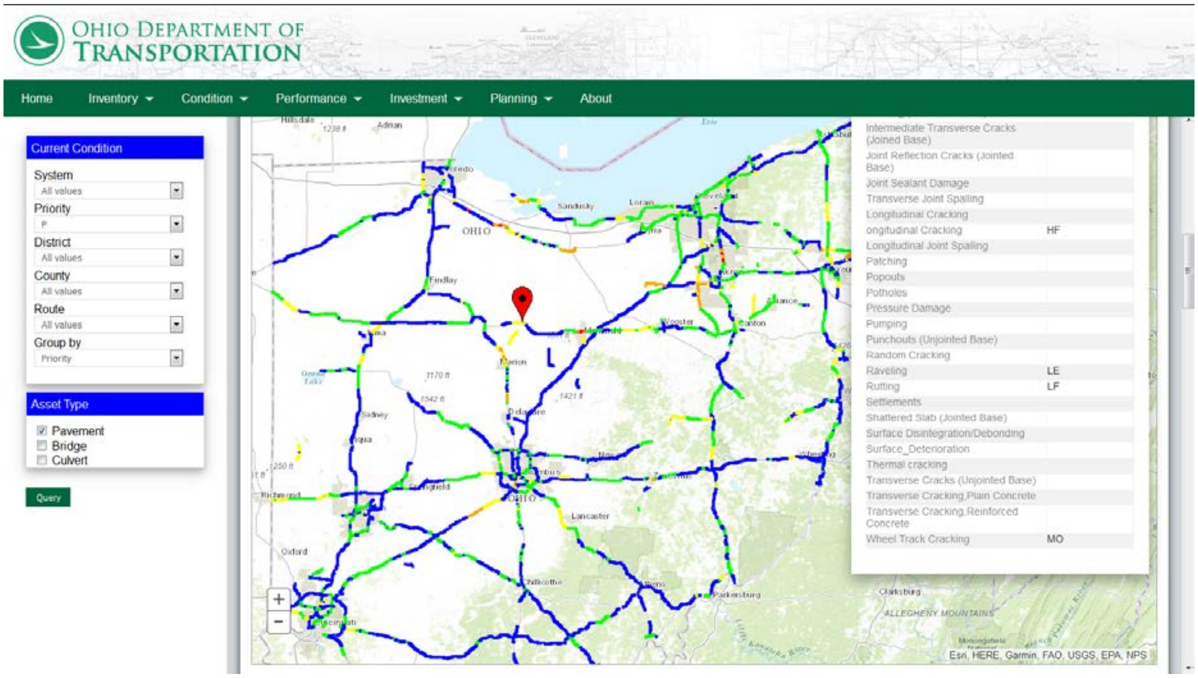
Development of Transportation Asset Management Decision Support Tools



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Prepared for:
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Final Report

RESEARCH

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16. Abstract

This study developed a web-based prototype decision support platform to demonstrate the benefits of transportation asset management in monitoring asset performance, supporting asset funding decisions, planning budget tradeoffs, and optimizing resource allocations. The goal is to build consensus and gain senior management support for implementing asset management throughout the Department, which requires investments for data collection and integration, standardization of process and definition, and management information system acquisition and implementation. A centralized transportation asset database that integrates data from various sources was built to support the data-driven decision support tools. This allows reports/presentations to be generated quickly and enables what-if analyses to be performed. A total of 23 functions were developed in five categories: inventory, condition, performance, investment, and planning. The tradeoff analysis function is developed for evaluating funding levels versus performance and cross-asset budget allocation decisions.

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

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Executive Summary

This research study has developed a web-based prototype decision support platform to help ODOT make sound transportation asset management and planning decisions based on reliable data and information. The platform is intended to support data-driven decisions at various levels, from statewide planning and rehabilitation policies, budget tradeoffs, district-level work plan development, to individual asset rehabilitation or replacement. The purpose of this study is to demonstrate the benefits of and to build consensus and gain senior management support for implementing asset management as the business process throughout the Department, which requires investments for data collection and integration, standardization of process and definition, and management information system acquisition and implementation.

A centralized transportation asset database that integrates data from various sources was built to support the data-driven decision support tools. This allows reports/presentations to be generated quickly and enables what-if analyses to be performed. A total of 23 functions were developed and grouped into five categories: inventory, condition, performance, investment, and planning. The tradeoff analysis function is developed for evaluating funding levels versus performance and cross-asset budget allocation decisions.

The decision support tools developed are intended to enable the Department to prudently allocate and efficiently utilize the limited resources available to maximize transportation asset performance. The various decision tools and methodologies developed in this study have been incorporated into the Transportation Asset Management Decision Support Tools Prototype (TAMDSTP) web site. This prototype web site provides a proving ground for ODOT to evaluate whether or not to adopt and to fully implement the data-driven approach of decision support.

INTRODUCTION

The Ohio Department of Transportation manages a transportation network that includes about 50,000 lane miles of highway pavements, approximately 12,700 bridges, more than 139,000 culverts, and over 5,600 miles of barriers as well as various other assets such as signs, lights, signals, and so on. Maintaining these transportation assets in a condition state of 'good repair' (in other words, "take care what we have") is of utmost importance in order for the Department to serve its mission of "providing easy movement of people and goods from place to place".

Transportation asset management (TAM) has been defined by AASHTO as: "a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives."

According to the Federal Highway Administration (FHWA), "an asset management decision-making framework needs to be guided by performance goals, cover an extended time horizon, draw from economics as well as engineering, and consider a broad range of assets. At its most basic level, Transportation Asset Management links user expectations for system condition, performance, and availability with system management and investment strategies. …. the focus is on performance of assets. The underlying goal of asset management is to take a broad approach to resource allocation and programming decisions that will provide greater value to the system and overall satisfaction for end users through improvements in program effectiveness and system performance."

"Transportation Asset Management provides for a fact-based dialogue among system users and other stakeholders, State government officials, and managers concerned with day-to-day operations. This dialogue results when relevant, objective, and credible information is made accessible to all participants in the decision-making process. As such, decisions can be based on detailed input regarding available resources, current system condition and performance, and estimates of future performance. The information underlying asset management-sometimes raw data and at other times data generated from the analytical process-is fundamental to an improved understanding of the economic tradeoffs, return on investment, and potential value of the end product."

The core principles of transportation asset management, based on NCHRP Report 551, *Performance Measures and Targets for Transportation Asset Management, Vol. I, Research Report*, 2006, p. ii, are:

- **Policy-driven –** Resource allocation decisions are based on a well-defined set of policy goals and objectives.
- **Performance-based –** Policy objectives are translated into system performance measures that are used for both day-to-day and strategic management.
- **Analysis of Options and Tradeoffs –** Decisions on how to allocate funds within and across different types of investments (e.g., preventive maintenance versus rehabilitation, pavements versus bridges) are based on an analysis of how different allocations will impact achievement of relevant policy objectives.
- **Decisions Based on Quality Information –** The merits of different options with respect to an agency's policy goals are evaluated using credible and current data.
- **Monitoring Provides Clear Accountability and Feedback –** Performance results are monitored and reported for both impacts and effectiveness.

The main objective of transportation asset management is to support the decision-making for allocating budget to different asset needs in order to maximize the benefits. The benefits of asset management as a decision support tool in making crucial funding decisions, planning budget trade-offs, monitoring asset performance, reducing asset life-cycle costs, and optimizing resource allocations may not be as apparent as the required investments in data collection and integration, process and definition standardization, and management information system acquisition and implementation, etc.

This research study was initiated to develop a prototype web-based platform that can demonstrate the benefits and capabilities of asset management as a decision support tool to the senior management. The goal is to help build consensus and support for implementing asset management throughout the Department.

Existing literatures on asset management decision support tools were reviewed and a prototype platform that contains a set of enabling decision support tools and processes have been developed.

The decision support tools developed include: 1) Asset inventory report for pavement, bridges, culverts, and barriers. 2) Asset condition report for pavement, bridges, and culverts, including current condition, condition history, and predicted future conditions, 3) Asset performance report, including individual project performance and average performance of various treatment activities, 4) Investment on assets, including past capital and maintenance expenditures, and 5) Asset Planning tools, including work plan evaluation and tradeoff analysis for assessing the impact of changes in funding level, funding allocation, and treatment strategies on future asset conditions.

The developed decision support tools prototype is supported by a database that contains data provided by ODOT. Currently, the database includes data for pavement, bridge, culvert, and barrier.

Ohio's transportation assets support the state's economic development and the lifestyle of all Ohioans. The public demands greater accountability in the effective use of state funds and increased linkage of performance and funding. The developed decision support platform provides tools for ODOT officials to demonstrate such accountability and linkage. Senior management and staff at all levels within ODOT can easily access information regarding the condition and performance of major transportation assets, evaluate the impact of funding level change, and optimize funding decisions.

Potential benefits include: significant cost savings, better internal communications both vertically and horizontally, and clear and concise reporting to the public, legislatures, and state and federal governments. In addition, the prototype platform provides a proving ground for concepts and ideas prior to committing major resources for the development of a full-blown implementation. In other words, it supports the 80/20 rule, that is, get 80% of the benefits from the first 20% of effort. It also helps to identify weaknesses of existing data and process in providing decision support, so that ODOT can focus efforts on addressing those areas to achieve quick, tangible results.

Existing Research Findings

Many transportation agencies are in various stage of implementing transportation asset management. Most agencies have similar basic decision support needs, but different degrees of sophistication in terms of data availability, performance modeling, etc. The research reviewed the existing literatures on using transportation asset management for decision support in order to learn the best practices before developing the decision support tools for ODOT.

The AASHTO Transportation Asset Management Guide: A Focus on Implementation (January 2011) provides a very detailed documentation on the enabling tools and processes for level-of-service planning, life-cycle management and asset preservation, and integrated cross-asset/cross-function decision making. It recommends a top-down approach to set outcome based goals and objectives as direct measurement of the degree to which the agency and its assets are accomplishing the agency's mission. The Guide also described in-detail a number of asset management implementation case studies including those at Colorado DOT, Missouri DOT, Wyoming DOT, Florida Turn Enterprise, and New Zealand Transport Agency. The research team reviewed the examples in this Guide and in other existing literatures to find the best practices in decision support tools for executive level asset management decisions.

Figure 1 shows the framework of a transportation asset management decision support system.

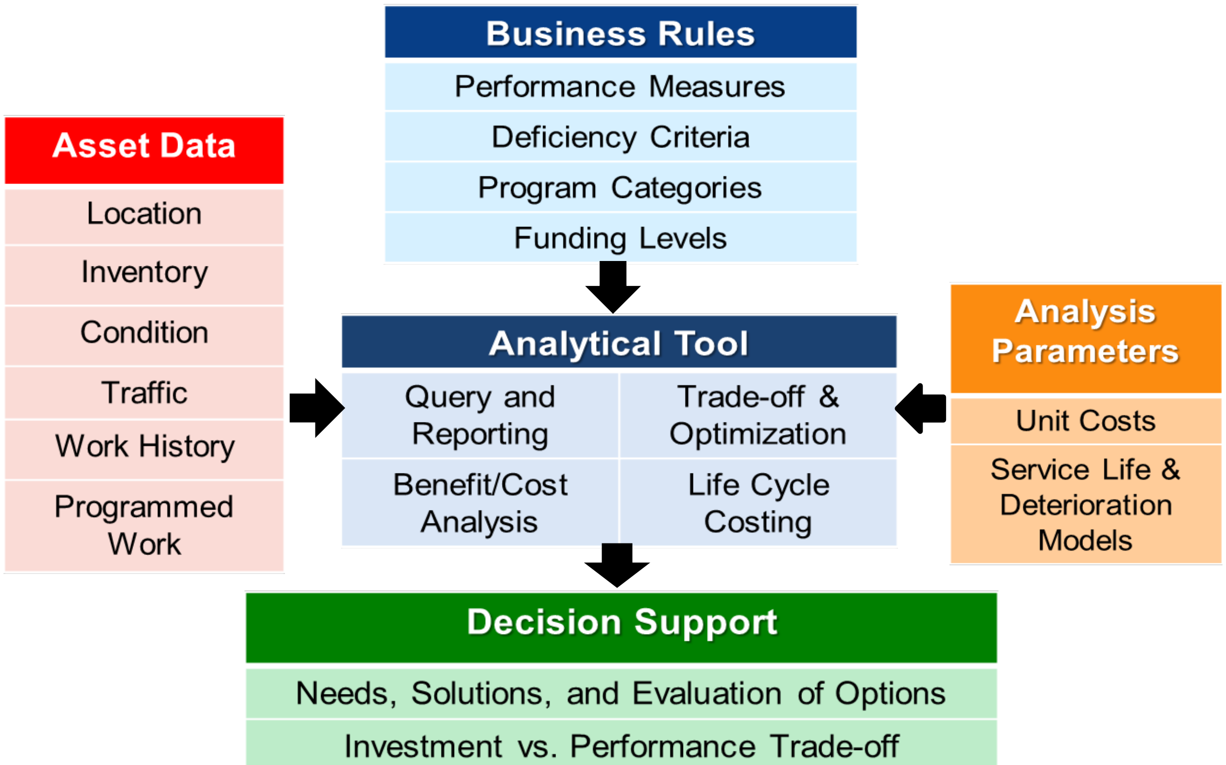

Figure 1: Context of Asset Management Decision Support Tool

(Adapted from AASHTO Transportation Asset Management Guide-A Focus on Implementation)

OBJECTIVES OF THE RESEARCH

The objectives of the original study are:

1. To develop a prototype platform that contains enabling decision support tools and processes for managing ODOT's transportation assets;
2. To develop an overall framework for the transportation asset database;
3. To develop a methodology and establish a generic criteria that allows ODOT to perform a cost/benefit analysis to determine whether or not time and efforts should be expended in data collection efforts on various assets/items;
4. To develop a framework for a work-order based process for updating asset inventory data.

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

5. To implement web-based asset management tools to support the transportation asset management and planning activities within ODOT with the ultimate goal of improving long-term asset performance.
6. To design and implement a centralized asset database that processes data from existing ODOT databases and from newly collected data to support the asset management tools.
7. To allow various ODOT Offices to access data and information in the asset database through the asset management tools via network connection.
8. To develop and implement a cross-asset optimization tool to minimize the whole life cost of preserving the major transportation assets under ODOT jurisdiction.

The objectives of the second addendum are:

9. To review existing literatures on methodologies for performing trade-off analysis.
10. To develop trade-off analysis tool for assisting transportation asset management decisions at ODOT.
11. To develop a data integration tool to combine transportation asset data from various sources within ODOT into a more uniform and searchable data set for supporting transportation asset management decisions.

GENERAL DESCRIPTION OF RESEARCH

The original research project consists of the following tasks:

- Task 1: Review of Existing Literatures and Identify the Decision Support Tools Desired
- Task 2: Determine the Data Required and Availability of Data in Existing ODOT Databases
- Task 3: Design the Framework of a Centralized Asset Database
- Task 4: Develop and Validate the Decision Support Tools
- Task 5: Develop a Methodology for Benefit/Cost Analysis of Data Collection Efforts
- Task 6: Develop the Framework for a Work-Order Based Process to Update Asset Inventories
- Task 7: Prepare and Submit Draft Final Report

The first addendum added the following tasks:

- Task 8: Specification of the User Interface and Output Requirements
- Task 9: Design and Implement a Centralized Asset Database to Support Web-based Front End
- Task 10: Literature Search in the area of Cross Asset Optimization Models
- Task 11: Implementation of the Asset Management Software Tools

The second addendum added following tasks:

- Task 12: Literature Search on Trade-off Analysis Methodologies
- Task 13: Selection of Methodology for Implementation
- Task 14: Design and Implementing the Trade-off Analysis Tool
- Task 15: Development of the Data Integration Tool
- Task 16: Documentation and Training

The above tasks are further described in the following paragraphs.

Task 1: Review of Existing Literatures and Identify the Decision Support Tools Desired

A detailed literature review was conducted to identify the best practices among other transportation agencies on enabling asset management decision support tools. Table A1 in Appendix A summarizes the literature review results on asset management decision support tools.

In collaboration with the ODOT project technical liaisons, the research team then identified the tools that are most likely to be useful to ODOT. These tools include: 'Dash board' style monitoring of the condition and key performance indicators of major assets, projected future conditions based on known performance trends, projection of future asset maintenance and rehabilitation costs and the corresponding asset condition, identification of asset replacement needs within a given time frame, coordination of projects among multiple assets to achieve cost savings and minimizing traffic disruptions.

Task 2: Determine the Data Required and Availability of Data in Existing ODOT Databases

The data required and available in the existing ODOT pavement database to support the decision support tools identified in Task 1 were reviewed. With assistance from ODOT's Office of Technical Services, Office of Structure Engineering, and Information Technology, the research team obtained the following data files from various existing databases: roadway inventory, project history, pavement condition, bridge condition, culvert condition, and barrier inventory. Future work plans were also obtained from the Office of Program Management, and maintenance history data (TMS) were also provided by the Office of Technical Services.

These original data were provided in either flat data files or Excel spreadsheets. These data were processed by the research team initially into Microsoft Access database files. Later on, the Access database files were imported into Microsoft SQL Server database. The maximum amount of data that can be stored in a single Access database is 2 GB. SQL Server database doesn't have such size limitation. Currently, the SQL Server database has about 13 GB of data.

Task 3: Design the Framework of a Centralized Asset Database

It was envisioned that a centralized transportation asset database that contains all the data required by the decision support tools would be populated from existing databases. Such a database would be able to accommodate additional data, including data that have not been collected in the past. This centralized asset database may also support other future asset management activities beyond the scope of the proposed project. Figure 2 shows the framework of such a centralized asset database.

Task 4: Develop and Validate the Decision Support Tools

A set of decision support tools were designed and developed, based upon the results of Tasks 1, 2, and 3. A web-based prototype platform was designed to host the tools and to have a consistent user interface for user to generate graphical and/or tabular reports/presentations based either on data queried from the asset database or calculated through various analytic models.

The initial set of tools includes Asset Inventory, Current Condition and Condition History of Pavement and Bridge Assets, Project History, Project Performance, Average Performance of Treatment Activities, and Planned Work. Through two addendums to the original project, additional tools were added subsequently. The research team worked with the Project Technical Liaison in testing and adapting the developed tools, and made arrangement with ODOT's Information Technology Division to host the developed prototype decision support tools and the backend database on ODOT intranet server.

Figure 3 shows the opening screen shot of the prototype decision support tools web site. The ribbon menu at the top shows decision support tool functions have been group into several categories, including: Inventory, Condition, Performance, Investment, and Planning. A detailed description of each function within these categories can be found in Appendix B.

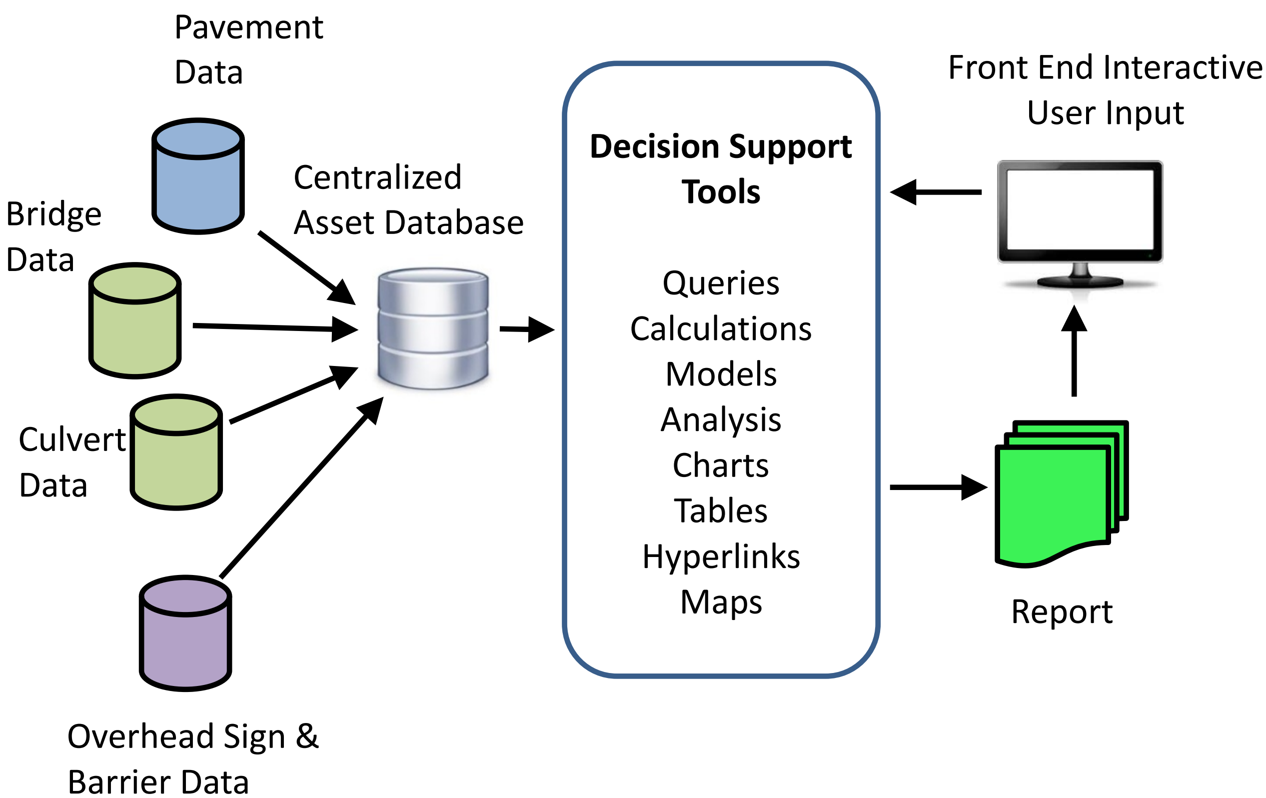

Figure 2: Framework of an Asset Management Decision Support System

Figure 3: TAMDSTP Web Site Portal

<u>Task 5: Develop a Methodology for Benefit/Cost Analysis of Asset Data Collection Efforts</u>

In order to evaluate whether or not the resources required for a specific asset data collection effort are justified, a methodology for benefit/cost analysis of data collection efforts was developed. This methodology establishes a generic criterion for ODOT to follow in order to determine whether or not time and effort should be expended on collecting a specific asset data.

The cost of collecting a specific asset data may include data collection equipment costs, labor costs, software and data storage/processing, and data analysis costs, etc. The overall cost of data collection depends upon the type of data to be collected and the frequency of such collection. The benefits of asset data collection include maintenance and replacement cost savings as a result of better planning and more informed decision making due to availability of quality asset information, and improved safety due to condition monitoring of assets such as culverts, lightings, guardrails, overhead signs, etc. Some of the benefits are difficult to quantify accurately. Therefore, the annual benefits are estimated as a percentage of the annual expenditures on the specific asset.

An Excel spreadsheet has been developed to demonstrate the benefit/cost analysis methodology. The Net Present Value, Benefit-Cost Ratio, and Rate of Return on Investment can be calculated for a specific data collection effort when the estimated costs and benefits are given.

<u>Task 6: Develop the Framework of a Work-Order Based Process to Update Asset Inventories</u>

Accurate, up-to-date, and usable asset inventory data are required to support asset management decisions. However, collecting and constantly updating such data involve tremendous efforts, especially for assets that are replaced or relocated on a regular basis. A process that updates asset inventories based on work-order and verified work-performed is necessary to keep the asset inventory data updated. This task focused on sign and culvert assets, but the process can be applied to other assets. The research team worked with the Office of Technical Services staff to understand the current status of data governance within ODOT and developed a recommended framework for a work-order based process to update asset inventories.

Task 7: Prepare and Submit Draft Final Report

A draft final report documenting the findings of the above tasks has been prepared and submitted for ODOT review.

Task 8: Specification of the User Interface and Output Requirements

Meetings with ODOT Staff were held to determine the specific functional details of the tools and the detailed specifications of the user interface and input/output requirements. ODOT Staff evaluated the prototype as it was being developed and a number of modifications and improvements were made based on their comments and suggestions.

Task 9: Design and Implement a Centralized Asset Database to Support Web-based Front End

Based on currently available data for various assets and anticipated future needs, an asset database was designed to support asset management and planning activities. A Microsoft SQL database was created to incorporate the various data received. However, the research team found that the data received from various ODOT Offices have inconsistent terminology, format, and reference system. Therefore, the data received often require significant amount of processing and checking before the data can be incorporated into the asset database. ODOT has recognized this issue and is currently addressing the data standardization, coordination and integration through its Data Governance process. In the meantime, the research team proposed the development of a data integration tool to help reduce the data processing effort. This is discussed in Task 15.

Task 10: Literature Search in the area of Cross Asset Optimization Models

Existing literatures on cross-asset optimization methodologies were reviewed. The results are summarized in Table A2 of Appendix A. A network-level condition prediction and optimization tool for pavement asset was developed as a result of a previous research project. A similar condition prediction model was developed for bridge asset for this project. These network-level condition prediction models lay the foundation for cross-asset coordination, optimization, or tradeoff analysis between the two major assets: pavement and bridges.

Task 11: Implementation of the Asset Management Software Tools

The software tools were implemented using Microsoft .NET Platform according to the specifications and requirements from Task 8. The front-end user interface is supported by a SQL Server database. A number of technical difficulties, most notably the displaying of dynamically generated condition map quickly, were encountered and eventually overcome and resolved by the research team. The tools developed were tested by the research team and ODOT staff, and revisions were made based on comments received.

Task 12: Literature Search on Tradeoff Analysis Methodologies

Existing literatures on tradeoff analysis were reviewed. Research documents, especially those documenting methodologies and/or practices at other transportation agencies for performing tradeoff analysis at various levels such as strategic level, system level, and project level were reviewed and summarized. Table A3 in Appendix A shows a summary of the literatures reviewed on tradeoff analysis methodologies. The more popular methodologies for Tradeoff Analysis include: Linear Programming, Goal Programming, Analytical Hierarchy Process, and Multiple-Attribute Utility Theory.

Task 13: Selection of Tradeoff Methodology for Implementation

Meetings with ODOT staff were held to discuss the specific needs within ODOT where tradeoff analysis would be most useful. The required functionalities of the trade-off analysis were determined. Two methodologies were selected as the tradeoff analysis methodologies for this study: the Linear Programming (LP) method and the Analytical Hierarchy Process (AHP) method. The LP method is the most widely used optimization technique, where a single linear objective function is maximized or minimized subject to a set of linear constraints. In order to use LP for Tradeoff Analysis among competing objectives, one main objective is selected as the objective function, and the other objectives are defined as constraints. The advantage of this approach is that a defined LP problem can be solved very efficiently using widely available, robust solver. The disadvantages of the LP approach are that the objectives must be expressed quantitatively and the threshold values for those objectives defined as constraints must be given by the user.

In contrast, the AHP method can accommodate both quantitative and qualitative objectives/criteria. Therefore, since its development in 1980s, it has been widely used for multi-objective decision making. It's an intuitive approach and has been recommended for transportation management trade-off analysis by AASHTO. AHP uses pair-wise comparison to determine the relative weights among multiple criteria/objectives. A more detailed description of the AHP methodology can be found in Appendix C of this report.

Task 14: Design and Implementing the Trade-off Analysis Tool

Based on the results of Tasks 12 and 13, a tradeoff analysis tool was designed and implemented within the existing TAM Decision Support Tool Prototype under the category of Planning. The Tradeoff Analysis tool includes both a Network Level Tradeoff function and a Project Level Tradeoff function. The Network Level Tradeoff function allows decision makers to see the impact of different budget allocations, such as between pavement and bridge assets, on future asset conditions. The Project Level Tradeoff function allows decision makers to 'rank' future projects by multiple criteria, such as asset condition (PCR for pavement or GA for bridges, for example), safety (e.g, rut depth), traffic level (ADT), and economic impact (e.g., TADT). The user can change the relative importance of criteria and/or the thresholds of the parameter(s) used in each criterion. Some sample results are presented in the Findings section of this report.

Task 15: Development of the Data Integration Tool

A data integration tool was developed to facilitate updating the asset database. This tool helps to verify whether or not the new data received match all the attributes (item name, format, etc.) of the existing data in the database, so that the new data can be merged with the existing data.

Task 16: Documentation and Training

The developed asset management decision support tools prototype has been documented in a user's manual, which is included as Appendix B of this final report. A training course for ODOT Staff may be conducted at the ODOT Central Office before the conclusion of the project. Additional demonstrations/trainings may be performed if deemed necessary.

FINDINGS OF THE RESEARCH EFFORT

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

I. Transportation asset management decision support tools prototype
II. Network Level and Project Level Tradeoff Analyses
III. Methodology for benefit-cost analysis of data collection effort
IV. Framework of a work-order based asset inventory updating process
V. Data Integration Tool

I. Transportation asset management decision support tools prototype

Implementing transportation asset management is a process of continuous improvement. The importance of senior management support cannot be overstated. The benefit of asset management as a decision support tool for making crucial funding decisions, planning budget trade-offs, monitoring asset performance, reducing asset life-cycle costs, and optimizing resource allocations may not be as apparent as the investments required for data collection and integration, process and definition standardization, and management information system acquisition and implementation, etc. An easily accessible platform that can demonstrate the benefits and capabilities of asset management as a decision support tool to the senior management is highly valuable in building consensus and support for implementing asset management throughout the Department.

A Transportation Asset Management Decision Support Tool Prototype has been developed as a result of this study to serve the purpose described above. Figure 5 shows an overview/outline of the tools/functions developed for this comprehensive, functioning Prototype. As shown, the decision support tools are grouped into five categories: inventory, condition, performance, investment, and planning. Each of the tools developed are described in this section. A detailed User Guide with example screen shots can be found in Appendix D of this report.

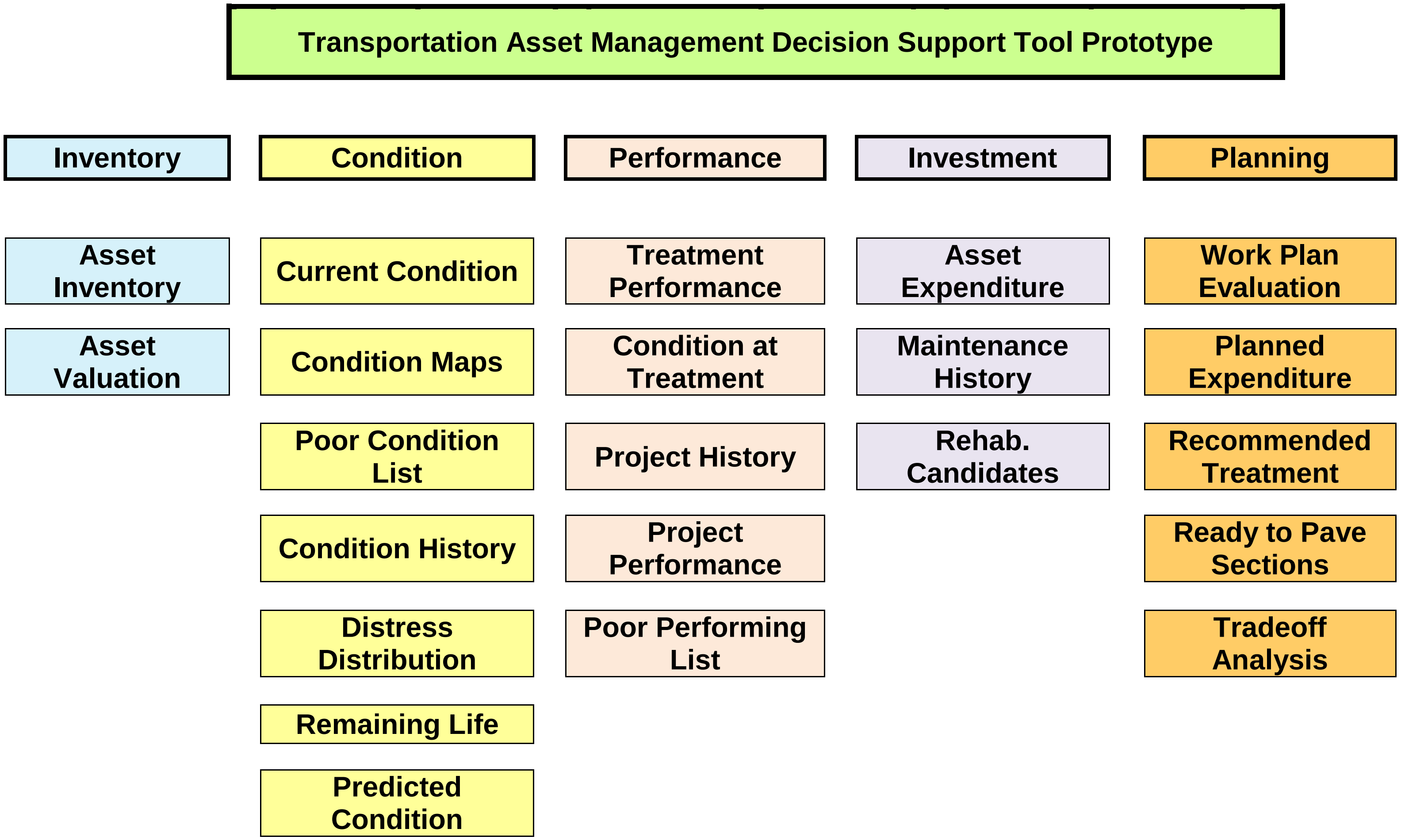

Figure 4: Overview of the TAM Decision Support Tool Prototype

Inventory

Two functions: Asset Inventory and Asset Valuation are included in this category. Asset Inventory includes inventory information of four major assets: pavement, bridge, culvert, and barrier. They can be queried based on (1) System, i.e. Interstate routes (IR), US routes (US), or State routes (SR), (2) Priority, i.e., Priority, General, or Urban routes, (3) Districts, (4) County, and (5) Routes. A specific query will generate a summary bar chart, which is hyperlinked (i.e., 'clickable') to reveal the detailed inventories. The detailed inventory tables can be exported to an Excel spreadsheet. The query menu and the hyperlink feature are consistent for most of the other functions in the developed Decision Support Tool Prototype.

Asset Valuation function includes similar features of the Asset Inventory function, but the total value of the selected assets is estimated based on the user modifiable asset replacement unit costs. The default replacement costs for pavement and bridge assets are $1,250,000 per lane-mile of pavement and $150 per square feet of bridge deck area.

Condition

The functions within this category include: (1) Current Condition, (2) Poor Condition List, (3) Condition History, (4) Distress Distribution, (5) Remaining Life, and (6) Predicted Condition.

The Current Condition function shows the current conditions of selected pavement, bridge, and culvert assets, in a color-coded GIS map and summarized the result in a bar chart. The User can drill down more details by clicking on a color-coded roadway segment (or bridge or culvert) in the map to bring up a pop-out window that shows the location and identification information such County, Route, Log, and detailed distresses. If the user clicks on a portion of the color-coded bar chart, a list of assets in that specific condition category will be displayed below the GIS map.

The Poor Condition List will generate a list of assets meeting the (poor) condition criteria given by the user.

The Condition History function shows the PCR history plot of any pavement segment selected by the user, given the County, Route, and Log points.

The Distress Distribution function allows the user to select a group of pavement segments, and then shows the percentages of pavements affected by each distress. The resulting bar graph is color-coded to show the extent and severity of each individual distress. A table below shows the detailed breakdown of distresses.

The Remaining Life function shows the remaining life of selected pavements in either a pie chart or a bar chart, grouped into categories of: zero remaining life, 1-5 years, 6-10 years, 11-15, years, 16-20 years, and 20+ years of remaining life.

The Predicted Condition function shows the predicted condition of selected pavements or bridges in a bar chart, categorized by condition states of Excellent, Good, Fair, Poor, and Very Poor. The predicted Average PCR values are also shown. Similar to Current Condition, the bar chart is hyperlinked to a list of pavements in the specific condition state. The predicted PCRs for a pavement segment in future years are displayed and if the user clicks on a PCR value, the corresponding distresses will be displayed. The condition prediction for pavement was developed as a result of a previous research study, Pavement Forecasting Models. However, the bridge condition prediction was developed in the current study.

Performance

The functions within Asset Performance category includes: (1) Treatment Performance, (2) Condition at Treatment, (3) Project History, (4) Project Performance, and (5) Poor Performing List.

The treatment performance function shows the average performance of a pavement treatment activity for a selected grouped pavements, such as for average performance of asphalt overlay on Priority system pavements in a District.

The Condition at Treatment function shows the average pavement condition (PCR) and distresses prior to a selected treatment activity in each District. This helps to explain differences in treatment performance among Districts and allows assessment of treatment timing decisions.

The Project History function shows all the previous pavement and bridge project performed on a stretch of highway. Pavement projects are shown color-coded line segments with different color denoting different treatment activities and bridge projects are shown as black dots. The resulting diagram is similar to ODOT's straight-line-diagram, but with the added benefits that when a specific pavement or bridge project are clicked upon, the details of that specific project will be displayed.

The Project Performance function allows the user to search for a specific project by its Project Number (PN) or Project ID (PID) and sees the pavement conditions (PCRs) trend after that project.

The Poor Performing List function will display a list of poor performing pavement sections based on the deterioration rates (PCR drops) and the number of rehabilitation treatments performed during a time period. The criteria for 'poor performing' can be modified by the user.

Investment

The Asset Investment functions include: (1) Asset Expenditure, (2) Maintenance History, and (3) Rehabilitation Candidates.

The Asset Expenditure function shows all the capital as well as maintenance expenditures that have been invested on a selected highway or groups of highways, such as for an entire District. The expenditure includes both pavement and bridge project costs.

The Maintenance History function shows a summary of maintenance expenditure for a selected pavement or a group of highways. Detailed maintenance expenditure and work performed are hyperlinked and can be displayed with a single click.

The Rehabilitation Candidates function will display a list of candidate pavement sections for rehabilitation based on ODOT's pavement rehabilitation treatment decision logic.

Planning

The Asset Planning category includes: (1) Work Plan Evaluation, (2) Planned Expenditure, (3) Recommended Treatment, (4) Ready-to-Pave Sections, and (5) Tradeoff Analysis.

The Work Plan Evaluation function allows the user to see the impact of the current work plan on predicted future network-level pavement and bridge conditions. The user can modified the current work plan by adding or removing planned projects and the effect on future pavement and bridge network conditions can be evaluated.

The Planned Expenditure function shows the planned capital expenditure on both pavement and bridge for a group of highways such as for all General system highways within a District according to the current work plan.

The Recommended Treatment function shows the recommended rehabilitation treatment activities for a group of pavements such as for all Priority system pavements within a District. The recommendations are based on ODOT's pavement rehabilitation treatment decision logic.

The Ready-to-Pave function displays the pavement sections that are planned for rehabilitation within the next few years, so that the Districts may perform only temporary or short-term fixes to these pavements.

The Tradeoff Analysis function is a major function developed in this study. It includes both a Network Level Tradeoff function and a Project Level Tradeoff function. The Network Level Tradeoff comprises tradeoff between funding level and future network condition. The Project Level Tradeoff involves ranking of proposed projects based multiple competing needs. The two tradeoff analyses are described in detail in the next section.

II. Network Level and Project Level Tradeoff Analyses

Tradeoff analysis is an important part of transportation asset management, particularly in a constrained budget environment such as now. The available asset preservation funds are usually insufficient to keep every asset component at the ideal condition level. Therefore, tradeoffs must be made for budget level versus asset performance, budget allocation between assets, and among competing projects.

This study developed tradeoff analysis functions to perform the following types of trade-offs analysis:

1. Tradeoff between budget and asset performance. This helps decision maker evaluate the budget invested on an asset (such as the Priority system pavements) versus its performance.
2. Tradeoff between different types of assets. This allows decision makers to evaluate the impact of different budget allocations between pavement and bridge assets on their future performance.
3. Tradeoff among competing projects. This ranks the competing projects based on multiple objectives such as asset preservation, safety improvement, congestion reduction, and economic development.

Tradeoff analysis generally involves multiple criteria – for example, cost and performance are often the two most common competing criteria. Different performance criteria often must be considered simultaneously before making a decision. Various multiple criteria decision-making methodologies have been develop to help with tradeoff analysis. This research study reviewed the existing research literatures on tradeoff analysis, and developed a tradeoff analysis tool customized for ODOT's needs.

At the network level, the impact of investment decisions on the two major asset categories: pavement and bridge on future asset condition levels can be determined. The optimal resource allocation among these two assets can be found by maximizing the selected performance measures resulting from the resource allocation, subject to budgetary constraints. The minimum budget required to maintain the pavement and bridge assets at the desired level of condition can also be determined.

At the project level, asset rehabilitation needs (i.e., proposed projects) are prioritized based on multiple criteria, and the work plan can be evaluated or modified as a result of changing budget level scenarios and tradeoffs can be evaluated.

A. Network Level Tradeoff Analysis

The Network Level Tradeoff Analysis generally comprises of tradeoff between funding level and future network condition. For pavement network and bridge network, respectively, the amount of budget invested directly affects future network conditions. Therefore, for a given total budget, the amounts allocated to pavement asset and to bridge asset will impact the future network condition of each asset.

It is assumed that the budgets allocated to both pavement and bridge assets will be spent prudently to achieve the highest possible overall network condition for each asset category. This is achieved through an underlying optimization model which uses Markov Condition Transition and Linear Programming optimization technique. The pavement network optimization model was developed and documented in a previous ODOT research study entitled: "Benefit Cost Models to Support Pavement Management Decisions". The bridge network optimization model uses a similar approach and was developed based on the bridge condition prediction model developed during this study.

In this research study, pavement network and bridge networks are optimized separately for the given budget allocation. The pavement network optimization model is described below:

Objective function:

The objective is to maximize the overall pavement network condition given a budget.

Maximize overall pavement network condition:

$$\sum_{t=1}^{T}\left[\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{g=1}^{G} X_{mig} * PCR_i\right] \qquad . . . (1)$$

where PCR_i = mid-value of the PCR range for the pavement condition state *i*

M = Pavement Type (Flexible, Rigid, Joint Concrete)

I = Pavement Condition States (Excellent, Good, Fair, Poor, very Poor)

G = Pavement treatment types (Do Nothing, Preventive, Thin Overlay, Minor, Major)

T = Number of Analysis years

X_{mig} = Percentage of pavement type *m* at condition *i* receiving the treatment type *g*

Constraints:

a) Sum of decision variables is one for each year. This constraint ensures that the decision variables in the optimization model represent the whole selected network.

$$\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{g=1}^{G} X_{mig} = 1 \ \textit{for all } t = 1,\ldots, T \qquad . . . (2)$$

b) Initial condition constraints assign the current condition distribution of the network to the optimization model.

$$\sum_{g=1}^{G} X_{1mig} = P_{mi} \ \textit{for all } m = 1, \ldots, M ; i = 1, \ldots, I \qquad . . . (3)$$

where P_{mi} = percentage of pavement type *m* in state *i* in current year

c) State transition constraints to assign the Markov prediction model

$$\sum_{g=1}^{G} X_{tmig} = \sum_{i=1}^{I}\sum_{g=1}^{G} X_{m(t-1)ig} * P_{pmgik} \ \textit{for all m=1, …, M; t=2, … , T; k=1, …, I} \quad . . . (4)$$

where P_{pmgik} = probability of pavement type *m* receiving treatment *g* moves from state *i* to *k*

d) Budget Constraints

$$\left[\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{g=1}^{G} X_{mig} * Unit\_Cost_{mg} * Total\_LaneMiles\right] \leq pBudget \ \textit{for all t=1, … ,T} \quad . . . (5)$$

where pBudget is the annual allocated budget for pavement network

e) Allowable Treatment constraints

$$X_{migt} = 0 \ \textit{for all t= 1, …, T ; Selected m,i,g} \quad . . . (6)$$

f) Non-negativity constraints

$$X_{migt} \geq 0 \ \textit{for all m,i,g and t} \quad . . . (7)$$

g) Deficiency Constraint (Poor and Very Poor) (optional)

The condition states *I* and *I-1* represent Poor and Very Poor condition states for pavement.

$$\sum_{m=1}^{M}\sum_{i=I-1}^{I}\sum_{g=1}^{G} X_{mig} \leq deficiency_{pt} \ \textit{for all t=2, … , T} \quad . . . (8)$$

Where $deficiency_{pt}$ = deficit target for pavement at the year t (i.e. sum of percentage pavement in poor and very poor condition)

The model in this report considers three pavement types, namely flexible, rigid and jointed concrete, each with its unique average deterioration trends. The pavement network condition is classified by five condition states: excellent, good, fair, poor, and very poor. Currently, the model includes five treatment categories for pavement: do nothing, preventive maintenance, thin overlay, minor rehabilitation, and major rehabilitation.

The bridge network optimization model has similar formulation to the pavement network model, except that separate deterioration trends for three different materials: (1) metal (steel) bridge, (2) reinforced concrete bridge, (3) timber bridge are determined using historical bridge General Appraisal (GA) scores.

Figure 5 shows the user interface for changing or updating (1) the available budget, (2) the average unit cost of treatment, and (3) allowable treatment types. The example shown is for Priority system highways.

1) Tradeoff between Budget Level and Performance Indices

Given a set of average unit cost and allowable treatments for pavements and bridges in the Priority and General systems (the default values are shown in Figure 6), the average Pavement conditions after 10 years for both Priority and General systems with different annual budgets are shown in Figure 7. The average unit cost of various treatments and the allowable treatment can be revised by the user.

Figure 7 shows that, as an example, based on the assumed average unit costs of treatment and the historical deterioration trends, the statewide Priority system pavement network would need an annual budget of approximately $280 million (in 2016 dollars) to maintain the average PCR at its 2016 level (Average PCR about 86) ten years from now. The General system pavement network has an average PCR of 81.5 in 2016. The annual budget level required to maintain the average PCR at 81.5 ten years from now is approximately $385 million (in 2016 dollars). Note that these required budgets are based on the assumptions shown in Figure 6 where thin overlays are allowed on Priority system pavements when the condition is Good (PCR between 84 and 75) or Fair (PCR between 74 and 65), while Chip Seals are not allowed on General system pavements. These assumptions can be changed by the user and would lead to different results.

Different time frames can be chosen by the user. This tool enables decision makers to evaluate the impact of investment level on future network condition. The network chosen may be a single District, in order to determine the required District budget.

