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# CENTER FOR TRANSPORTATION INFRASTRUCTURE AND SAFETY



## **MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**

by

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**A National University Transportation Center  
at Missouri University of Science and Technology**

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**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**SUMMARY REPORT**

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National University Transportation Center  
at the Missouri University of Science & Technology

by

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The opinions, findings, and conclusions expressed in this report are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## EXECUTIVE SUMMARY

The following report documents a research project on pavement preservation performed by the Missouri University of Science and Technology (Missouri S&T) and the University of Missouri-Columbia (UMC) on behalf of the Missouri Department of Transportation (MoDOT). The report consists of a Summary Report followed by six detailed technical reports. To achieve the goal of reducing maintenance costs and improving minor road ratings, MoDOT has embarked upon a plan of formalizing its maintenance/preservation planning. To assist in developing the plan, MoDOT contracted with the Missouri S&T and UMC to conduct a research project, entitled "MoDOT Pavement Preservation Research Program". The product of this research would become a part of MoDOT's overall Pavement Management System. The overall objective of the research was to provide a *process* that would allow MoDOT to do more selective planning, better engineering and more effective maintenance to minimize costs while maintaining adequate safety and performance of Missouri's pavements. Six Guidance Documents were to ultimately be created which would act as guidelines for MoDOT's Pavement Specialists and Engineers. The work was divided into six Tasks, each with its own research team.

The objective of Task 1 was to develop data for use in MoDOT's pavement preservation program based primarily on historical information available throughout MoDOT. The purpose of Task 1 was to develop a framework for data collection and management that uses a *methodology* that can subsequently be implemented by MoDOT in the future across the state as it fully develops its pavement management system. Data integration from divisions within MoDOT (Planning, Construction and Materials, and Maintenance) will be necessary for a complete system. A pilot database was developed to exemplify the methodology and for initial use by investigators in Tasks 2 through 6 and MoDOT. Numerous databases maintained by MoDOT residing in the above three divisions were located, collected, supplemented, verified, and summarized. Recommendations for improvements to present data collection procedures and repositories were developed.

In regard to Task 2, pavement performance models describe the deterioration behavior of pavements. They are essential in a pavement management system if the goal is to make more objective, reliable, and cost-effective decisions regarding the timing and nature of pavement maintenance activities. The general objective of Task 2 was to develop performance models for a variety of pavement families and pavement preservation treatments used by MoDOT. Linear least-squares and non-linear iterative regression techniques have been used to evaluate models that predict the International Roughness Index (IRI), the pavement condition measure most widely used today. Modeling was also investigated for the 20-point Condition Index (CI). Although the CI has been recently replaced by the 10-point PASER rating system, a significant amount of CI data exists, simultaneous modeling efforts were minimal, and MoDOT may desire future development of correlations between the CI and PASER. And, there is insufficient PASER data for modeling purposes. Predictor variables shown to be significant in predicting IRI and CI are pavement surface age and commercial traffic volume. The investigation

into climate, subgrade soil type, and pavement thickness as additional predictor variables is still underway.

The overarching goal of the MoDOT Pavement Preservation Research Program, Task 3: *Pavement Evaluation Tools – Data Collection Methods*, was to identify and evaluate methods to rapidly obtain network-level and project-level information relevant to in situ pavement condition to enable pavement maintenance decisions. The focus of these efforts was to explore existing and new technologies that can be used to collect data and develop the knowledge, procedures, and techniques that will allow MoDOT to perform pavement evaluation. Application of these technologies will ultimately enable pavement maintenance decisions that minimize cost and maintain/improve pavement quality. At the time of this report, a summary of the investigated methods is being compiled, and a comparative analysis is nearing completion. This report presents a summary of methods previously used by MoDOT to evaluate pavement condition, a summary of methods investigated to evaluate pavement and subsurface conditions, and a summary of the completed and ongoing work to date. Final results will be published at a later date.

The overall objective of the MoDOT Pavement Preservation Research Program, Task 4: *Site Specific Pavement Condition Assessment*, was to thoroughly assess the cost-effectiveness and utility of selected non-invasive technologies as applicable to MoDOT roadways. The intent was to develop a guidance document focused on the utility and cost-effectiveness of project-applicable and network-applicable non-invasive imaging technologies. The optimal utilization of appropriate non-invasive imaging technologies will result in more accurate pavement assessments at significantly reduced costs. Assessment of the utility and cost-effectiveness of the tested network-applicable non-invasive imaging tools was based, in large part, on the analyses of data acquired along two designated roadways. Assessment of the utility and cost-effectiveness of the tested project-applicable non-invasive imaging tools was based, in large part, on the analyses of data acquired along eight designated roadways. At the time of this report, all data have been collected from the network-level and project-level sites and processed, and data interpretation and analysis is nearing completion. This report presents an overview of the project-level and network-level sites investigated, and a summary of the completed and ongoing work to date. Final results will be published at a later date.

The general objective of Task 5 was to provide a manual that the Missouri Department of Transportation (MoDOT) can use to select the most appropriate pavement treatment for a given roadway project. The selection procedure will include a benefit/cost assessment method. Salient to any pavement management system is the process of determining potential treatment options, and the subsequent selection of the final treatment choice. Task 5 thus entails the development of pavement treatment trigger tables/decision trees and the treatment candidate selection process. Armed with the treatment tables and the selection process, MoDOT will be able to select appropriate treatments by use of treatment matrices showing the most appropriate applications for given specific site conditions and then be able to perform a benefit/cost analysis and/or economic lifecycle cost analysis for each candidate treatment. The idea in using the decision table/tree is to decide which optional treatments will be required to

move the System Rating of a given road from “Poor” into “Good”, or in an extreme case, from “Poor-Unsafe” to “Poor-Safe”. The selection of the optimum treatment from the possible ones would be done in a network prioritization activity (not part of this research project). This research project is currently underway, and the efforts to develop the treatment trigger tables are still in-progress. The input to the trigger tables could entail such factors as an overall condition indicator, smoothness, individual distress types-extent-severity (eg. surface defects, surface deformation, cracking, patches and potholes, wear, polishing, map cracking, D-cracking, pop-outs, scaling, spalling, shallow reinforcing, corner cracks, faulting), subgrade/base drainage, pavement type, history of treatment (including construction and material quality), and some measure of traffic, either actual ADT’s or as a functional classification (e.g. interstate), and driving speed. Table output would be one or more feasible potential appropriate treatments, which would consider pavement condition, traffic, climate (which affects construction timing and treatment performance), work zone duration (e.g. traffic control issues), time of year construction, construction quality risk, availability of quality contractors and quality materials, longevity of treatment, and availability of funding. Trigger tables/trees could include preservation treatments (chip seals, microsurfacing, slurry seals, ultrathin bonded asphalt wearing surface (UBAWS), crack sealing, crack filling, thin overlays, mill and fill, profile milling, hot in-place recycling, diamond grinding) and rehabilitation (structural hot mix asphalt (HMA) overlays, bonded and unbonded concrete overlays, rubblizing/ break and seat, cold in-place recycling, full depth reclamation, load transfer retrofit and joint repair, partial/ full depth repair).

The objective of Task 6 was to develop the concept and framework for a procedure to routinely re-calibrate and update the Trigger Tables and Treatment Performance Models. The scope of work for Task 6 includes a limited review of the recent pavement management systems literature for key elements for inclusion, strategies and procedures used to ‘update’ pavement performance (deterioration) models, and triggers for initiating a treatment evaluation. Because this is a relatively new process, the task will entail contacting and surveying several state DOT’s that already have an updating process in place. The task will include interaction with MoDOT personnel in order to be sure that the proposed framework for the re-calibration procedure can incorporate what MoDOT already does to update triggers and performance models and is compatible with current practices in MoDOT. As the framework for the re-calibration process is developed, the draft framework will be prepared and shared with MoDOT for discussion and comments. A final document describing the framework will be submitted for the deliverable from Task 6. To reap full benefit from the overall pavement maintenance program, it will then be incumbent upon MoDOT personnel to adapt and implement the re-calibration framework in order to realize the full potential of the modified pavement management process.

## **AUTHOR ACKNOWLEDGEMENTS**

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# 1 INTRODUCTION

## 1.1 REPORT ORGANIZATION

The following report documents a research project on pavement preservation performed by the Missouri University of Science and Technology (Missouri S&T) and the University of Missouri-Columbia (UMC) on behalf of the Missouri Department of Transportation (MoDOT). The report consists of a Summary Report followed by six detailed technical reports. Section 1 of the Summary Report presents the report organization and background for the study. The project work plan is presented in Section 2 and includes the overall objectives, scope, and project tasks of the research study. Following the project work plan, the summary findings, conclusions, and recommendations are presented task by task in Section 3. Detailed Technical Reports A through F are attached following the Summary Report, which provides the detailed specifics of each Task undertaken in this research investigation. The Summary Report provides the project highlights in terms of findings, conclusions, and recommendations, while Technical Reports A through F provide the background, detailed approaches, experimental procedures and processes, results, findings, conclusions, and recommendations.

## 1.2 BACKGROUND

### 1.2.1 Project Background

MoDOT has a goal of achieving two critical and timely operational needs:

- Reduced system-wide pavement maintenance costs;
- Maintaining the service rating of major roads ( $\geq 85\%$  good rating) and improving the rating for minor roads.

To achieve the goal of reducing maintenance costs and improving minor road ratings, MoDOT embarked upon a plan of formalizing its maintenance/preservation planning. To assist in developing the plan, MoDOT contracted with the Missouri S&T and UMC to conduct a research project, entitled “MoDOT Pavement Preservation Research Program”. The product of this research would become a part of MoDOT’s overall Pavement Management System.

### 1.2.2 Pavement Management Systems

A Pavement Management System (PMS) has been defined as “a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in serviceable conditions over a period of time”. A portion of PMS is the “identification of pavement maintenance, preservation, and rehabilitation recommendations that optimize the use of available funding” (AASHTO 2011). Fig. 1.1 shows the concept of the change in a given pavement’s condition over time, and the optimum time for various interventions.

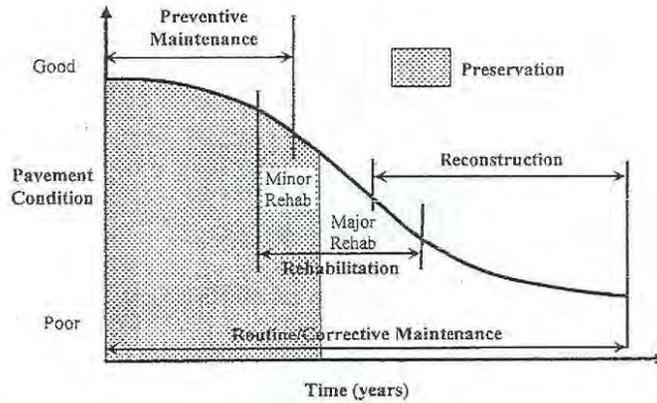


Figure 6-1. Relationship between pavement condition and different categories of pavement treatment (adapted from Peshkin et al. 2007).

Fig. 1.1 – Conceptual plot of pavement condition vs. time (AASHTO 2011).

Fig. 1.2 shows the concept of comparing different treatment strategies at different intervention times with the subsequent consequences. The curves represent models; the initial or original curve would be termed a “Family Model” and each of the other curves would be “Treatment Impact Models”.

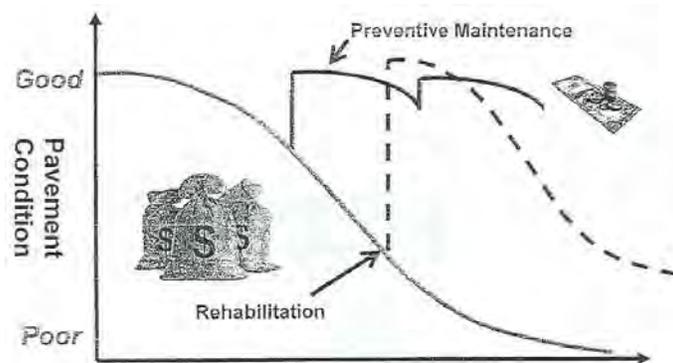


Figure 6-2. Pavement condition as a function of time.

Fig. 1.2 – Conceptual plot of pavement condition vs. time with different interventions (AASHTO 2011).

The thrust of this research was concentrated on preventive maintenance and preservation as shown in Fig. 1.1.



