective functions and constraints, a linear programming model for pavement maintenance and rehabilitation optimization at the network-level is formulated and implemented in ODOTPMIS. The following figure shows the user interface.

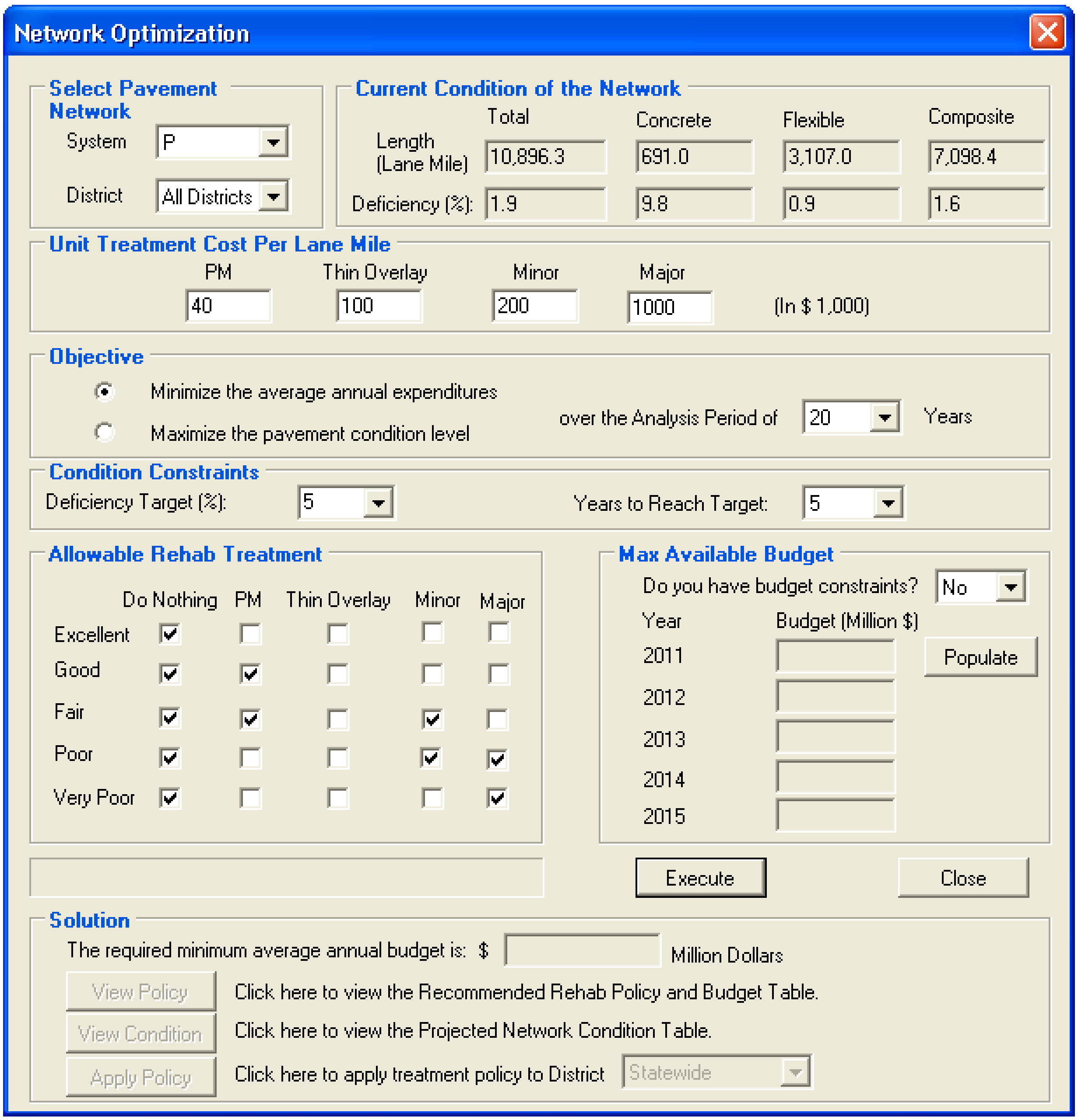

Figure 1. Optimization User Interface

The network-level optimization model is implemented using Microsoft Visual Basic .NET (2008) and IBM ILOG CPLEX 12.1. The optimization tool is composed of four parts:

pavement database, data preparation, optimization analysis and results output. The pavement database stores current and historical pavement conditions, project history, and road inventory data for analysis. The data preparation part enables the user to define pavement condition states (Excellent, Good, Fair, Poor, and Very Poor) by selecting the corresponding PCR thresholds; to generate the current pavement condition distribution table for further analysis; and to determine the year from which historical condition data are used to generate the Markov transition probability matrices. The optimization analysis part allows the user to select the pavement network for optimization; to input unit cost for each type of repair treatment; to choose appropriate objective functions; to set pavement condition constraints; to select allowable treatments for pavements in different condition states; and to enter the maximum available budget for each year in the analysis period. The results output part enables the user to view the projected pavement condition distribution, the optimized recommended treatment policy, and the corresponding budget allocation for the analysis period of up to 30 years. A complete user manual for the updated PMIS, including all the newly developed network optimization function, is included in Appendix B of this report.

II. Validation of the Results of the Optimization Models

The General System network is used as an example in validating the results of the network optimization models. The analysis period is assumed to be 20 years. The allowable treatments assumed for General System pavements are shown in Table 2. Pavements in poor and very poor condition are those with PCR scores of less than 65. It has been shown in previous research study that thin overlay is not a cost effective treatment for pavements in poor and very poor conditions. Therefore, thin overlay is not an allowable treatment for poor and very poor pavements, but can be used for pavements with Fair condition. Also, it is assumed that no preventive maintenance (PM) would be performed on General System pavements. As described earlier, the allowable treatment constraint is user-selectable and can be changed easily during model set up.

Table 2. Allowable Treatments for General System Pavements

Condition	Do Nothing	PM	Thin Overlay	Minor Rehab	Major Rehab
Excellent	Yes				
Good	Yes				
Fair	Yes		Yes	Yes	
Poor	Yes			Yes	Yes
Very Poor	Yes			Yes	Yes

The optimization results are calculated using the optimization tool in PMIS. The deficiency level is defined as the percentage of pavements in poor and very poor conditions. Currently, the General System has a deficiency level of 8.75%. The minimum average annual cost to reduce (or increase) the deficiency from the current level to a specified target level within 5 year and maintain the target deficiency level afterward for the rest of the analysis period is calculated using the PMIS optimization tool.

Figure 2 shows that when the minimum average annual cost versus the target deficiency level is plotted, it forms a lower bound envelop as compared to various other treatment policies. The results labeled by “1” to “10” in Figure 2 are obtained by applying the same policy, shown in Table 3, to the entire General system every year. Policy 2 yields a solution which is the closest to the optimization result, however, the required budget to implement this policy is very high in the first year, as shown in Figure 3.

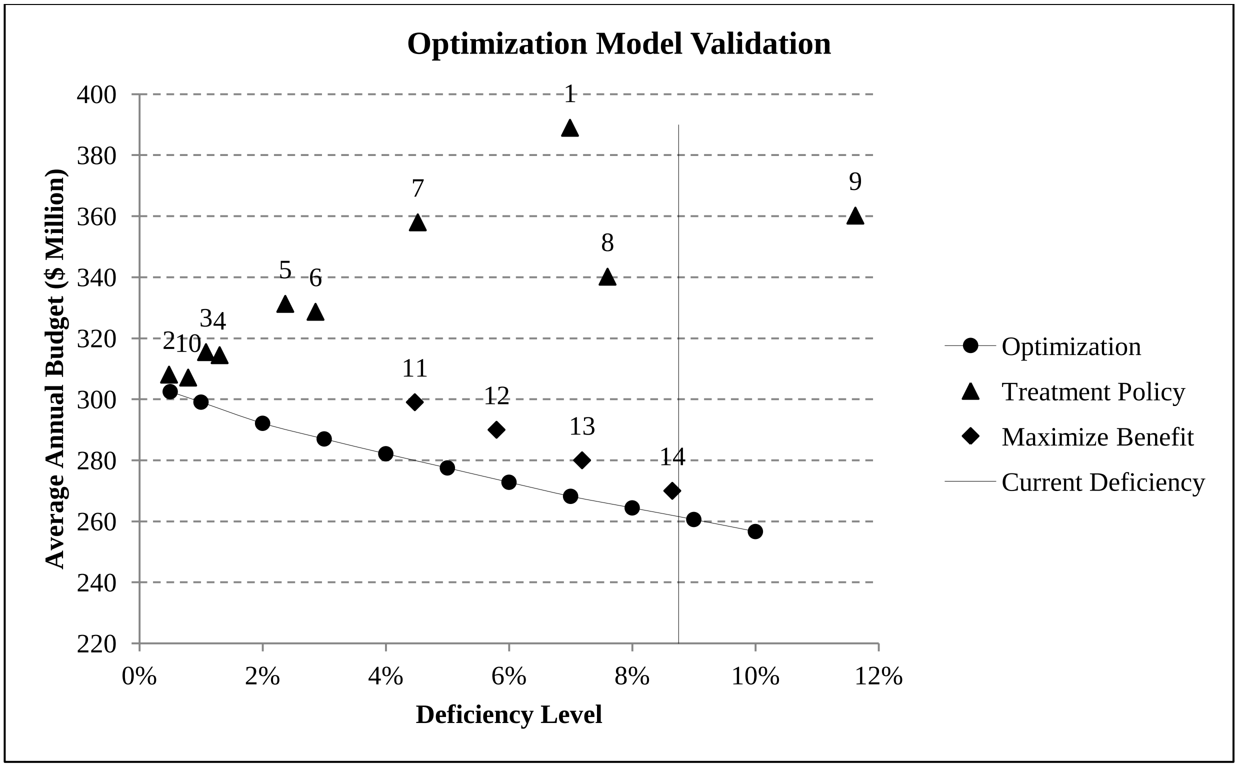

Figure 2. Validation of the Optimization Model Using Cost Versus Deficiency

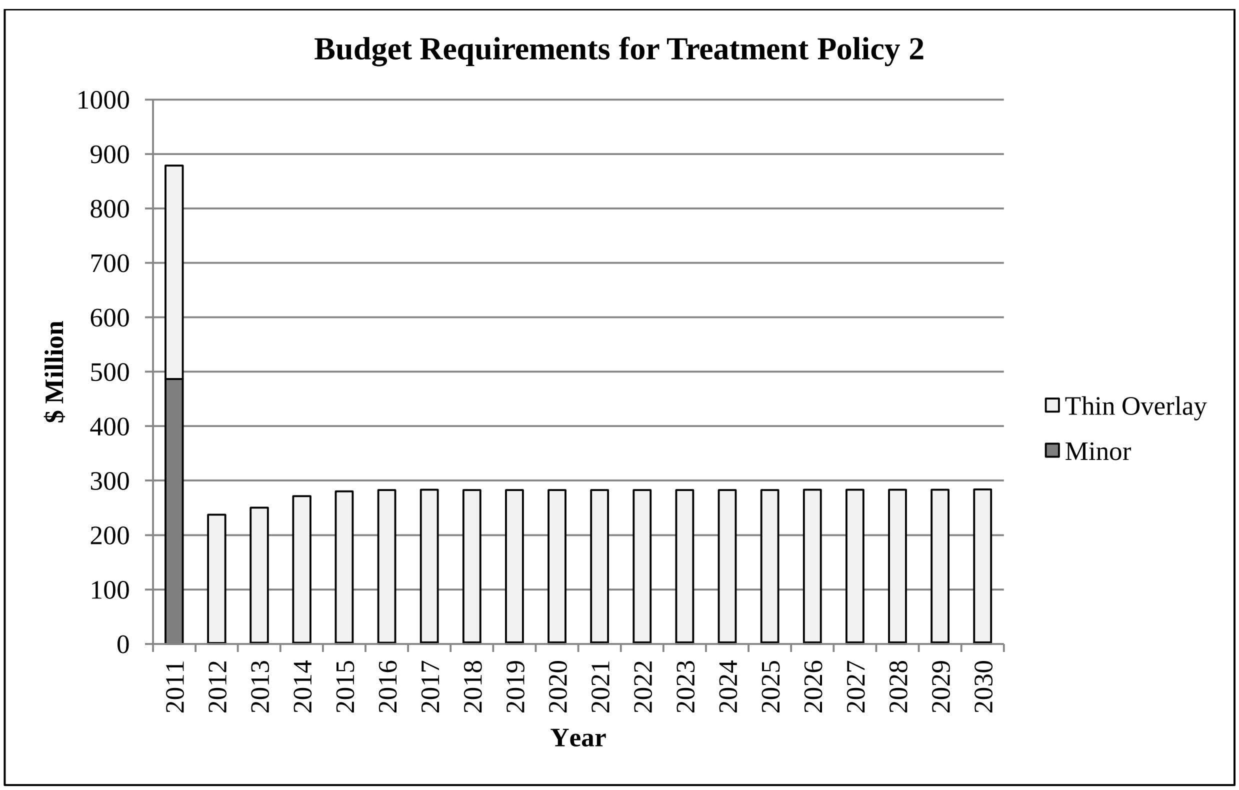

Figure 3. Budget Requirements for Treatment Policy 2

Table 3. Treatment Policies Used in Validation

	Treatment Policy 1					Treatment Policy 2				
Condition	DN	PM	ThinAC	Minor	Major	DN	PM	ThinAC	Minor	Major
E	1	0	0	0	0	1	0	0	0	0
G	1	0	0	0	0	1	0	0	0	0
F	1	0	0	0	0	0	0	1	0	0
P	0	0	0	1	0	0	0	0	1	0
VP	0	0	0	1	0	0	0	0	1	0

	Treatment Policy 3					Treatment Policy 4				
Condition	DN	PM	ThinAC	Minor	Major	DN	PM	ThinAC	Minor	Major
E	1	0	0	0	0	1	0	0	0	0
G	1	0	0	0	0	1	0	0	0	0
F	0.2	0	0.8	0	0	0.2	0	0.8	0	0
P	0	0	0	1	0	0.2	0	0	0.8	0
VP	0	0	0	1	0	0	0	0	1	0

	Treatment Policy 5					Treatment Policy 6				
Condition	DN	PM	ThinAC	Minor	Major	DN	PM	ThinAC	Minor	Major
E	1	0	0	0	0	1	0	0	0	0
G	1	0	0	0	0	1	0	0	0	0
F	0.5	0	0.5	0	0	0.5	0	0.5	0	0
P	0	0	0	1	0	0.2	0	0	0.8	0
VP	0	0	0	1	0	0	0	0	1	0

	Treatment Policy 7					Treatment Policy 8				
Condition	DN	PM	ThinAC	Minor	Major	DN	PM	ThinAC	Minor	Major
E	1	0	0	0	0	1	0	0	0	0
G	1	0	0	0	0	1	0	0	0	0
F	0.8	0	0.2	0	0	0.8	0	0.2	0	0
P	0	0	0	1	0	0.5	0	0	0.5	0
VP	0	0	0	1	0	0	0	0	1	0

	Treatment Policy 9					Treatment Policy 10				
Condition	DN	PM	ThinAC	Minor	Major	DN	PM	ThinAC	Minor	Major
E	1	0	0	0	0	1	0	0	0	0
G	1	0	0	0	0	1	0	0	0	0
F	1	0	0	0	0	0	0	1	0	0
P	0.5	0	0	0.5	0	0.5	0	0	0.5	0
VP	0	0	0	1	0	0	0	0	1	0

In Figure 2, the results labeled by "11", "12", "13, and "14" are obtained from the optimization tool using the maximization model, with annual budget constraint of $300, $290, $280, and $270 million dollars, respectively. For example, given an annual budget of $270 million, the General System can achieve at best a deficiency level of 8.7%, if the optimal policies recommended are implemented. Figure 4 shows how the annual budget of $270 million should be spent in order to achieve the best network condition with a deficiency level of 8.7%.

The lower bound envelop indicates that no other treatment policy can maintain a steady-state deficiency level at a lower cost than the optimization solution. Therefore, the solution is the optimal solution.

This example shows that to maintain the General System at its current condition states with a deficiency level of 8.75%, at least 262 million dollar of MR&R expenditures would be required. Note this is only possible if the corresponding optimized treatment policies are followed. However, it should be noted that the optimized treatment polices may fluctuates from one year to the next during the analysis period. The actual required budget may also vary from year to year -- generally higher initially and reaches a steady level after a few years, as shown in Figure 5.

A budget constraint can be added to restrict the budget below a specified level. For example, Figure 6 shows the annual budget requirement and allocation for the same 8% deficiency target as in Figure 5, but with the annual budget restricted to no more than $310 million.

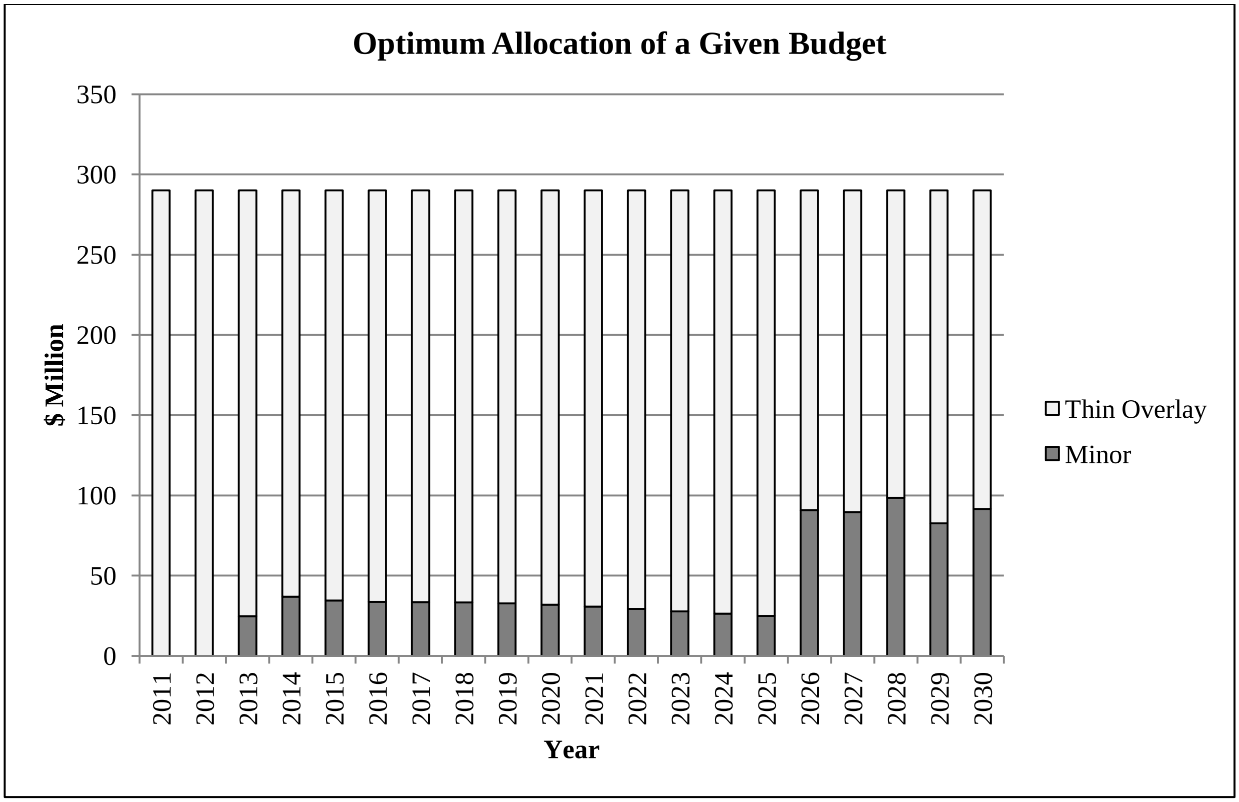

Figure 4. Optimal Allocation of a Given Budget of $270 Million (Result 12)

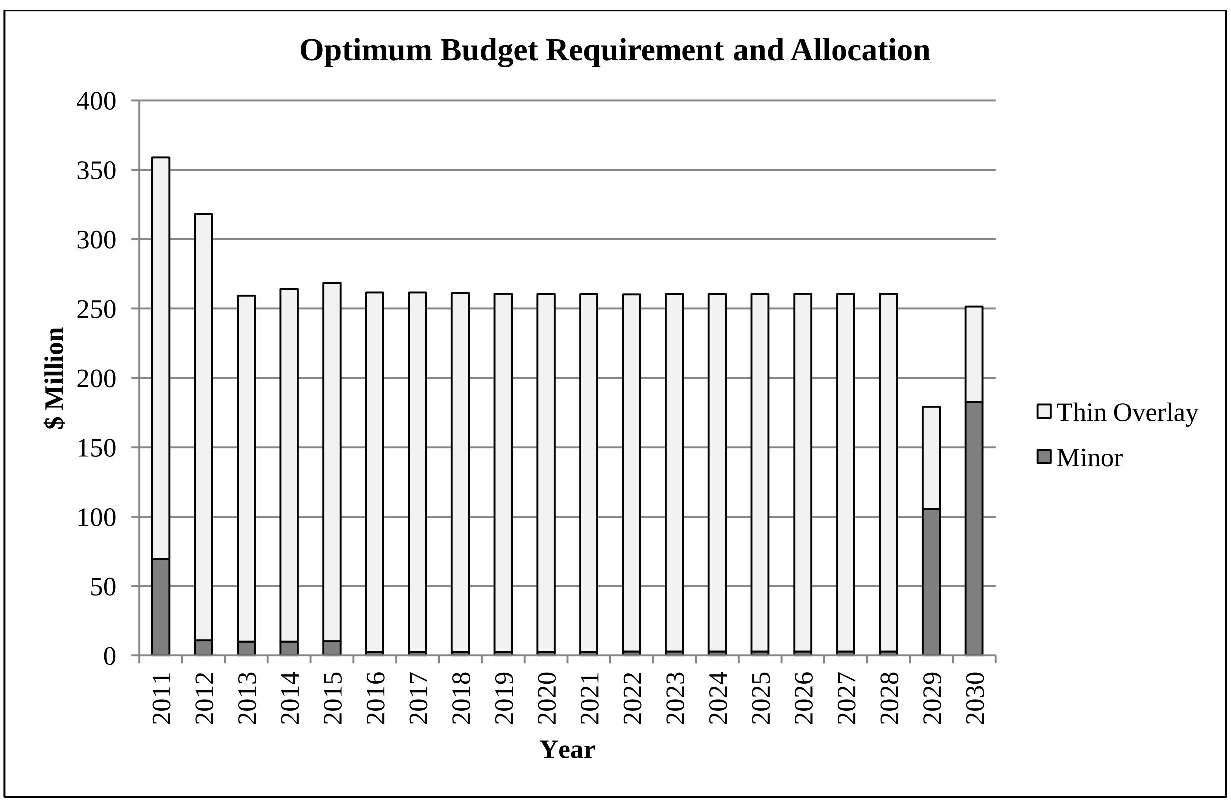

Figure 5. Optimum Budget Requirement and Allocation for a Deficiency Target of 8%

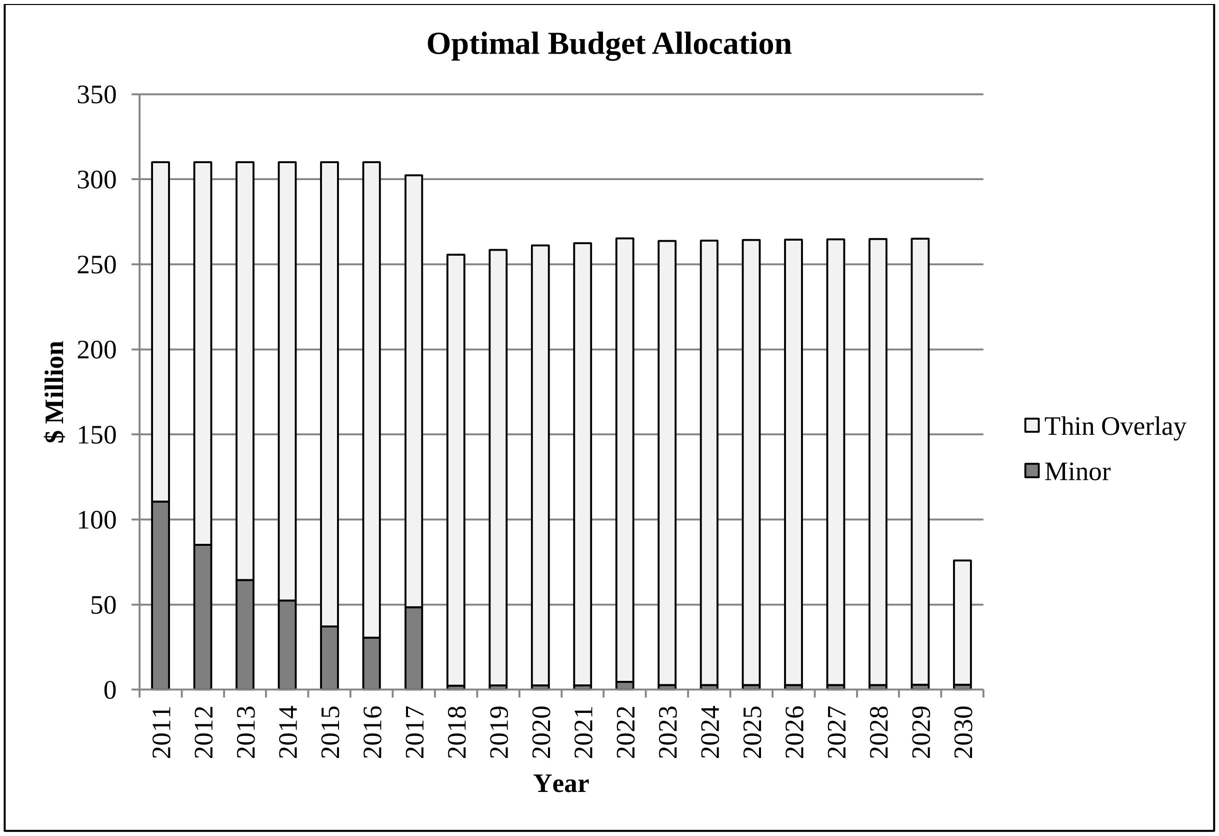

Figure 6. Budget Requirement with Budget Constraints for a Deficiency Target of 8%

III. Minimum Budget Required to Achieve a Desired Condition Level

The optimization tool is able to calculate the minimum budget required to improve the overall pavement network condition to a certain level and to determine the corresponding fund allocation among different maintenance and rehabilitation treatments.

For example, the minimum budget required to reduce the deficiency level of Priority System pavements from 2.7% to 1% and the corresponding budget allocation plan are shown in this section.

The unit costs of four types of maintenance and rehabilitation treatments are shown in Table 4.

Table 4. Unit Cost of Maintenance and Rehabilitation Treatments

Treatment	Preventive Maintenance	Thin Overlay	Minor Rehab	Major Rehab
Cost ($1,000 per lane-mile)	40	100	200	1,000

Pavement conditions are classified into five categories based on PCR scores as shown in Table 5.

Table 5. Pavement Condition Classification

Pavement Condition	PCR score range
Excellent	PCR >= 85
Good	75 =< PCR < 85
Fair	65 =< PCR < 75
Poor	55 =< PCR < 65
Very Poor	PCR < 55

Table 6 presents the current overall pavement condition distribution. Since pavements in poor and very poor conditions are considered to be "deficient", the current network deficiency level is 2.7%.

Table 6. Current Pavement Condition Distribution

Pavement Condition Category	Excellent	Good	Fair	Poor	Very Poor
Proportion (%)	66.1	22.8	8.4	2.4	0.3

Optimization Results

The optimization model without budget constraints yields a theoretical optimized solution for the problem. Since no maximum available annual maintenance and rehabilitation budget is defined, the mathematical optimization model could recommend any amount of pavement mileage to be repaired in each year in order to minimize the total cost over the analysis period, which is 20 years in this case. Table 7 and Figure 7 show the recommended budget allocation for each type of treatment. Table 8 and Figure 8 show the corresponding projected pavement condition distribution.

Table 7. Recommended Treatment Budget

Year	Recommended Budget ($ Million)				
	PM	Thin Overlay	Minor Rehab	Major Rehab	Total Budget
2011	0.7	0.0	78.7	0.0	79.4
2012	19.9	0.0	93.3	30.7	143.9
2013	11.6	0.0	195.1	0.0	206.7
2014	13.2	0.0	143.7	0.1	156.9
2015	14.5	0.0	141.0	0.0	155.6
2016	15.9	0.0	136.9	0.0	152.8
2017	17.5	0.0	129.7	0.1	147.2
2018	18.9	0.0	121.7	0.1	140.6
2019	20.1	0.0	116.9	0.1	137.0
2020	20.8	0.0	114.8	0.1	135.6
2021	21.5	0.0	112.7	0.1	134.2
2022	22.1	0.0	111.7	0.1	133.8
2023	22.5	0.0	111.5	0.1	134.0
2024	21.8	0.0	111.9	0.1	133.8
2025	22.2	0.0	112.6	0.1	134.9
2026	22.1	0.0	115.6	0.1	137.7
2027	23.2	0.0	112.4	0.1	135.7
2028	22.3	0.0	117.1	0.1	139.5
2029	16.1	0.0	143.9	0.1	160.0
2030	33.9	0.0	78.7	0.1	112.6

Average = 140.6

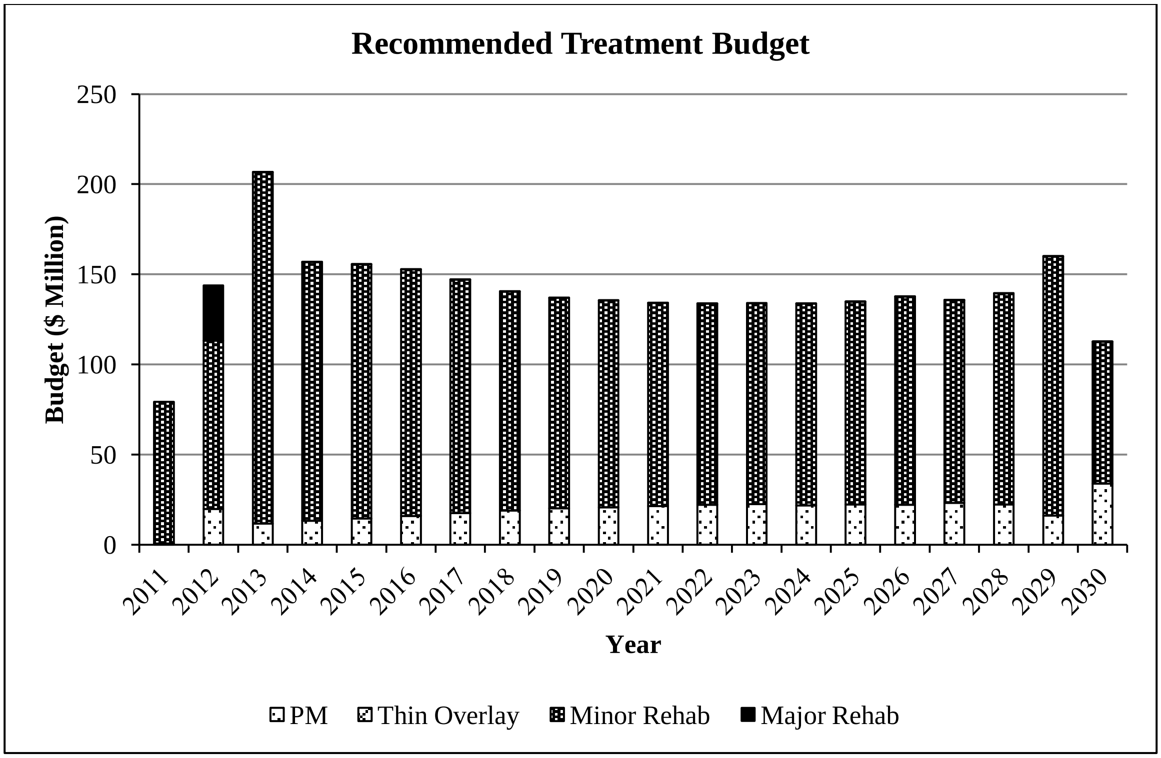

Figure 7. Recommended Treatment Budget (1)

Table 8. Projected Pavement Condition Distribution

Year	Condition Distribution (%)				
	Excellent	Good	Fair	Poor	Very Poor
2011	66.1	22.8	8.4	2.4	0.3
2012	58.6	27.1	12.2	1.8	0.3
2013	56.1	29.7	12.7	1.5	0.0
2014	57.1	30.5	11.5	1.0	0.0
2015	56.2	31.2	11.6	1.0	0.0
2016	55.7	31.6	11.7	1.0	0.0
2017	55.4	31.8	11.8	1.0	0.0
2018	55.1	32.1	11.8	1.0	0.0
2019	54.8	32.3	11.9	1.0	0.0
2020	54.4	32.6	12.1	1.0	0.0
2021	54.0	32.8	12.2	1.0	0.0
2022	53.7	33.0	12.4	1.0	0.0
2023	53.4	33.1	12.5	1.0	0.0
2024	53.2	33.2	12.6	1.0	0.0
2025	52.8	33.4	12.8	1.0	0.0
2026	52.5	33.6	13.0	1.0	0.0
2027	52.3	33.6	13.1	1.0	0.0
2028	52.2	33.7	13.1	1.0	0.0
2029	52.1	33.7	13.2	1.0	0.0
2030	52.1	33.7	13.2	1.0	0.0

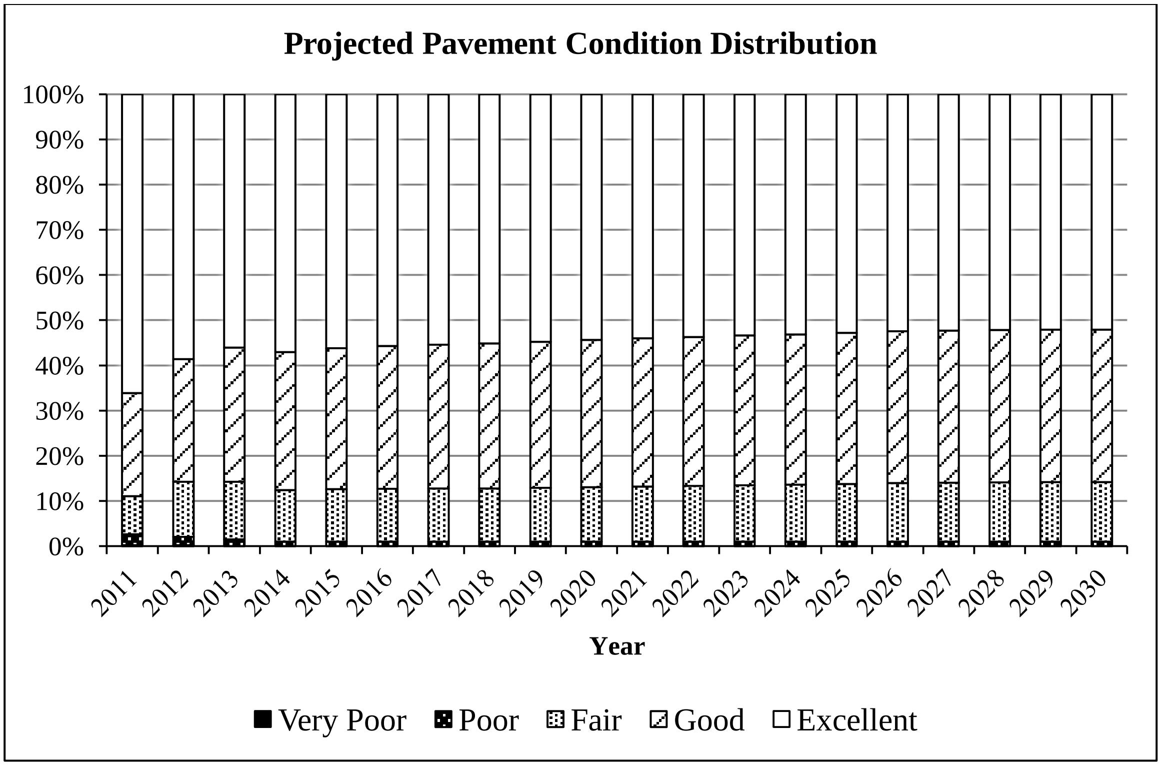

Figure 8. Projected Pavement Condition Distribution (1)

From Table 7 and Figure 7, it can be seen that the required budget for the year 2013 is $206.7 million, much higher than the other years. Table 8 and Figure 8 indicate that the deficiency level is reduced gradually from 2.7% to 1%. It should be noted that the funds for years after 2014 are used to maintain the deficiency level at 1%, since pavements tend to deteriorate over years. This result may not be suitable for practical use, since the recommended budget for the third year may be beyond the available maximum annual budget. Besides, the recommended annual budget varies significantly in the first several years, which makes the treatment strategy difficult to be implemented by highway agencies. In order to deal with these issues, a set of budget constraints can be added to the model. The optimization model with budget constraints can provide an optimal solution under the constraint that recommended budgets do not exceed the maximum available budget for each year. The average annual pavement expenditure obtained from this model is higher, since more constraints are included.