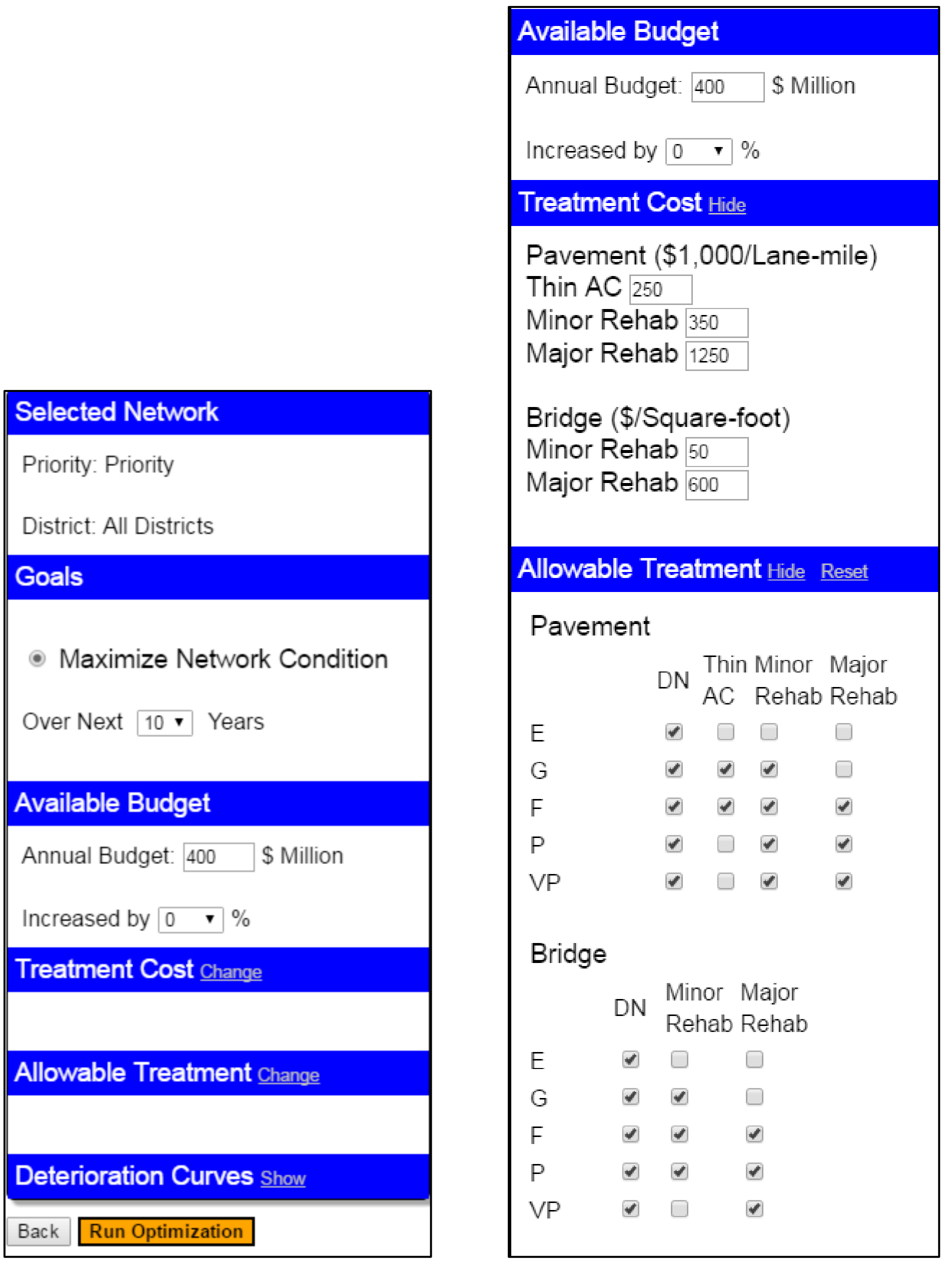

Figure 5: Interface for changing or updating (1) the available budget, (2) the average unit cost of treatment, and (3) allowable treatment types for Priority system highways

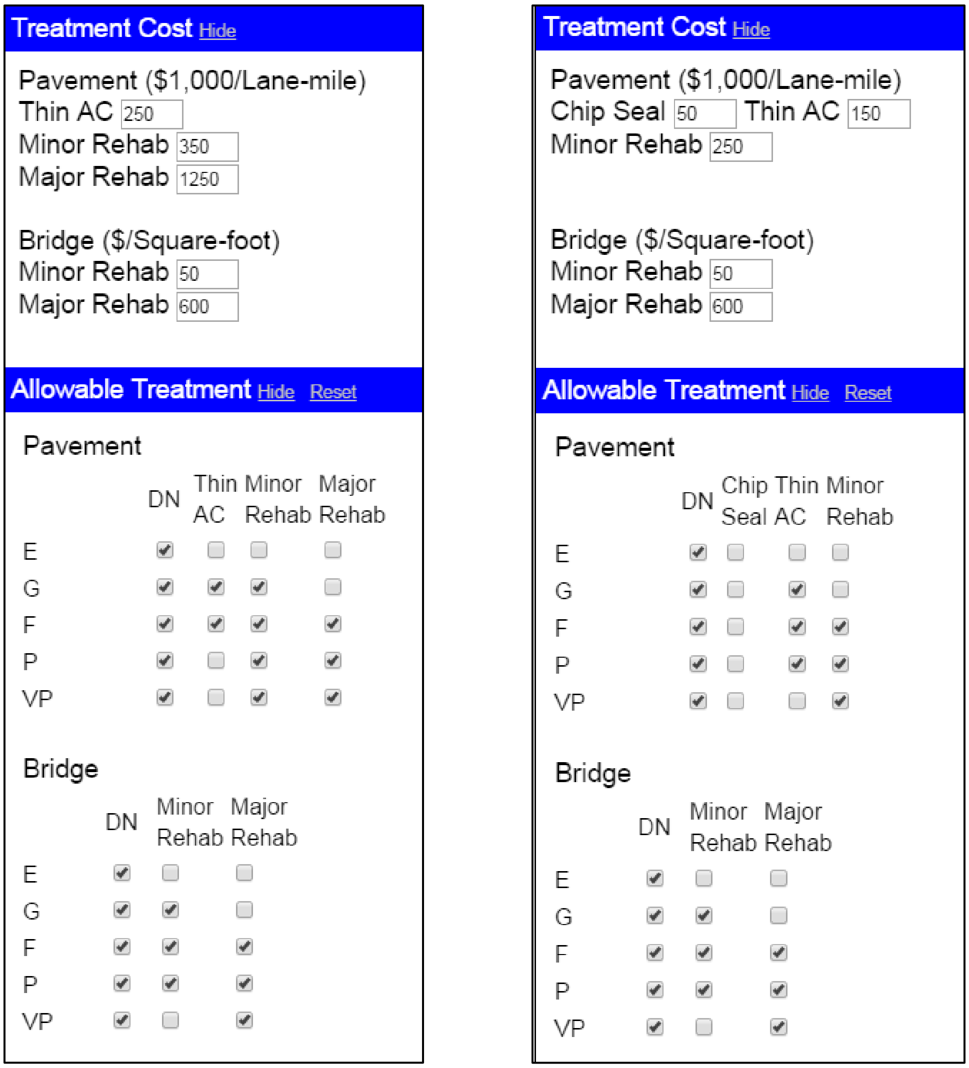

Figure 6: Default values for treatment unit cost and allowable treatments for Priority and General systems respectively

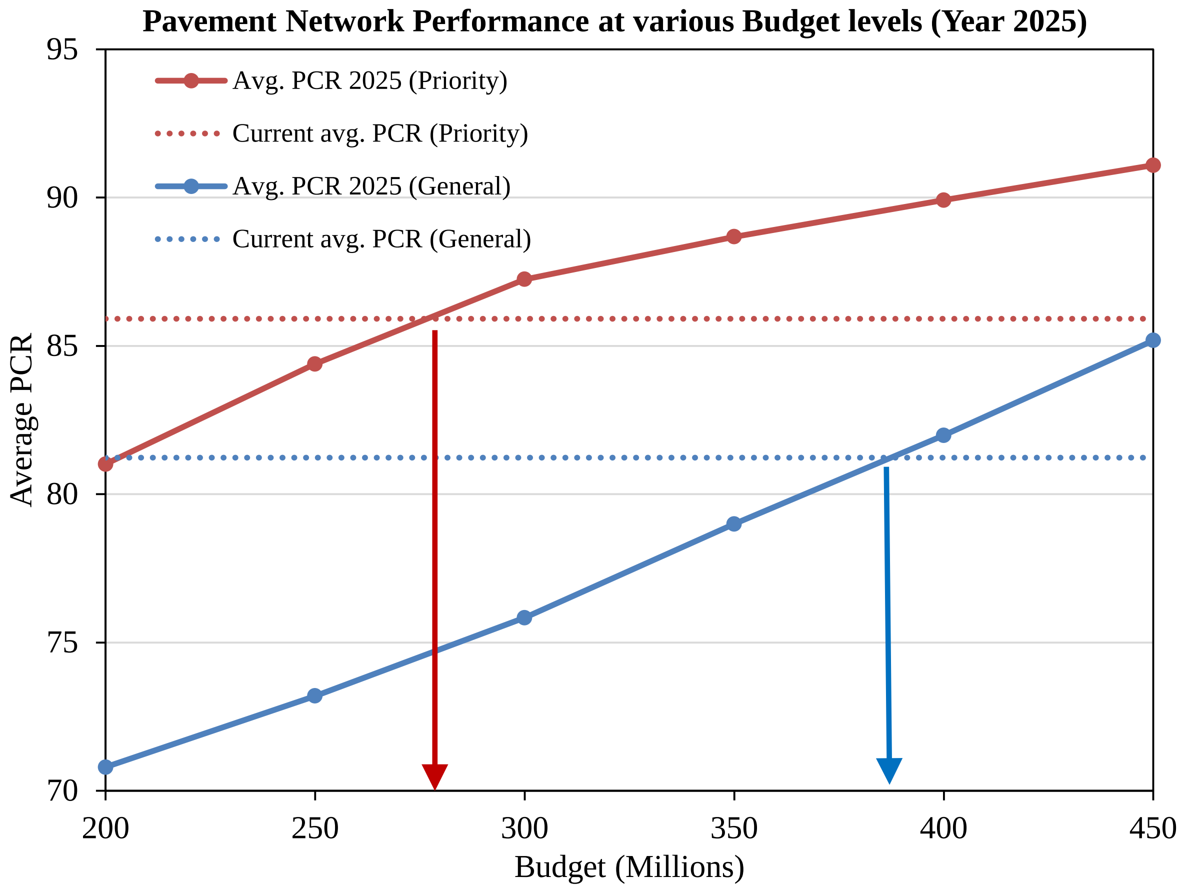

Figure 7: Average PCR score of the pavement network after 10 years at various budget levels for both Priority and General Systems

Pavement network condition can also be summarized by the percentage of pavements within the network that are 'deficient' – in this study 'deficiency' is defined as in Poor or Very Poor conditions. Note that throughout this report, a pavement in Excellent condition means its PCR is from 85 to 100, Good condition means PCR is from 75 to 84, Fair (65-74), Poor (55-64), and Very Poor is 54 or below. Therefore, "deficient' means PCR below 65.

Figure 8 shows that in 2016, about 1.7% of the pavements in the Priority system are considered as 'deficient', whereas about 7.7% of the pavements in the General system are deemed 'deficient'. As the annual budget increases, the percentage of pavements that will be deficient ten years from now decreases. To keep the deficiency level at or below its current level, the Priority system requires about $270 million of annual budget, and the General system requires about $390 million of annual budget. Both are in constant 2016 dollars.

The budget levels required to maintain the average PCR score are fairly close to the budget levels required to maintain the deficiency level ($280 M versus $270 M and $385 versus $390, respectively for Priority and General systems, even though the two condition indicators are not exactly the same.

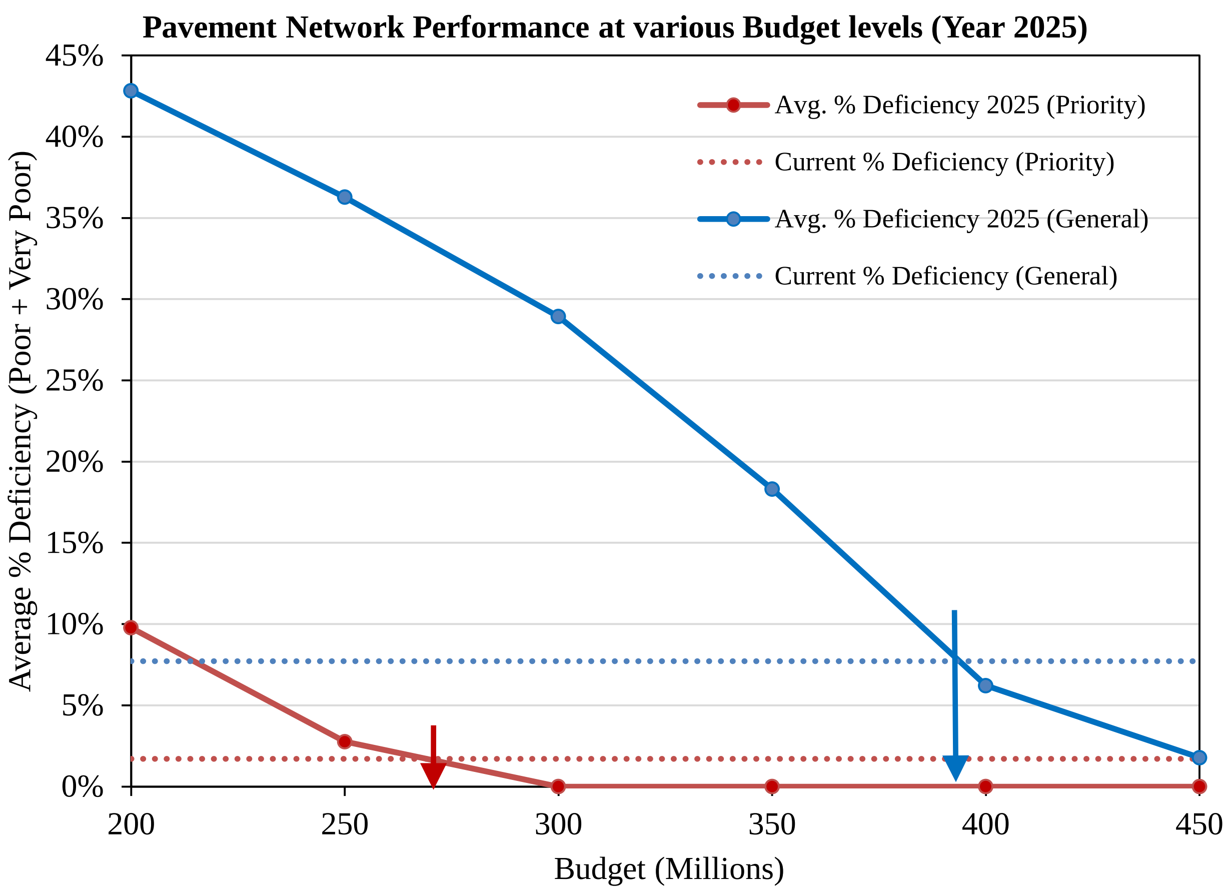

Figure 8: Average % deficiency for pavement network after 10 years at various budget levels for Priority and General Systems

2) Tradeoff for Budget Allocations between Asset Classes

The developed Network Level Tradeoff function enables the user to apply different budget allocations between pavement and bridge assets and view the resulting future network condition for each asset. Through this iterative process, an optimal allocation can be determined. Other important parameters that can be set by the user include: (1) overall budget available, (2) allowable treatment activities at a particular asset condition level, (3) unit cost of treatment activities.

Given an assumed total annual budget of $400M for Priority system and with the given allowable treatments and rehabilitation treatment unit costs as shown in Figure 6, Figure 9 shows the current conditions of Priority system pavement and bridge assets and a tradeoff bar allowing the user to apply different allocations of the available annual budget. The current average PCR of the Priority system pavements is about 86 and the current average GA is 6.5. In this hypothetical example, an allocation of $340 M to the pavement assets and $60 M to the bridge assets is assumed. Figure 10 shows how these allocated budgets would be spent to achieve the maximum network conditions. In this example, pavement asset is allocated a lot more budget than bridge assets, due to pavement deteriorates much faster than bridge, therefore, with a 10 year analysis period, the impact of funding levels is more pronounced for pavement asset than for bridge asset.

Figures 11 and 12 show the predicted network conditions of the pavement and bridge assets, respectively.

Figures 13-19 show a similar example of budget tradeoff between pavement and bridge assets for the General system. The total available budget is assumed to be $420 M.

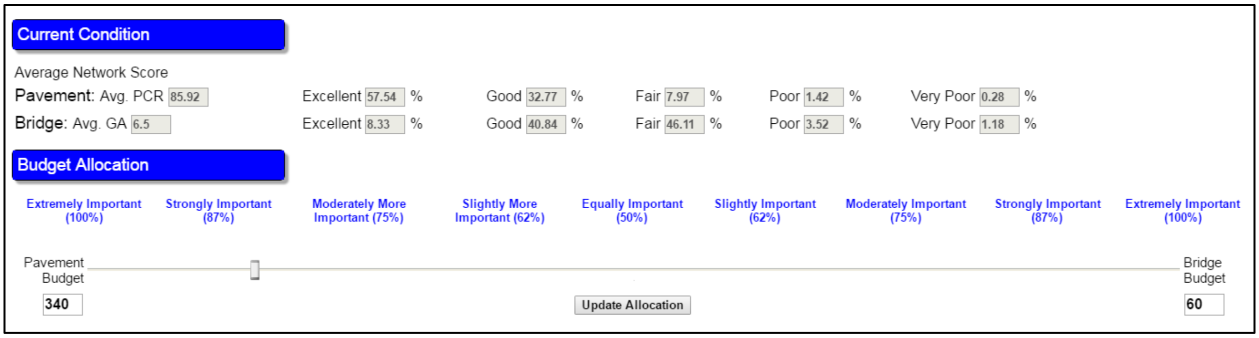

Figure 9: Current condition of Priority system and trade-off bar

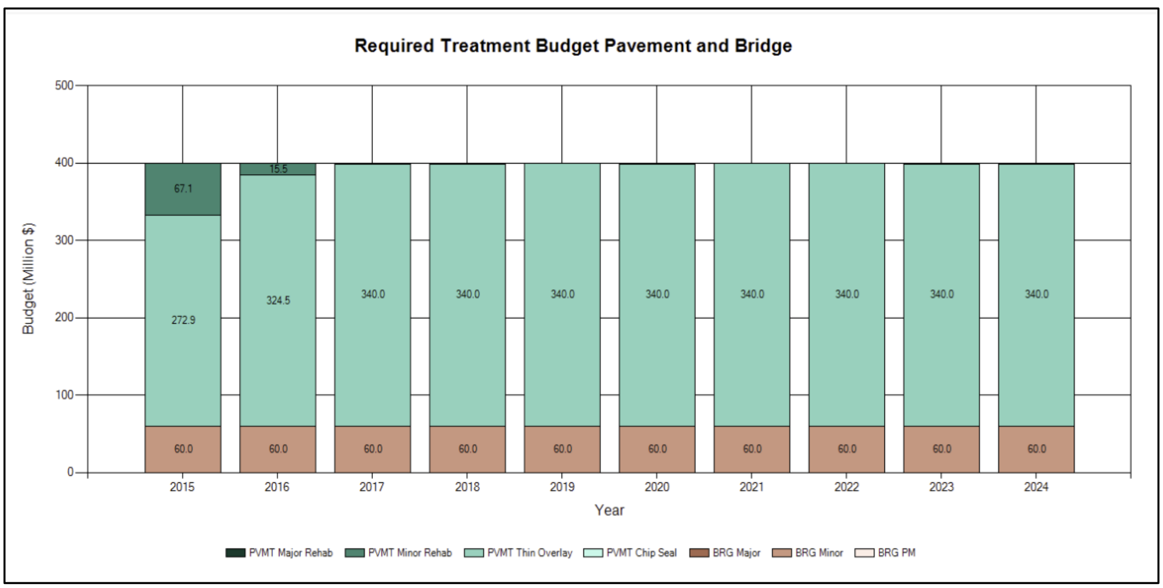

Figure 10: Budget allocation graph for Priority system between Pavements and Bridge

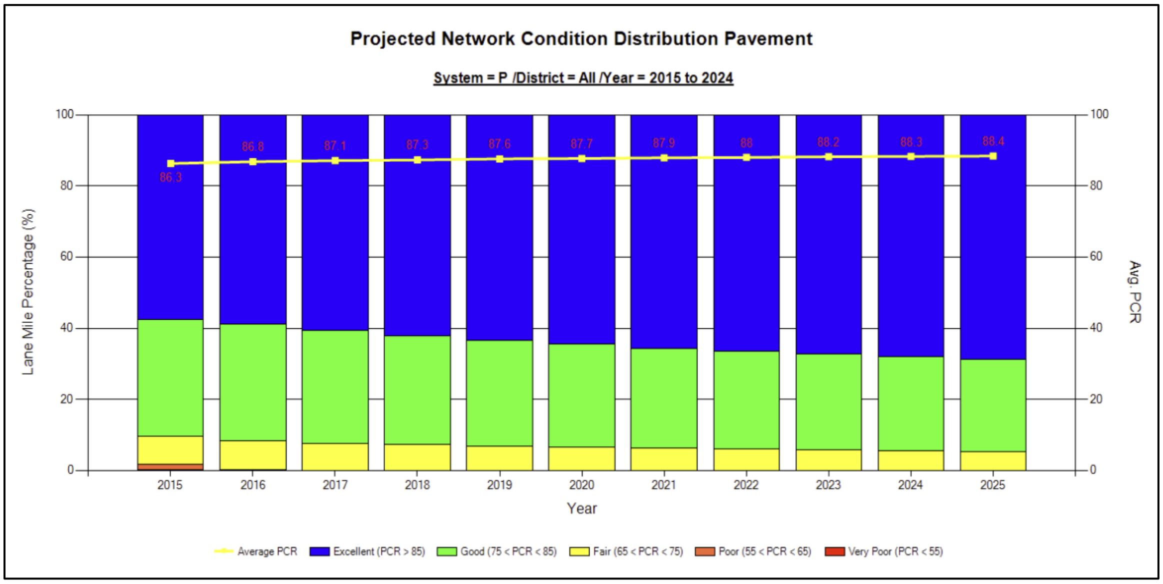

Figure 11: Priority system predicted condition distribution bar chart for Pavement network

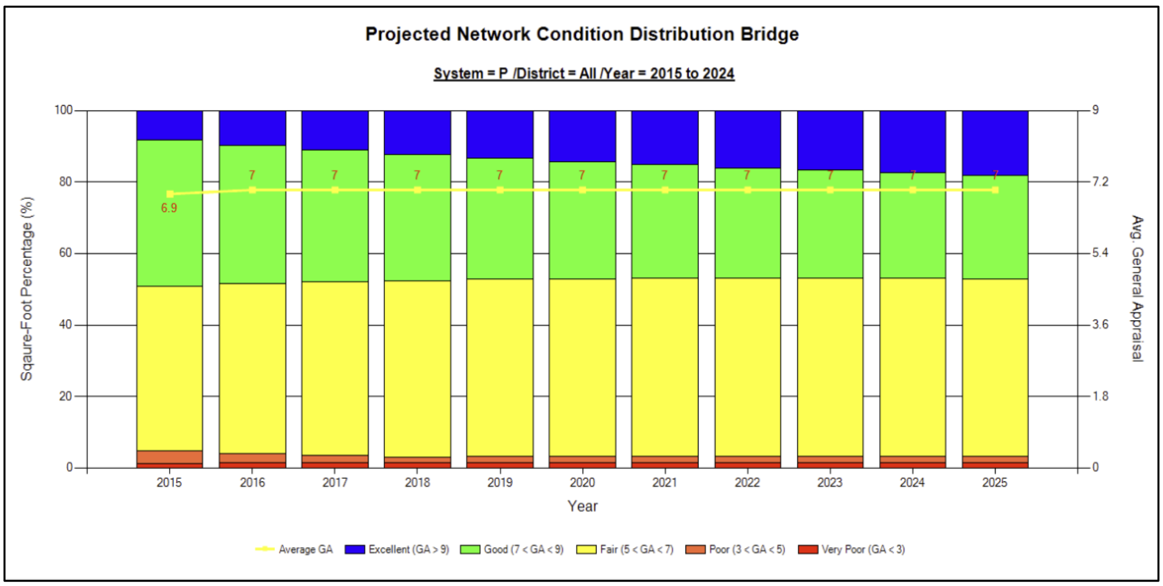

Figure 12: Priority system predicted condition distribution bar chart for Bridge network

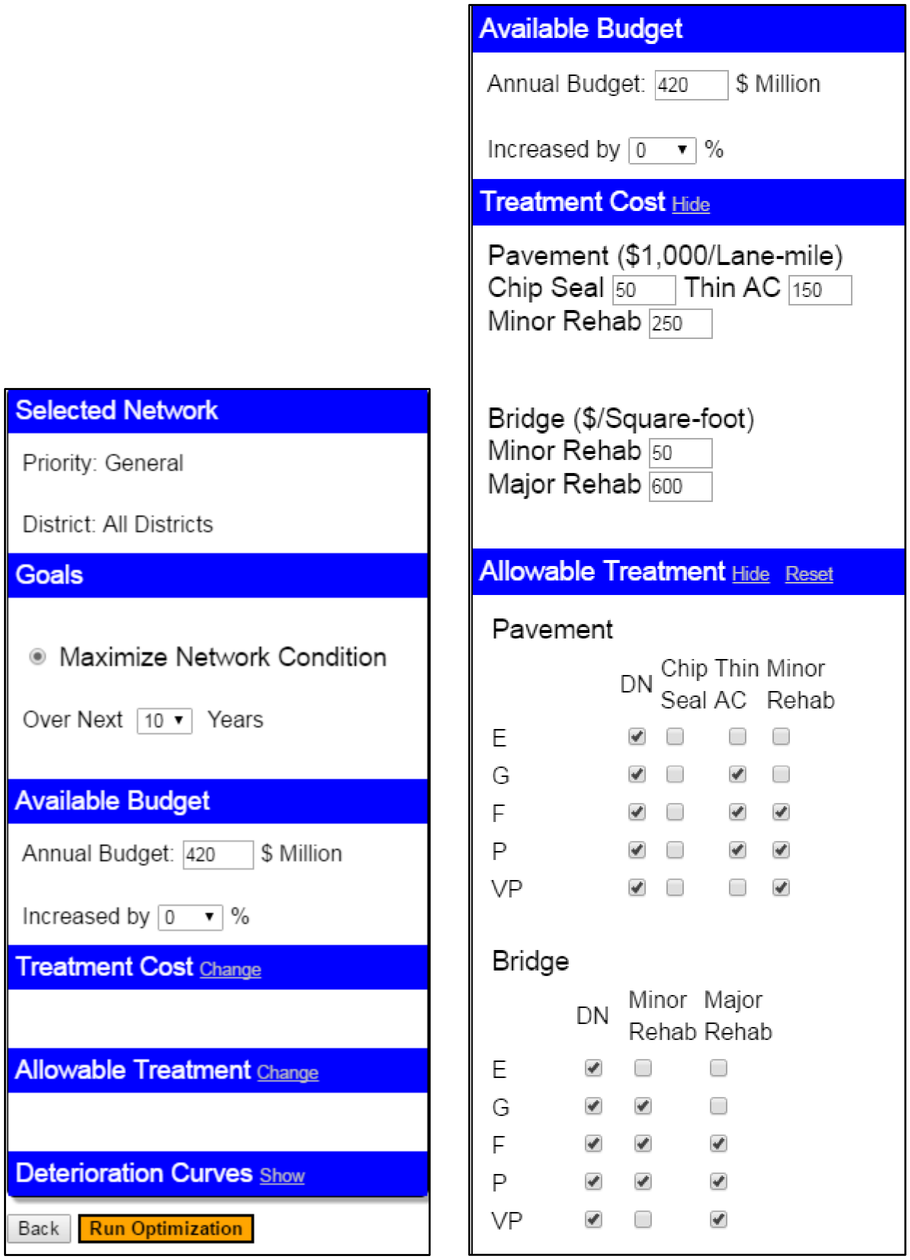

Figure 13: Interface for changing or updating (1) the available budget, (2) the average unit cost of treatment, and (3) allowable treatment types for General system highways

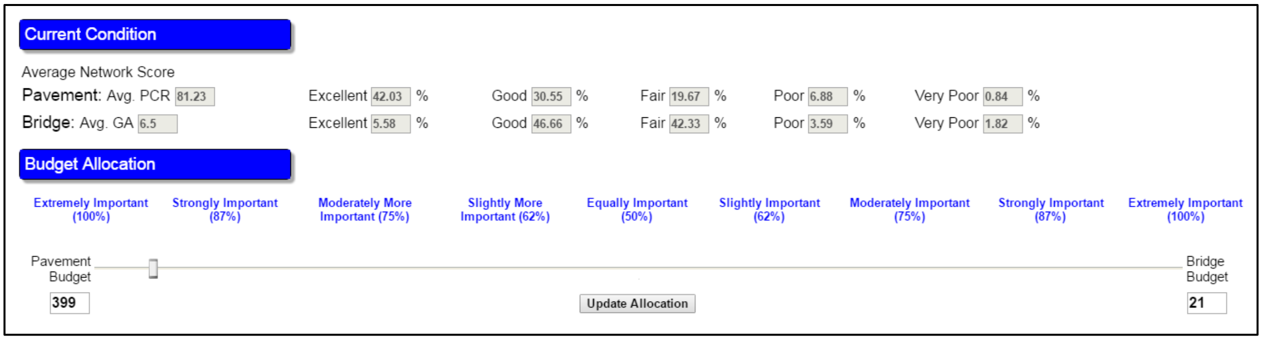

Figure 14: Current condition of General system and trade-off bar

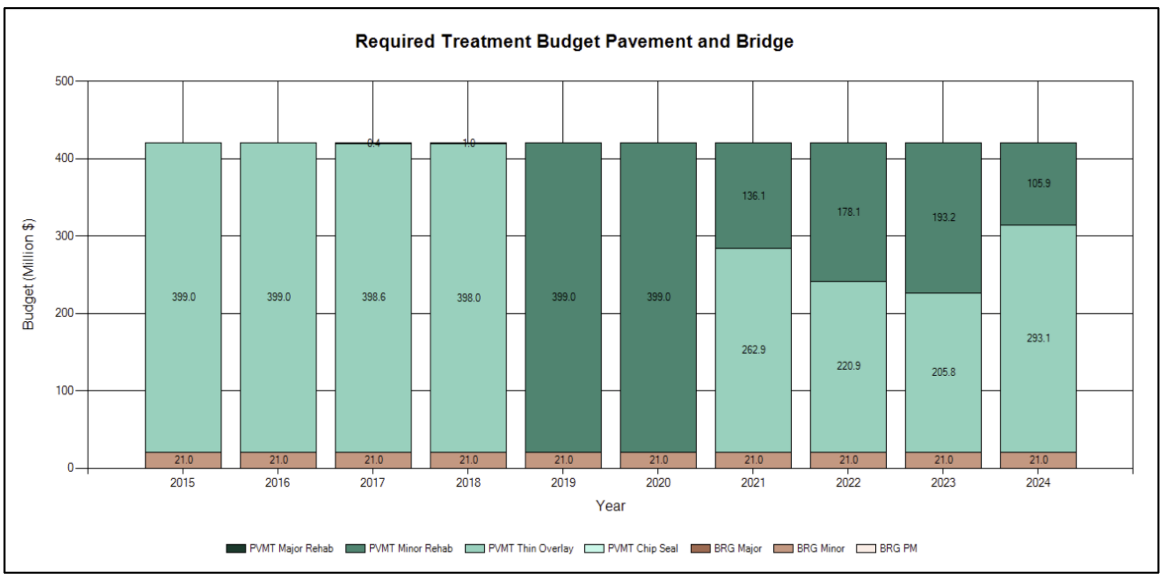

Figure 15: Budget allocation graph for General system between Pavements and Bridge

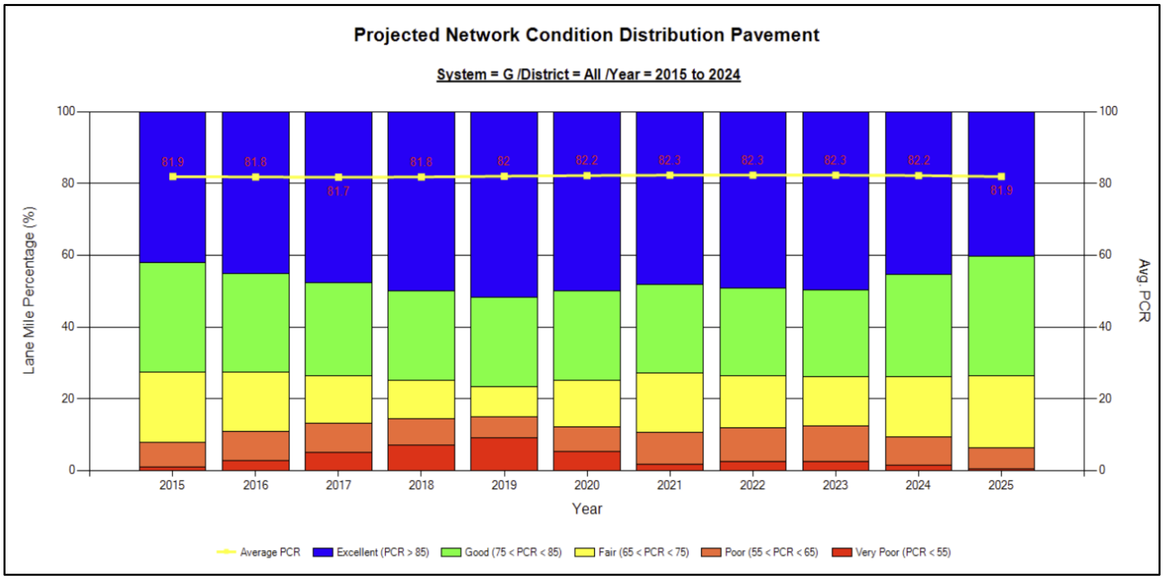

Figure 16: General system predicted condition distribution bar chart for Pavement network

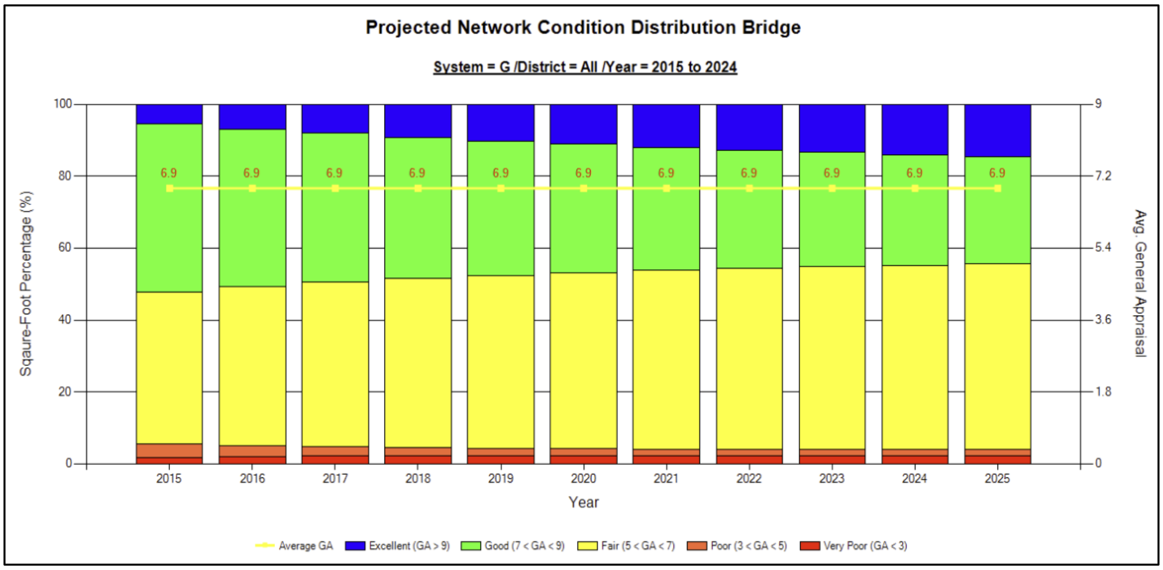

Figure 17: General system predicted condition distribution bar chart for Bridge network

3) Tradeoff Analysis for Evaluating Different Treatment Strategies

For illustration, Figure 18 shows the comparison of two different treatment policies or strategies for Priority system of allowing thin overlay on Good and Fair pavements versus only allowing minor rehabilitation.

As can be seen from Figure 18, allowing thin overlays as treatment option can significantly reduce the required budget. Obviously, this result is dependent upon the assumptions shown in Figure 7 that for Priority system pavements, the average thin overlay cost ($250 K per lane mile) is significantly less than the average cost of minor rehabilitation ($350 K per lane mile).

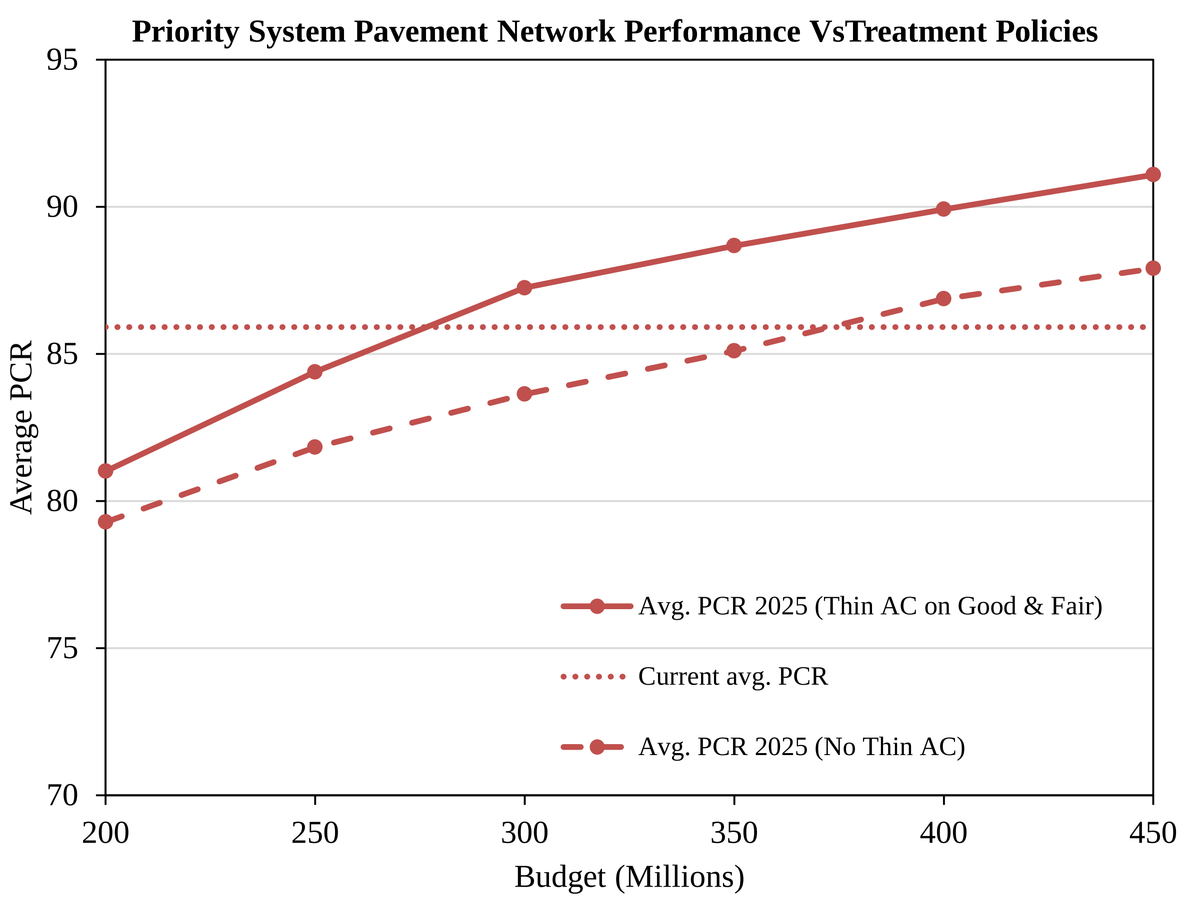

Figure 18: Priority System Rehabilitation Treatment Policies Comparison Example

Figure 19 compares the two different allowable treatment policies: allowing Chip Seal as a treatment option on General system pavements versus not allowing Chip Seal as a treatment. Based on the assumption shown in Figure 7 that on General system pavements, the average chip seal cost ($50 K per lane mile) is significantly less than the average thin overlay cost ($150 K per lane mile), allowing chip seal as treatment option on General system pavements can result in very significant reduction in required budget (about $90 M for the entire State).

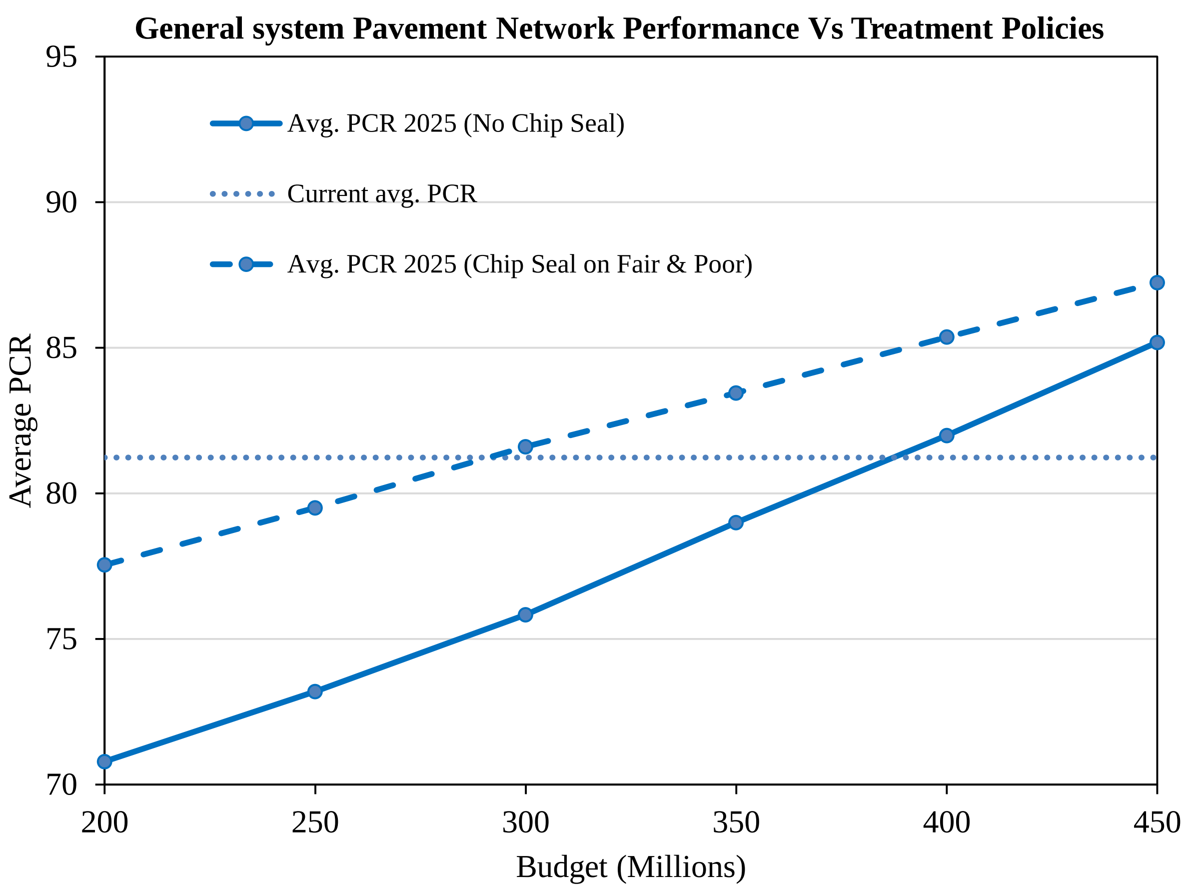

Figure 19: General System Rehabilitation Treatment Policies Comparison Example

The two examples above illustrate that different treatment strategies can be evaluated based on predicted future network conditions and budget needs. However, it should be cautioned that these are hypothetical cases and may represent the upper bounds of possible savings resulting from performing thin overlay for Priority system pavements or chip seals on General system pavements. Actual savings are likely less, as actual situations may not allowed thin overlay or chip seals to be performed on all pavements that are eligible.

B. Project Level Tradeoff Analysis

Tradeoff analysis at the Project Level can be considered as prioritization of different projects based on a set of competing objectives. This section describes the approach used to develop the project level prioritization with multiple objectives. A multi-objective decision making methodology called Analytical Hierarchy Process (AHP) is employed to determine the relative weights of different objectives for pavement and bridge separately and ultimately a combined weight is determined for each project for ranking of the projects. A brief description of the AHP methodology can be found in Appendix C of this report.

The AHP methodology uses a pairwise comparison to determine the relative weights of each objective. The more important object will have a higher weight. Given there are n objectives, the total number of pairwise comparison equals $\frac{n!}{2(n-2)!}$.

For example, for pavement asset, a rehabilitation project may have one or more of the following objectives:

(1) Asset Preservation,

(2) Congestion Mitigation,

(3) Safety Improvement, and

(4) Economic development.

The relative importance of each objective can be determined by using pairwise comparison. Since there are four objectives, the number of pairwise comparison equals $\frac{4!}{2(4-2)!} = 6$

Figure XX shows an example of such pairwise comparisons. In this example, Asset Preservation is deemed moderately more important than Congestion Mitigation. Asset Preservation is deemed slightly more important than Safety Improvement. Asset Preservation is strongly more important than Economic Development. Safety Improvement is slightly more important than Congestion Mitigation. Congestion Mitigation is slightly more important than Economic Development. And lastly, Safety Improvement is between slightly and moderately more important than Economic Development.

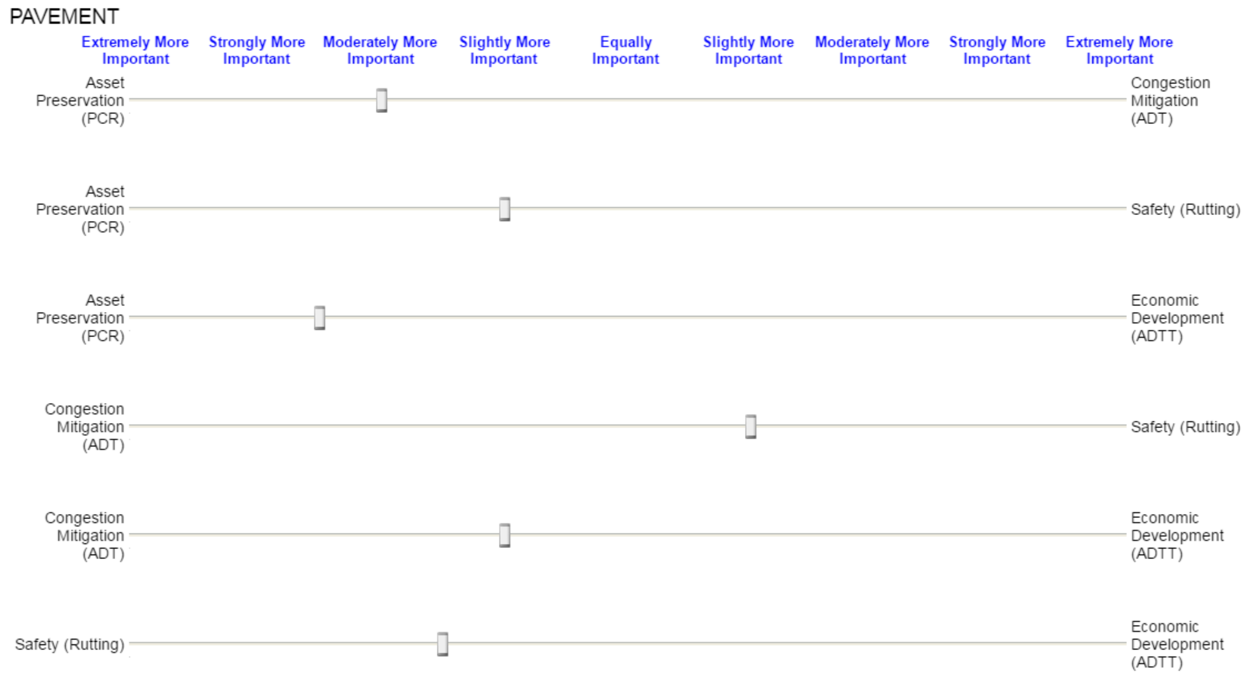

Figure 20: Pairwise Comparison of Objectives

For this study, the Asset Preservation objective is accomplished through improvement of the pavement condition (PCR). A pavement section with a low PCR score has higher potential for improvement than a pavement section that has a higher PCR score. Therefore, rehabilitating this lower PCR pavement section would help to achieve the Asset Preservation objective more than rehabilitating a pavement section with higher PCR score.

It is also assumed that rehabilitating a pavement section with higher traffic volume in term of average daily traffic (ADT) would have higher potential to help achieve the Congestion Mitigation objective than rehabilitating a pavement section with lower ADT.

For the Safety Improvement objective, this study uses the rutting distress as a representation, because it is readily available in the asset database. Rehabilitating a pavement section that has a high rutting distress will help to achieve the Safety Improvement objective than rehabilitating a pavement section that has lower rutting distress. Currently, the asset database does not include traffic crash data. If crash data are available, they can be used as a measure for Safety Improvement instead.

For the Economic Development objective, this study uses the Truck Average Daily Traffic (TADT) as a measure. It is assumed that a pavement section with a high TADT would have a higher impact on Economic Development than a pavement with a lower TADT.