In general, the pavement treatment selection process within a Pavement Management System (PMS) entails the following steps. This information was taken from the updated AASHTO Guide to Pavement Management (AASHTO 2011) that MoDOT strongly recommended to the project team. Based on the AASHTO Guide, the following is the nine-step procedure that a MoDOT Pavement Specialist would use for implementing the *modified pavement management flowchart* (Fig. 2.1). The procedure would be followed for a given proposed road maintenance/preservation/rehabilitation project. The word “retrieve” is used to emphasize that the data, models, and tables to be used would already exist:

- Step 1-Retrieve annual road condition survey (eg. ARAN) data
- Step 2- Retrieve site historical data: eg. materials, thicknesses, subgrade soil, drainage, weather, construction records
- Step 3- Retrieve traffic counts: Average Daily Traffic (ADT) and percentage trucks, or Average Daily Truck Traffic (ADTT)
- Step 4- Conduct a site-specific condition survey (visual, coring, non-destructive testing)
- Step 5- Combine information from steps 1 through 4 into a “Site Status”. Identify the roadway as a certain “Pavement Family” type (see Table 2.1)
- Step 6- With “Site Status”, enter appropriate “Treatment Trigger Table” and select several alternate treatments (Table 2.2) appropriate for the assigned Family
- Step 7- With the appropriate “Treatment Impact (Performance) Models,” conduct a benefit/cost or marginal cost effectiveness analysis for each potential treatment (Fig. 2.2).
- Step 8- Using the calculated cost effectiveness of all treatments and all projects, conduct a network-level (county, region or state-wide) project prioritization list. Project prioritization could be based on other considerations in addition to benefit/cost.
- Step 9- Recalibrate or update Trigger Tables, Family Models, and Treatment Impact (Performance) Models as additional performance monitoring data become available, technologies in assessment or pavement materials change, agency policies change (this is an on-going step resulting in a sustainable process that leads to the best evidence-based decisions, even as the “evidence” (available data and information) changes over time)



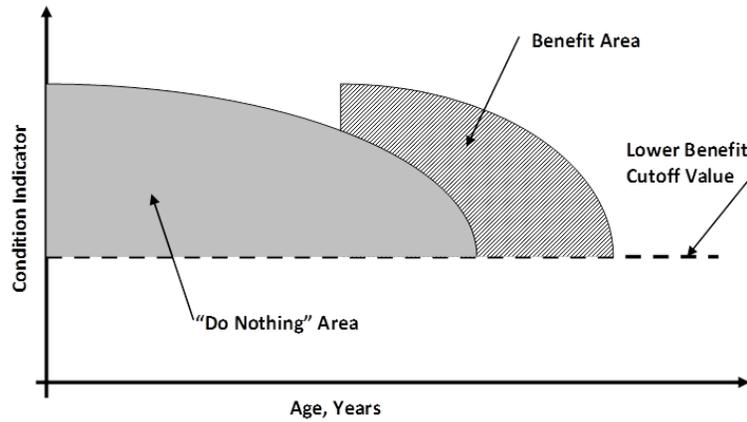


Fig. 2.2 – Illustration of benefit calculation using increased pavement performance (after AASHTO 2011). The cross-hatched area represents the benefit achieved by applying a specific treatment to a pavement.

**Table 2.1 – Potential definitions of pavement families in Missouri, i.e., types of pavements (two for flexible, one for composite, and six for rigid pavements).**

Flexible:
▪ < 7 in. Full-depth asphalt <sup>1</sup>
▪ ≥7 in. Full-depth asphalt <sup>1</sup>
Composite:
• Asphalt over concrete
Concrete:
▪ JPCP, 15 ft joint spacing
▪ JRCP, 61.5 ft joint spacing
▪ CRCP
▪ Bonded concrete overlay over concrete
▪ Unbonded concrete overlay over concrete
▪ Concrete over asphalt (whitetopping)

<sup>1</sup> may include nominal unbound granular base

<sup>2</sup>As Tasks 1 and 2 of the proposed program are completed, it is possible the number of Pavement Families could be more or less than the example shown here

**Table 2.2 – Example of pavement treatment types used in Missouri (not limited to MoDOT)**

<b>Pavement Treatment Types</b>
▪ Crack/joint sealing/filling
▪ Chip sealing, fog sealing, scrub sealing
▪ Micro-surfacing, onyx slurry sealing
▪ Thin HMA overlays: 1 ¾, 1 ¼ or 1-in.
▪ Unbonded Asphalt Wearing Surface (UBAWS)
▪ Structural overlays: 3 ¾, 3 ¼ or 2 ¾-in. thickness
▪ Mill & fill, mill & overlay (see above overlays)
▪ Asphalt Cold In-Place Recycling (CIR)
▪ Asphalt Hot In-place Recycling (HIR)
▪ Full Depth Reclamation (FDR)
▪ Diamond grinding
▪ Load transfer retrofit & joint repair
▪ Partial/ full depth repair

### **1.4.2 Project Tasks**

For this research project, six tasks were identified that are necessary to develop the pavement management process for MoDOT through collaborations with MoDOT personnel. The following pavement preservation program tasks, as shown in Fig. 2.2, provide the necessary efforts of each step in the pavement preservation process. The tasks are mapped to the chapters in the AASHTO 2011 “Guide to Pavement Management”.

1. Task 1: Historical Data Mining and Production of Data
2. Task 2: Family and Treatment Impact Models
3. Task 3: Pavement Evaluation Tools-Data Collection Methods
4. Task 4: Site Specific Condition Assessment
5. Task 5: Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process
6. Task 6: Re-Calibration of Triggers and Performance Models

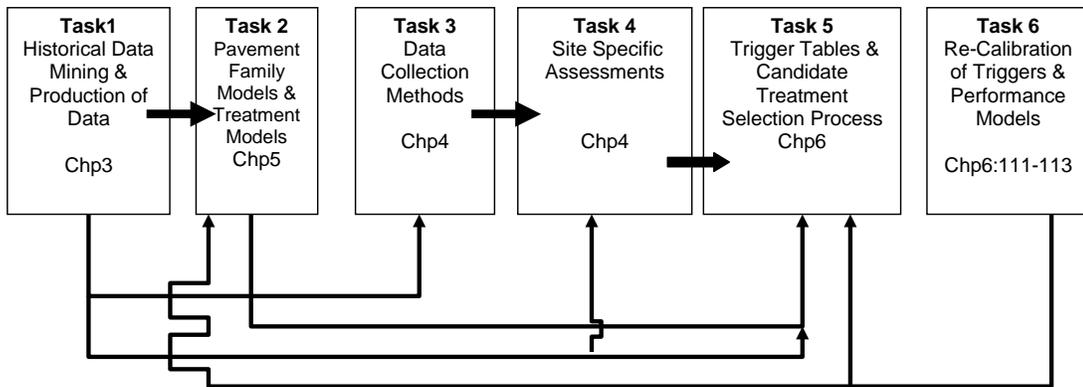


Fig. 2.3 – Tasks in the Pavement Preservation Program and their interactions. Chapter references refer to the pertinent section of AASHTO (2011).

During the pavement preservation research program, members of the research team interacted with small MoDOT resource teams to explore the types of data sources that were available. As it turned out, certain kinds of data did not exist or were too difficult for MoDOT to retrieve and supply to the research team; when this necessitated a different approach, the scope of the project would necessarily shift. The following are examples of decisions that were only possible after the contract began and there was interaction that occurred between Missouri S&T/UMC and MoDOT personnel: finalizing the types of pavement families, finalizing types and levels of detail in the trigger tables, types of performance models that were feasible, method of creating and populating the performance models, condition indices that needed to be tracked, kinds of data that needed to be collected by MoDOT in the future, and methods of inventorying data (considering any constraints imposed by MoDOT capabilities).

In the following sections are discussions of each of the individual tasks.

## 2.4 Task 1: Historical Data Mining and Production of Data

Task 1 involved development of methods of historical data mining and production of data necessary for the research project including information on subgrade, traffic, climate, existing pavement structure conditions, and data on the historical performance of all pavement types under all condition types. Secondly, the Task 1 effort was to develop a Guidance Document on the practice of reduction and analysis of historical pavement performance data (Step 2 Fig. 2.1), which should be made available for inclusion in MoDOT’s System Programming Software. The purpose of Task 1 was to develop a data collection *methodology* that can subsequently be used by MoDOT pavement treatment planners in the future across the state as MoDOT fully develops its pavement management system. In the *pavement preservation research* program, enough real data will be mined to validate the viability of the methodology. This may require securing data from other state departments of transportation (state DOTs) to augment what is available from MoDOT. Deliverables are: 1) data retrieval methodology “Guidance Document”, and 2) sufficient data to develop the models and trigger tables required in Tasks 2 and 5. The sub-tasks are listed below:

1. Sub-task 1A - Conduct literature review
2. Sub-task 1B - Identify and access MoDOT data sources
3. Sub-task 1C - Retrieve pavement data for use by the upcoming tasks in this research project
4. Sub-task 1D - Develop a methodology for data management
5. Sub-task 1E - Prepare Guidance Document

## **2.5 Task 2: Family and Treatment Impact Models**

Task 2 involved the examination of all pavement types identified in the MoDOT system and the grouping of each into a *Pavement Family Model*. Then, a selection of up to two to five prominent pavement treatment types per family model (say, a total of  $9 \times 5 = 45$  treatments/family combinations) and the development of *Treatment Impact Performance Models* (Fig. 2.1) using data produced from Task 1 was to be done. These pavement deterioration models based on Missouri practices, geological conditions, meteorological conditions and historical performance evidence were to be incorporated into Task 5 and used in Step 7 Fig. 2.1. Task 2 will document what other state DOTs have already done and will adapt and adopt the treatment impact performance models as appropriate (Chapter 5 AASHTO 2011). It is recognized that not every treatment method used by MoDOT had sufficient data to a create treatment model. Missing treatments will have to be added as MoDOT accumulates data in the future. Deliverables are: 1) *Pavement Family Models*, and 2) *Several Treatment Impact (Performance) Models* per Family Model. The sub-tasks are listed below:

1. Sub-task 2A- Conduct literature review
2. Sub-task 2B – Gain an understanding of MoDOT’s experience with performance modeling and its expectations for any newly developed models, create the pavement families, and compile the database into a usable format for model-building
3. Sub-task 2C - Conduct development of pavement performance models and treatment impact models

## **2.6 Task 3: Pavement Evaluation Tools-Data Collection Methods**

Concurrent with other tasks, Task 3 explored the production of currently used and newer kinds of data to be collected either by ARAN during the annual condition survey or by separately-deployed systems, including FWD, RDD, GPR, and others, and guidance to rapidly obtain broad-area information for use in Step 1 (Fig. 2.1), and collected detailed design parameters and site conditions (in situ section details, soil moisture, and soil/pavement stiffness, among others) for pavements designated for maintenance for use in Task 4 (Fig. 2) and Steps 4, 5 and 6 (Fig. 2.1) (Chapter 4 AASHTO 2011). Deliverables are comparative summaries of State-of-the-Art methods to collect pavement data (focus on non-invasive methods). The sub-tasks are listed below:

1. Sub-task 3A: Evaluate methods used by MoDOT

2. Sub-task 3B: Evaluate methods used in the pavement industry
3. Sub-task 3C: Evaluate methods being developed from research
4. Sub-task 3D: Develop comparative benefit-cost analysis
5. Sub-task 3E: Select, procure, and test of methods to evaluate in Task 4

## **2.7 Task 4: Site Specific Condition Assessment**

Task 4 involved development of a manual for site specific condition assessments. The deliverable is a Guidance Document including a matrix on what site assessment technologies are applicable, how to employ them and what site condition data can be obtained for use in Steps 1 and 4 (Fig. 2.1). The Guidance Document was to detail the types of information desired and the methods (existing or new) to obtain the information. The types of information to be included were: traffic, subgrade characteristics such as soil classification, granular base (thickness, quality), drainage, pavement structure, and climate. The level of detail will be specified as a function of the importance of the specific roadway (Chapter 4 AASHTO 2011). The sub-tasks are listed below.

1. Sub-task 4A: Select sites
2. Sub-task 4B: Schedule and acquire data
3. Sub-task 4C: Process data
4. Sub-task 4D: Interpret and analyze data
5. Sub-task 4E: Prepare Guidance Document

## **2.8 Task 5: Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process**

Task 5 involved the creation of Treatment Trigger Tables and a Treatment Candidate Selection Process. A procedure was to be furnished to select appropriate treatments (design) including a treatment matrix showing the most appropriate applications for given specific site conditions (Step 6 Fig. 2.1) and to perform a Benefit/Cost Analysis and/or Economic Lifecycle Cost Analysis (Step 7 Fig. 2.1) for each candidate treatment to ultimately recommend a specific treatment. (Chapter 6 and Chapter 7 AASHTO 2011). The idea in using the table is to decide what optional treatments it will take to move the System Rating from Poor into Good, or in an extreme case, from Poor-Unsafe to Poor-Safe. Deliverables are: 1) *Trigger tables*, and 2) benefit/cost methodology (roadway project specific). The sub-tasks are listed below.

1. Sub-task 5A: Procure laboratory equipment and MEPDG software
2. Sub-task 5B: Conduct literature search
3. Sub-task 5C: Engage in discussions with MoDOT to obtain information about pavement types, treatment types, selection criteria, mixes, and past history
4. Sub-task 5D: Conduct treatment option analysis using MEPDG and/or other software
5. Sub-task 5E: Conduct mixture testing and analysis

6. Sub-task 5F: Create a draft manual of treatment trigger tables and benefit/cost procedures
7. Sub-task 5G: Review the draft Task 5 manual and a final version is completed
8. Sub-task 5H: Provide training of MoDOT personnel in use of the product (trigger tables and benefit/cost calculations)

## **2.9 Task 6: Re-Calibration of Triggers and Performance Models**

Task 6 involved the development of the framework that will guide MoDOT in creation of a procedure to re-calibrate the Trigger Tables and Treatment Performance Models and update the treatment selection process and the project prioritization process (Step 9 Fig. 2.1). The deliverables is the document describing the framework to develop the process to update (re-calibrate) the Trigger Tables and the Treatment Impact Models. The sub-tasks are listed below.