IV. Effect of allowable treatments on required budget

The optimization tool can perform a sensitivity analysis to test the impact of different allowable treatments on the required average annual budget. For instance, the decision-maker is interested in the effect of preventive maintenance (PM) on the average annual budget. The two different sets of allowable treatments are shown in Table 9 and Table 10. While in Table 9 PM is allowed to be conducted on pavements in good and fair conditions, it is not allowed in Table 10.

Table 9. Allowable Treatments (A)

Condition	Do Nothing	PM	Thin Overlay	Minor Rehab	Major Rehab
Excellent	Yes				
Good	Yes	Yes			
Fair	Yes	Yes		Yes	
Poor	Yes			Yes	Yes
Very Poor	Yes				Yes

Table 10. Allowable Treatments (B)

Condition	Do Nothing	PM	Thin Overlay	Minor Rehab	Major Rehab
Excellent	Yes				
Good	Yes				
Fair	Yes			Yes	
Poor	Yes			Yes	Yes
Very Poor	Yes				Yes

Results and Discussions

Eleven deficiency level scenarios are analyzed for this problem, as shown in Figure 9.

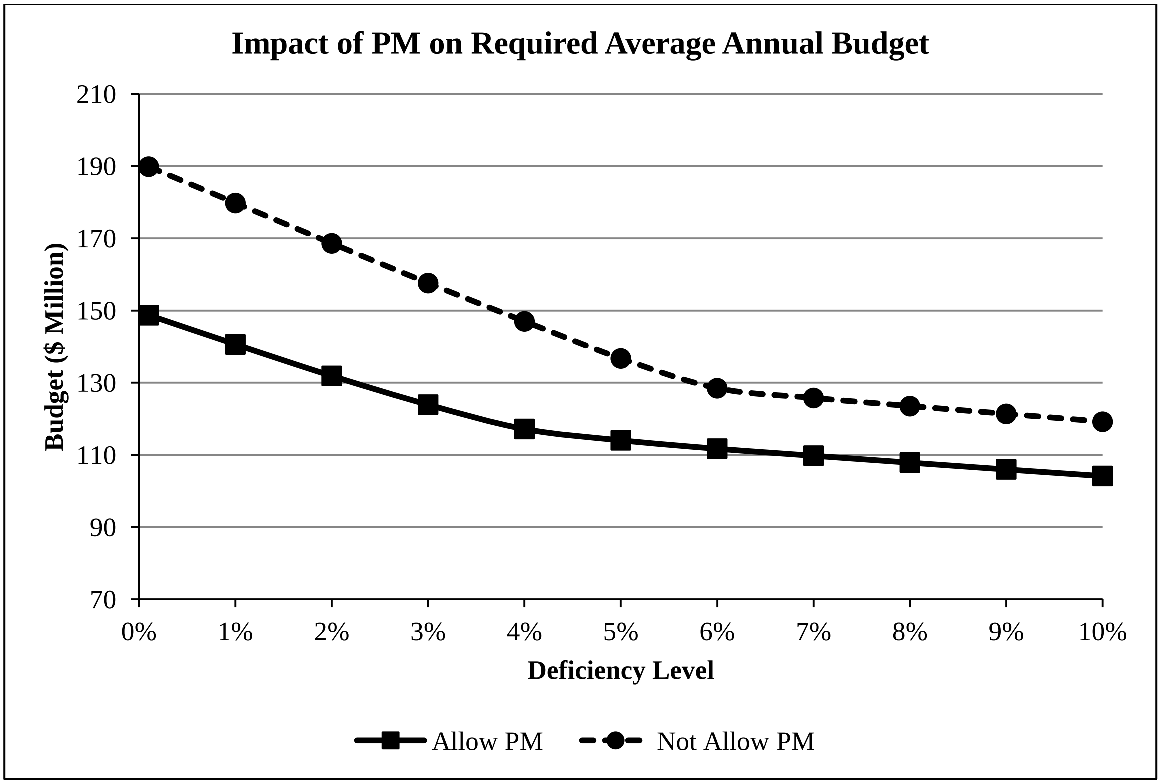

Figure 9. Impact of PM on Required Average Annual Budget

The objective is to minimize the total pavement expenditure in 20 years and the deficiency level target is to be achieved within three years. Budget constraints are not included in this optimization model, since the purpose is to seek the theoretical minimum budget to achieve a certain deficiency level.

It can be seen from Figure 9 that the impact of PM on the required average annual budget is quite significant. If PM is not allowed to be conducted, it would cost much more money to achieve the same condition level given the allowable treatments specified in Table 9 and Table 10. The approximate differences are $36 million for deficiency levels below 4% and $17 million for deficiency levels above 4%.

It should be noted that a sensitivity analysis can also be performed, based on the results shown in Figure 9, to investigate the relationship between condition level target and the required average annual budget. For instance, given the allowable treatments shown in Table 10 where PM is not allowed, it can be seen from Figure 9 that when the deficiency level is below 6%, the slope is larger. This means that the required annual budget is more sensitive at lower deficiency levels.

V. Optimum budget allocation among treatment types

The optimization tool is capable of generating the budget allocation plan among various repair treatments to maximize the entire pavement network condition when the available budget level has already been determined.

For instance, the available annual budget is $140.6 million and the objective is to maximize the proportion of pavements in Excellent, Good, and Fair conditions over the whole analysis period.

Results and Discussions

Figure 10 shows the recommended budget allocation among different maintenance and rehabilitation treatments. Figure 11 shows the corresponding predicted pavement condition distribution.

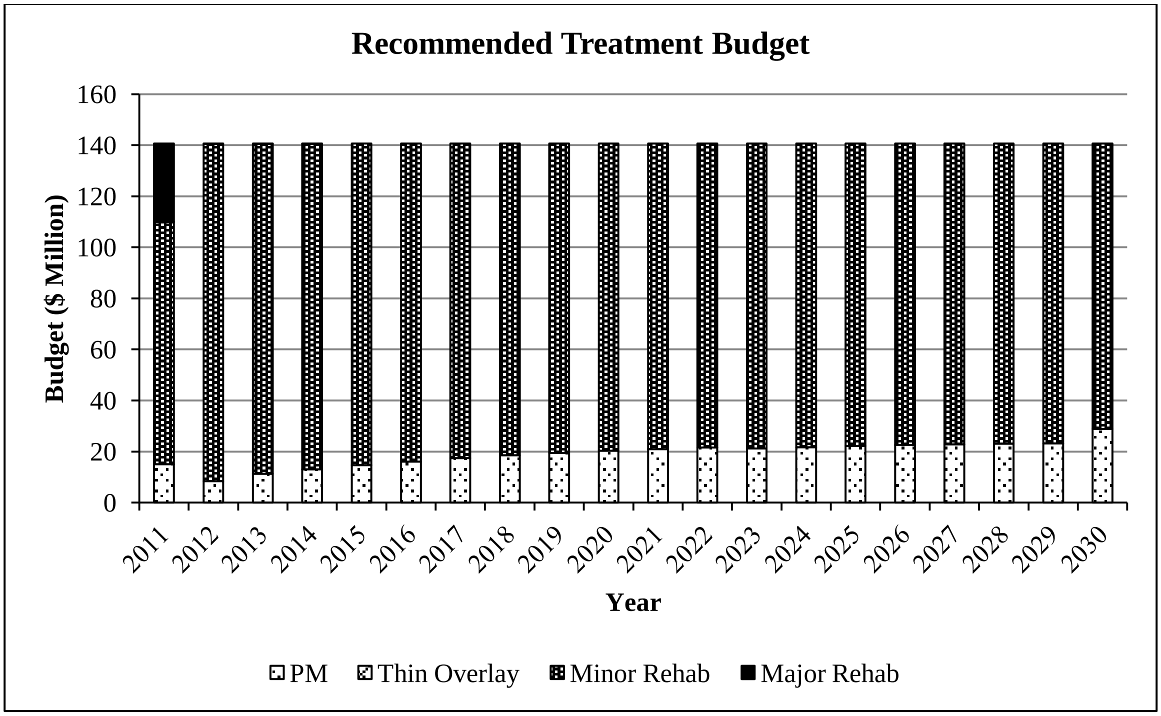

Figure 10. Recommended Treatment Budget (2)

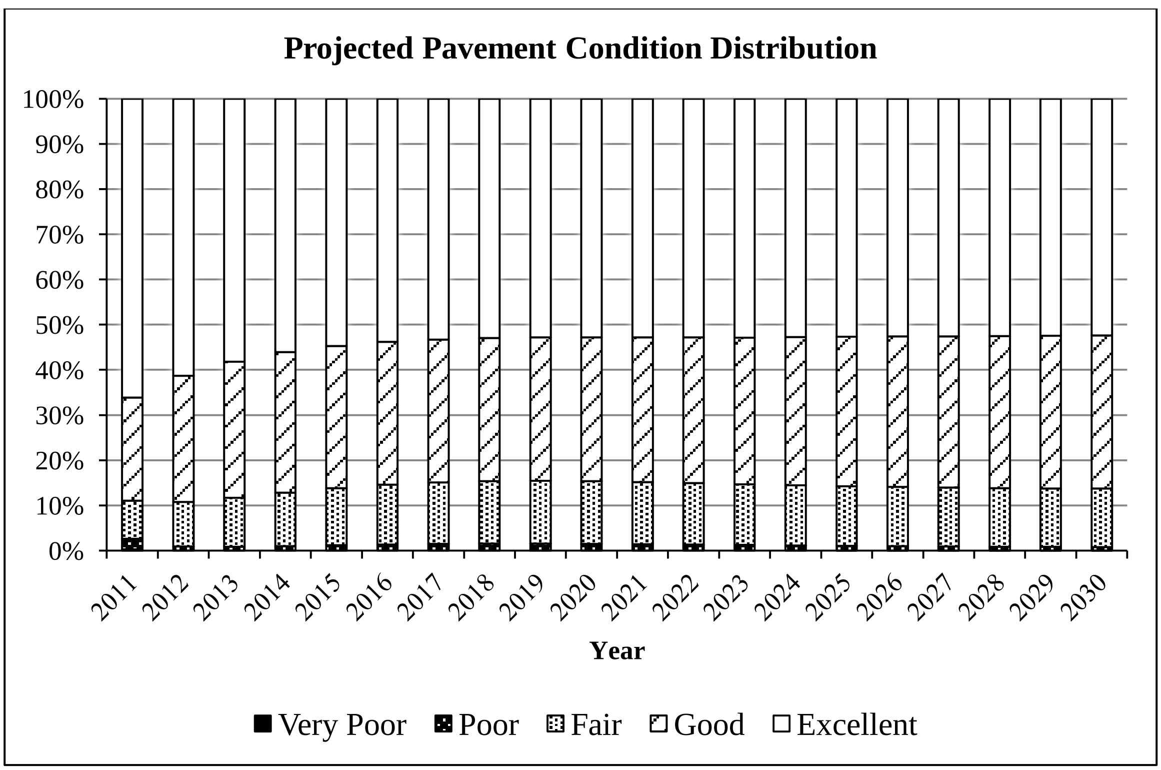

Figure 11. Projected Pavement Condition Distribution (2)

VI. Optimum budget allocation among Districts

The optimization tool provides two approaches to generate the budget allocation plan among different districts to achieve a desired condition level of the entire pavement network: (1) applying a statewide treatment policy to individual districts, and (2) doing optimization for each district separately.

For example, if the performance target is to reduce the deficiency level from 2.7% to 1% within three years, the optimum budget allocation among districts is shown below.

Applying Statewide Policy to Each District

The first approach (Approach A) is to apply a statewide treatment policy to all the 12 districts in Ohio. The goal of this policy is to achieve an overall deficiency level of less than 1% in the entire state within three years. A treatment policy matrix is generated for each pavement type (concrete, flexible, and composite) and each year (2011 to 2030). Table 11 shows the flexible pavement treatment policy for the year 2011. The required budget (Table 12) and the corresponding pavement network deficiency level (Table 13) for each district are calculated by applying the recommended treatment policy obtained from the statewide optimization.

Table 11. Flexible Pavements Treatment Policy for Year 2011

Last Treatment	Condition	Recommended Treatment				
		Do Nothing	PM	Thin Overlay	Minor	Major
PM	Excellent	100%	0%	0%	0%	0%
PM	Good	100%	0%	0%	0%	0%
PM	Fair	100%	0%	0%	0%	0%
PM	Poor	0%	0%	0%	0%	0%
PM	Very Poor	0%	0%	0%	0%	0%
Thin Overlay	Excellent	100%	0%	0%	0%	0%
Thin Overlay	Good	100%	0%	0%	0%	0%
Thin Overlay	Fair	100%	0%	0%	0%	0%
Thin Overlay	Poor	0%	0%	0%	100%	0%
Thin Overlay	Very Poor	0%	0%	0%	0%	0%
Minor	Excellent	100%	0%	0%	0%	0%
Minor	Good	100%	0%	0%	0%	0%
Minor	Fair	31%	69%	0%	0%	0%
Minor	Poor	0%	0%	0%	100%	0%
Minor	Very Poor	0%	0%	0%	0%	0%
Major	Excellent	100%	0%	0%	0%	0%
Major	Good	100%	0%	0%	0%	0%
Major	Fair	100%	0%	0%	0%	0%
Major	Poor	0%	0%	0%	100%	0%
Major	Very Poor	0%	0%	0%	0%	0%

Table 12. Required Budget Obtained by Applying Statewide Policy to Each District

Year	Budget for Each District ($ Million)											
	1	2	3	4	5	6	7	8	9	10	11	12
2011	0.0	8.7	7.3	18.0	2.8	13.7	0.2	2.5	11.4	4.2	4.5	6.2
2012	8.7	20.9	33.4	22.0	7.6	11.9	5.4	6.2	4.1	7.8	10.1	5.8
2013	3.9	10.1	19.0	29.0	16.2	36.3	13.2	32.9	4.8	8.4	14.5	18.4
2014	4.6	7.4	11.7	17.9	10.7	27.6	12.2	26.0	6.0	7.5	10.2	15.1
2015	5.6	7.4	10.6	17.1	9.5	26.6	13.0	25.6	7.1	7.6	9.7	15.7
2016	6.6	7.5	10.3	17.2	8.7	25.1	13.0	23.7	8.0	7.9	9.2	15.6
2017	7.2	7.5	10.2	17.0	8.3	23.6	12.4	21.5	8.6	7.3	8.8	14.8
2018	7.6	7.3	10.2	16.6	8.1	22.3	11.6	19.6	9.2	6.1	8.3	13.7
2019	7.9	7.2	10.5	16.5	8.0	21.1	11.1	18.1	9.6	5.8	8.1	13.2
2020	8.1	7.2	10.9	16.7	8.1	20.4	10.8	17.0	9.9	5.6	8.0	12.9
2021	8.1	7.2	11.3	16.8	8.2	19.7	10.5	16.3	10.1	5.4	7.9	12.6
2022	8.1	7.2	11.7	16.9	8.2	19.3	10.4	16.0	10.3	5.3	8.0	12.5
2023	8.1	7.2	12.0	17.1	8.3	19.0	10.3	15.8	10.4	5.3	8.0	12.5
2024	8.0	7.2	12.3	17.1	8.4	18.7	10.2	15.7	10.4	5.2	8.1	12.4
2025	8.0	7.2	12.6	17.3	8.5	18.8	10.3	15.8	10.5	5.3	8.2	12.6
2026	8.0	7.3	12.9	17.7	8.6	19.1	10.5	16.2	10.6	5.4	8.4	12.9
2027	7.7	7.2	12.9	17.3	8.5	18.7	10.3	16.4	10.3	5.4	8.2	12.6
2028	7.9	7.4	13.1	18.0	8.8	19.3	10.7	16.3	10.6	5.6	8.6	13.1
2029	8.9	8.5	14.3	21.4	9.6	21.8	12.4	19.6	11.2	6.1	10.0	16.0
2030	6.4	5.7	11.6	13.9	7.3	15.6	8.9	12.0	9.0	6.1	6.6	9.7

Table 13. Predicted Deficiency Level Obtained by Applying Statewide Policy to Each District

	Deficiency Level for Each District (%)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
2011	0.0	8.2	4.6	3.5	1.9	2.7	0.1	0.5	6.4	2.1	1.4	1.1
2012	2.1	6.2	4.7	3.8	1.0	1.2	0.6	0.5	0.4	1.9	2.6	0.9
2013	0.3	1.6	2.1	2.3	1.7	1.9	1.1	1.8	0.2	0.7	2.2	1.1
2014	0.6	1.1	1.1	1.3	0.9	1.3	1.0	1.1	0.4	0.5	1.4	0.7
2015	1.0	0.9	0.8	1.2	0.9	1.2	1.2	1.1	0.6	0.6	1.2	0.7
2016	1.3	0.8	0.7	1.2	0.9	1.2	1.3	1.1	0.7	0.6	1.1	0.7
2017	1.6	0.7	0.7	1.2	0.9	1.2	1.3	1.1	0.9	0.5	1.0	0.7
2018	1.8	0.7	0.6	1.2	1.0	1.1	1.3	1.0	0.9	0.5	0.9	0.7
2019	1.9	0.6	0.6	1.2	1.0	1.1	1.3	1.0	1.0	0.6	0.9	0.7
2020	1.9	0.6	0.6	1.2	1.1	1.1	1.3	1.0	1.0	0.6	0.8	0.7
2021	1.9	0.6	0.6	1.2	1.1	1.0	1.3	1.0	1.0	0.6	0.8	0.8
2022	1.9	0.7	0.7	1.1	1.1	1.0	1.2	1.1	1.0	0.6	0.8	0.8
2023	1.8	0.7	0.7	1.1	1.1	1.0	1.2	1.1	1.0	0.7	0.8	0.8
2024	1.8	0.7	0.7	1.1	1.1	1.0	1.2	1.1	1.0	0.7	0.8	0.9
2025	1.7	0.7	0.7	1.1	1.0	1.0	1.1	1.1	1.0	0.7	0.8	0.9
2026	1.6	0.8	0.8	1.1	1.0	0.9	1.1	1.1	0.9	0.7	0.8	1.0
2027	1.5	0.8	0.8	1.1	1.0	0.9	1.1	1.2	0.9	0.8	0.9	1.0
2028	1.5	0.8	0.8	1.2	1.0	1.0	1.1	1.0	0.9	0.9	0.9	1.0
2029	1.4	0.8	0.8	1.2	0.9	1.0	1.1	1.0	0.8	1.0	0.9	1.1
2030	1.3	0.8	1.0	1.0	1.1	1.0	1.1	0.9	1.1	1.1	0.9	0.9

Optimizing Pavement Expenditure for Each District

The second approach (Approach B) is to run optimization district by district with the same performance target. In this case, the minimum required budget (Table 14) for each district to reach the deficiency level of 1% within three years is calculated separately. Table 15 shows the corresponding pavement network deficiency level for each district.

Table 14. Required Budget Obtained by Optimizing Pavement Expenditure for Each District

Year	Budget for Each District ($ Million)											
	1	2	3	4	5	6	7	8	9	10	11	12
2011	1.2	9.2	21.8	23.7	2.8	8.8	0.2	1.3	11.4	2.9	9.5	4.6
2012	3.1	18.2	18.0	21.2	10.0	21.3	5.8	16.0	0.7	5.5	10.9	7.8
2013	5.8	13.1	20.5	27.2	13.1	35.1	13.0	25.5	5.4	9.1	10.5	15.1
2014	6.8	6.7	9.4	17.2	10.5	27.3	13.8	26.4	6.5	7.4	9.6	15.6
2015	7.5	6.6	9.5	17.3	9.7	26.2	13.6	25.2	7.5	7.2	9.2	15.6
2016	8.0	6.9	9.6	17.1	9.1	24.8	13.0	23.3	8.7	6.9	8.8	15.4
2017	8.2	7.1	9.8	16.8	8.7	23.3	12.2	21.3	9.1	6.4	8.4	14.4
2018	8.3	7.2	10.1	16.7	8.4	21.9	11.5	19.5	9.4	6.0	8.2	13.8
2019	8.3	7.2	10.5	16.6	8.2	20.8	10.9	18.0	9.7	5.7	8.1	13.3
2020	8.1	7.3	11.0	16.7	8.2	20.1	10.6	17.5	9.9	5.5	8.0	13.1
2021	8.0	7.3	11.4	16.8	8.2	19.5	10.3	16.7	9.9	5.4	7.9	12.9
2022	7.9	7.2	11.8	17.0	8.2	19.1	10.2	16.3	10.0	5.2	8.0	12.8
2023	7.8	7.2	12.1	17.2	8.3	18.9	10.2	16.1	10.1	5.3	8.1	12.7
2024	7.8	7.2	12.3	17.2	8.3	18.6	10.2	15.9	10.2	5.4	8.2	12.7
2025	7.7	7.2	12.6	17.5	8.4	18.7	10.3	16.0	10.2	5.7	8.2	12.8
2026	7.7	7.3	12.9	17.9	8.4	19.1	10.6	16.2	10.2	5.4	8.3	13.0
2027	7.8	7.2	12.5	18.0	8.5	19.0	10.7	15.0	10.2	5.4	8.5	12.8
2028	7.8	7.3	13.1	18.1	8.6	19.4	10.8	16.7	10.3	5.4	8.5	13.2
2029	8.8	8.5	15.9	19.7	10.5	22.5	12.2	18.4	12.7	5.6	9.7	14.1
2030	6.6	6.0	9.6	15.4	6.6	15.0	8.8	14.5	7.7	5.3	7.2	11.8

Table 15. Predicted Deficiency Level Obtained by Optimizing Pavement Expenditure for Each District

	Deficiency Level for Each District (%)											
Year	1	2	3	4	5	6	7	8	9	10	11	12
2011	0.0	8.2	4.6	3.5	1.9	2.7	0.1	0.5	6.4	2.1	1.4	1.1
2012	1.0	5.8	3.4	2.7	1.0	1.6	0.6	0.6	0.4	1.7	1.3	1.1
2013	1.0	3.4	2.2	1.8	1.3	1.6	1.0	1.0	1.3	1.4	1.1	1.0
2014	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2015	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2016	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2017	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2018	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2019	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2020	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2021	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2022	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2023	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2024	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2025	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2026	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2027	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2028	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2029	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2030	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Comparison between Two Results

Based on Table 12 and Table 14, although the required budgets for each year obtained by the two approaches are different, the average annual costs for the entire state are nearly the same: $140.5 million for Approach A and $ 140.6 for Approach B. As shown in Figure 12, the difference between the average annual budgets for each district yielded by the two approaches is not significant either. Therefore, the two approaches recommend almost the same amount of total budget for each district over the analysis period.

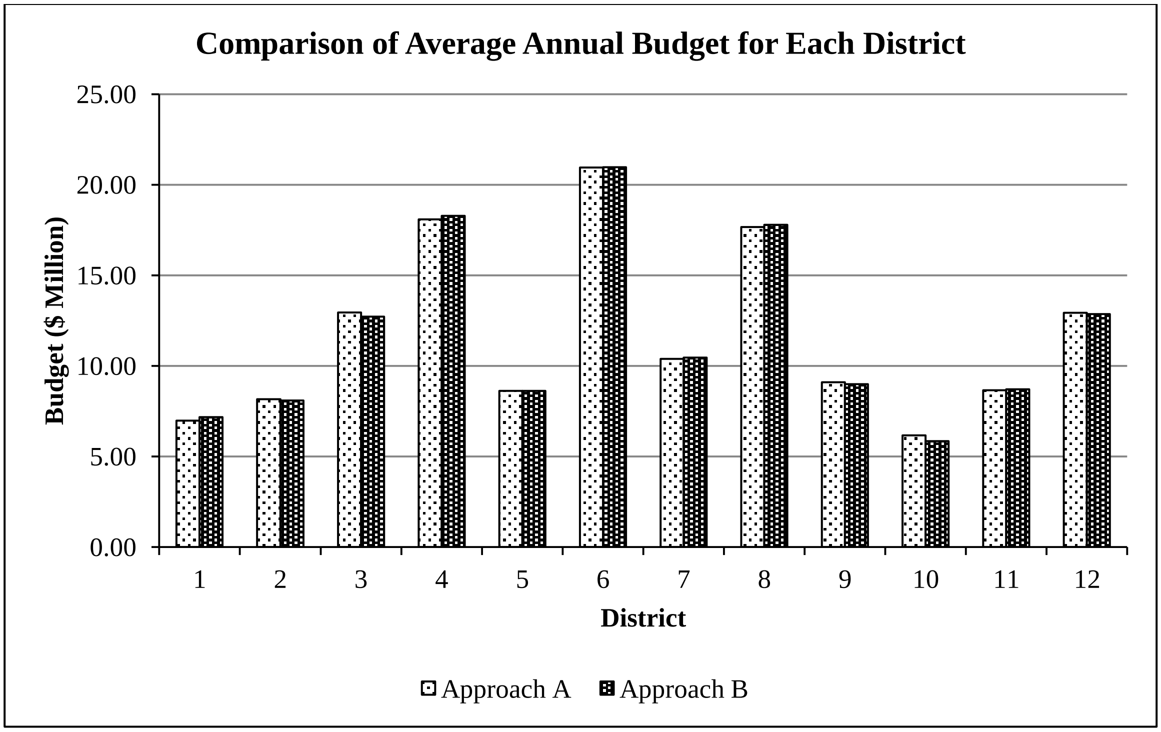

Figure 12. Comparison of Average Annual Budget for Each District

Based on Table 13, the predicted deficiency levels obtained by Approach A vary significantly from district to district, although the overall deficiency level of the entire state is maintained at the desired level (1%). On the other hand, as shown in Table 15, Approach B yields a result that every district can keep a deficiency level of 1% from the third year on. The main reason is that Approach B generates an optimized treatment policy to achieve the desired performance target for each of the 12 districts separately; whereas Approach A takes a global view of the pavement network in the entire state. The budget allocation plan recommended by Approach B is better than that of Approach A, since it can achieve a more balanced condition distribution among the 12 districts using the same amount of money.

CONCLUSIONS AND RECOMMENDATIONS

Prudent use of available maintenance and rehabilitation budget is essential to maintain and preserve the existing highway network during this challenging economic environment. Selection of the most beneficial projects among competing needs and determination of the most cost-effective rehabilitation strategies are not simple tasks. This research study has developed models and tools to support pavement maintenance and rehabilitation planning and management decisions.

Based on the findings of this research study, the following conclusions can be made:

1. Use of network level optimization will results in more effective use of maintenance, rehabilitation and reconstruction funds.
2. The network level optimization model developed in this research project can be used to determine the minimum cost required and the corresponding treatment policy to achieve a desired target state of the network. Furthermore, it can be used to evaluate the impact of various condition targets and treatment polices on the required network level budget.
3. The model can also be used to determine the best network condition state achievable with a given network budget, and the corresponding treatment policy. Consequently, it can determine the optimal allocation of available budget among MR&R treatment categories and among Districts or between the Priority and General systems.
4. Additional constraints such as the required budget must be within a realistic range may be added to the optimization model, so that the solution may be more practical.
5. The results of optimization show that conducting preventive maintenance (PM) on pavements before they deteriorate into poor conditions can save a considerable amount of money.
6. The minimum budget required versus the allowable deficiency level relation is not linear. For example, for Priority system, the curve becomes relatively flat after 5% allowable deficiency. In other words, the cost saving resulting from raising the allowable deficiency level to more than 5% would be minimal and would not justify the poorer network condition.

7. The optimization model of minimizing cost calculates the budget requirements subject to pavement condition constraints for each year; whereas the model of maximizing benefit generates a best funds allocation plan with a given amount of budget. The pavement deficiency level trends obtained from the two models may not match, even if the same total amount of money is spent over the analysis period.
8. Conducting network optimization for each district, so that each district has its own treatment policy will lead to more equalized condition state among districts than applying the statewide optimal treatment policy to individual districts.

The following recommendations are made based on the findings of this study:

1. It is recommended that ODOT adopts a network level optimization approach to determine future MR&R budget needs, funding allocations, and treatment policies. The potential cost savings are substantial and the ability to demonstrate optimal use of budget is a significant bonus.
2. Currently, only pavement asset, which accounts for perhaps 60~70% of the overall expenditures, is included in the network optimization model. It is recommended that all other transportation assets within the network, such as bridges, culverts, guardrails, etc., be included as well, so that the resulting budget needs and funding allocations will be more representative of the entire actual network.
3. Cross-asset optimization that includes multiple or all assets could result in potentially even greater savings compared with only optimizing individual assets. Therefore, it is recommended that ODOT sponsors research studies to investigate the feasibility and availability of cross-asset optimization models.

IMPLEMENTATION PLAN

The network level optimization model and procedure developed in this study have been incorporated into the ODOT-PMIS as a network optimization tool. This tool has been tested and used by the research team to produce the results shown in this report. Additional descriptions of the optimization tool can be found in the undated ODOT-PMIS user manual in Appendix B of this report. This tool may be used by ODOT to evaluate whether or not to adopt and to fully implement the results and recommendations of the study.

It should be noted that although the optimization tool works and generates very useful and usable results, it is by no means a final product. It is considered an offshoot of the research effort. However, it can readily serve as a foundation or advanced prototype for future full implementation if ODOT chooses to do so. One area of improvement, for example, could be to provide means for additional constraints beyond those already considered to be easily added by the user to the optimization model.

Since the network level optimization function is most likely to be used by the senior management for budget planning, funding allocation, or treatment policy determination purposes, the commitment and support from the senior management are essential in implementing the results of this study.

APPENDIX A. REFERENCES

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APPENDIX B. ODOTPMIS USER MANUAL

TABLE OF CONTENTS

SECTION 1. INTRODUCTION

The Infrastructure Information System Laboratory at the University of Toledo has developed a Pavement Database for the Ohio Department of Transportation using the Microsoft Access database format. The ODOTPMIS includes the database and a set of reporting tools to extract the data necessary for pavement performance analysis.

This section of the user's manual includes installation procedures of the ODOTPMIS, an introduction to the menu items, and a brief overview of the basic operations.

1.1 System Installation

Newer versions and updates of ODOT PMIS can be downloaded from http://www.eng.utoledo.edu/~ychou/ODOTPMIS. After downloading the "ODOTPMIS.Zip," please unzip the file and double click the "ODOTPMIS.exe." During installation, follow the on-screen instruction of Install Shield to install ODOTPMIS successfully. The default directory where PMIS is installed is "C:\ODOTPMIS_NET\." Users can change this installation directory by selecting a different location. FIGURE B- 1 shows the sequential steps in installing ODOTPMIS.