Through the pairwise comparison process, the relative weight for each objective can be calculated using the AHP method as described in Appendix D. For this example, since there are four objectives, a 4x4 matrix is formed based on the pairwise comparison above:

$$\begin{bmatrix} & PCR & ADT & Rutting & ADTT \\ PCR & 1 & 5 & 3 & 7 \\ ADT & 1/5 & 1 & 1/3 & 3 \\ Rutting & 1/3 & 3 & 1 & 5 \\ ADTT & 1/7 & 1/3 & 1/5 & 1 \end{bmatrix}$$

Multiply the above matrix by itself results in:

$$\begin{bmatrix} & PCR & AADT & Rutting & ADTT \\ PCR & 4 & 21.33 & 9.07 & 44 \\ AADT & 0.94 & 4 & 1.87 & 9.07 \\ Rutting & 1.98 & 9.33 & 4 & 21.33 \\ ADTT & 0.42 & 1.98 & 0.94 & 4 \end{bmatrix}$$

Table ZZZ shows the calculations involved in the weight calculation. Figure YY shows the calculated relative weights (i.e., importance) based on the pairwise comparison in Figure XX.

TABLE 1: Process of the weight calculation

	PCR	ADT	Rutting	ADTT	Sum	Weight	Remarks
PCR	4.00	21.33	9.07	44.00	78.40	78.4/138.26 **= 0.561**	PCR Weight
ADT	0.94	4.00	1.87	9.07	15.87	15.87/138.26 **=0.119**	ADT Weight
Rutting	1.98	9.33	4.00	21.33	36.65	**0.26**	Rut Weight
ADTT	0.42	1.98	0.94	4.00	7.34	**0.06**	ADTT Weight
				Total	**138.26**		

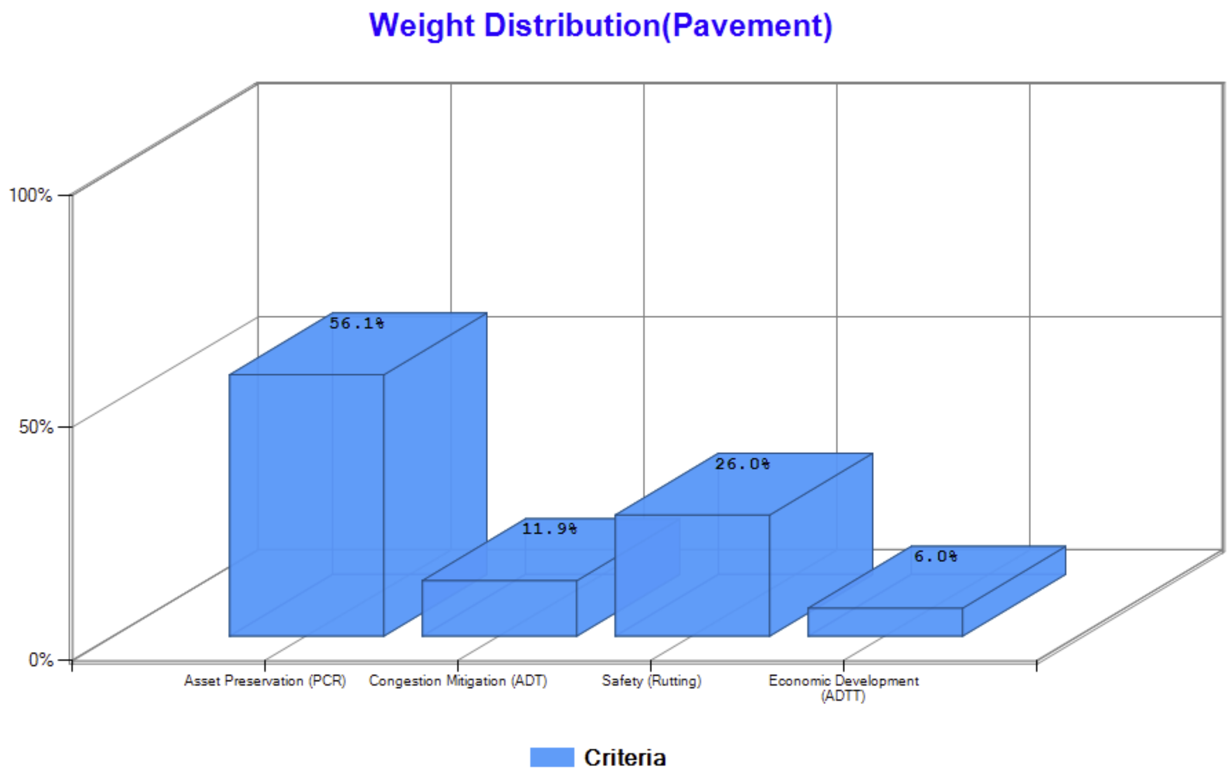

Figure 21: The Relative Weight for Each Objective as Determined by AHP

For each pavement section, its relative importance (weight) in accomplishing each objective is estimated based on the default values shown in Table YYY. These default weight values can be modified by the user as desired.

The overall priority weight for a specific pavement section can then be determined based on its PCR, rutting distress deduct, ADT, and ADTT. For example, a pavement section with a current PCR of 62, a rutting distress deduct of 6, an ADT of 9,600 and ADTT of 850 would have an overall weight of (0.561x0.75 + 0.119x0.75 + 0.26x0.8 + 0.06x0.75 = 0.763. In contrast, a second pavement section with a current PCR of 59, a rutting distress of 6, an ADT of 4,200 and ADTT of 220 would have an overall weight of (0.561x0.75 + 0.119x0.20 +0.26x0.8 + 0.06x0.20) = 0.665. Therefore, the first pavement section has higher priority weight due to higher traffic volume and truck traffic.

TABLE 2: Default Weights for Individual Pavement Section

(a) Asset Preservation Objective

Pavement Asset Condition	PCR Range	Weight
Good	80~100	0.05
Fair	66~79	0.20
Poor	0~65	0.75

(b) Congestion Mitigation Objective

Traffic Volume	ADT Range	Weight
High	> 5,000	0.75
Medium	1,000 – 5,000	0.20
Low	0 – 999	0.05

(c) Safety Improvement Objective

Pavement Rutting	Rutting Distress Deduct	Weight
Acceptable	< = 5	0.20
Not Acceptable	> 5	0.80

(d) Economic Development Objective

Truck Traffic Volume	ADTT Range	Weight
High	> 750	0.75
Medium	75 – 750	0.20
Low	0 – 74	0.05

Similarly, a priority weight can be determined for each bridge rehabilitation project based on a single objective or multiple objectives.

Many proposed projects include both pavement and bridge work and involve multiple pavement sections and multiple bridges. When a project includes multiple pavement sections, the priority weights for every individual pavement sections are determined separately, and then averaged to be the overall pavement priority weight for that project. Similarly, an average bridge priority weight is calculated for a project including multiple bridges.

Projects may be prioritized based on their pavement priority weight or bridge priority weight or a combination of the two weights. For instance, a project's overall priority weight may be the higher of the pavement and bridge weights. Alternatively, the project weight may be determined by taking the average of its pavement and bridge weights, if both weights are present. If a project includes only work on one type of asset, say, pavement, then the overall project weight equals its pavement priority weight. The former approach is currently implemented.

Table 2 shows the results for the project prioritization for district 2 in 2017. Projects with tied priority weights are further sorted based on their PCR or GA scores, with lower PCR/GA ranked higher on the priority list. If the PCR and GA scores are also tied, then higher traffic sections receive higher priority.

Table 3: Prioritized List of Projects for District 2 in 2017 (Top 20 shown)

Rank	PID	Year	District	#Bridges	Lane Miles	Avg PCR	Avg Rutting	Avg GA	Avg ADT	Avg ADTT	Pavement Weight	Bridge Weight	Project Weight
1	93918	2016	2	0	6.84	46	5.6	0	12796	802	0.763	0	0.763
2	92127	2016	2	1	19.2	60.3	5.23	7	9614	1359	0.763	0.242	0.763
3	97011	2019	2	0	2.42	61	6	0	12843	903	0.763	0	0.763
4	85266	2018	2	1	0	0	0	4	30990	2060	0	0.749	0.749
5	101327	2020	2	1	0	0	0	4	27911	1879	0	0.749	0.749
6	92095	2015	2	1	0	0	0	4	17807	2347	0	0.749	0.749
7	92331	2016	2	1	0	0	0	4	14930	1011	0	0.749	0.749
8	101556	2019	2	1	0	0	0	4	14930	1011	0	0.749	0.749
9	79901	2021	2	1	0	0	0	4	14350	970	0	0.749	0.749
10	79991	2016	2	3	0	0	0	4.3	47873	4067	0	0.749	0.749
11	85269	2016	2	1	23.62	58.4	6.53	7	6299	561	0.73	0.196	0.73
12	92361	2020	2	0	6.04	65	5.6	0	6010	720	0.73	0	0.73
13	97012	2018	2	2	5.54	63	3.9	4.5	6170	380	0.574	0.703	0.703
14	95792	2021	2	0	20.74	58.6	6.09	0	3288	661	0.665	0	0.665
15	95793	2017	2	1	19.01	60	6.09	6	3497	415	0.665	0.2	0.665
16	101281	2018	2	1	13.78	62	5.49	5	1927	215	0.665	0.2	0.665
17	88513	2015	2	0	5.12	64	5.6	0	3430	560	0.665	0	0.665
18	92128	2019	2	0	12.16	65	6	0	1410	167	0.665	0	0.665
19	84079	2017	2	1	7.58	40	6	5	420	30	0.638	0.159	0.638
20	99869	2018	2	0	1.68	51	4.2	0	25233	1705	0.607	0	0.607

III. A Methodology for Benefit Cost Analysis of Data Collection Effort

A critical role of an asset database is to provide decision makers with reliable asset inventory and condition data in order to support asset management decisions such as estimating the required maintenance/replacement costs to maintain the asset at a desirable condition. However, collecting asset-related data usually requires valuable resources such as costs for equipment, manpower, etc. that are also in demand elsewhere. Therefore, the benefits of a specific data collection effort need to be evaluated versus the cost and resources required to justify such effort.

A benefit-cost analysis is a systematic evaluation of the economic advantages (benefits) and disadvantages (costs) of a set of investment alternatives. Typically, a "Base Case" is compared to one or more Alternatives (which have some significant improvement compared to the Base Case). The analysis evaluates incremental differences between the Base Case and the Alternative(s). In other words, a benefit-cost analysis tries to answer the question: What additional benefits will result if this Alternative is undertaken, and what additional costs are needed to bring it about?

The objective of a benefit-cost analysis is to translate the effects of an investment into monetary terms and to account for the fact that benefits generally accrue over a long period of time while capital costs are incurred primarily in the initial years, in other words, it has two main purposes: 1) to determine if an investment or decision is sound, and 2) to provide a basis for comparing projects which involves comparing the total expected cost of each option against its total expected benefits.

A methodology for benefit/cost analysis of data collection efforts has been developed in this study. This methodology establishes a generic criterion for ODOT to follow in order to determine whether or not time and effort should be expended in data collection efforts on various assets or items.

The cost of asset data collection can be broken down to annualized equipment costs, labor costs, etc. The benefits of asset data collection include cost savings as a result of better planning and more informed decision making due to availability of quality asset information. These benefits may be difficult to quantify into dollar amounts. Therefore, they may be expressed as a percentage of the annual expenditures on the asset.

The Benefit Cost Analysis involves the following steps:

1. List alternatives (in this case, collecting versus not collecting a specific asset data).
2. Determine the analysis time frame (say, for example, at least as long as the typical life span of the asset of interest).
3. Estimate the interest rate or discount rate, which is the nominal interest rate minus the inflation rate.
4. Estimate all costs associate with data collection effort such as the equipment costs (including initial acquisition and subsequent maintenance/replacement), annual labor costs, data processing and management costs, etc.
5. Estimate all the benefits that will result from the information the collected data provide. This may include improved planning and cost savings due to additional information about an asset's inventory and/or condition.
6. Convert all costs and benefits into dollar amounts.
7. Calculate the Net Present Values of each alternative
8. Calculate the Internal Rate of Return of each alternative
9. Perform sensitivity analysis
10. Make recommendation

Costs of Data Collection Effort:

The costs required for a specific asset data collection effort generally include:

1) Equipment to Collect Data for Inventories: devices such as cameras, sensors, counters, computers and etc.
2) Personnel: number of personnel x work hours. The number of personnel and hours depends on the specific type and amount of data to be collected.
3) Data management: The collected data need to be processed, stored, and updated regularly. This requires software and data specialists such as programmers for writing codes to process and incorporate the collected data and analysts to turn the collected into useful information.

Benefits of Collected Data:

Benefits that likely will result from the information provided by the collected data may include:

1) Savings results from better planning of the maintenance and replacement of the asset,
2) Potential safety improvement due to less down time of the asset,
3) Potential travel time savings due to less down time of the asset, and
4) Improved driving public satisfaction due to less down time of the asset.

Many of the benefits are difficult to quantify accurately. Therefore, in this study, instead of attempting to quantify every benefit and translate it into dollar amount, the total annual benefit of the data collection effort is estimated as a percentage of the annual expenditure on the asset of interest. This means that the data collection effort potential will result in savings of a percentage (for example, 10 percent) of the annual expenditure on the asset.

An important factor which can affect the benefit cost analysis is the time frame of time period considered. In this study, given the perpetual nature of most transportation assets (i.e., most assets are replaced or rehabilitated at the end of their current life span), a 30 year time frame is assumed. If an asset has a life span longer than that (e.g., culverts and bridge typically lasted 75 years or longer), then a time frame equal to the asset life span may be used.

Three measures are often used for benefit cost analysis:

1) Net Present Value (NPV),
2) Benefit-Cost Ratio, and
3) Internal Rate of Return (or simply called Rate of Return)

A Microsoft Excel spreadsheet program was created to calculate these measures, given the input of initial capital cost, annual costs, and annual benefits. Figure ZZZ shows an example, where data collection effort is being considered on an asset that has a current annual expenditure of ~$10 million dollars. An Interest Rate of 5% and Inflation Rate of 3% is assumed in this case (resulting in a Discount Rate or 'true interest rate' of 5% - 3% = 2%). The data collection effort requires an initial capital investment on equipment of $500,000 and annual costs (such as personnel and equipment maintenance) of $200,000 for the current year. It is assumed that the equipment will be replaced after 10 years. Assuming the benefits of this data collection effort would result in 3% of savings of the annual asset expenditure and this saving would be realized after 3 years. That is, no benefits in the first 3 years.

Based on the above, it can be seen in Figure ZZZ that this particular hypothetical data collection effort will result in NPV of savings of $92,739 over a 30 year period. The Benefit Cost ratio is 1.07 and the Rate of Return on Investment is 2.5%.

When a 3.3% of savings of annual asset expenditure is assumed while all other parameters remain the same as the above example, the NPV of savings becomes $944,699 over 30 years, the B/C ratio increases to 1.18 and the Rate of Return is 6.3%. Conversely, when a 2.7% of savings of annual asset expenditure is assumed, the NPV becomes negative $759,221 (i.e., losing this amount over 300 years), the B/C ratio reduces to 0.97 and the rate of return becomes negative 3%. Therefore, the benefits estimate as a percentage of asset expenditure is a crucial parameter in determining whether or not a specific data collection effort would be worthwhile.

Depending on the specific data that would be collected, the resulting benefits may result in savings of perhaps one or two percentages of the annual expenditure on that asset. If this is true, than the above example data collection effort would not be justified.

This spreadsheet tool provides a quick and easy way to perform a generic benefit cost analysis for any data collection efforts. A sensitivity analysis is recommended, especially on the benefits estimate parameter.

Interest Rate	**=**	**5%**
Inflation rate	**=**	**3%**
Annual Asset Expenditure =		**$ 10,000,000**
Benefit Percentage =		**3.00%**
Discount Rate	=	2%
Net Present Value of Savings =		**$92,739**
Benefit/Cost Ratio =		**1.07**
Rate of Return on Investment =		**2.5%**

Year	Capital Costs	Annual Costs	Total Costs	Total Benefits	Savings
1	$ 500,000	$ 200,000	$ 700,000	0	$ (700,000)
2		$ 206,000	$ 206,000	0	$ (206,000)
3		$ 212,180	$ 212,180	0	$ (212,180)
4		$ 218,545	$ 218,545	$ 300,000	$ 81,455
5		$ 225,102	$ 225,102	$ 309,000	$ 83,898
6		$ 231,855	$ 231,855	$ 318,270	$ 86,415
7		$ 238,810	$ 238,810	$ 327,818	$ 89,008
8		$ 245,975	$ 245,975	$ 337,653	$ 91,678
9		$ 253,354	$ 253,354	$ 347,782	$ 94,428
10		$ 260,955	$ 260,955	$ 358,216	$ 97,261
11	$ 671,958	$ 268,783	$ 940,741	$ 368,962	$ (571,779)
12		$ 276,847	$ 276,847	$ 380,031	$ 103,184
13		$ 285,152	$ 285,152	$ 391,432	$ 106,280
14		$ 293,707	$ 293,707	$ 403,175	$ 109,468
15		$ 302,518	$ 302,518	$ 415,270	$ 112,752
16		$ 311,593	$ 311,593	$ 427,728	$ 116,135
17		$ 320,941	$ 320,941	$ 440,560	$ 119,619
18		$ 330,570	$ 330,570	$ 453,777	$ 123,207
19		$ 340,487	$ 340,487	$ 467,390	$ 126,904
20		$ 350,701	$ 350,701	$ 481,412	$ 130,711
21	$ 903,056	$ 361,222	$ 1,264,278	$ 495,854	$ (768,424)
22		$ 372,059	$ 372,059	$ 510,730	$ 138,671
23		$ 383,221	$ 383,221	$ 526,052	$ 142,831
24		$ 394,717	$ 394,717	$ 541,833	$ 147,116
25		$ 406,559	$ 406,559	$ 558,088	$ 151,530
26		$ 418,756	$ 418,756	$ 574,831	$ 156,075
27		$ 431,318	$ 431,318	$ 592,076	$ 160,758
28		$ 444,258	$ 444,258	$ 609,838	$ 165,580
29		$ 457,586	$ 457,586	$ 628,133	$ 170,548
30		$ 471,313	$ 471,313	$ 646,977	$ 175,664
Total =	$ 2,075,014	$ 9,515,083	$ 11,590,097	$ 12,212,890	$ 622,793

Figure 22: Benefit Cost Analysis Spreadsheet Example

IV. Framework of a Work-Order Based Asset Inventory Updating Process

Accurate, current, and usable asset inventory data are essential to support asset management decisions. However, given the size of the asset inventories, to keep the data updated is a tremendous task. For example, there are hundreds of thousands of signs and culverts in the State highway system. Thousands are replaced or relocated each year with many new ones installed by various jurisdictions. Therefore, without a systematic process, it's difficult to ensure the asset inventories are reliably updated.

ODOT currently is undertaking a data governance initiative to standardize, coordinate, and integrate existing and future data sources, applications, and reporting at the Department. A key concept is to treat data as a highly valuable asset and therefore needs to be managed through established policy, standards, and procedures. This is a continuous process that requires participation and collaboration throughout the agency.

The desired data flow starts with data collected by each asset stake holder based on a set of standardized attributes and stored in an inventory system. Such data are validated against the enterprise data set (i.e., Roadway Inventory and Linear Referencing System) to ensure accuracy of locations. Corrections are required if discrepancies are found. The validated inventory and work history data are then sent and stored in an enterprise data warehouse to be used by various applications/users such as the pavement/maintenance management systems, the mapping system (TIMS), the decision support tools, and other business processes to produce a work plan. The approved work plan is executed and based on actual work performed on both capital and maintenance projects, the inventories are updated.

A work-order based process to update asset inventories has been proposed after reviewing existing literatures and consultation with the Office of Technical Services Staff. Figure 23 shows the framework for such a process. This proposed process requires an on-line work flow that links and shares data among different stakeholders within the Department. Therefore, data standardization and location reference reconciliation are essential. Once this process is implemented, asset inventories (and also asset condition and work history) would be updated automatically, after each work order has been completed and verified.

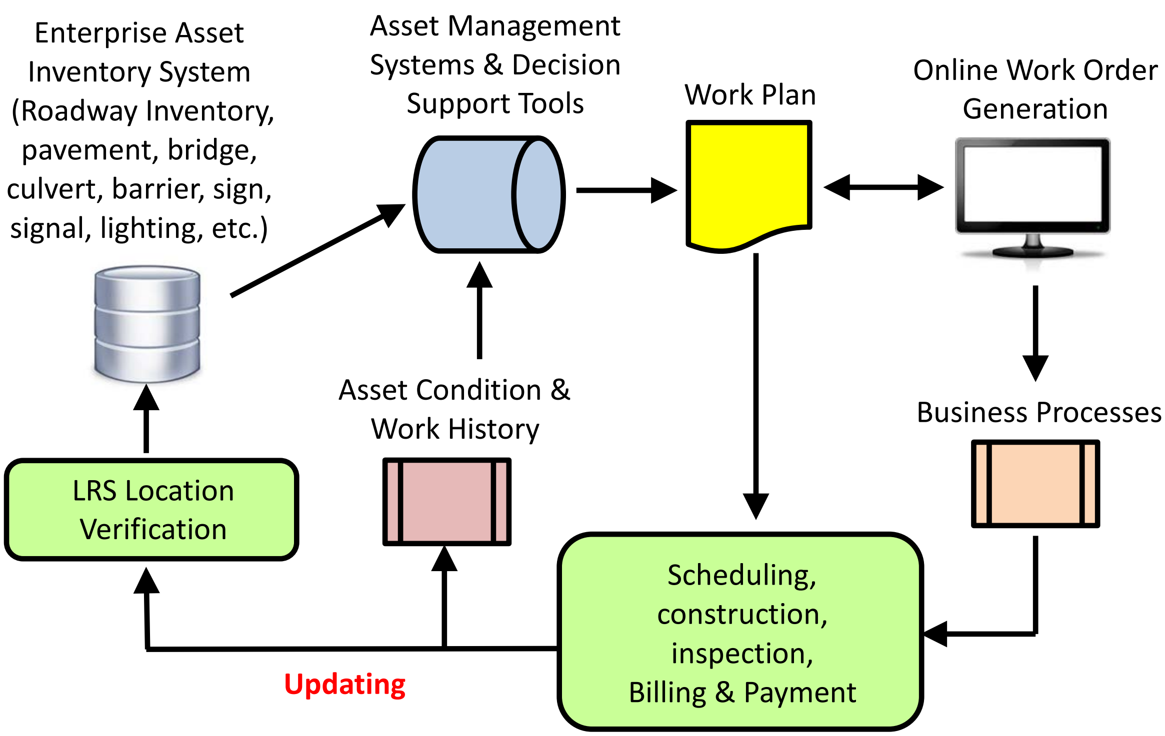

Figure 23: Framework of a Work-Order Based Asset Inventory Updating Process

V. Data Integration Tool

Currently, asset data are collected, stored, and managed by different Offices. The asset data from different Offices or databases often don't have the same field name spelling, data format, or consistent fields. This makes it difficult to integrate them into a 'searchable' centralized database. ODOT is embarking on a data governance effort to address this problem.

In the meantime, a data integration tool was developed as part of this study to facilitate the incorporation of asset data from existing ODOT data sources maintained by various ODOT Offices. It also checks for consistency of data items and format in the data received in different years, and alerts the user for any discrepancies before the data are incorporated into the asset database.

The SQL asset database that supports the web decision support tools is consist of a number of tables which can be categorizes as look-up tables and data tables. Look-up tables are for information purposes such as to translate the activity codes to the activity names. These tables usually do not need to be updated or changed. For the data tables, there are of two kinds: 1) tables directly updated, including roadway inventory, work plan, maintenance data file (i.e., tms), and data for bridges, culverts, and other assets; 2) tables generated each year by processing pavement condition data, project history data, and roadway inventory data using a window-based applications. Inconsistency may occur with the new data received each year. For example, tms data table has Route name "075" whereas DATA_ODOT has the Route name "075R". Thus, the data integration tool is developed to ensure the updated data will be in the same format as in the database.

The "Data Integration" tool takes the new data in an Excel file (.xls and .xlsx) and adds the new data into a specified table in the SQL database. The columns in each table which are used in database queries are named as "key columns" which include: Priority, System, District, County, Route, and NLFID. Database table to be updated is selected using the dropdown menu and the tool detects the "key columns" present in that particular database table.

After selecting an Excel file, the tool looks for the "key columns" from the database table in the Excel file. If any of the "key columns" are not found, such as Priority, System, Route, or County, the tool can generate these using the other found "key columns". For example, the column NLFID contains information for the columns "County", "Route", and "System"; if "County", "Route", and/or "System" are not present in the Excel file, the tool can generate these columns automatically if NLFID is present.

For all the other columns, each column in the Excel file must be assigned to a column from the selected database table if they do not automatically match. This prevents error in inserting records that have inconsistent column names. The tool also prevents any Excel columns from being inserted into the database table if the Excel column has a data type that is invalid for the database table's column. For example, if the Excel column "County" with a data type of string with length 3 is assigned to the column "District" with an integer data type, the tool will detect this and prevent the insertion/replacement process from occurring.

Once all of the Excel columns have been assigned to a database column and all "key columns" (*) are assigned, the user may proceed with the database query. The user may choose to insert the data into the database table, or to replace the database table entirely with data from the Excel table.

Table 4 shows a list of the tables in the asset database separated by their data source.

Figure 24 shows the user interface for data integration tool. The dropdown menu lists the data tables from the existing asset database. In this example it shows the "Work Plan" table is to be updated. The "Choose File" button is used to select the Excel file which has the latest data or the data to be updated. For the database columns that match the name exactly in the Excel file, the tool automatically updates the corresponding drop down. The user needs to manually assign the corresponding columns for the ones that don't match.

Table 1: List of tables in the asset database separated by data sources

Data Source	Table Names	Remarks
Processed by PMIS and Windows Application	a) Look-up tables Maintenance Activity Pavement Distress Code Highway Functional Class Markov Family Distress (Pavement) Markov Family PCR (Pavement) Rehabilitation Cost Repair Logic and Limits Pavement Deterioration Slope Structural Number (Bridge) b) Data tables Pavement Condition Data (DATA_ODOT) Pavement Initial Condition Bridge Initial Condition Bridge Markov Transition Bridge GIS Data Culvert Deterioration Culvert Markov Transition Estimated Remaining Life Project List Detail	Consistent in format
ODOT and other sources and directly added to the database	Sign and Lighting Inventory Barrier and Pavement Inventory Bridge Condition Data Bridge Project History Treatment Activity Details (TMS) Work Plan (Project List)	Inconsistent in format

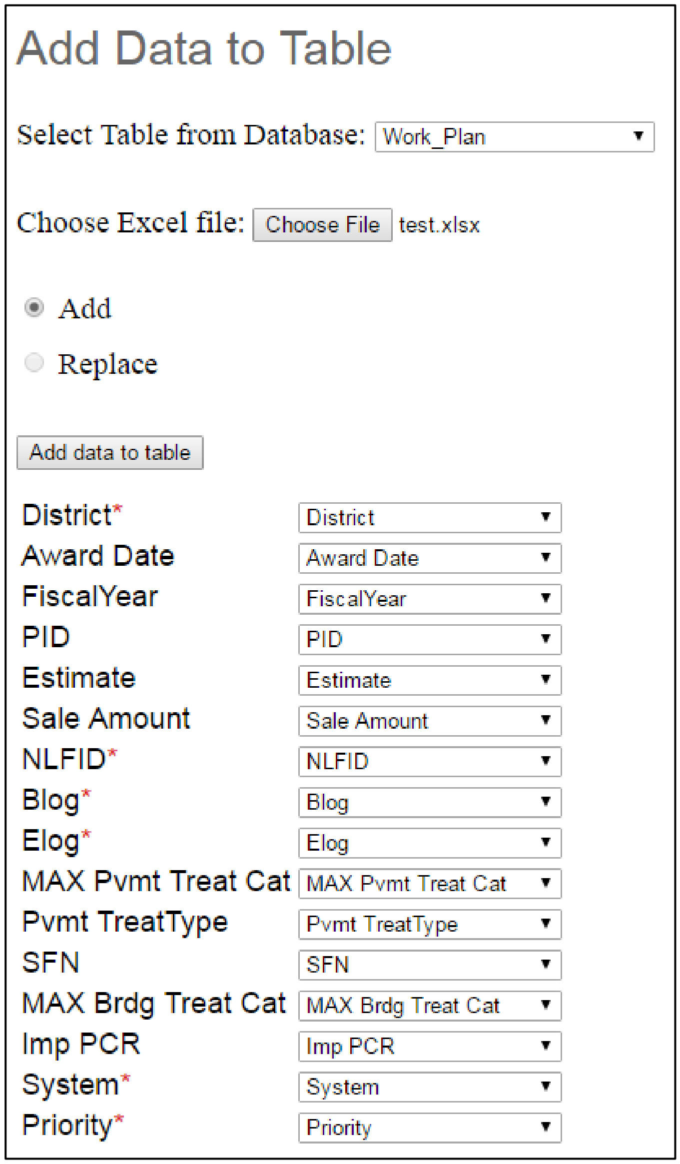

Figure 24: Data integration tool user interface

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

"Taking care what we have" is a top priority for ODOT. It means ODOT must maintain and upkeep the existing transportation assets in a state of good repair in order to achieve overall user satisfaction. This research study has developed a web-based prototype decision support platform to help ODOT make sound transportation asset management and planning decisions based on reliable data and information.

The purpose of this study is to demonstrate the benefits of transportation asset management as a decision support tool in monitoring asset performance, supporting asset funding decisions, planning budget tradeoffs, and optimizing resource allocations. The goal is to build consensus and gain senior management support for implementing asset management throughout the Department, which requires investments for data collection and integration, standardization of process and definition, and management information system acquisition and implementation.

A centralized transportation asset database that integrates data from various sources was built to support the data-driven decision support tools. This allows reports/presentations to be generated quickly and enables what-if analyses to be performed. A total of 23 functions were developed in five categories: inventory, condition, performance, investment, and planning. The tradeoff analysis function is developed for evaluating funding levels versus performance and cross-asset budget allocation decisions.

The decision support tools developed are intended to enable the Department to prudently allocate and efficiently utilize the limited resources available to maximize transportation asset performance. The various decision tools and methodologies developed in this study have been incorporated into the Transportation Asset Management Decision Support Tools Prototype (TAMDSTP) web site as discussed in this report. Additional descriptions of the decision support tools can be found in the TAMDSTP manual in Appendix B of this report. This prototype web site provides a proving ground for ODOT to evaluate whether or not to adopt and to fully implement the data-driven approach of decision support.

The TAMDSTP can be used by ODOT staff at all levels. However, the work plan evaluation and tradeoff analysis tools would be most useful to the senior management for budget planning, funding allocation, or treatment policy determination purposes.

The anticipated benefits of this project include: significant cost savings in maintaining and renewing ODOT's vast transportation assets, better internal communications both vertically and horizontally on the benefits of asset management, and clear and concise reporting to the public, legislatures, and state and federal governments regarding the condition and performance of the state transportation system.

The primary beneficiaries of the research results are ODOT decision-makers and engineers involved with transportation asset management. The secondary beneficiaries may include other ODOT engineers, other highway agencies, politicians and legislatures, and the general public.

Conclusion

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

1. The various functions and methodologies developed in this study have been incorporated into the Transportation Asset Management Decision Support Tools Prototype (TAMDSTP) web site. This prototype demonstrates that such data-driven tools can be very useful to senior management in making asset management and planning decisions. The predicted future conditions and the graphical display of the consequences of different funding levels enable the decision makers to make investment and allocation decisions to achieve the desired goal and objectives.
2. The web-based platform and the structured, menu-style user interface allow easy access and exploration of a large amount of transportation asset data and to find the specific

information of interest to the user. It can be used to support both network level and project level decisions.

3. The network-level tradeoff analysis tool developed in this study can be used to evaluate the impact of various budget scenarios on future asset conditions. It can also be used to evaluate different budget allocations and/or treatment policies or strategies.
4. The project-level tradeoff analysis tool enables the prioritization of projects based on consideration of multiple objectives. Other tools such as the project performance tool enable the investigation of the performance of a particular pavement section.
5. The resulting graphical figures, maps, and tables are useful for internal and external communications. All the tables generated can be exported to Excel spreadsheet for reporting or further analysis.
6. The quality of the data in terms of accuracy and consistency is very important for the user to have confidence in the result. Therefore, it is essential that the data in the asset database be carefully verified, standardized, and kept up-to-date.

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

1. It is recommended that ODOT implement an agency-wide data governance process to ensure accurate, consistent, and reliable asset data are collected, processed, stored, and updated in standardized formats and procedures.
2. ODOT can use the prototype decision support platform to evaluate the various tools developed for their potential for full implementation in an enterprise decision support system.
3. It is recommended that demonstrations and trainings on how to use the prototype tools be conducted to staff at various ODOT Offices and Districts. Feedbacks and comments should be collected for potential improvements.
4. The web-based platform enables the developed tools to be modified and additional tools and functions to be added relatively easily. Therefore, based on the feedback of ODOT users, continuous improvements of the decision support tools are recommended.

APPENDIX A. SUMMARY OF LITERATURE REVIEWS

Table A1: Summary of Literature Review and Current State of Practice in Decision Support Tools for Transportation Asset Management

Title/State	Author/Publication	Year	Brief Summary
MnDOT State of Minnesota	MnDOT website <http://www.dot.state.mn.us/assetmanagement/>	2017	MnDOT asset management considers the asset classes as pavements, bridges, highway culverts, deep storm water tunnels, overhead sign structures, and high-mast light tower structures. For pavement data inventory, Highway Pavement Management application (HPMA) is used which has pavement deterioration model and project selection models. Pontis/ Bridge Replacement and Improvement Management (BRIM) is used for bridge inventory and analysis. Risk management analysis, life-cycle cost consideration (LCCA), and performance gap are used as decision making tool to be considered while making the financial plan and investment strategies.
Annual Report State of Virginia	Virginia Department of Transportation <http://www.virginiadot.org/projects/resources/VDOT_Annual_Report_2015_Final_Feb_18_2016.pdf>	2016	VDOT uses the continuing digital imaging and automated crack detection technology for pavement condition monitoring. Critical Condition Index (CCI) is developed using the assessment. VDOT uses Pontis software to record the bridge condition data for each structure. Optimization to determine the total cost covering an optimal mix of maintenance strategies from preservation to major rehabilitation is done using the pavement management software. In addition to the condition index, it takes into account the traffic volume, maintenance history, structural and subgrade strength. Similarly, for bridge needs assessment, unit cost of repair, deterioration curves, action-effectiveness models and simulation rules & thresholds along with the condition rating are used in the Pontis software to list the recommended actions and cost per structure.

Title/State	Author/Publication	Year	Brief Summary
SHOPP Project Prioritization; Caltrans State of California	California Department of Transportation <http://www.dot.ca.gov/assetmgmt/documents/SHOPP_2016_ProjectPrioritizationPilotPhase2.pdf>	2016	Caltrans have developed a prioritization model by analyzing and prioritizing the projects under State Highway Operation and Protection Program (SHOPP). It uses a quantitative basis for decision making based on the objective, data-driven values and cost consideration. Multi-attribute value theory (MAVT) approach is used for the prioritization. Weights for the different objectives are determined and a linear additive multi-attribute value function is then used to combine the products of weighted values to determine the overall weight of the project. Finally, the portfolios of projects are analyzed for sensitivity to changes which provides insight in decision making.
Montana's Approach to Asset Management The State of Montana	Revenue and Transportation Interim Committee Transportation Asset management Plan <http://www.mdt.mt.gov/publications/docs/plans/2015-tamp-report.pdf>	2015	The Performance Programming Process (P3) serves as the asset management system for MDT with objectives of optimal funding allocation and investment plan based on system performance goals. Pavement Management System manages pavement condition data with condition ratings as riding index (RI), rut index (Rut), alligator crack index (ACI), and miscellaneous crack index (MCI). Based on P3 method, the future pavement conditions are projected considering the treatments and life-cycle cost. Bridge inventory contains structure condition, deck condition, and structural deficiency as performance measures. Future bridge conditions are determined using a direct relationship between funding levels, bridge conditions, and overall performance level. Risk management and performance gap assessment help in the decision making for allocating the funds and developing investment strategies.

Title/State	Author/Publication	Year	Brief Summary
Transportation Asset Management Case Studies: The Colorado Experience State of Colorado	Colorado DOT <https://www.codot.gov/programs/tam> <https://www.fhwa.dot.gov/infrastructure/asstmgmt/dico05.cfm>	2015	Colorado DOT has been practicing a risk-based asset management plan with goals to make the transportation system most cost-effective and safe to move people, goods and information. The plan includes eleven assets programs; surface treatment, bridges, maintenance, buildings, intelligent transportation system (ITS), road equipment, culverts, geohazards, tunnels, traffic signals, and walls. The plan documents current and predicted asset conditions, performance goals, procedure for data analysis and decision making, investment strategies recommended for the lowest life-cycle costs, and a framework for risk inclusion in the decisions. Asset Investment Management System (AIMS) is developed to predict the long-term performance of each asset with different budget scenarios. The following software are used for various asset systems; DTMIS CT (pavement analysis), BrM (bridge condition, culverts), SAP (maintenance LOS, Fleet, ITS, buildings), and geo-hazards management plan (geo-hazards). The Colorado experience (2015) discussed the data integration framework. AASHTO's Pontis is used as a database for bridge inventory and condition information. PMS is based on the current condition and performance goals, estimates the future needs and recommends most cost effective pavement surface treatments. Maintenance management system (MMS) tracks the expenditures and accomplishment by activities. Budget and financial management system provides the information regarding the true cost of activities. Finally, a GIS based interface is used for displaying and analyzing environmental impacts, mapping maintenance needs for decision making etc.

Title/State	Author/Publication	Year	Brief Summary
GEORGIA DOT RESEARCH PROJECT 09-03 FINAL REPORT State of Georgia	GEORGIA DOT RESEARCH PROJECT 09-03 FINAL REPORT <http://www.dot.ga.gov/BuildSmart/research/Documents/0903_Asset_Mgt.pdf>	2012	GDOT uses highway maintenance management system (HMMS) to track and inspect the maintenance works, and develop a work program according to the equipment costs, labor costs and material costs. This results an annual needs-based budget, annual work program and a comparison of actual versus estimated costs. Pavement condition evaluation system (PACES) rates each road-mile every year based on the assessment survey data and provides overall network condition, determines treatment activity types, predicts future condition for given budget, and determines the cost of works that need to be done. Pipe Inventory provides condition assessment of pipes and recommends the treatment activities. Bridge information management system (BIMS) stores bridge inspection data and generates deficiency reports, determines necessary repairs for budgeting and funding decisions. Life cycle cost analysis (LCCA) tool is used to compare lifecycle costs of different pavement types to make the decisions between construction and rehabilitation. Highway performance monitoring system (HPMS) stores a variety of road inventory as mandated by FHWA data consisting of 98 items which is used for allocating the funds by Federal Government. Benefit/Cost (B/C) tool is used in project prioritization process as part of decision making process.

Title/State	Author/Publication	Year	Brief Summary
Managing and Maintaining Roadway Assets The Utah Journey	U.S. Department of Transportation Federal Highway Administration <https://www.fhwa.dot.gov/asset/hif12016/hif12016.pdf>	2012	UDOT manages its roadside assets with the use of a performance-based data-driven approach in decision making. UDOT has also explored the use of Lidar and High Definition Imagery to get a perfect inventory of approximately nineteen roadway assets. The DOT has been using Maintenance Management Quality Assurance (MMQA) programs since 1997for the infrastructure maintenance and the effectiveness of maintenance activities. MMQA+ which is an enhanced MMQA program, was developed in 2003 providing the for refined and enhanced decision support. The software gives a rating from A to F for the level of maintenance. The MMQA+ system also helped the agency to implement a zero based budget instead of previous incremental process where the budget for next year is assigned based on system condition, available funds and target performance with the zero baseline. This made Utah DOT achieve a significant progress in achieving its strategic goal.
Comprehensive transportation asset management: The North Carolina Experience, Part Two	FHWA <https://www.fhwa.dot.gov/asset/hif12006/hif12006.pdf>	2012	The NCDOT has Asset Management with the objective of “take care of existing assets”. A thirty year long range state transportation plan (LRSTP) is developed furcating the revenue and spending. This results in a more detailed 10 year transportation program and resource plan which is used to develop a work plan with span of 5 years. With updates in PMS, BMS, and maintenance management system, agency is able to conduct trade-off within and across the assets.

Title/State	Author/Publication	Year	Brief Summary
Statewide Capital Investment Strategy State of New Jersey	New Jersey Department of Transportation, NJ TRANSIT, New Jersey Turnpike Authority, and South Jersey Transportation Authority. <http://www.nj.gov/transportation/capital/cis/pdf/scis_full.pdf>	2011	The 10 Year Statewide Capital Investment Strategy (SCIS) is a decision-making tool used by State of New Jersey to develop investment options for transportation program categories based upon goals, objectives, and performance measures. The goal of the SCIS is to develop an annual spending level that can achieve the performance objectives of the NJDOT, NJT, NJTA and SJTA. The SCIS report clearly depicts the current and future condition of New Jersey's transportation system; outlines recommended investment patterns, based on alternative funding scenarios; presents an analysis that documents the investments required to address needed transportation improvements over the next ten years; makes clear policy and action recommendations; and represents a consensus of SCIS partner transportation agencies.
Asset Management State of Oregon	Oregon department of Transportation <http://www.oregon.gov/ODOT/TD/asset_mgmt/ManagementSystems.shtml>	2010	Oregon Transportation Management System (OTMS) helps the decision makers in selecting cost-effective programs and projects. The function of OTMS is to inventory roadway and other transportation assets; collect, analyze, and summarize data; identify and track performance measures; identify needs and help determine strategies and actions to address those needs; and monitor and evaluate the effectiveness of strategies and actions that are implemented. There are nine managing systems included in the OTMS: Future Assets, Bridges, Pavements, Freight & Intermodal, Congestion, Environmental, Safety, Maintenance, and Traffic. This system enables each asset class and operational data source individuality and the freedom to choose its asset-specific tools, while remaining part of the overall performance-based TAM system.

Title/State	Author/Publication	Year	Brief Summary
Visualization of Transportation Assets with Geo-browsers: Cost Effective Tools for Exploration, Interaction, and Decision Making	M.T.Darter, T.A. Lasky, and B.Ravani	2010	Use geobrowsers such as Google Earth, Bing Maps, ArcGIS explorer, and World Wind to transforms data into images for interpretation; thus, increase the effectiveness of decision making, communication, and planning.
Applying Asset Management to the Interstate Highway System	NCHRP. NCHRP Report 632, Transportation Research Board	2009	The report provides guidance on implementing an asset management approach for the IHS, taking into account the basic motives for implementation, the focus area, previous approaches, and the internal and external stakeholders involved in the implementation. By taking advantage of best practices in asset management and risk management, highway system owners and operators can identify and combat the effects of deteriorating infrastructure, minimize costly system disruptions, and keep the national highway system running.
Management Systems: Driving Performance A Glance at Data-Driven Decision making Practices	FHWA <http://www.fhwa.dot.gov/asset/if09021/index.cfm>	2009	As the transportation community moves from a program philosophy of being reactive and utilizing the worst-first approach, to that of developing a more strategic approach to asset management, more State transportation agencies are using many of the TAM principles to preserve the system and maximize its performance. TAM relies on data and data analysis to optimize the planning, preservation, improvement, and replacement of assets. Instead of simply accounting for existing infrastructure and a series of individual projects, TAM looks at the whole network and makes strategic decisions as to how specific resources-money and staff-should be deployed.

Title/State	Author/Publication	Year	Brief Summary
U. S. Domestic Scan Program: Best Practices in Transportation Asset Management State of Utah	AASHTO, FHWA, NCHRP Project 20-68 <http://onlinepubs.trb.org/onlinepubs/trbnet/acl/ncrhp2068_domestic_scan_tam_final_report.pdf>	2007	The asset management system (AMS) has been implemented within a commercially available off-the-shelf software package called dTIMS CT. The AMS allows for a "stovepipe" type analysis for any asset and allows for a "cross-asset analysis and optimization". UDOT utilizes the cross asset analysis and optimization functionality of the dTIMS CT asset management system using condition performance measures and Remaining Service Life (RSL). This strategic-level analysis uses an incremental benefit/cost optimization approach to determine strategic funding levels among asset groups. Data and model results from each of the lower-level asset-specific management systems are fed into the strategic-level asset management system for analysis.
Asset Management at the Vermont Agency of Transportation State of Vermont	Vermont Agency of Transportation, Policy & Planning Division <http://knowledge.fhwa.dot.gov/tam/aashto.nsf/All+Documents/64A19FA1C033772B8525730300565CF7/$FILE/VT%20Asset%20Management%20One%20Pager.pdf >	2007	The decision-making process in Vermont Agency of Transportation (VTrans) involves prioritizing projects based on the numeric scores and selecting the project with the top priority. The scoring system includes safety, traffic volume, availability of alternate routes, future maintenance and reconstruction costs, and priorities assigned by regional planning commission. VTrans' Paving Section uses the Deighton's dTIMS pavement management software to develop its paving program. AASHTO's PONTIS bridge management software is used for VTrans' bridge system. VTrans' Operation Division uses Maintenance Activity Tracking System (MATS) to record its highway maintenance work, uses facility inventory and condition reporting software to calculate a building health index and to recommend repairs in a priority sequence. VTrans uses software from Maximus to track equipment usage and to optimize maintenance and replacement cycles at the least cost for Central Garage Fleet and Equipment. VTrans has started a long-term effort to integrate data from the independent asset-management systems into an improved data ware house. The objective is to improve decision-making for transportation-program managers and to help evaluate among asset classes.

Title/State	Author/Publication	Year	Brief Summary
Highway Economic Requirements System-State: The Indiana Experience State of Indiana	U.S. Department of Transportation, FHWA <https://www.fhwa.dot.gov/infrastructure/asstmgmt/csin06.pdf>	2006	InDOT is moving towards the use of highway economic requirement system (HERS) - state version from the customized one. With this software, InDOT develops project-specific long-range plan using the tools such as Indiana Statewide Travel Demand Model (ISTDM) which provides analytical framework for system performance and deficiency analysis, Traffic Forecasting Tool (TFT) which provides relation of forecasted volume, available capacity and level of service, Major Corridor Investment Benefit Analysis System (MCIBAS) which offers benefit-cost analysis of alternatives showing the direct impact of highway improvements on future traffic volume, speeds and distances. Thus, InDOT is able to develop Fiscally-Constrained Long-Range Transportation Plan (LRTP) with 25 year of span, Route Concept Reports which have major reconstruction projects, Planning Studies which have system-wide impacts to various highway facilities.

Title/State	Author/Publication	Year	Brief Summary
Asset Management in Planning and Operations: A Peer Exchange State of Maryland	Hendren, P. Transportation Research Circular E-C076 <http://onlinepubs.trb.org/onlinepubs/circulars/ec076.pdf>	2005	Several tools were developed by Maryland State Highway Administration for its TAM. Most of the system data are stored in a GIS database. A variety of other tools have been developed that allow for access to construction history data, pavement and bridge condition information, bridge inventory information, and traffic and accident data. The majority of these tools are database systems that allow for user queries and data reporting, however, some of the systems are text and graphic reports that are updated on a regular basis. PONTIS is used to rate the condition of bridges and large structures, whereas a scoring system based on various factors (primarily community requests) is used to identify and prioritize urban revitalization projects. A project- and life-cycle-based system driven by needs and age prioritization is used for drainage projects. A project-based system driven by needs identification is used by the Congestion Relief and Safety programs. A network-based system driven by optimization is used for pavement management. An in-house developed system is used to evaluate various funding strategies to maintain and improve the pavement network. The system utilizes an optimization approach to maximize program benefits while operating under budgetary and policy constraints. An investment strategy is developed to establish outcome- and output-based targets for District offices. District offices attempt to develop resurfacing programs that will achieve these targets using an in-house developed project selection tool.