1. Sub-task 6A: Search, compile and synthesize recent literature
2. Sub-task 6B: Gather, compile, and synthesize information from State DOTs
3. Sub-task 6C: MoDOT existing elements and processes
4. Sub-task 6D: Prepare draft concept and framework document
5. Sub-task 6E: Discuss and comment on draft framework document
6. Sub-task 6F: Prepare final framework document

### 3 TASK SUMMARIES: FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

#### 3.1 Task 1: Historical Data Mining and Production of Data

- **Sub-task 1A: *Conduct literature review:*** The team has reviewed reports from 15 state DOTs including Mississippi, Louisiana, Virginia, Colorado, and South Dakota. The literature review focused on data collection and organization as related to the different pavement families and family-treatments. A number of references and data products have been organized at a common access Internet site called “www.ibackup.com”, which all investigators have access for data sharing. Subtask 1A is 100% complete.
- **Sub-task 1B: *Identify and access MoDOT data sources:*** Raw or “unit” International Roughness Index (IRI) data has been determined to be the only practical response variable **currently** in use by MoDOT that is available to the researchers for use in developing pavement performance and treatment impact models for prediction purposes. Work is still underway to also use pre-2010 condition index data as a response variable in developing performance and treatment impact models. In addition to raw ARAN data, the research team has successfully gathered data from MoDOT’s TMS (ARAN viewer, STIP, etc.), SS Pavement History data using ArcGIS software, TR50 traffic reports, project history maps (ragmaps), archived plan sheets folder, Central district pavement plan Excel files, and concrete summary (2-AA) and asphalt summary sheets. As a result of an on-site visit with Brad Brown (Southwest District Pavement Specialist), a greater understanding of the pavement selection process and program planning at the District level was achieved for the various levels of traffic. This included the interplay of route ADT, treatment type, material type, projected treatment life, and available budget. The Task 1 team also learned about the part of the maintenance program that is uploaded to the Pavement Tool by the District. The team can now access this part of the Pavement Tool through the MoDOT Sharepoint system. It appears that no additional historical maintenance data beyond what is contained in the detailed District spreadsheets is available through the Pavement Tool that would be useful for model development. However, the Pavement Tool is under investigation as to its utility in understanding decision-making strategies for pavement maintenance. Information similar to that of the Southeast District is being pursued at the Central District. Subtask 1B is 99% complete.
- **Sub-task 1C: *Retrieve pavement data for use by the upcoming tasks in this research project:*** The Task 1 team has finished collecting all data currently available from the Pavement Tool for all families (full depth asphalt, full-depth concrete, composite). The Task 1 effort is closely coordinated with Task 2, where pavement performance (deterioration) and treatment impact models are being developed for predictive purposes. Data retrieval and query procedures have been described in previous quarterly reports to MODOT. Those procedures were applied to finish data collection from the aforementioned databases for all pavement families. Since the last report, additional MoDOT maintenance personnel have been recruited to check for any in-

house or contract maintenance/treatment data missed by the research team. The data retrieved by the Task 1 team will be distributed to the appropriate maintenance superintendents via the district assistant maintenance engineer (e.g. Jason Shafer in the Central District). This should, theoretically, increase the accuracy of the effort as those more closely associated with the selected pavement sections will be evaluating the currently-collected maintenance data. Subtask 1C is 95% complete.

- **Sub-task 1D:** *Develop a methodology for data management:* The Task 1 document summarizes various MoDOT data sources and explains the procedures for gleaning useful modeling information from those sources. The report therefore draws on the experiences of Sub-tasks 1A through 1C. The report also summarizes the data collected and addresses the remaining data collection needs for an improved pavement management system. By documenting data sources, data collection procedures, and data collection needs, the report should be a useful tool for future development and improvement of MoDOT's Pavement Management System. Subtask 1D is 95% complete.
- **Sub-task 1E:** *Prepare Guidance Document:* The data management document from Subtask 1D will also serve as the guidance document. Subtask 1E is 80% complete.

## 3.2 Task 2: Family and Treatment Impact Models

### 3.2.1 Work Completed

- **Sub-task 2A:** *Conduct literature search:* Numerous publications have been identified and procured in regard to other state DOT's trigger table methodology. Sub-task 2A is 75% complete.
- **Sub-task 2B:** *Engage in significant discussions with MoDOT to obtain information needed to understand MoDOT's experience with performance modeling and their expectations for any newly developed models, create the pavement families, and compile the database into a usable format for model-building:* Team members have met with and/or corresponded with MoDOT personnel at both the District and Central levels across three divisions in regard to pavement maintenance strategies/policies affecting potential pavement performance (deterioration) models and treatment impact models. Sub-task 2B is 95% complete.
- **Sub-task 2C:** *Conduct development of pavement performance models and treatment impact models:* As data from Task 1 became available, numerous models were attempted, including performance models (IRI and Condition Number) for both pavement families and individual routes. Models included three families (Full-Depth Asphalt, Composite, and Concrete) along with family model main effects (independent or predictor variables): Surface Age, Commercial Traffic Volume, Pavement Thickness (total thickness or verifiable, cumulative treatment thickness, depending on the pavement family), and Climate Parameters (precipitation and temperature). Treatment



impact models will be generated using the same pool of potential main effects, but regressions will be applied to subsets of the family model data in which each subset corresponds to a particular treatment; e.g. 1 inch overlays on a full-depth asphalt pavement, thick overlays on a composite pavement, or diamond grinding on a concrete pavement. The Task 2 research team has continued to investigate climate as another potential main effect in predicting pavement performance, specifically in relation to asphalt pavement preservation. A recent report indicates that two climate parameters correlate to the effectiveness of pavement preservation techniques better than other climate parameters: the number of days per year below freezing and the number of wet days ( $\geq 0.1$  in. or 2.5 mm of precipitation) per year. A more extensive set of data from the National Climatic Data Center (NCDC) was obtained and used to create isolines for both weather parameters and to plot them onto the state map. Data from weather stations across Missouri and adjacent states that was fairly recent and as complete as possible (i.e. continuously collected over time) was averaged and associated with the appropriate station. This resulted in data from 87 weather stations being used to create the isolines. Sub-task 2C is 40 % complete.

### 3.2.2 Work Currently Underway

- Sub-tasks 2A and 2B are nearing completion. Upon completion of the maintenance data acquisition, the performance models (Sub-task 2C) can be then be completed.

## 3.3 Task 3: Pavement Evaluation Tools-Data Collection Methods

### 3.3.1 Work Completed

At the time of this report, Sub-tasks 3A, 3B, 3C, and 3E (Section 1.3) have been completed.

- **Sub-task 3A:** *Summarize methods routinely used by MoDOT to assess pavement condition:* All districts have been polled, and the information has been compiled (Table 2.2). Sub-task 3A is 100% complete.
- **Sub-task 3B:** *Summarize commercially-available methods to assess pavement condition:* Commercially-available methods have been investigated and summarized (Table 2.1). Sub-task 3B is 100% complete.
- **Sub-task 3C:** *Summarize methods currently being researched:* Methods currently being researched at the time of this report have been summarized and are undergoing final edits by the investigators. Sub-task 3C is 100% complete.
- **Sub-task 3E:** *Method selection for Task 4:* Methods have been selected to carry out the project-level and network-level investigations conducted in Task 4. Procurement and testing of air-launched GPR equipment (GSSI Roadscan 2 System – twin 2GHz Horn antennae) and GPS unit (Trimble GeoXH) was completed. Mounting of the GPR unit to the front of a vehicle was designed and fabricated, and the GPR unit was tested before acquiring the data in Task 4. The GPR unit mounted to a vehicle is shown in Fig. 3.1. Sub-task 3E is 100% complete

### 3.3.2 Work Currently Underway

At the time of this report, work is currently underway on Sub-task 3D (Section 1.3).

- **Sub-task 3D: *Comparative analysis of methods investigated:*** A comparative analysis of the methods investigated is nearing completion. Sub-task 4D is estimated to be 90% complete.

### 3.3.3 Final Report Content

The final report for this task will present comparative summaries of available technologies that can be used to collect data on pavement condition. The summary will be used to provide guidance to MoDOT on network level or project level data collection. Technologies will be summarized in terms of applicability to network-level or project-level data production, types of pavement condition data collected (distress, structural capacity, surface characteristics), data collection method (manual, automated, semi-automated), and other advantages, disadvantages and limitations. Descriptions of each technology will also be provided, in addition to current and previous usage by MoDOT and its contractors. Another summary table will be developed to describe and compare the planning and cost-related aspects of each technology such as crew size, cost per day, area per day, lane closure requirements, level of expertise in data acquisition/processing, etc.

## 3.4 Task 4: Site Specific Condition Assessment

### 3.4.1 Work Completed

At the time of this report, Sub-tasks 4A, 4B, and 4C (Section 1.3) have been completed.

- **Sub-task 4A: *Site Selection:*** All eight project-level sites and both network-level sites have been identified. The project-level sites and network-level sites are presented in Section 2.2 and Section 2.3, respectively. Sub-task 4A is 100% complete.
- **Sub-task 4B: *Schedule and Acquisition:*** Acquisition of data at the project level and network sites has been completed. The project-level sites and network-level sites are presented in Section 2.2 and Section 2.3, respectively. Pavement core location selection and extraction has been completed. Sub-task 4B is 100% complete.
- **Sub-task 4C: *Processing:*** Processing of data at the project level and network sites has been completed. The project-level sites and network-level sites are presented in Section 2.2 and Section 2.3, respectively. Pavement core laboratory testing and logging has been completed. Sub-task 4C is 100% complete.

### 3.4.2 Work Currently Underway

At the time of this report, work is currently underway on Sub-tasks 4D and 4E (Section 1.3). The following discussion contains details of the work currently underway for each of the five sub-tasks.

- **Sub-task 4D: *Interpretation and Analysis*:** Interpretation and analysis of the data for all eight project-level sites and both network-level sites is nearing completion. Sub-task 4D is estimated to be 90% complete.
- **Sub-task 4E: *Guidance Document*:** Work on the guidance document has been initiated. This sub-task is ongoing. Sub-task 4E is estimated to be 10% complete.

### 3.4.3 Final Report Content

The final report for this task will present interpreted geophysical data acquired using each non-invasive imaging technology from each project-level and network-level site included in this project. The final report will also report information about pavement core control acquired at each project-level and network-level site. The effectiveness of each non-invasive imaging technology will be evaluated in terms of its ability to achieve the investigation survey objectives (Section 2.1). Finally, a guidance document (Section 3.2.1) will be developed in the Task 4, based on the findings from this work.

## 3.5 Task 5: Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process

### 3.5.1 Work Completed

- **Sub-task 5A: *Procure laboratory equipment and AASHTOware software*:** Purchase or design and fabrication of the following has been completed: Asphalt Mixture Performance Tester (AMPT), Asphalt Pavement Analyzer (APA) Hamburg and digital upgrade, four conditioning ovens with support shelves, gyratory compactor mold spacers, gyratory compactor mold modification, core drill permanently mounted, core holding jig, and core holding saw jig. The AMPT compressor was replaced by the vendor. Sub-task 5A is 100% complete.
- **Sub-task 5B: *Conduct literature search*:** The literature search has been initiated. Numerous publications have been identified, procured, and reviewed. Sub-task 5B is 50% complete.
- **Sub-task 5C: *Engage in discussions with MoDOT to obtain information about pavement types, treatment types, selection criteria, mixes, and past history*:** The Task 5 team has met with or has held telephone/email conversations with a number of MoDOT personnel from different divisions one-on-one in regard to choice of mix designs, pavement maintenance policies, lab equipment, and subgrade soils data. From these discussions, decisions were made in choosing mix types to study in sub-task 5E. Sub-task 5C is 90% complete.
- **Sub-task 5D: *Conduct treatment option analysis using AASHTOware and/or other software*:** The state's geologic areas/soil associations have been examined in a preliminary way leading to a first pass through the AASHTOware software for a variety of pavement scenarios, comparing different treatment designs. Also, MoDOT's AASHTOware local calibration constants have been applied to the software. It was noted that there are several bugs in the software and the software supplier has been notified. Three BP-1 mixes have been evaluated via the AASHTOware software. Preliminary

conclusions are that volumetrics seem to impact predicted performance the most, with the fatigue cracking prediction the most sensitive performance criteria. Sub-task 5D is 20% complete.