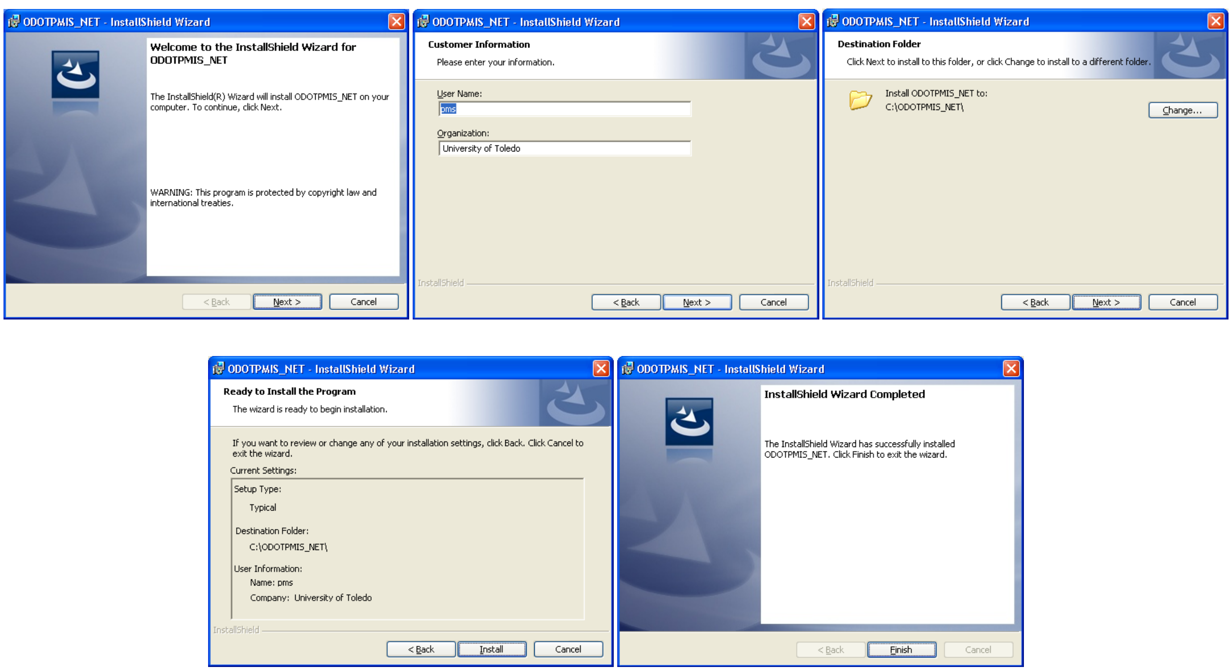


FIGURE B- 1. Installation Procedure

1.2 Uninstallation

ODOTPMIS should be uninstalled before a reinstallation. When uninstalling an older version of the ODOTPMIS, the database is deleted automatically.

1.3 System Requirements

Recommended software platform requirements for running this package are:

1. Windows 98 / Me / 2000 / XP/ 7
2. Microsoft Access 2000 or newer

Recommended minimum hardware platform requirements for running this package are:

1. Pentium II 300Mhz CPU
2. 128MB RAM
3. 14" color monitor
4. 2GB free hard disk space
5. Mouse
6. Color printer
7. 4MB video memory
8. CD-ROM drive

1.4 Compact Database

Users may find it is necessary to compact the database when its size exceeds 1GB. The database can be compacted by the following process.

1. Choose “Compact and Repair Database” in the “File” menu
2. Open the Access database file “ODOT_Pavement_DB_static.mdb” and in the “Tools” menu, choose “Database Utilities,” and click on “Compact and Repair Database”

This operation may take 5 – 10 minutes, depending on the size of the database and the specifications of the computer.

SECTION 2. USER INTERFACE

2.1 User Interface

ODOTPMIS was developed using Microsoft Visual Basic .NET to replicate common window-based graphical user interfaces. As such, the PMIS interface utilizes drop down menus located at the top of the screen, a number of buttons located beneath the menus, and an object browser to list queries and tables stored in the pavement management database. The following is a screenshot of ODOTPMIS.

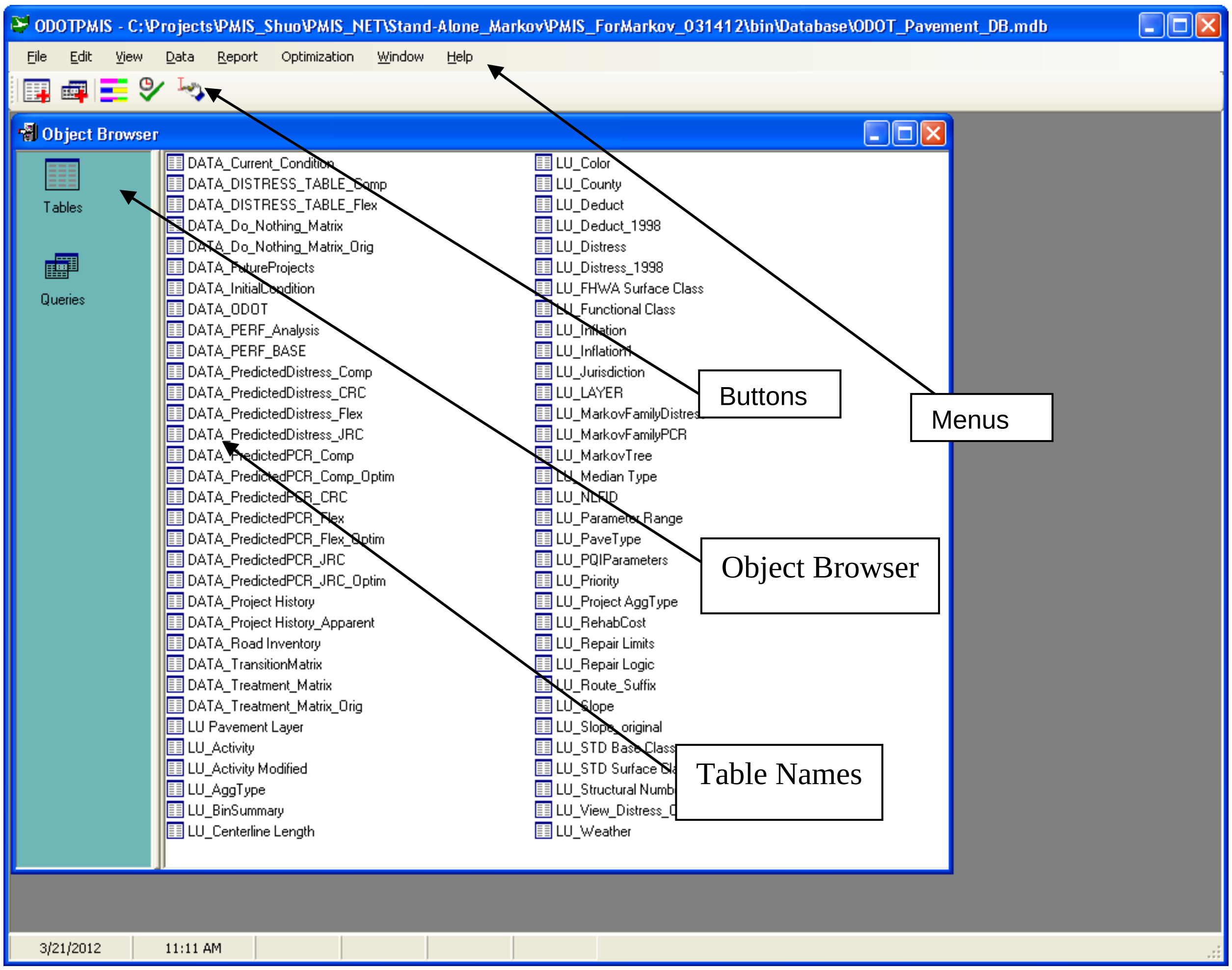


FIGURE B- 2. ODOTPMIS User Interface

2.2 Required Tables

For the PMIS utility to operate, several Data and Look-Up tables are required in the database. The tables are:

TABLE B- 1. PMIS Required Tables

DATA_ Project History_Apparent	LU_MarkovFamilyDistress	LU_Slope
DATA_FutureProjects	LU_MarkovFamilyPCR	LU_STD Base Class
DATA_InitialCondition	LU_MarkovTree	LU_STD Surface Class
DATA_ODOT	LU_Median Type	LU_Structural Number
DATA_PERF_Analysis	LU_NLFID	LU_Weather
DATA_PERF_BASE	LU_Parameter Range	LU_STD Surface Class
DATA_Project History	LU_PaveType	LU_Structural Number
DATA_Road Inventory	LU_PQIParameters	LU_Weather
LU Pavement Layer	LU_Priority	LU_STD Surface Class
LU_Activity	LU_Project AggType	LU_Structural Number
LU_Activity Modified	LU_RehabCost	LU_Weather
LU_AggType	LU_Repair Limits	LU_Structural Number
LU_BinSummary	LU_Repair Logic	LU_Weather
LU_Centerline Length	LU_Route_Suffix	LU_Color
LU_FHWA Surface Class	LU_Deduct_1998	LU_COST
LU_Functional Class	LU_Distress	LU_County
LU_Inflation	LU_Distress_1998	LU_Deduct
LU_Jurisdiction	LU_LAYER	LU_View_Distress_Code

PMIS prevents all operations from being performed in the database if any of these tables are missing.

SECTION 3. FILE MENU

The following figure shows the "File" menu options.

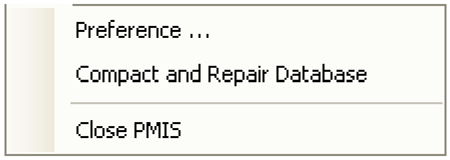


FIGURE B- 3. ODOTPMIS File Menu

3.1 Preference

This option is used to set the default options for ODOTPMIS as shown in FIGURE B- 4. The presence or absence of a checkmark next to an option indicates its state.

Startup options appear when the application is opened. These are explained below.

1. **Show Splash Window**: Displays a window showing application information when ODOTPMIS is opened.

Exit options appear when the application is closed. These are explained below.

1. **Confirm Exit**: Displays a warning confirmation window when users attempt to close the application.
2. **Compact Database Before Exit**: Compacts the database before each close.

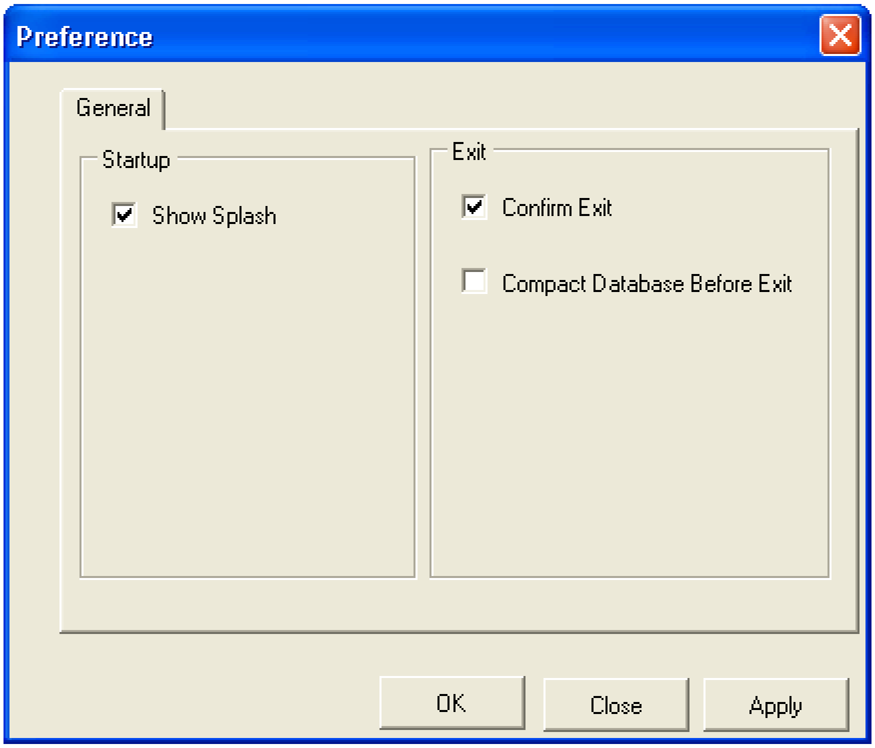


FIGURE B- 4. Preference Setup Interface

3.2 Compact and Repair Database

The "Compact and Repair Database" command activates a utility that compresses the database, which increases the analysis speed. This command should be performed regularly to ensure optimal performance. ***WARNING: If the database is allowed to reach its maximum size of two gigabytes, none of the PMIS functions will function***. Furthermore, at two gigabytes, the database cannot be used for executing queries. To prevent or alleviate these problems, compact the database regularly.

3.3 Close PMIS

This option is used to exit from the PMIS application.

SECTION 4. EDIT MENU

The “Edit” menu contains commands for opening and deleting tables and queries. This menu will affect whichever data type is displayed in the object browser, either a query or table. The commands included on this menu are “Open,” and “Delete,” The following figure shows the drop down menu.

FIGURE B- 5. ODOTPMIS Edit Menu

4.1 Open

This option opens a table for editing values. To open a table, highlight a table in the object browser and select “Open” in the edit menu.

4.2 Delete

This command deletes the selected table or query from the database.

SECTION 5. VIEW MENU

The “View” menu contains commands for ensuring that the toolbars and the object browser are updated and visible. The commands include “Show Toolbar,” “Show Object Browser,” and “Refresh Object Browser.”

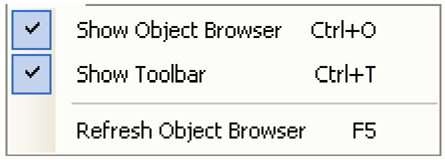


FIGURE B- 6. ODOTPMIS View Menu

5.1 Show Object Browser (Shortcut Key: CTRL+O)

This option is used to show the object browser. The presence of a check mark next to its name in the “View” menu indicates that the object browser will be displayed in the main ODOTPMIS window.

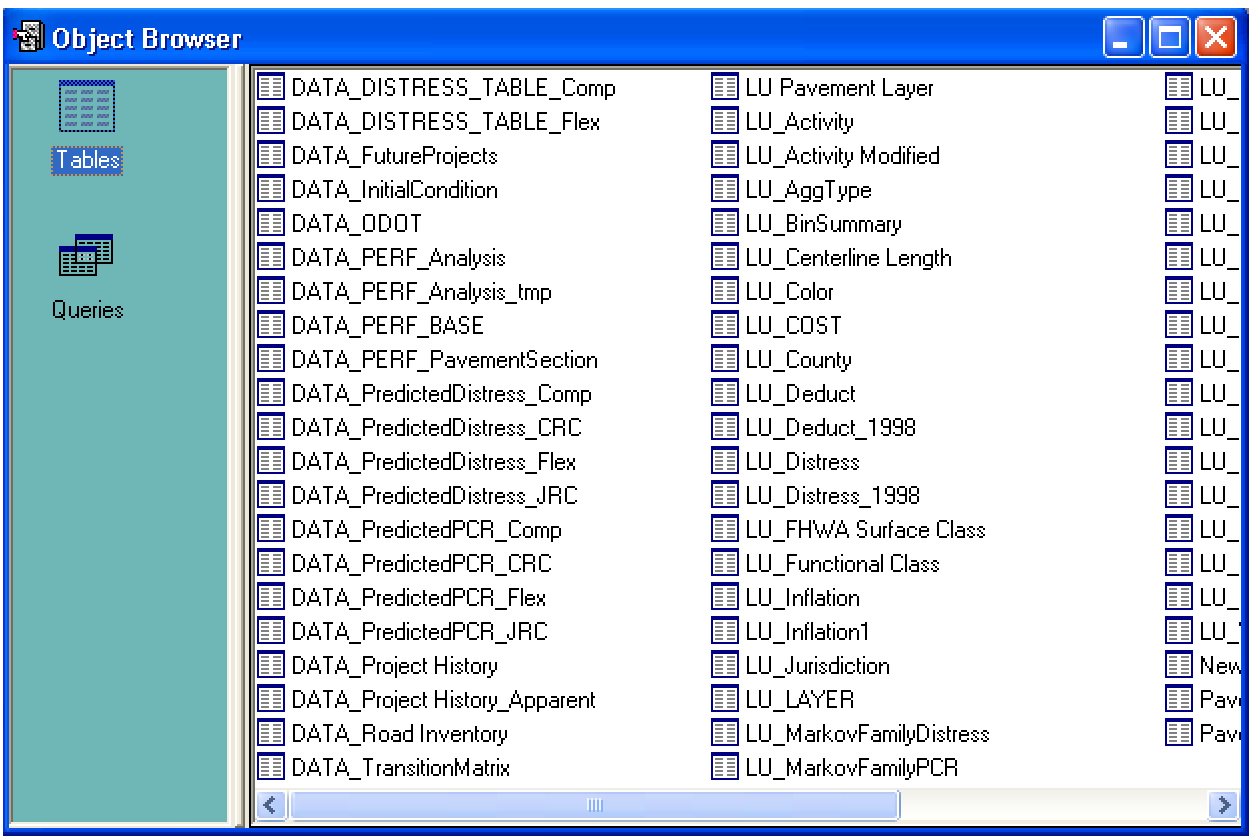


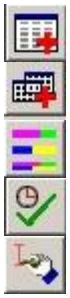
FIGURE B- 7. Show Object Browser

The object browser displays a list of the tables and queries in the current database. The object browser contains two filters:

1. **Tables**: Displays a list of all the tables in the database
2. **Queries**: Displays a list of all the queries in the database

5.2 Show Toolbar (Shortcut Key: CTRL+T)

This option is used to show or hide the toolbar, which contains the following buttons:



New Table
New Query
Linear Superposition
Pavement Condition History Plot
Project History Entry

FIGURE B- 8. Tool Bar Options

5.3 Refresh Object Browser (Shortcut Key: F5)

This option is used to refresh the object browser to display updated information.

SECTION 6. DATA MENU

The “Data” menu contains functions that add or modify tables needed for the successful operation of PMIS.

FIGURE B- 9. ODOTPMIS Data Menu

6.1 Load Road Inventory (Required)

This tool shows users how to update the road inventory table with new data from text files. The road inventory table includes the following information: road geometry, classification, priority, system, and traffic volume. **This table should be updated every year**. The name of this table in ODOTPMIS is *DATA_Road Inventory*.

Note: Field values must be in the order specified in TABLE B- 2.

TABLE B- 2. Field Order, Name and Data Format

Order	Field Name	Data Type	Size
1	RIKey	Long Integer	4
2	Jurisdiction	Text	1
3	County	Text	3
4	Route	Text	4
5	Route Suffix	Text	1
6	Year	Integer	2
7	Blog	Single	4
8	Elog	Single	4
9	Section Length	Text	4
10	Log Point Suffix	Text	1
11	Road Identification	Text	1
12	Data Type	Text	4
13	Data Status	Text	1
14	Transaction	Text	1
15	Inventory Perpetuation Date	Text	4
16	FIPS Code	Text	3
17	Mile Class	Text	1
18	System Class	Text	1
19	Standard Surface Classification	Text	1

20	Standard Base Classification	Text	1
21	Summary FHWA Surface Type	Text	2
22	Surface Width	Single	4
23	Summary Roadway Width	Single	4
24	Population (100's)	Long Integer	4
25	Left Side Standard Surface Class	Text	1
26	Left Side Standard Base Class	Text	1
27	Left Side FHWA Surface Type	Text	2
28	Left Side Surface Width	Single	4
29	Median Width	Single	4
30	Right Side Standard Surface Class	Text	1
31	Right Side Standard Base Class	Text	1
32	Right Side FHWA Surface Type	Text	2
33	Right Side Surface Width	Single	4
34	Year in Inventory	Integer	2
35	National Highway System (NHS)	Text	1
36	System	Text	2
37	Highway Performance Monitoring System	Text	1
38	Maintenance Route Type	Text	2
39	Population (over/Under 5000)	Text	1
40	Municipality Name	Text	16
41	Divided Highway Indicator	Text	1
42	Access Control	Text	1
43	Lanes	Byte	1
44	district	Byte	1
45	Number of Lanes (two character)	Text	2
46	Station Equation Sort Field	Text	1
47	Priority	Text	1
48	Area Code	Text	3
49	Functional Class	Text	2
50	Car ADT	Long Integer	4
51	Truck ADT	Long Integer	4
52	Total ADT	Long Integer	4
53	ADT - Year of counts	Long Integer	4
54	ESALx1000	Long Integer	4
55	NLFID	Text	14

6.2 Load Project History (Required)

This tool shows users how to update the project history table with new data from text files. **This table should be updated every year.** The name of this table in ODOTPMIS is *DATA_Project History*.

Note: Field values must be in the order specified in TABLE B- 3.

TABLE B- 3. Field Order, Name and Data Format

Order	Field Name	Data Type	Size
1	Entry	Integer	2
2	Suffix	Text	2
3	System	Text	2
4	PRIORITY	Text	255
5	Jurisdiction	Text	1
6	NLFID	Text	20
7	DISTRICT	Byte	1
8	County	Text	3
9	Route	Text	4
10	Station	Text	4
11	APP BLOG	Single	4
12	APP ELOG	Single	4
13	APP YEAR	Integer	2
14	Blog	Single	4
15	Elog	Single	4
16	Year	Integer	2
17	PN	Text	20
18	PID	Text	20
19	Special Project	Text	255
20	LANES	Byte	1
21	Activity Code	Integer	2
22	EPTHL1	Text	20
23	EPTHL2	Text	20
24	EPTHL3	Text	20
25	EPTHL4	Text	20
26	EPTHL5	Text	20
27	EPTYL1	Text	50
28	EPDescL1	Text	50
29	EPTYL2	Text	50
30	EPDescL2	Text	50
31	EPTYL3	Text	50
32	EPDescL3	Text	50
33	EPTYL4	Text	50
34	EPDescL4	Text	50
35	EPTYL5	Text	50
36	EPDescL5	Text	50
37	EPTHREM	Text	20
38	PTHA1	Single	4
39	PTHA2	Single	4
40	PTHA3	Single	4

41	PTHA4	Single	4
42	PTHA5	Single	4
43	PTYA1	Text	50
44	PDescA1	Text	50
45	PTYA2	Text	50
46	PDescA2	Text	50
47	PTYA3	Text	50
48	PDescA3	Text	50
49	PTYA4	Text	50
50	PDescA4	Text	50
51	PTYA5	Text	50
52	PDescA5	Text	50
53	SCAGGTY	Text	5
54	GRINDING	Text	50
55	FLEXIBLE REPAIRS	Text	50
56	RIGID REPAIRS	Text	50
57	PAVEMENT SPECIAL	Text	5
58	PAVE_COST	Double	8
59	TOTAL_COST	Double	8
60	EST_COST	Double	8
61	DATE_OPEN	Date/Time	8
62	DATE MODIFIED	Date/Time	8
63	DATE ENTERED	Date/Time	8
64	NOTES	Memo	-
65	SN_ADD	Single	4
66	Modified Activity Code	Integer	2
67	New Activity Code	Long Integer	4
68	New Activity Prefix	Integer	2
69	Thickness Added	Single	4

6.3 Load Data ODOT (Required)

This tool shows users how to update the *Data_ODOT* table with new data from text files. In ODOTPMIS, pavement condition data such as PCR, RN, IRI, PSI, etc. are stored in the *DATA_ODOT* table. This table also stores all road classification and distress data. **This pavement condition data should be updated annually.**

Note: Field values must be in the order specified in TABLE B- 4.

TABLE B- 4. Field Order, Name and Data Format

Order	Field Name	Data Type	Size
1	Key	Long Integer	4
2	District	Byte	1
3	NLFID	Text	14
4	County	Text	3
5	Route	Text	4
6	Station	Text	4
7	Year	Integer	2
8	Blog	Single	4
9	Elog	Single	4
10	HCS	Integer	2
11	LIRI	Integer	2
12	RIRI	Integer	2
13	RN	Single	4
14	PSI	Single	4
15	Jurisdiction	Text	1
16	Mile Class	Text	1
17	Surface Type	Text	1
18	Surface Width	Byte	1
19	Sum Roadway Width	Byte	1
20	National Highway System (NHS)	Text	1
21	Route Type	Byte	1
22	Divided - RI	Text	1
23	Access Control	Text	1
24	Urban Area Code	Integer	2
25	Functional Class	Integer	2
26	TRUCK ADT	Long Integer	4
27	Total ADT	Long Integer	4
28	ESALx1000	Long Integer	4
29	MPC	Byte	1
30	Rater 1	Text	3
31	NHS Field	Text	1
32	Rater 2	Text	3
33	Pavement Type	Byte	1
34	Project Number	Text	10
35	Divided - PCR	Text	2
36	Lanes	Byte	1
37	PCR Date	Date/Time	8
38	Pave Type	Text	50
39	PRIORITY	Text	1
40	Code 1	Text	2
41	Code 2	Text	2

42	Code 3	Text	2
43	Code 4	Text	2
44	Code 5	Text	2
45	Code 6	Text	2
46	Code 7	Text	2
47	Code 8	Text	2
48	Code 9	Text	2
49	Code 10	Text	2
50	Code 11	Text	2
51	Code 12	Text	2
52	Code 13	Text	2
53	Code 14	Text	2
54	Code 15	Text	2
55	Code 16	Text	2
56	Code 17	Text	2
57	Code 18	Text	2
58	Code 19	Text	2
59	Code 20	Text	2
60	Code 21	Text	2
61	Code 22	Text	2
62	Code 23	Text	2
63	Code 24	Text	2
64	Code 25	Text	2
65	CodeValue 1	Single	4
66	CodeValue 2	Single	4
67	CodeValue 3	Single	4
68	CodeValue 4	Single	4
69	CodeValue 5	Single	4
70	CodeValue 6	Single	4
71	CodeValue 7	Single	4
72	CodeValue 8	Single	4
73	CodeValue 9	Single	4
74	CodeValue 10	Single	4
75	CodeValue 11	Single	4
76	CodeValue 12	Single	4
77	CodeValue 13	Single	4
78	CodeValue 14	Single	4
79	CodeValue 15	Single	4
80	CodeValue 16	Single	4
81	CodeValue 17	Single	4
82	CodeValue 18	Single	4
83	CodeValue 19	Single	4
84	CodeValue 20	Single	4

85	CodeValue 21	Single	4
86	CodeValue 22	Single	4
87	CodeValue 23	Single	4
88	CodeValue 24	Single	4
89	CodeValue 25	Single	4
90	PCR ODOT	Byte	1
91	PCR	Byte	1
92	CRD	Single	4
93	STRD	Single	4
94	TDC	Single	4
95	System	Text	2
96	Base	Text	1
97	PQI	Byte	1

6.4 Generate Data Table (Required)

This tool should be run whenever *DATA_ODOT* or *DATA_Project history* has been updated.

This tool calculates some fields in *DATA_ODOT* and *DATA_Project History* and creates some base tables for further analysis. The following fields in *DATA_ODOT* are calculated: Individual Deducts, CRD, PQI, System, Jurisdiction, and Pave Type. The following fields in *DATA_Project History* are calculated: SN_ADD, Modified Activity Code, and Thickness Added. The following base tables are created: DATA_Project History_Apparent, DATA_PERF_BASE, DATA_PERF_ANALYSIS, DATA_InitialCondition. This tool also generates the Markov prediction tables: DATA_PredictedDistress_JRC, DATA_PredictedDistress_CRC, DATA_PredictedDistress_Flex, DATA_PredictedDistress_Comp, DATA_PredictedPCR_JRC, DATA_PredictedPCR_CRC, DATA_PredictedPCR_Flex, DATA_PredictedPCR_Comp.

6.5 Import Planned Projects (Optional)

This tool allows the importing of a work plan into ODOTPMIS. Generally, the work plan file contains the planned treatments for the future, project cost, and location information. The imported file is stored in *DATA_FutureProjects*. Each time this tool is used to import a new work plan, the previous existing work plan in ODOTPMIS is overwritten. To import condition data correctly, the source data file must have the required format.

Stored Table: DATA_FutureProjects
Data file type: Microsoft Excel File
Data format: Shown in
TABLE B- **5**.

In the work plan file, certain columns can be left empty if they do not contain data. However, the necessary fields (bolded) "PID," "NLF ID," "County Begin Number," "County End Number," and "Pavement Treatment Type" should contain values.

TABLE B- 5. Work Plan File Format

Order	Field Name	Example
1	**PID**	21052
2	SUM Adjusted Total Amt	8300000
3	Sale Amount	
4	District	
5	Project Name (ie CRS)	
6	Primary Work Category	
7	Award Date Current	
8	Award Date Actual	
9	Requested STIP Yr	2009
10	**NLF ID**	SLUCSR00002**C
11	**County Begin Number**	30.23
12	**County End Number**	30.8
13	Actual Priority Miles	0
14	Actual Urban Miles	0
15	Actual General Miles	1.14
16	MAX Pvmt Treat Category Cd	
17	**Pavement Treatment Type**	60 - AC Overlay with Repairs

6.6 Additional Tools (Optional)

The following tools are optional, but allow users to perform more advanced options to get information from the PMIS database.

6.6.1 Populate Performance Base Table

The "Populate Performance Base Table" function opens a window to display variances of user specified attributes in *DATA_ODOT* over time with respect to specified values of *DATA_Project History*.

This tool replaces the "Key" and "Entry" numbers in the *DATA_PERF_BASE* table. The keys are replaced with the selected values in the "DATA_ODOT" list box and entries are replaced with selected parameter values in "DATA_Project History" list box.

Note: The resultant table cannot exceed 256 columns in width. Thus, if many parameters are desired, the number of years selected should be decreased or conversely, if many years are selected, the number of parameters may need to be reduced.

Source Table: DATA_PERF_BASE, DATA_Project History_Apparent, DATA_ODOT
Output Table: The default name is *Result_Base*. However, the user can assign a different table name by changing the text in the "Output Table Name" textbox.

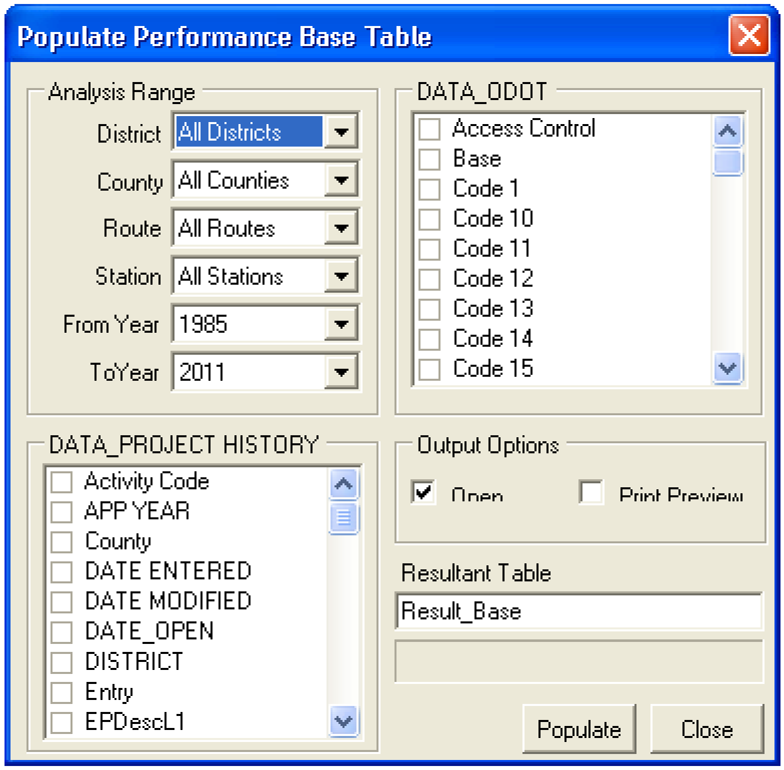


FIGURE B- 10. Populate Performance Base Table

6.6.2 Populate Performance Analysis Table

The "Populate Performance Analysis Table" tool determines the changes of selected DATA_ODOT values between consecutive projects on the same pavement section with respect to data in DATA_Project History_Apparent.

This tool replaces the key and entry numbers in the *DATA_PERF_ANALYSIS* table with the selected values. The Fields Corresponding to Entry-1, Entry and Entry2 List boxes are used to select fields from *DATA_Project History_Apparent* table and Fields Corresponding to Key List box is used to select fields from *DATA_ODOT* table. Like the Populate Performance Base Table tool, the resultant table can support a maximum of 256 columns of data.

Source Table: DATA_PERF_ANALYSIS, DATA_Project History, DATA_ODOT
Output Table: The default name is *Result_Analysis*. However the user can assign a different table name by changing the text in the "Output Table Name" textbox.