Title/State	Author/Publication	Year	Brief Summary
Asset Management in Planning and Operations: A Peer Exchange District of Columbia	Hendren, P. Transportation Research Circular E-C076 <http://onlinepubs.trb.org/onlinepubs/circulars/ec076.pdf>	2005	A street-oriented system (SIS) based on 1990 FHWA pavement management system (PMS) requirements is utilized by District of Columbia as a decision support tool for transportation asset management. The system has a fully developed geographic information system (GIS) link to allow mapping and the analysis of program decisions against other factors, projects, and programs such as lighting improvements, development activities, or utility investments. The AM system works off the SIS and makes an initial attempt to allocate resources. The AM system favors maintenance activities. Data are collected by an automated distress survey van. Tunnel, retaining wall, and culvert management systems and a PONTIS upgrade to enhance its usefulness to D.C. are being pursued. The goal is to connect all systems with the SIS through a unified, GIS-linked database. Future enhancements to allow what-if exercises, shifting between programs, will be processed manually.
Analytical Tools for Asset Management	NCHRP. NCHRP Report 545, Transportation Research Board <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_545.pdf >	2005	This report presents two tools developed to support tradeoff analysis for transportation asset management. These software tools and the accompanying documentation are intended for state departments of transportation (DOTs) and other transportation agencies to help them improve their ability to identify, evaluate, and recommend investment decisions for managing the agency's infrastructure assets. A gap analysis conducted in the first phase of the study revealed that many existing asset management systems are not being used to their full potential. A need was identified for tools that could be integrated with existing systems to improve an agency's ability to analyze and predict the impacts of investments at the network and program levels on overall system performance. This report and software will be very useful tools for analysts and decision-makers in three major functional areas within state DOTs: (1) policy, planning, and program development; (2) engineering (construction, maintenance, and operations); and (3) budget and finance.

Title/State	Author/Publication	Year	Brief Summary
Asset Management Overview : Current Practices in TAM	FHWA <https://www.fhwa.dot.gov/asset/if08008/amo_06.cfm>	2004	State of Maryland DOT has an AM with the goal of “maximize the effectiveness of existing systems” under State Highway Administration (SHA). Following the primary objective, SHA determines the funding strategies such that the highway network health is maximum within the funding constraints. This procedure consists of five steps; condition assessment, network-level planning, project selection, project advertisement, and construction. Linear programming model used to develop the investment strategies with the specific objective and constraints of budget. The model lists the lane miles of each five conditions with the recommended treatment type but doesn’t specify the particular highway. Then, grouping the pavement and treatments, model can generate the performance scenarios to predict the future performances, cost and benefits across the network. Project selection tool (PST) developed by SHA, linked to inventory let the user to access roadway condition, traffic level, goals of the district, and recommended number of lane-miles for treatment data. District and pavement division afterwards list the potential projects with cost estimates then PST compares effectiveness of individual project towards meeting the goals. This AM approach is known for using formal performance measures, cooperation between central leaders and districts, and long term optimization.
Asset Management Overview : Current Practices in TAM	FHWA <https://www.fhwa.dot.gov/asset/if08008/amo_06.cfm>	2004	Michigan DOT mandated the AM by law and has established transportation asset management council (TAMC). TAMC produces annual budget in response to the overall system needs or priorities. The major three performance measures out of 100 are bridge condition, pavement condition and customer satisfaction. Bridge inspection frequency is 2 years with National Bridge Inventory (NBI), pavement condition is evaluated on the basis of ride smoothness, cracking, and rutting, and customer satisfaction through the survey and feedbacks. Thus, DOT is developing data collection and management systems for long-range plan with optimization.

Title/State	Author/Publication	Year	Brief Summary
Best Practices for Linking Strategic Goals to Resource Allocation and Implementation Decisions	Midwest Regional University Transportation Center	2004	This report assembles a set of tools, based on the experiences and best practices in a diverse set of states, for linking strategic goals to resource allocation. Based on detailed documentation of the practices in five states—Florida, Maryland, Michigan, Montana, and Pennsylvania—a synthesis of best practice of strategic planning, asset management, and the linkage between the two was developed.

Title/State	Author/Publication	Year	Brief Summary
Asset Management Overview : Current Practices in TAM Asset Management Plan : Florida DOT (2015) State of Florida	FHWA <https://www.fhwa.dot.gov/asset/if08008/amo_06.cfm> <http://www.fdot.gov/planning/TAMP/TAMP - 2015.pdf>	2004	As an asset management system, Florida DOT has "program and policy planning" process which links policies with financial planning, programming, and performance monitoring continuously. It begins with a 20-year long policy framework plan and a 10-year long detailed program and resource plan. Based upon which, a 5-year long work plan (i.e. listing of projects) is developed and reviewed annually. The budget is allocated in the proportion of district's proportion of deficient lane-miles and bridges. Considering the preservation of the existing system first, three inventory-driven and performance-based systems- PMS, BMS and maintenance rating program- are developed. Annual pavement condition survey evaluates ride quality, crack severity, and average depth of wheelpath ruts of which a rating of below 6 in a scale of 10 is recommended for treatment. Life-cycle cost analysis determines the most cost effective treatment type. Bridges are inspected every 2 year and identified whether it needs preventive maintenance, minor or major repair works. The overall maintenance condition is calculated based on the sampling of roadway, roadside, vegetation and aesthetics, traffic services, and drainage three times a year. Threshold of the rating is 80 for acceptance. Half of the remaining budget is then allocated for the strategic system which ensures the goals of mobility and economic prosperity. Improvement needs are based on pavement condition, congestion, safety, intermodal connectivity, and economic development whereas the performance measures for quantity and quality of the service are level of service, vehicle miles traveled, and percentage of system heavily congested. The whole process is a bottom-up gathering inputs from many MPOs.
Project Selection Process State of Texas	Texas Department of Transportation	2003	This document explains the funding allocation and project-selection process followed by the Texas Department of Transportation. Five steps are considered in the project-selection process: identify needs, consider funding, planning, project development, and construction.

Title/State	Author/Publication	Year	Brief Summary
Transportation Asset Management Case Studies: Economics in Asset Management: The New York Experience State of New York	FHWA. USDOT, Publication No. FHWA-IF-05-024 <http://www.fhwa.dot.gov/infrastructure/asstmgmt/dinytoc.cfm>	2003	NYSDOT has developed an analysis tool, the TAM Tradeoff Model, which provides a technical platform for making tradeoffs at the program level. Four pre-existing management systems that support the department's goal areas—pavements, bridges, safety, and mobility—provide input to this new tool. The TAM Tradeoff Model could compare investment candidates selected by one stovepipe management system to those selected by others. This model draws available economic and performance data from almost 2,000 investment candidates identified by the separate management systems. The tradeoff model ranks these projects both within and among program areas based on benefit-cost ratios. Implementing projects with the highest benefit-cost ratios maximizes benefits to highway users. The power of the TAM Tradeoff Model is its ability to assess the cost-effectiveness of treating groups of assets taken together, such as facilities in a corridor. Such a tool is important for allocating resources to appropriate goal areas so as to maximize benefits to the public.

Title/State	Author/Publication	Year	Brief Summary
Integrating Bridge Management Systems into the Business Process and Software Environment of the State DOT: Three States' Experiences: California, Michigan, and Mississippi	SOLON F. BLUNDELL Cambridge Systematics, Inc. JERRY SMITH Mississippi Department of Transportation ROBERT KELLEY Michigan Department of Transportation MIKE JOHNSON California Department of Transportation	1999	The departments of transportation of California, Michigan, and Mississippi have developed general transportation management systems (TMS) that incorporate the Pontis bridge management system (BMS) developed by the American Association of State Highway and Transportation Officials. The technical and business challenges presented by these efforts have been numerous and complex: identifying the users of the systems and the data they require to do their jobs effectively; defining the database structure of the TMS; arranging for the transfer of data among the various systems with which the TMS must interact; establishing business processes and workflows; establishing ownership and responsibility for data; establishing data validation protocols; arranging for the input of data from field inspections; arranging for the integration of data that may be collected at disparate times and places. This paper shares some of the experiences of these three states, focusing on the interaction between the BMS and the other systems and processes with which it collaborates within the framework of the broader TMS.

Table A2: Summary of Literature Review and Current State of Practice in Cross-Asset Optimization Models for Transportation Asset Management

Title/State	Author/Publication	Year	Brief Summary
Cross-Asset Optimization at Colorado DOT State of Colorado	<http://onlinepubs.trb.org/onlinepubs/conferences/2012/assetmgmt/presentations/OtherAssets-Richrath.pdf>	2012	Beyond just pavement and bridge, to maintain the level of service, fleet and intelligent transportation systems (ITS), CDOT is practicing cross-asset optimization. The objective of the optimization is to maximize the life and utility of interconnected assets at network level and coordinate the construction and maintenance activities at project level.
Cross Asset Analysis and Optimization State of Utah	<http://www.cpe.vt.edu/pavementevaluation/presentations/Fox-Ivey.pdf>	2010	Cross-Asset optimization is conducted at strategic level for pavements, bridges and safety. The effect of shifting budgets from pavement to bridge asset can be studied with the help of optimization results.
Cross-Assets Trade-off Analysis: Why are we still talking about it?	Mrawira & Amador 2009	2009	A linear programming model developed for the cross-asset optimization using the TAMWORTH software which is a geo-spatial strategic linear programming matrix generator and interpreter. This software is capable of generating the investment scenarios for assets using inventory data and treatment effects. The objective of the optimization is to maximize the benefit to overall average condition or minimize the agency costs for a given target condition. The database in the case study is from NBDOT, Canada, consists of pavement and bridge asset. At network-level, the goal of strategic long-term investment planning (SLTIP) is to generate realistic future needs for the network at a specified level of service. For a given investment scenario, the model optimizes the network condition.

Title/State	Author/Publication	Year	Brief Summary
Goal Programming Methodology for Integrating Pavement and Bridge Programs	Ravirala & Grivas 1995 *Journel of Transportation Engineering*	1995	Both at the network and project level, optimization model is developed by goal programming formulation for bridge and pavement sections. The overall goal is to optimizing those sections for maintenance and repair (M&R) works. Bridge and pavement sections where M&R works can be implemented simultaneously are grouped as “Integrable unit” and are considered along with the pavement and bridge assets in the optimization model. The objective of the optimization model is minimizing the deviations from the total M&R expenditure of each class and maximizing the benefits of implementing the M&R works on an “Integrable unit”. The model consists of various such 15 goals.
Integration of pavement and bridge management systems: a case study	Grivas & Schultz. 1994 *Conference Proceedings*	1994	Cross-asset optimization is employed with a goal programming based formulation for capital program development at network level. The goals are specified condition levels for bridge and pavement with the objective of minimal deviations from the targets. Lane miles of pavement at certain state that receiving particular type of treatment in a given year is the decision variable for pavement and for bridge, square feet of deck area in each span type receiving each type of treatment in a given year is the decision variable. Further, grouping the pavement, bridge and auxiliary items as the “planning section”, the optimization model has broader scope in long-term highway needs analysis and develop multi-year economic programs.

Table A3: Summary of Literature Review and Current State of Practice in Trade-off Analysis for Transportation Asset Management

Title/State	Author/Publication	Year	Brief Summary
A Hybrid Pareto Frontier Generation Method for Trade-off Analysis in Transportation Asset Management	Bai et al. 2015 *Computer-Aided Civil and Infrastructure Engineering*	2015	Evaluating the set of projects in terms of network performance measures, corresponding network level performance is determined. The model has the objective of minimization the total cost for cost versus performance measure trade-off whereas maximization of network level performance measures for trade-off between two objectives given the budget and performance constraints. A hybrid method computes the solution of the formulation. The case study in the research considers IRI, BCR, RSL, average travel speed and crash rate as the performance measures to evaluate the overall impact of project implementation. A set of "Pareto frontier" i.e. solution sets are graphed to conduct the trade-off between cost versus performance measure and in between the performance measures.
Cross-Asset Resource Allocation Framework for Achieving performance sustainability	Dehghani et al. 2013 *TRB 2361*	2013	Based on functional, structural and environmental performance indices, an optimal resource allocation framework is developed. The framework can study the impacts of various parameters in resource allocation by conducting sensitivity analysis. For the initial resource allocation, experts' opinion is exercises and optimal resource allocation is obtained by updating the scenario multiple times. The optimal maintenance strategy maximizes the performance over time, minimizes the cost and reduce the impacts on environment over the life. Even in a similar class of assets, best maintenance treatment are selected for each asset based on the available budget. Individual asset performance measures such as IRI, cracking, bridge condition states in a scale of 0 to 10, later being the best condition. These performance indices are converted into asset health indices (AHI) and their integration gives corridor health index (CHI). The overall corridor health index (OCHI) are compared to the set goals and the objectives.

Title/State	Author/Publication	Year	Brief Summary
Decision Methodology for Allocating Funds across Transportation Infrastructure Assets	Gharaibeh et al. 2006 *Journal of Infrastructure Systems*	2006	A sample highway network in Champaign County, Illinois is considered to implement the proposed methodology. Each asset is evaluated based on the performance indicators, efficiency and asset adequacy, and pre-specified threshold values. The relationship between the expenditure and overall performance for each class is established from the regression analysis. Using the multi-attribute utility theory (MAUT), utility function for all asset class are developed. Then four funding allocation scenarios; maximizing the efficiency, maximizing the percent adequate, maximize the utility and a manual allocation are evaluated.
Economics in Asset Management — The New York Experience State of New York	FHWA <https://www.fhwa.dot.gov/infrastructure/asstmgmt/diny06.cfm>	2003	NYDOT considers PMS, BMS, safety management and mobility as the major area for the economic analysis at asset class-level and project-level for evaluation of investment candidates. Trade-off model ranks candidate projects based on the benefit-cost ratio such that implementing projects with highest benefit-cost ratio maximizes benefits to highway users. The measure for the benefit is "excess user cost".
Development of Prototype Highway Asset Management System	Gharaibeh et al. 1999 *Journal of Infrastructure Systems*	1999	A case study in Champaign County based on spatial and statistical analysis of pavement condition, safety and congestion management using GIS based software "InfraManage" found the asset integration critical in urban areas. Pavements, bridges, culverts, signs, and intersections are evaluated using the performance measure indices, namely, efficiency and asset adequacy to integrate the assets. Efficiency relates current vehicle mile travelled (VMT) for linear assets while traffic volume for the point assets compares to the values at unlimited funding condition. While asset adequacy is based on threshold values of asset condition, accident rate and volume-to-capacity ratios which can be pre-specified by the agencies. Relationship between investment level and efficiency is established by regression analysis which facilitates the model to perform trade-off among the alternative investments with the objective of maximizing the performance within the given budget.

Title/State	Author/Publication	Year	Brief Summary
Optimization Approach for Allocation of funds for manitenance and preservation of the existing highway system (Abridgement)	Sinha et al. 1981 *TRB 826*	1981	Using the Indiana Highway System, a goal programming technique model for optimum allocation of State and Federal funds for improvement and maintenance of the existing highway system. An example with six improvement activities, four routine maintenance activities and four system objective is presented in the research, and model is studied for in-depth study of the trade-off involved under various scenarios.

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APPENDIX C. ANALYTIC HIERACHY PROCESS (AHP)

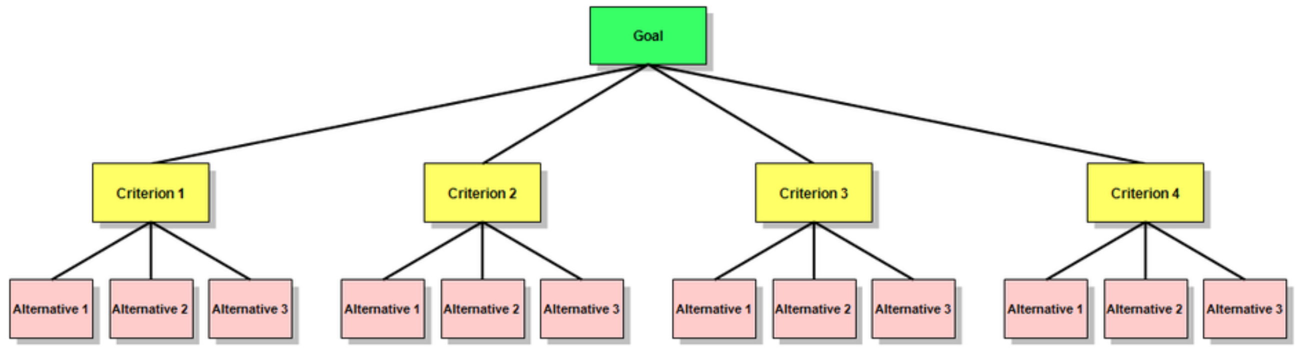
The analytic hierarchy process (AHP) is a technique for analyzing multi-objective decision-making problems. It has been used widely in many fields and can be used to organize very complex decision problems. AHP has unique advantages when important elements of the decision are difficult to quantify.

Decision situations to which the AHP can be applied may include, but are not limited to:

- Choice - The selection of one alternative from a given set of alternatives, usually where there are multiple decision criteria involved.
- Prioritization - Determining the relative merit of members of a set of alternatives, as opposed to selecting a single one or merely ranking them
- Resource allocation - Apportioning resources among a set of alternatives

The first step in the analytic hierarchy process is to model the problem as a *hierarchy*, consisting of an overall *goal*, a group of options or *alternatives* for reaching the goal, and a group of factors or *criteria/objectives* that relate the alternatives to the goal. The criteria/objectives can be further broken down into sub-criteria/objective, sub-sub-criteria/objective, and so on, in as many levels as the problem requires. A criterion/objective may not apply uniformly, but may have graded differences wherein a little sweetness is enjoyable but too much sweetness can be unpleasant. In that case the criterion is divided into sub-criteria indicating different intensities of the criterion: e.g. low, medium, high and these intensities are prioritized through comparisons under the parent criterion, sweetness. A civil engineering example you may be familiar with is the asphalt binder content in asphalt concrete mixtures. Not enough asphalt binder content would cause the mixtures to develop premature cracking, but too much asphalt binder could cause too much flow of the mixture which leads to pavement rutting.

Constructing a hierarchy typically involves significant discussion, research, and discovery by those involved. Even after its initial construction, it can be changed to accommodate newly-thought-of criteria/objectives or criteria/objectives not originally considered to be important; alternatives can also be added, deleted, or changed.



First, the goal, criteria, and alternatives of a decision problem are identified. The relative importance of each criterion versus other criteria in achieving the goal can be evaluated using pairwise comparison. The results are expressed as a '<u>criteria comparison</u>' matrix.

Each alternative is then compared with other alternatives using one criterion at a time, also through pairwise comparison. The results are expressed as '<u>alternative comparison'</u> matrices, one for each criterion. The core of the AHP method is to determine the relative weights, i.e., the relative importance of the different criteria and the relative rank of the alternatives under each criteria. The relative 'weights' are determined by multiplying the matrix by itself, then sum the rows, then 'normalize' the resulting vector by dividing each element by the column total to obtain the 'eigenvector'. Iterate the matrix multiplication process until the differences between two consecutive eigenvectors are negligible.

The Fundamental Scale for Pairwise Comparisons		
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

For example, under Criteria 1: Alternative A1 is moderately more desirable than A2, and A1 is extremely more desirable than A3. A2 is strongly more desirable then A3. The resulting matrix is:

$$\begin{array}{c} \\ A1 \\ A2 \\ A3 \end{array} \begin{array}{c} \begin{matrix} A1 & A2 & A3 \end{matrix} \\ \begin{bmatrix} 1/1 & 3/1 & 9/1 \\ 1/3 & 1/1 & 5/1 \\ 1/9 & 1/5 & 1/1 \end{bmatrix} \end{array}$$

Multiply the matrix by itself to find the eigenvector:

$$\begin{bmatrix} 1 & 3 & 9 \\ 1/3 & 1 & 5 \\ 1/9 & 1/5 & 1 \end{bmatrix} \begin{bmatrix} 1 & 3 & 9 \\ 1/3 & 1 & 5 \\ 1/9 & 1/5 & 1 \end{bmatrix} = \begin{bmatrix} 3 & 7.800 & 33 \\ 1.222 & 3 & 13 \\ 0.289 & 0.733 & 3 \end{bmatrix} => \begin{bmatrix} 43.800 \\ 17.222 \\ 4.022 \end{bmatrix} => \begin{bmatrix} 43.8/65.044 \\ 17.222/65.044 \\ 4.022/65.044 \end{bmatrix} = \begin{bmatrix} 0.673 \\ 0.265 \\ 0.062 \end{bmatrix}$$

Σ=65.044 Σ=1.000

Do the same for all other criteria.

If the decision problem has 5 criteria and 6 alternatives, then the criteria comparison matrix would be a 5x5 matrix, and there would be a total of five 6x6 alternatives comparison matrices, one for each criterion.

APPENDIX D. TAMDSTP USER MANUAL

1. Home

The home button briefly describes the web tool.

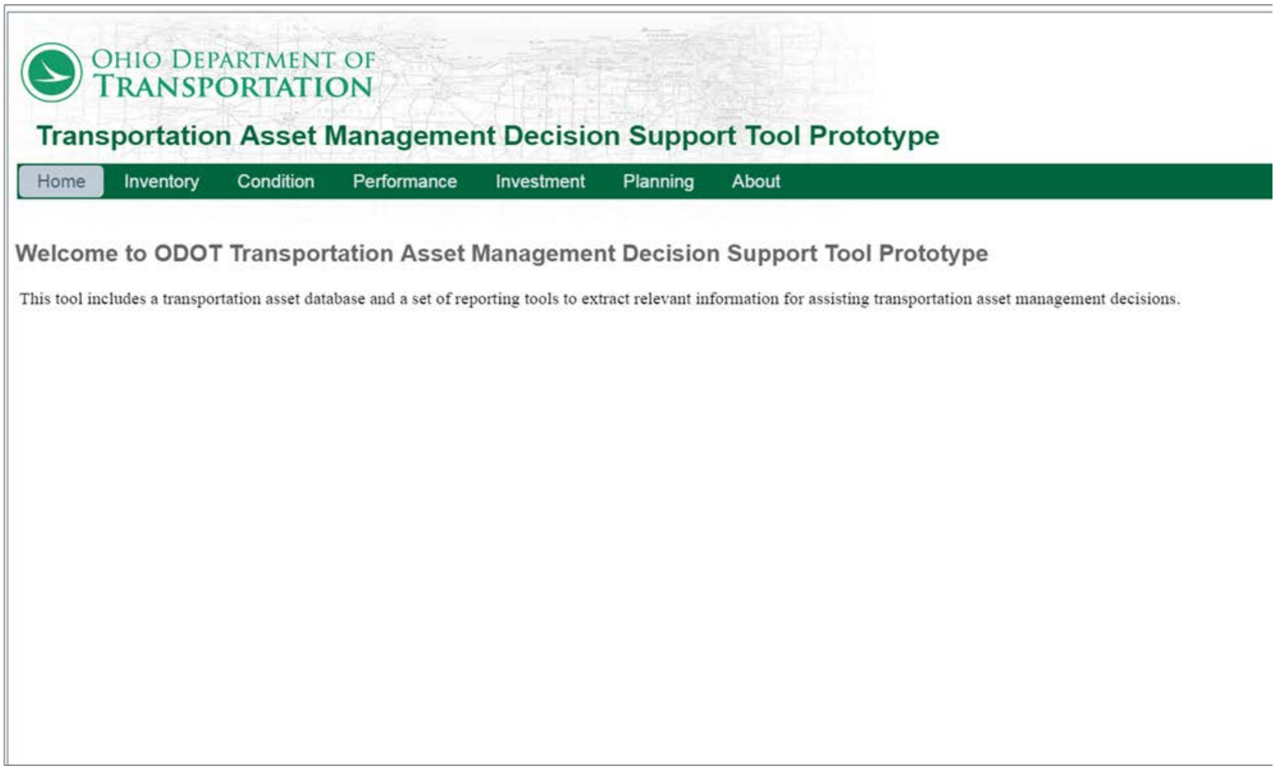


Figure D-1: Home screen in the web tool

2. Inventory

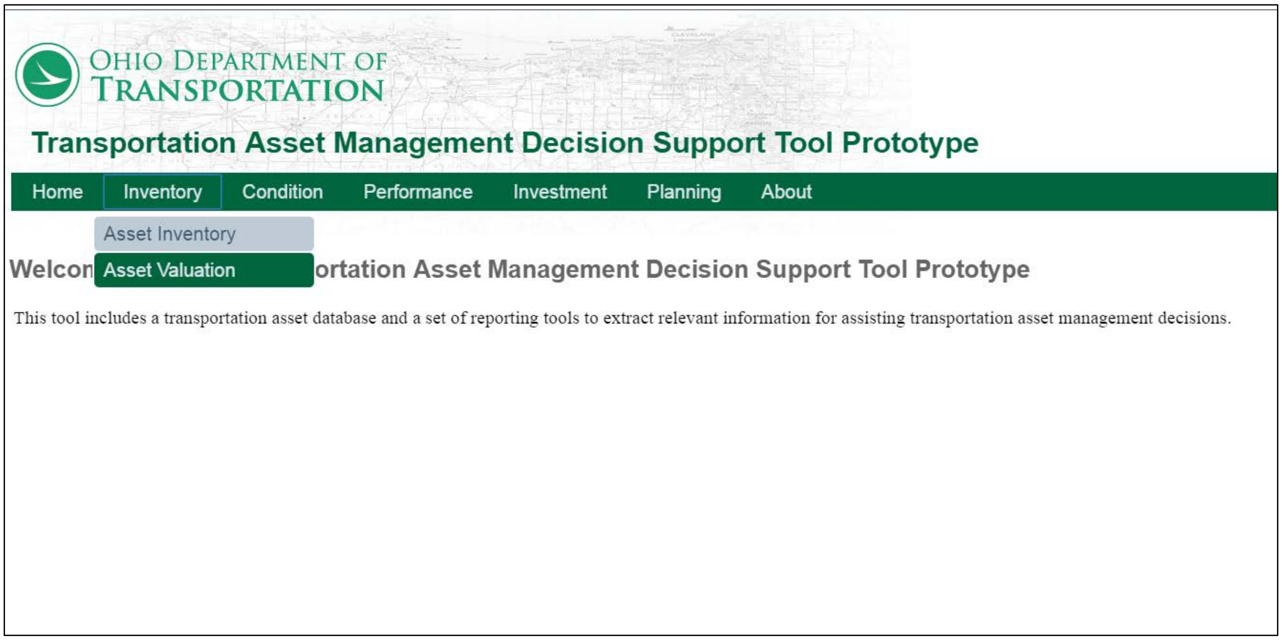
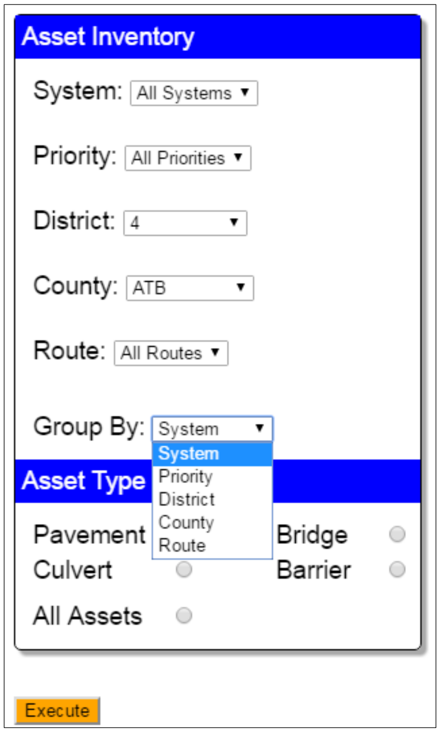


Figure D-2: Sub-menu under the "Inventory" menu

2.1. Asset Inventory



The Asset Inventory tool helps to show user the present inventory of various assets across the state. The inventory can be filtered by system, priority, district, county or route. The result can be grouped according to the system, priority, district, county or route.

Figure D-3 shows the selection for inventory of pavement in District 4, Ashtabula (ATB) County where the asset inventory is grouped according to system. Figure D-4 and D-6 show the chart showing the pavement and bridge asset respectively for the selection made.

Figure D-3: Asset inventory selection panel

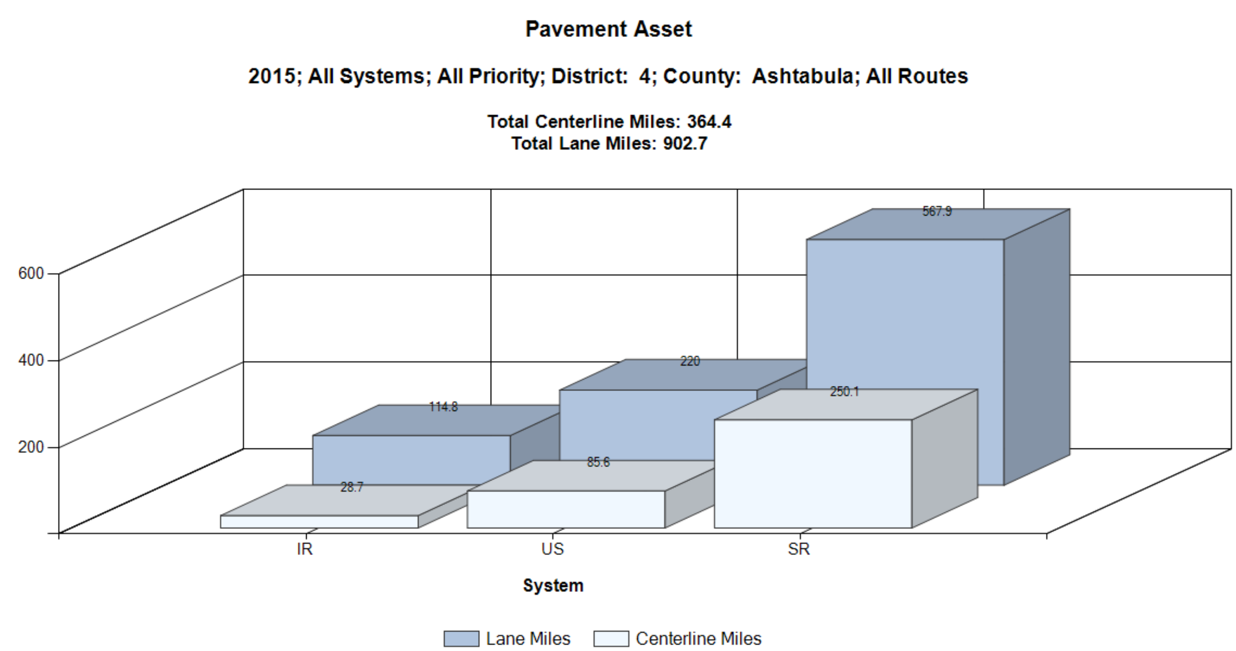


Figure D-4: Pavement Asset Inventory grouped by system

Hyperlink: Clicking on any chart area gives the detail about the pavement sections in the very selection. Figure D-5 shows the details of the selection from the output inventory chart in US system for the centerline miles in district 4, Ashtabula County.

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NLFID	District	County	Route	Blog	Elog	Section Length	Lanes	Surface Width	Priority
SATBUS00006*DC	4	ATB	006D	0	0.06	0.1	4	63	G
SATBUS00006*FC	4	ATB	006F	0	0.08	0.1	2	20	G
SATBUS00006**C	4	ATB	006R	0	2.63	2.6	2	20	G
SATBUS00006**C	4	ATB	006R	2.63	17.47	14.8	2	24	G
SATBUS00006**C	4	ATB	006R	17.47	21.9	4.4	2	21	G
SATBUS00006**C	4	ATB	006R	21.9	22.37	0.5	2	24	G
SATBUS00006**C	4	ATB	006R	22.37	22.4	0.0	4	60	G
SATBUS00006**C	4	ATB	006R	22.4	22.47	0.1	4	50	G
SATBUS00006**C	4	ATB	006R	22.47	22.53	0.1	4	58	G
SATBUS00006**C	4	ATB	006R	22.53	22.56	0.0	4	63	G
SATBUS00006**C	4	ATB	006R	22.56	29.95	7.4	2	24	G
SATBUS00006**C	4	ATB	006R	29.95	32.6	2.6	2	18	G
SATBUS00020**C	4	ATB	020R	0	2.01	2.0	4	40	G
SATBUS00020**C	4	ATB	020R	2.01	2.06	0.0	4	40	U

Figure D-5: Details of the pavement asset in the selection

Similarly, Figure D-6 shows the bridge inventory for the selections as shown. Clicking on the chart area gives the details of the selection. Figure D-7 shows the details of the IR System bridges from the resulting chart where deck area is between 5000 and 10000 sq. ft.

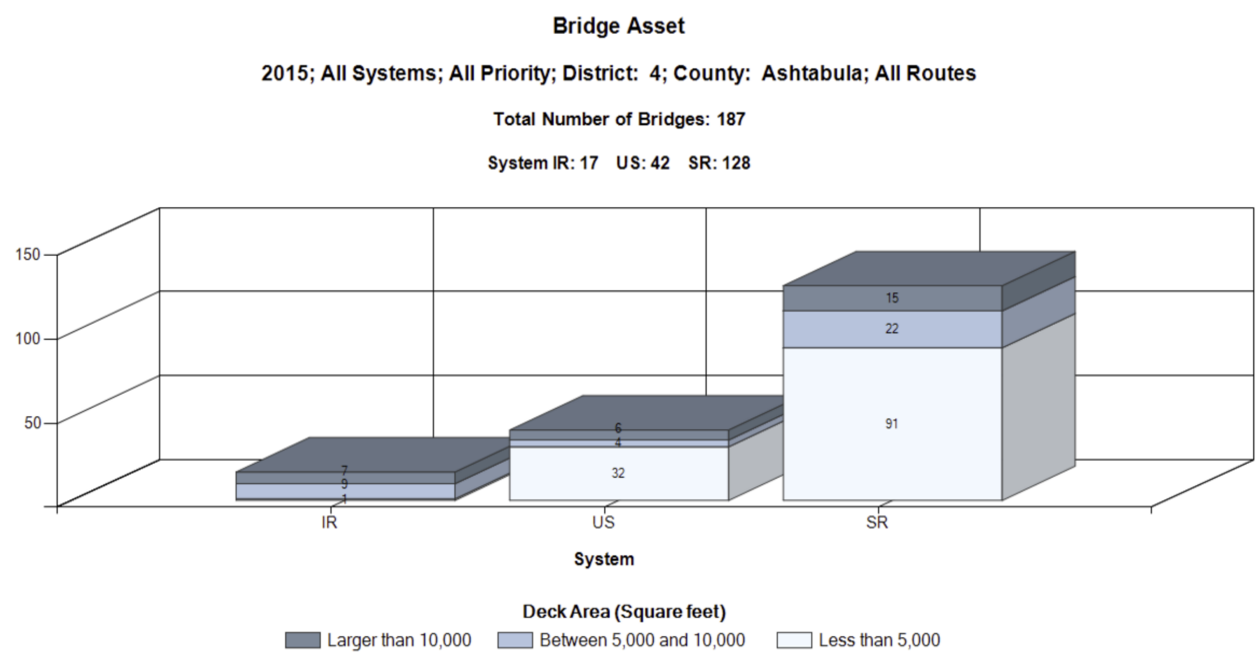

Figure D-6: Bridge Asset Inventory grouped by system

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NLFID	District	County	Route	Blog	Elog	Priority	Latitude	Longitude	Deck_Area	General_Appraisal
SATBIR00090**C	4	ATB	90R	9.31	9.34	P	41.798587	-80.834771	6071	5
SATBIR00090**C	4	ATB	90R	9.31	9.34	P	41.798587	-80.834771	6684	5
SATBIR00090**C	4	ATB	90R	14.5	14.53	P	41.829605	-80.748774	8600	9
SATBIR00090**C	4	ATB	90R	22.72	22.74	P	41.899411	-80.622981	5016	6
SATBIR00090**C	4	ATB	90R	22.72	22.74	P	41.899411	-80.622981	5016	6
SATBIR00090**C	4	ATB	90R	27.7	27.72	P	41.929243	-80.535474	5156	6
SATBIR00090**C	4	ATB	90R	27.7	27.72	P	41.929243	-80.535474	5156	6
SATBIR00090**C	4	ATB	90R	28.39	28.43	P	41.9348	-80.524263	8837	6
SATBIR00090**C	4	ATB	90R	28.39	28.43	P	41.9348	-80.524263	8837	6

Figure D-7: Details of the bridge asset from the selection

Similarly, we can get the inventory details for culvert and barrier too.

2.2. Asset Valuation

Asset Valuation is found under "Inventory" menu. User can enter the unit cost of replacement per lane for pavements and per square ft. of the deck area for bridge which ultimately gives the replacement cost of the pavement and bridge separately. Figure D-8 shows an example for the estimated replacement cost of the assets for selected all systems, all priorities, district 2, Lucas County, route 075R with average unit cost of replacement for pavement as $ 1,250,000 per lane mile and for bridge as $ 120 per square ft.

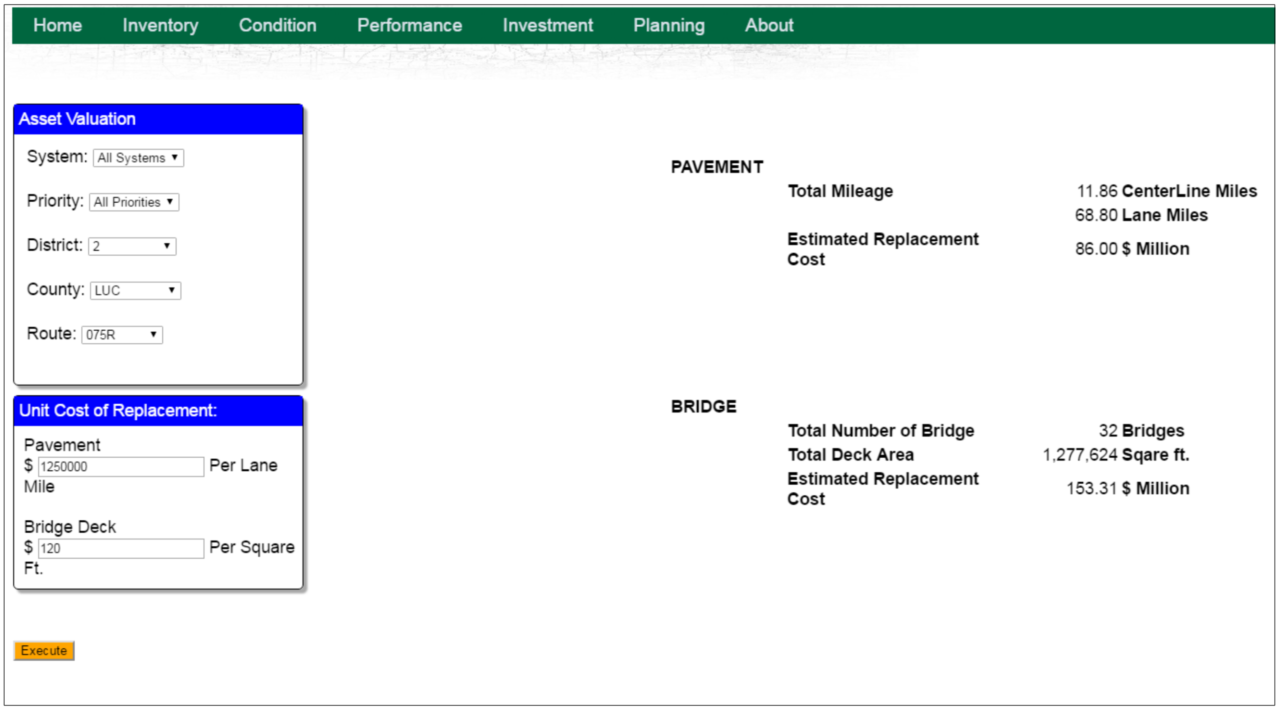


Figure D-8: Asset valuation for the selected network and unit cost of replacement

3. **Asset Condition**

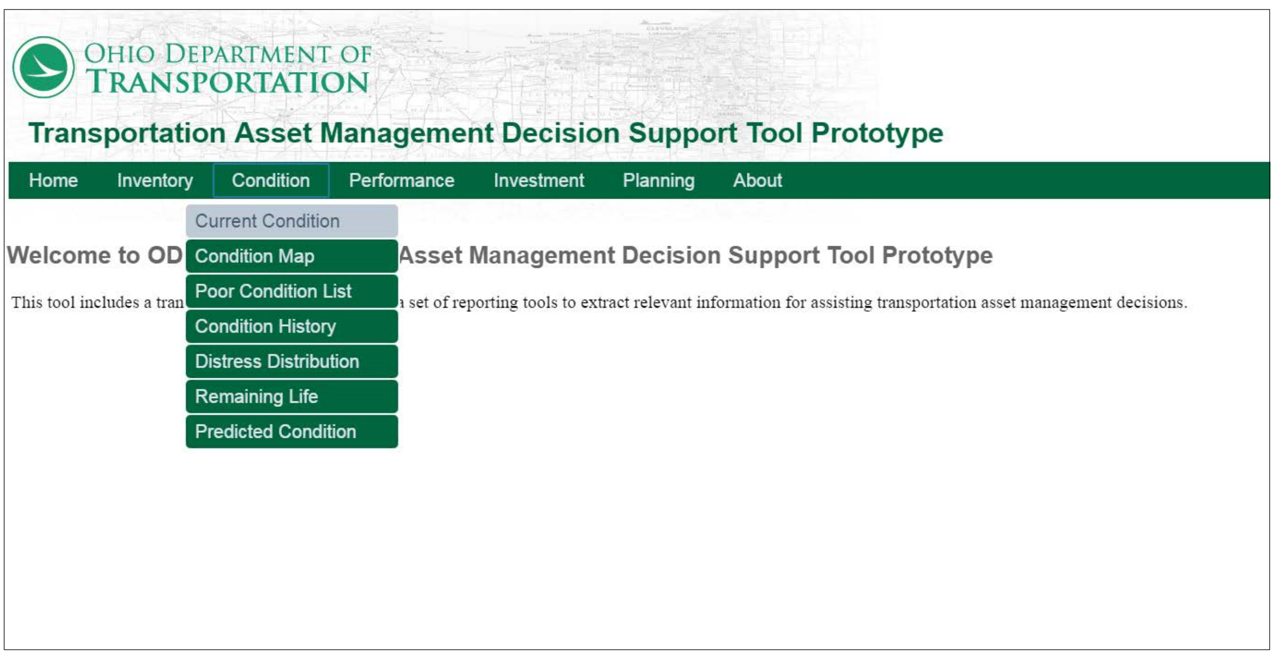


Figure D-9: Sub-menu under Condition tab

3.1. Current Condition

Current condition tool helps to display and visualize the current condition of various assets. Suppose we want current condition of all the priority roads in district 2. Select “All values” in System, “P” in Priority, “2” in District, “All Values” in County and “All values” in Route. Let us group it by “Priority”. Check on “Pavement” in asset type for the pavement condition and check “Bridge” for bridge condition.

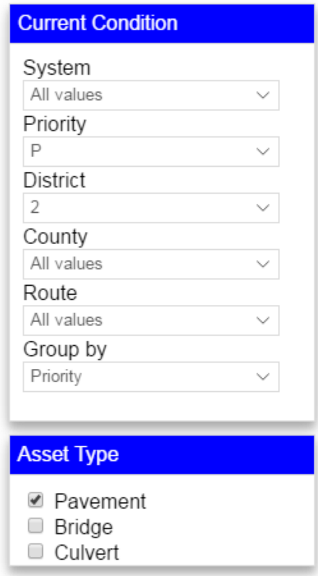


Figure D-10: Selection panel for current condition

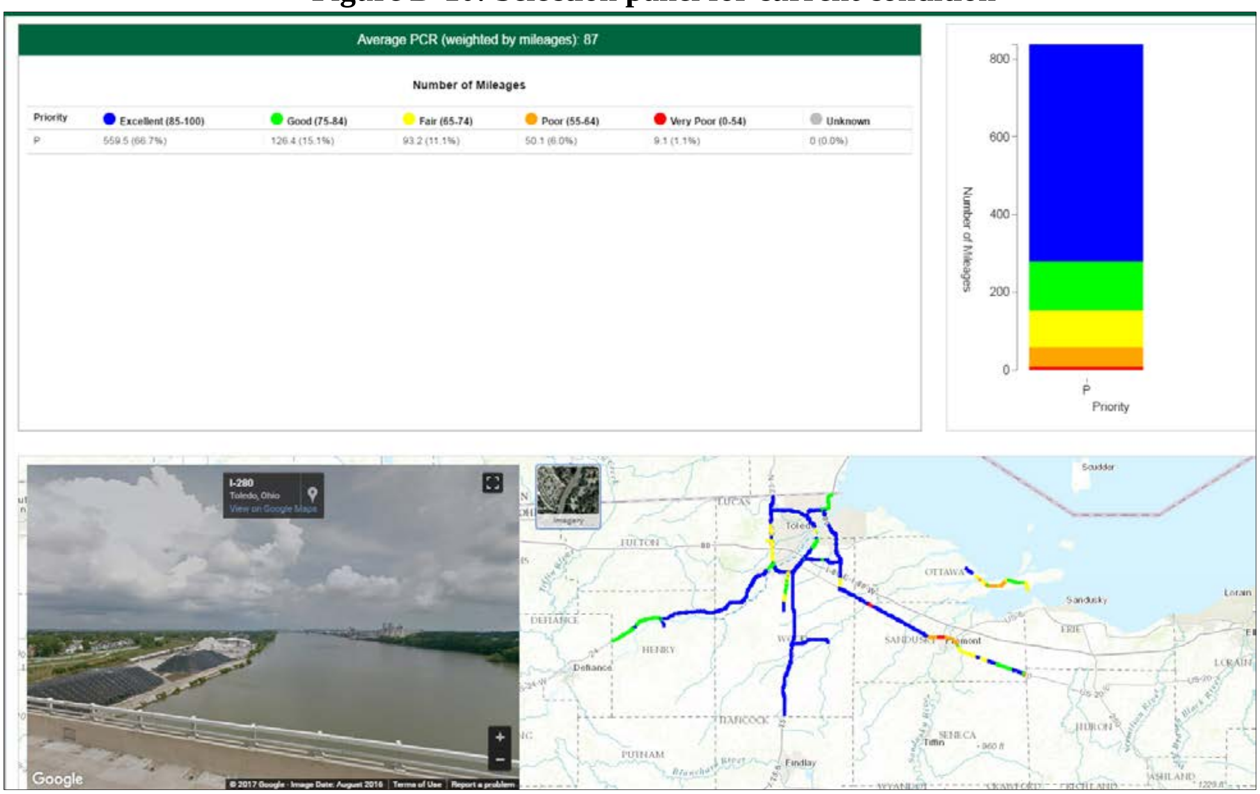


Figure D-11: Current condition of pavement for the selected area and priority

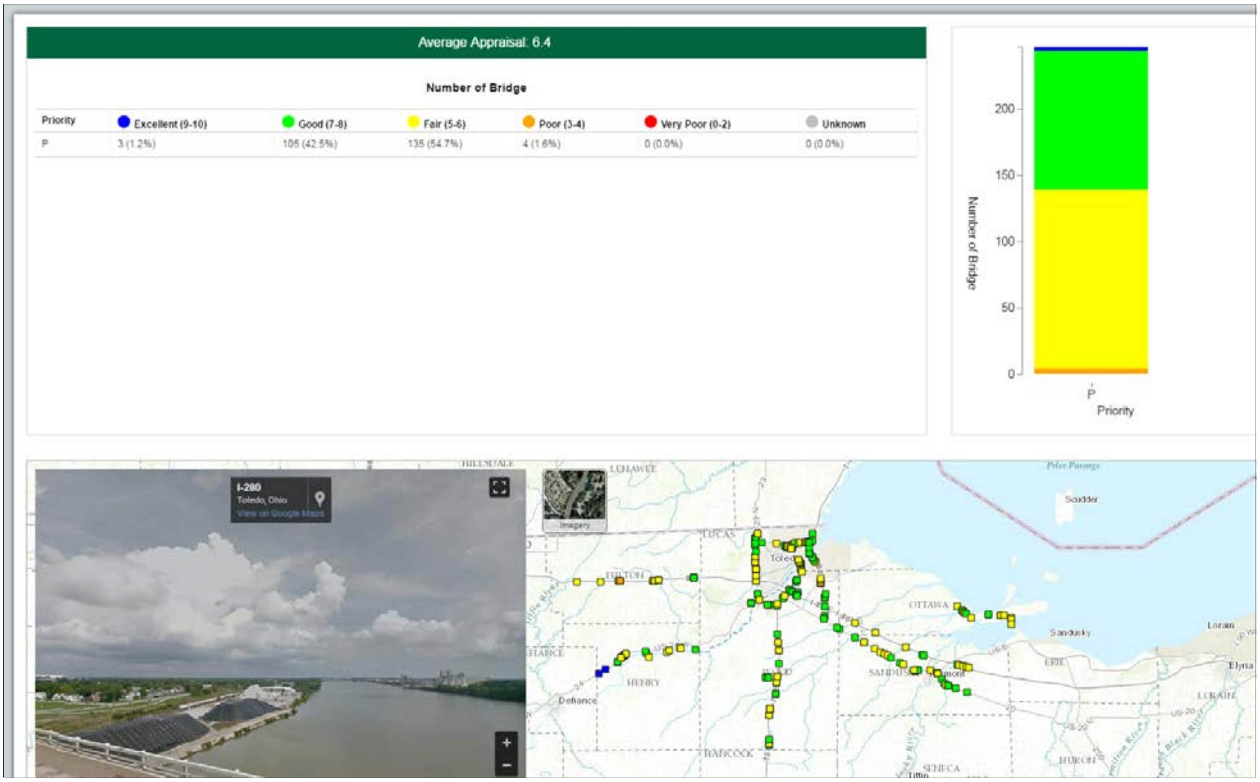


Figure D-12: Current condition of bridge for the selected area and priority

We can check the condition of individual asset or all assets at once. Clicking on any pavement section as shown in google maps shows the google street view image and details of that pavement section.