- **Sub-task 5E: *Conduct mixture testing and analysis:*** In regard to pavement treatment evaluation, longevity of various treatments must be predicted. The subject of sub-task 5E is to perform laboratory testing of HMA mix types to 1) provide input to the AASHTOware software for use in service life predictions (varying mix designs, thicknesses, base support, subgrade, climate, and traffic), and 2) compare AASHTOware predictions to results of performance testing such as APA rut depth, Hamburg Loaded Wheel rutting/stripping characteristics, and Tensile Strength Ratio (TSR). Planning for the mix selection has been completed. The general approach is to narrow the scope of HMA mix types to be evaluated to those that would be used for maintenance on minor routes. It was decided to eliminate Superpave and BP-3 mixes and concentrate on surface leveling (SL) and Bituminous Pavement (BP) mixes. Because SL and BP-2 mixes are virtually the same in many cases, the final experimental design called for BP-1 and SL mix types. Two levels of quality (Good and Marginal) per mix type are being evaluated to give a range of behavior in the AASHTOware and performance testing. “Good” means high quality aggregate, proper volumetrics, proper binder content, proper dust/effective binder ratio, minimal deleterious materials content, and so forth. “Marginal” relates to these attributes being barely approved in design and possibly even worse as-produced. All mix designs approved by MoDOT’s field office in 2011 of SL, BP-1, BP-2, and BB were examined as well as aggregate quality records. Two aggregate sources (formations/ledges) were chosen. The Marginal aggregate source and the Good aggregate source have both been identified and sampled. Design of three BP-1 mixes (Good, Marginal (In-Spec), Marginal In-Tolerance (Out-of-Spec)) has been completed and testing begun. The binder for all mixes was a PG64-22 (one supplier). The mixes were subjected to Hamburg Loaded Wheel and TSR testing. The results of the Hamburg testing for the Good, Marginal, and Marginal-out-of-specification mixes. The Texas DOT criteria for limestone mixes with a non-modified binder PG 64-22 (similar to MoDOT’s BP plant mixes) is equal to or less than 12.5 mm rutting at 5000 cycles. The Good mix met this requirement with about 5550 cycles at 12.5 mm rut depth. Very little stripping was observed by visual inspection. The TSR for the Good mix was 86, well over the MoDOT section 401 minimum requirement of 70. For the Marginal In-Spec mix, the Hamburg results showed about 3040 cycles at 12.5 mm, failing the Texas DOT threshold. The TSR was 28, badly failing MoDOT’s section 401 specification. The visual exam showed a loss of matrix and considerable broken aggregate. As expected, the Marginal Out-of-Specification mix fared worse than the In-Specification mix: the Hamburg results resulted in about 2440 cycles at 12.5 mm, failing the Texas DOT threshold. The TSR was 23, badly failing MoDOT’s section 401 specification. The visual exam showed a loss of matrix and considerable broken aggregate. Sub-task 5E is 12% complete.

### 3.5.2 Work Currently Underway

- **Sub-task 5B: *Conduct literature search:*** The literature search needs to be completed.

- **Sub-task 5C:** *Engage in discussions with MoDOT to obtain information about pavement types, treatment types, selection criteria, mixes, and past history:* Several more maintenance personnel need to be interviewed complete the information-gathering in regard to treatment selection, mix history, and pavement maintenance policies.
- **Sub-task 5D:** *Conduct treatment option analysis using AASHTOware and/or other software:* More analysis using AASHTOware needs completion for the rest of the mixes.
- **Sub-task 5E:** *Conduct mixture testing and analysis:* The remaining mixes need to be tested in the laboratory.
- **Sub-task 5F:** *Create a draft manual of treatment trigger table/decision trees and benefit/cost procedure:* Sub-task 5F is zero % complete.
- **Sub-task 5G:** *MoDOT reviews the draft Task 5 manual and a final version is completed:* Sub-task 5G is zero % complete.
- **Sub-task 5H:** *Provide training of MoDOT personnel in use of the product (trigger tables and benefit/cost calculations):* Sub-task 5H is zero % complete.

### 3.6 Task 6: Re-Calibration of Triggers and Performance Models

#### 3.6.1 Work Completed

- **Sub-task 6A:** *Search, Compilation and Synthesis of Recent Literature:* Literature review efforts have focused on examples from other states. In particular, the team has reviewed reports from Kansas, Iowa, Mississippi, Louisiana, Virginia, and Colorado. The literature review is focusing on pavement condition assessment, how the assessment is used in pavement modeling, and especially how the models are updated. Subtask 6A is 50% complete.
- **Sub-task 6B:** *Information Gathering, Compilation and Synthesis from State DOTs:* Work on the literature review of Subtask 6A has narrowed down the list of potential states for further study related to pavement model updating procedures. The Task 6 team has reached out to Michigan and Kansas DOTs to discuss their pavement model updating procedures. Both states sent reports that have been reviewed by the Task 6 team. The reports seem to indicate the models used for each state's respective pavement management system have been verified but not explicitly updated as new data are collected. In addition, the Task 6 team recently received a report addressing model updating from CALTRANS, and the Task 6 team has reached out for more information from Utah, Virginia, and Washington DOTs. Subtask 6B is 50% complete.
- **Sub-task 6C:** *MoDOT Existing Elements and Processes:* The Task 6 team has discussed with MoDOT the models used in the pavement tool that was developed for MoDOT. One main objective of the pavement tool is to plan future maintenance treatments. Consistent with this objective, the models are simply predictions of treatment lifespan. The team discussed with Jay the possibility of incorporating models from the Pavement Thrust (Tasks 2 and 5) into the pavement tool. In addition, the Task 6 team continues to

have conversations with team members from Task 1 and Task 2 to discuss MoDOT's pavement data sources (Task 1) and the modeling process (Task 2). Subtask 6C is 90% complete.

- **Sub-task 6D:** *Prepare Draft Concept and Framework Document:* The Task 6 team has developed a detailed outline for the draft document and is in the process of completing the first draft concurrent with work on Subtasks 6A through 6C. Subtask 6D is 25% complete.

### 3.6.2 Work Currently Underway

- **Sub-task 6A:** *Search, Compilation and Synthesis of Recent Literature:* The literature review is currently being completed.
- **Sub-task 6B:** *Information Gathering, Compilation and Synthesis from State DOTs:* The literature review is currently being completed.
- **Sub-task 6C:** *MoDOT Existing Elements and Processes:* The team is currently finishing discussions with MoDOT in regard to exploration of MoDOT's updating potential.
- **Sub-task 6D:** *Prepare Draft Concept and Framework Document:* The researchers are preparing the draft document.
- **Sub-task 6E:** *Discussion and Comment on Draft Framework Document:* Work on this subtask will begin after Subtask 6D is complete. Subtask 6E is zero% complete.
- **Sub-task 6F:** *Preparation of Final Framework Document:* Work on this subtask will begin after Subtask 6E is complete. Subtask 6F is zero% complete.

#### 4 RECOMMENDATIONS

The benefits of the *Pavement Preservation Research* program (cost savings with respect to pavement maintenance and improved level of pavement performance ratings) will be sustainable only if the Trigger Tables, Treatment Impact Models, and the treatment selection methodology are re-calibrated and updated periodically. Failure to do so will ultimately lead to pavement management (preservation/rehabilitation) decisions being based on inadequate, outdated or even incorrect information. The data and information on which the pavement management process as delivered by the Pavement Preservation program are not static. They will continue to evolve in such areas as: technology, policies, desired sustainability level of pavements, and other contributing factors. For the program to have the maximum and sustainable benefit, periodic updating is required and will result in continual increasing accuracy of both pavement condition forecasts and refinement of the decisions among most appropriate (performance-wise and cost-wise) treatments for pavements under given conditions.

The overall project is on-going. Final results will be published at a later date.

## **5 REFERENCES**

Zimmerman, K.A., Smadi, O., Peshkin, D.G. and Wolters, A.S., 2011, "Guide to Pavement Management: A Proposed Replacement to the 2001 AASHTO Pavement Management Guide-Draft," AASHTO, Washington, D.C., (draft June 30, 2011), 188 pp.



## **APPENDICES**

- A. Task 1: Historical Data Mining and Production of Data
- B. Task 2: Family and Treatment Impact Models
- C. Task 3: Pavement Evaluation Tools-Data Collection Methods
- D. Task 4: Site Specific Condition Assessment
- E. Task 5: Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process
- F. Task 6: Re-Calibration of Triggers and Performance Models





**APPENDIX A**  
**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**TASK 1 REPORT**  
**DATA COLLECTION FOR PAVEMENT MANAGEMENT:**  
**HISTORICAL DATA MINING AND PRODUCTION OF DATA**

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The opinions, findings, and conclusions expressed in this report are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## EXECUTIVE SUMMARY

The research reported in this document was performed by researchers from the Missouri University of Science and Technology and the University of Missouri-Columbia. The objective of Task 1 was to develop data for use in MoDOT's pavement preservation program based primarily on historical information available throughout MoDOT. The purpose of Task 1 was to develop a framework for data collection and management that uses a *methodology* that can subsequently be implemented by MoDOT in the future across the state as it fully develops its pavement management system. Data integration from divisions within MoDOT (Planning, Construction and Materials, and Maintenance) will be necessary for a complete system. A pilot database was developed to exemplify the methodology and for initial use by investigators in Tasks 2 through 6 and MoDOT. Numerous databases maintained by MoDOT residing in the above three divisions were located, collected, supplemented, verified, and summarized. Recommendations for improvements to present data collection procedures and repositories were developed.

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# 1 INTRODUCTION

Effective and efficient data collection is essential to pavement management. Task 1 of the MoDOT Pavement Preservation Research Program was therefore to establish data collection methodologies and produce useful data for the research program. This chapter describes the motivation for the work and outlines the work and the rest of this report. This report serves as both a summary of procedures and findings from Task 1 as well as a guidance document for future pavement management data collection efforts.

## 1.1 Goal

The principal goal of the MoDOT Pavement Preservation Research Program Task 1: *Data Collection for Pavement Management: Historical Data Collection and Production of Data* was to collect data for use in the pavement preservation program based on historical information available from MoDOT and other sources. The data collection efforts focused on present needs (for this project) and the need for long-term pavement data collection efforts.

## 1.2 Objectives

The primary objectives of this task were to:

- Identify data needs for development of a pavement management system
- Locate the required data sources within MoDOT's organization
- Locate the required data sources from other entities
- Collect a sufficient amount of pavement data to support efforts by other tasks within the Pavement Preservation Research program
- Summarize the data sources and collection efforts in a guidance document (this report)

## 1.3 Scope of Work

The following work was performed in this task:

- Types of data recommended for collection were identified from the AASHTO guide to pavement management (AASHTO 2012) and from other states' efforts.
- Required data for development of a pavement management system were located within MoDOT's organization.
- Pavement data were collected and summarized to provide input for other Pavement Preservation Research program tasks.
- Methods of data collection were summarized and recommendations for improvements to data collection procedures were developed.

## 1.4 Organization of the Report

Chapter 1 presents the goal, objectives, and scope of this task. Chapter 2 presents background information from national sources as well as from other states. Chapter 3 describes the MoDOT data sources consulted and methods of accessing each of them. Chapter 4 describes how the

data were collected for use by other Tasks in the Pavement Preservation Research program. Chapter 5 contains a summary, conclusions, and recommendations for improvements to the pavement management data collection methods.

## **2 BACKGROUND AND LITERATURE REVIEW**

Previous MoDOT work regarding pavement management, national guidance, and the practice of other states were consulted before developing the data collection methodology of Task 1. The emphasis of this literature review was to identify the types of data that should be collected and, to a lesser extent, to identify data collection techniques. Data collection techniques developed for other states, while helpful, were of limited use since the collection techniques developed for Task 1 were constrained by the availability and organization of MoDOT's data.

### **2.1 MoDOT Publications**

The MoDOT Pavement Maintenance Direction (MoDOT 2010) guide was the primary MoDOT document utilized at the very beginning of the project. It summarized policy changes due to the major reduction in the overall MoDOT budget, and introduced the 10-point Pavement Surface Evaluation and Rating (PASER) system of visually rating the condition of a pavement surface. Prior to 2010, MoDOT used a 20-point condition index that was a mathematical combination of ride and distress indices. This document, along with earlier MoDOT publications (Donahue 2002; Noble et al. 2003), informed the research team of the recent history of MoDOT's efforts to improve its transportation management system and maintenance/rehabilitation program.

Other MoDOT publications that were useful in providing background and current policy included the "Pavement Design and Type Selection Process" report (2004), the "Geology and Soils Manual" (1962), the final report of "Implementing the AASHTO Mechanistic-Empirical Pavement Design Guide in Missouri - Volumes I and II" (2009), the Missouri Standard Specifications for Highway Construction, the MoDOT Engineering Policy Guide, and the MoDOT Pavement Design Manual.

### **2.2 AASHTO Pavement Management Manual**

The American Association of State Highway and Transportation Officials (AASHTO) published the second edition of its guide to pavement management in 2012 (AASHTO 2012). This document provided the basis for much of the work performed under the MoDOT Pavement Preservation Research program.

Chapter 3 of the AASHTO guide describes the types of inventory data typically collected to support a pavement management system. These include all relevant data not associated with the condition assessment (pavement performance). The guide lists basic inventory data including location, route classification, and geometry of the pavement section as well as structural information for the pavement (e.g. layer types, thicknesses, and history). The other major class of data needed for the inventory is traffic data. Chapter 3 also includes discussion of data integration, noting that the inventory information sources are often housed in different departments within an agency (i.e. pavement history data from a maintenance division; traffic from a planning division). Chapter 3 also includes discussion of data segmentation, which is

pertinent because the different data types are collected at different spatial frequencies. The Guide states that “bringing the information from these disparate systems into a common decision-making framework exponentially increases the value of the information collected.”

Condition assessment is addressed in Chapter 4 of the AASHTO guide. Condition assessment for pavement is either *functional* or *structural*. Functional measures focus on performance from a user perspective, often by measuring roughness; structural measures are tied to pavement distress, often measured with deflection methods. The guide summarizes a survey performed by the Federal Highway Administration (FHWA) that shows roughness is the most commonly collected pavement condition data type for all surface types, but other measures (rutting, cracking, etc.) are also commonly collected. The chapter also presents methods of developing pavement condition indices from various pavement measurements. Also discussed are various methods of network-level pavement condition assessment. Emerging technology is making network-level assessment of structural measures feasible.