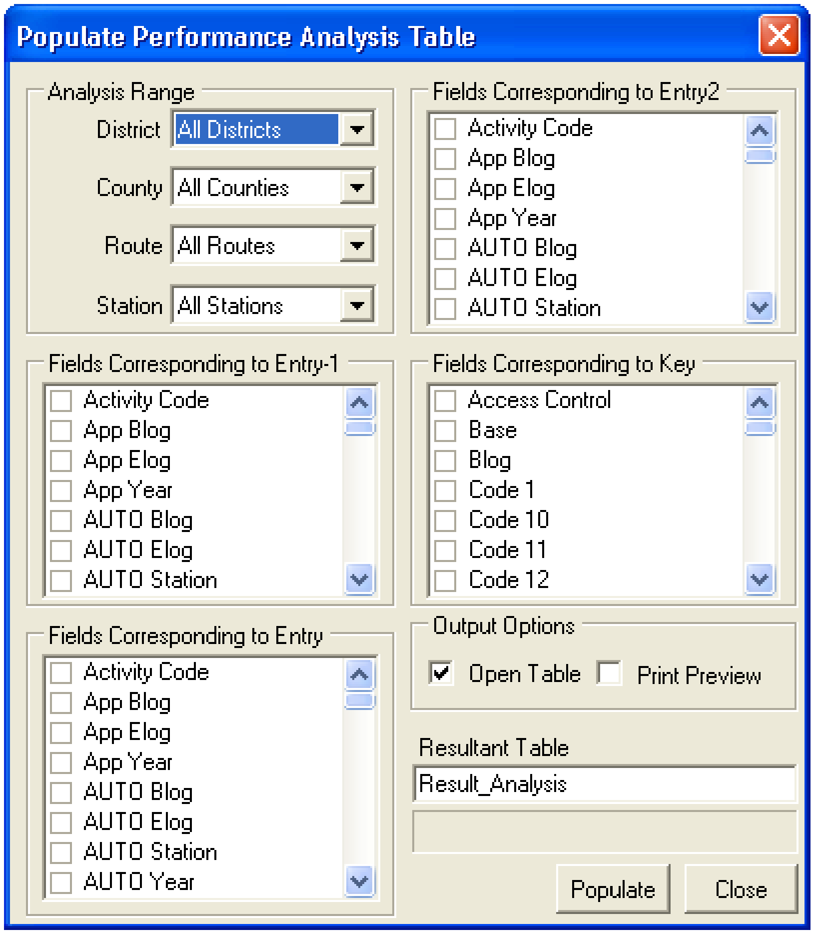


FIGURE B- 11. Populate Performance Analysis Table

6.6.3 Populate District Field

This tool is used to populate the district field in a table, provided the selected table contains a "County" field.

6.6.4 Generic Classification Tool

This tool, shown in FIGURE B- 12, is used to classify numerical fields in a table. If the original field name in the table is [fieldname], a new field called [fieldname classification] will be added to the table.

If the table selected is [DATA_PERF_ANALYSIS], this field will automatically show in the "Group By" list box provided on most of the analysis tools, such as "Average Deterioration Trend," "Time To Treatment (Actual)," "Time To Treatment Survival Analysis" and "Derived Performance Trend."

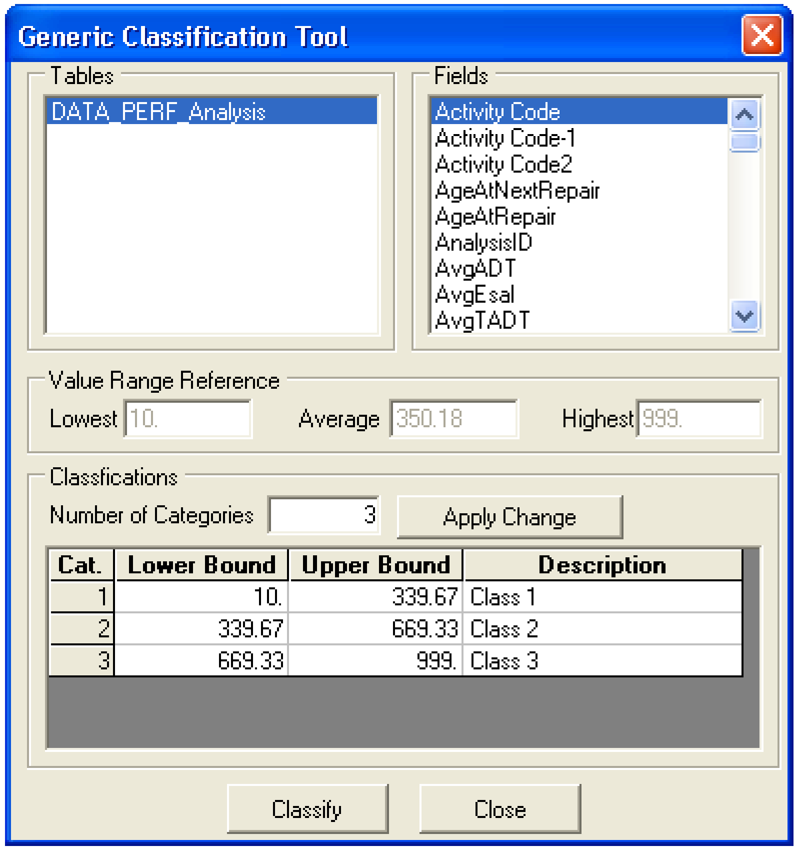


FIGURE B- 12. Generic Classification Tool

Value Range Reference Options

Lowest: Lowest value of the parameter
Average: Average value of the parameter
Highest: Highest value of the parameter

Classifications Options

Number of Categories **: Number of categories to classify the selected "Fields"**
Apply Change **(button): Enter number of categories in the "Number of Categories" text box and click this button to change the categories**
Lower Bound **: Lower bound/limit of a category (This value cannot be changed.)**
Upper Bound **: Upper bound/limit of a category (This value can be changed. The changed value becomes the lower bound of the next category.)**
Description **: The description of each category. This description for each category of fields is stored as a new field in the table.**

Example:

The following example classifies AvgESAL in [DATA_PERF_ANALYSIS] into two categories: High, If ESAL ≥ 1500 and Low if ESAL < 1500.

1. Open the "Generic Classification Tool"

2. In the “Tables” list select “DATA_PERF_ANALYSIS”
3. In the “Fields” list select “AvgEsal”
4. Change the number of categories to 2 and click the “Apply Change” button
5. Change the Upper bound of Category 1 to 1500 and change its description to “Low”
6. Change the description of Category 2 to “High”
7. Click the “Classify” button
8. Close the tool and open the “Average Performance Trend” under the “Report” menu. “AvgEsal Classification” will be displayed in the “GroupBy” list.

6.6.5 Linear Superposition

This function is embedded in several other functions, such as Generate Data Tables and Generic Classification Tool.

The “Linear Superposition Operation” is a merge of multiple tables to obtain a single dynamically segmented table. The output is stored in the “Output Table.” If the output table named in the input box already exists, the tool will ask the user to replace the existing table or exit from the tool. FIGURE B- 13 shows the user interface.

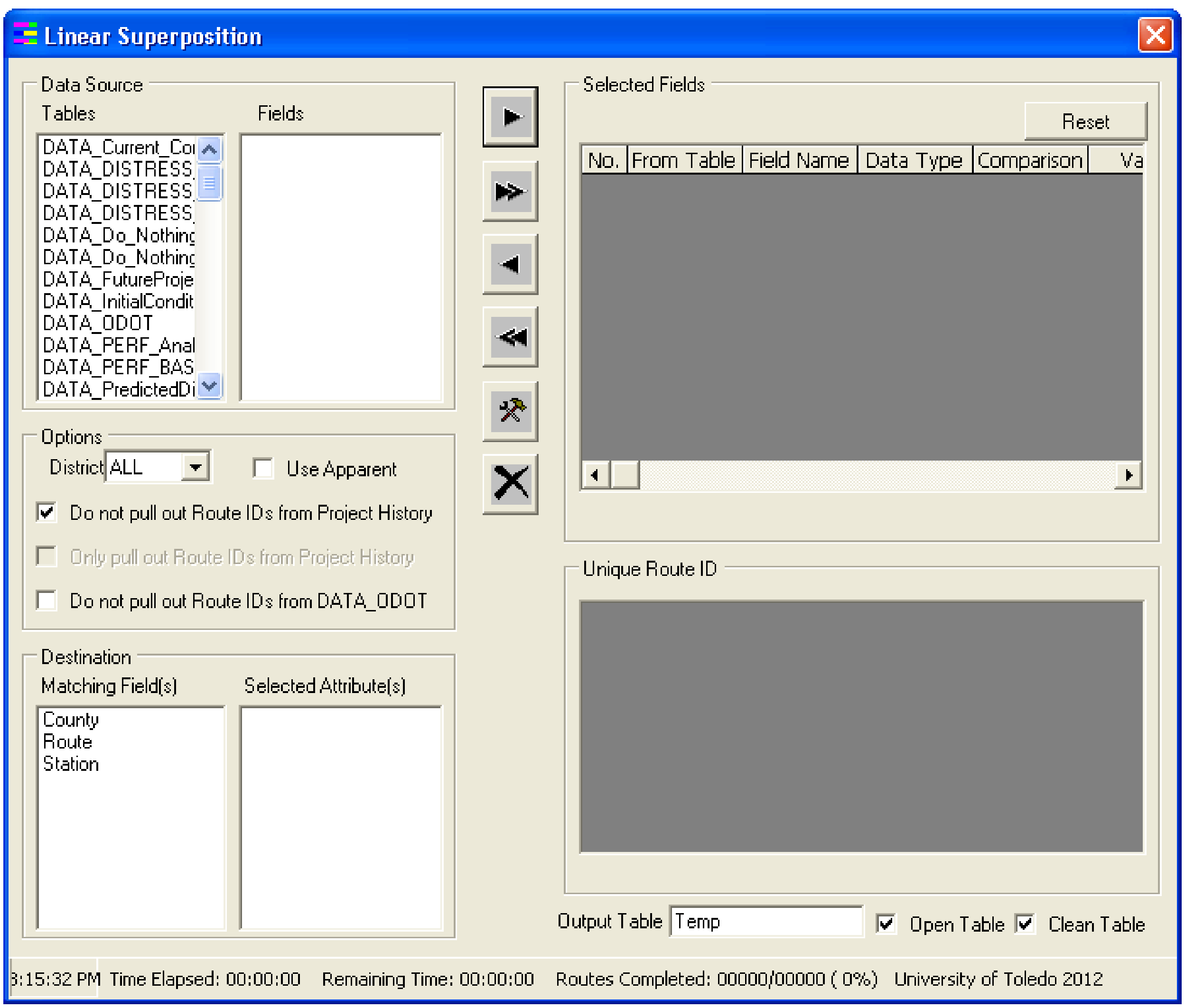


FIGURE B- 13. Linear Superposition User Interface

Commands

Tables: Lists all the tables in the database
Fields: Lists all the fields of the table selected under “Available Tables”
Selected Fields: Lists all the selected fields from “Fields”

The attributes listed in the “Fields” list box can be added to the query in three ways:

1. Select a field in the “Fields” list and drag it into the “Selected Fields” list (a hand icon  will appear when dragging and dropping)
2. Double click a field to be selected under “Fields”
3. Select a field under “Fields” and click 

The “Selected Field” window also provides the option of constraining the records selected for merging. The comparison field in the “Selected Field” window provides a drop down list of how the constraint is to be implemented (≥, ≤, >, <, or =). The “Value” column specifies the desired value of the constraint.

Matching Fields

The “Matching Field” sub-window lists the fields required for merging. The default selections are “County,” “Route,” and “Station,” as they typically specify a linear feature. In some situations, “Year” may also be included.

Adding Matching Fields

Two techniques exist for adding additional selections into the “Matching Field” box. To remove a matching field, double click a field in the “Matching Fields” sub-window.

1. Double click on field under “Selected Fields”
2. Select a field under “Selected Fields” and drag it to the “Matching Fields” box

The “Pull Out” option check boxes under “Options” limit the tables used to create internal program indices. Consequently, if DATA_Project History or DATA_ODOT is excluded in the analysis, its respective index should not be pulled out.

The “Unique Route ID” window displays all unique linear features specified in the merge. Each button is assigned a specific operation and described below.

 Add a selected field

 Add all fields from a table

 Remove a selected field

 Remove all the selected fields

 Run the linear superposition operation

 Stop the linear superposition operation

Reset the values in the "Comparison" and "Value" columns of "Selected Fields"

Example 1:

The following example shows how to obtain the PCR History for Route 032R in Adams County.

1. Select DATA_ODOT in the "Tables" list
2. Select PCR in the "Fields" list, and double click it to include it in the "Selected Fields" list
3. Under the "Fields" list, add "County" and "Route"
4. In the "County" row, double click the "Value" column and enter "ADA"
5. In the "Route" row, double click the "Value" column and enter "032R"
6. Click the  button

At this point, the "Linear Superposition" window should resemble FIGURE B- 14.

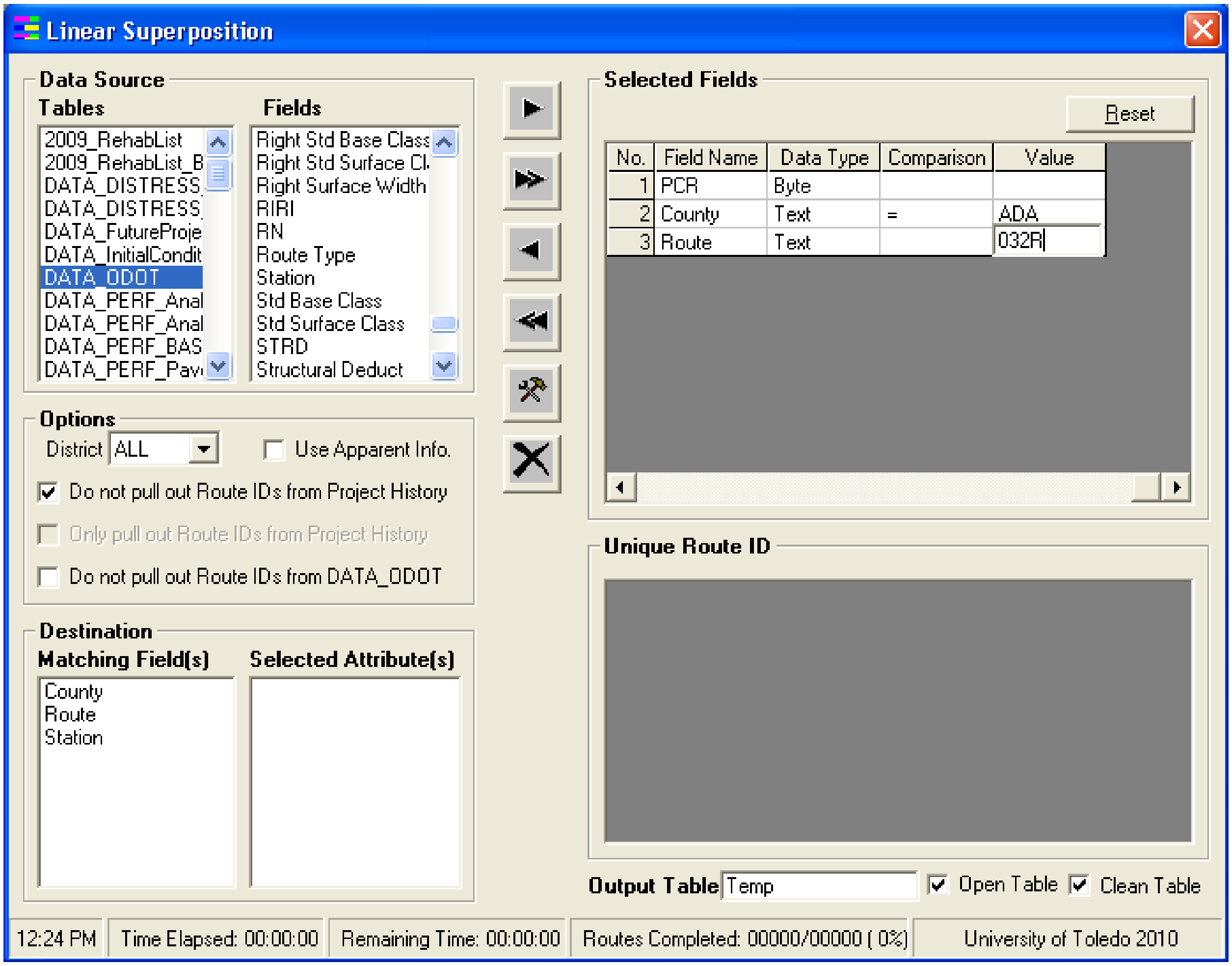


FIGURE B- 14. Get PCR Series for Route 032R in Adams County

The result should resemble FIGURE B- 15 . Note: Not all PCRs are displayed because of the size of the window. Scroll to reveal the hidden PCRs.

Table: Temp

County	Route	Station	Blog	Elog	PCR_1985	PCR_1986	PCR_1987	PCR_1988	PCR_1
ADA	032R	DOWN	0	0.35	89	91	88	86	
ADA	032R	DOWN	0.35	2.33	89	91	88	86	
ADA	032R	UP	0	2.33	89	91	88	86	
ADA	032R	DOWN	2.33	2.84	89	91	88	86	
ADA	032R	UP	2.33	2.84	89	91	88	86	
ADA	032R	DOWN	2.84	6.29	89	91	78	81	
ADA	032R	UP	2.84	6.29	89	91	78	84	
ADA	032R	DOWN	6.29	6.67	89	91	79	79	
ADA	032R	UP	6.29	6.67	89	91	79	83	
ADA	032R	DOWN	6.67	6.8	89	91	79	79	
ADA	032R	UP	6.67	6.8	89	91	79	83	
ADA	032R	DOWN	6.8	7.73		91	79	79	
ADA	032R	UP	6.8	7.73		91	79	83	
ADA	032R	DOWN	7.73	9.13	75	91	79	79	
ADA	032R	UP	7.73	9.27	72	91	79	83	
ADA	032R	UP	9.27	10.48	72	91	79	83	
ADA	032R	DOWN	9.13	11.04	75	91	79	79	
ADA	032R	UP	10.48	11.21	72	91	79	83	
ADA	032R	UP	11.21	11.41	72	91	79	83	

Record: 1 of 32

FIGURE B- 15. PCR Series for Route 032R in Adams County

Example 2:

To obtain the treatment history as well as the PCR history for Route 032R in Adams County, follow this procedure:

1. Select DATA_Project History in the "Tables" list
2. Double click "Activity Code" in the "Fields" list to include it in the "Selected Fields" list
3. Select DATA_ODOT in the "Tables" list
4. Double click "PCR" in the "Fields" list to include it in the "Selected Fields" list
5. Add "County" and "Route to the "Selected Fields" list
6. In the "County" row, double click the "Value" column and enter "ADA"
7. In the "Route" row, double click the "Value" column and enter "032R"
8. Click the  button
9. After above 8 operations, the interface looks like the following figure

At this point, the "Linear Superposition" window should resemble FIGURE B- 16.

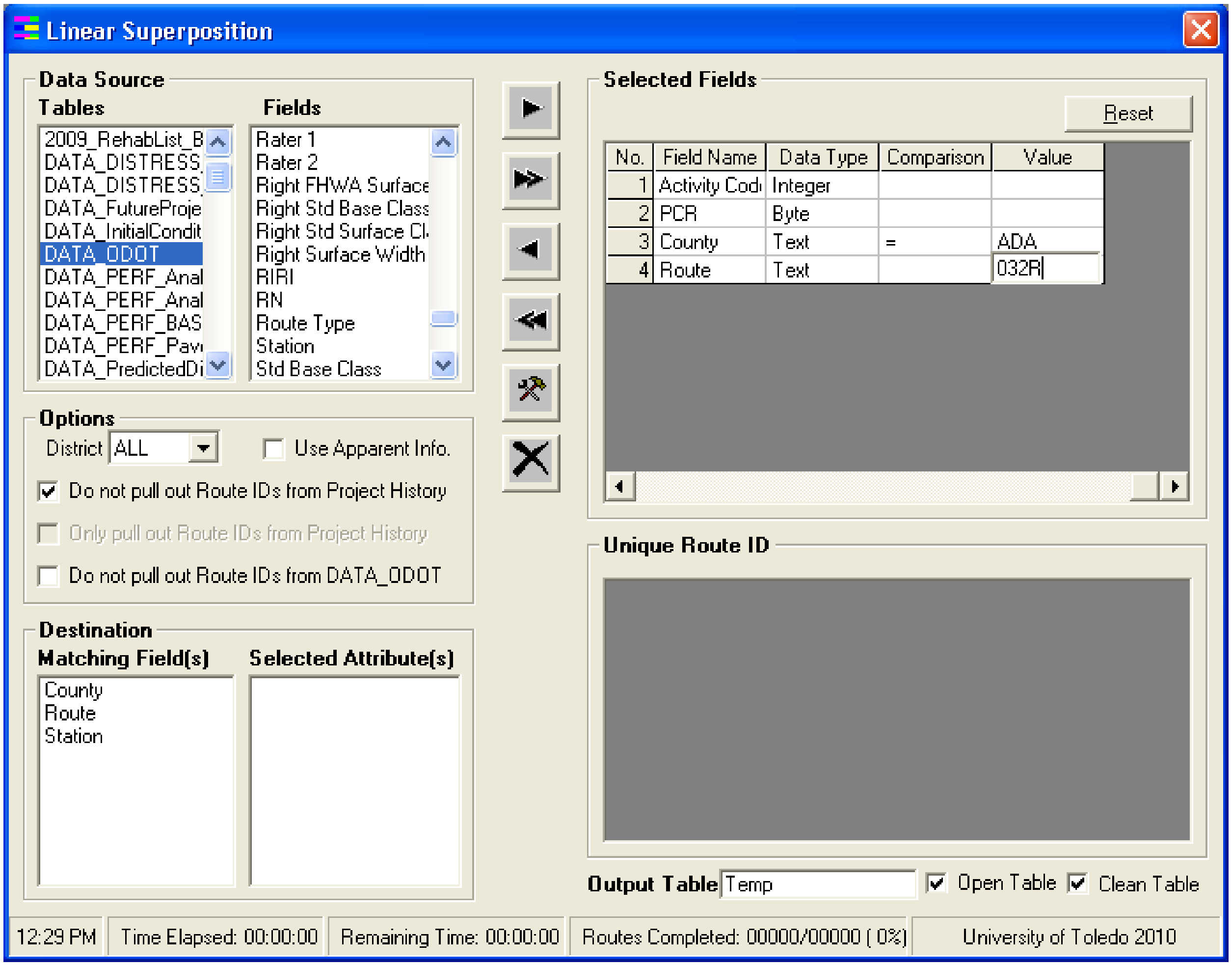


FIGURE B- 16. Get PCR and Treatment History for Route 032R in Adams County

The result should resemble FIGURE B- 17. Note: Not all PCRs are displayed because of the size of the window. Scroll to reveal the hidden PCRs.


Table: Temp

County	Route	Station	Blog	Elog	Activity	Activity	Activity	Activity	Act
ADA	032R	DOWN	0	0.35					
ADA	032R	DOWN	0.35	1.67					
ADA	032R	UP	0	1.67					
ADA	032R	DOWN	1.67	2.33					
ADA	032R	UP	1.67	2.33					
ADA	032R	DOWN	2.33	2.62					
ADA	032R	UP	2.33	2.62					
ADA	032R	DOWN	2.62	2.84					
ADA	032R	UP	2.62	2.84					
ADA	032R	DOWN	2.84	6.29				100	
ADA	032R	UP	2.84	6.29				100	
ADA	032R	DOWN	6.29	6.67			100	100	
ADA	032R	UP	6.29	6.67			100	100	
ADA	032R	DOWN	6.67	6.8			100	100	
ADA	032R	UP	6.67	6.8			100	100	
ADA	032R	DOWN	6.8	7.73			100	100	
ADA	032R	UP	6.8	7.73			100	100	
ADA	032R	DOWN	7.73	9.13			100	100	
ADA	032R	UP	7.73	9.27			100	100	

Record: 1 of 66

FIGURE B- 17. PCR and Treatment History for Route 032R in Adams County

6.6.6 Clean Pavement Data Table

This tool is used to remove redundancy in dynamically segmented tables. This tool is embedded in most functions which require merging similar pavement sections. For example, the two records in TABLE B- 6 represent consecutive sections in a road and are identical except for the “Blog” and “Elog” figures. Therefore, these two records can be merged.

TABLE B- 6. Original Data

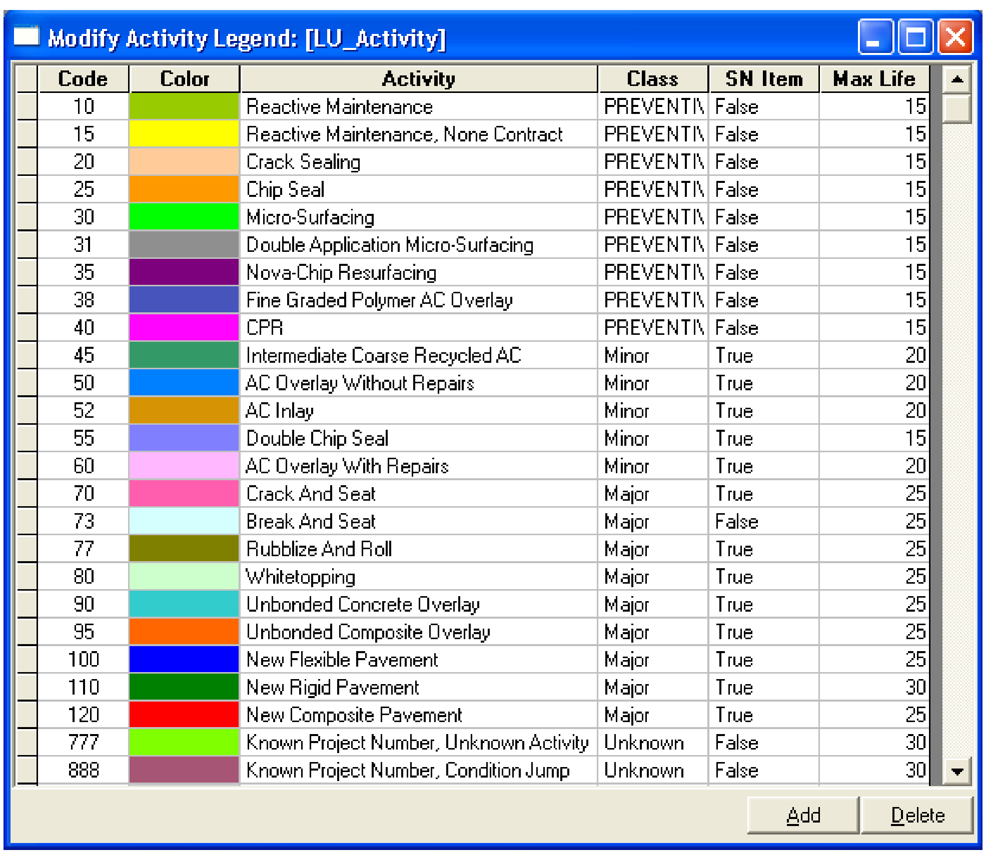
County	Route	Station	Blog	Elog	Year	PCR
ADA	032R	Down	2.33	2.84	2002	91
ADA	032R	Down	2.84	6.29	2002	91

TABLE B- 7. Data After Using Clean Pavement Data Table Function

County	Route	Station	Blog	Elog	Year	PCR
ADA	032R	Down	2.33	6.29	2002	91

6.6.7 Modify Activity Legend

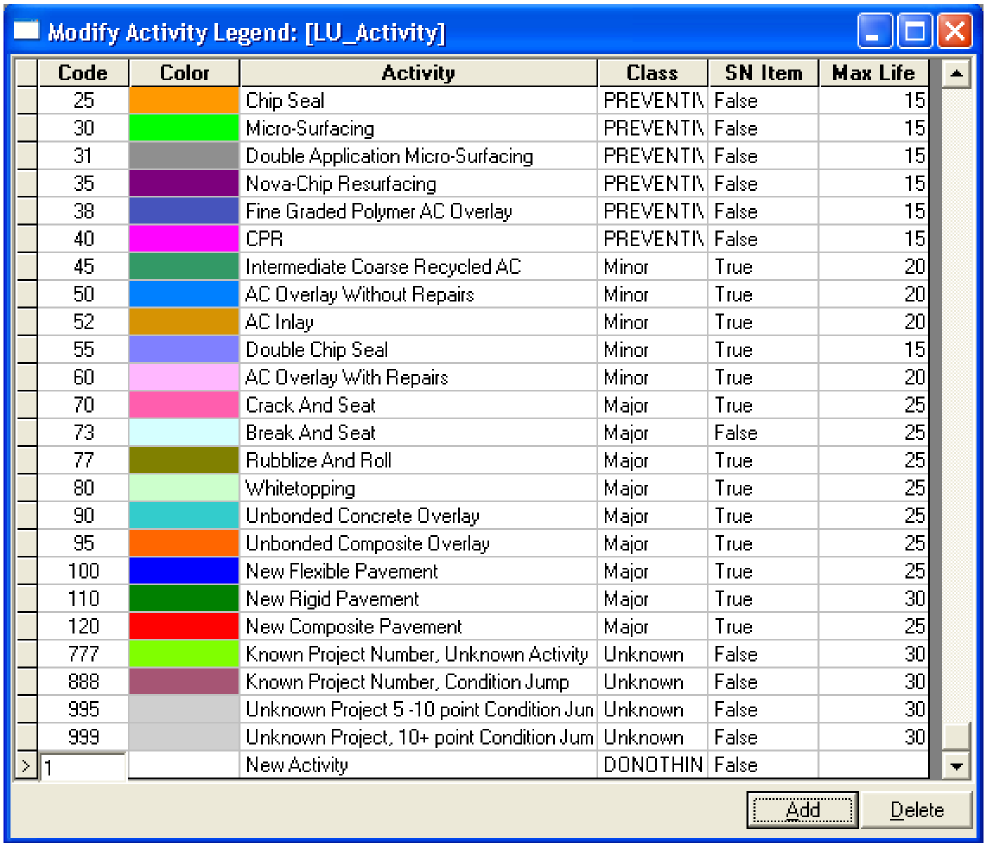
This tool is used to add new activity codes, modify activity legend colors for project history checking, and ensure data integrity between the activity code and the modified activity code.



Code	Color	Activity	Class	SN Item	Max Life
10		Reactive Maintenance	PREVENTIV	False	15
15		Reactive Maintenance, None Contract	PREVENTIV	False	15
20		Crack Sealing	PREVENTIV	False	15
25		Chip Seal	PREVENTIV	False	15
30		Micro-Surfacing	PREVENTIV	False	15
31		Double Application Micro-Surfacing	PREVENTIV	False	15
35		Nova-Chip Resurfacing	PREVENTIV	False	15
38		Fine Graded Polymer AC Overlay	PREVENTIV	False	15
40		CPR	PREVENTIV	False	15
45		Intermediate Coarse Recycled AC	Minor	True	20
50		AC Overlay Without Repairs	Minor	True	20
52		AC Inlay	Minor	True	20
55		Double Chip Seal	Minor	True	15
60		AC Overlay With Repairs	Minor	True	20
70		Crack And Seat	Major	True	25
73		Break And Seat	Major	False	25
77		Rubblize And Roll	Major	True	25
80		Whitetopping	Major	True	25
90		Unbonded Concrete Overlay	Major	True	25
95		Unbonded Composite Overlay	Major	True	25
100		New Flexible Pavement	Major	True	25
110		New Rigid Pavement	Major	True	30
120		New Composite Pavement	Major	True	25
777		Known Project Number, Unknown Activity	Unknown	False	30
888		Known Project Number, Condition Jump	Unknown	False	30

FIGURE B- 18. Modify Activity Legend

To add a new activity code, click “Add.” This will add a new row at the end of the window (FIGURE B- 19). Enter the required information including the “Code” (numerical), “Color,” “Activity,” “Class,” “SN Item,” and “Max Life.” Avoid entering duplicate data.



Code	Color	Activity	Class	SN Item	Max Life
25		Chip Seal	PREVENTIV	False	15
30		Micro-Surfacing	PREVENTIV	False	15
31		Double Application Micro-Surfacing	PREVENTIV	False	15
35		Nova-Chip Resurfacing	PREVENTIV	False	15
38		Fine Graded Polymer AC Overlay	PREVENTIV	False	15
40		CPR	PREVENTIV	False	15
45		Intermediate Coarse Recycled AC	Minor	True	20
50		AC Overlay Without Repairs	Minor	True	20
52		AC Inlay	Minor	True	20
55		Double Chip Seal	Minor	True	15
60		AC Overlay With Repairs	Minor	True	20
70		Crack And Seat	Major	True	25
73		Break And Seat	Major	False	25
77		Rubblize And Roll	Major	True	25
80		Whitetopping	Major	True	25
90		Unbonded Concrete Overlay	Major	True	25
95		Unbonded Composite Overlay	Major	True	25
100		New Flexible Pavement	Major	True	25
110		New Rigid Pavement	Major	True	30
120		New Composite Pavement	Major	True	25
777		Known Project Number, Unknown Activity	Unknown	False	30
888		Known Project Number, Condition Jump	Unknown	False	30
995		Unknown Project 5 -10 point Condition Jun	Unknown	False	30
999		Unknown Project, 10+ point Condition Jum	Unknown	False	30
1		New Activity	DONOTHIN	False	

FIGURE B- 19. Add New Activity

6.6.8 Edit Lookup table

This tool updates the lookup tables necessary for all analyses in ODOTPMIS.