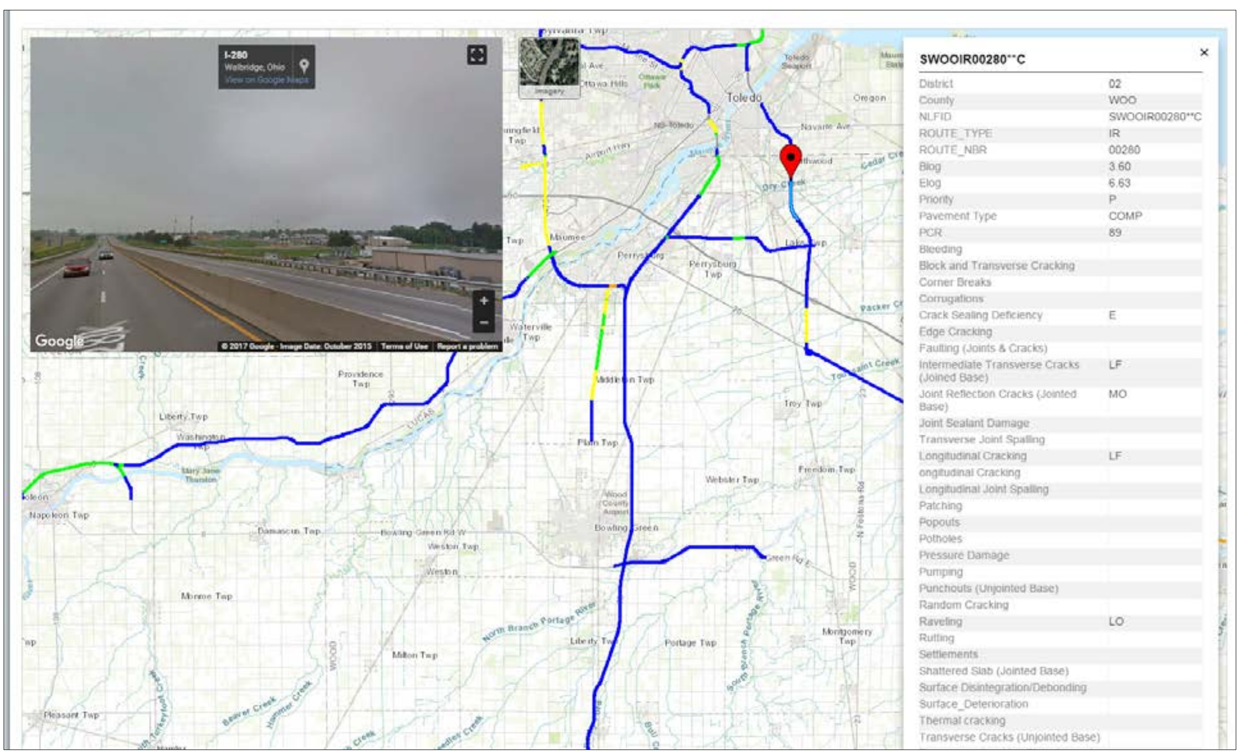


Figure D-13: Details of the pavement section selected

Similarly, clicking on any bridge shown in google maps displays the google street view image of that bridge as well as details of the bridge.

SWOOIR00280C**

District	02
County	WOO
NLFID	SWOOIR00280**C
ROUTE_TYPE	IR
ROUTE_NBR	00280
Blog	3.60
Elog	6.63
Priority	P
Pavement Type	COMP
PCR	89
Bleeding	
Block and Transverse Cracking	
Corner Breaks	
Corrugations	
Crack Sealing Deficiency	E
Edge Cracking	
Faulting (Joints & Cracks)	
Intermediate Transverse Cracks (Joined Base)	LF
Joint Reflection Cracks (Jointed Base)	MO
Joint Sealant Damage	
Transverse Joint Spalling	
Longitudinal Cracking	LF

Figure D-14: Details of pavement section selected

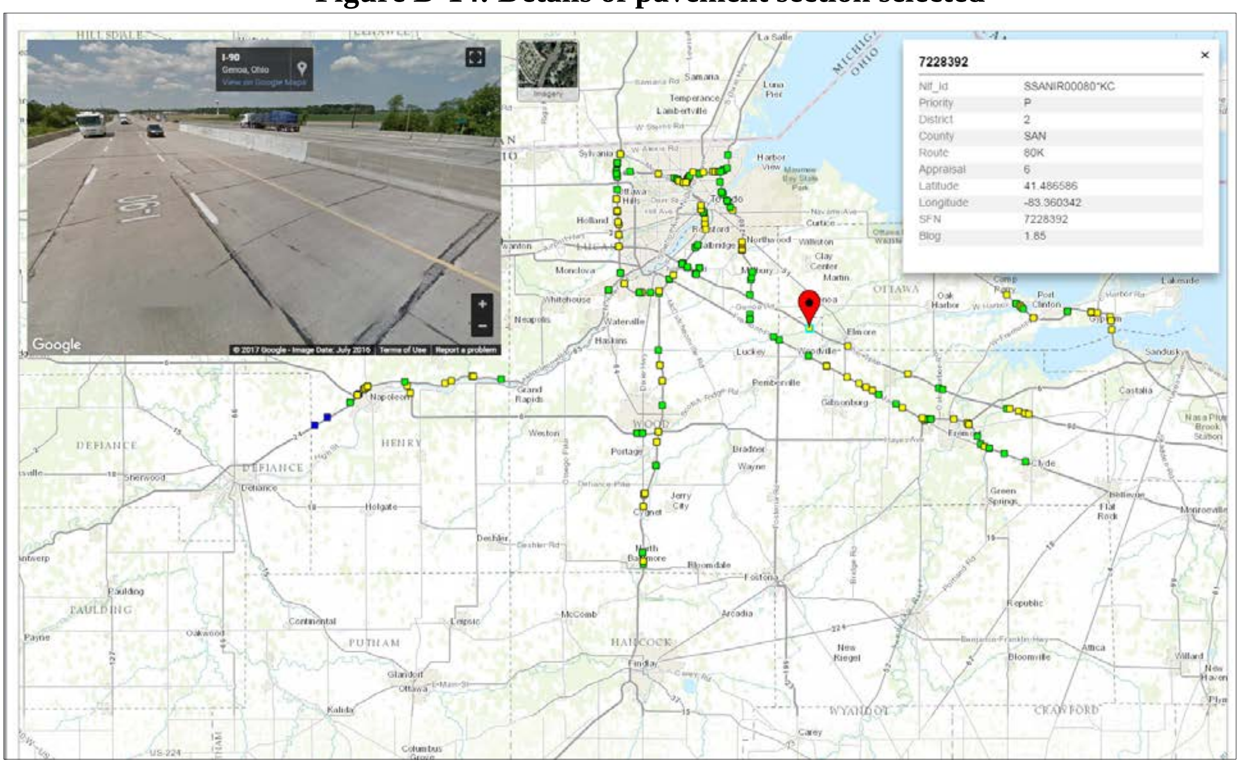


Figure D-15: Details of the bridge selected with google image

7228392	
Nlf_Id	SSANIR00080*KC
Priority	P
District	2
County	SAN
Route	80K
Appraisal	6
Latitude	41.486586
Longitude	-83.360342
SFN	7228392
Blog	1.85

Figure D-16: Details of the bridge selected

3.2.Condition Map

To see the condition of pavement or bridge, following steps are performed in the screen:

1) Click select district button in the top right corner below the full screen option which will list the districts. Select one of the districts or select all to view condition map all over the state.

2) Click on "Pavement" button to view the pavement condition or "Bridge" button to view the bridge condition.

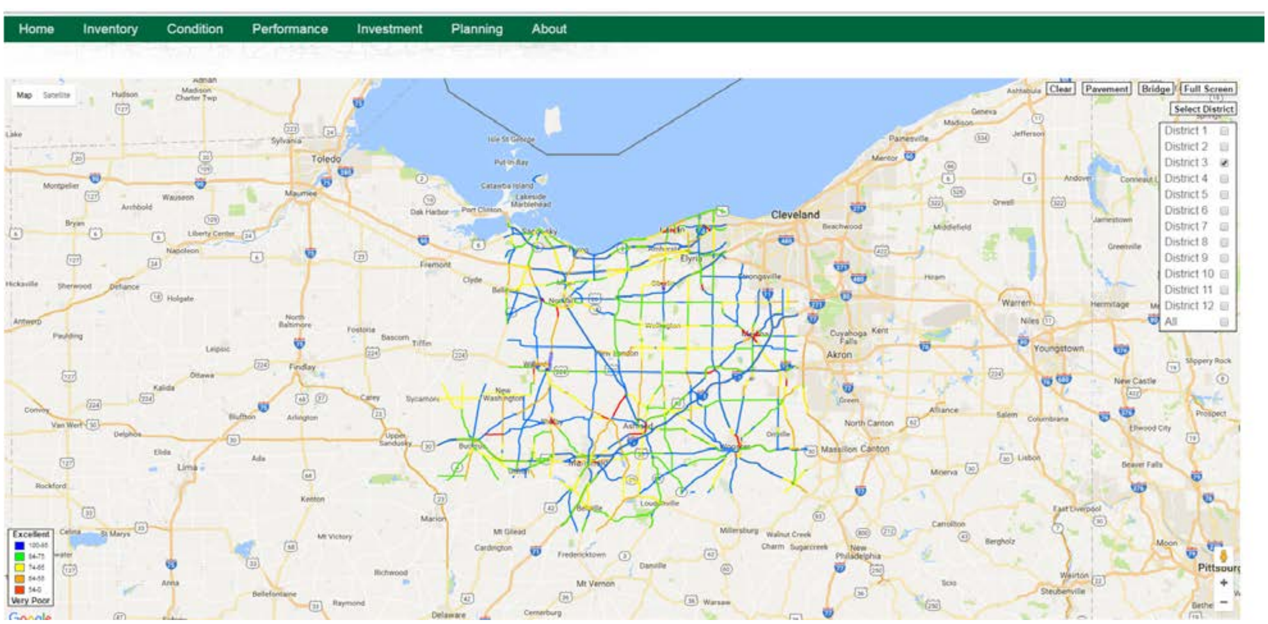


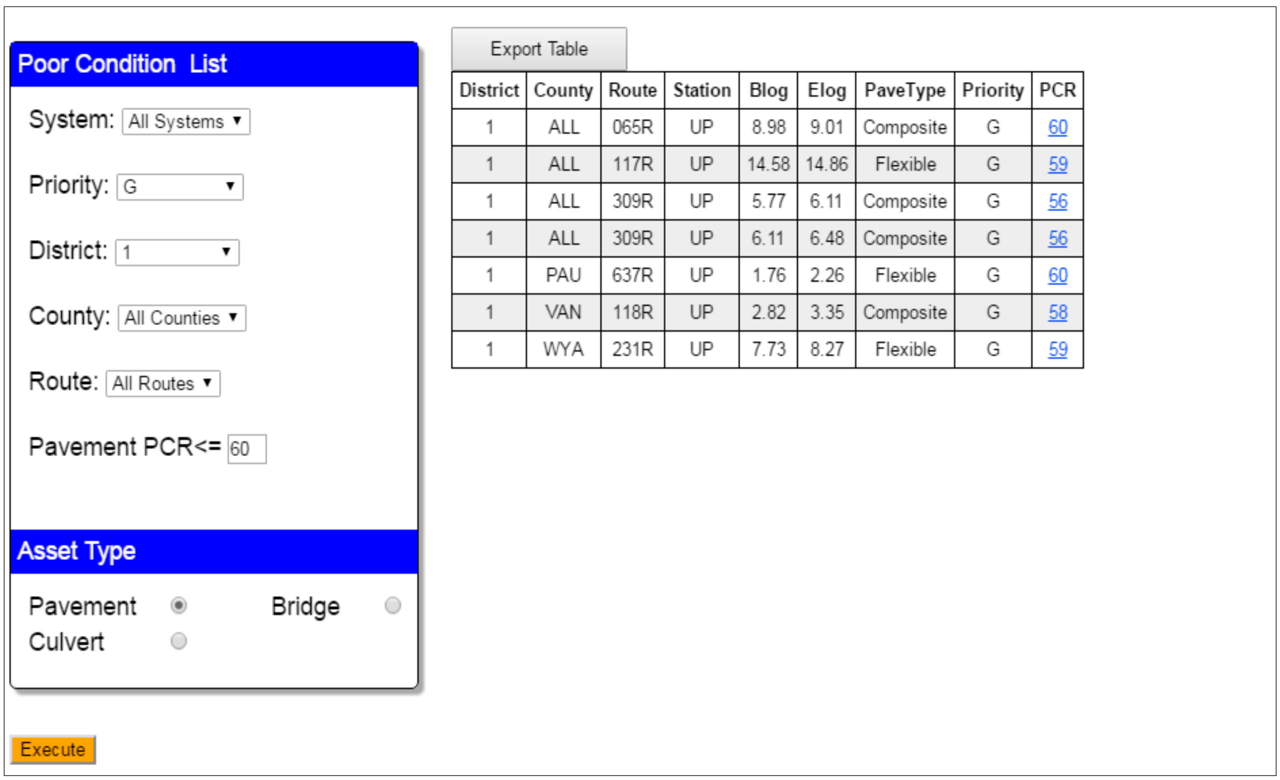
Figure D-17: Pavement condition in District 3

3) Use the clear button to clear the selection and start over with the new selection.

   To see the condition map in detail, the "Current Condition" tool as described in 3.1 can be used.

3.3. Poor Condition List

For the poor condition list, a threshold PCR for pavement, GA for bridge and GA for culverts is used. User can enter the value for the minimum value of PCR for poor condition list of the pavements and the list of the pavement sections is displayed for the given selection.
For example, if a user wants to display list of pavement sections performing poor in "All systems", "general (G)" priority, district 1, "All counties" and "All routes" with the threshold PCR as 60, it will display the following result as shown in figure D-18.



District	County	Route	Station	Blog	Elog	PaveType	Priority	PCR
1	ALL	065R	UP	8.98	9.01	Composite	G	60
1	ALL	117R	UP	14.58	14.86	Flexible	G	59
1	ALL	309R	UP	5.77	6.11	Composite	G	56
1	ALL	309R	UP	6.11	6.48	Composite	G	56
1	PAU	637R	UP	1.76	2.26	Flexible	G	60
1	VAN	118R	UP	2.82	3.35	Composite	G	58
1	WYA	231R	UP	7.73	8.27	Flexible	G	59

Figure D-18: Poor pavement condition list

Similarly, we can list the poor performing bridges and culverts too.

Hyperlink: The process involved or the deductions made while calculating the PCR in the resulting table can be further seen by clicking the underlined blue PCR value in the table.

Figure D-19 shows the detail calculation of PCR for the first row of the result in figure D-18.

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District	County	Route	Station	Blog	Elog	Pavement Type	Priority	PCR
1	ALL	065R	UP	8.98	9.01	Composite	G	60

2015 Condition PCR:60

	Distress	Severity/Extent	Deduct
1	Raveling	MO	3
2	Bleeding		
3	Patching	HO	3
4	Surface Disintegration/Debonding		
5	Rutting	MO	4.2
6	Pumping	O	3
7	Shattered Slab (Jointed Base)		
8	Settlements		
9	Transverse Cracks (Unjointed Base)		
10	Joint Reflection Cracks (Jointed Base)	HF	9.6
11	Intermediate Transverse Cracks (Joined Base)	MF	3.8
12	Longitudinal Cracking	HO	2
13	Pressure Damage/Upheaval	MO	1.5
14	Crack Sealing Deficiency	E	5
15	Corrugations		
16	Corner breaks (Jointed Base)	HO	5
17	Punchouts (Unjointed Base)		

Total Deduct = 40

Figure D-19: Deductions to calculate the PCR of the selected section of pavement

3.4. Condition History

Condition history tool helps plotting the trend of different pavement parameters over the time. Parameters for each route can be plotted to give a pattern showing change in them over the history.

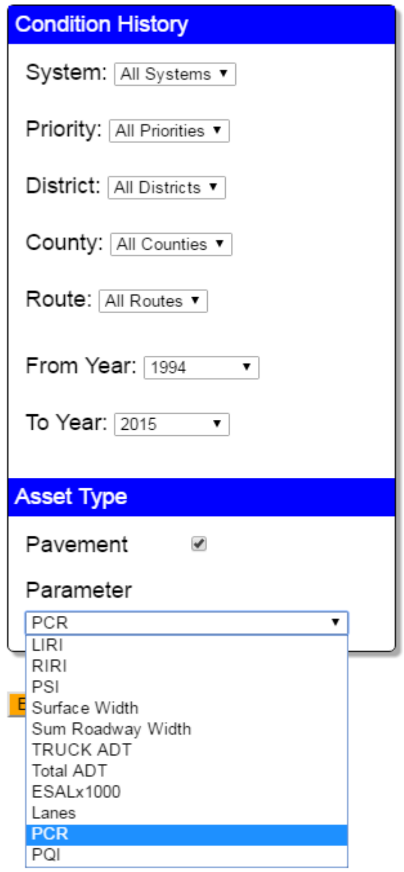


Figure D-20: Pavement parameters

For example, if we want to see the PCR history of route "475R" in "All systems", "All Priority", District 2, Lucas County from Year 1994 to 2015, the PCR history for every section of road in that particular route can be plotted. The tabulated PCR history for every road segment in the selected route is as shown in figure D-21.

All Systems; All Priority; District: 2; County: Lucas; Route: 475R

	Blog	Elog	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Plot	0	0.8	77	88	62	62	61	59	56	99	98	97	94	93	93	91	89	84	82	80	79	79	98	95
Plot	0.8	0.94	80	86	70	64	65	59	56	99	98	97	94	93	93	91	89	84	82	80	79	79	98	95
Plot	0.94	2.5	80	86	70	64	65	64	60	54	99	96	95	93	93	90	89	84	81	77	75	75	70	66
Plot	2.5	3.12	80	86	70	64	65	64	60	54	99	96	95	93	93	90	89	84	81	77	75	75	100	66
Plot	3.12	3.14	79	80	77	73	74	64	60	54	99	96	95	93	93	90	89	84	81	77	75	75	100	66
Plot	3.14	3.15	79	80	77	73	74	72	68	60	99	96	95	93	93	90	89	84	81	77	75	75	100	66
Plot	3.15	4	79	80	77	73	74	72	68	60	99	96	95	93	93	90	89	84	81	77	75	75	100	66
Plot	4	5.23	79	80	77	73	74	72	68	60	99	96	95	93	93	90	89	84	81	77	75	75	100	100
Plot	5.23	5.25	78	79	77	76	77	72	68	60	99	96	95	93	93	90	89	84	81	77	75	75	100	100
Plot	5.25	7.53	78	79	77	76	77	77	68	61	99	97	96	96	96	94	94	89	89	84	81	81	79	76
Plot	7.53	8.95	78	79	77	76	77	77	68	61	99	97	96	96	96	94	94	89	89	84	81	81	79	100
Plot	8.95	8.97	77	97	94	93	93	77	68	61	99	97	96	96	96	94	94	89	89	84	81	81	79	100
Plot	8.97	9.63	77	97	94	93	93	87	86	85	81	98	97	94	91	83	79	74	72	67	98	98	90	89
Plot	9.63	9.64	100	97	95	94	94	93	92	91	99	99	97	96	96	94	79	74	72	67	98	98	90	89
Plot	9.64	9.88	100	97	95	94	94	93	92	91	99	99	97	96	96	94	98	98	96	96	96	96	86	84
Plot	9.88	9.9	100	97	95	94	94	93	92	91	99	99	97	96	96	96	98	98	96	96	96	96	86	84
Plot	9.9	10.2	100	97	95	94	94	93	92	91	99	99	97	96	96	96	93	90	89	83	77	78	70	72
Plot	10.2	10.25	100	99	96	93	93	93	92	91	99	99	97	96	96	96	93	90	89	83	77	78	70	72
Plot	10.25	10.68	100	99	96	93	93	89	81	79	78	78	82	80	78	78	78	78	75	75	70	70	68	68
Plot	10.68	10.69	100	99	96	93	93	92	92	91	90	99	97	95	96	96	96	94	91	89	87	84	79	79
Plot	10.69	11.43	100	97	94	94	94	92	92	91	90	99	97	95	96	96	96	94	91	89	87	84	79	79
Plot	11.43	11.46	100	97	94	94	93	92	92	91	90	99	97	95	96	96	96	94	91	89	87	84	79	79
Plot	11.46	11.75	100	97	94	94	93	92	92	92	88	99	97	95	91	84	82	76	72	71	71	69	67	61
Plot	11.75	13.36	75	97	94	94	94	94	92	90	88	99	97	95	91	84	82	76	72	71	71	69	67	61
Plot	13.36	13.38	75	97	94	94	94	94	92	90	88	99	97	95	91	84	82	76	72	71	71	69	67	61
Plot	13.38	13.5	75	97	94	94	94	94	92	90	88	99	97	95	91	84	82	76	72	71	71	69	67	61
Plot	13.5	14.19	62	97	94	94	94	94	92	91	88	99	97	95	91	84	82	76	72	71	71	69	67	61
Plot	14.19	14.3	62	97	94	94	94	94	92	91	88	99	97	95	91	84	82	76	72	71	100	69	67	61
Plot	14.3	14.48	62	97	94	94	94	94	92	91	88	99	97	95	91	84	82	76	72	71	100	98	97	61
Plot	14.48	14.51	62	97	94	94	94	94	92	91	88	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	14.51	14.56	100	97	94	94	92	94	92	91	88	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	14.56	14.68	100	97	94	94	92	94	92	91	84	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	14.68	15.66	100	97	94	94	92	86	86	83	84	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	15.66	15.67	100	97	94	94	92	86	87	84	84	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	15.67	15.73	100	97	94	94	92	92	87	84	84	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	15.73	16.03	100	97	94	94	94	92	87	84	84	99	97	95	91	84	82	76	72	71	100	98	97	94
Plot	16.03	16.42																					97	94

Figure D-21: PCR values for the selection

When plot [Plot] button in the table is clicked, it displays a graph showing the trend of PCR in the range of year selected. Figure D-22 shows the plot of PCR from the first row of the table in figure D-21.

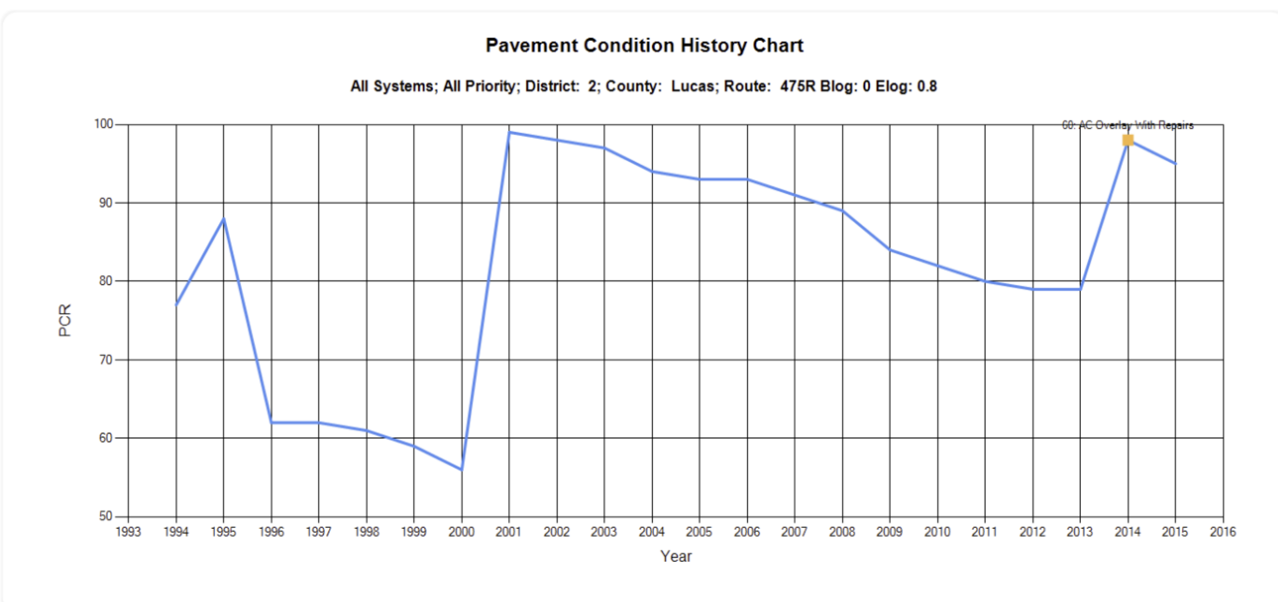


Figure D-22: PCR history plot for the selection

3.5. Distress Distribution

Distress distribution shows the distribution of different types of distresses in the pavement section with the results showing the percentage of pavement affected with each type, severity and extent of distress.

Figure D-23: Selection panel for distress distribution

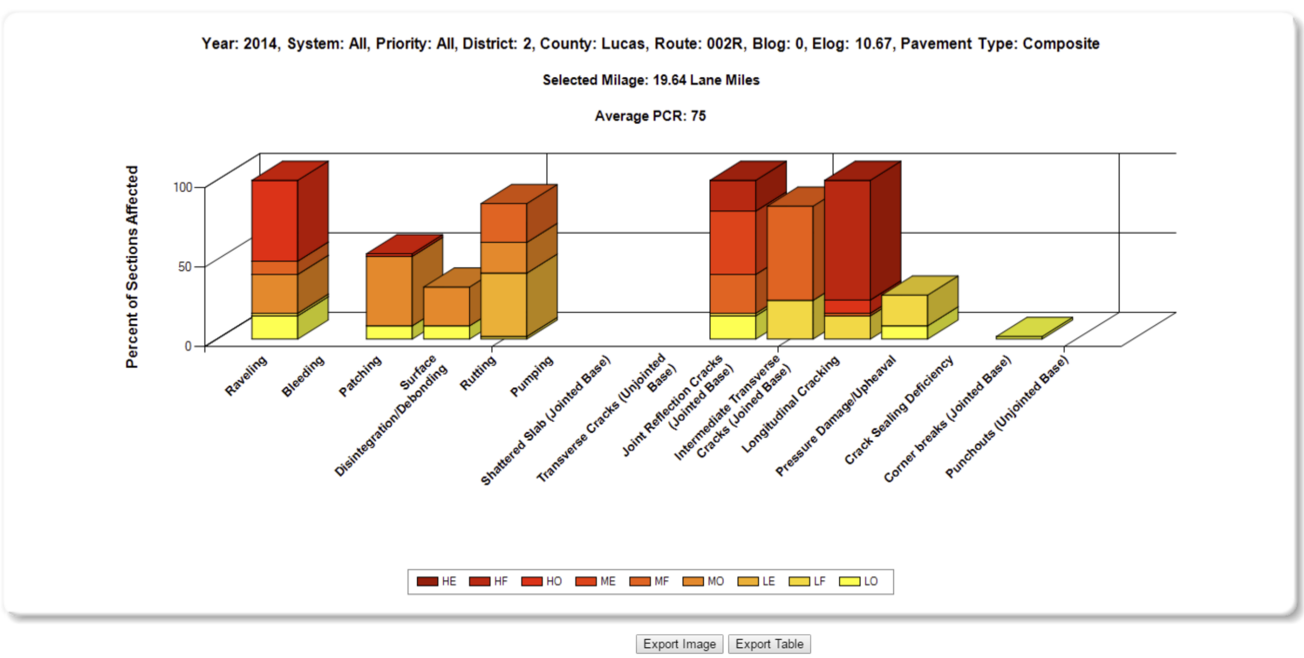


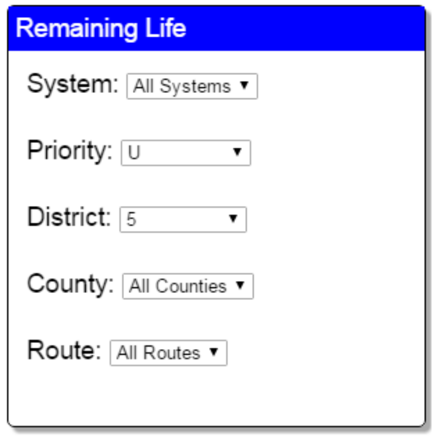
Figure D-24: Distress distribution for the selection

Figure D-24 shows the results for the selected pavement section distress distribution where Systems: “All Systems”, Priority: “All Priorities”, District: “2”, County: “Lucas”, Route: “002R” between the pavement section from Blog 0 to Elog 10.67. The distribution is for the composite pavement in year 2014. The execute button shows the result both in graphical and table format.

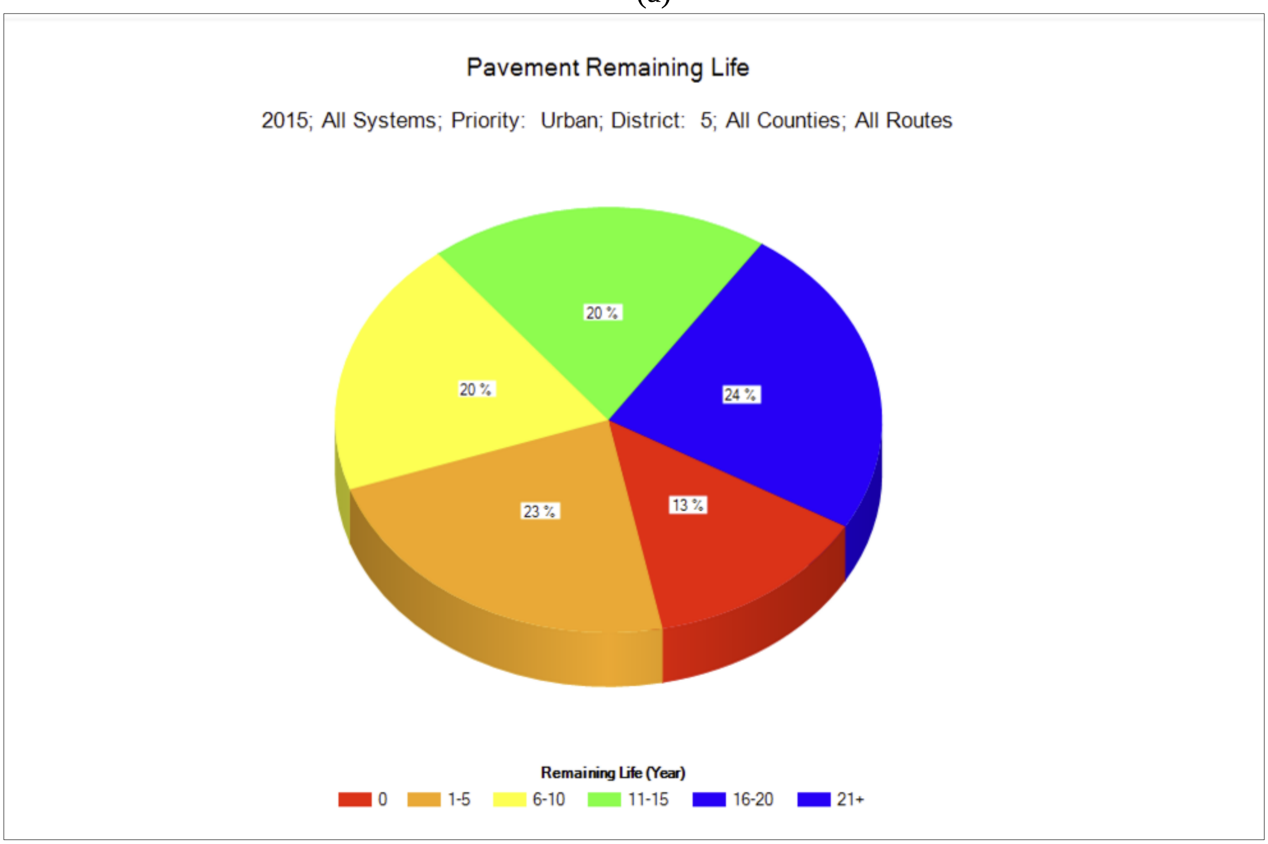
The export image button downloads image in .png format and the export table button downloads the data in excel format.

3.6. Remaining Life

The remaining life tool helps to show the pavement remaining life for the different selection as desired. Suppose we want the remaining life of pavement sections for Priority: “Urban (U)” roads in “All systems” for “All Counties” and “All routes” in District: “5”. Clicking on the “Execute” button after all the selection will give the result as shown in figure D-25 (b) in a pie chart format.



(a)



(b)

Figure D-25: (a) Remaining life selection panel (b) Pavement remaining life in a pie chart format

<u>Hyperlink</u>: Clicking on the pie chart area will produce a detail report with every pavement section with their PCR in it.
For example, if the yellow area (Rem Life 6-10) is clicked in the resulting pie chart above, it will yield the following result.

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NLFID	District	County	Route	Station	Blog	Elog	Pavement Type	Priority	System	RemLife	Current PCR
SCOSSR00016**C	5	COS	016R	DOWN	8.93	9.9	4	U	SR	8	76
SCOSSR00016**C	5	COS	016R	UP	8.93	9.9	4	U	SR	8	74
SCOSSR00083**C	5	COS	083R	UP	8.05	8.32	3	U	SR	6	77
SFAIUS00022**C	5	FAI	022R	UP	15.35	18.05	3	U	US	6	90
SFAISR00204**C	5	FAI	204R	UP	0	0.36	3	U	SR	8	83
SFAISR00256**C	5	FAI	256R	UP	3.65	4.38	3	U	SR	9	98
SGUEUS00022**C	5	GUE	022R	UP	7.37	8.23	4	U	US	8	83
SGUEUS00022**C	5	GUE	022R	UP	8.41	8.69	4	U	US	9	85
SGUEUS00040**C	5	GUE	040R	DOWN	9.25	9.35	4	U	US	10	82
SGUEUS00040**C	5	GUE	040R	UP	8.23	9.25	4	U	US	9	87
SGUESR00209**C	5	GUE	209R	UP	8.1	8.2	4	U	SR	9	87
SKNOSR00013*DC	5	KNO	013D	UP	0.19	0.31	4	U	SR	6	72
SKNOSR00229**C	5	KNO	229R	UP	8.48	9.51	4	U	SR	6	72
SLICSR00013*DC	5	LIC	013D	UP	0.21	0.32	2	U	SR	10	88
SLICSR00013**C	5	LIC	013R	UP	9.1	9.31	3	U	SR	7	81
SLICSR00013**C	5	LIC	013R	UP	9.59	9.69	3	U	SR	7	81
SLICSR00013**C	5	LIC	013R	UP	9.79	9.84	3	U	SR	9	83
SLICSR00013**C	5	LIC	013R	UP	12.95	13.02	4	U	SR	9	85
SLICSR00013**C	5	LIC	013R	UP	13.04	13.15	4	U	SR	9	85
SLICSR00013**C	5	LIC	013R	UP	13.22	13.36	4	U	SR	9	85
SLICSR00013**C	5	LIC	013R	UP	13.43	13.45	4	U	SR	9	85
SLICSR00013**C	5	LIC	013R	UP	13.5	13.54	4	U	SR	9	85
SLICSR00013**C	5	LIC	013R	UP	13.56	13.97	4	U	SR	9	85
SLICSR00016**C	5	LIC	016R	UP	2.78	3.02	3	U	SR	9	87
SLICSR00016**C	5	LIC	016R	UP	5.06	5.44	3	U	SR	10	89
SLICUS00040**C	5	LIC	040R	UP	0	0.36	4	U	US	8	82

Figure D-26: Details of the pavement section

The hyperlink for the PCR in the blue underlined values generates the table for the deductions involved in the calculation of PCR. Figure D-27 shows the PCR details for the first row in figure above.

Distress Condition PCR:76

	Distress	Severity/Extent	Deduct
1	Raveling	MO	3
2	Bleeding		
3	Patching	LO	0.9
4	Surface Disintegration/Debonding		
5	Rutting	LO	1.8
6	Pumping		
7	Shattered Slab (Jointed Base)		
8	Settlements		
9	Transverse Cracks (Unjointed Base)		
10	Joint Reflection Cracks (Jointed Base)	HF	9.6
11	Intermediate Transverse Cracks (Joined Base)		
12	Longitudinal Cracking	HF	4
13	Pressure Damage/Upheaval	LO	1
14	Crack Sealing Deficiency	F	4
15	Corrugations		
16	Corner breaks (Jointed Base)		
17	Punchouts (Unjointed Base)		

Total Deduct = 24

Figure D-27: Details of deductions in PCR for the pavement section selected

The results can be displayed in a bar chart too.

Click on the "Show bar chart" [Show Bar Chart] button to display results in a bar chart. The hyperlink i.e. clicking the bar chart will show same details as from pie chart. We can go back to pie chart format by clicking the "Show Pie Chart" button.

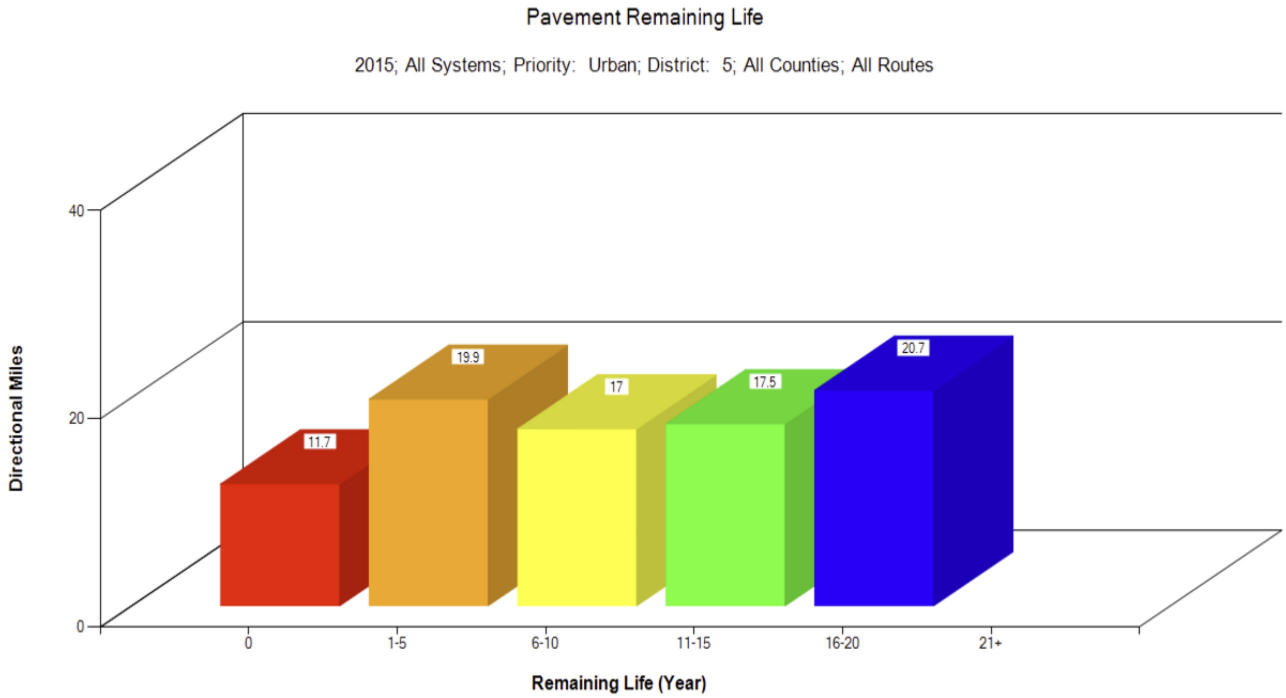
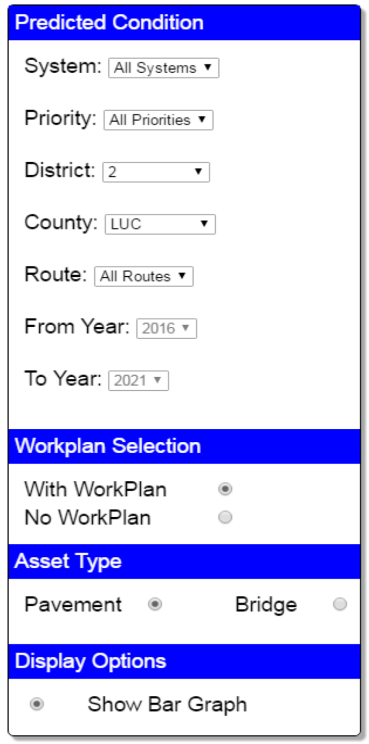


Figure D-28: Pavement remaining life in a bar chart

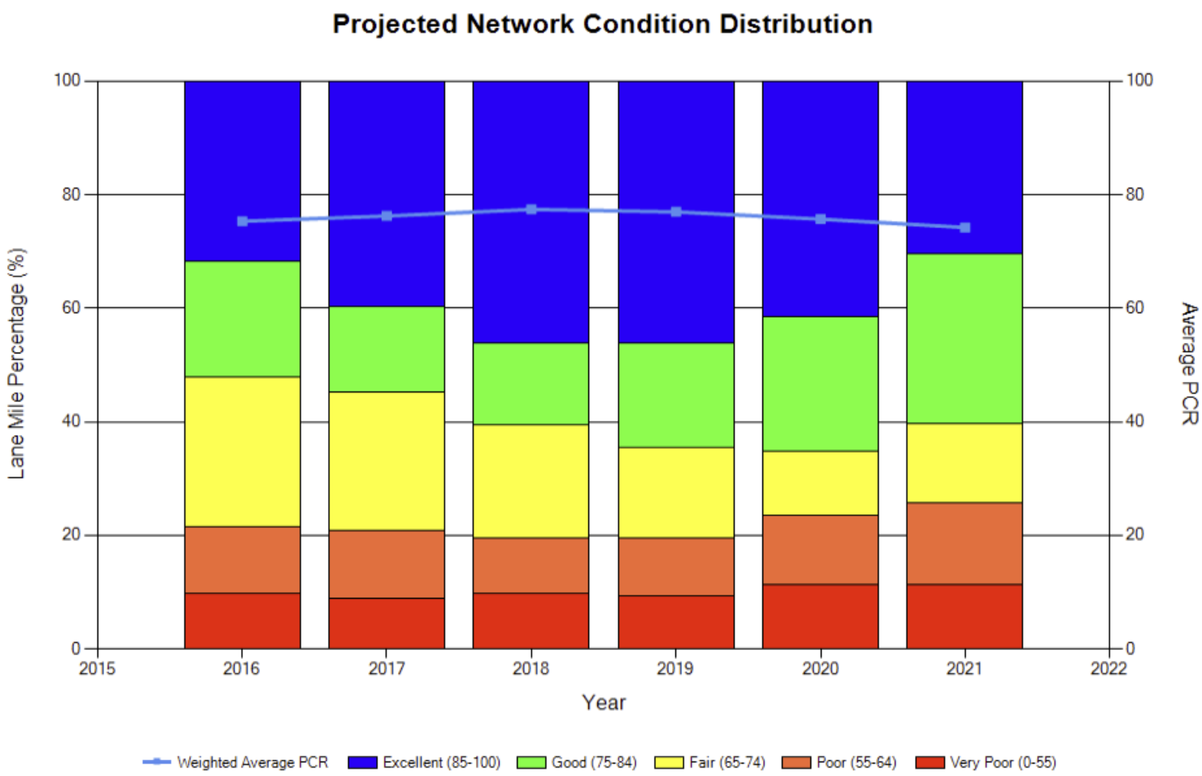
3.7. Predicted Condition

The predicted condition tab predicts the pavement and bridge condition up to 2021. There are two options: (i) with work plan & (ii) without work plan.

Suppose if we want to display the predicted condition for Lucas County in District 2 considering the work plan. Select "All systems", "All priorities", District "2", County "Lucas", "All routes". Click on the "Execute" button. This will produce a bar graph showing the weighted average PCR and condition of the pavement sections in lane mile percentage through 2021. The result for pavement predicted condition with work plan is shown in figure D-29 (b).



(a)



(b)

Figure D-29: (a) Predicted condition selection panel (b) Projected pavement network condition

Hyperlink: Clicking on any area of the bar graph will give the details of the predicted values of PCR from the selected years. Suppose, if we click on the green part (very good) of the graph in the year 2018, it will yield the resulting table as shown in figure D-30.

The hyperlinks in the PCR values generate a table for distress deduction details as described previously in other tools. With work plan will generate the predicted values considering the work plan maintenance plans so that there would be some changes in the PCR and GA values after the maintenance and rehabilitation for a year is encountered whereas without work plan will show the continuous deterioration trend.

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NLFID	District	County	Route	Blog	Elog	Station	System	Priority	Pavement Type	lanes	PCR_2016	PCR_2017	PCR_2018	PCR_2019	PCR_2020	PCR_2021	ActivityYear	Activity Code	Activity_Name
SLUCIR00280**C	2	LUC	280R	4.5	4.67	DOWN	IR	P	Jointed Concrete	7	89	86	83	80	77	74			
SLUCIR00280**C	2	LUC	280R	4.67	4.77	DOWN	IR	P	Jointed Concrete	7	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	4.77	4.9	DOWN	IR	P	Jointed Concrete	7	89	86	83	80	77	74			
SLUCIR00280**C	2	LUC	280R	4.9	4.99	DOWN	IR	P	Jointed Concrete	7	89	86	83	80	77	74			
SLUCIR00280**C	2	LUC	280R	4.99	5.09	DOWN	IR	P	Jointed Concrete	7	89	86	83	80	77	74			
SLUCIR00280**C	2	LUC	280R	5.09	5.2	DOWN	IR	P	Jointed Concrete	7	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	5.2	5.45	DOWN	IR	P	Jointed Concrete	7	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	5.45	5.75	DOWN	IR	P	Jointed Concrete	4	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	1.69	2.05	UP	IR	P	Jointed Concrete	6	90	87	84	81	78	75			
SLUCIR00280**C	2	LUC	280R	2.05	2.07	UP	IR	P	Jointed Concrete	6	90	87	84	81	78	75			
SLUCIR00280**C	2	LUC	280R	2.07	2.72	UP	IR	P	Jointed Concrete	6	90	87	84	81	78	75			
SLUCIR00280**C	2	LUC	280R	2.72	2.82	UP	IR	P	Jointed Concrete	6	90	87	84	81	78	75			
SLUCIR00280**C	2	LUC	280R	5.09	5.2	UP	IR	P	Jointed Concrete	7	89	85	81	77	73	70			
SLUCIR00280**C	2	LUC	280R	5.2	5.45	UP	IR	P	Jointed Concrete	7	89	85	81	77	73	70			
SLUCIR00280**C	2	LUC	280R	5.45	5.75	UP	IR	P	Jointed Concrete	4	89	85	81	77	73	70			
SLUCSR00002**C	2	LUC	002R	11.79	13.62	UP	SR	U	Asphalt	4	89	86	83	80	77	74			
SLUCSR00002**C	2	LUC	002R	13.62	13.78	UP	SR	U	Asphalt	4	89	86	83	80	77	74			
SLUCSR00002**C	2	LUC	002R	22.39	22.52	UP	SR	U	Asphalt	4	83	81	79	77	75	73			
SLUCSR00002**C	2	LUC	002R	22.52	25.49	UP	SR	U	Asphalt	4	83	81	79	77	75	73			
SLUCSR00002**C	2	LUC	002R	25.49	27.25	UP	SR	U	Asphalt	4	83	81	79	77	75	73			
SLUCSR00002**C	2	LUC	002R	27.25	27.26	UP	SR	G	Asphalt	4	85	82	80	77	74	71			
SLUCSR00002**C	2	LUC	002R	27.26	27.5	UP	SR	G	Asphalt	4	85	82	80	77	74	71			
SLUCSR00002**C	2	LUC	002R	27.5	27.69	UP	SR	G	Asphalt	4	85	82	80	77	74	71			
SLUCSR00002**C	2	LUC	002R	27.69	27.8	UP	SR	G	Asphalt	4	85	82	80	77	74	71			
SLUCUS00020*AC	2	LUC	020A	2.23	2.24	UP	US	G	Asphalt	2	91	88	84	81	77	93	2021	38	Fine Graded Polymer AC Overlay
SLUCUS00020*AC	2	LUC	020A	2.24	3.48	UP	US	G	Asphalt	2	91	88	84	81	77	93	2021	38	Fine Graded Polymer AC Overlay
SLUCUS00020*AC	2	LUC	020A	3.55	3.97	UP	US	G	Asphalt	2	91	88	84	81	77	93	2021	38	Fine Graded Polymer AC Overlay
SLUCUS00020*AC	2	LUC	020A	3.97	4.92	UP	US	G	Asphalt	2	91	88	84	81	77	93	2021	38	Fine Graded Polymer AC Overlay

Figure D-30: Predicted detail network condition for pavements

Similarly, the network condition for bridges can be displayed. Click on the “Bridge” asset type and for the desired selection we get the results for the prediction. Suppose, the similar selection as above for bridge is taken. It will give the following result.