## **2.3 State DOTs**

### **2.3.1 General**

Numerous state DOT Pavement Management Systems (PMS) were reviewed in an effort to discover the types of data necessary for creating performance models and trigger tables. The DOTs were Mississippi, Louisiana, Colorado, Virginia, South Dakota, Nebraska, North Carolina, Arizona, Pennsylvania, Minnesota, North Dakota, Oklahoma, Oregon, Washington, and Texas. Several are discussed below.

Common features of various DOT PMS included division of the systems into pavement families by pavement type and traffic level, producing performance models based on both IRI and some sort of condition indices, collection of detailed distress data, using ARAN van for data collection, and creation of “homogeneous sections” (uniform structural, geometric characteristics, traffic, etc. along the length) for each model based on traffic, thickness, material types, and other parameters.

Data collected by other DOTs for their PMS include pavement types, traffic, truck traffic, pavement thickness, subgrade type, pavement distress types, extent, and severity, intervals of maintenance, climate, and IRI. Thus, knowledge of these types of data guided the project researchers in seeking similar information in the MoDOT and other data sources.

### **2.3.2 Mississippi DOT**

George (2000) authored a report about the prediction models used by the Mississippi DOT’s PMS, which was initiated in 1986. The report describes the PMS database and modeling data, particularly the partitioning of roadways into homogenous sections. Data collected for each section in the database were consistent with the discussion from the AASHTO guide (2012). The 26 pavement models in the report were based on a composite condition index that included IRI, and various distress measures. The models included subgrade characteristics. Pavement types

were divided into five families. Data collected included pavement types, thicknesses, joint and reinforcement information, percent trucks, age, maintenance type, IRI, and 11 types of distress, along with severity and extent.

### **2.3.3 Louisiana DOT**

In 2009, Khattak et al. issued a report addressing performance models used in Louisiana's PMS. Phase I of the accompanying project assessed the data collection for the PMS. The authors noted good pavement distress data were available beginning in 1995, and that the data are collected continuously for 0.1-mile long segments. The study also found that maintenance and rehabilitation data were recorded but not accessible through the PMS. In addition, various location referencing systems were used by Louisiana's DOT. The authors note that various types of distress indices were collected and recommended expanding the types of distress to be more specific (e.g. alligator cracking, block cracking, etc.) rather than use the term "random cracking." IRI and 11 types of distress data was collected, along with severity and extent.

### **2.3.4 Colorado DOT**

Colorado's system, initiated in the late 1980's, had families that were comprised of four pavement types and five traffic levels. Climate was included as a variable in partitioning of homogenous sections as well as pavement thickness. Curve types were site-specific and family. Models predicted distress and performance. Data collected included pavement types, thicknesses, IRI, and four types of distress, along with severity and extent.

### **2.3.5 Virginia DOT**

Virginia's system, initiated in the early 1980's, included five pavement families. Data collected included roughness, rut depth, patching, and various crack measurements (distress severity and extent was included), truck traffic, and age since last treatment.

### **2.3.6 South Dakota DOT**

South Dakota's system, begun in 1977, had 12 pavement families. IRI and 11 types of distress data was collected, along with severity and extent. Distress and performance models numbered 168.



### 3 DATA SOURCES

This chapter defines the requirements for the data collection efforts of Task 1 before providing detailed explanations of the MoDOT data sources used to address the requirements. The MoDOT data sources are organized by pavement performance data (primarily IRI) and pavement family data (primarily pavement history but also additional ancillary data). The range of data sources involves several divisions of MoDOT, including Construction and Materials, Maintenance, Transportation Planning, and Traffic and Safety. This chapter provides some historical and agency context on each data source, but the emphasis is on providing useful descriptions and retrieval guidance for each data source. Besides MoDOT data sources, U.S. Department of Agriculture (USDA) and National Oceanic and Atmospheric Administration (NOAA) resources are presented.

#### 3.1 Data Requirements

The primary purpose of data collection efforts for pavement management is to provide input for the decision processes. For the Pavement Preservation Research program, which involves developing one aspect of MoDOT's pavement management system, data collection efforts are primarily intended for Tasks 2 and 5. Task 2 uses Task 1 data to establish pavement families and treatment models. The decision rationales established in Task 5 are closely related to Task 2 and therefore use data from Task 1 in a similar manner. Tasks 3 and 4 also use data from Task 1, but to a much lesser extent. Task 3 considers Task 1 data sources in its analysis of new collection methods, and Task 4 occasionally considered Task 1 data in selecting and analyzing specific sites.

The critical inputs for pavement management decision processes are pavement performance data and pavement family data. Performance data for pavements are generally categorized as *functional* or *structural*. The efforts for this project focused on functional measures from the ARAN van video, the International Roughness Index (IRI), and from condition distress indices, although some consideration was given to structural measures from the falling weight deflectometer (FWD). If pavement performance is considered to be the response (or dependent) variable, pavement family data can be considered the predictor (or independent) variables. The organization of pavement families is described in the report for Task 2, but was generally accomplished by pavement type, defined by the pavement history, traffic level, and possibly by functional classification. Additional pavement family data such as subgrade, total pavement thickness, and climate were also considered.

#### 3.2 Pavement Performance Data

As for other transportation agencies, MoDOT's use of pavement performance data has evolved significantly over the last 25 years, primarily as a result of technology related to pavement performance measurement devices but also because of shifting ideas on pavement management. Current practice emphasizes IRI, a functional measure that decreases with

increasing ride quality, and the Pavement Surface Evaluation and Rating (PASER), a visual rating standard that assigns integers from 1 to 10 for failed roads to new construction, respectively. Visual ratings are assigned manually by MoDOT personnel using images captured by the Automatic Road Analyzer (ARAN) van. Previous performance measures include the Present Serviceability Rating (PSR), calculated from IRI and a visual distress rating consistent with the Long Term Pavement Performance Distress Identification Manual (FHWA, 2003).

The research team primarily used ARAN video data and IRI data in its consideration of pavement performance and condition indices to a lesser extent. ARAN video data was accessed via MoDOT's Transportation Management System (TMS). IRI data was accessed via MoDOT's ARAN inventory database, which contained other useful data as well.

### **3.2.1 MoDOT TMS and ARAN Video**

Many MoDOT personnel likely appreciate the usefulness of the ARAN video, which captures a visual record of MoDOT's roadways on an annual, biennial, or triennial basis. Still images from the ARAN van can be accessed from MoDOT's TMS webpage on MoDOT's Intranet. MoDOT's TMS contains many other useful data sources related to pavements. Therefore, three sets of access instructions are presented below. The first addresses TMS access, in general. The second addresses TMS Maps, which is useful for obtaining general information for any roadway, including Travelway ID numbers, which differ from route numbers and which are used throughout TMS. The final set of instructions addresses ARAN video data.

To access the TMS homepage:

1. From the homepage of MoDOT's Intranet, click the "Division/Business Offices" link on the top/horizontal navigation bar.
2. Click on the last link to go to Transportation Planning.
3. Click the "TMS Web Homepage" link on the left/vertical navigation bar.
4. Enter the general access MoDOT credentials.

To access TMS maps:

1. From the TMS homepage, click on the graphical "TMS Maps" link on the right side of the page.
2. The map should show up via Microsoft Silverlight. It might be helpful to click the upper rightmost icon to enlarge to full screen.
3. Click on the "layers" button, which is top center just under the heading. Clicking on any of the options that appear will bring up a legend. Clicking different headings on each legend will display different data on the map. Many different types of data are available through these maps.
4. Clicking the button with a blue circle and an "i" on the left side of the screen near the top will bring up the "Identify" box that provides detailed information based on the route that you click on. This can be used, among many other things, to pull up travelway ID numbers for various routes. For example, the travelway ID for I-44 is 10. This was accessed by loading the "Travelway\_Data" legend, then selecting "Functional Class" on the legend, and then clicking on I-44 after clicking the "Identify" button.

- For loading speed, it is helpful to zoom into the area of interest before loading the layers of interest.

To access ARAN video:

- From the TMS homepage, click on the graphic “ARAN Viewer” link on the right side of the page.
- The video/photograph from the ARAN van is displayed as shown in Fig. 3.1, with pavement quality data shown on the right side of the screen. The buttons below the ARAN video image are used to progress from one image to the next (or to the previous).
- To move to a different route, click the “New Location” button on the top of the screen. As mentioned above, the travelway ID can be ascertained from the TMS Maps.
- A plot of IRI and a map of the location can be shown by using the “IRI Graph” and “Inset Map” checkboxes (respectively) near the top of the page.

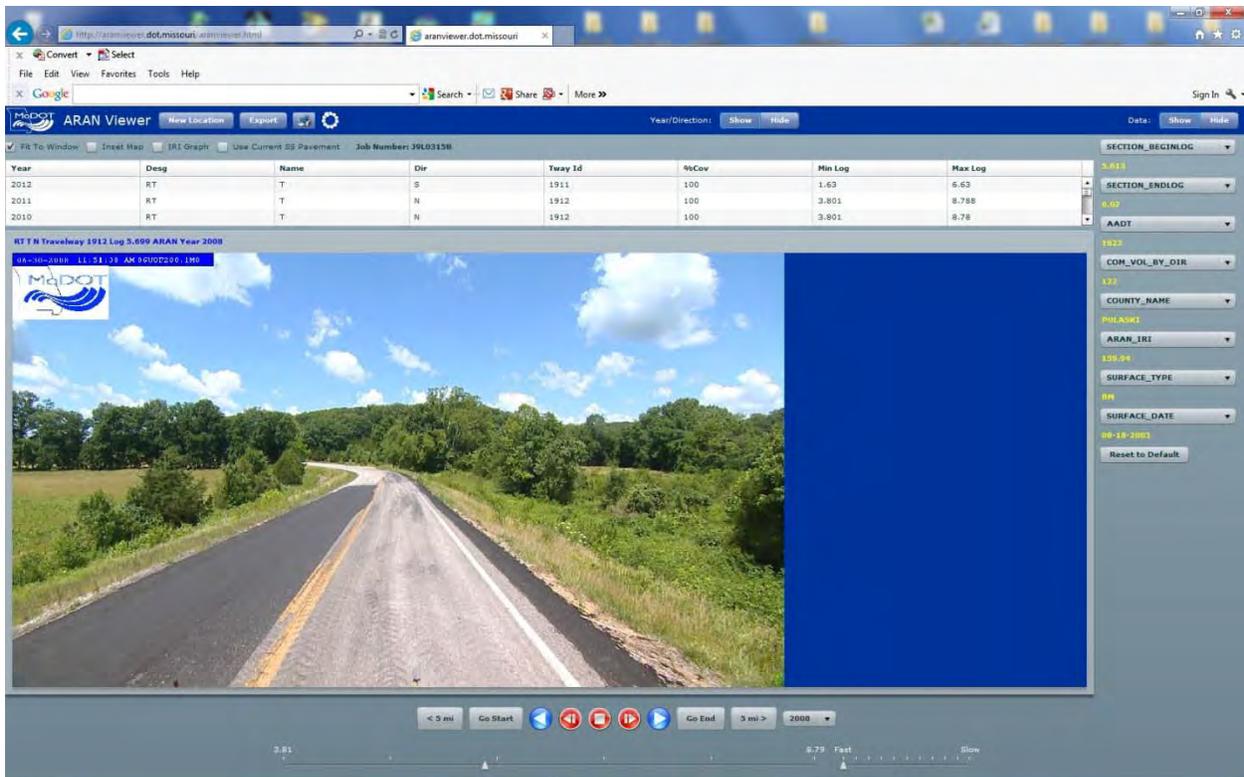


Fig. 3.1 – Example of ARAN video viewed via MoDOT’s TMS homepage.

### 3.2.2 SS Pavement Database

The TMS webpage described above is a convenient interface by which MoDOT users can access data stored in TMS databases. Much of the data for Task 1 was collected directly from one such database, the SS Pavement database, rather than by using the TMS webpage. Accessing the database directly allows for more efficient data collection and allows data to be filtered according to user criteria. Database software such as Microsoft Access is necessary to retrieve and filter data from the TMS database files, which were provided to the research team by

MoDOT's planning division, which oversees TMS. By using Microsoft Access, users can query the databases by route, traffic, surface type, or any of the other fields in the SS Pavement database. Definitions for the SS Pavement database fields were provided by MoDOT and are included as Appendix 1A.

Another way to view the data contained in the SS Pavement database is through GIS software such as ESRI ArcMap. Using GIS to view the data is advantageous when location is of primary interest, and GIS provides a convenient means for visualizing data.

A pair of important notes on using ARAN inventory and SS Pavement data:

- 20-point condition index data dates back to 1988 and was discontinued in 2009, and raw IRI data (i.e. a record every 0.02 miles) dates back to 1993. However, the 1997 to 2001 (inclusive) IRI data was not used due to an algorithm error during these years.
- The SS Pavement databases are "dynamically segmented," which refers to the way the locations of each data point are referenced. Practically speaking, this means the logmiles of each data segment in the databases could differ from year to year because any change to the roadway information (i.e. not just re-alignment but also any addition of traffic data, speed limit data, functional information, etc.) results in a new segmentation. This necessitates flexibility and some creativity (e.g. averaging) for purposes of data analysis.

### **3.3 Pavement History Data**

The pavement performance data from Section 3.2 are interpreted through the framework of pavement families in order to develop useful models for the pavement management system. The families and models are described in more detail in the Task 2 report. Pavement history is a critical input for explaining pavement performance and developing family models. This section describes data sources used to establish pavement history for a given roadway segment.