Table to Apply: [LU_XXXXX]
Tool to use: [Data] → [Edit Lookup Table]

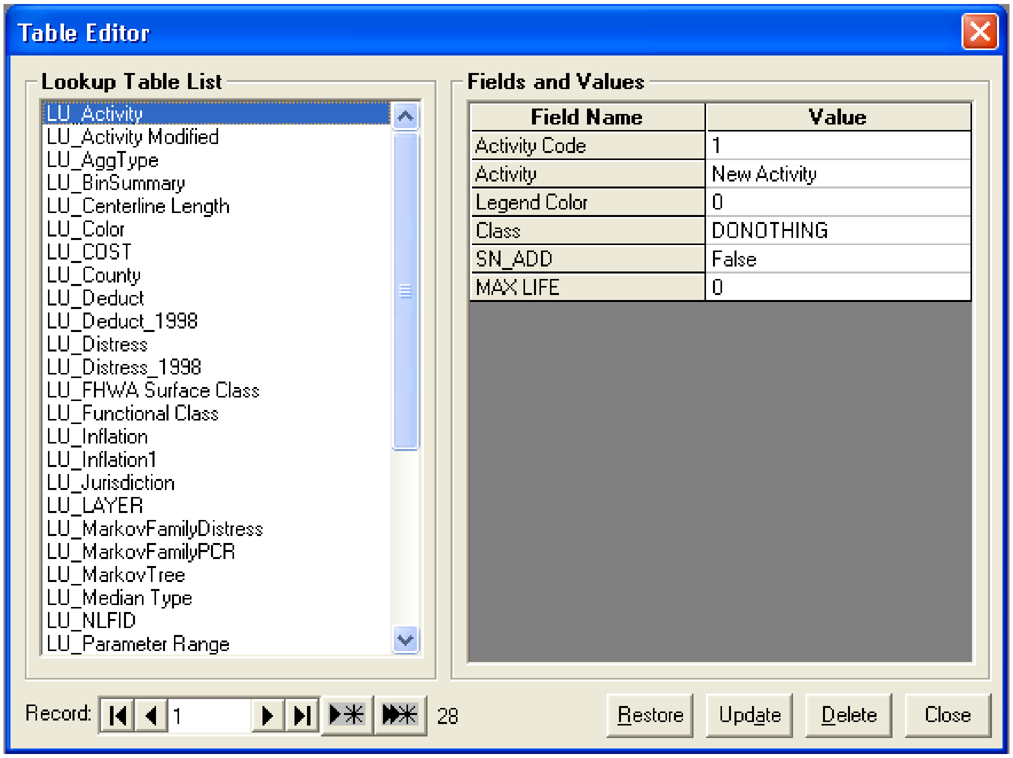
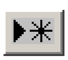
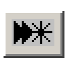


FIGURE B- 20. Edit Lookup Table

Users can add, modify, or delete a current record in a lookup table. However, the user cannot change the field name or add/delete a field from a lookup table.

	Record navigator
	Add a new blank record
	Copy the current record as a new record
	Restore the original record
	Update and make all changes permanent
	Delete current record. Deleted records cannot be restored.
	Close this tool

Example 1:

In the current ODOT database, only ten distresses are defined for Continuous Reinforced Concrete pavement. To change distress information for distress code 11 for pavement type 1 (Continuous Reinforced Concrete),

1. Select “Edit Lookup Table” under the “Data” menu
2. Select LU_Distress in the “Lookup Table” list
3. Go to “Pavement Type 1” and “Code 11” by using the  button in the record navigator. The interface of the tool should resemble FIGURE B- 21.
4. Click the “Field Name” to be changed

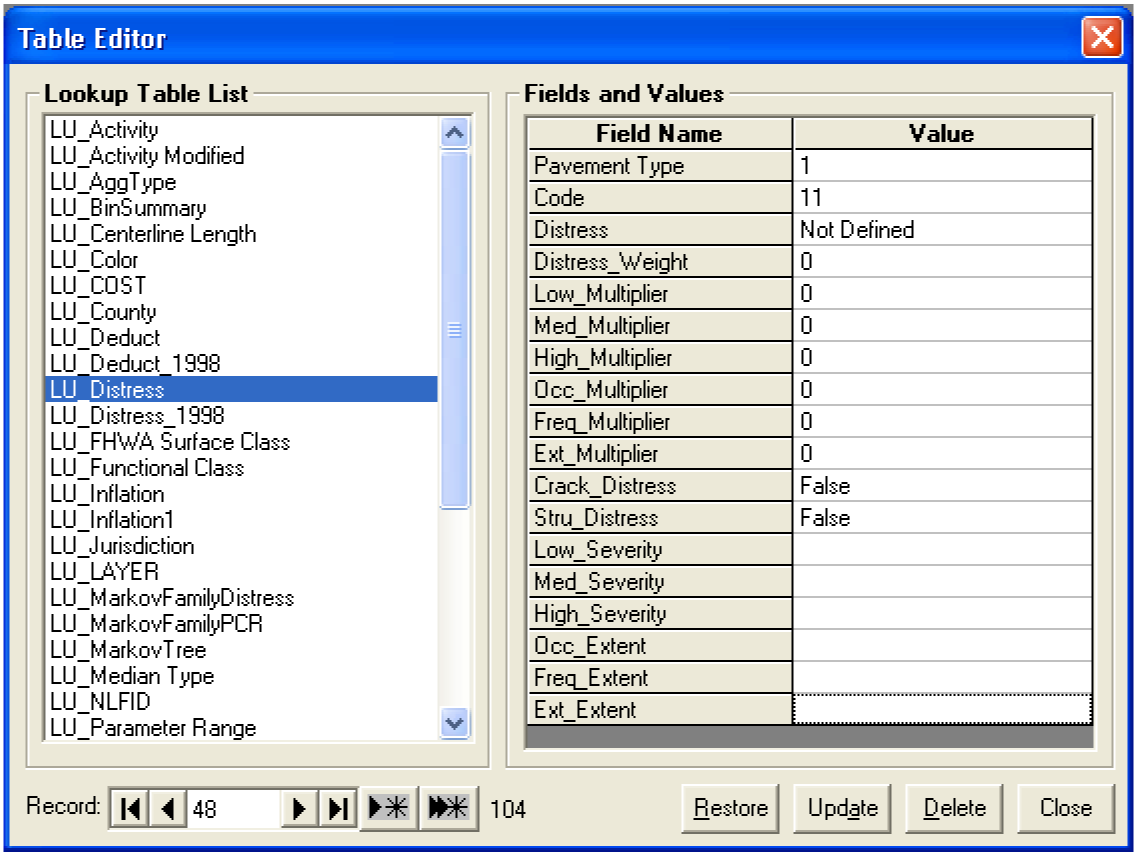
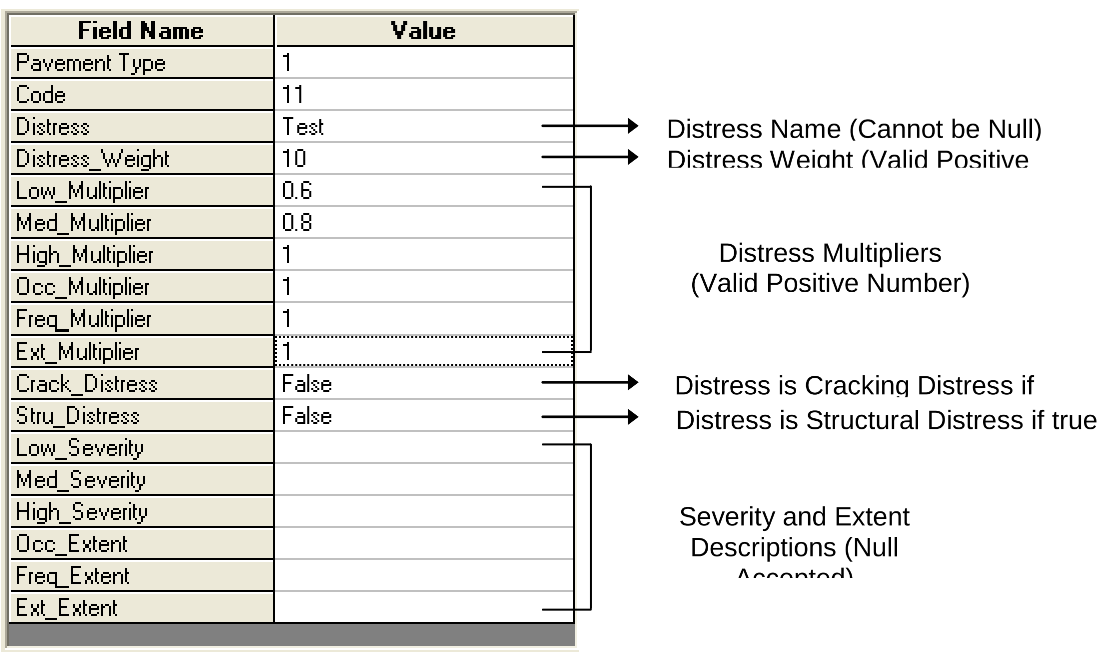


FIGURE B- 21. LU_Distress Table

FIGURE B- 22 demonstrates the valid format of the data to be entered.



Field Name	Value
Pavement Type	1
Code	11
Distress	Test
Distress_Weight	10
Low_Multiplier	0.6
Med_Multiplier	0.8
High_Multiplier	1
Occ_Multiplier	1
Freq_Multiplier	1
Ext_Multiplier	1
Crack_Distress	False
Stru_Distress	False
Low_Severity	
Med_Severity	
High_Severity	
Occ_Extent	
Freq_Extent	
Ext_Extent	

FIGURE B- 22. Modifying LU_Distress

5. After entering the changes, click "Update"

6. The changes will be made in two tables: LU_Distress and LU_Deduct. ODOTPMIS uses LU_Deduct table to calculate “PCR,” “Structural Deduct,” “Cracking Deduct,” and individual deducts.
7. To restore old values, click “Restore.” This only works if the user clicks the “Restore” button before closing the tool, and only restores one record at a time.

SECTION 7. REPORT MENU

This menu contains tools to generate reports of the database.

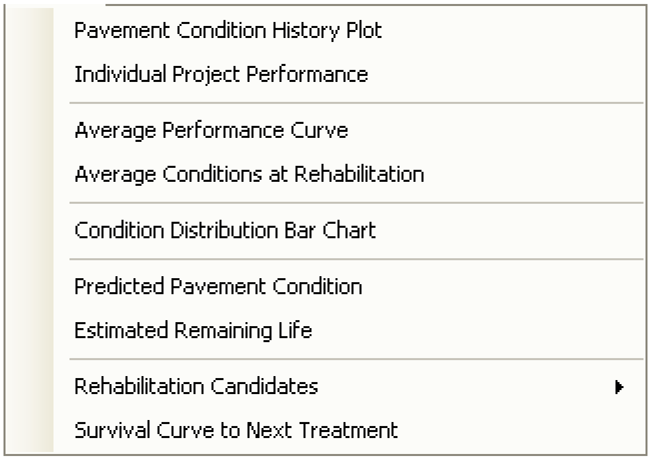


FIGURE B- 23. ODOTPMIS Report Menu

7.1 <u>Pavement Condition History Plot</u>

This tool, shown in FIGURE B- 24, is used for viewing the changes in pavement condition over time for a particular route within a county. The tool also uses colored backgrounds to indicate the repair history of the selected route.

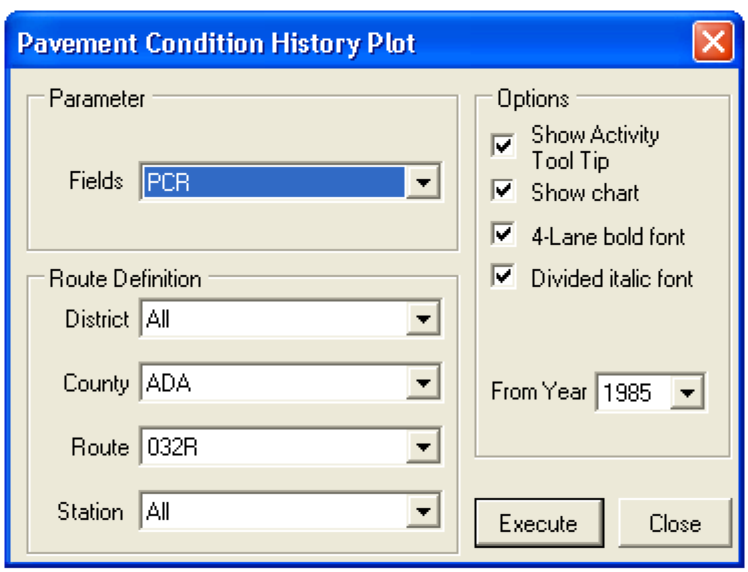


FIGURE B- 24. Pavement Condition History Plot

The plot shown in FIGURE B- 25 was generated by selecting “ADA” under “County,” “032R” under “Route.” FIGURE B- 26 demonstrates the PCR data and repair history for each section of the selected route.

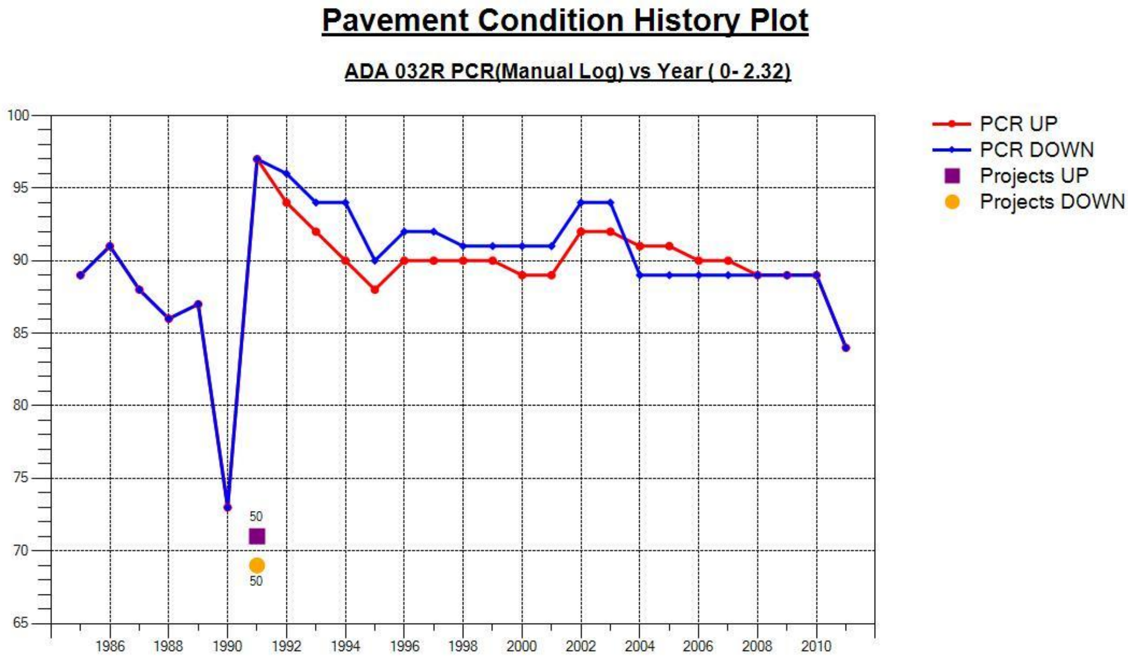


FIGURE B- 25. Pavement Condition History Plot

Pavement Condition History Plot - ADA 032R PCR(Manual Log)

Yr\Log	0	2.32	2.33	2.83	6.07	6.28	6.65	6.67	6.78	7.72	9.11	9.25	10.48	11.02	11.19	11.4	11.81	12.55	12.65	12.84	14.7	14
U1985	89	89	89	89						72	72	72	72	72	72	72	72	72	72	72	93	
D1985	89	89	89	89	89	89	89	89		75	75	75	75	75	75	75	75	75	75	75	97	97
U1986	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	92	
D1986	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	92	92
U1987	88	88	88	78	78	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	91	
D1987	88	88	88	78	78	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	91	91
U1988	86	86	86	84	84	83	83	83	83	83	83	83	83	83	83	83	83	83	83	83	94	
D1988	86	86	86	81	81	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	94	94
U1989	87	87	87	84	84	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	89	
D1989	87	87	87	84	84	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80		
U1990	73	73	73	77	77	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	83	
D1990	73	73	73	78	78	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	83	83
U1991	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	
D1991	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97	97
U1992	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	
D1992	96	96	96	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94
U1993	92	92	92	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	92	
D1993	94	94	94	92	92	91	91	91	91	91	91	91	91	91	91	91	91	91	91	91	94	94
U1994	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	
D1994	94	94	94	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
U1995	88	88	88	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	88	
D1995	90	90	90	87	87	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89
U1996	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	
D1996	92	92	92	89	89	86	86	86	86	86	86	86	86	86	86	86	86	86	86	86	88	88
U1997	90	90	90	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	89	90	
D1997	92	92	92	88	88	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	88	88

FIGURE B- 26. Pavement Condition History Plot Data

7.2 Individual Project Performance

In the “Report” menu, click “Project Performance.” This tool generates the individual project performance reports.

Source Table: DATA_Project History_Apparent, DATA_ODOT
Output Table: The default name for the output table is "Individual Project Performance." Users can update this table name by changing the text in the "Output Table" text box.

FIGURE B- 27 shows the window used for generating this report. The "Analysis Range" frame selects the project number and parameters to be used to generate the report.

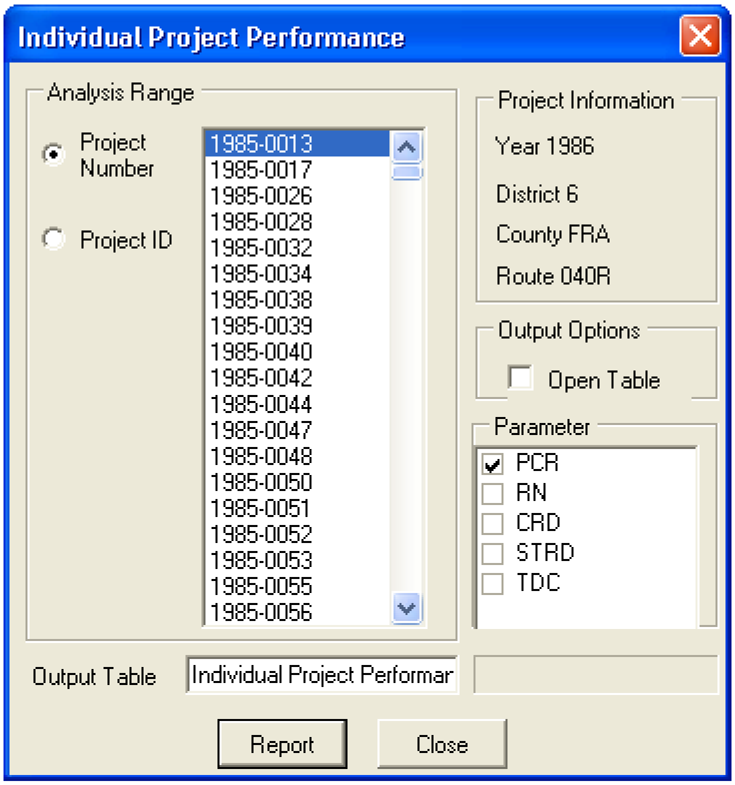


FIGURE B- 27. Individual Project Performance

Example:

FIGURE B- 28 shows the Project Performance Report for Project Number 1990-0788 for PCR. This report is generated by selecting "Project Number 1990-0788" in the "Project Number" list box, and "PCR" in the "Parameter" list box.

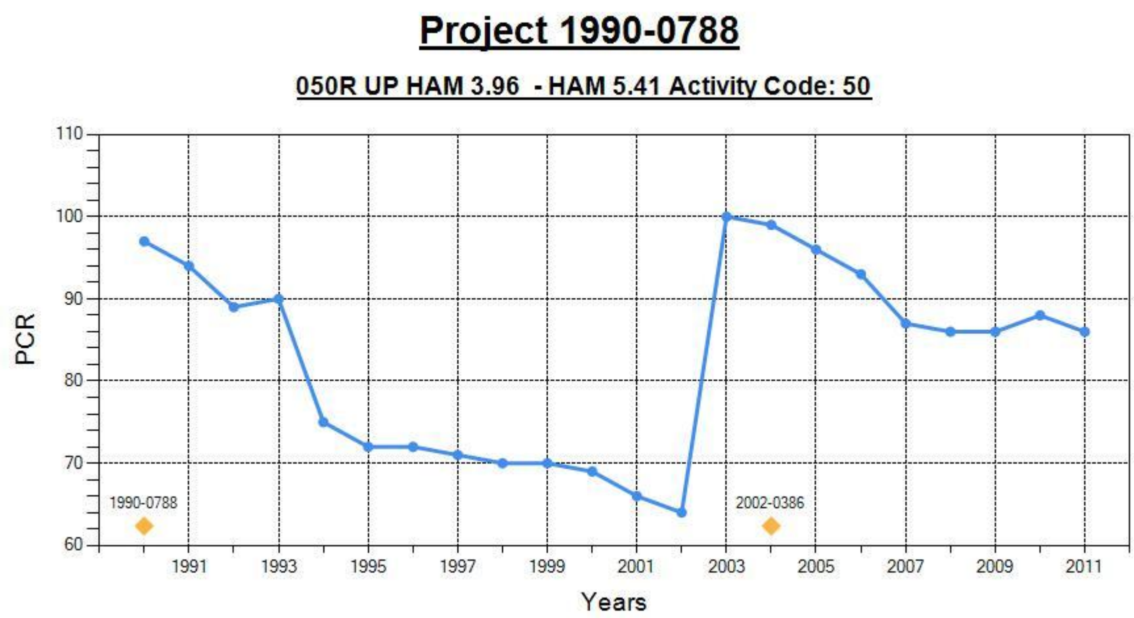


FIGURE B- 28. Example of Individual Project Performance Output – Chart

Project 1990-0788

County	HAM	HAM	HAM	HAM	HAM	HAM	TUS	TUS	TUS	TUS	TUS	TUS
Route Station	050R DOWN	050R DOWN	050R DOWN	050R UP	050R UP	050R UP	021R UP	093R UP	250R UP	250R UP	250R UP	250R UP
Activity Code	50	50	50	50	50	50	50	50	50	50	50	50
Blog-Elog	3.76 - 3.9	3.9 - 3.96	3.96 - 5.41	3.76 - 3.9	3.9 - 3.96	3.96 - 5.41	0 - 1.47	1.08 - 2.14	0 - 2.22	2.22 - 3.68	3.68 - 4.99	4.99 - 5.21
1990	97	97	97	97	97	97		69				
1991			94			94						
1992			89			89	89	57	94	93	93	93
1993			90			90						
1994			70			75	80	85	78	79	79	79
1995			72			72	79		77	77	77	77
1996	72	72	72	72	72	72	79	67	70	69	69	69
1997	66	66	66	71	71	71	77	65	69	69	69	69
1998	65	65	65	70	70	70	99	64	99	99	99	99
1999	64	64	64	70	70	70	96	61	92	97	93	92
2000	62	62	62	69	69	69	95	61	89	91	89	94
2001	58	58	58	66	66	66	93	97	79	88	88	92
2002	56	56	56	64	64	64	86	94	78	88	85	83
2003	100	100	100	100	100	100	84	92	76	85	80	80
2004	99	99	99	99	99	99	82	92	74	74	70	80
2005	94	94	94	96	96	96	75	86	74	70	69	75
2006	91	91	91	93	93	93	73	82	70	66	62	75
2007	82	82	82	87	87	87	73	74	70	66	63	74
2008	82	82	82	86	86	86	72	72	64	64	63	76
2009	81	81	81	86	86	86	70	67	98	98	98	98
2010	86	86	86	88	88	88	67	66	98	98	98	98
2011	83	83	83	86	86	86	98	62	97	97	91	96

FIGURE B- 29. Example of Individual Project Performance Output – Data

7.3 Average Performance Curve

This tool generates an average performance report for parameters from DATA_ODOT.

Source Table: DATA_PERF_ANALYSIS, DATA_ODOT
Intermediate Table Generated: DATA_PERF_CURVE

Output Table: The default name for the output table is “Average Deterioration Trend Analysis.” Users can update this table name by changing the text in the “Output Table name” text box.

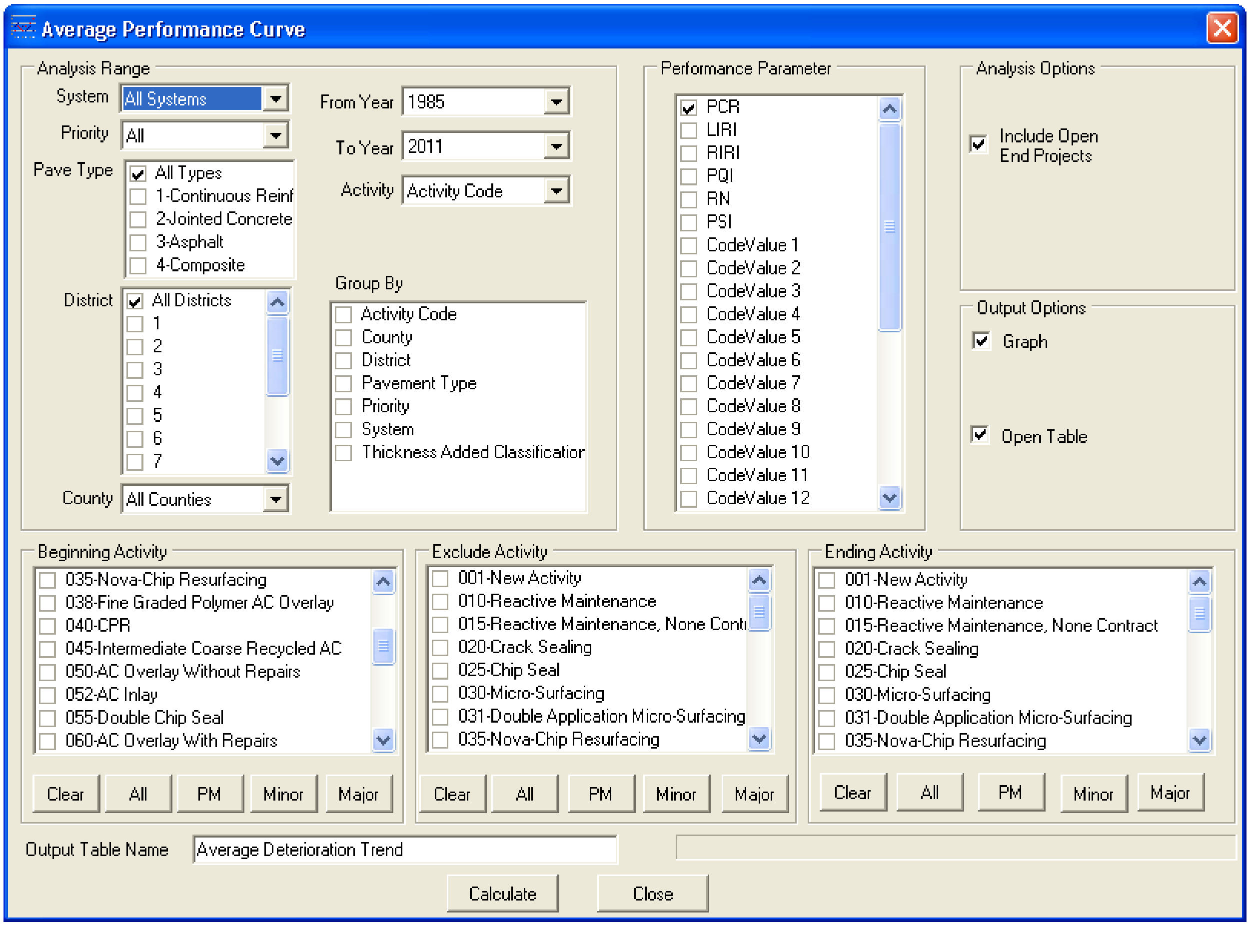


FIGURE B- 30. Average Deterioration Trend User Interface

Analysis Options

Include Open End Projects: Enabling this option will include open-ended projects (projects/pavements which still exist)

Example:

The following example shows the average deterioration trend report for PCR for all systems, priorities, pavement types and counties in district 1 for Activity codes 50 and 60 and from 1985 to 2011. Select following options on the tool:

1. “All Systems” under “System”
2. “All” under “Priority”
3. “1” under “District”
4. “All Counties” under “County”
5. “All Types” under “Pave Type”
6. “All Directions” under “System”
7. “1985” under “From Year,” and “2011” under “To Year”
8. “Activity Code” under “Activity” list

9. “PCR” under “Parameters”
10. “50” and “60” under “Beginning Activity” list, and “Add All” under “Ending Activity” list

Enter an output table name in the “Output Table Name” text box and click “Execute.”

FIGURE B- 31 shows the average deterioration trends for PCR and RN.

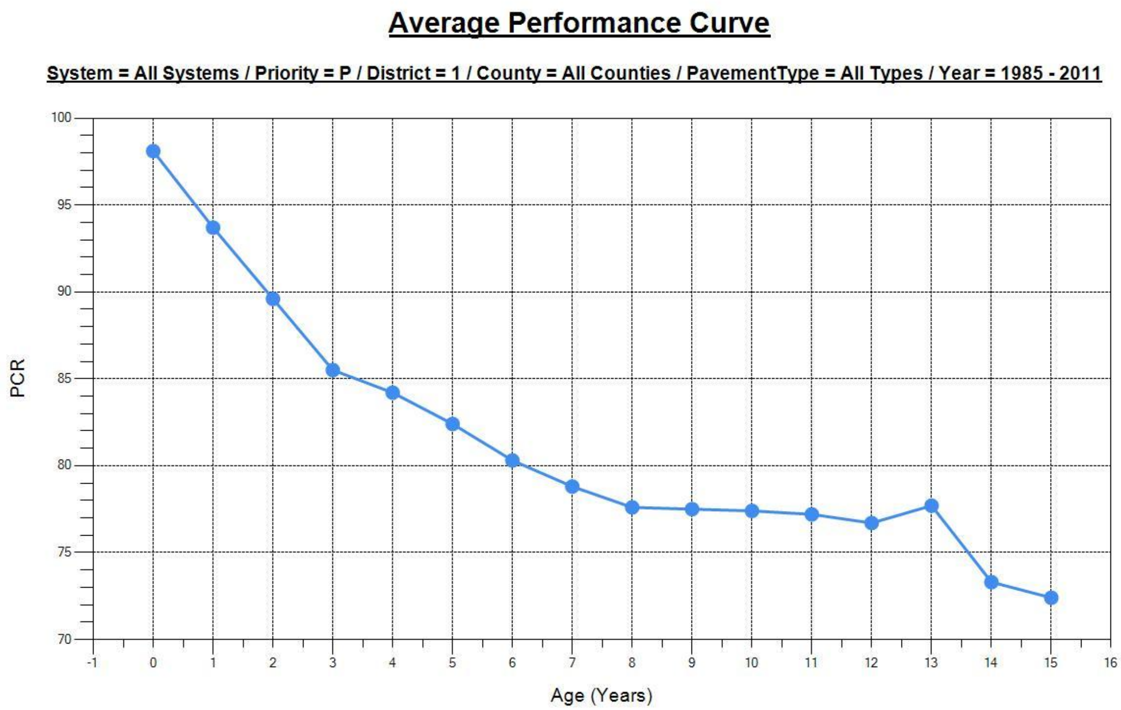


FIGURE B- 31. Performance Trend Curve

This tool also generates a mileage chart as shown in FIGURE B- 32.

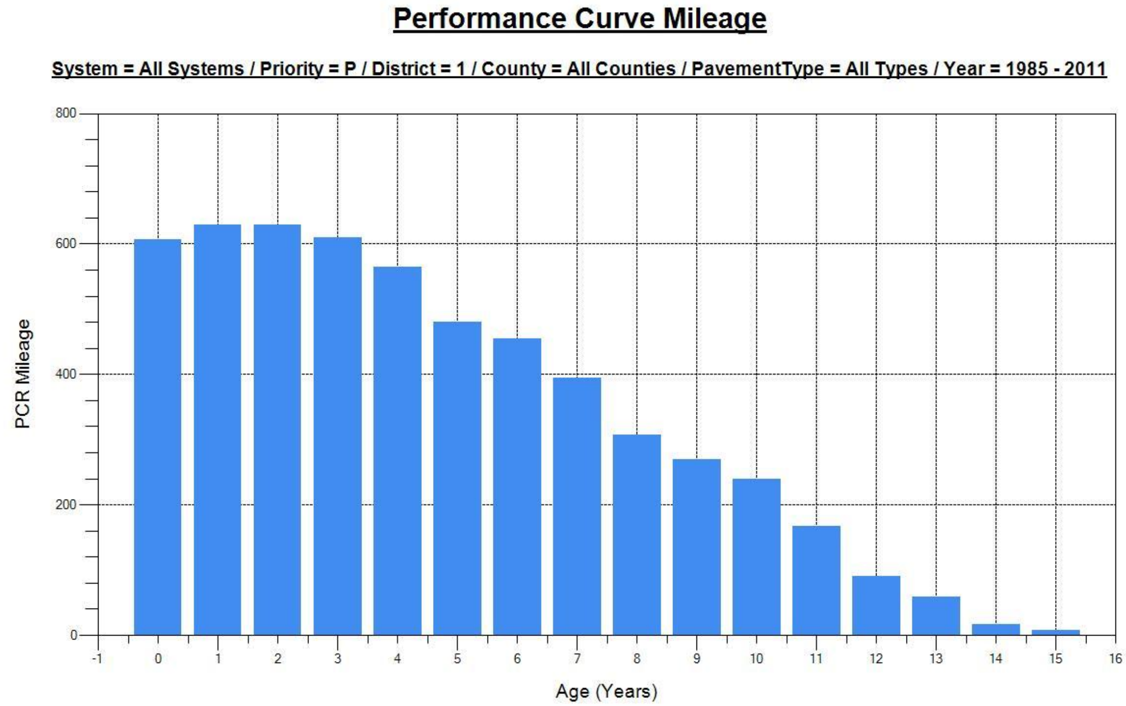


FIGURE B- 32. Performance Curve Mileage

7.4 Average Conditions at Rehabilitation

This tool generates an average condition at rehabilitation report. This report can show the average condition, in terms of PCR score or individual distress, when the selected rehabilitation activities are conducted.