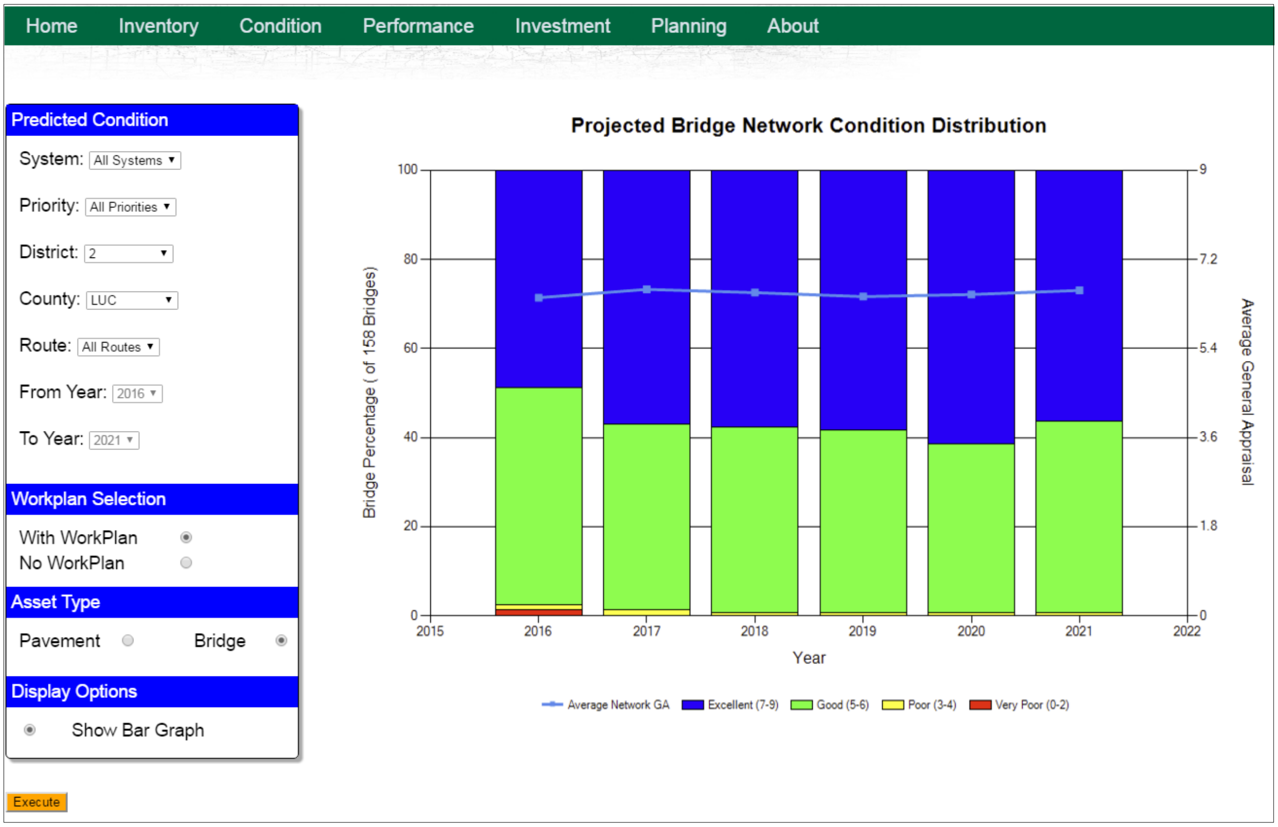

Figure D-31: Predicted bridge network condition for the selection

Hyperlink: Clicking anywhere in the bar graph shows the details of all the bridges with their predicted values through 2021. For example, clicking on the blue part (excellent condition) of the graph in 2018 will yield the following tabulated result.

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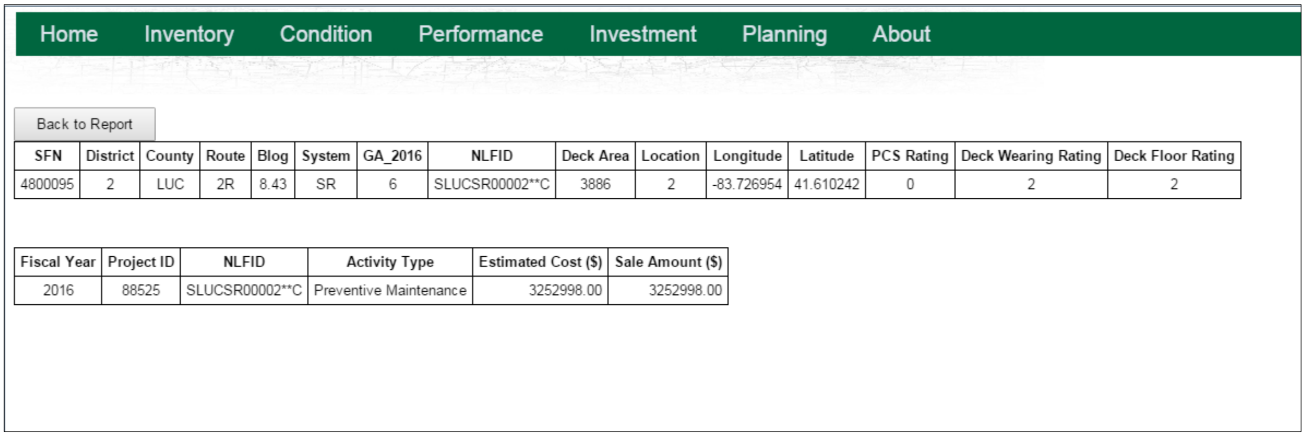
	SFN	District	County	Route	Blog	System	Priority	Type	Deck Area	GA_2016	GA_2017	GA_2018	GA_2019	GA_2020	GA_2021	Year of First Activity
1	4800095	2	LUC	002R	8.43	SR	G	CONCRETE	3886	7	6.9	6.8	6.7	6.6	6.5	2016
2	4800133	2	LUC	002R	9.46	SR	G	CONCRETE	11604	7	7	6.9	6.8	6.7	6.6	2017
3	4800184	2	LUC	002R	10.26	SR	G	STEEL	26749	7	7	6.8	6.7	6.6	6.5	2017
4	4800222	2	LUC	002R	16.58	SR	U	STEEL	5909	8	7.8	7.7	7.6	7.5	7.4	
5	4800249	2	LUC	002R	18.15	SR	U	STEEL	19063	7	6.8	6.7	6.6	6.5	6.4	
6	4800303	2	LUC	002R	18.62	SR	U	STEEL	237960	8	7.8	7.7	8	7.8	7.7	2016
7	4800370	2	LUC	002R	24.87	SR	U	CONCRETE	1281	8	7.9	7.8	7.7	7.6	7.5	
8	4800389	2	LUC	002R	25.24	SR	U	STEEL	31528	7	6.8	6.7	6.6	6.5	6.4	
9	4800419	2	LUC	002R	26.5	SR	U	CONCRETE	958	8	7.9	7.8	7.7	7.6	7.5	
10	4800966	2	LUC	020A	1.11	US	G	CONCRETE	5673	7	6.9	6.8	6.7	6.6	6.5	
11	4800982	2	LUC	020A	7.26	US	G	CONCRETE	366	8	7.9	7.8	7.7	7.6	7.5	
12	4801008	2	LUC	020A	9.46	US	G	PRESTRESSED CONCRETE	5317	7	6.9	6.8	6.7	6.6	6.6	
13	4800478	2	LUC	020R	1.94	US	G	CONCRETE	420	8	7.9	7.8	7.7	7.6	7.5	
14	4800559	2	LUC	020R	6	US	G	CONCRETE	3122	7	6.9	6.8	6.7	6.6	6.5	2016
15	4800605	2	LUC	020R	9.54	US	G	STEEL	22314	6	7	6.8	6.7	6.6	6.5	2015
16	4800796	2	LUC	020R	15.3	US	U	PRESTRESSED CONCRETE	10807	7	6.9	6.8	6.7	6.6	6.6	
17	4800923	2	LUC	020R	19.07	US	U	STEEL	65930	7	6.8	6.7	6.6	6.5	6.4	
18	4801083	2	LUC	023R	10.06	US	P	STEEL	9892	7	6.8	6.7	6.6	6.5	6.4	
19	4801113	2	LUC	023R	10.06	US	P	STEEL	11625	7	6.8	6.7	6.6	6.5	6.4	
20	4801148	2	LUC	023R	10.74	US	P	STEEL	8191	7	6.8	6.7	6.6	6.5	6.4	
21	4801172	2	LUC	023R	10.74	US	P	STEEL	8191	7	6.8	6.7	6.6	6.5	6.4	

Figure D-32: Predicted bridge network condition for excellent bridges

Clicking on the hyperlink in SFN of bridge will give the details about that specific bridge. For example, if the SFN in the first row of the result above i.e. SFN: “4800095” is clicked, it will yield the following result.



SFN	District	County	Route	Blog	System	GA_2016	NLFID	Deck Area	Location	Longitude	Latitude	PCS Rating	Deck Wearing Rating	Deck Floor Rating
4800095	2	LUC	2R	8.43	SR	6	SLUCSR00002**C	3886	2	-83.726954	41.610242	0	2	2

Fiscal Year	Project ID	NLFID	Activity Type	Estimated Cost ($)	Sale Amount ($)
2016	88525	SLUCSR00002**C	Preventive Maintenance	3252998.00	3252998.00

Figure D-33: Bridge details for the specific bridge selected

4. **Performance**

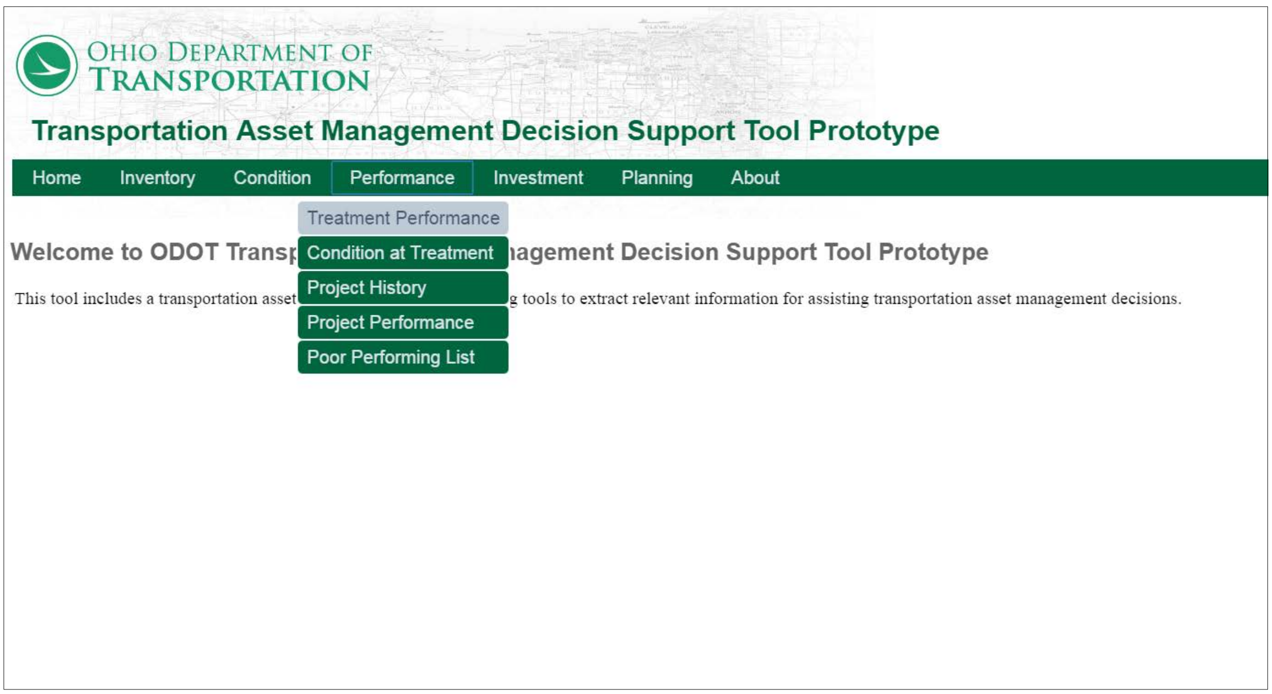


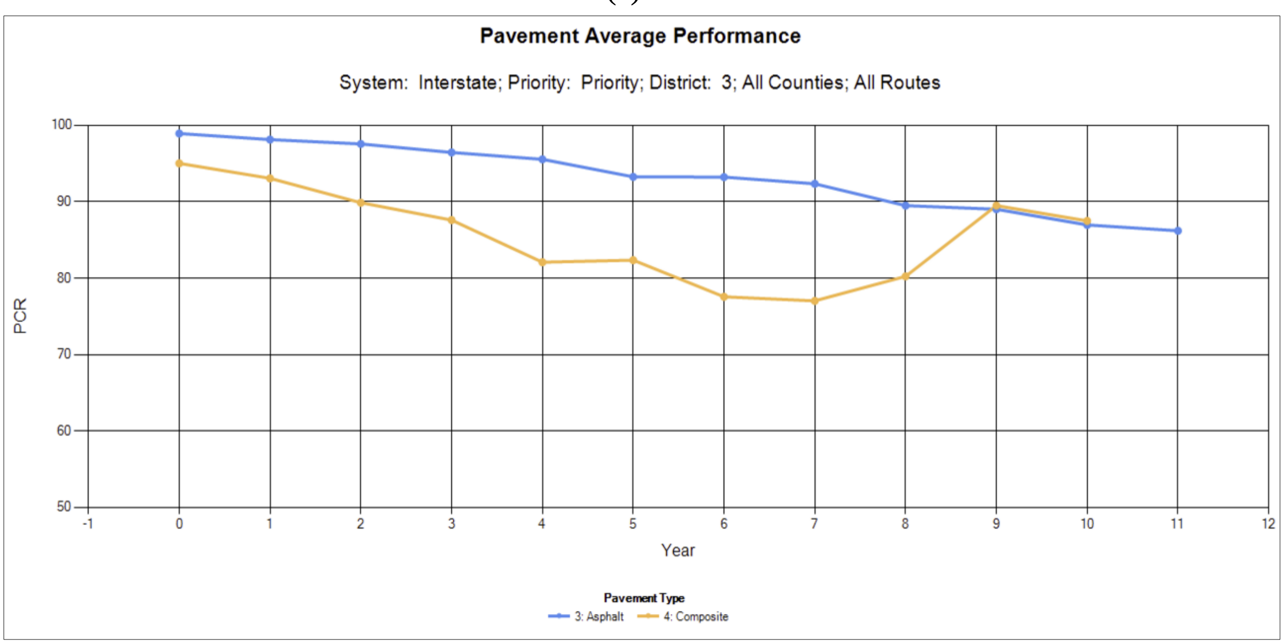
Figure D-34: Sub-menu under Performance tab

4.1. Treatment Performance

The treatment performance tool helps to see the performance of the maintenance activities applied in the pavement condition. The treatment performance is governed by the selection of the “Activity code” from the selection panel. User has to select at least one activity for the results. Results can be generated as per the pavement type and grouped by: pavement type, activity code, system, priority, district or county. The results can be seen for the years from 1985 to 2015. For example: if the user wants to show the treatment performance with activity code

“10”, “20”, “30”, “50” and “60” with the System: “IR”, Priority: “P”, District “3”, Pavement type: “All”, From year: “2000”, To year: “2015” and the results to be grouped by “Pavement type”, it will yield the following results after clicking the “Execute” button.

(a)

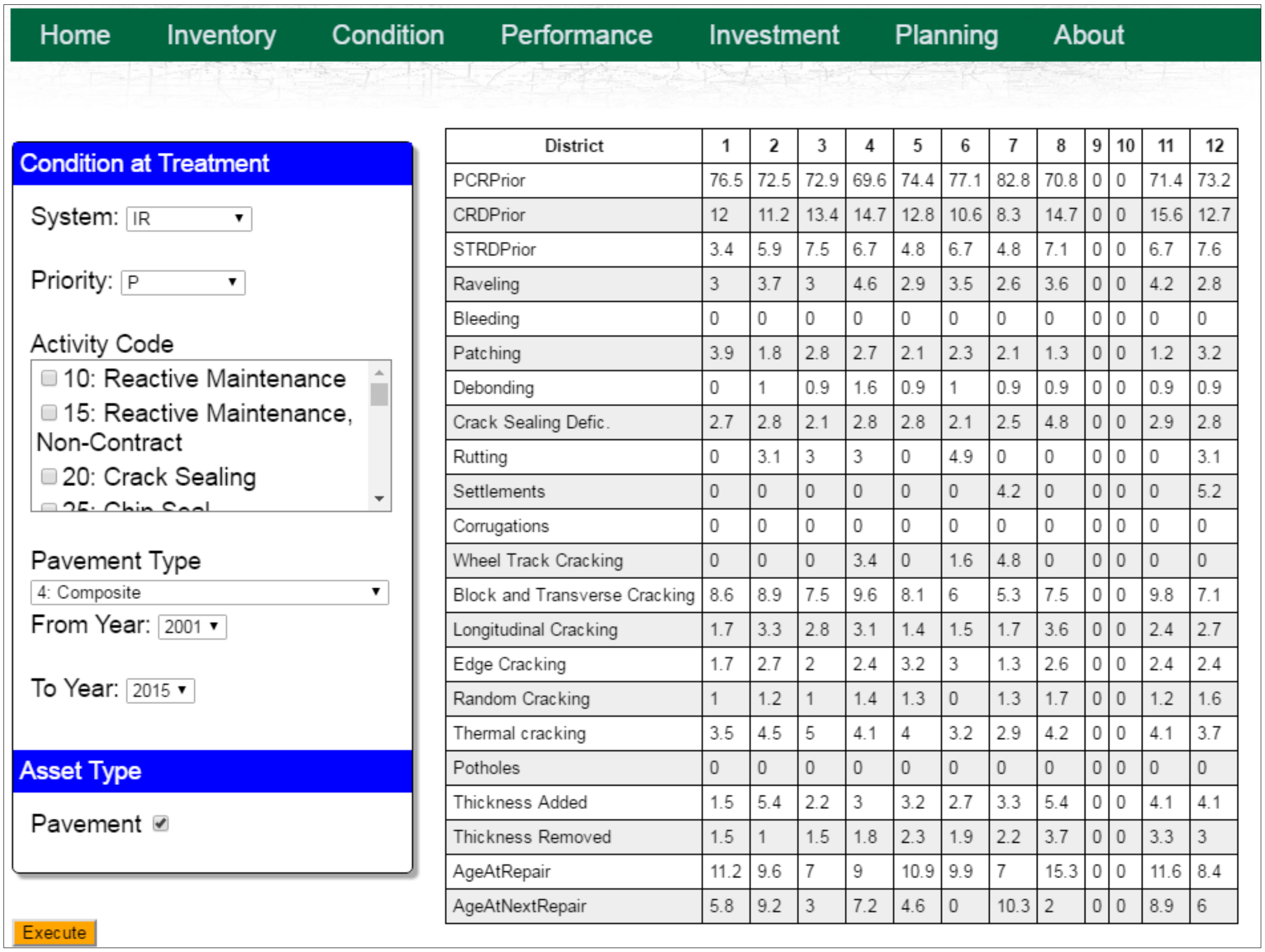


(b)

Figure D-35: (a) Treatment performance selection panel (b) Treatment performance with selected activities

4.2. Condition at Treatment

Condition at treatment allows user to determine the average pavement condition at which the maintenance activities listed as activity codes are performed in all districts.
User has to select at least one activity code relevant to the pavement type selected.
For example, if the user wants to know the condition at treatment with “Activity code 60: AC overlay with repairs” in “IR System”, “Priority P” and “Composite pavement” type, it will yield the following result.



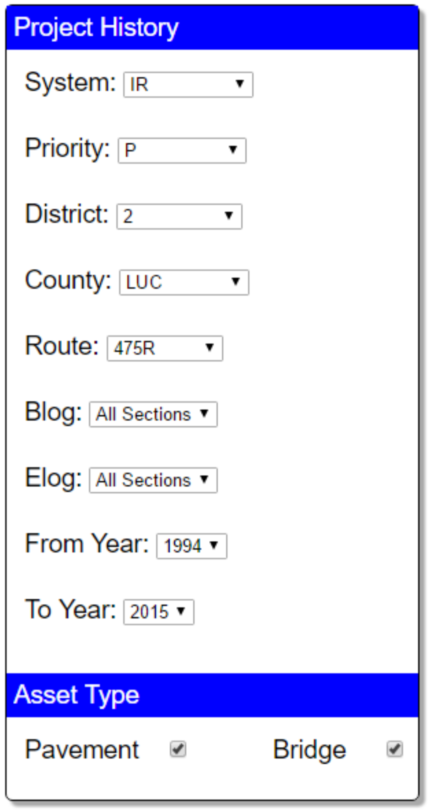
District	1	2	3	4	5	6	7	8	9	10	11	12
PCRPrior	76.5	72.5	72.9	69.6	74.4	77.1	82.8	70.8	0	0	71.4	73.2
CRDPrior	12	11.2	13.4	14.7	12.8	10.6	8.3	14.7	0	0	15.6	12.7
STRDPrior	3.4	5.9	7.5	6.7	4.8	6.7	4.8	7.1	0	0	6.7	7.6
Raveling	3	3.7	3	4.6	2.9	3.5	2.6	3.6	0	0	4.2	2.8
Bleeding	0	0	0	0	0	0	0	0	0	0	0	0
Patching	3.9	1.8	2.8	2.7	2.1	2.3	2.1	1.3	0	0	1.2	3.2
Debonding	0	1	0.9	1.6	0.9	1	0.9	0.9	0	0	0.9	0.9
Crack Sealing Defic.	2.7	2.8	2.1	2.8	2.8	2.1	2.5	4.8	0	0	2.9	2.8
Rutting	0	3.1	3	3	0	4.9	0	0	0	0	0	3.1
Settlements	0	0	0	0	0	0	4.2	0	0	0	0	5.2
Corrugations	0	0	0	0	0	0	0	0	0	0	0	0
Wheel Track Cracking	0	0	0	3.4	0	1.6	4.8	0	0	0	0	0
Block and Transverse Cracking	8.6	8.9	7.5	9.6	8.1	6	5.3	7.5	0	0	9.8	7.1
Longitudinal Cracking	1.7	3.3	2.8	3.1	1.4	1.5	1.7	3.6	0	0	2.4	2.7
Edge Cracking	1.7	2.7	2	2.4	3.2	3	1.3	2.6	0	0	2.4	2.4
Random Cracking	1	1.2	1	1.4	1.3	0	1.3	1.7	0	0	1.2	1.6
Thermal cracking	3.5	4.5	5	4.1	4	3.2	2.9	4.2	0	0	4.1	3.7
Potholes	0	0	0	0	0	0	0	0	0	0	0	0
Thickness Added	1.5	5.4	2.2	3	3.2	2.7	3.3	5.4	0	0	4.1	4.1
Thickness Removed	1.5	1	1.5	1.8	2.3	1.9	2.2	3.7	0	0	3.3	3
AgeAtRepair	11.2	9.6	7	9	10.9	9.9	7	15.3	0	0	11.6	8.4
AgeAtNextRepair	5.8	9.2	3	7.2	4.6	0	10.3	2	0	0	8.9	6

Figure D-36: Pavement condition at treatment for all districts

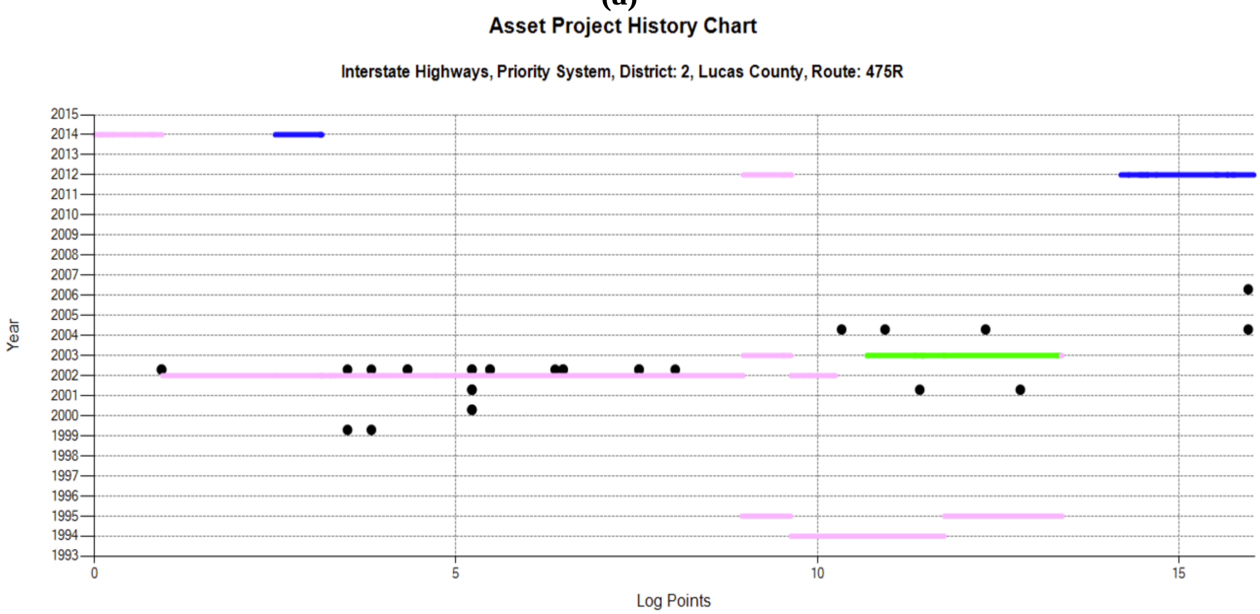
4.3. Project history

Project history shows all the projects performed in a particular segment of road. User has to enter a route to see the results.
Suppose, we want the project history of I475 in district 2, Lucas County from 1994 to 2015, then the following selections should be made.

> “ IR” System, “P” Priority, District “2”, County “Lucas”, Route “475R”, “All sections” in Blog, “All sections” in Elog, From Year “1994”, To Year “2015”



(a)



(b)

Figure D-37: (a) Project history selection panel (b) Asset Project History for the selected route

<u>Hyperlink</u>: The small dots in the graphs represent bridges and the lines represent pavement sections. Clicking on the dot will give details of the bridge project performed and clicking on the line gives the details about the pavement in the project.

Figure D-38: Showing a bridge and pavement section in a project

Clicking on the bridge shown as a black dot in the red circle gives the details about the bridge as shown below.

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ID	SFN	Start Date	Bridge Work Type	Description	End Date	State Project Number	PID Number	Start Year	End Year
39589	4807111	8/8/2002 12:00:00 AM	41	DECK OVERLAY (ASPHALTIC CONCRETE)			22705	2002	

Figure D-39: Details of a bridge in the project

Similarly, clicking on the green line inside the orange area as shown in figure gives the detail about that particular segment in the project.

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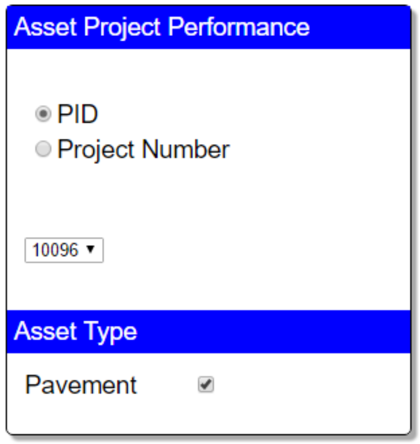
County	Route	Blog	Elog	Station	year	PN	PID	PAVE_COST($)	TOTAL_COST($)	Activity Code	Activity Name	Thickness Added	SN_ADD	NOTES
LUC	475R	8.97	16.4	U/D	2003	2002-0340	22754		3796142.98	60	AC Overlay With Repairs			MICROSURFACING W/ WARRANTY MICRO SURFACE WITH WARRANTY
LUC	475R	8.97	16.4	U/D	2003	2002-0340	22754		3796142.98	60	AC Overlay With Repairs			MICROSURFACING W/ WARRANTY MICRO SURFACE WITH WARRANTY
LUC	475R	8.97	16.42	U/D	2003	2002-0340	22754		3796142.98	30	Micro-Surfacing	0.25		MICROSURFACING W/ WARRANTY MICRO SURFACE WITH WARRANTY

Figure D-40: Details of the pavement section selected

4.4. Project Performance

The performance of the projects can be shown by either the Project ID (PID) or the project number. For the PID, select a PID for which the data is required and click execute.



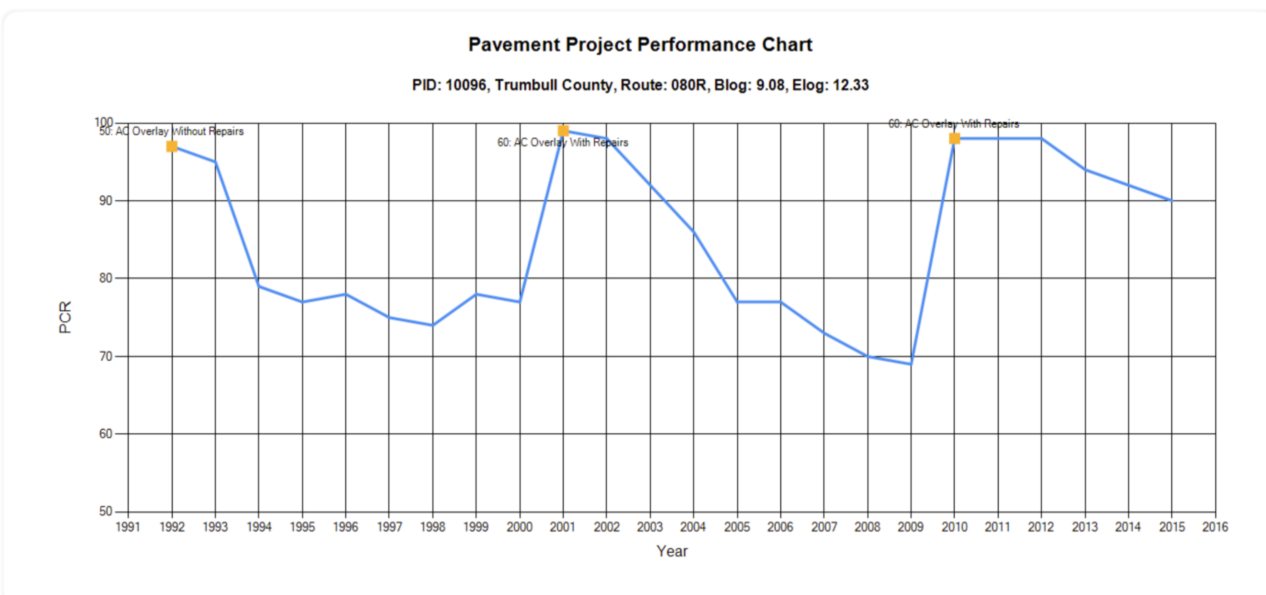
(a)

	County	Route	Blog	Elog	Station	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Plot	TRU	080R	9.08	12.33	DOWN	97	95	79	77	78	75	74	78	77	99	98	92	86	77	77	73	70	69	98	98	98	94	92	90
Plot	TRU	080R	9.08	12.33	UP	97	95	80	77	74	66	73	78	74	99	98	92	83	74	69	74	69	63	98	98	98	97	94	89

(b)

Figure D-41: (a) Asset Project performance selection panel (b) Project performance of selected PID

The plot button of the pavement performance further helps to display graphical representation of the effect of treatment type in project performance in the selected dates.

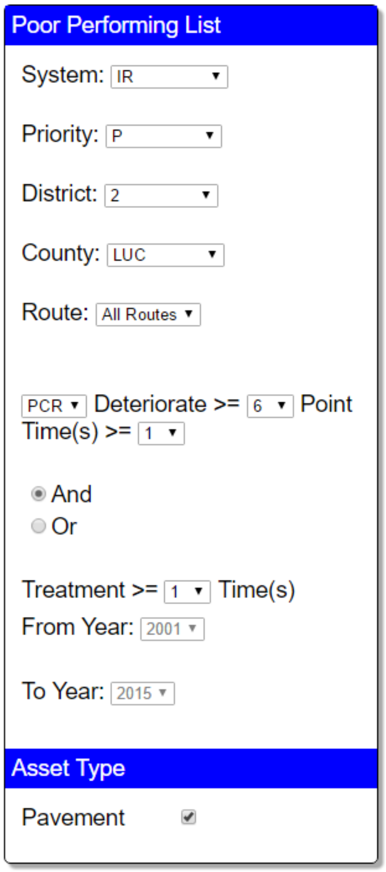


	County	Route	Blog	Elog	Station	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Plot	TRU	080R	9.08	12.33	DOWN	97	95	79	77	78	75	74	78	77	99	98	92	86	77	77	73	70	69	98	98	98	94	92	90
Plot	TRU	080R	9.08	12.33	UP	97	95	80	77	74	66	73	78	74	99	98	92	83	74	69	74	69	63	98	98	98	97	94	89

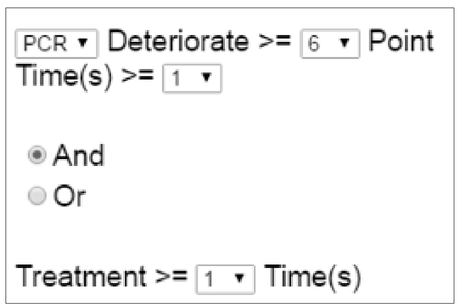
Figure D-42: Pavement project performance chart for the selected section

4.5. Poor Performing list

Poor performing list tool helps user identify the pavement sections which undergo more deterioration and/or those sections getting more treatments.



(a)



(b)

Figure D-43: (a) Poor Performing List selection panel (b) Criteria or conditions for poor performing pavement

Condition (i) The default values: PCR deteriorate > = 6 point time(s) > = 1 indicates the total deterioration of PCR for the pavement section is at least by 6 points more than once during the year 2001 – 2015.

Condition (ii) Treatment > = 1 time(s) indicates that the pavement section got treatment at least one time during the year 2001- 2015.

Let us find the poor performing pavement list from the Lucas County in the interstate highways. Since the list can be generated by either making both condition to be met or making one of the conditions met. Let both conditions be met. Let the values in the condition are default values. Select “IR” System, “P” Priority, District “2”, County “LUC” and Route “All Routes”. Clicking the execute button gives the following result as in figure D-44.

Export to Excel

District	County	Route	Station	Blog	Elog	2001_PCR	2002_PCR	2003_PCR	2004_PCR	2005_PCR	2006_PCR	2007_PCR	2008_PCR	2009_PCR	2010_PCR	2011_PCR	2012_PCR	2013_PCR	2014_PCR	2015_PCR	#Treatment	#PCR_Drop
2	LUC	023R	UP	9.63	10.03	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	10.03	10.06	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	10.06	10.38	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	10.38	10.58	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	10.58	10.77	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	10.77	11.11	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	11.11	11.61	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	11.61	11.78	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	11.78	11.88	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	11.88	11.99	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	11.99	12.48	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	023R	UP	12.48	12.65	77	75	95	93	91	88	82	79	77	73	74	70	98	91	89	2	2
2	LUC	024R	UP	12.86	12.96	99	99	96	96	96	96	91	90	90	87	100	100	88	82	82	1	1
2	LUC	075R	UP	0	0.27	96	96	94	94	94	92	86	82	79	78	75	98	97	89	87	1	1
2	LUC	075R	UP	2.01	2.05	66	66	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1
2	LUC	075R	UP	2.31	2.34	61	64	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1
2	LUC	075R	UP	2.34	3.12	61	64	99	94	93	89	79	73	70	63	65	64	71	100	100	2	2
2	LUC	075R	UP	3.12	3.13	61	64	99	94	93	89	79	73	70	63	65	64	71	100	100	2	2
2	LUC	075R	UP	3.13	3.32	61	64	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1
2	LUC	075R	UP	3.32	3.33	62	62	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1
2	LUC	075R	UP	3.49	3.99	62	62	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1
2	LUC	075R	UP	3.99	4.02	62	62	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1
2	LUC	075R	UP	4.02	4.32	94	87	99	94	93	89	79	73	70	63	65	64	71	100	100	1	1

Figure D-44: Poor performing pavement list for the selection and condition

Hyperlink: Clicking on the hyperlink for "PCR_2015" in the first row yields following result.

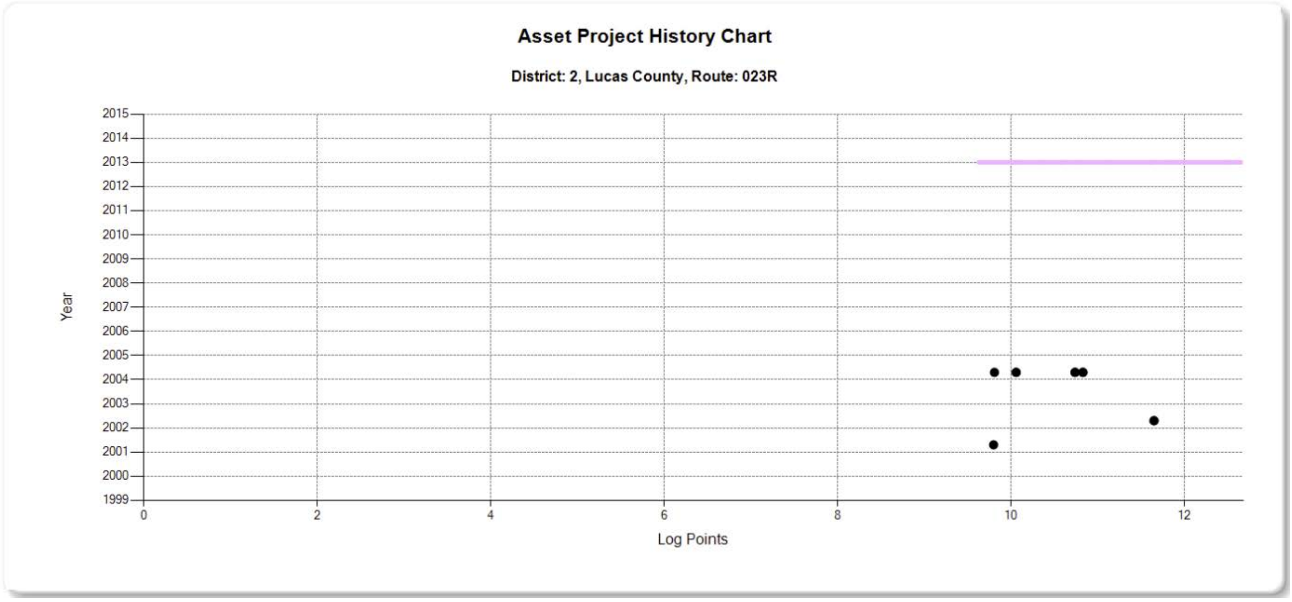
2015 Distress Condition PCR:89

	Distress	Severity/Extent	Deduct
1	Raveling	LF	2.4
2	Bleeding		
3	Patching		
4	Surface Disintegration/Debonding		
5	Rutting		
6	Pumping		
7	Shattered Slab (Jointed Base)		
8	Settlements		
9	Transverse Cracks (Unjointed Base)		
10	Joint Reflection Cracks (Jointed Base)	LE	2.4
11	Intermediate Transverse Cracks (Joined Base)		
12	Longitudinal Cracking	MO	1.2
13	Pressure Damage/Upheaval		
14	Crack Sealing Deficiency	E	5
15	Corrugations		
16	Corner breaks (Jointed Base)		
17	Punchouts (Unjointed Base)		

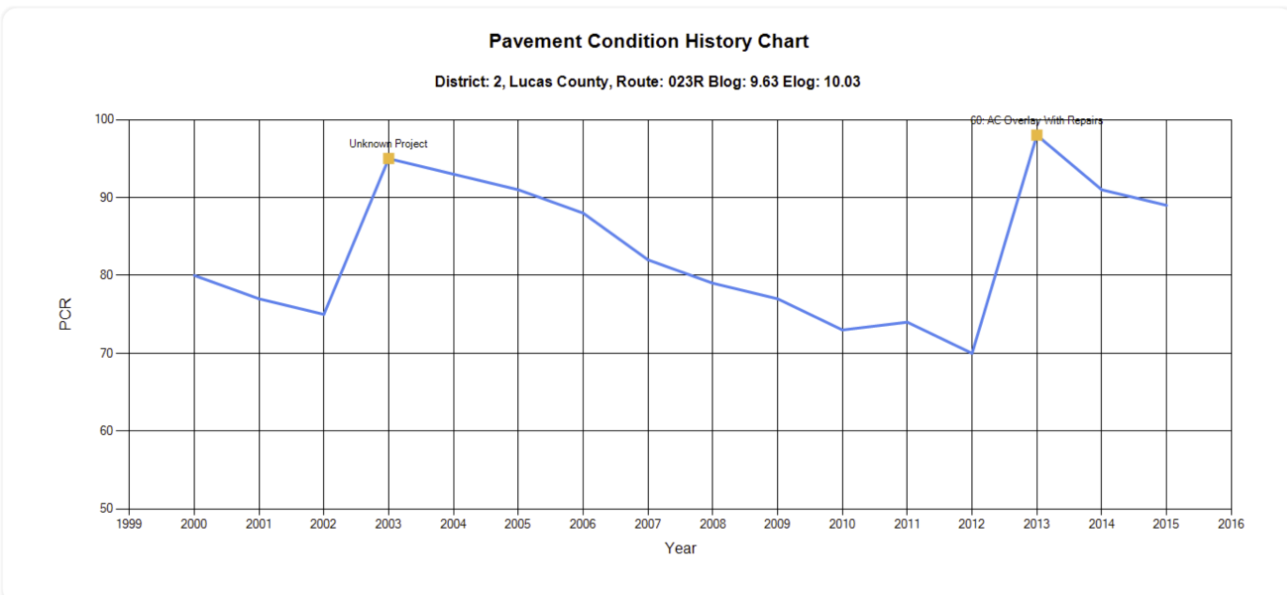
Total Deduct = 11

Figure D-45: PCR details for the selected hyperlink

Hyperlink: Clicking on the hyperlink for the "#Treatment" in the first row gives following result.



(a)



(b)

Figure D-46: (a) Project history for the selected pavement section (b) Treatments performed in the pavement section

5. Investment

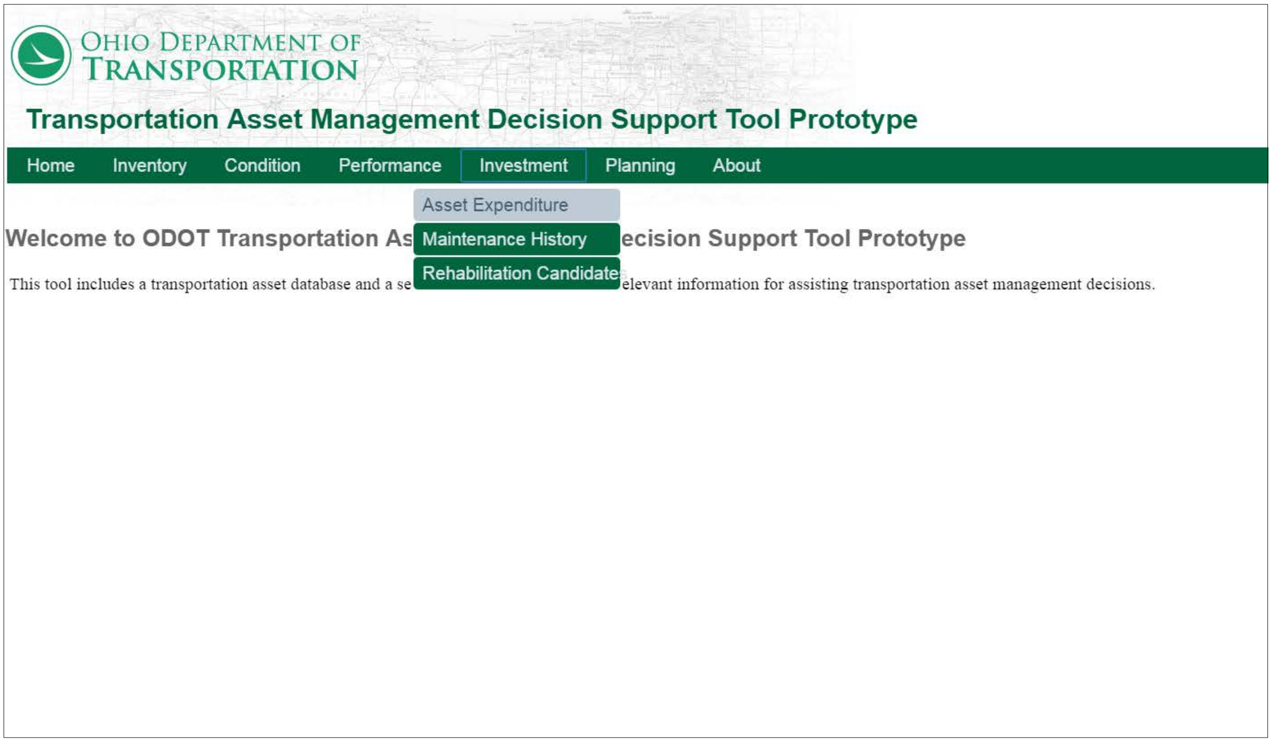


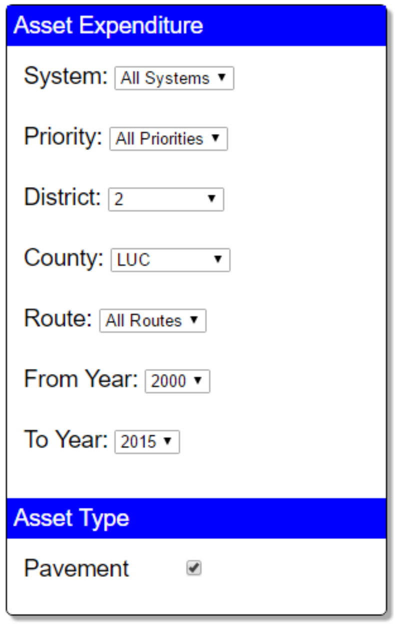
Figure D-47: Sub-menu under Investment tab

5.1. Asset Expenditure

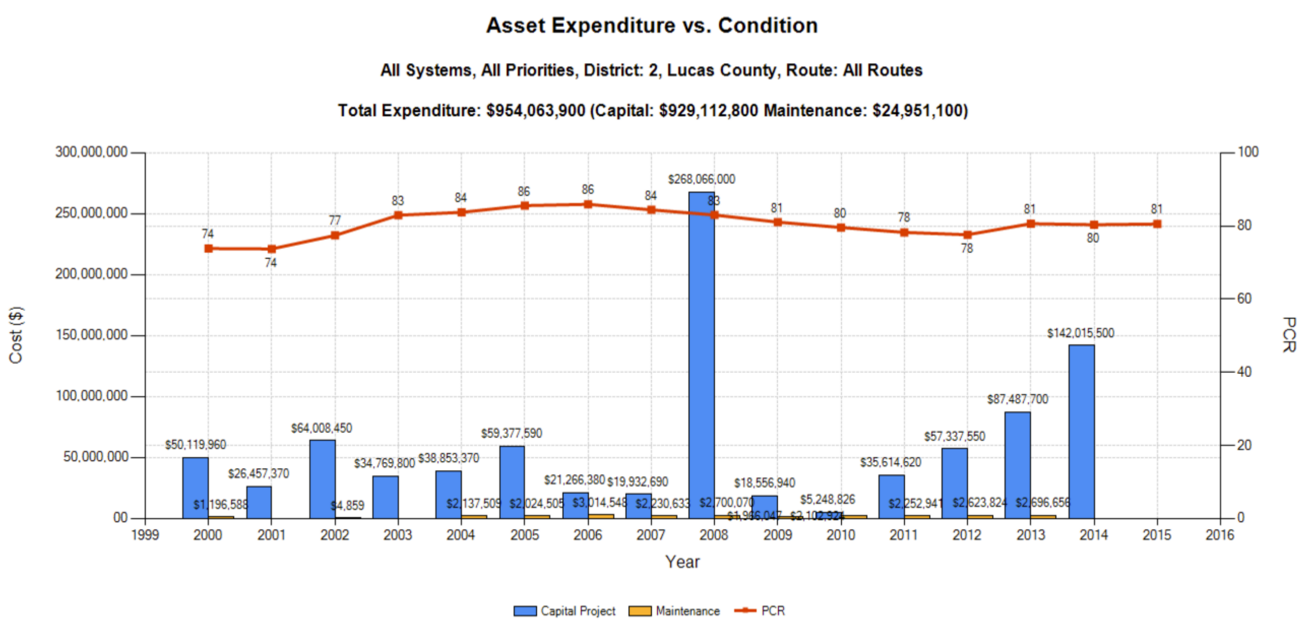
Asset expenditure tool helps to find the capital project cost and the maintenance cost along with the average pavement condition every year.