#### **3.3.1 Project History Maps**

Project history maps, also known as "rag maps," are a rather useful tool for establishing the early history of a roadway segment. An example portion of a rag map is shown in Fig. 3.2. The maps contain a plan view of major routes in the county with notes showing the extents and listing the general summary of projects and major maintenance along the route. The original, paper maps were maintained by highway engineers but have since been digitized (scanned). The project history starts as early as the 1920s and typically ends in the 1990s. There is one map per county, and the maps can be accessed through the TMS intranet:

<http://wwwi/intranet/tp/products/projecthistory/projecthistorymaps.htm>

As is evident from Fig. 3.2, the maps contain a considerable number of project records. More recent projects often include project numbers, which can be used to obtain project plans as described in the next section.



route. The research team scanned all asphalt summary sheet tables to Adobe PDF and disseminated the files to MoDOT through an online file repository.

Route	County	Project	Contract	Location Description	Log Mile:	Treatment	History
71	Nodaway	JIP2187	100514-102	NBL from Rte A to Bus. 71	556+79.41 to 176+90.22 7.2 miles	Type 3 Micro	2004 – 1.75" SP125C on top of 4" C.I.R. 1974 – 4" asphalt 1956 – 9" PCCP 1956 – 4" Type 3 Agg. Base

*Fig. 3.3 – Example of an asphalt summary sheet listing, for Route 71 in District 1, 2010.*

### 3.3.4 Concrete 2-AA Sheets

Similar to asphalt summary sheets, concrete “2-AA” sheets provide a record of construction for concrete projects. The sheets are as-built summary sheets for concrete paving projects, and they provide more detailed information than the asphalt summary sheets, with a single project spanning multiple large sheets, an example of which is shown in Fig. 3.4. Information contained on the Concrete 2-AA sheets includes the typical section of the pavement, the materials used and their source (i.e. the quarry name), subgrade type and preparation method, weather on the day of pour, concrete mix proportions, reinforcement, and joints, among other useful information. The entire set of Concrete 2-AA sheets is quite large and is organized by district and then by county. The research team scanned all Concrete 2-AA sheets to Adobe PDF and disseminated the files to MoDOT through an online file repository.



### **3.4 Pavement Maintenance Data**

The collection of data associated with in-house MoDOT pavement maintenance work has been the most challenging process in Task 1, and is still underway. Full-surface preservation treatments such as chip seals, scrub seals, fog seals, etc. are sometimes performed by MoDOT maintenance personnel but details of the work (e.g. specific location, date of the work, material quantities, thickness, and type) are not documented in a uniform, consistent, and organized manner. This type of information usually resides with district pavement specialists and/or maintenance personnel in electronic form and/or on a personal experiential basis.

Researchers are making personal visits to various District Pavement Specialists and Maintenance Supervisors to review the information for each project section in order to: 1) verify the data that the researchers have found (see above discussions), 2) add any treatments that were missing in the MoDOT central databases, and 3) review the pavement selection and maintenance planning procedures in-place at the district level.

### **3.5 Other Ancillary Pavement Data**

Pavement history through construction projects (Section 3.3) and maintenance (Section 3.4) was critical for establishing pavement families for the modeling of Tasks 2 and 5. Other ancillary data were also considered in these models. Each is described in this section.

#### **3.5.1 Traffic**

Traffic data, especially truck (commercial) traffic, is an important predictor of pavement performance because it describes the loading history of a pavement. There are several ways to access traffic data throughout MoDOT's TMS databases. Traffic data (Annual Average Daily Traffic (AADT) and commercial volume [trucks]) are included as fields in the SS Pavement database, and traffic data are also shown as a user views ARAN video data (both described in Section 3.3). Another, slightly more comprehensive way to view traffic data is to generate reports of traffic data ("TR 50" reports):

1. From the TMS homepage, click the "TMS Reports" link on the top/horizontal navigation bar.
2. Enter MoDOT login credentials.
3. Click "Traffic/Congestion Reports" on the folder listing that comes up, then click "Traffic Information TR50."
4. Enter data for the desired year(s), district ("CD" = central district), county, designation, and travelway, then click "Travelways" under "Navigation" to select the locations.
  - a. In the page that comes up, click the radio button next to the travelway. A list of reference points should then appear.
  - b. Click on the radio button next to the desired beginning location in the list that comes up, then click, "Update Begin Log."



- c. Click on the radio button next to the desired ending location in the list that comes up, then click, “Update End Log.”
- d. Click the “OK” button near the top of the page.
- e. This should return you to the original TR50 page with the log miles filled in.
5. Under “Traffic Info Types”, select both “AADT” and “Total Commercial Volume” by holding the control button while clicking.
6. Click the “Submit Report” button under “Navigation”.
7. A pop-up window with the results will appear. Clicking the quantity values (blue links) will pull up a map of the data.

Typically, all three sources for traffic data were consistent, though the dynamic segmentation issues associated with the SS Pavement database made the ARAN values slightly more reliable, so these were primarily used for data collection. For larger roads, traffic data could differ between the two directions (e.g. northbound vs. southbound), but for smaller volume roads, both directions were assumed to be the same.

### **3.5.2 Subgrade**

Specific subgrade data is available from some project documents (e.g. Concrete 2-AA sheets as described in Section 3.3.4). Additionally, specific data can be obtained from Preliminary Geotechnical Reports for a given project. The reports are discussed in the EPG Section 320.1 and can be obtained from the Soils and Geology section of the Construction and Materials division. Unfortunately, soil investigations for minor routes probably do not exist, unless there was a re-alignment or a bridge or other structure had been built. More generalized data can be found in the 1962 Geology & Soils Manual and updated soil association files at Soils and Geology.

Another source of data regarding subgrade can be found from the U.S. Department of Agriculture (USDA) soil surveys, which are organized by county. Utilization of these soil surveys for modeling purposes is still under consideration. The website URL is as follows:

<http://websoilsurvey.nrcs.usda.gov/app/>

To retrieve data for a given roadway segment:

1. Access the USDA website.
2. Left-click on the “START WSS” button.
3. Left-click on “State and County” on the menu on the left side of the screen
4. Select state and county of interest from drop down menus.
5. Left-click on the “View” button.
6. Left-click on the “Zoom In” magnifying glass icon located on the top/horizontal toolbar and delineate the area of interest on the map by clicking and holding down the cursor, drawing a perimeter around the desired area. It is recommended that at this stage to delineate a fairly large area.

7. Left-click on the polygon icon on the AOI Interactive Map/horizontal toolbar, then left-click points around the roadway to delineate the “Area of Interest” (AOI). It is recommended to keep the area as tight to the roadway as possible. When finished, double left-click.
8. To set up for printing, left-click on “Preferences” on the top/horizontal toolbar.
9. Left-click on “Remember Preferences...”
10. De-select the “Open Links and PDFs...”. Left-click on the “Save Preferences” button. Steps 8-10 should not have to be repeated during the session.
11. Left-click on the “Soils Data Explorer” tab on the top/ horizontal tab selection area, as shown in Fig. 3.5.

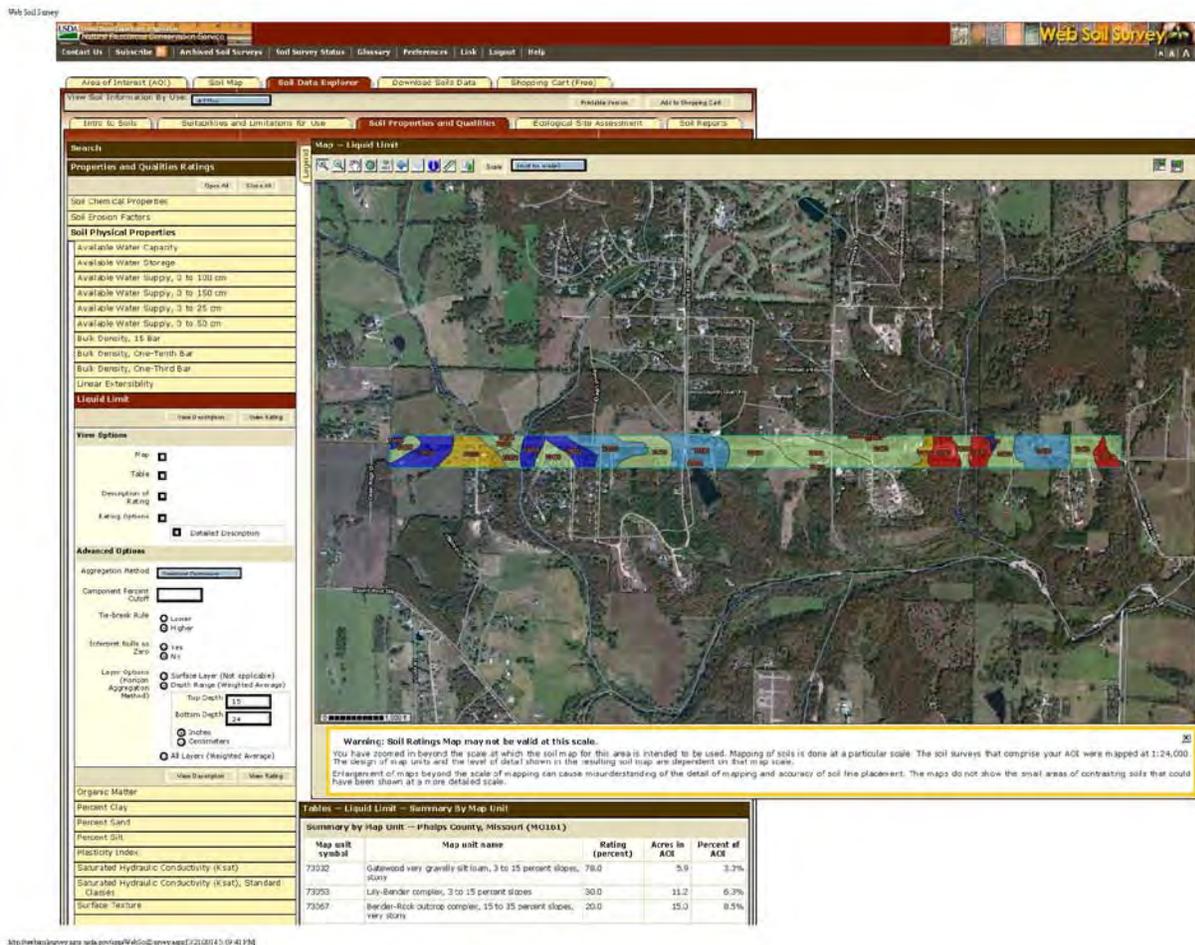


Fig. 3.5 – USDA “Soil Physical Properties” view of a delineated roadbed with Liquid Limit displayed.

12. Left-click on the “Soil Properties and Qualities” tab on the top/ horizontal tab selection area.
13. Left-click on the “Soil Physical Properties” choice on the left side of the screen.
14. Choose the soil property of interest (such as “Liquid Limit” [LL]) for all Map Units by left-clicking the property listed.

15. Left-click on the "All Layers" radio button.
16. Choose the "Aggregation Method" by clicking on the choice. This deals with what values will be displayed, depending on the rules governing the choice. For an overall description of what is in the soil units, choose "Dominant Condition".
17. Left-click on the "View Rating" button. The soil properties of interest (eg. LL) is in the "Rating (Percent)" column. Also of interest is the "Percent AOI" column.
18. Left-click on "Printable Version" on the top/horizontal toolbar.
19. Left-click on "View".
20. Left-click on the print icon. Select pages to print. Select "OK".
21. Left-click on the previous page arrow.
22. Repeat steps 14-20 for other soil properties such as Plasticity Index (PI), Percent Clay, Percent Silt, and Percent Sand to be able to classify the soil and predict swell potential and frost susceptibility.
23. To determine details of the soils in each soil unit at depth, and to determine % Rock Fragments, left-click on "Soil Reports" in the top/horizontal tab selection area.
24. Left-click on "Soil Physical Properties" on the left side of the screen.
25. Left-click on "Engineering Properties" on the left side of the screen.
26. Left-click on "Include Minor Soils" if displaying all soils is desired
27. Left-click on "View Soil Report". This will display each Map Unit and subsets of Soil Names (eg. associations), percent of each Soil Name, different soil layers at various depths, soil classification, and ranges of properties.
28. Print as in steps 18-20.
29. Left-click on "Particle Size and Coarse Fragments" on the left side of the screen.
30. Left-click on "View Soil Report".
31. Print as in steps 18-20.

The "Map Unit" soil numbers are contoured on the maps, as shown in Fig. 3.5. The "Percent AOI" is displayed and is the percent of the roadway delineated as that Map Unit. Map Units may be made up of several Soil Names. These are shown in Fig. 3.6 (just the first one "70302" is showing). Not shown in Fig 3.6 but on the actual screen display are each Soil Name within each Map Unit, and the Soil Name percents within the Map Unit. Thus, to obtain the percent of an association within the delineated roadway, the % Map Unit would be multiplied by the % Soil Name within that Map Unit.