Source Table: DATA_PERF_ANALYSIS, DATA_ODOT
Output Table: Average Conditions at Rehabilitation

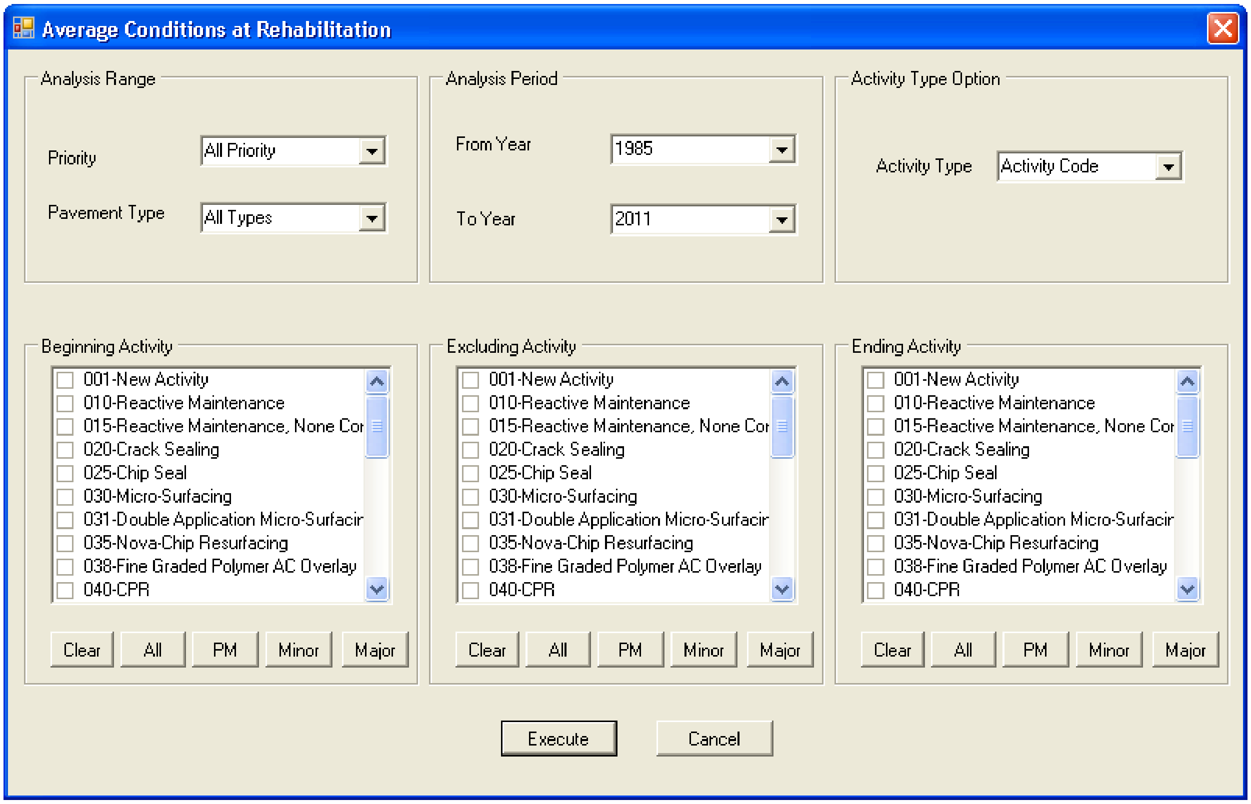


FIGURE B- 33. Average Conditions at Rehabilitation

Example:

The following example shows the average conditions at rehabilitation report for all priorities, composite pavements for Activity codes 50 and from 1985 to 2011. Select following options on the tool:

1. "All Priority" under "Priority"
2. "4-Composite" under "Pavement Type"
3. "1985" under "From Year," and "2011" under "To Year"
4. "Activity Code" under "Activity"
5. "50" under **"**Beginning Activity" list, "PM" under Excluding Activity, and "Minor" and "Major" under "Ending Activity" list

FIGURE B- 34 shows the average conditions at rehabilitation report generated by this tool.

Average Conditions at Rehabilitation

	Average Conditions at Rehabilitation											
	All Priority System Composite Pavements Activity 50 from 1985 to 2011											
District	1	2	3	4	5	6	7	8	9	10	11	12
PCRPrior	70.4	71.2	66.6	66.8	69.2	67.5	68.7	65	73.8	66.5	68.8	64.6
CRDPrior	14.29	14.2	15.66	14.26	13.85	14.34	14.24	14.05	11.56	17.54	11.03	14.48
STRDPrior	14.3	14.51	16.16	15.47	15.26	15.56	14.49	15.9	11.86	17.73	14.86	16.54
Raveling	3	2.81	3.32	3.83	3.56	2.8	2.92	2.88	2.97	3.46	2.58	3.13
Bleeding	0.36	0.44	0.2	0.43	0.51	0.59	0.4	1.14	0.11	0.13	1.36	1.01
Patching	1.64	1.89	1.84	1.87	0.97	1.72	2.19	2.96	0.58	0.51	1.31	2.41
Surface Disintegration/Debonding	0.01	0	0.27	0.29	0.52	0.41	0.02	0.75	0.07	0.03	1.13	0.63
Rutting	4.78	3.83	5.9	5.97	5.42	5.48	5.58	4.51	5.67	6.42	6.29	5.63
Pumping	0.03	0.44	0.33	0.29	0.9	0.55	0.36	0.52	0.13	0.04	0.12	0.13
Shattered Slab (Jointed Base)	0	0.1	0.37	0.62	0.56	1.09	0.29	2.45	0.22	0.01	1.16	1.49
Settlements	0	0.4	0.38	0.33	0.51	0.64	0.29	1.19	0.13	0.12	1.45	0.73
Transverse Cracks (Unjointed Base)	0	0	2.29	2.39	2.94	0.29	0.04	0	1.49	8.26	2.87	0.03
Joint Reflection Cracks (Jointed Base)	9.52	8.74	7.46	7.21	6.79	8.85	8.74	8.97	6.42	4.91	4.81	8.69
Intermediate Transverse Cracks (Joined E	2.69	2.96	2.79	1.95	1.39	2.35	3.05	2.86	1.88	1.44	1.24	2.98
Longitudinal Cracking	2.06	2.26	2.89	2.8	2.33	2.42	2.13	2.65	1.7	2.97	2.93	3.59
Pressure Damage/Upheaval	0.85	0.88	0.52	0.57	0.9	0.89	0.85	1.15	0.37	0.41	0.41	0.62
Crack Sealing Deficiency	4.73	4.17	4.62	4.23	3.56	4.1	4.36	3.04	4.36	4.87	3.54	4.12
Thickness Added	2.64	2.3	2.18	2.32	2.43	2.22	2.14	3.14	2.5	1.98	2.28	3.14
Thickness Removed	2.36	1.9	1.54	1.42	1.75	1.46	1.79	1.75	1.65	1.32	1.98	2.76
Age at Repair	7.4	12	9	7.5	6.2	9.5	6.7	10.1	8.7	7	10.2	9.8
Age at Next Repair	9.6	11.3	11.2	12.1	9.4	8.7	8.5	11.5	12.9	11.9	10.3	10.7

FIGURE B- 34. Average Conditions at Rehabilitation

7.5 Condition Distribution Bar Chart

This report gives the condition (in terms of PCR) distribution in miles by pavement type, district, year, etc

Source Table: DATA_ODOT, LU_Parameter Range (parameter categories defined by ODOT)
Output Table: The default name for the output table is “Condition Distribution Bar Chat”. Users can update this table name by changing the text in the “Output Table name” text box.

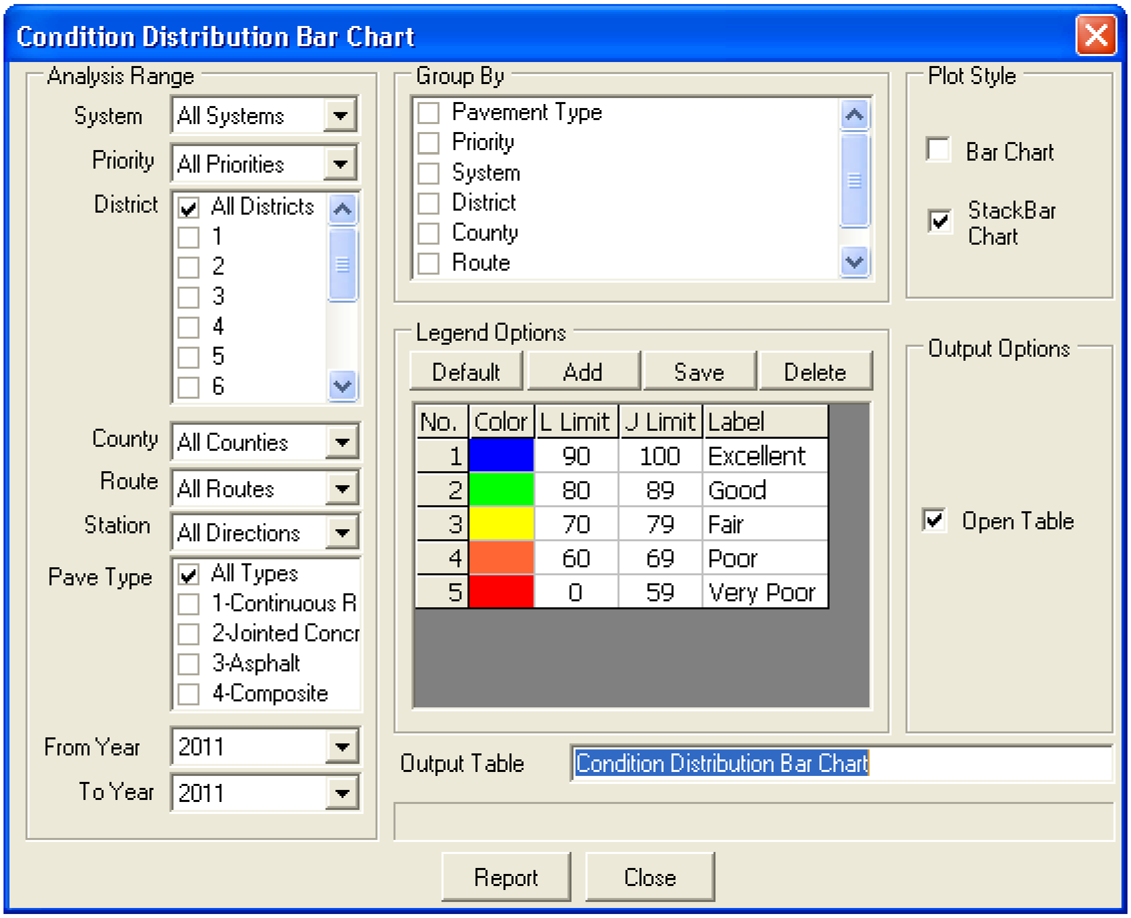


FIGURE B- 35. Condition Distribution Bar Chart

Example:

FIGURE B- 36 shows the Condition Distribution Report in miles in District 1 for each year from 2003 to 2011.

This report is generated by selecting "All Systems" under "System," "All" under "Priority," "1" under "District," "All Counties" under "County," "All Types" under "Pave Type," "2003" under "From Year," "2011" under "To Year," "Year" under "Group By," and "Stackbar Chart" under "Plot Style."

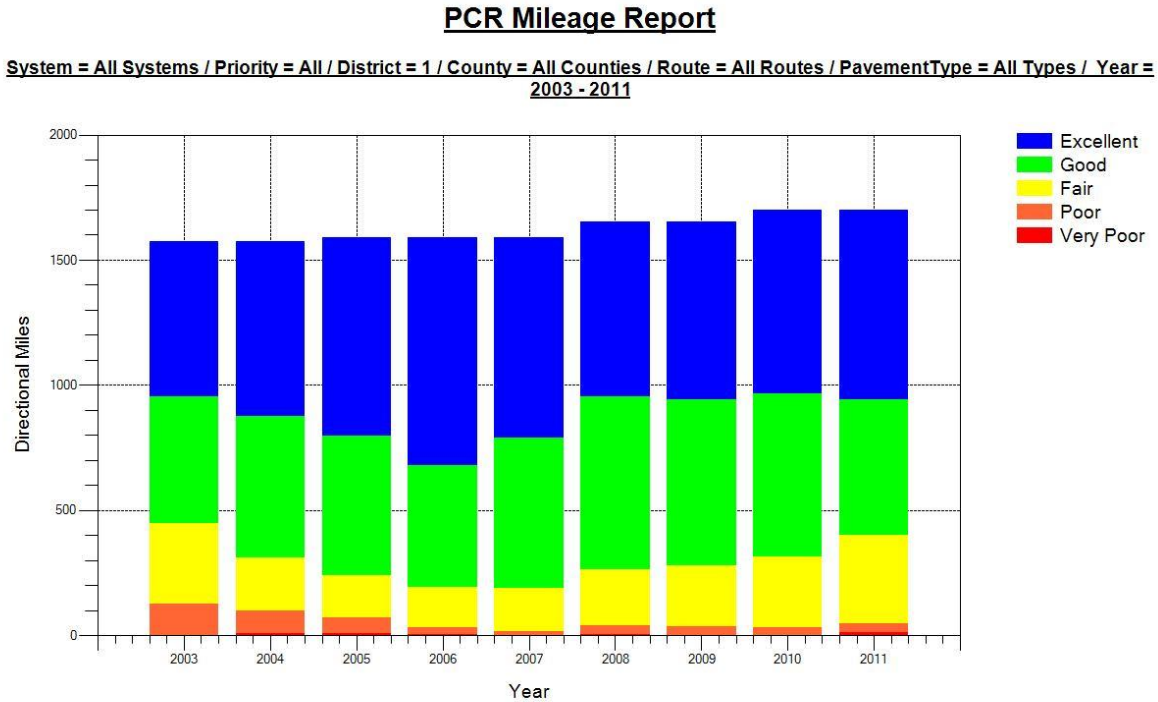


FIGURE B- 36. Condition Distribution Bar Chart Report

7.6 <u>Predicted Pavement Condition</u>

This tool can be used to view the Markov predicted pavement conditions. FIGURE B- 37 shows the user interface to view the predicted conditions.

Source Table: DATA_Transition Matrix,
DATA_PredictedPCR_JRC, DATA_PredictedDistress_JRC,
DATA_PredictedPCR_CRC, DATA_PredictedDistress_CRC,
DATA_PredictedPCR_Flex, DATA_PredictedDistress_Flex,
DATA_PredictedPCR_Comp, DATA_PredictedDistress_Comp, and
DATA_FutureProjects

Output Table: The default name for the output table is "Predicted Pavement Condition." Users can update this table name by changing the text in the "Output Table name" text box.

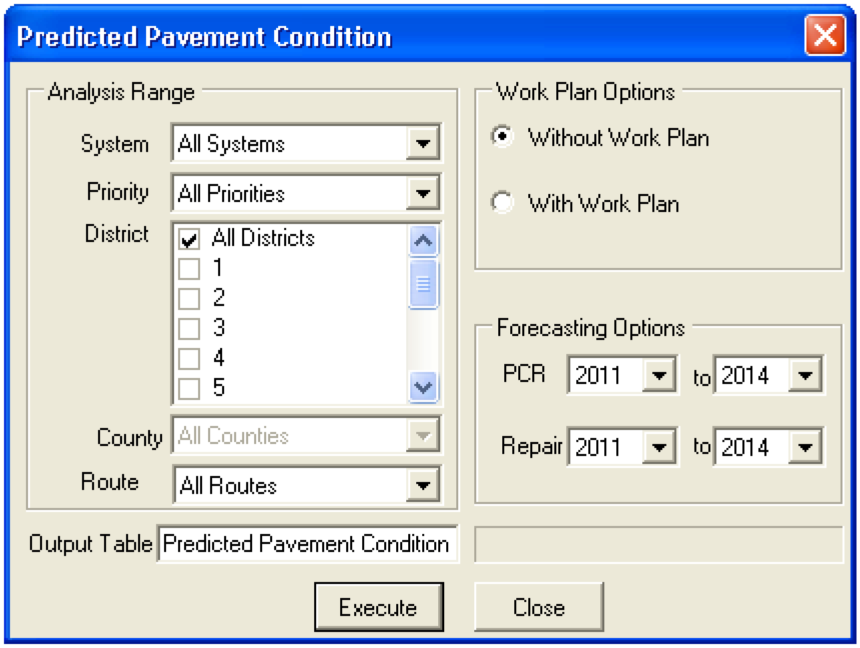


FIGURE B- 37. View Predicted Pavement Condition

Work Plan Options

Without Work Plan: Analysis based on original PCR and distress predictions
With Work Plan: Analysis based on result from overlay of PCR and distress predictions with DATA_FutureProjects file

Example 1:

To view pavement conditions with the plan for District 3, select the following options:

1. "3" under "District"
2. "Without Work Plan" under "Work Plan Options"
3. "2011" under "Start Year"
4. "2015" under "Forecast Upto"

Enter an output table name in the "Output Table Name" text box and click "Execute."

This procedure generates two grids: (1) "view pavement condition with planned treatments," which displays the predicted PCR overlaid with planned treatments and (2) "view pavement condition with planned treatments – recommended treatments," which displays the recommended treatments from the current year until 2010.

View pavement condition without planned treatment for District 3

PaveID	District	County	Route	Station	Blog	Elog	Pave Type	Priority	Route	PCR 2011	2012	2013	2014	2015
1	3	ASD	003R	UP	0	2.74	3	G	003R	91	86	82	78	73
2	3	ASD	003R	UP	2.74	3.03	4	G	003R	91	90	88	86	84
3	3	ASD	003R	UP	3.03	3.85	3	G	003R	86	82	78	73	68
4	3	ASD	003R	UP	3.85	3.94	4	G	003R	91	89	87	85	83
5	3	ASD	003R	UP	3.94	4.4	3	G	003R	87	84	80	76	71
6	3	ASD	003R	UP	4.4	5.1	3	G	003R	87	84	80	76	71
7	3	ASD	003R	UP	5.1	5.18	3	G	003R	89	86	82	79	74
8	3	ASD	003R	UP	5.18	5.53	3	G	003R	89	86	82	79	74
9	3	ASD	003R	UP	5.53	5.63	3	G	003R	89	86	82	79	74
10	3	ASD	003R	UP	5.63	5.94	4	G	003R	89	87	85	83	81
11	3	ASD	003R	UP	5.94	6.1	4	G	003R	77	74	71	67	64
12	3	ASD	003R	UP	6.1	6.27	4	G	003R	89	89	87	85	83
13	3	ASD	003R	UP	6.27	6.81	4	G	003R	92	91	88	86	83
14	3	ASD	003R	UP	6.81	8.22	4	G	003R	72	66	62	60	58
15	3	ASD	030R	DOWN	0	0.16	2	P	030R	94	93	92	91	90
16	3	ASD	030R	DOWN	0.16	3.85	2	P	030R	94	93	92	91	90
17	3	ASD	030R	DOWN	3.85	3.9	4	P	030R	98	95	91	88	85
18	3	ASD	030R	DOWN	3.9	5.9	4	P	030R	98	95	91	88	85

FIGURE B- 38. View Pavement Condition without Planned Treatments

The second grid with recommended treatments is shown in FIGURE B- 39.

View Recommended Treatments for District 3 _ without planned treatments

PaveID	District	County	Route	Station	Blog	Elog	Pave Type	Priority	Route	Recommended Treatment 2011	2012	2013	2014	2015
1	3	ASD	003R	UP	0	2.74	3	G	003R	Bin120	Bin120	Bin120	Bin124	Bin124
2	3	ASD	003R	UP	2.74	3.03	4	G	003R	Bin110	Bin110	Bin110	Bin110	Bin110
3	3	ASD	003R	UP	3.03	3.85	3	G	003R	Bin120	Bin120	Bin124	Bin124	Bin124
4	3	ASD	003R	UP	3.85	3.94	4	G	003R	Bin110	Bin110	Bin110	Bin110	Bin110
5	3	ASD	003R	UP	3.94	4.4	3	G	003R	Bin120	Bin120	Bin120	Bin126	Bin127
6	3	ASD	003R	UP	4.4	5.1	3	G	003R	Bin120	Bin120	Bin120	Bin126	Bin127
7	3	ASD	003R	UP	5.1	5.18	3	G	003R	Bin120	Bin120	Bin120	Bin127	Bin127
8	3	ASD	003R	UP	5.18	5.53	3	G	003R	Bin120	Bin120	Bin120	Bin127	Bin127
9	3	ASD	003R	UP	5.53	5.63	3	G	003R	Bin120	Bin120	Bin120	Bin127	Bin127
10	3	ASD	003R	UP	5.63	5.94	4	G	003R	Bin110	Bin110	Bin110	Bin110	Bin110
11	3	ASD	003R	UP	5.94	6.1	4	G	003R	Bin117	Bin117	Bin117	Bin117	Bin119
12	3	ASD	003R	UP	6.1	6.27	4	G	003R	Bin110	Bin110	Bin110	Bin110	Bin110
13	3	ASD	003R	UP	6.27	6.81	4	G	003R	Bin110	Bin110	Bin110	Bin110	Bin110
14	3	ASD	003R	UP	6.81	8.22	4	G	003R	Bin114	Bin114	Bin112	Bin112	Bin112
15	3	ASD	030R	DOWN	0	0.16	2	P	030R	Bin P11	Bin P11	Bin P11	Bin P11	Bin P11
16	3	ASD	030R	DOWN	0.16	3.85	2	P	030R	Bin P11	Bin P11	Bin P11	Bin P11	Bin P11
17	3	ASD	030R	DOWN	3.85	3.9	4	P	030R	Bin P2	Bin P2	Bin P2	Bin P2	Bin P2
18	3	ASD	030R	DOWN	3.9	5.9	4	P	030R	Bin P2	Bin P2	Bin P2	Bin P2	Bin P2

FIGURE B- 39. View Pavement Condition without Planned Treatments – Recommended Treatments

7.7 Estimated Remaining Life

This tool can be used to estimate the remaining life of pavement sections based on certain PCR and/or distress thresholds. FIGURE B- 40 shows the user interface to view the predicted conditions.

Source Table: DATA_PredictedPCR_JRC, DATA_PredictedDistress_JRC, DATA_PredictedPCR_CRC, DATA_PredictedDistress_CRC, DATA_PredictedPCR_Flex, DATA_PredictedDistress_Flex, DATA_PredictedPCR_Comp, DATA_PredictedDistress_Comp.

Output Table: The default name for the output table is "Remaining Life." Users can update this table name by changing the text in the "Output Table name" text box.

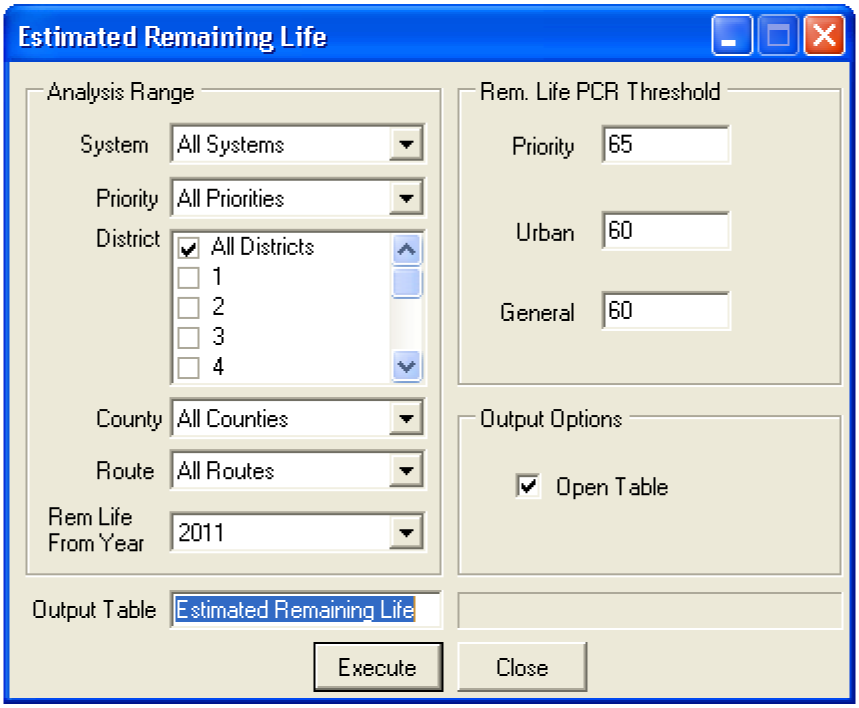


FIGURE B- 40. Estimated Remaining Life

Rem. Life PCR Threshold

Enter PCR thresholds in the text boxes. The remaining life is calculated by the time until the current PCR reaches the specified PCR threshold.

Example 1:

To view the remaining life for "General System Pavements" from 2011 based on a PCR threshold of 55, select the following options:

1. "G" under "Priority"
2. "2011" under "Rem Life From Year"
3. "55" in the "General" text box under "Rem. Life PCR Threshold"

Enter an output table name in the "Output Table Name" text box and click "Execute."

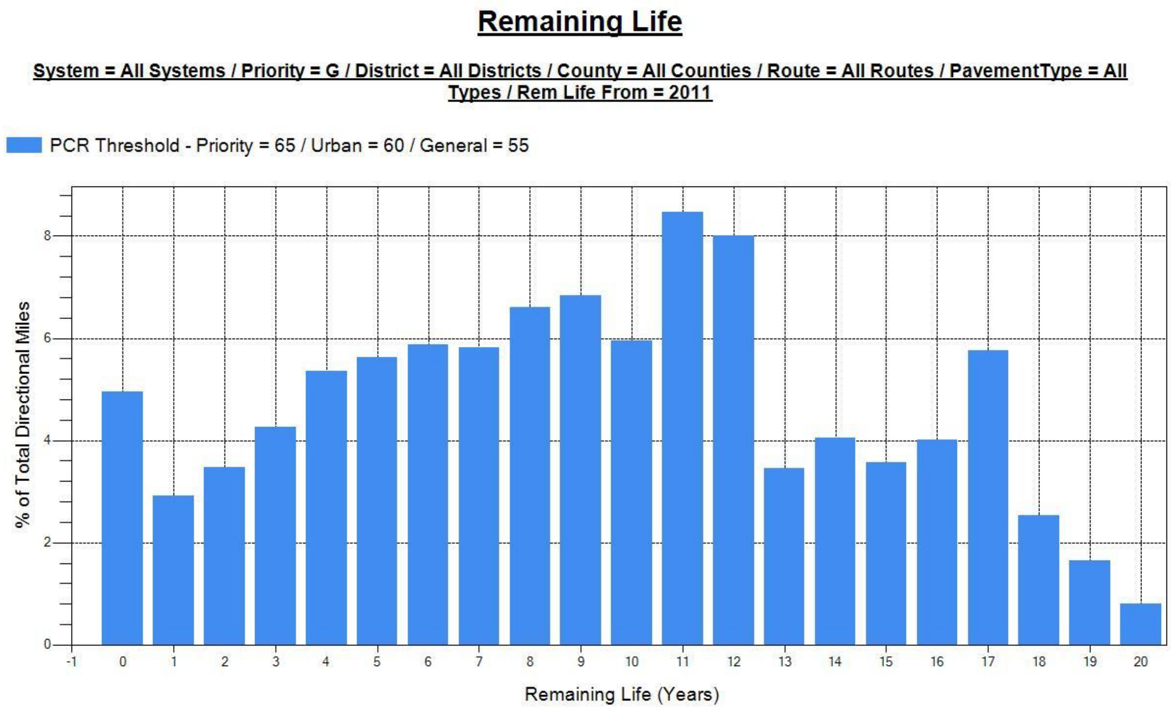


FIGURE B- 41. Remaining Life on General Systems

7.8 Rehabilitation Candidates

This menu is used to generate a rehabilitation candidate list based on the treatment decision trees provided by ODOT. The tools available under this menu are "Generate Statewide Rehab List," "Generate U/G Rehab List," "Generate Priority Rehab List," "Priority System Major Rehab List," and "Modify Repair Logic." For all the tools under this menu, the following tables are used in the background:

Source Tables: DATA_ODOT, DATA_Project History_Apparent, DATA_PERF_BASE, LU_Repair Logic, LU_Repair Limits

7.8.1 Generate Statewide Rehab List

This tool generates the recommended treatments for all the pavement sections in the database for the latest available PCR. The user interface is shown in FIGURE B- 42. The output is stored in the table name given in the "Output Table" text box. In addition to this output table, this tool also generates a bin summary table that contains the directional miles that fall under each bin category. If the output table name is [table name], the bin summary table created will be named [table name_Bin Summary].

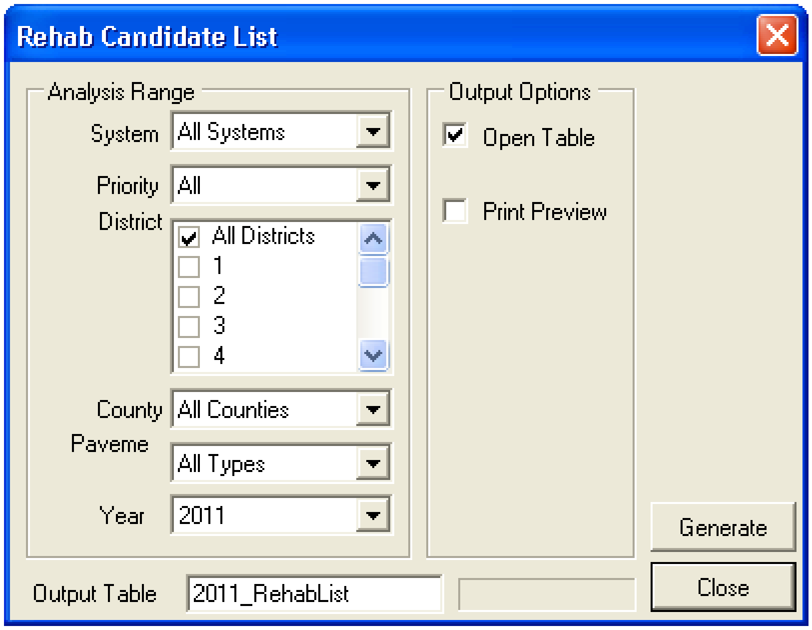


FIGURE B- 42. Rehab Candidates

7.8.2 General U/G Rehab List

This tool generates the recommended treatments (bin's) list only for pavement sections on urban and general systems. The user interface is similar to above in FIGURE B- 42, however, in the "Priority" combo box, the default value is "U/G."

7.8.3 General Priority Rehab List

This tool generates the recommended treatments (bin's) list only for pavement sections on urban and general systems. The user interface is similar to FIGURE B- 42, however the "Priority" combo box is defaulted to "P."

7.8.4 Priority System Major Rehab List

This tool generates the candidate sections eligible for major rehab on priority systems based on the decision tree provided by ODOT. The user interface is shown in FIGURE B- 43. The decision tree and repair logic are also shown in the user interface.

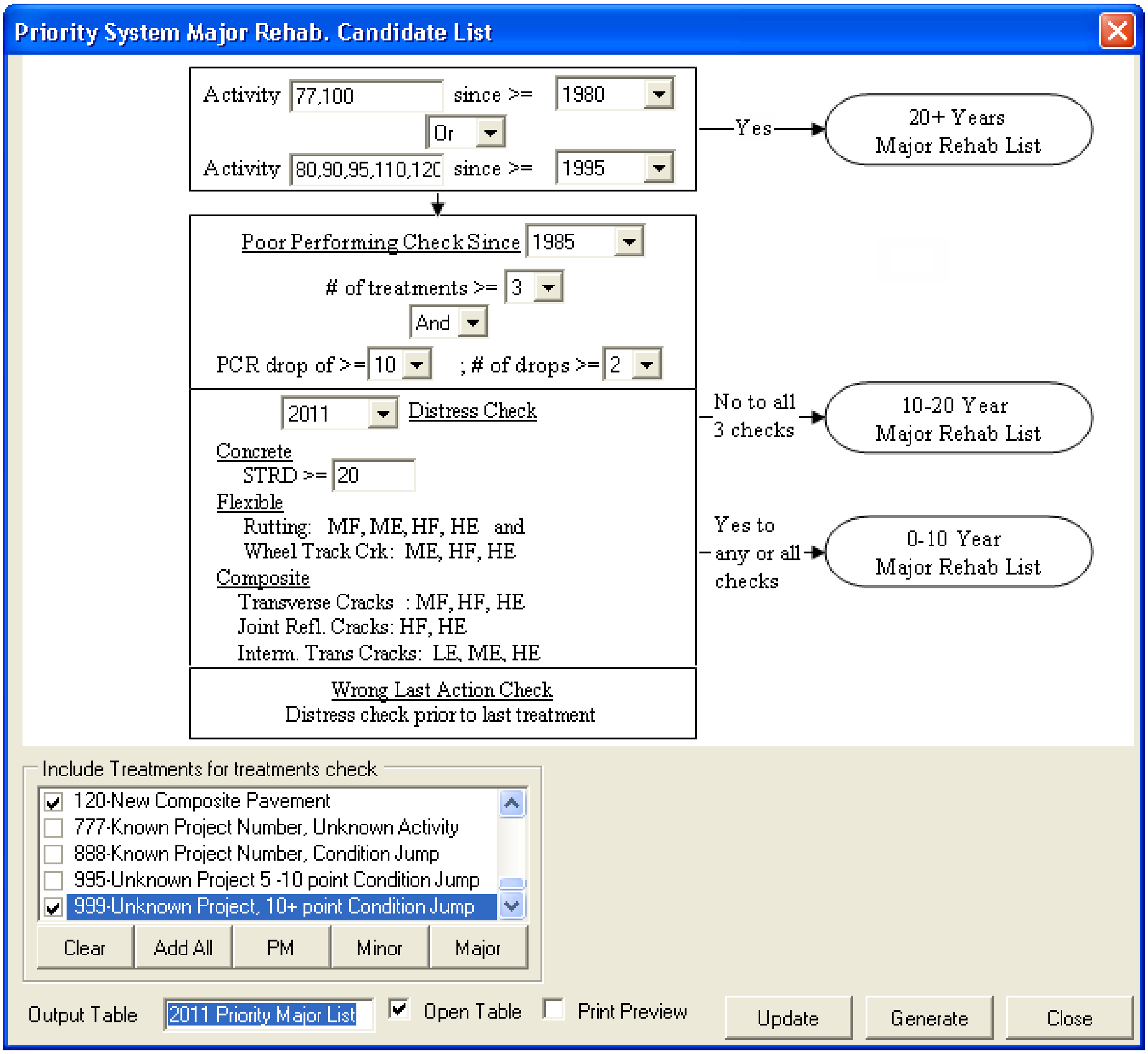


FIGURE B- 43. Priority System Major Rehab List

Include Treatments for Treatments Check

This option allows the user to select the treatments that will be included in the "# of treatments" check in the decision tree.