Suppose, if we want the asset expenditure and the average pavement condition for whole road network in Lucas County from year 2000 to 2015.

Select “All systems”, “All Priorities”, District “2”, “LUC” County, “All Routes”, From Year “2000” and To Year “2015” in the selection panel and click execute. This yields a result showing Asset expenditure vs Condition graph as shown in figure.



(a)



(b)

Figure D-48: (a) Asset Expenditure selection panel (b) Asset expenditure vs asset condition

Hyperlink: Clicking on the small square for average PCR gives the detail condition of all the pavement sections. For example, clicking on the PCR for 2013 gives following result.

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Year	District	County	Route	Blog	Elog	Station	PCR
2013	2	LUC	051D	0	0.06	UP	98
2013	2	LUC	475R	0	0.09	DOWN	77
2013	2	LUC	475R	0	0.09	UP	79
2013	2	LUC	025D	0	0.1	UP	73
2013	2	LUC	295R	0	0.11	UP	79
2013	2	LUC	065R	0	0.17	UP	97
2013	2	LUC	246R	0	0.26	UP	81
2013	2	LUC	075R	0	0.27	DOWN	96
2013	2	LUC	075R	0	0.27	UP	97
2013	2	LUC	064R	0	0.32	UP	77
2013	2	LUC	051R	0	1.12	UP	79
2013	2	LUC	280R	0	1.61	DOWN	98
2013	2	LUC	280R	0	1.61	UP	98
2013	2	LUC	020A	0	2.23	UP	78
2013	2	LUC	080K	0	3.98	DOWN	67
2013	2	LUC	080K	0	3.98	UP	66
2013	2	LUC	020R	0	6.09	UP	66
2013	2	LUC	024R	0	6.19	DOWN	98
2013	2	LUC	024R	0	6.23	UP	98
2013	2	LUC	051D	0.06	0.12	UP	27
2013	2	LUC	475R	0.09	0.18	DOWN	77
2013	2	LUC	475R	0.09	0.18	UP	79
2013	2	LUC	025D	0.1	0.31	UP	91
2013	2	LUC	295R	0.11	2.47	UP	98

Figure D-49: Condition for all segments from selection for 2013

Similarly, clicking on the bar graphs for the maintenance and Capital project for 2013 gives the results shown in Figure D-50.

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Asset Type	Maintenance Cost
Ancillary Activity	$392,525
Barrier	$34,502
Berming	$0
Bridge	$329,576
Culvert	$0
Drainage	$500,295
Highway Ancillary Activity	$363,432
Pavement	$673,080
Pavement Marking	$0
Traffic Operation	$401,963
Other	$1,281
Total	**$2,696,655**

(a)

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Year	District	County	Route	Blog	Elog	Station	Activity	Cost	Project Number	PID
2013	2	LUC	475R	0	0.93	U/D	60	6,494,643	2014-0032	88646
2013	2	LUC	280R	0	1.62	U/D	60	8,449,496	2013-0174	87825
2013	2	LUC	295R	0	6.19	U/D	200	30,417,763	2009-0201	80446
2013	2	LUC	065R	0.48	0.815	U/D	60	1,041,978	2013-N223	93957
2013	2	LUC	065R	0.52	0.97	U/D	60	1,041,978	2013-N223	93957
2013	2	LUC	065R	0.864	0.96	U/D	60	1,041,978	2013-N223	93957
2013	2	LUC	065R	1.58	2.37	U/D	60	1,041,978	2013-N223	93957
2013	2	LUC	065R	1.6	2.37	U/D	60	1,041,978	2013-N223	93957
2013	2	LUC	475R	1.98	3.13	U/D	100	17,788,904	2009-0104	75937
2013	2	LUC	051R	3.26	3.49	U/D	60	1,022,022	2012-N117	91131
2013	2	LUC	065R	4.49	5.01	U/D	60	549,182	2012-N197	91349
2013	2	LUC	024R	5.2	8.89	U/D	200	30,417,763	2009-0201	80446
2013	2	LUC	024R	6.19	12.73	U/D	200	39,175,977	2009-8015	80444
2013	2	LUC	184R	6.49	7.48	U/D	60	885,820	2013-N238	93915
2013	2	LUC	051R	7.49	7.861	U/D	50	1,897,217	2012-N049	81792
2013	2	LUC	051R	7.933	8.88	U/D	50	1,897,217	2012-N049	81792
2013	2	LUC	475R	11.38	11.39	U/D	909	1,394,725	2013-0385	94619
2013	2	LUC	475R	12.38	12.39	U/D	909	1,394,725	2013-0385	94619
2013	2	LUC	002R	15.24	15.27	U/D	60	1,041,978	2013-N223	93957
2013	2	LUC	020R	16.61	18.62	U/D	60	2,850,683	2012-N219	89293
2013	2	LUC	002R	17.29	18.6	U/D	60	1,022,022	2012-N117	91131
2013	2	LUC	002R	19.99	20	U/D	50	1,041,978	2013-N223	93957

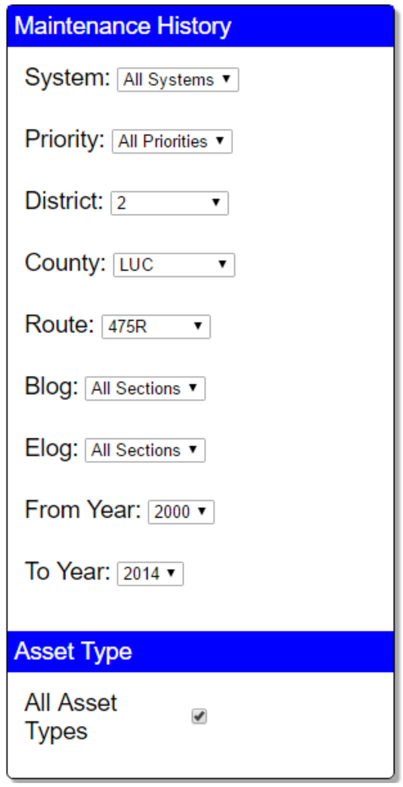
(b)

Figure D-50: (a) Maintenance cost details (b) Capital project details for 2013

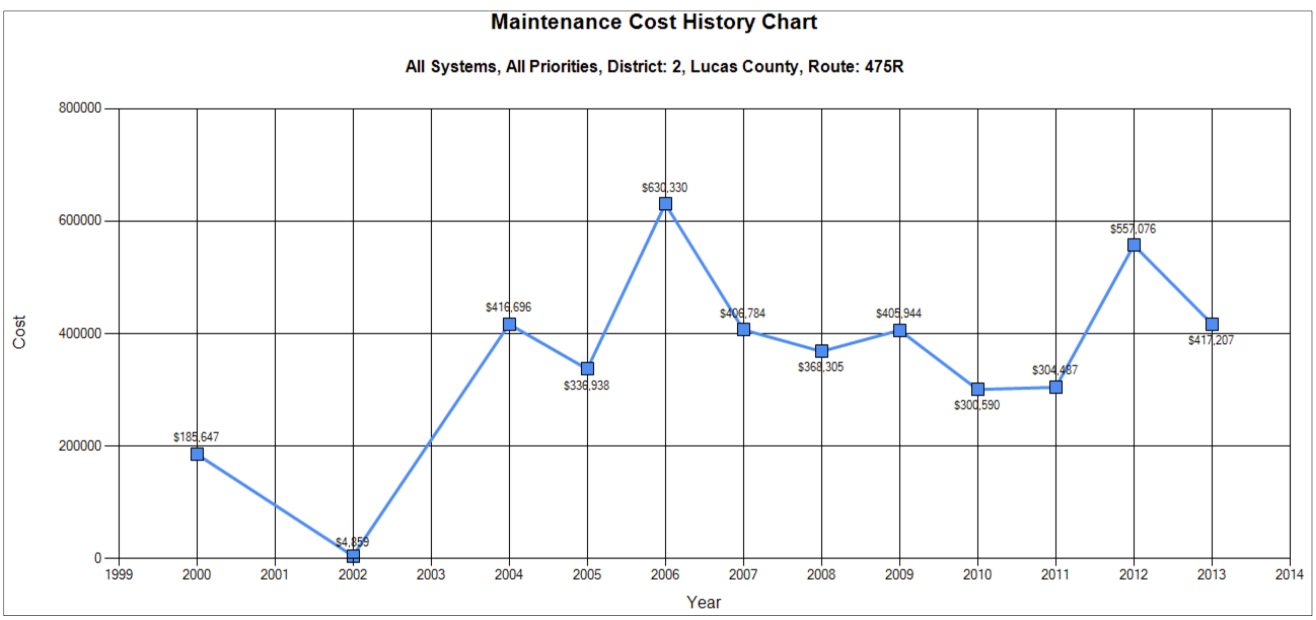
5.2 Maintenance History

The Maintenance History tool helps to show the total cost and details of cost for maintenance activities carried out for all assets during a period of time.

For example, if we want the maintenance history for I475 in District 2, Lucas County from year 2000 to 2014, clicking the "Execute" button after all the selection gives the following result.



(a)



(b)

Figure D-51: (a) Maintenance history selection panel (b) Maintenance history for I475 in Lucas County

Hyperlink: Clicking on the small squares as shown in red circle for the maintenance cost gives the following result.

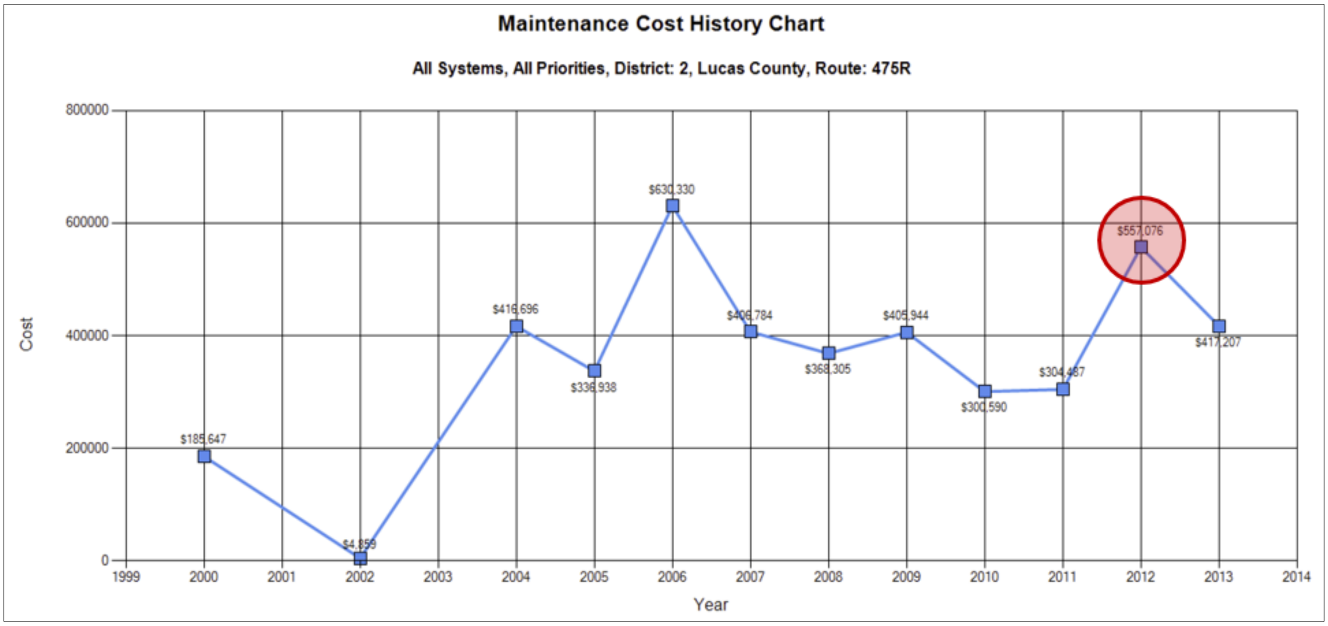


Figure D-52: Hyperlink for maintenance history

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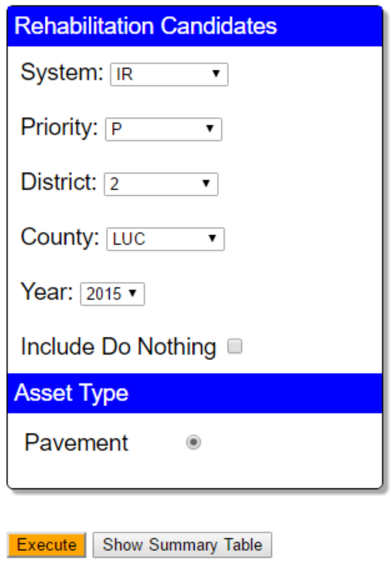
Asset Type	Maintenance Cost
Ancillary Activity	$59,520
Barrier	$17,314
Berming	$0
Bridge	$187,243
Culvert	$0
Drainage	$26,175
Highway Ancillary Activity	$171,785
Pavement	$56,275
Pavement Marking	$0
Traffic Operation	$38,764
Other	$0
Total	**$557,076**

Figure D-53: Maintenance details for 2012 from the hyperlink

5.3 Rehabilitation Candidates

This tool helps in identifying the pavement sections needing rehabilitation. We can include the sections requiring no treatment too.

For example, if we desire to display the rehab candidates for all the interstate highways in Lucas county for 2015 without displaying the segments with no treatment. Figure D- 54 (a) shows the input for the desired results. Click on execute to show results.



(a)

Rehabilitation Candidates List
Year: 2015, Interstate Highways, Priority: Priority, District: 2, County: Lucas

NLFID	District	County	Route	Blog	Elog	Station	PRIORITY	System	Pavement Type	PCR	Structural Deduct	Total ADT	Truck ADT	Rec'Treat
SLUCIR00075**C	2	LUC	075R	0.91	1.67	DOWN	P	IR	Composite	77	4.92	69330	10320	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	0.91	1.67	UP	P	IR	Composite	73	9.24	69330	10320	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	4.52	4.82	UP	P	IR	Composite	74	5.92	87970	10640	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	4.69	4.82	DOWN	P	IR	Composite	70	11.84	87970	10640	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	4.82	5.05	DOWN	P	IR	Composite	70	11.84	90700	13764	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	4.82	5.05	UP	P	IR	Composite	74	5.92	90700	13764	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	7.78	11.86	DOWN	P	IR	Composite	75	6.84	67239	16026	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00075**C	2	LUC	075R	7.78	11.86	UP	P	IR	Composite	77	7.32	67239	16026	Bin P6 Activity 60 (Overlay With Repairs)
SLUCIR00475**C	2	LUC	475R	0.94	3.15	DOWN	P	IR	Composite	67	7.2	63661	6505	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	0.94	3.15	UP	P	IR	Composite	66	7.2	63661	6505	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	3.15	3.82	DOWN	P	IR	Composite	67	7.2	68860	6730	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	3.15	3.82	UP	P	IR	Composite	66	7.2	68860	6730	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	3.82	4	DOWN	P	IR	Composite	67	7.2	68860	6730	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	3.82	4	UP	P	IR	Composite	66	7.2	68860	6730	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	5.25	7.53	DOWN	P	IR	Flexible	73	9.1	74950	6850	Bin P26 Activity 60 (Overlay With Repairs)
SLUCIR00475**C	2	LUC	475R	5.25	7.53	UP	P	IR	Flexible	76	7.15	74950	6850	Bin P26 Activity 60 (Overlay With Repairs)
SLUCIR00475**C	2	LUC	475R	9.9	10.25	UP	P	IR	Flexible	72	9.5	56080	5230	Bin P26 Activity 60 (Overlay With Repairs)
SLUCIR00475**C	2	LUC	475R	9.94	10.25	DOWN	P	IR	Flexible	68	12.65	56080	5230	Bin P26 Activity 60 (Overlay With Repairs)
SLUCIR00475**C	2	LUC	475R	10.25	10.68	UP	P	IR	Jointed Concrete	68	14	56080	5230	Bin P15 Activity Overlay With Repairs(60)
SLUCIR00475**C	2	LUC	475R	10.68	11.46	DOWN	P	IR	Flexible	78	8.9	55158	5215	Bin P24 Activity 30(Micro-Surfacing), 31(Double Application Micro-Surfacing),38(Fine Graded Polymer AC Overlay) or 50(AC Overlay Without Repairs)
SLUCIR00475**C	2	LUC	475R	10.68	11.46	UP	P	IR	Flexible	79	8.9	55158	5215	Bin P24 Activity 30(Micro-Surfacing), 31(Double Application Micro-Surfacing),38(Fine Graded Polymer AC Overlay) or 50(AC Overlay Without Repairs)
SLUCIR00475**C	2	LUC	475R	11.46	14.48	DOWN	P	IR	Composite	59	14.8	62538	5478	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)
SLUCIR00475**C	2	LUC	475R	11.46	14.48	UP	P	IR	Composite	61	13.8	62538	5478	Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)

(b)

Figure D-54: (a) Selection panel (b) Rehabilitation candidates for the selection

The "Show Summary Table" button [Show Summary Table] displays the summary of the rehabilitation candidates displaying total miles of network treated.

Rehabilitation Candidates List Summary
Year: 2015, Interstate Highways; Priority: Priority, District: 2; County: Lucas

Recommended Treatment	Total Miles
All Treatment:	29.94
Bin P1 Activity 77(Rubblize And Roll), 90(Unbonded Concrete Overlay), New Flexible Pavement(100) or New Rigid Pavement(110)	12.16
Bin P6 Activity 60 (Overlay With Repairs)	10.57
Bin P26 Activity 60 (Overlay With Repairs)	5.22
Bin P24 Activity 30(Micro-Surfacing), 31(Double Application Micro-Surfacing),38(Fine Graded Polymer AC Overlay) or 50(AC Overlay Without Repairs)	1.56
Bin P15 Activity Overlay With Repairs(60)	0.43

Figure D-55: Rehabilitation Candidates List Summary

The hyperlink for the PCR (underlined blue value) shows the details of the deductions made from the distress in PCR calculation as discussed in the previous tools.

6. Planning

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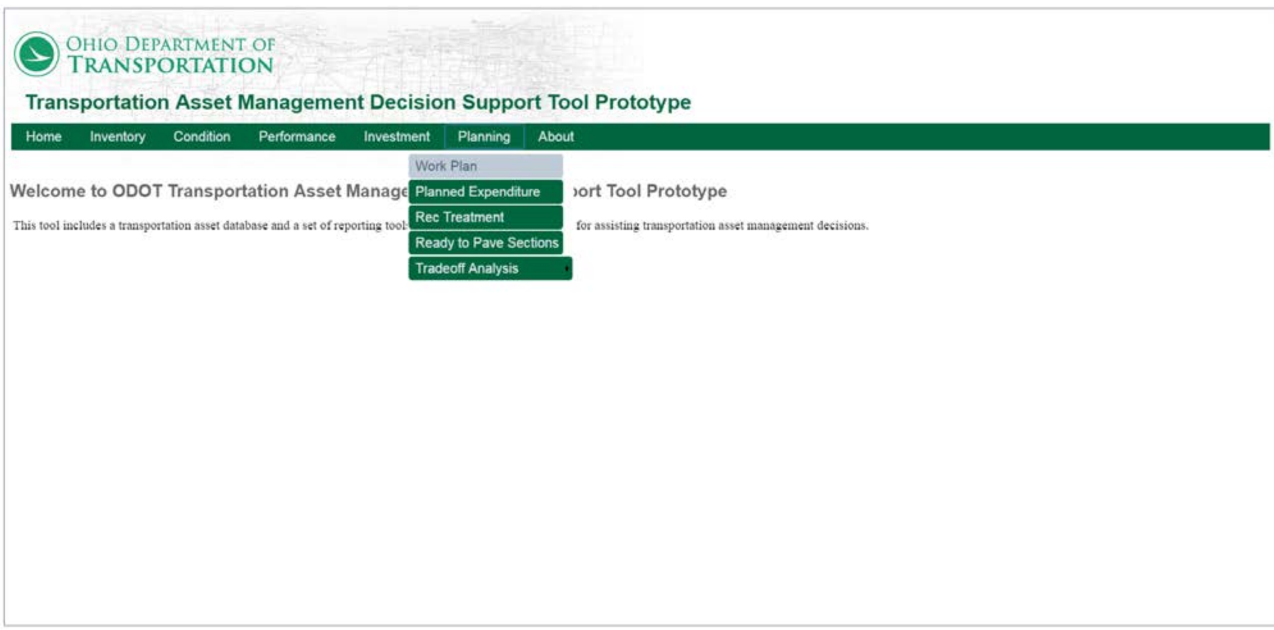


Figure D-56: Sub-menu under "Planning" tab

6.1 Work plan

"Download the Stored Work Plan" button downloads the present stored work plan in the database in the excel format.

A stored trial work plan can be uploaded with the "Upload the Trial Work Plan" button. The trial work plan is valid in that particular session only. User can upload the Work Plan by choosing their file from "Choose File" button.

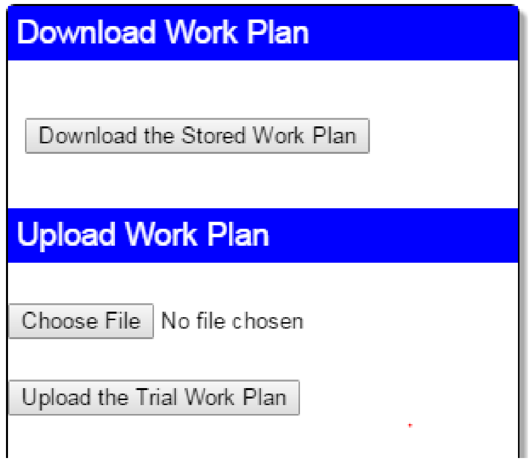
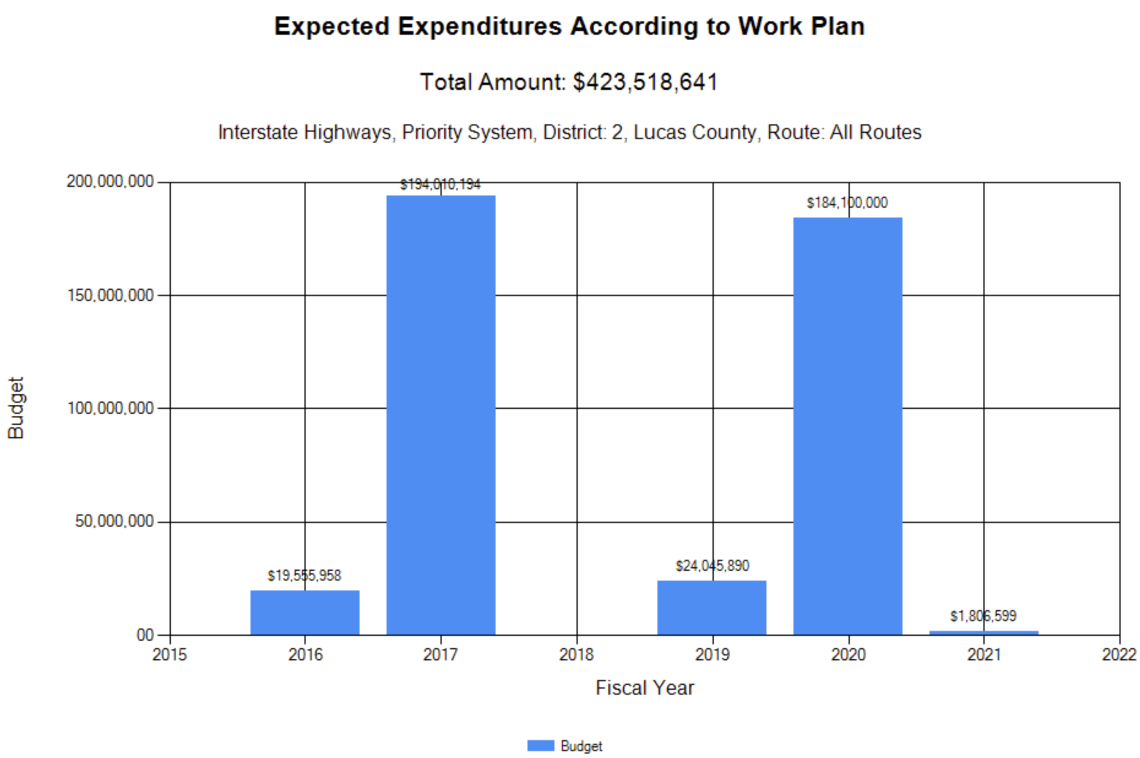


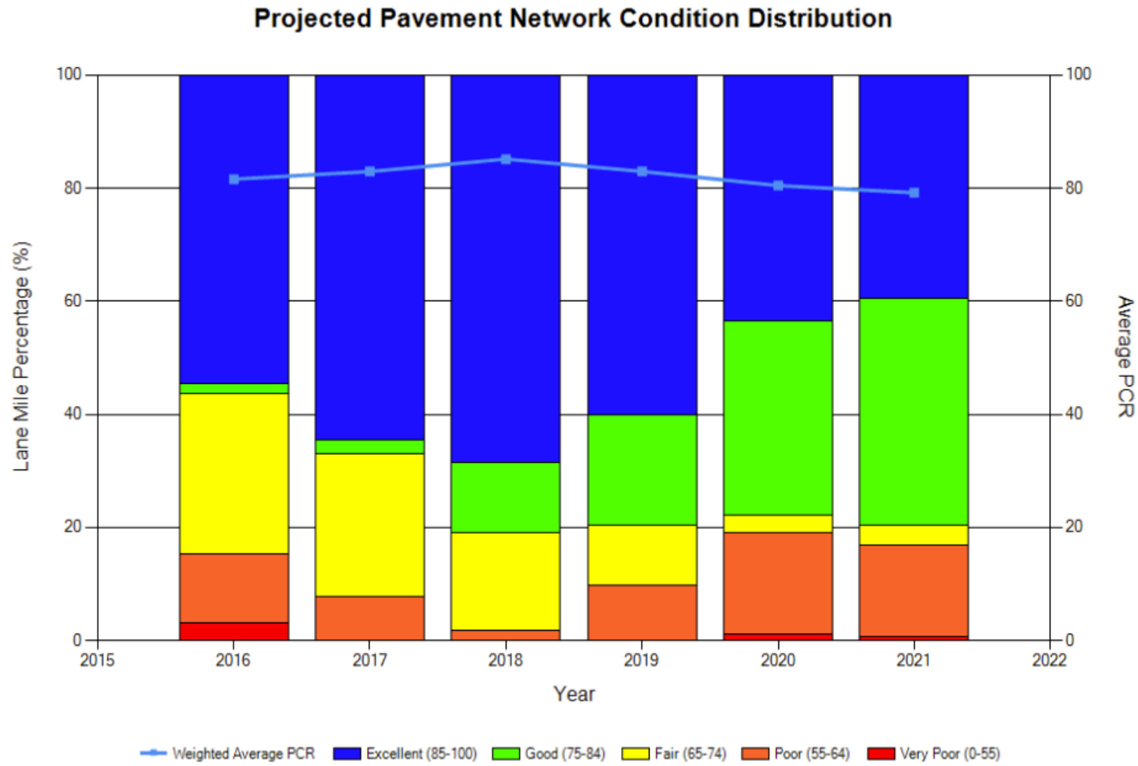
Figure D-57: Work plan selection options

Suppose we want the planned expenditures and the predicted condition of the assets (Pavement & Bridge) in Lucas County for all the interstate roads in it. Select “IR” System, “P” Priority, District “2”, “Lucas” County and “All Routes” from the selection panel. The years in work plan are fixed from 2016 to 2021. Click on the “Planned Expenditure and Predicted Conditions” button 

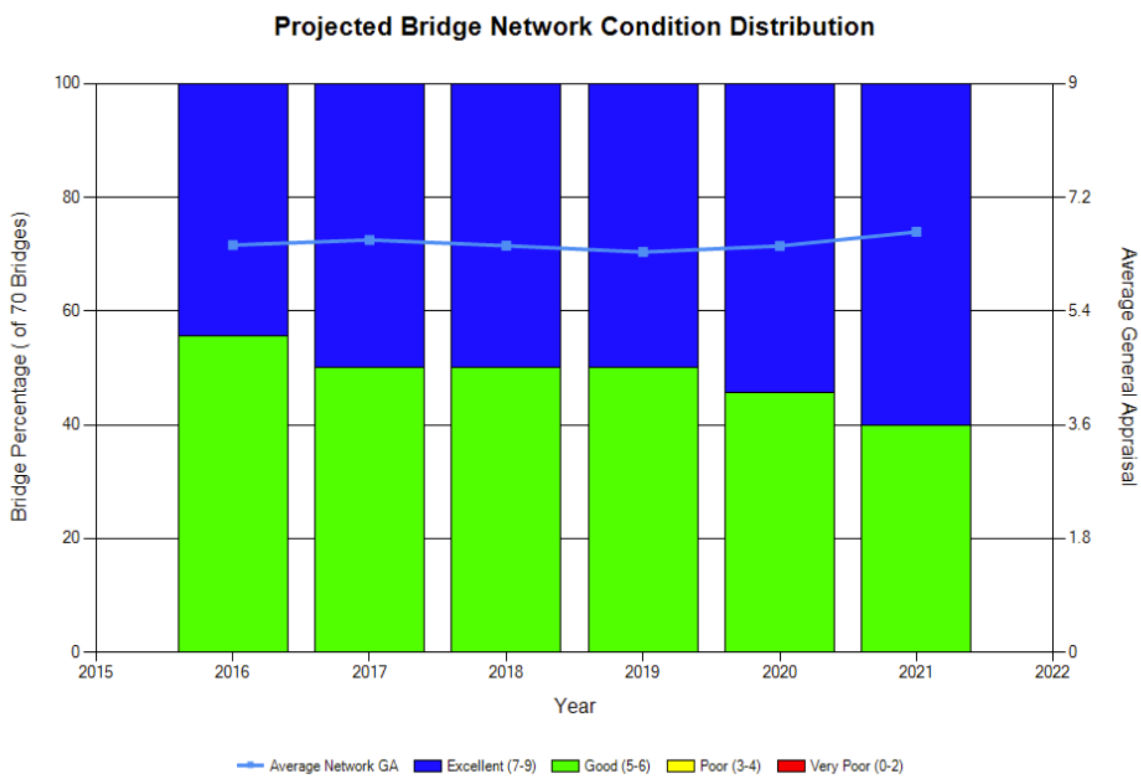
 to show the results. Results for the expected expenditures, projected pavement and bridge network condition are displayed as shown in figures D-58.



(a)



(b)



(c)

Figure D- 58: (a) Expected expenditures, (b) projected pavement network condition and (c) projected bridge network condition

Hyperlink: Clicking on the hyperlink i.e. the bar charts in the results give the details of the expenditure for that specific year. Similarly, the clicking on the bar chart area in the projected pavement and bridge network condition gives the details of the condition of those assets for the results of the year clicked.

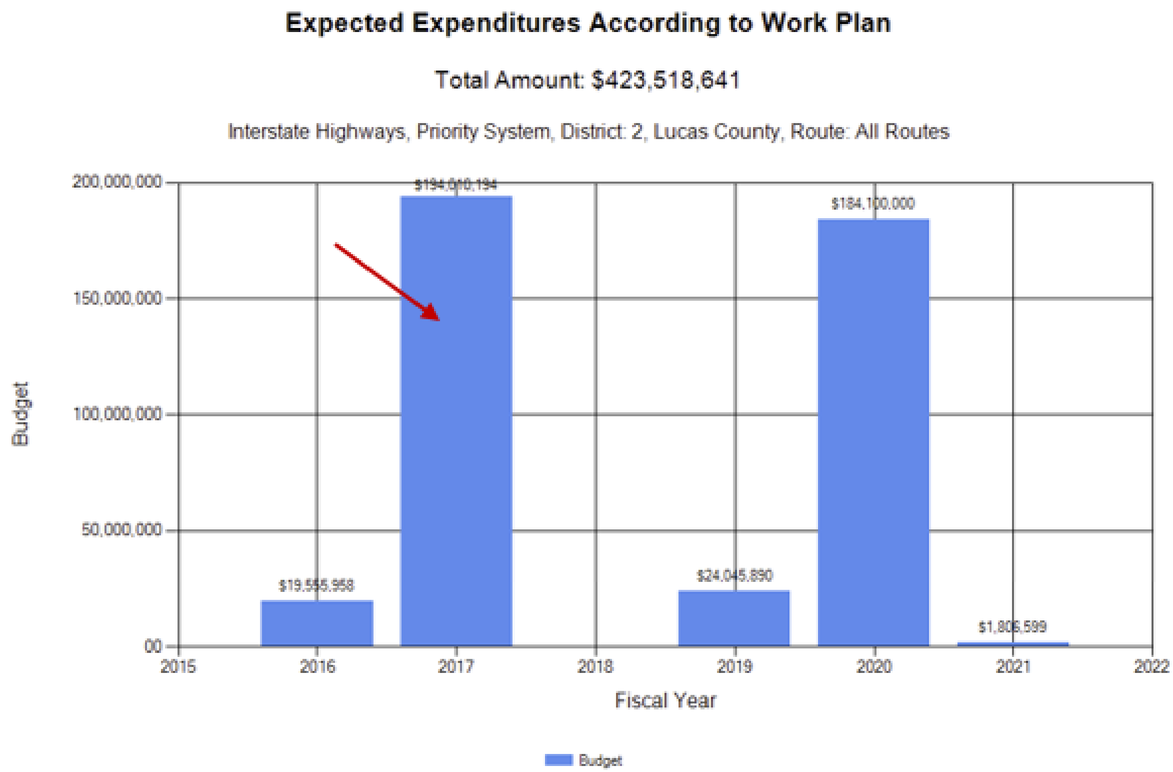


Figure D-59: Showing the hyperlink for expenditure details in 2017

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System	Priority	District	FiscalYear	PID	Estimate	NLFID	Blog	Elog	SFN	MAX Pvmt Treat Cat	Pvmt TreatType
IR	P	2	2017	93416	2,961,200	SLUCIR00475**C	0.97	3.09		Minor Rehabilitation	60 - AC Overlay with Repairs
IR	P	2	2017	93416	2,961,200	SLUCIR00475**C	3.35	4.33		Preventive Maintenance	38 - Fine Graded Polymer AC Overlay
IR	P	2	2017	93416	2,961,200	SLUCIR00475**C	4.38	5.05		Minor Rehabilitation	38 - Fine Graded Polymer AC Overlay
IR	P	2	2017	93416	2,961,200	SLUCIR00475**C	5.54	6.05		Minor Rehabilitation	60 - AC Overlay with Repairs
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.1	2.75		Major Rehabilitation	60 - AC Overlay with Repairs
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.3		4802853		
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.39		4802888		
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.68		4802942		
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.68		4802977		
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.88		4802950		
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	1.99		4803000		
IR	P	2	2017	93594	188,186,794	SLUCIR00075**C	2.33		4803094		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	2.82		4805844		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	2.87		4805836		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	2.95		4806018		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	2.96		4805992		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	3.72		4806107		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	3.76		4806115		
IR	P	2	2017	100170	2,062,200	SLUCIR00280**C	4.25		4805860		
IR	P	2	2017	102066	200,000	SLUCIR00280**C	3.76		4806115		
IR	P	2	2017	102116	600,000	SLUCIR00280**C	3.76		4806115		

Figure D-60: Details of the expected expenditures for 2017

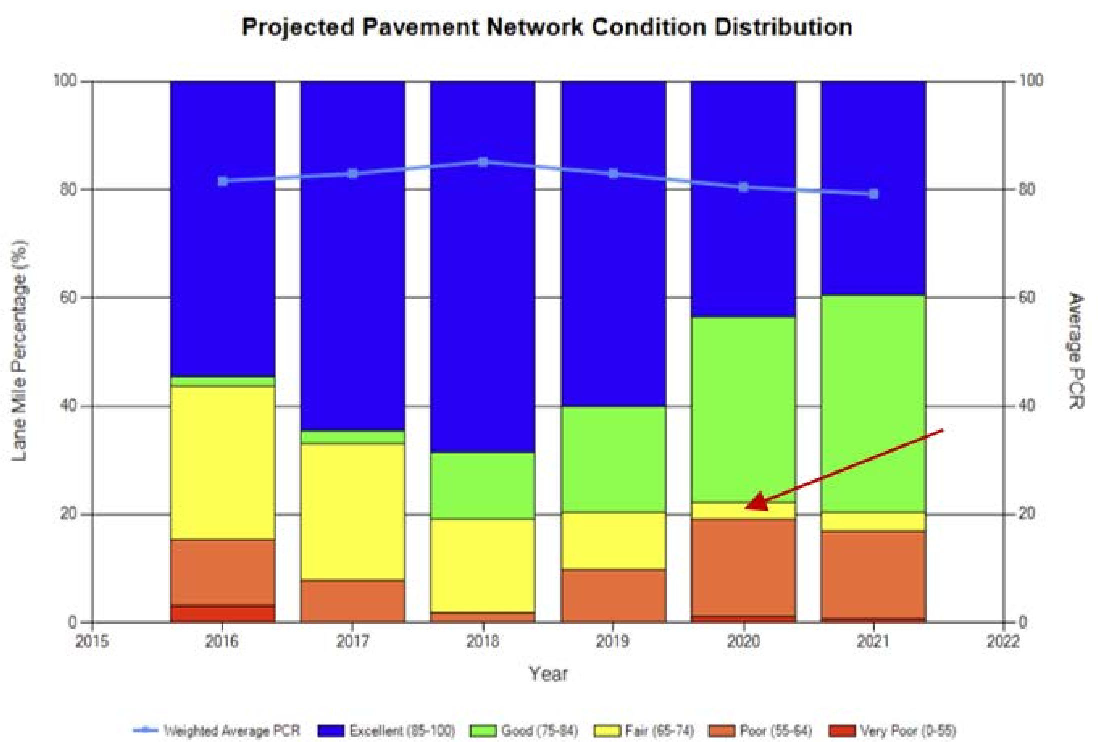

Figure D-61: Showing the hyperlink for projected "Fair" pavement condition details in 2020

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NLFID	District	County	Route	Blog	Elog	Station	System	Priority	Pavement Type	lanes	PCR_2016	PCR_2017	PCR_2018	PCR_2019	PCR_2020	PCR_2021	ActivityYear	Activity Code	Activity_Name
SLUCIR00280**C	2	LUC	280R	4.67	4.77	DOWN	IR	P	Jointed Concrete	7	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	5.09	5.2	DOWN	IR	P	Jointed Concrete	7	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	5.2	5.45	DOWN	IR	P	Jointed Concrete	7	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	5.45	5.75	DOWN	IR	P	Jointed Concrete	4	85	81	77	73	69	65			
SLUCIR00280**C	2	LUC	280R	5.09	5.2	UP	IR	P	Jointed Concrete	7	89	85	81	77	73	70			
SLUCIR00280**C	2	LUC	280R	5.2	5.45	UP	IR	P	Jointed Concrete	7	89	85	81	77	73	70			
SLUCIR00280**C	2	LUC	280R	5.45	5.75	UP	IR	P	Jointed Concrete	4	89	85	81	77	73	70			

Figure D-62: Details of the projected “Fair” condition pavements in 2020

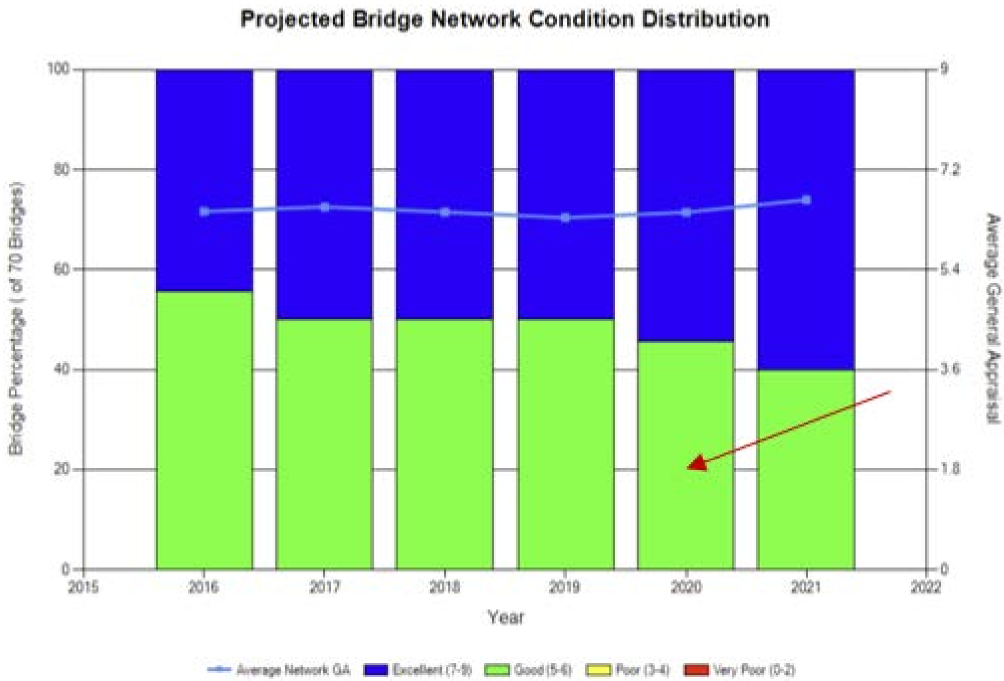

Figure D-63: Showing the hyperlink for projected “Good” bridges in 2020

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	SFN	District	County	Route	Blog	System	Priority	Type	Deck Area	GA_2016	GA_2017	GA_2018	GA_2019	GA_2020	GA_2021	Year of First Activity
1	4804805	2	LUC	075R	1.98	IR	P	STEEL	8428	6	5.9	5.8	5.7	5.7	7	2021
2	4803396	2	LUC	075R	4.61	IR	P	STEEL	9031	6	5.9	5.8	5.7	5.7	7	2015
3	4803604	2	LUC	075R	4.9	IR	P	STEEL	8945	6	5.9	5.8	5.7	5.7	7	2021
4	4803639	2	LUC	075R	5.04	IR	P	STEEL	10140	6	5.9	5.8	5.7	5.7	7	2021
5	4803663	2	LUC	075R	5.04	IR	P	STEEL	17965	6	5.9	5.8	5.7	5.7	7	2021
6	4803698	2	LUC	075R	5.2	IR	P	STEEL	10592	6	5.9	5.8	5.7	5.7	7	2015
7	4803728	2	LUC	075R	5.2	IR	P	STEEL	10646	6	5.9	5.8	5.7	5.7	7	2015
8	4803752	2	LUC	075R	5.77	IR	P	STEEL	288529	6	5.9	5.8	5.7	5.7	5.6	2015
9	4803876	2	LUC	075R	6.7	IR	P	STEEL	14553	6	5.9	5.8	5.7	5.7	7	2015
10	4804058	2	LUC	075R	7.62	IR	P	STEEL	17265	6	5.9	5.8	5.7	5.7	7	2015
11	4804171	2	LUC	075R	7.78	IR	P	STEEL	6243	6	5.9	5.8	5.7	5.7	7	2015
12	4804260	2	LUC	075R	8.07	IR	P	STEEL	8773	6	5.9	5.8	5.7	5.7	7	2015
13	4804325	2	LUC	075R	8.17	IR	P	STEEL	8105	6	5.9	5.8	5.7	5.7	7	2015
14	4805674	2	LUC	280R	1.82	IR	P	CONCRETE	2056	6	5.9	5.8	5.8	5.7	5.7	
15	4807294	2	LUC	475R	3.15	IR	P	STEEL	25306	5	4.9	4.8	4.7	4.7	4.6	
16	4807286	2	LUC	475R	3.15	IR	P	STEEL	25306	6	5.9	5.8	5.7	5.7	5.6	
17	4807383	2	LUC	475R	4.33	IR	P	CONCRETE	7610	6	5.9	5.8	5.8	5.7	5.7	2022
18	4807413	2	LUC	475R	4.33	IR	P	CONCRETE	5038	6	5.9	5.8	5.8	5.7	5.7	2022
19	4807472	2	LUC	475R	5.22	IR	P	STEEL	6469	5	4.9	4.8	4.7	4.7	4.6	
20	4807502	2	LUC	475R	5.22	IR	P	STEEL	6469	5	4.9	4.8	4.7	4.7	4.6	

Figure D-64: Details of the projected "Good" bridges in 2020

The hyperlink for the bridge further show the details about that specific bridge. Clicking on the hyperlink for SFN in the first row of the results gives the following details.

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SFN	District	County	Route	Blog	System	GA_2016	NLFID	Deck Area	Location	Longitude	Latitude	PCS Rating	Deck Wearing Rating	Deck Floor Rating
4804805	2	LUC	75R	1.98	IR	6	SLUCIR00075**C	8428	RAMP 2-F OVER SR25 SB	-83.548901	41.645023	7	1	1

Fiscal Year	Project ID	NLFID	Activity Type	Estimated Cost ($)	Sale Amount ($)
2021	101116	SLUCIR00075**C	Preventive Maintenance	1456599.00	

Figure D-65: Details of the bridge with SFN "4804805"

6.2 Planned Expenditure

Planned expenditures function shows the expected expenditures in the pavement and bridge network according to the work plan.

Suppose, to show the expected expenditures in I475 in Lucas County from 2017 to 2022, we select District "2", County "LUC", Route "475R", From Year "2017" and To Year "2022". Click on "Execute" to show the results. Results from the selection are shown in figure D-66.