To classify each fine-grained layer in each association as to the AASHTO method and to calculate Group Index (GI), the LL, PI, and % minus #200 sieve are required. To estimate swell potential by the Seed method, PI and % clay (< 0.002 mm) are required. To classify soil as to frost susceptibility by the U.S. Corps of Engineers method, PI and % silt and % sand are required. Unfortunately, the USDA and AASHTO do not agree on what constitutes the particle size boundaries between clay, silt, and sand. To confound the issue, the USDA clay, silt, and sand percents are of the minus 0.02 mm (#10 sieve) rather than total soil. And, there is no #200 sieve value shown for individual associations. USDA defines Rock Fragments as greater than 2 mm.

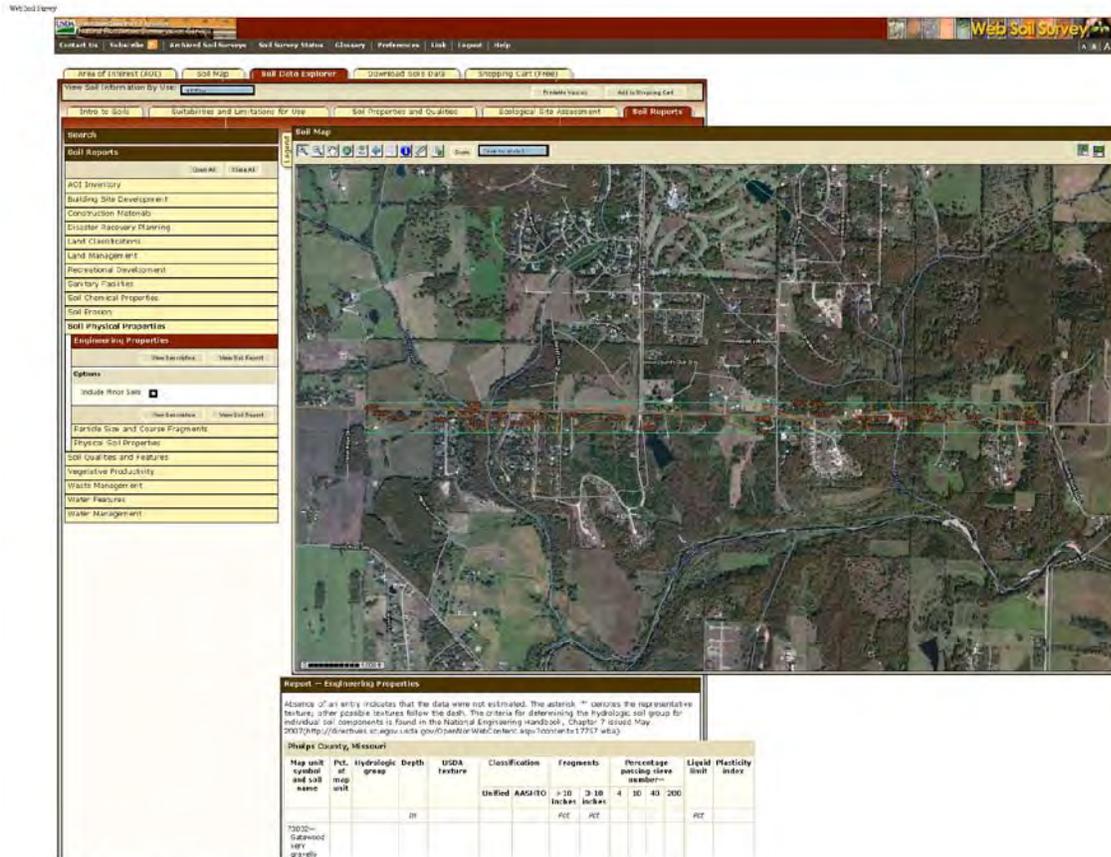


Fig. 3.6 – USDA “Soil Reports” view of a delineated roadbed with all soil Map Unit contours displayed.

To navigate through all this, the following is recommended:

1. Set up a spreadsheet and enter LL, PI, % clay, % silt, % sand, an average % Rock Fragments.
2. Calculate the % finer-than (<) 2mm material by: (100-%total Rock Fragments).
3. Adjust the %'s from < 2mm-basis to total soil-basis by multiplying the each % by the %< 2mm:

$$\begin{aligned} \% \text{ clay, total} &= (\% < 2\text{mm})(\% \text{ clay from website})/100 \\ \% \text{ silt, total} &= (\% < 2\text{mm})(\% \text{ silt from website})/100 \\ \% \text{ sand, total} &= (\% < 2\text{mm})(\% \text{ sand from website})/100 \end{aligned}$$

4. Calculate an approximate % minus #200 by: (% silt, total + % clay, total).

Now the soils can be classified, GI calculated, % swell calculated, and frost susceptibility adjudged. Weighted averages of each soil's % swell, GI, and frost susceptibility can be calculated for the entire roadway using the percents discussed above. MoDOT does not have any hard-and-fast rules about what constitutes a problematic swelling soil and frost susceptible soil for subgrades.

### 3.5.3 Climate

Climate data is available from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). At the present, data that is pertinent to pavement treatment performance are number of days below freezing per year, and number of days with greater than 0.1 in. precipitation per year.

Directions for extracting climate data from NOAA NCDC website:

Go to this website

<http://www.ncdc.noaa.gov/cdo-web/>



Fig. 3.7 – NCDC Climate Data Online (CDO) homepage.

Click on “Search Tool” link (bottom left, blue box)

This is the first screen visible.

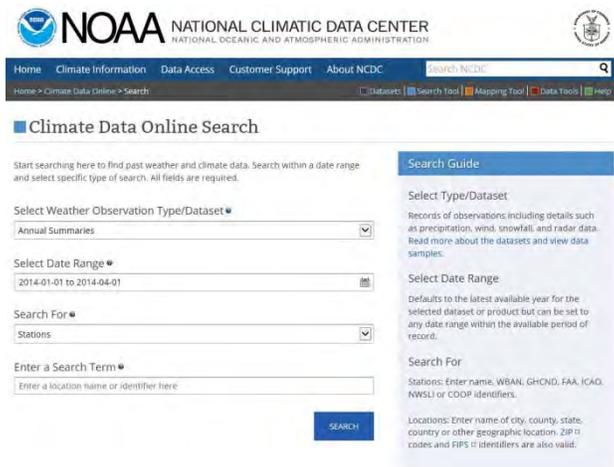


Fig. 3.8 – NCDC CDO Search Tool default first page.

Annual Summaries is the default choice for “Select Weather Observation Type/Dataset.” Do not change this selection.

“Select Date Range” is an option one will have to select. Click on the little calendar to the far right in the “Select Date Range” box.



Fig. 3.9 – NCDC CDO Search Tool, Select Data Range calendars.

In the left calendar, select a beginning date for data (in this example, January 1, 1990 was chosen). The right calendar has the most recent date that data is available (in this example, April 1, 2014 is left as-is). Click on the “Apply” button. You will see that the dates chosen are now in the “Select Date Range” box. Leave the “Search For” default selection of “Stations” as-is. In the “Enter Search Term” box, one can enter several different search terms but in this

example, all weather stations in Missouri, US are searched for by typing “MO US” in the box. Click on the “Search” button.

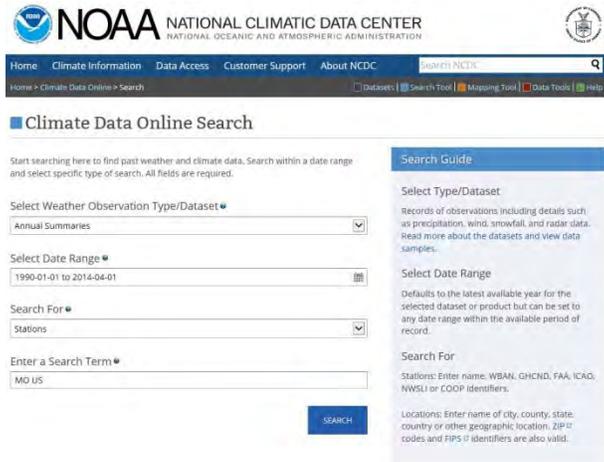


Fig. 3.10 – NCDC CDO Search Tool, Enter Search Term page.

Below is the next window that will appear.

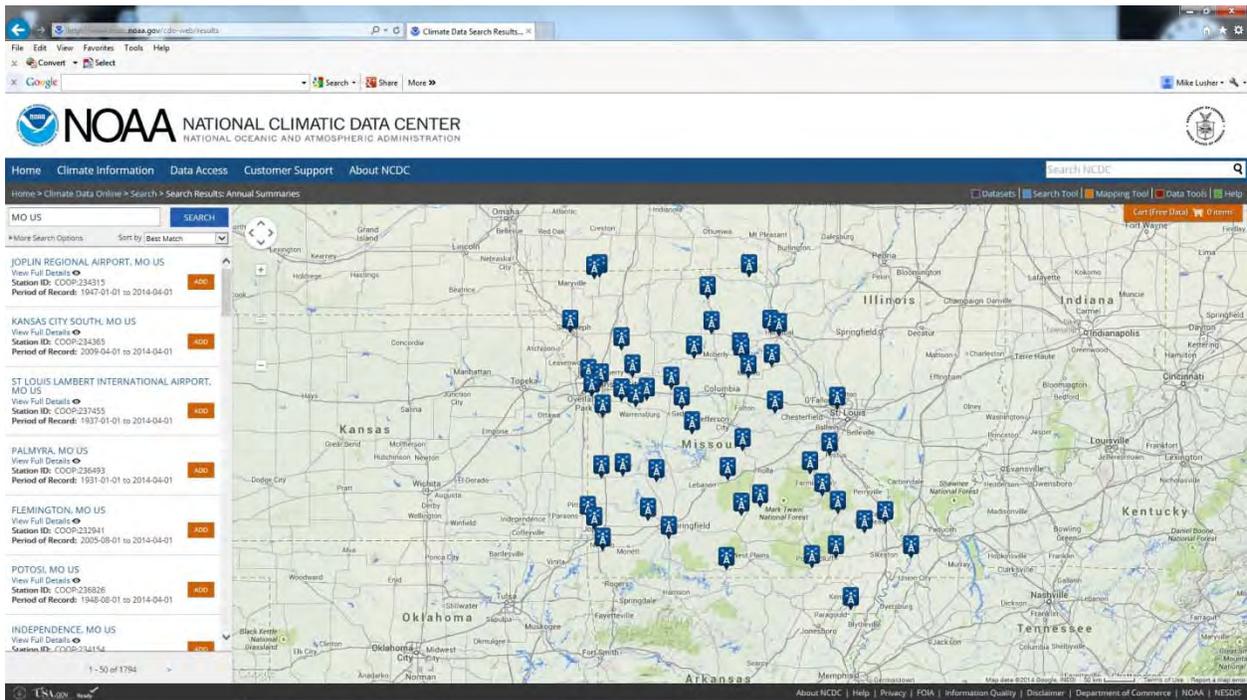


Fig. 3.11 – NCDC CDO Search Tool, search results.

The next step is to add the desired “Stations” to your ‘shopping’ cart (see upper right corner of screen). One still has to use some judgment when selecting stations because of the “Period of

Record” date for each station, although one selected a “Date Range” previously in the process. In this example, only those Missouri stations that had a “Period of Record” that encompassed the desire “Date Range” are ‘added’ to the cart. The next image shows what happens when certain stations are added.

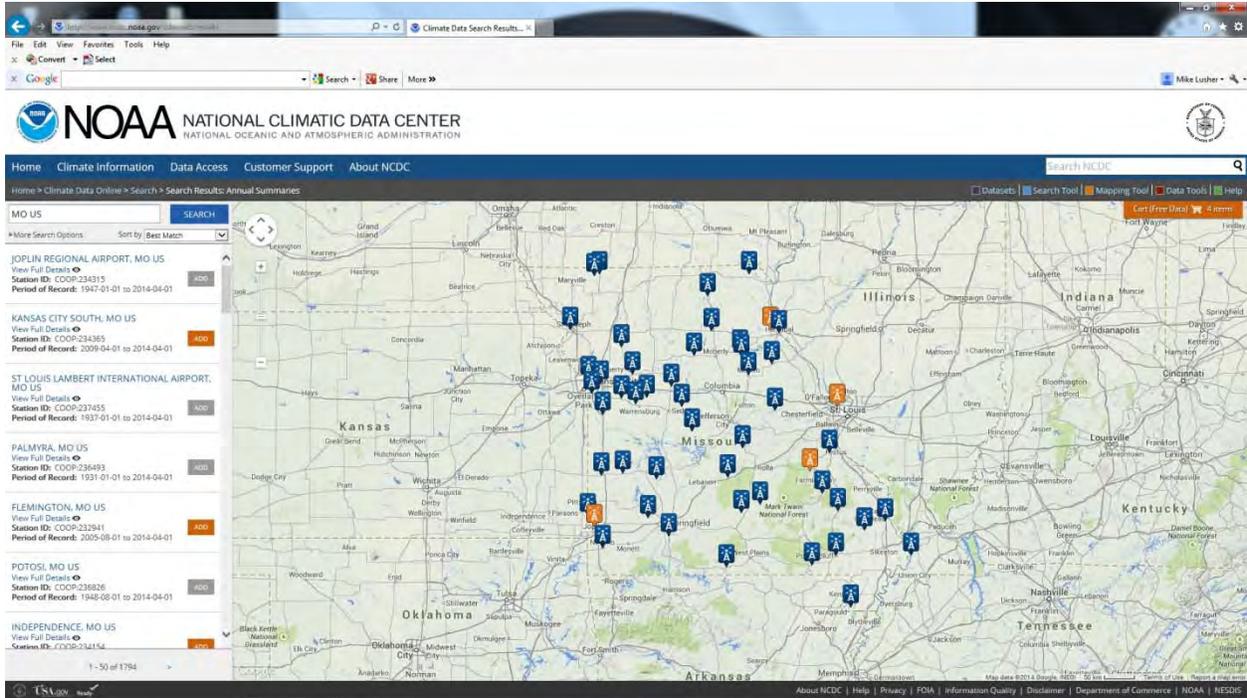


Fig. 3.12 – NCDC CDO Search Tool, add select search results to data cart (part 1).