Merge Continuous Sections Options

These options allow the user to control how continuous sections are merged. The options provided are

Default: Two continuous sections are merged into a single record by considering the "Minimum PCR," "Maximum Total ADT," and "Truck ADT" between the sections, provided the remaining fields are equal

All Equal: Two continuous sections are merged into a single record if all the fields are equal

All Min: Two continuous sections are merged into a single record by considering the "Minimum of PCR," "Total ADT," and "Truck ADT" between the sections provided the remaining fields are equal

All Max: Two continuous sections are merged into a single record by considering the "Maximum of PCR," "Total ADT," and "Truck ADT" between the sections provided the remaining fields are equal

All Avg: Two continuous sections are merged into a single record by considering the "Average of PCR," "Total ADT," and "Truck ADT" between the sections provided the remaining fields are equal

7.8.5 Poor Performing Pavement List

This tool generates a list of pavement sections with a quantity of PCR drops greater than or equal to a specified value, and with specific treatments performed. PCR Drop for this tool is defined as decrease in PCR value between any two years.

Source Table: DATA_Project History_Apparent, DATA_ODOT, DATA_PERF_BASE
Output Table: The default name for the output table is "Poor Performing Pavement List." Users can update this table name by changing the text in the "Output Table name" text box.

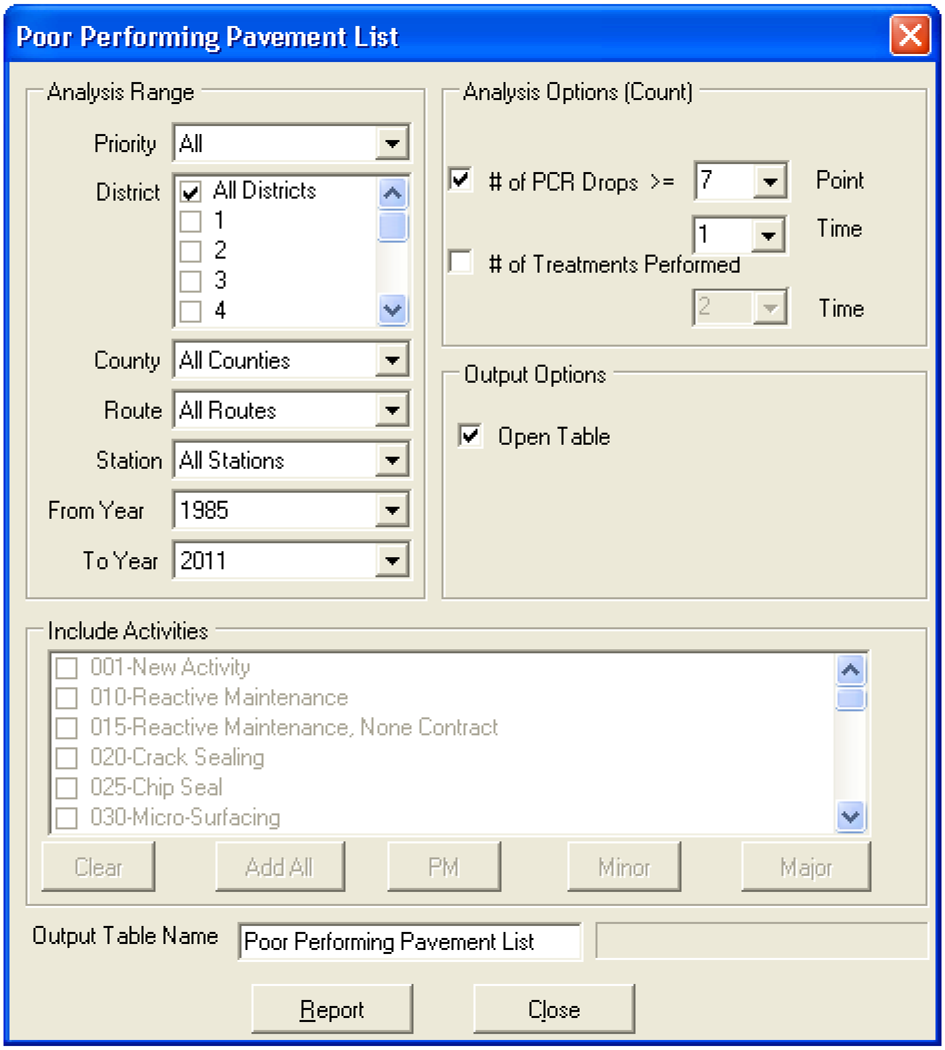


FIGURE B- 44. Poor Performing Pavement List

Analysis Options

PCR Drop >=: When checked, this option will calculate the number of PCR Drops greater than or equal to the value selected in the drop down box and between the values selected in the "From Year" and "To Year" drop down boxes

 # Of Treatments Performed: When checked, this option will calculate the number of treatments performed between the values selected in the "From Year" and "To Year" drop down boxes. The treatments selected in "Include Activities" will be counted

7.9 Survival Curve to Next Treatment

This tool is used to calculate the time to the next treatment based on the Kaplan-Meier Survival Curve method.

Source Table: DATA_PERF_ANALYSIS
Intermediate Table Generated: DATA_PERF_REMLIFE
Output Table: The default name for the output table is "Pavement Survival Life Analysis." Users can update this table name by changing the text in the "Output Table name" text box.

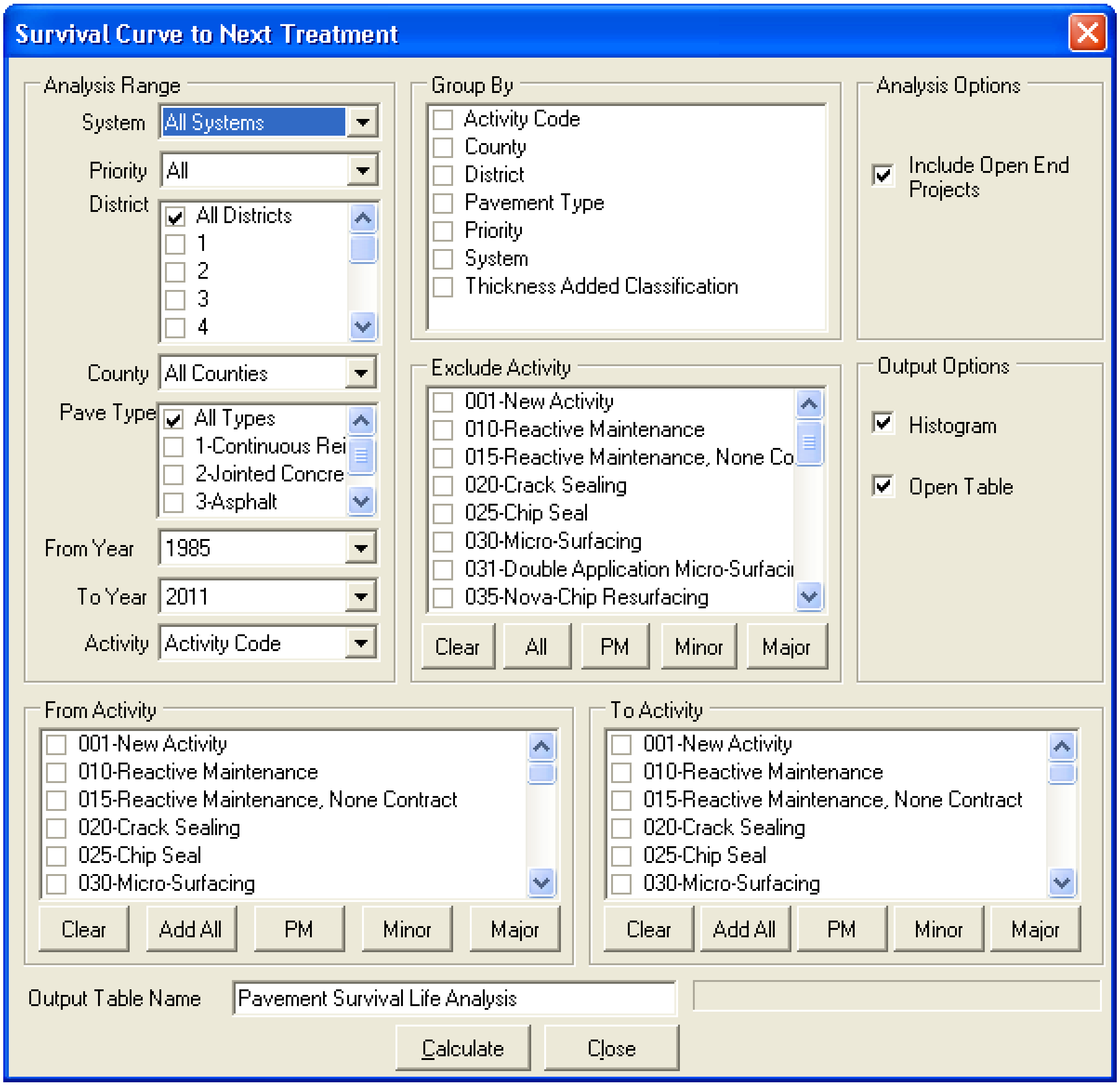


FIGURE B- 45. Survival Curve to Next Treatment User Interface

Analysis Options

Include Open End Projects: Checking this option will include open-ended projects (projects or pavements still in existence)

Output Options

Histogram: This option plots a histogram showing the number of censored and uncensored points for each section.

Open Table: This option opens a table showing the data used to generate the plots.

Survival Analysis Output

In certain scenarios including open ended projects, the survival curve will not reach zero percent surviving. This curve is called a stub survival curve. In the PMIS, a Weibull survival function is used to complete the survival curve. The Weibull fit, along with the original survival curve, is shown in the output graph.

Example 1:

The following example shows the survival analysis of “Overlay on Priority System Flexible Pavements.” Select the following options on the tool:

1. “All Systems” under “System”
2. “All” under “Priority”
3. “All Districts” under “District”
4. “All Counties” under “County”
5. “All Types” under “Pave Type”
6. “All Directions” under “System”
7. “1985” under “From Year,” and “2011” under “To Year”
8. “Activity Code” under “Activity” list
9. “50” and “60” under **“**From Activity” list, and “Add All” under “To Activity” list

Enter an output table name in the “Output Table Name” text box and click “Calculate.”

FIGURE B- 46 shows the “Survival Curve (Raw Data),” the survival curve obtained using the raw data. It can be seen that this survival curve does not reach 0% probability, and any estimates using this curve are not reliable. Hence a “Survival Curve (Weibull Fit)” is fitted to the original curve.

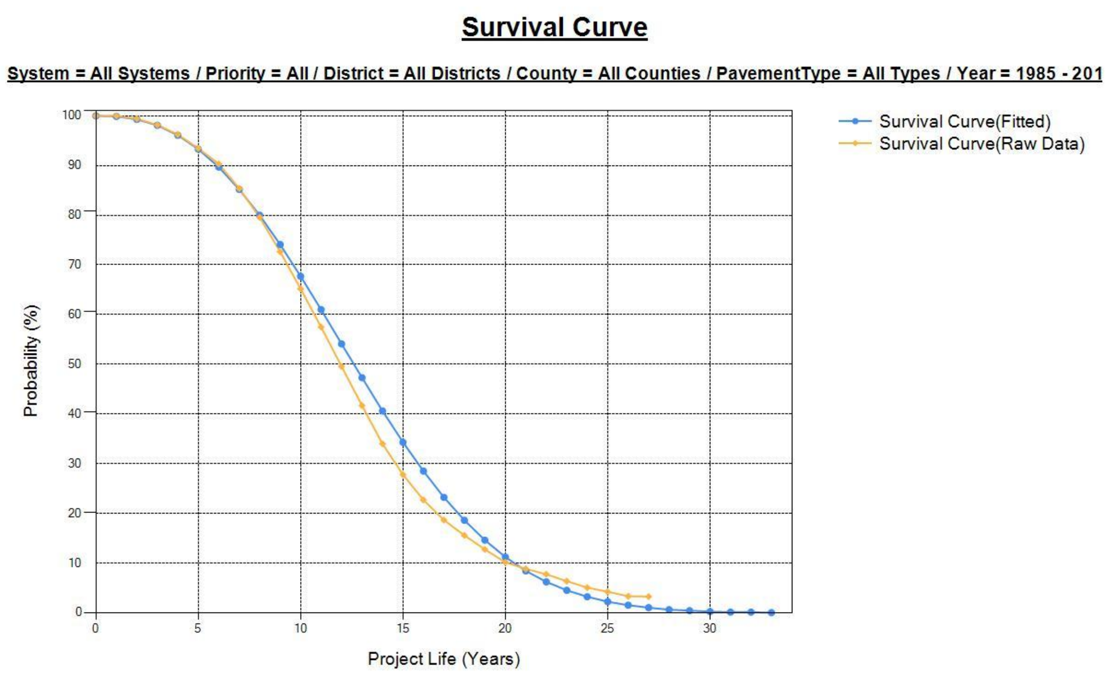


FIGURE B- 46. Survival Curve to Next Treatment Output for Overlays on Priority System

A histogram showing mileages of projects that have been repaired and still exist can also be generated by selecting “Histogram” under “Output Options.” FIGURE B- 47shows the mileage histogram for the survival curve in FIGURE B- 46.

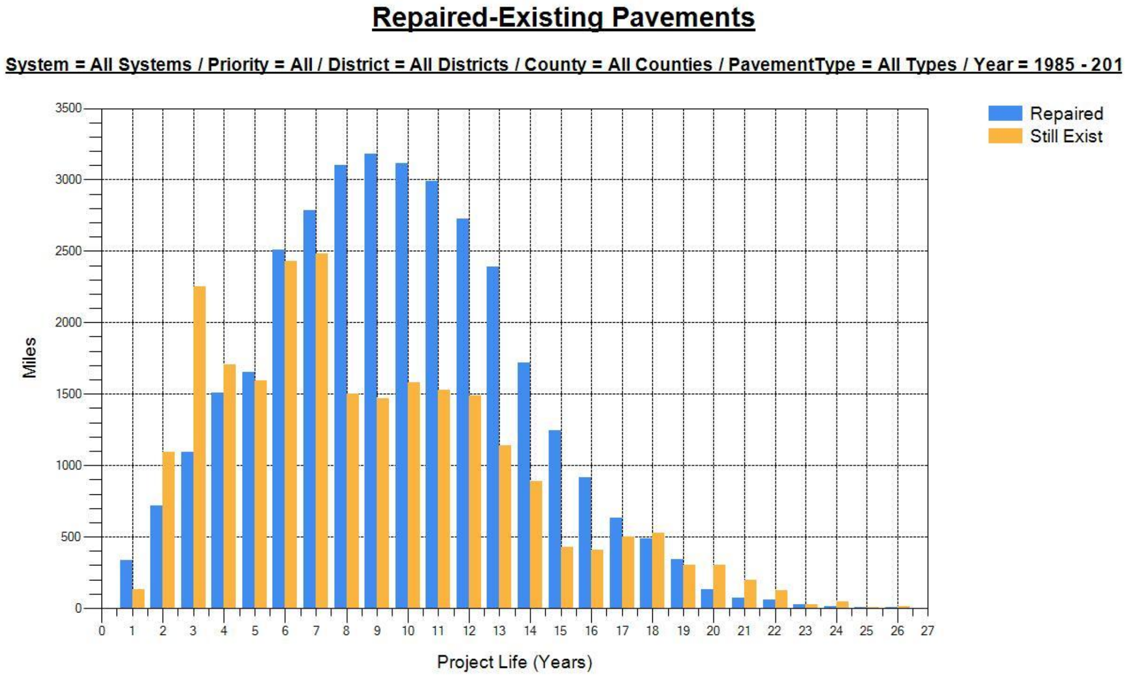


FIGURE B- 47. Survival Curve to Next Treatment Mileage Histogram

SECTION 8. OPTIMIZATION MENU

This menu contains tools to generate the optimal pavement maintenance and rehabilitation strategies.

8.1 Generate Optimization Base Tables

This tool generates the base tables containing the Markov transition matrices and current pavement network condition distribution for further optimization analysis. It should be noted that this function must be run when new project history data or new PCR data have been imported, or when the pavement condition category thresholds need to be modified. FIGURE B-48 shows the user interface.

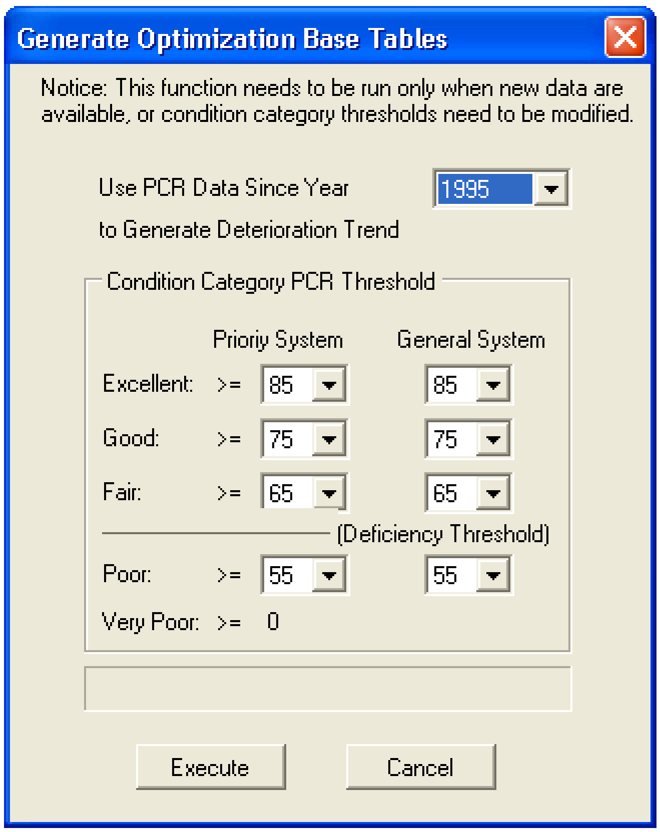


FIGURE B- 48. Generate Optimization Base Tables User Interface

Users can select the year since which the PCR data are used to generate the Markov transition matrices in the "Use PCR Data Since Year" combo box. Users can also define the pavement condition categories by selecting the corresponding PCR thresholds in the "Condition Category PCR Threshold" group box. The following tables will be generated and stored by this function: DATA_Do_Nothing_Matrix, DATA_Treatment_Matrix, DATA_Current_Condition.

8.2 Network Optimization

This tool generates the optimal pavement maintenance and rehabilitation strategies at the network-level. FIGURE B- 49 shows the user interface.

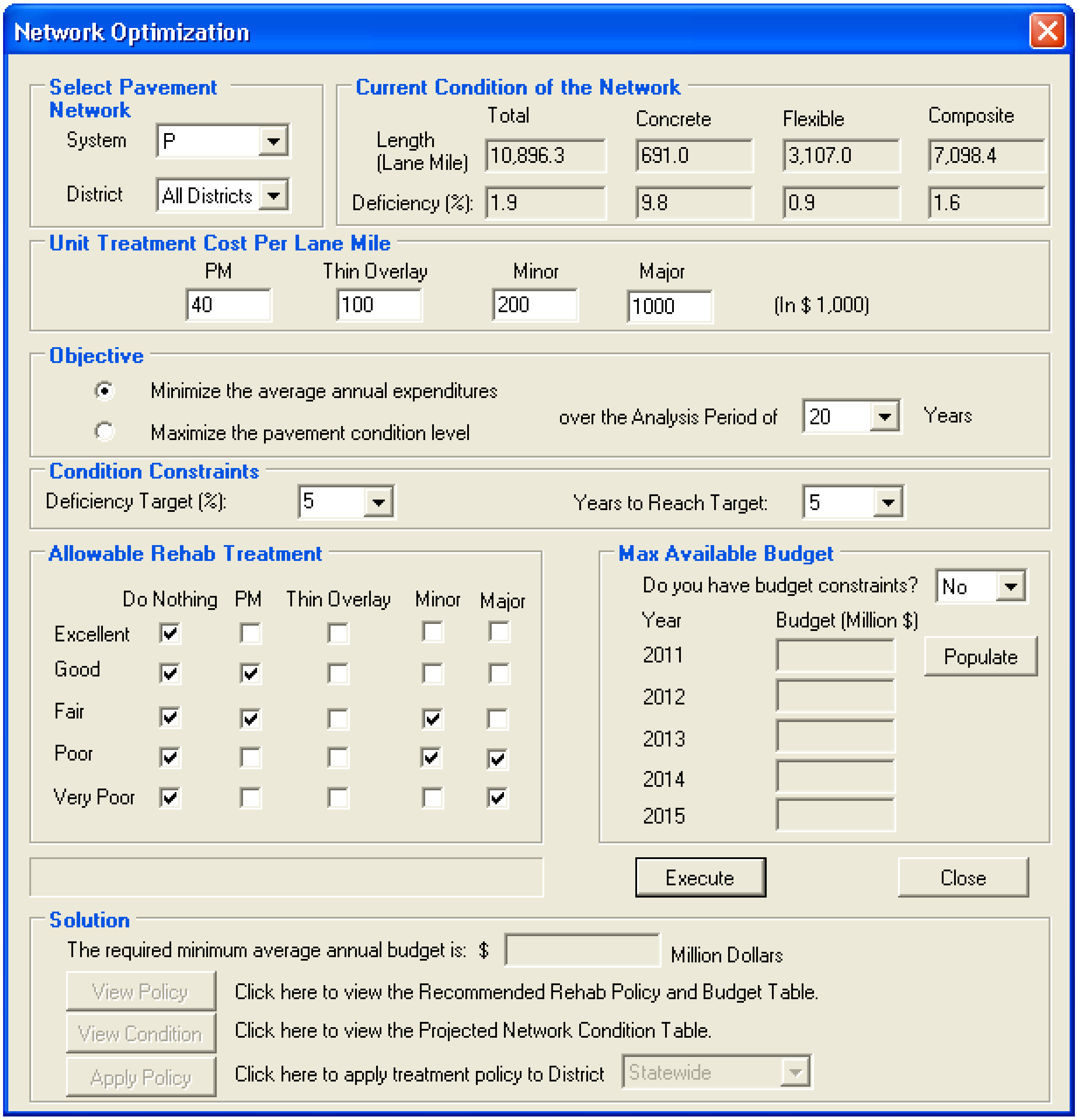


FIGURE B- 49. Network Optimization User Interface

Select Pavement Network

Users can select the appropriate pavement network for optimization by choosing the system priority and the district.

Current Condition of the Network

This group box shows the mileage information and the current deficiency level for each pavement type of the selected network.

Unit Treatment Cost Per Lane Mile

Users can enter the unit cost for each type of treatment, including Preventive Maintenance, Thin Overlay, Minor Rehab and Major Rehab.

Objective

Users can choose the appropriate objective function by selecting the corresponding radio button, and define the analysis period in the combo box.

Condition Constraints

Users can set pavement network condition level target in the “Deficiency Target” box, and specify the number of years it would take to achieve the target in the “Years to Reach Target” box.

Allowable Rehab Treatment

Users can select the allowable treatments for each pavement condition category by checking corresponding checkbox.

Max Available Budget

Users can enter the maximum available budget for each year in the analysis period if there is a budget constrain in the problem to be analyzed.

Solution

This group box shows the optimal solution including: the required minimum average annual budget (shown in the text box), the recommended rehabilitation policy and budget allocation (by clicking the “View Policy” button), and the projected pavement network condition distribution (by clicking the “View Condition” button).

Users can also apply the optimized treatment policy to other districts by selecting the district in the “District” combo box.

Example 1:

To calculate the minimum budget required to reduce the deficiency level of the priority system to 1% within three years and to determine the corresponding fund allocation among different maintenance and rehabilitation treatments, assuming that the default allowable treatments are used, the maximum available budget for each year is $ 150 million, and the analysis period is 20 years, please follow:

1. Select “P” under “System” and “All districts” under “District”.
2. In the “Objective” group box, select “Minimize the average annual expenditure” and choose “20” under “Analysis Period”.

3. In the "Condition Constraints" group box, select "1" under "Deficiency Level" and select "3" under "Years to Reach Target".
4. In the "Max Available Budget" group box, select "Yes" under "Do you have budget constraints?", enter "150" under "2011", and then click on "Populate".
5. Click on "Execute".

Outputs:

In the "Solution" group box, the average annual budget "$131.65" is shown in the text box, as presented in FIGURE B- 50.

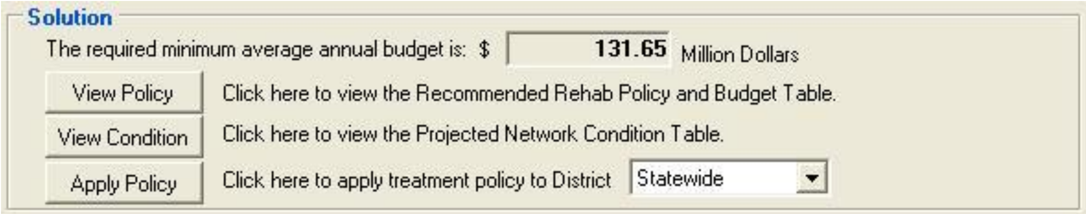


FIGURE B- 50. The Optimized Solution for Example 1

The projected pavement network condition distribution chart and the recommended treatment budget and allocation for each year are shown in FIGURE B- 51 and FIGURE B- 52 respectively. To save the chart, please click on the "Export" button.

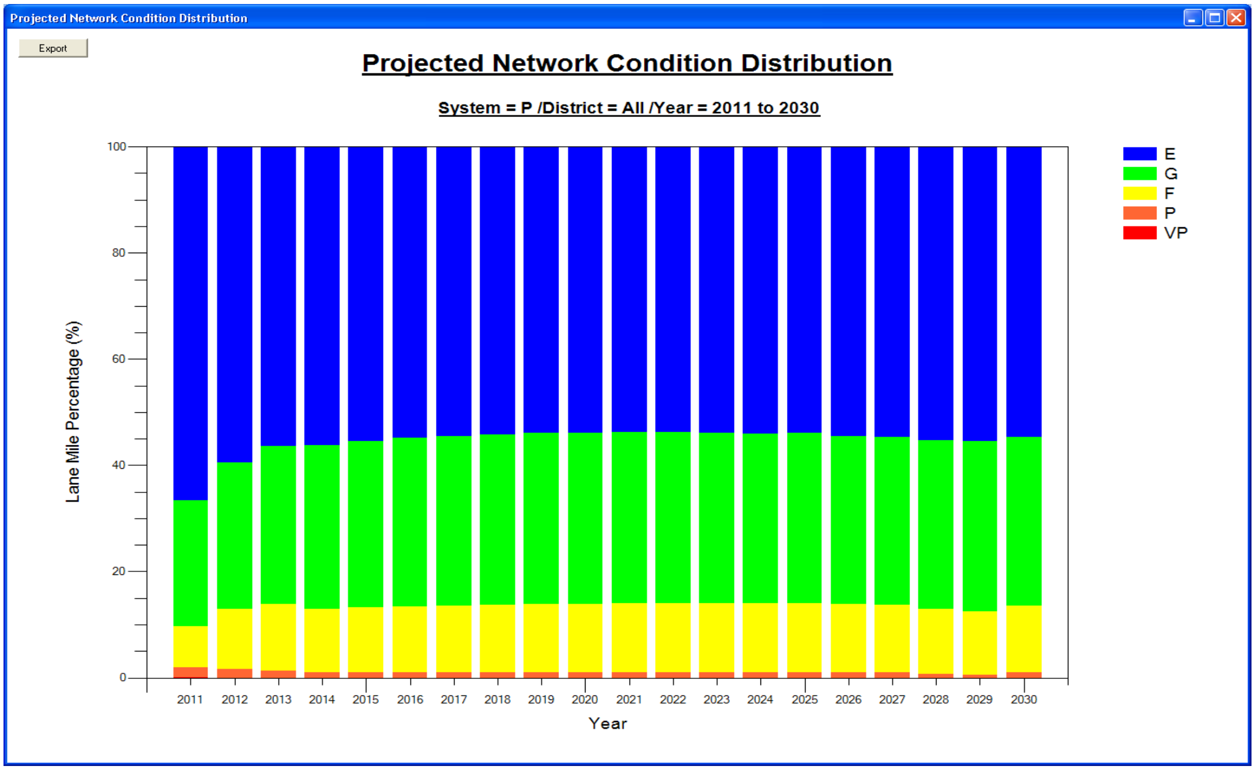


FIGURE B- 51. Projected Pavement Network Condition Distribution for Example 1

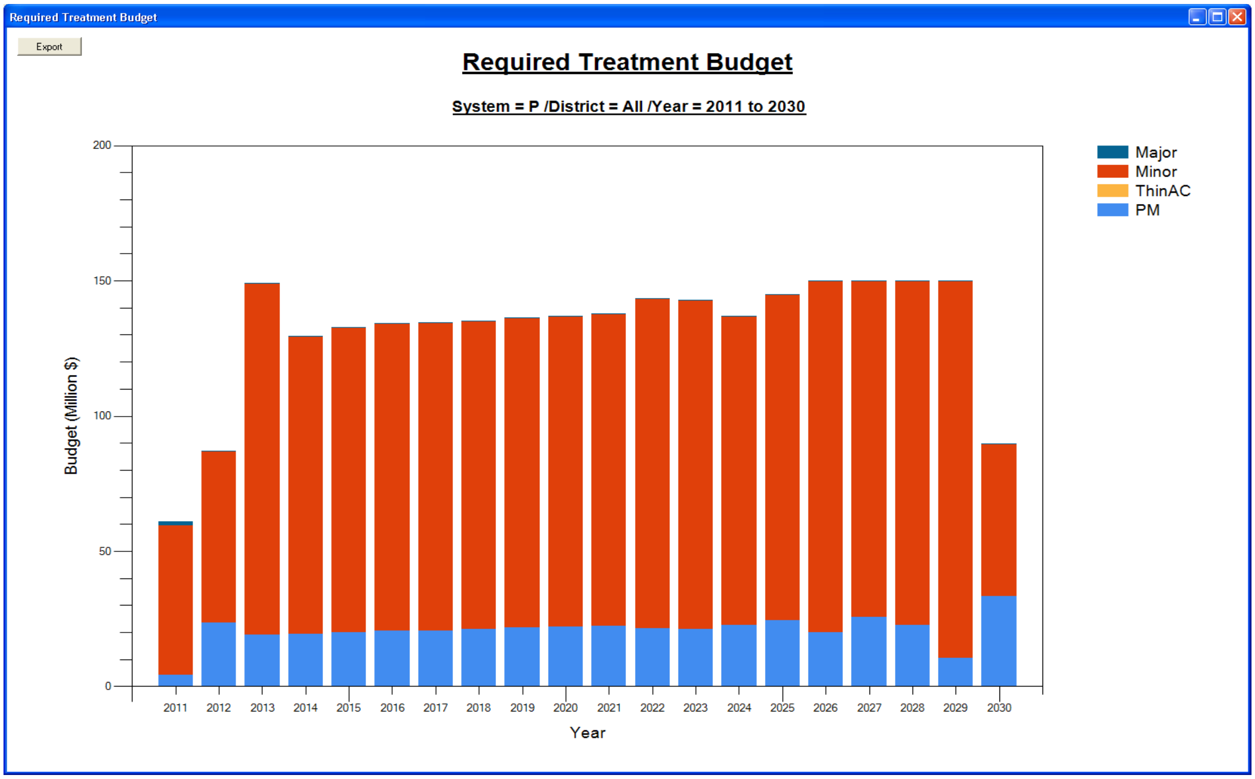


FIGURE B- 52. Recommended Treatment Budget and Allocation for Example 1

To view the "Projected Condition Distribution" table as shown in FIGURE B- 53, please click on the "View Condition" button in the "Solution" group box.