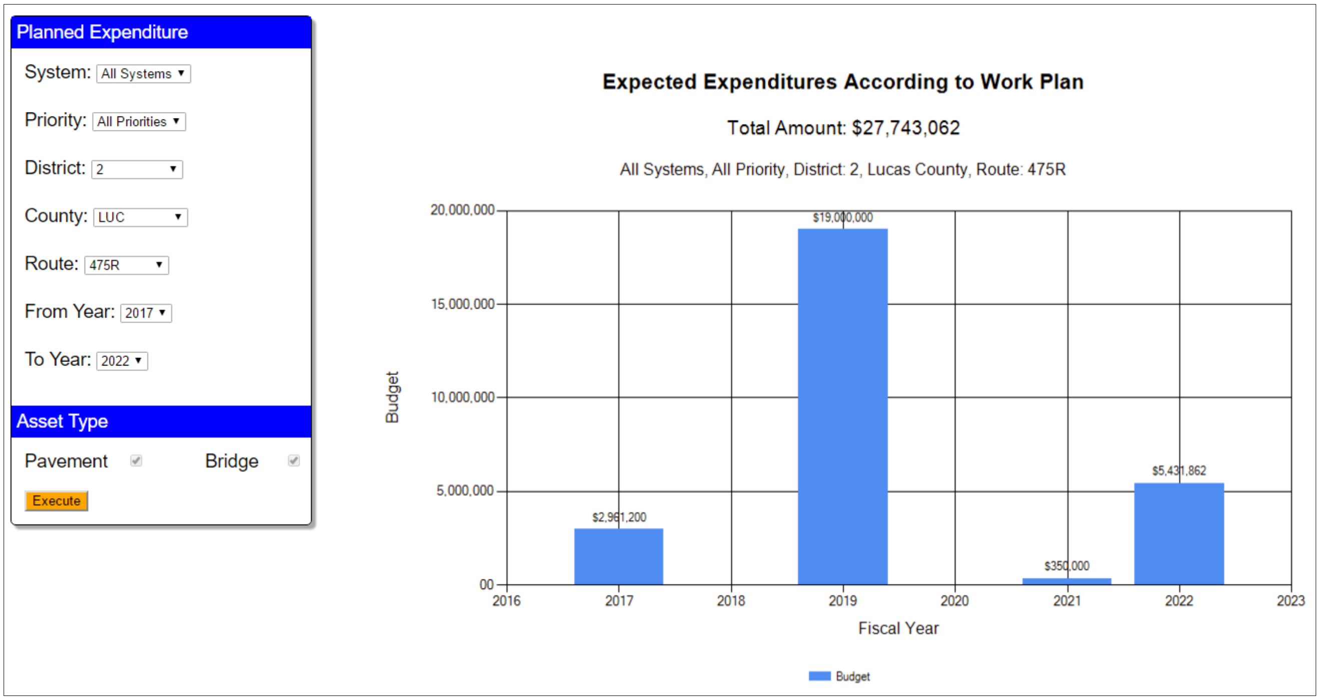

Figure D-66: Expected expenditures for the selected network

Clicking the bar graph for 2019 in the above result gives the details of the project from workplan.

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System	Priority	District	FiscalYear	PID	Estimate	NLFID	Blog	Elog	SFN	MAX Pvmt Treat Cat	Pvmt TreatType
IR	P	2	2019	99731	19,000,000	SLUCIR00475**C	1.15	3.14		New Construction	200 - New Pavement (Bypass,New Alignment,etc)

Figure D-67: Project details for 2019

6.3 Recommended Treatment

Recommended Treatment tool helps to recommend a treatment type according to the pavement condition.

Suppose we want to show the recommended treatment for the Interstate highways I475 for year 2016 to 2023 in Lucas County, District 2. Select “IR” Priorities, “P” Priority, District “2”, “Lucas” County, “475R” Route, From Year “2016” and To Year “2023”.
Clicking the “Execute” button gives the following result.

	NLFID	District	County	Route	Blog	Elog	Station	System	Priority	Pavement Type	lanes	PCR 2016	RecTreat 2016	PCR 2017	RecTreat 2017	PCR 2018	RecTreat 2018	PCR 2019	RecTreat 2019	PCR 2020	RecTreat 2020	PCR 2021	RecTreat 2021	PCR 2022	RecTreat 2022	PCR 2023	RecTreat 2023
1	SLUCIR00475**C	2	LUC	475R	10.25	10.66	DOWN	IR	P	2	4	73	Bin P17	70	Bin P17	67	Bin P15	64	Bin P15	61	Bin P10	58	Bin P10	55	Bin P10	52	Bin P10
2	SLUCIR00475**C	2	LUC	475R	10.66	10.68	DOWN	IR	P	2	4	73	Bin P17	70	Bin P17	67	Bin P15	64	Bin P15	61	Bin P10	58	Bin P10	55	Bin P10	52	Bin P10
3	SLUCIR00475**C	2	LUC	475R	10.66	10.68	UP	IR	P	2	4	65	Bin P15	62	Bin P15	59	Bin P15	56	Bin P10	53	Bin P10	50	Bin P10	47	Bin P10	44	Bin P10
4	SLUCIR00475**C	2	LUC	475R	10.25	10.66	UP	IR	P	2	4	65	Bin P15	62	Bin P15	59	Bin P15	56	Bin P10	53	Bin P10	50	Bin P10	47	Bin P10	44	Bin P10
5	SLUCIR00475**C	2	LUC	475R	9.64	9.94	DOWN	IR	P	3	4	96	Bin P21	92	Bin P21	88	Bin P21	84	Bin P21	80	Bin P21	77	Bin P24	74	Bin P26	71	Bin P26
6	SLUCIR00475**C	2	LUC	475R	10.68	11.33	DOWN	IR	P	3	4	74	Bin P26	70	Bin P26	68	Bin P26	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22	58	Bin P22
7	SLUCIR00475**C	2	LUC	475R	11.33	11.36	DOWN	IR	P	3	4	74	Bin P26	70	Bin P26	68	Bin P26	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22	58	Bin P22
8	SLUCIR00475**C	2	LUC	475R	11.36	11.43	DOWN	IR	P	3	4	74	Bin P26	70	Bin P26	68	Bin P26	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22	58	Bin P22
9	SLUCIR00475**C	2	LUC	475R	11.43	11.46	DOWN	IR	P	3	4	74	Bin P26	70	Bin P26	68	Bin P26	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22	58	Bin P22
10	SLUCIR00475**C	2	LUC	475R	10.68	11.33	UP	IR	P	3	4	75	Bin P26	72	Bin P26	70	Bin P26	68	Bin P23	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22
11	SLUCIR00475**C	2	LUC	475R	11.33	11.36	UP	IR	P	3	4	75	Bin P26	72	Bin P26	70	Bin P26	68	Bin P23	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22
12	SLUCIR00475**C	2	LUC	475R	11.36	11.43	UP	IR	P	3	4	75	Bin P26	72	Bin P26	70	Bin P26	68	Bin P23	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22
13	SLUCIR00475**C	2	LUC	475R	11.43	11.46	UP	IR	P	3	4	75	Bin P26	72	Bin P26	70	Bin P26	68	Bin P23	66	Bin P23	64	Bin P22	62	Bin P22	60	Bin P22
14	SLUCIR00475**C	2	LUC	475R	9.94	10.2	DOWN	IR	P	3	4	66	Bin P26	64	Bin P22	61	Bin P22	59	Bin P22	56	Bin P22	54	Bin P22	52	Bin P22	50	Bin P22
15	SLUCIR00475**C	2	LUC	475R	10.2	10.25	DOWN	IR	P	3	4	66	Bin P26	64	Bin P22	61	Bin P22	59	Bin P22	56	Bin P22	54	Bin P22	52	Bin P22	50	Bin P22
16	SLUCIR00475**C	2	LUC	475R	5.25	7.53	DOWN	IR	P	3	4	70	Bin P26	67	Bin P26	63	Bin P22	60	Bin P22	57	Bin P22	54	Bin P22	51	Bin P22	49	Bin P22
17	SLUCIR00475**C	2	LUC	475R	5.25	7.53	UP	IR	P	3	4	74	Bin P26	71	Bin P26	69	Bin P26	66	Bin P26	63	Bin P22	60	Bin P22	57	Bin P22	54	Bin P22
18	SLUCIR00475**C	2	LUC	475R	9.64	9.88	UP	IR	P	3	4	82	Bin P21	80	Bin P21	78	Bin P26	76	Bin P26	74	Bin P26	72	Bin P23	70	Bin P23	68	Bin P23
19	SLUCIR00475**C	2	LUC	475R	9.88	9.9	UP	IR	P	3	4	82	Bin P21	80	Bin P21	78	Bin P26	76	Bin P26	74	Bin P26	72	Bin P23	70	Bin P23	68	Bin P23
20	SLUCIR00475**C	2	LUC	475R	9.9	10.2	UP	IR	P	3	4	70	Bin P26	68	Bin P26	65	Bin P22	63	Bin P22	60	Bin P22	58	Bin P22	55	Bin P22	53	Bin P22
21	SLUCIR00475**C	2	LUC	475R	10.2	10.25	UP	IR	P	3	4	70	Bin P26	68	Bin P26	65	Bin P22	63	Bin P22	60	Bin P22	58	Bin P22	55	Bin P22	53	Bin P22
22	SLUCIR00475**C	2	LUC	475R	14.51	15.5	DOWN	IR	P	3	8	91	Bin P21	89	Bin P21	86	Bin P21	84	Bin P21	82	Bin P21	79	Bin P24	77	Bin P26	74	Bin P26
23	SLUCIR00475**C	2	LUC	475R	15.73	15.76	DOWN	IR	P	3	8	91	Bin P21	89	Bin P21	86	Bin P21	84	Bin P21	82	Bin P21	79	Bin P24	77	Bin P26	74	Bin P26
24	SLUCIR00475**C	2	LUC	475R	2.5	3.15	DOWN	IR	P	3	4	60	Bin P22	56	Bin P22	53	Bin P22	50	Bin P22	47	Bin P22	44	Bin P22	42	Bin P22	40	Bin P22
25	SLUCIR00475**C	2	LUC	475R	14.19	14.3	DOWN	IR	P	3	4	48	Bin P22	45	Bin P22	42	Bin P22	39	Bin P22	37	Bin P22	35	Bin P22	34	Bin P22	32	Bin P22
26	SLUCIR00475**C	2	LUC	475R	14.3	14.48	DOWN	IR	P	3	4	48	Bin P22	45	Bin P22	42	Bin P22	39	Bin P22	37	Bin P22	35	Bin P22	34	Bin P22	32	Bin P22
27	SLUCIR00475**C	2	LUC	475R	14.48	14.51	DOWN	IR	P	3	8	91	Bin P21	89	Bin P21	86	Bin P21	84	Bin P21	82	Bin P21	79	Bin P24	77	Bin P26	74	Bin P26
28	SLUCIR00475**C	2	LUC	475R	15.5	15.73	DOWN	IR	P	3	8	91	Bin P21	89	Bin P21	86	Bin P21	84	Bin P21	82	Bin P21	79	Bin P24	77	Bin P26	74	Bin P26
29	SLUCIR00475**C	2	LUC	475R	15.76	15.85	DOWN	IR	P	3	8	91	Bin P21	89	Bin P21	86	Bin P21	84	Bin P21	82	Bin P21	79	Bin P24	77	Bin P26	74	Bin P26
30	SLUCIR00475**C	2	LUC	475R	15.85	16.03	DOWN	IR	P	3	8	91	Bin P21	89	Bin P21	86	Bin P21	84	Bin P21	82	Bin P21	79	Bin P24	77	Bin P26	74	Bin P26

Figure D-68: Recommended treatment for the pavement section selected

Clicking the hyperlink for the treatment type shows the type of treatment shown in the code.

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Bin	Activity Description
Bin P15	Minor Rehab

Figure D-69: Details of the recommended treatment type Bin P15

6.4 Ready to Pave Sections

Ready to Pave Sections tool helps to see the pavement sections and bridge ready to get a maintenance or rehabilitation in the desired year.

Suppose we want to see the pavement sections and bridge in 2017 for Interstate highways in Lucas County. Select "IR" System, "P" Priority, District "2", County "LUC", "All Routes" and Year "2017". Clicking the execute button shows the result for the selection.

No.	Year	PID	District	Estimate	NLFID	Blog	Elog	MAX Pvmnt Trt Cat	Pvmnt Trt Type	SFN	MAX Bdge Trt Cat	System	Priority
1	2017	93416	2	$2,961,200.00	SLUCIR00475**C	0.97	3.09	Minor Rehabilitation	60 - AC Overlay with Repairs			IR	P
2	2017	93416	2	$2,961,200.00	SLUCIR00475**C	3.35	4.33	Preventive Maintenance	38 - Fine Graded Polymer AC Overlay			IR	P
3	2017	93416	2	$2,961,200.00	SLUCIR00475**C	4.38	5.05	Minor Rehabilitation	38 - Fine Graded Polymer AC Overlay			IR	P
4	2017	93416	2	$2,961,200.00	SLUCIR00475**C	5.54	6.05	Minor Rehabilitation	60 - AC Overlay with Repairs			IR	P
5	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.1	2.75	Major Rehabilitation	60 - AC Overlay with Repairs			IR	P
6	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.3				4802853	New Construction	IR	P
7	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.39				4802888	New Construction	IR	P
8	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.68				4802942	New Construction	IR	P
9	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.68				4802977	New Construction	IR	P
10	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.88				4802950	New Construction	IR	P
11	2017	93594	2	$188,186,794.00	SLUCIR00075**C	1.99				4803000	New Construction	IR	P
12	2017	93594	2	$188,186,794.00	SLUCIR00075**C	2.33				4803094	New Construction	IR	P
13	2017	100170	2	$2,062,200.00	SLUCIR00280**C	2.82				4805844	Preventive Maintenance	IR	P
14	2017	100170	2	$2,062,200.00	SLUCIR00280**C	2.87				4805836	Preventive Maintenance	IR	P
15	2017	100170	2	$2,062,200.00	SLUCIR00280**C	2.95				4806018	Preventive Maintenance	IR	P
16	2017	100170	2	$2,062,200.00	SLUCIR00280**C	2.96				4805992	Preventive Maintenance	IR	P
17	2017	100170	2	$2,062,200.00	SLUCIR00280**C	3.72				4806107	Preventive Maintenance	IR	P
18	2017	100170	2	$2,062,200.00	SLUCIR00280**C	3.76				4806115	Preventive Maintenance	IR	P
19	2017	100170	2	$2,062,200.00	SLUCIR00280**C	4.25				4805860	Preventive Maintenance	IR	P
20	2017	102066	2	$200,000.00	SLUCIR00280**C	3.76				4806115	Reactive Maintenance	IR	P
21	2017	102116	2	$600,000.00	SLUCIR00280**C	3.76				4806115	Preventive Maintenance	IR	P

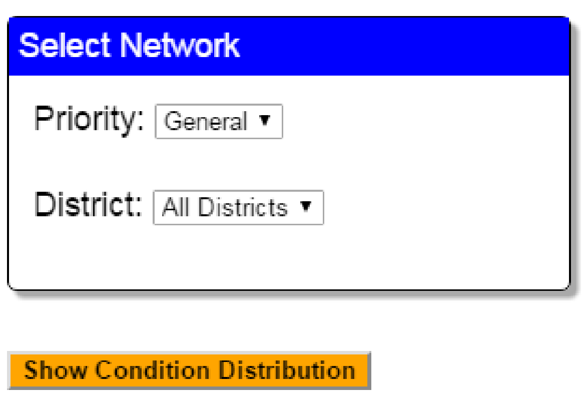
Figure D-70: Details of the project for the selection

6.5 Trade-off Analysis

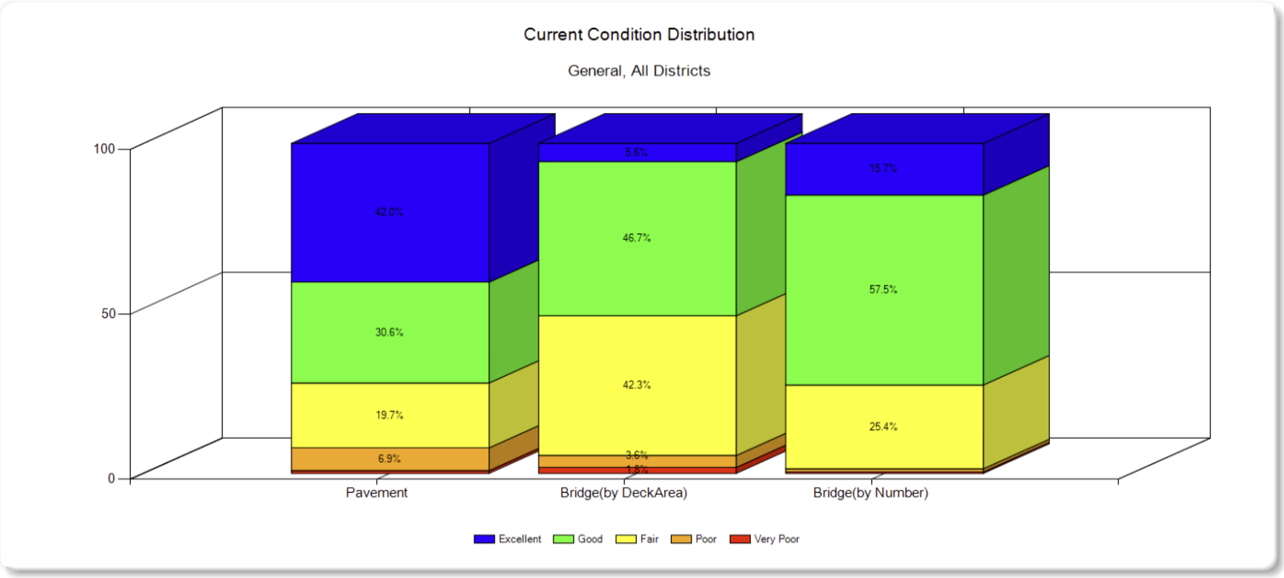
Trade-off analysis is done in two different levels: (i) Network Level & (ii) Project Level.

6.5.1 Network Level Tradeoff

The network level trade-off tool helps to maximize the network condition and recommend the treatments for the future with given budget, unit costs for treatment and allowable treatments.



(a)

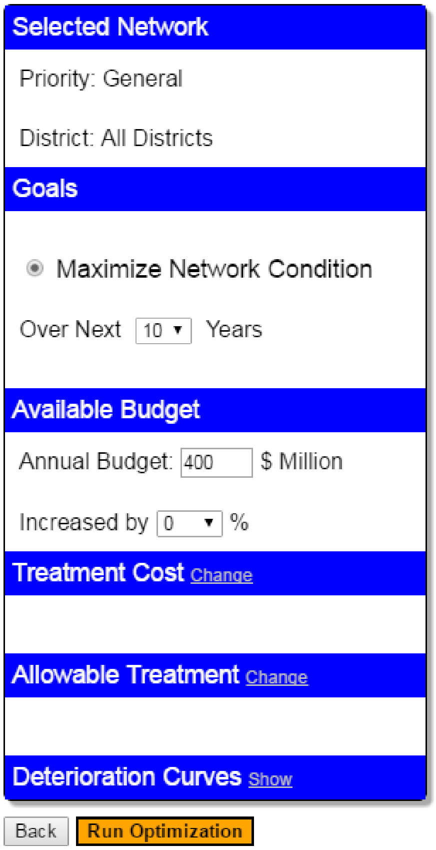


	Quantity	Value
Pavement	29,880(Lane-mile)	37,350($Million)
Bridge Area	22,873,050(by DeckArea)	2,745($Million)
Bridge Number	7,571(by Number)	2,745($Million)

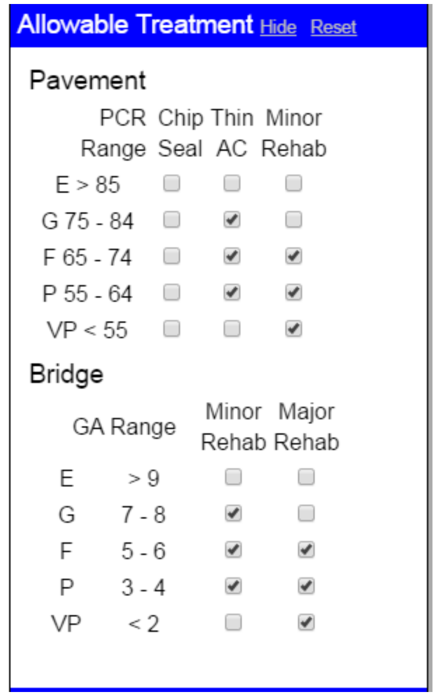
(b)

Figure D-71: Distribution of network (a) Network selection (b) Condition distribution for pavement and bridge

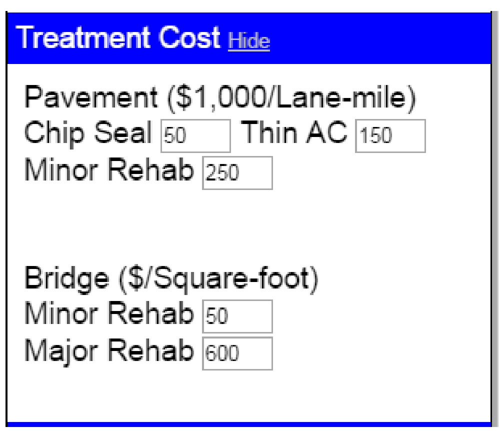
Suppose, the user wants to run the optimization for “General” priority roads in “All Districts” to maximize network condition over next 10 years.



(a)



(b)



(c)

Figure D-72: Optimization parameters (a) User input panel (b) Allowable treatments for pavement & bridge conditions under change button (c) Unit treatment costs under change button

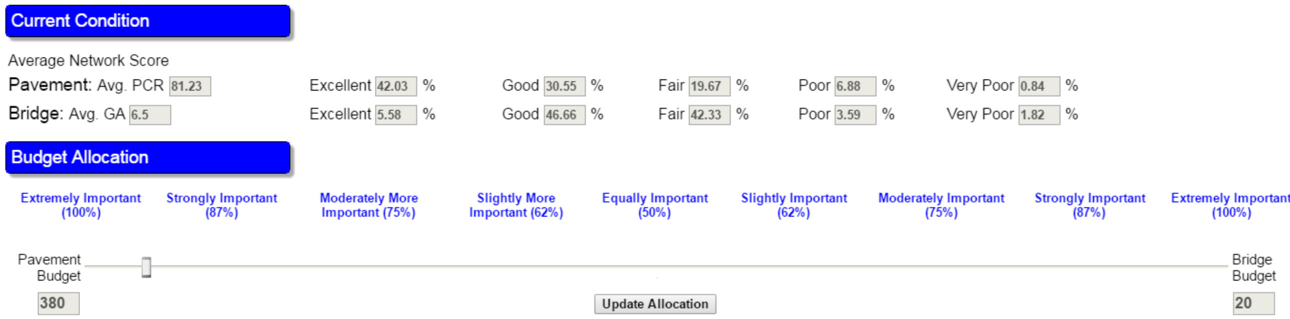
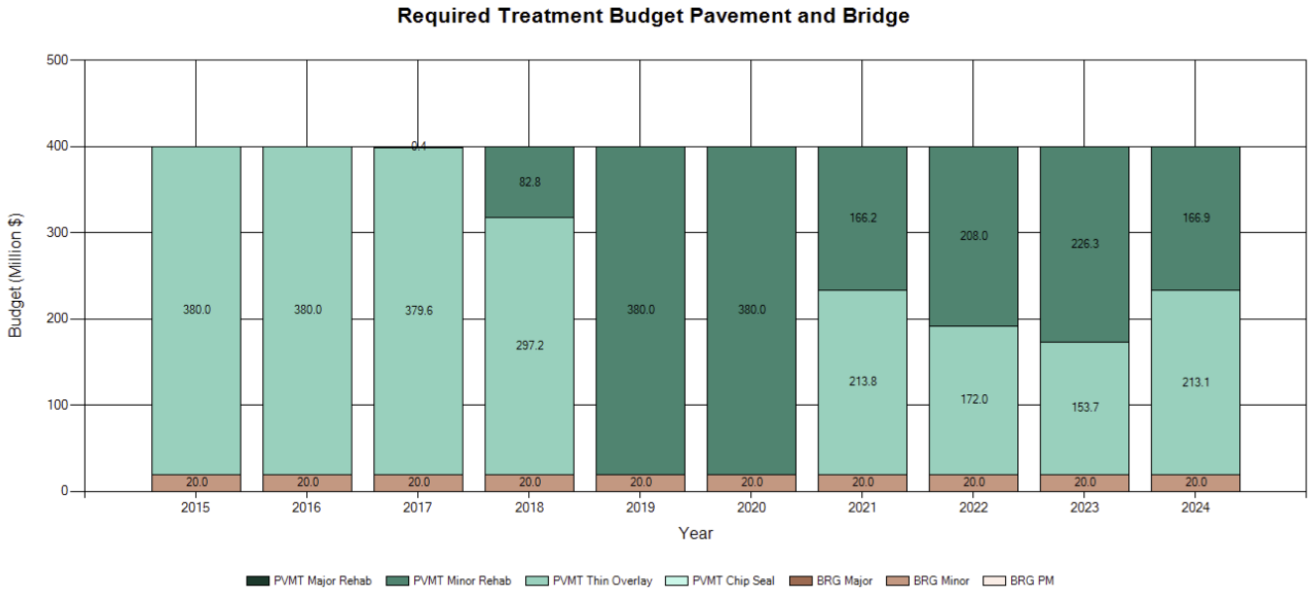


Figure D-73: Current condition for the selected network and budget allocation for the optimization

Suppose, we allocate the total annual budget constant at $ 400 Million and the allowable treatment and treatment costs to be default as shown in figure D-72. Let the budget allocation be $380 Million for pavement and $20 Million for bridge. The “Run Optimization” button shows the results showing required treatment budget every year and the projected network condition distribution for pavement and bridge.

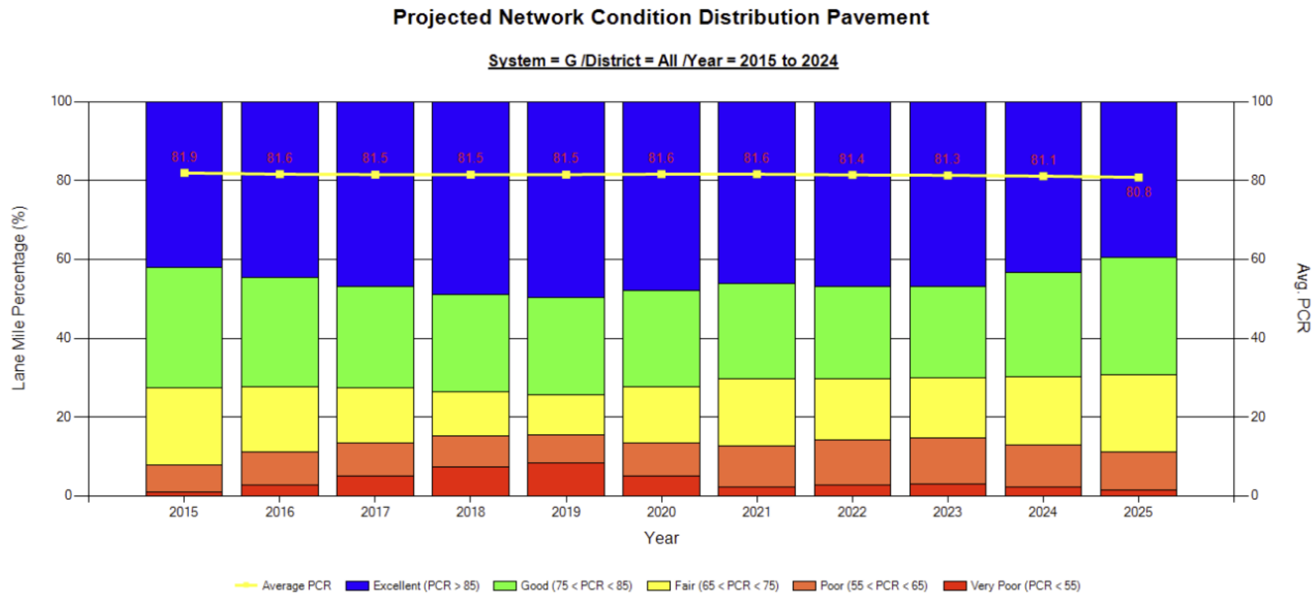


(a)

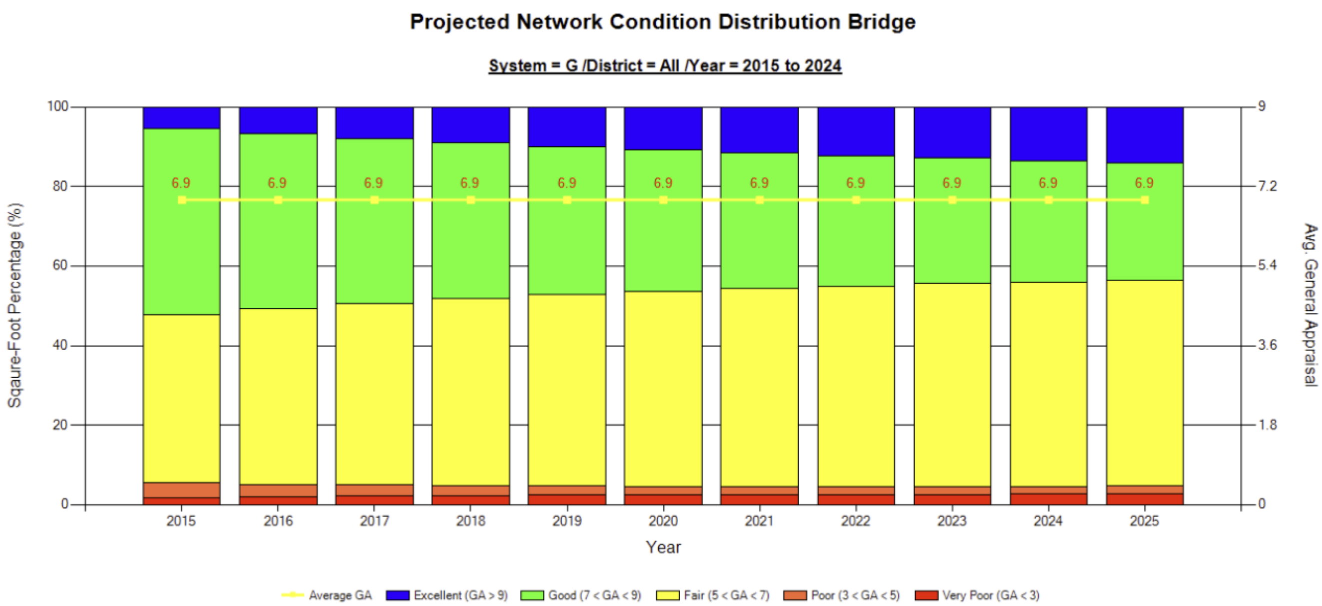
Pavement (Lane Miles)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
PVMT Minor Rehab	0	0	1	331	1,520	1,520	665	832	905	668
PVMT Thin AC	2,533	2,533	2,531	1,981	0	0	1,425	1,147	1,025	1,421
PVMT Chip Seal	0	0	0	0	0	0	0	0	0	0

Bridge (Square Foot)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
BRG Major Rehab	0	0	0	0	0	0	0	0	0	0
BRG Minor Rehab	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000

(b)



(c)



(d)

Figure D-74: Optimization results (a) treatment budget for pavement and bridge (b) Total lane miles and deck area treated for pavement and bridge respectively (c) projected network condition for pavement (d) projected network condition for bridge

6.5.2 Project Level Tradeoff

The project level trade-off tool helps prioritizing the projects assigned in the work plan according to various pavement and bridge criteria. The prioritization can be done for each district and year.

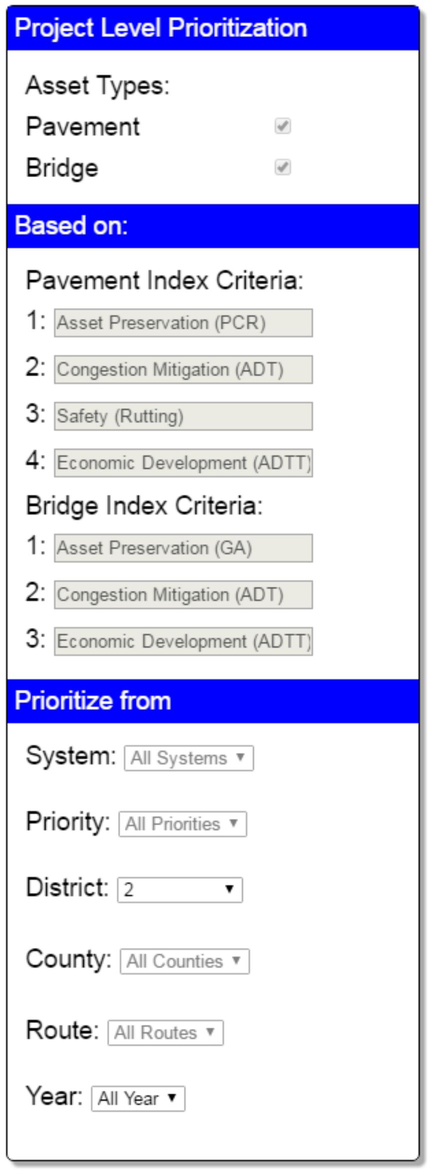
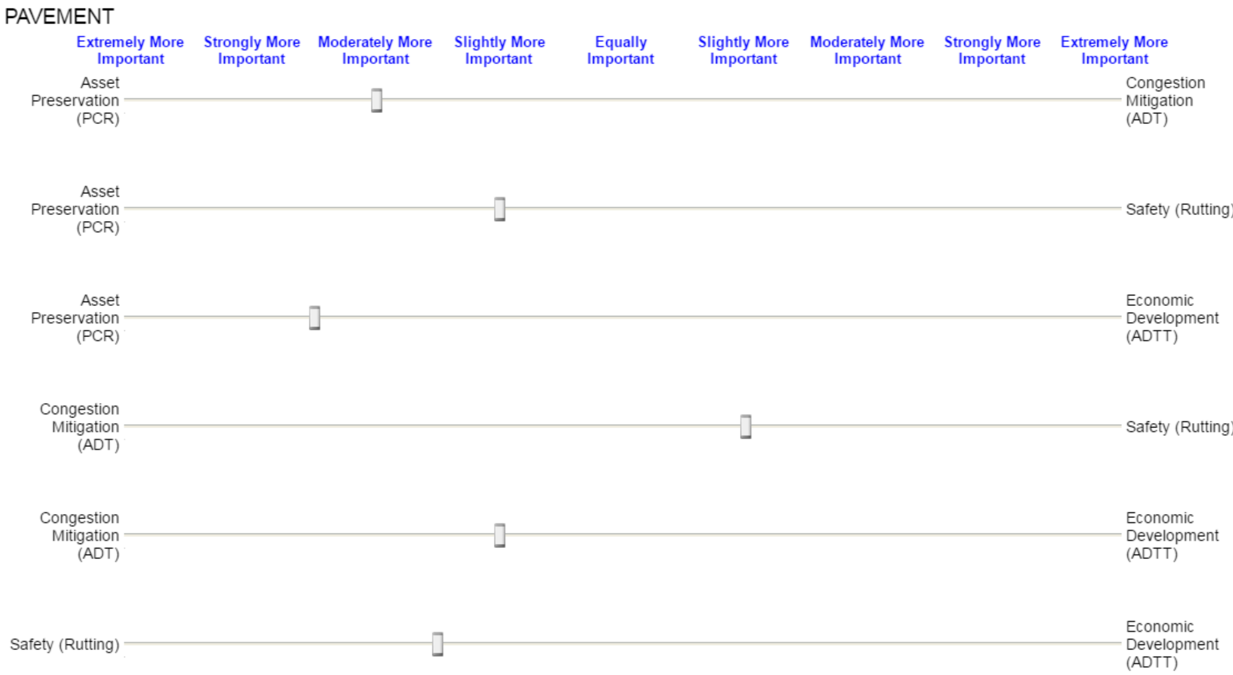
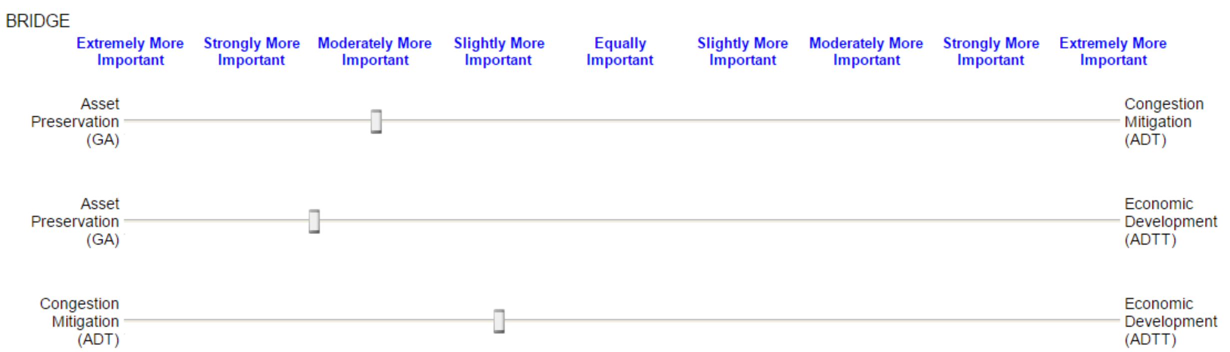


Figure D-75: Selection panel for project level prioritization

Suppose we want to prioritize the all the projects in the work plan for district 2.
The first step is the pairwise comparison of the pavement and bridge criteria separately. The sliders can be moved to enter the relative importance of criteria.



(a)

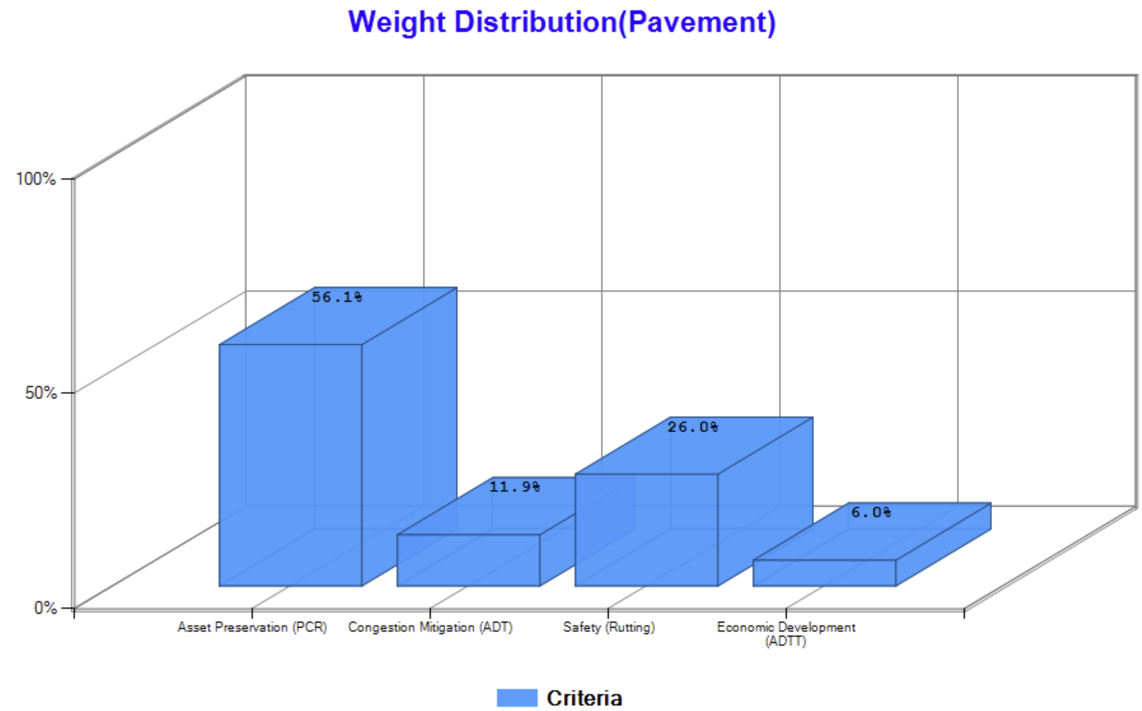


(b)

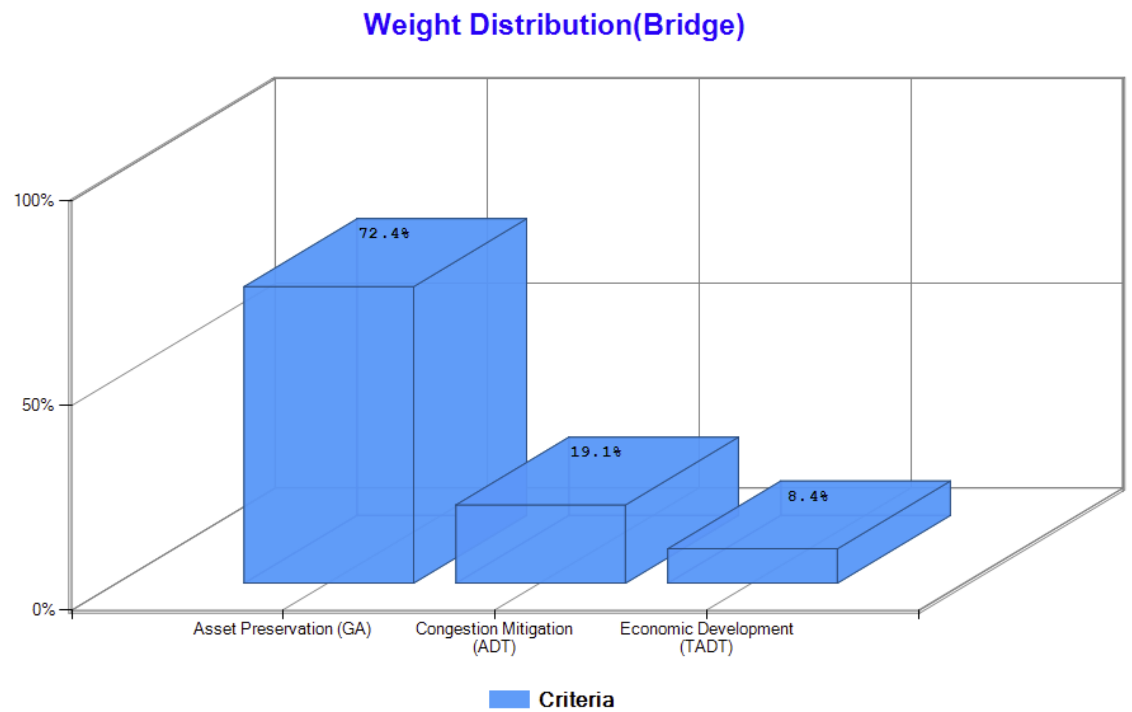
Figure D-76: Pairwise comparison of the asset criteria: (a) Pavement criteria (b) Bridge criteria

The “Show weight chart” button 

displays the weights of different criteria for pavement and bridges separately.



(a)



(b)

Figure D-77: Weight distribution from the pairwise comparison: (a) Pavement criteria weights (b) Bridge criteria weights

The “Next” button takes us to the next page showing the criteria range and weight for condition or level of criteria in project assets.

Criteria Range and Weight for Project Assets

PAVEMENT

Condition	Asset Preservation(PCR) (0-100)	Weight (0-1)	Condition	Safety (Rutting) (0-10)	Weight (0-1)
Very Good	> = 80	0.05	*Not-Acceptable*	> = 5	0.8
Fair	66 - 79	0.20			
Poor	0 - 65	0.75	*Acceptable*	0 - 4.9	0.2

BRIDGE

Condition	Asset Preservation(GA) (0-9)	Weight (0-1)
Very Good	> = 7	0.05
Fair	5 - 6.9	0.20
Poor	0 - 4.9	0.75

TRAFFIC DATA (For both pavement and bridge)

Level	AADT	Weight (0-1)	ADTT	Weight (0-1)
High	> 5000	0.75	> 750	0.75
Medium	1000 - 5000	0.20	75 - 750	0.20
Low	0 - 999	0.05	0 - 74	0.05

Change Weight

Figure D-78: Criteria range and weight for different project assets

The values in this page are default. The weights can be changed by clicking the “Change Weight” button in the bottom. This enables the weight text boxes and user can change the weight for different level or condition of the criteria. User have to make sure that the sum of weights is equal to one for every criteria.

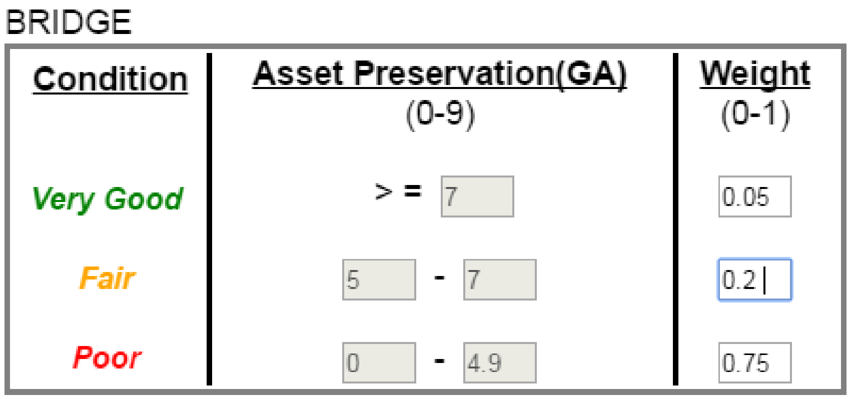


Figure D-79: Changing the condition weight of GA

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Prioritized project list for District: 2 ; Year : All Year

Rank	PID	Year	District	#Bridges	Lane_Miles	Avg_PCR	Avg_Rutting	Avg_GA	Avg_ADT	Avg_ADTT	Pavement Weight	Bridge Weight	Project Weight
1	93918	2016	2	0	6.84	46	5.6	0	12796	802	0.763	0	0.763
2	92127	2016	2	1	19.2	60.3	5.23	7	9614	1359	0.763	0.242	0.763
3	97011	2019	2	0	2.42	61	6	0	12843	903	0.763	0	0.763
4	85266	2018	2	1	0	0	0	4	30990	2060	0	0.749	0.749
5	101327	2020	2	1	0	0	0	4	27911	1879	0	0.749	0.749
6	92095	2015	2	1	0	0	0	4	17807	2347	0	0.749	0.749
7	92331	2016	2	1	0	0	0	4	14930	1011	0	0.749	0.749
8	101556	2019	2	1	0	0	0	4	14930	1011	0	0.749	0.749
9	79901	2021	2	1	0	0	0	4	14350	970	0	0.749	0.749
10	79991	2016	2	3	0	0	0	4.3	47873	4067	0	0.749	0.749
11	85269	2016	2	1	23.62	58.4	6.53	7	6299	561	0.73	0.196	0.73
12	92361	2020	2	0	6.04	65	5.6	0	6010	720	0.73	0	0.73
13	97012	2018	2	2	5.54	63	3.9	4.5	6170	380	0.574	0.703	0.703
14	95792	2021	2	0	20.74	58.6	6.09	0	3288	661	0.665	0	0.665
15	95793	2017	2	1	19.01	60	6.09	6	3497	415	0.665	0.2	0.665
16	101281	2018	2	1	13.78	62	5.49	5	1927	215	0.665	0.2	0.665
17	88513	2015	2	0	5.12	64	5.6	0	3430	560	0.665	0	0.665
18	92128	2019	2	0	12.16	65	6	0	1410	167	0.665	0	0.665
19	84079	2017	2	1	7.58	40	6	5	420	30	0.638	0.159	0.638
20	99869	2018	2	0	1.68	51	4.2	0	25233	1705	0.607	0	0.607
21	95676	2017	2	0	2.33	55.3	1	0	17954	1213	0.607	0	0.607
22	96344	2015	2	0	5.01	56.6	4.72	0	26119	1738	0.607	0	0.607
23	85271	2016	2	1	10.08	64	2.4	7	6440	1360	0.607	0.242	0.607
24	99991	2020	2	1	0	0	0	4	4730	123	0	0.598	0.598
25	101340	2022	2	1	0	0	0	4	3060	240	0	0.598	0.598

Figure D-80: Prioritized project list with top 25 projects in District 2

The resulting table can be exported in the excel format by clicking the export to excel button. Hyperlink: Clicking on the hyperlink for PID gives the details of the project. Suppose, clicking the PID "92127" in the second row displays the following result.

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Year	PID	District	Estimate	NLFID	Blog	Elog	MAX Pvmnt Trt Cat	Pvmnt Trt Type	SFN	MAX Bdge Trt Cat	System	Priority
2016	92127	2	$3,860,000.00	SLUCUS00020**C	0	8	Minor Rehabilitation	60 - AC Overlay with Repairs			US	G
2016	92127	2	$3,860,000.00	SLUCUS00020**C	6				4800559	Preventive Maintenance	US	G

Figure D-81: Details of the selected project