Table: Output_Projected Condition Distribution

PavementType	Year	E	G	F	P	VP	E_Mileage	G_Mileage	F_Mileage	P_Mileage	VP_Mileage
All	2011	0.6666	0.2367	0.0773	0.0193	0.0001	7263.6	2579.2	842.1	209.9	1.5
All	2012	0.5952	0.2746	0.1142	0.016	0	6485.6	2992.3	1244.1	174.2	0.1
All	2013	0.5635	0.2981	0.1254	0.013	0	6139.5	3248.3	1366.8	141.4	0.3
All	2014	0.5628	0.3071	0.1202	0.01	0	6132.2	3345.9	1309.2	108.7	0.3
All	2015	0.5539	0.3134	0.1227	0.01	0	6035.3	3415.2	1336.8	108.7	0.3
All	2016	0.5486	0.3169	0.1245	0.01	0	5977.4	3452.8	1357.1	108.7	0.3
All	2017	0.5453	0.3188	0.1258	0.01	0	5942	3474.2	1371.1	108.7	0.3
All	2018	0.5419	0.3209	0.1273	0.01	0	5904.4	3496.2	1386.8	108.7	0.3
All	2019	0.5396	0.3219	0.1285	0.01	0	5879.8	3507.7	1399.8	108.7	0.3
All	2020	0.5383	0.3224	0.1293	0.01	0	5865.1	3513.3	1409	108.7	0.3
All	2021	0.5375	0.3226	0.1299	0.01	0	5856.3	3515.2	1415.8	108.7	0.3
All	2022	0.537	0.3226	0.1304	0.01	0	5851.3	3515	1421.1	108.7	0.3
All	2023	0.5388	0.3215	0.1297	0.01	0	5870.6	3503.2	1413.5	108.6	0.3
All	2024	0.5399	0.3205	0.1296	0.01	0	5883	3492.4	1411.9	108.6	0.4
All	2025	0.5387	0.3207	0.1307	0.01	0	5869.6	3493.9	1423.8	108.6	0.4
All	2026	0.5448	0.3165	0.1287	0.01	0	5936.3	3448.6	1402.5	108.6	0.4
All	2027	0.547	0.3155	0.1274	0.01	0	5960.8	3437.9	1388.7	108.6	0.4
All	2028	0.5533	0.3176	0.122	0.007	0	6029.3	3460.4	1329.5	76.8	0.4
All	2029	0.5548	0.3206	0.1188	0.0057	0	6045.1	3493.9	1294.3	62.6	0.4
All	2030	0.5468	0.3171	0.1261	0.01	0	5958	3455.1	1374.1	108.6	0.4
Concrete	2011	0.6501	0.1157	0.1358	0.0984	0	449.2	80	93.8	68	0
Concrete	2012	0.7932	0.1619	0.0446	0.0001	0.0001	548.1	111.9	30.8	0.1	0.1
Concrete	2013	0.76	0.1959	0.0436	0.0002	0.0003	525.2	135.4	30.1	0.1	0.2
Concrete	2014	0.7389	0.2123	0.0483	0.0002	0.0003	510.6	146.7	33.4	0.1	0.2
Concrete	2015	0.72	0.2268	0.0526	0.0002	0.0003	497.5	156.7	36.4	0.1	0.2
Concrete	2016	0.7035	0.2389	0.0571	0.0002	0.0003	486.1	165.1	39.5	0.1	0.2
Concrete	2017	0.6904	0.2479	0.0611	0.0002	0.0003	477.1	171.3	42.2	0.2	0.2
Concrete	2018	0.6596	0.2679	0.0719	0.0003	0.0004	455.8	185.1	49.7	0.2	0.2
Concrete	2019	0.6398	0.2783	0.0813	0.0003	0.0004	442.1	192.3	56.2	0.2	0.2
Concrete	2020	0.6294	0.283	0.0869	0.0003	0.0004	434.9	195.5	60	0.2	0.3
Concrete	2021	0.6245	0.2846	0.0903	0.0003	0.0004	431.5	196.6	62.4	0.2	0.3
Concrete	2022	0.6225	0.2844	0.0924	0.0003	0.0004	430.2	196.5	63.8	0.2	0.3
Concrete	2023	0.6537	0.2686	0.077	0.0003	0.0004	451.7	185.6	53.2	0.2	0.3

Recor 1 of 80 Previous Next

FIGURE B- 53. Projected Condition Distribution Table for Example 1

To view the "Recommended Budget and Treatment Mileage" table as shown in FIGURE B- 54, please click on the "View Policy" button in the "Solution" group box.

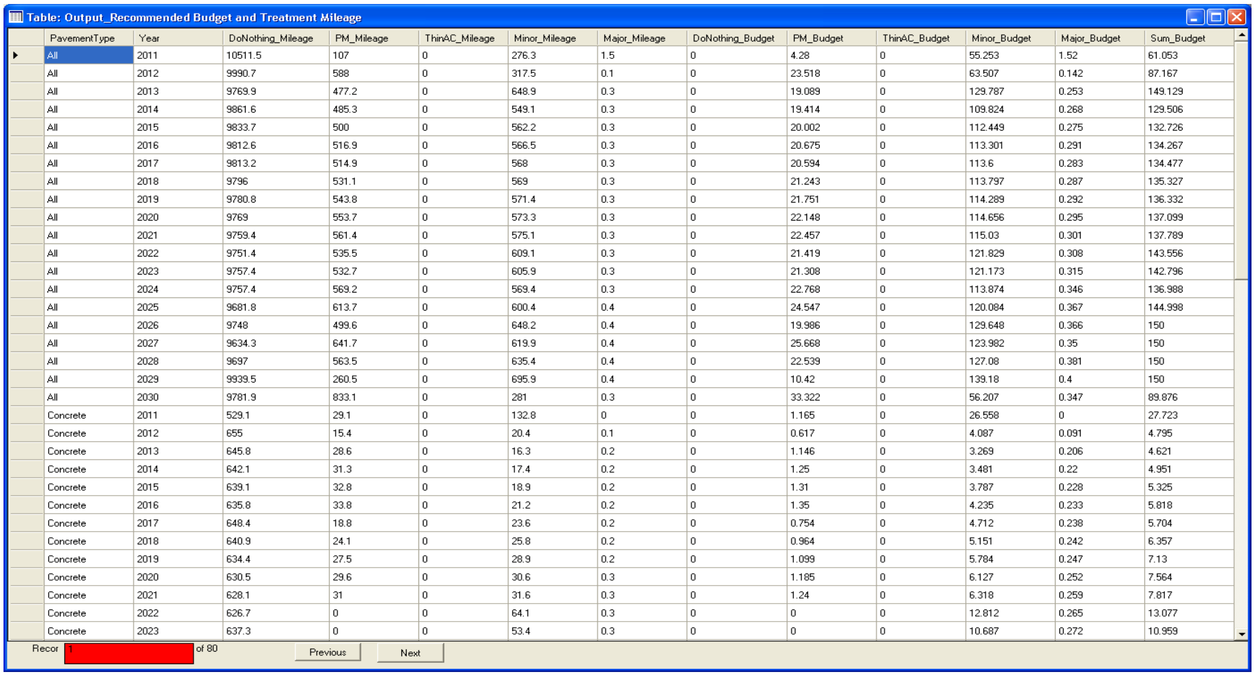


Table: Output_Recommended Budget and Treatment Mileage

PavementType	Year	DoNothing_Mileage	PM_Mileage	ThinAC_Mileage	Minor_Mileage	Major_Mileage	DoNothing_Budget	PM_Budget	ThinAC_Budget	Minor_Budget	Major_Budget	Sum_Budget
All	2011	10511.5	107	0	276.3	1.5	0	4.28	0	55.253	1.52	61.053
All	2012	9990.7	588	0	317.5	0.1	0	23.518	0	63.507	0.142	87.167
All	2013	9769.9	477.2	0	648.9	0.3	0	19.089	0	129.787	0.253	149.129
All	2014	9861.6	485.3	0	549.1	0.3	0	19.414	0	109.824	0.268	129.506
All	2015	9833.7	500	0	562.2	0.3	0	20.002	0	112.449	0.275	132.726
All	2016	9812.6	516.9	0	566.5	0.3	0	20.675	0	113.301	0.291	134.267
All	2017	9813.2	514.9	0	568	0.3	0	20.594	0	113.6	0.283	134.477
All	2018	9796	531.1	0	569	0.3	0	21.243	0	113.797	0.287	135.327
All	2019	9780.8	543.8	0	571.4	0.3	0	21.751	0	114.289	0.292	136.332
All	2020	9769	553.7	0	573.3	0.3	0	22.148	0	114.656	0.295	137.099
All	2021	9759.4	561.4	0	575.1	0.3	0	22.457	0	115.03	0.301	137.789
All	2022	9751.4	535.5	0	609.1	0.3	0	21.419	0	121.829	0.308	143.556
All	2023	9757.4	532.7	0	605.9	0.3	0	21.308	0	121.173	0.315	142.796
All	2024	9757.4	569.2	0	569.4	0.3	0	22.768	0	113.874	0.346	136.988
All	2025	9681.8	613.7	0	600.4	0.4	0	24.547	0	120.084	0.367	144.998
All	2026	9748	499.6	0	648.2	0.4	0	19.986	0	129.648	0.366	150
All	2027	9634.3	641.7	0	619.9	0.4	0	25.668	0	123.982	0.35	150
All	2028	9697	563.5	0	635.4	0.4	0	22.539	0	127.08	0.381	150
All	2029	9939.5	260.5	0	695.9	0.4	0	10.42	0	139.18	0.4	150
All	2030	9781.9	833.1	0	281	0.3	0	33.322	0	56.207	0.347	89.876
Concrete	2011	529.1	29.1	0	132.8	0	0	1.165	0	26.558	0	27.723
Concrete	2012	655	15.4	0	20.4	0.1	0	0.617	0	4.087	0.091	4.795
Concrete	2013	645.8	28.6	0	16.3	0.2	0	1.146	0	3.269	0.206	4.621
Concrete	2014	642.1	31.3	0	17.4	0.2	0	1.25	0	3.481	0.22	4.951
Concrete	2015	639.1	32.8	0	18.9	0.2	0	1.31	0	3.787	0.228	5.325
Concrete	2016	635.8	33.8	0	21.2	0.2	0	1.35	0	4.235	0.233	5.818
Concrete	2017	648.4	18.8	0	23.6	0.2	0	0.754	0	4.712	0.238	5.704
Concrete	2018	640.9	24.1	0	25.8	0.2	0	0.964	0	5.151	0.242	6.357
Concrete	2019	634.4	27.5	0	28.9	0.2	0	1.099	0	5.784	0.247	7.13
Concrete	2020	630.5	29.6	0	30.6	0.3	0	1.185	0	6.127	0.252	7.564
Concrete	2021	628.1	31	0	31.6	0.3	0	1.24	0	6.318	0.259	7.817
Concrete	2022	626.7	0	0	64.1	0.3	0	0	0	12.812	0.265	13.077
Concrete	2023	637.3	0	0	53.4	0.3	0	0	0	10.687	0.272	10.959

Recor 1 of 80 Previous Next

FIGURE B- 54. Recommended Budget and Treatment Mileage Table for Example 1

To apply the statewide optimized treatment policy to district 1, please select “1” under “District” in the “Solution” group box, and then click on the “Apply Policy” button.

The projected pavement network condition distribution chart and the recommended treatment budget and allocation for district 1 obtained by applying the statewide policy are shown in FIGURE B- 55 and FIGURE B- 56 respectively. The “Projected Condition Distribution” table and the “Recommended Budget and Treatment Mileage” table are presented in FIGURE B- 57 and FIGURE B- 58 respectively.

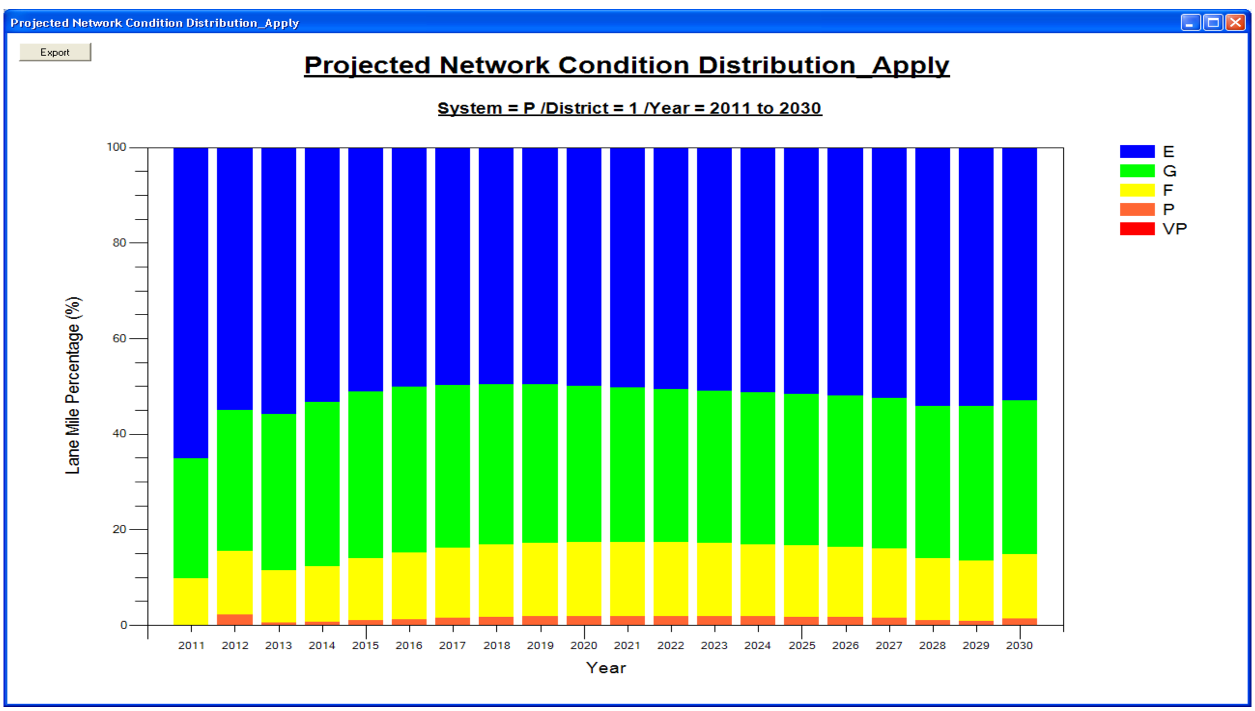


FIGURE B- 55. Projected Pavement Network Condition Distribution for District 1

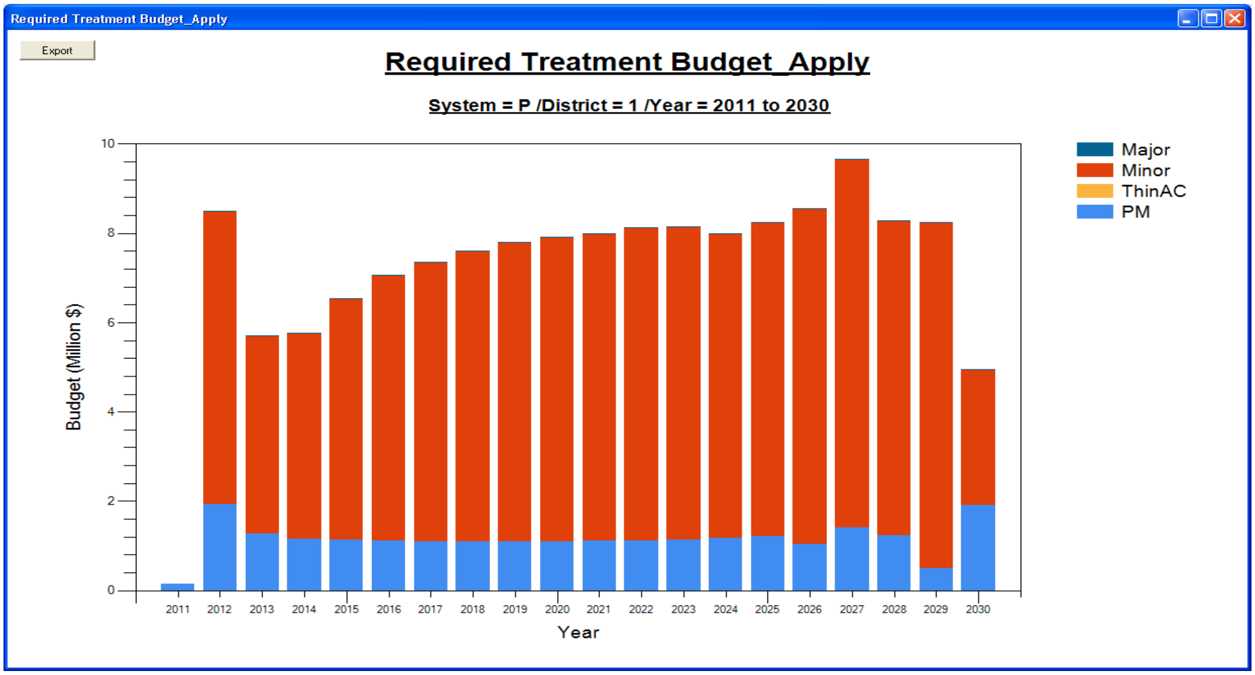


FIGURE B- 56. Recommended Treatment Budget and Allocation for District 1

Table: Output_Apply_Recommended Budget and Treatment Mileage

District	PavementType	Year	DoNothing_Mileage	PM_Mileage	ThinAC_Mileage	Minor_Mileage	Major_Mileage	DoNothing_Budget	PM_Budget	ThinAC_Budget	Minor_Budget	Major_Budget	Sum_Budget
1	All	2011	598.4	3.6	0	0	0	0	0.146	0	0	0	0.146
1	All	2012	520.8	48.4	0	32.8	0	0	1.937	0	6.566	0.002	8.505
1	All	2013	548.2	31.7	0	22.2	0	0	1.268	0	4.439	0.003	5.71
1	All	2014	549.9	29.1	0	23	0	0	1.164	0	4.608	0.004	5.776
1	All	2015	546.4	28.6	0	27	0	0	1.145	0	5.398	0.005	6.548
1	All	2016	544.2	28.2	0	29.7	0	0	1.126	0	5.939	0.005	7.07
1	All	2017	543.2	27.6	0	31.3	0	0	1.103	0	6.252	0.006	7.361
1	All	2018	542.1	27.3	0	32.6	0	0	1.094	0	6.516	0.007	7.617
1	All	2019	541.2	27.4	0	33.5	0	0	1.094	0	6.702	0.007	7.803
1	All	2020	540.4	27.6	0	34.1	0	0	1.103	0	6.81	0.007	7.92
1	All	2021	539.8	28	0	34.3	0	0	1.118	0	6.862	0.008	7.988
1	All	2022	539.2	27.8	0	35.1	0	0	1.111	0	7.011	0.008	8.13
1	All	2023	538.6	28.3	0	35.1	0	0	1.133	0	7.017	0.008	8.158
1	All	2024	538.4	29.6	0	34	0	0	1.185	0	6.802	0.009	7.996
1	All	2025	536.5	30.4	0	35.1	0	0	1.215	0	7.029	0.01	8.254
1	All	2026	538.4	26.2	0	37.5	0	0	1.047	0	7.495	0.01	8.552
1	All	2027	525.5	35.3	0	41.2	0	0	1.414	0	8.232	0.01	9.656
1	All	2028	536	30.9	0	35.2	0	0	1.235	0	7.032	0.011	8.278
1	All	2029	551	12.3	0	38.8	0	0	0.493	0	7.751	0.011	8.255
1	All	2030	539.1	47.7	0	15.2	0	0	1.91	0	3.034	0.01	4.954
1	Concrete	2011	18.8	0	0	0	0	0	0	0	0	0	0
1	Concrete	2012	18.6	0	0	0.2	0	0	0.001	0	0.032	0	0.033
1	Concrete	2013	18.1	0.2	0	0.6	0	0	0.006	0	0.115	0.001	0.122
1	Concrete	2014	17.8	0.3	0	0.8	0	0	0.01	0	0.162	0.001	0.173
1	Concrete	2015	17.5	0.4	0	0.9	0	0	0.015	0	0.185	0.002	0.202
1	Concrete	2016	17.4	0.5	0	1	0	0	0.019	0	0.194	0.003	0.216
1	Concrete	2017	17.5	0.4	0	1	0	0	0.015	0	0.195	0.003	0.213
1	Concrete	2018	17.4	0.5	0	1	0	0	0.018	0	0.194	0.004	0.216
1	Concrete	2019	17.3	0.5	0	1	0	0	0.021	0	0.194	0.005	0.22
1	Concrete	2020	17.3	0.6	0	1	0	0	0.023	0	0.192	0.005	0.22
1	Concrete	2021	17.2	0.6	0	1	0	0	0.025	0	0.191	0.006	0.222
1	Concrete	2022	17.2	0	0	1.6	0	0	0	0	0.326	0.006	0.332
1	Concrete	2023	17.4	0	0	1.4	0	0	0	0	0.282	0.006	0.288

Recor 1 of 80 Previous Next

FIGURE B- 57. Projected Condition Distribution Table for District 1

Table: Output_Apply_Projected Condition Distribution

District	PavementType	Year	E	G	F	P	VP	E_Mileage	G_Mileage	F_Mileage	P_Mileage	VP_Mileage
1	All	2011	0.6511	0.2515	0.0974	0	0	392	151.4	58.6	0	0
1	All	2012	0.5497	0.2957	0.1323	0.0223	0	331	178	79.6	13.4	0
1	All	2013	0.5578	0.327	0.11	0.0052	0	335.8	196.8	66.2	3.1	0
1	All	2014	0.5332	0.3432	0.1168	0.0069	0	321	206.6	70.3	4.1	0
1	All	2015	0.512	0.3484	0.1297	0.0098	0	308.3	209.8	78.1	5.9	0
1	All	2016	0.5013	0.3468	0.1394	0.0125	0	301.8	208.8	83.9	7.5	0
1	All	2017	0.4971	0.342	0.1461	0.0148	0	299.2	205.9	88	8.9	0
1	All	2018	0.4958	0.3365	0.151	0.0167	0	298.5	202.6	90.9	10	0
1	All	2019	0.497	0.3311	0.1539	0.018	0	299.2	199.3	92.7	10.8	0
1	All	2020	0.4995	0.3265	0.1552	0.0188	0	300.7	196.6	93.4	11.3	0
1	All	2021	0.5027	0.323	0.1552	0.019	0	302.7	194.5	93.5	11.4	0
1	All	2022	0.506	0.3206	0.1545	0.0189	0	304.6	193	93	11.4	0
1	All	2023	0.5099	0.3188	0.1528	0.0185	0	307	191.9	92	11.1	0
1	All	2024	0.5135	0.3179	0.1508	0.0178	0	309.2	191.4	90.8	10.7	0
1	All	2025	0.5156	0.3181	0.1492	0.017	0	310.4	191.5	89.8	10.3	0
1	All	2026	0.5206	0.3167	0.1464	0.0163	0	313.4	190.7	88.1	9.8	0
1	All	2027	0.5243	0.3162	0.1439	0.0157	0	315.6	190.4	86.6	9.4	0
1	All	2028	0.5414	0.3194	0.1296	0.0095	0	326	192.3	78	5.7	0
1	All	2029	0.541	0.3239	0.1266	0.0085	0	325.7	195	76.2	5.1	0
1	All	2030	0.5305	0.3204	0.1356	0.0134	0	319.4	192.9	81.7	8	0
1	Concrete	2011	1	0	0	0	0	18.8	0	0	0	0
1	Concrete	2012	0.892	0.0976	0.0104	0	0	16.8	1.8	0.2	0	0
1	Concrete	2013	0.8051	0.1562	0.0386	0	0	15.2	2.9	0.7	0	0
1	Concrete	2014	0.7521	0.1921	0.0558	0	0.0001	14.2	3.6	1	0	0
1	Concrete	2015	0.7201	0.2145	0.0653	0	0.0001	13.6	4	1.2	0	0
1	Concrete	2016	0.7017	0.2279	0.0702	0	0.0001	13.2	4.3	1.3	0	0
1	Concrete	2017	0.6919	0.2357	0.0723	0.0001	0.0002	13	4.4	1.4	0	0
1	Concrete	2018	0.6784	0.2455	0.0758	0.0001	0.0002	12.8	4.6	1.4	0	0
1	Concrete	2019	0.6683	0.252	0.0794	0.0001	0.0002	12.6	4.7	1.5	0	0

Recor 1 of 80 Previous Next

FIGURE B- 58. Recommended Budget and Treatment Mileage Table for District 1

Example 2:

This example is to illustrate the process of maximizing the benefit of the available budget. It is assumed that the available annual budget is $150 million, the default allowable treatments are used, and the analysis period is 20 years. To generate the pavement maintenance and rehabilitation strategy which maximizes the improvement of the priority system pavement network condition, please follow:

1. Select “P” under “System” and “All districts” under “District”.
2. In the “Objective” group box, select “Maximize the pavement condition level” and choose “20” under “Analysis Period”.
3. In the “Max Available Budget” group box, select “Yes” under “Do you have budget constraints?”, enter “150” under “2011”, and then click on “Populate”.
4. Click on “Execute”.

Outputs:

The projected pavement network condition distribution chart and the recommended treatment budget and allocation for each year are shown in FIGURE B- 59 and FIGURE B- 60 respectively. To save the chart, please click on the “Export” button.

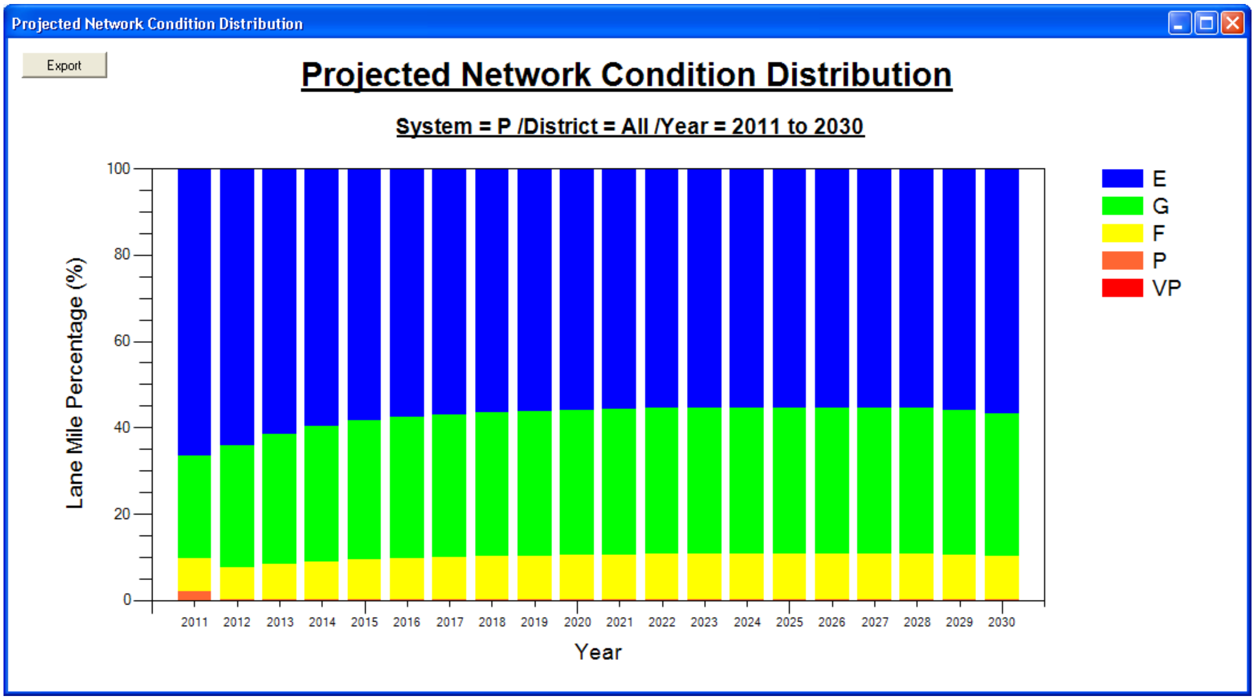


FIGURE B- 59. Projected Pavement Network Condition Distribution for Example 2

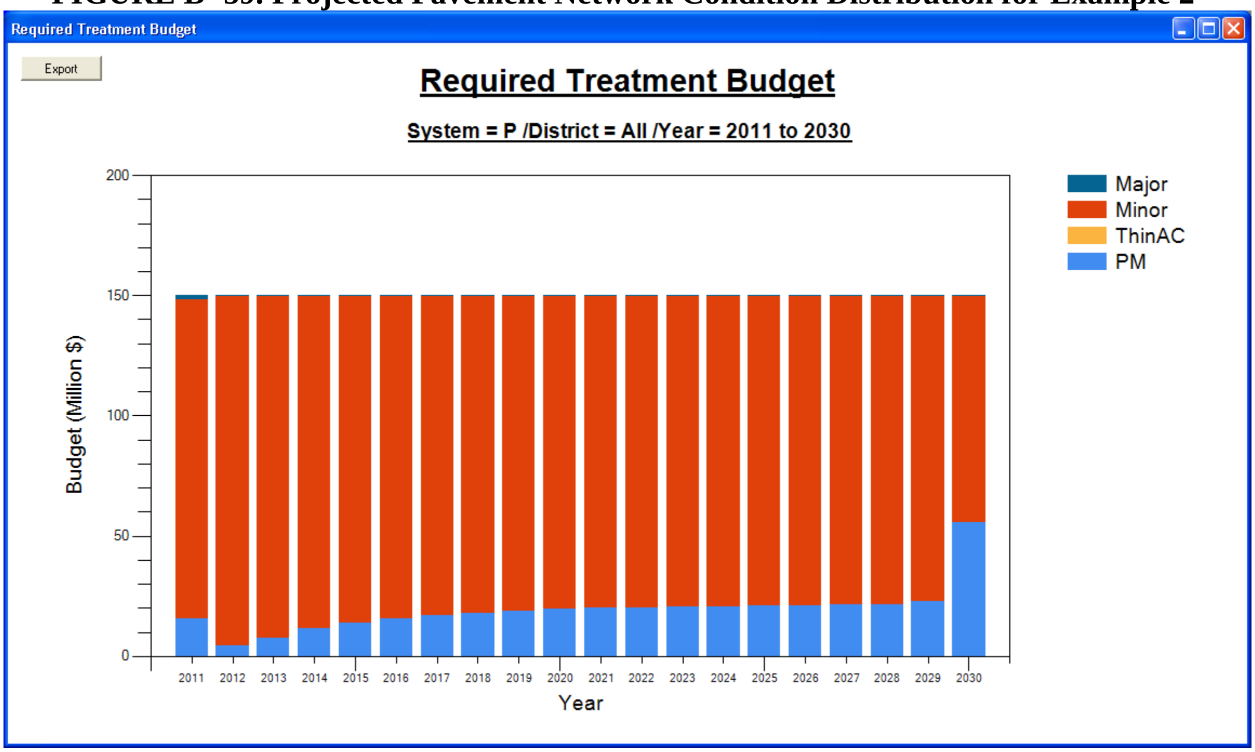


FIGURE B- 60. Recommended Treatment Budget and Allocation for Example 2

As described in Example 1, to view the "Projected Condition Distribution" table please click on the "View Condition" button, to view the "Recommended Budget and Treatment Mileage" table, please click on the "View Policy" button, and to apply the optimized treatment policy to other districts, please select the appropriate district under "District" in the "Solution" group box, and then click on the "Apply Policy" button.

SECTION 9. WINDOW MENU

The "Window" menu includes normal Microsoft functions for controlling the simultaneous display of multiple open windows.

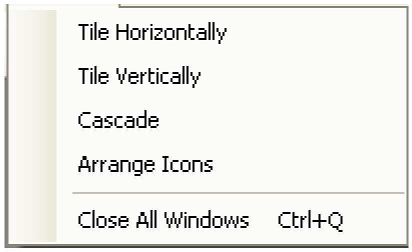


FIGURE B- 61. ODOTPMIS Window Menu

9.1 Tile Horizontally

Horizontally tile all non-minimized windows.

9.2 Tile Vertically

Vertically tile all non-minimized windows.

9.3 Cascade

Cascade all non-minimized windows.

9.4 Arrange Icons

Arrange icons for minimized windows.

9.5 Close All Windows (Shortcut Key: CTRL+Q)

Close all opened tables and queries.

SECTION 10. HELP MENU

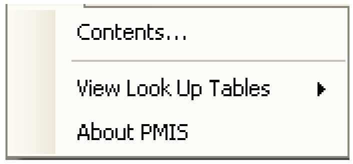


FIGURE B- 62. ODOTPMIS Help Menu

10.1 Contents

Click this option to open the help file. The help file can also be activated by pressing the F1 key. Select the form or tool in question and press F1. Help for that topic will be displayed.

10.2 View Lookup Table

This function shows the description of activity code, distress code and pavement type code.

10.2.1 Activity Code

Click this option to view the legend color, activity description, class, maximum life of the activity codes.

10.2.2 Distress Code

Click this option to view the distress code and the corresponding description.

10.2.3 Pavement Type

Click this option to view the pavement type and the corresponding description.

10.3 About

This option provides downloads of the latest updates for ODOTPMIS and specifies the current version number.

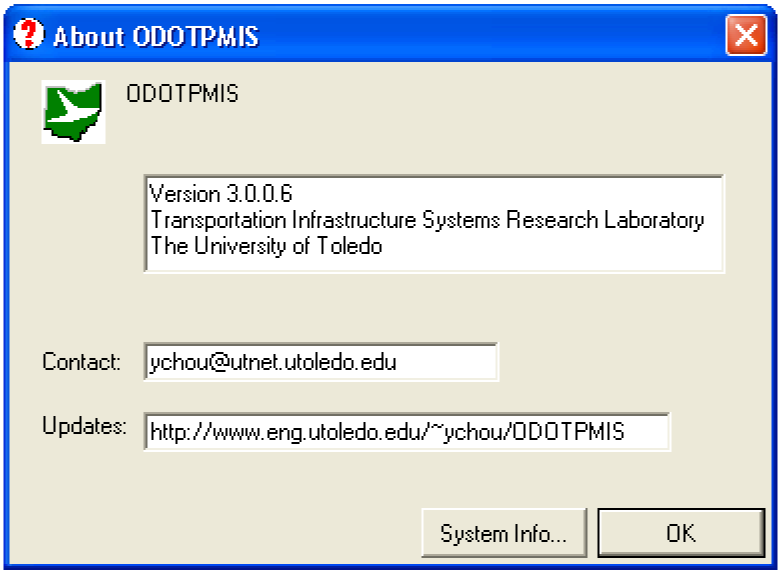


FIGURE B- 63. ODOTPMIS About Dialog Box