In this example, the Joplin, St. Louis Lambert Airport, Palmyra, and Potosi stations were added (note that the add buttons become grayed-out and the selected station icon towers change color from blue to orange). For this example, a few more stations were selected/added by scrolling down.



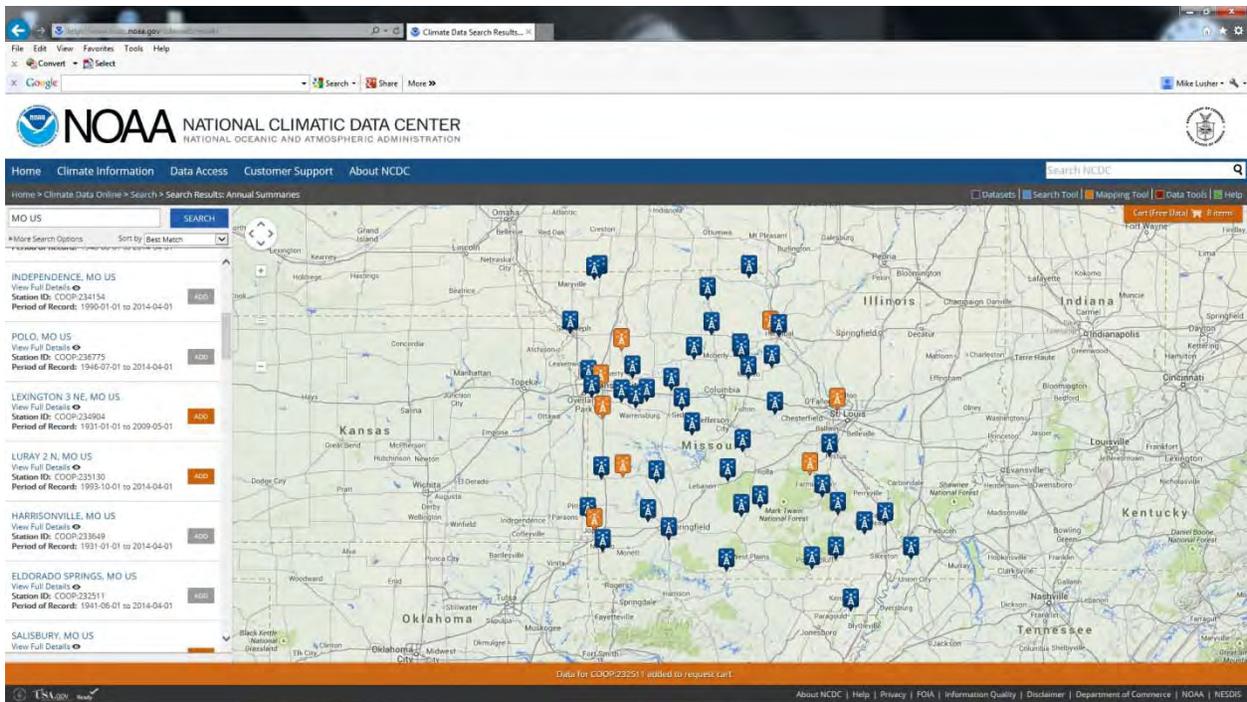


Fig. 3.13 – NCDC CDO Search Tool, add select search results to data cart (part 2).

Four more stations were added: Independence, Polo, Harrisonville, and El Dorado Springs. Note the change in colors again. Assuming one has chosen all stations desired, click on the “Cart (Free Data) – 8 items” link in the upper right corner of the page.

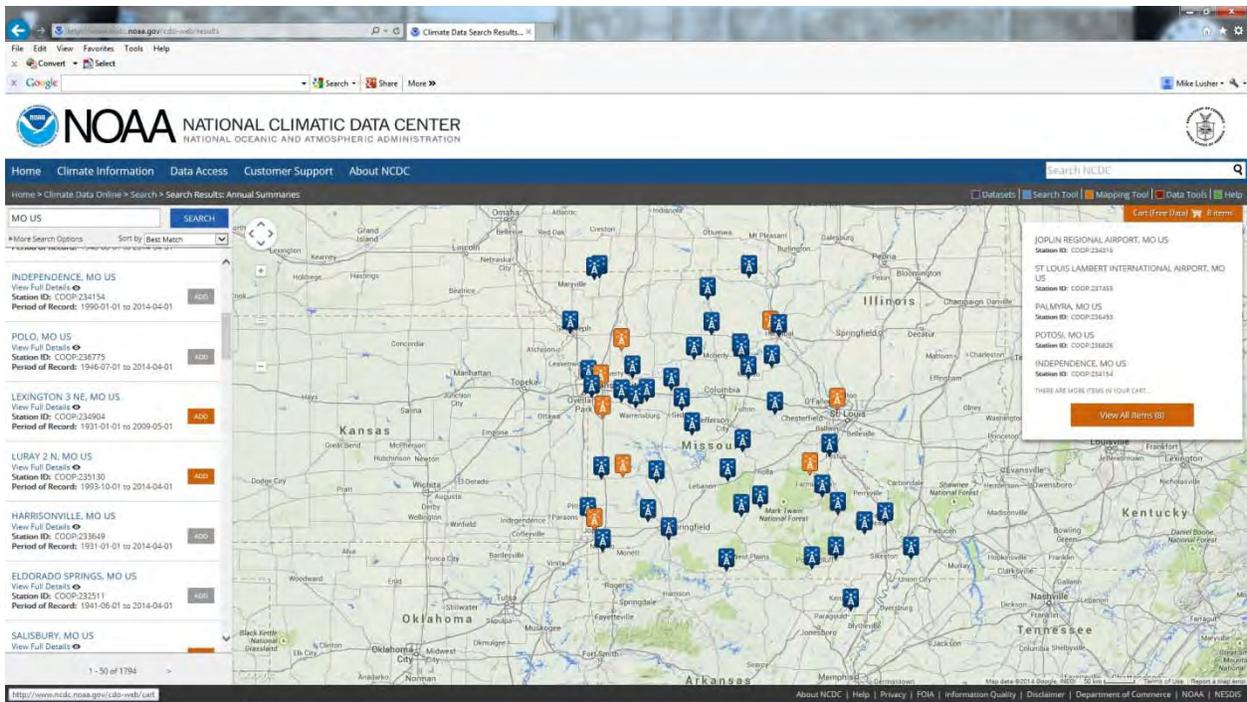


Fig. 3.14 – NCDC CDO Search Tool, view data cart contents drop-down.

Next, click on the “View All Items (8)” button in the drop down menu (upper right corner of page). Below is the next page that will appear.

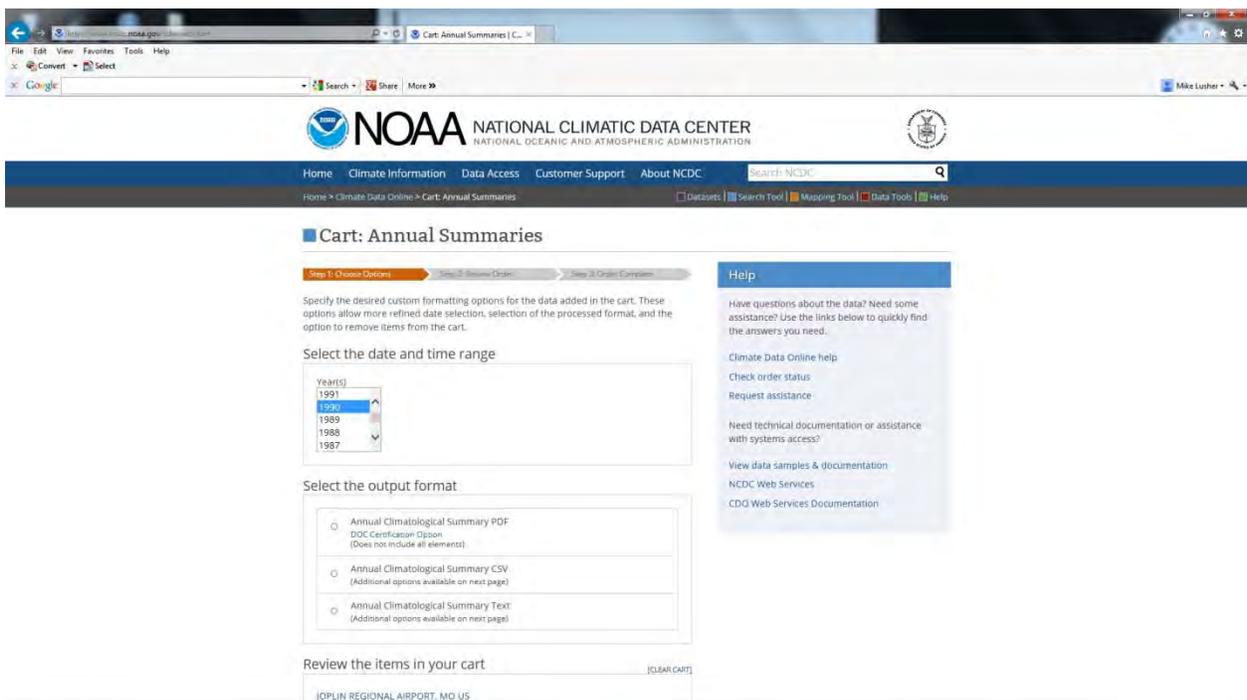


Fig. 3.15 – NCDC CDO Search Tool, requested data formatting options selection page.

One will note that there is another requirement for choosing date range in the “Select the date and time range.” In this example, the same range of years was selected by, first, scrolling down and highlighting the year “1990.” The yearly range originally desired was 1990 to 2014, so scroll up until 2014 is visible, hold down the “shift” key, and click on the year “2014.” Below is the next view.

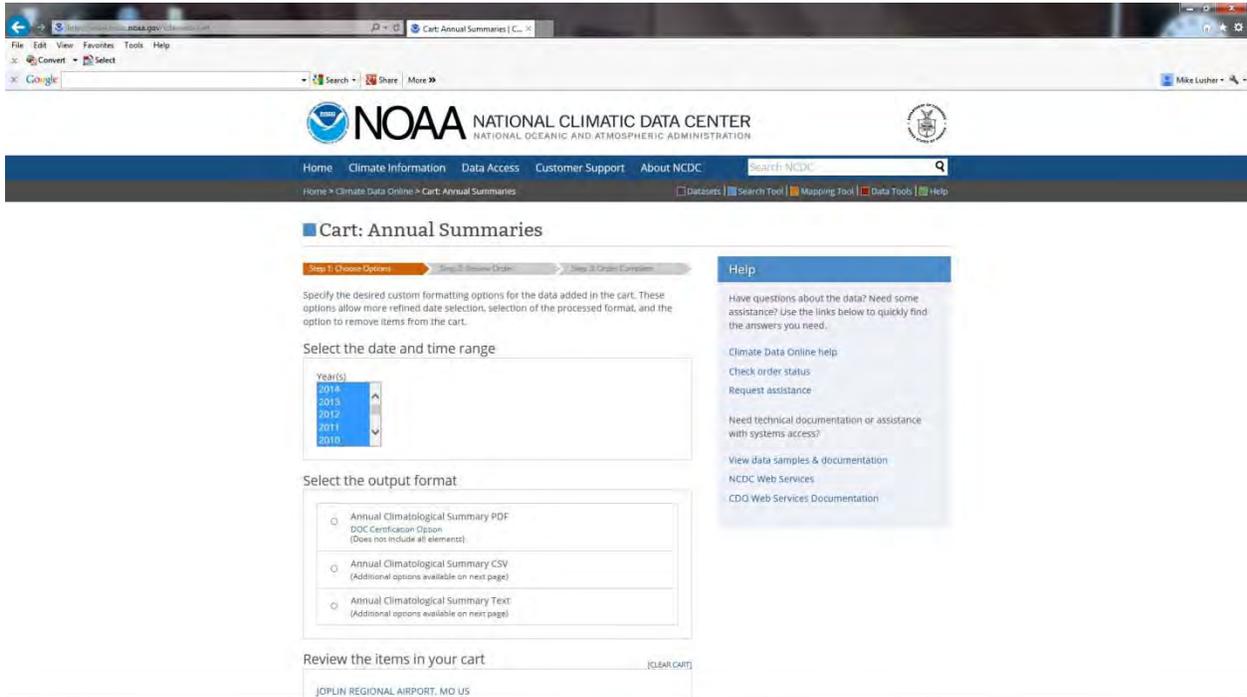


Fig. 3.16 – NCDC CDO Search Tool, requested data Time Range selection.

One can see that all years from 2014 down to 1990 are highlighted blue meaning they are selected. Next, select “Annual Climatological Summary CSV” by clicking on the radio button to the left of that box. Below shows the next view.

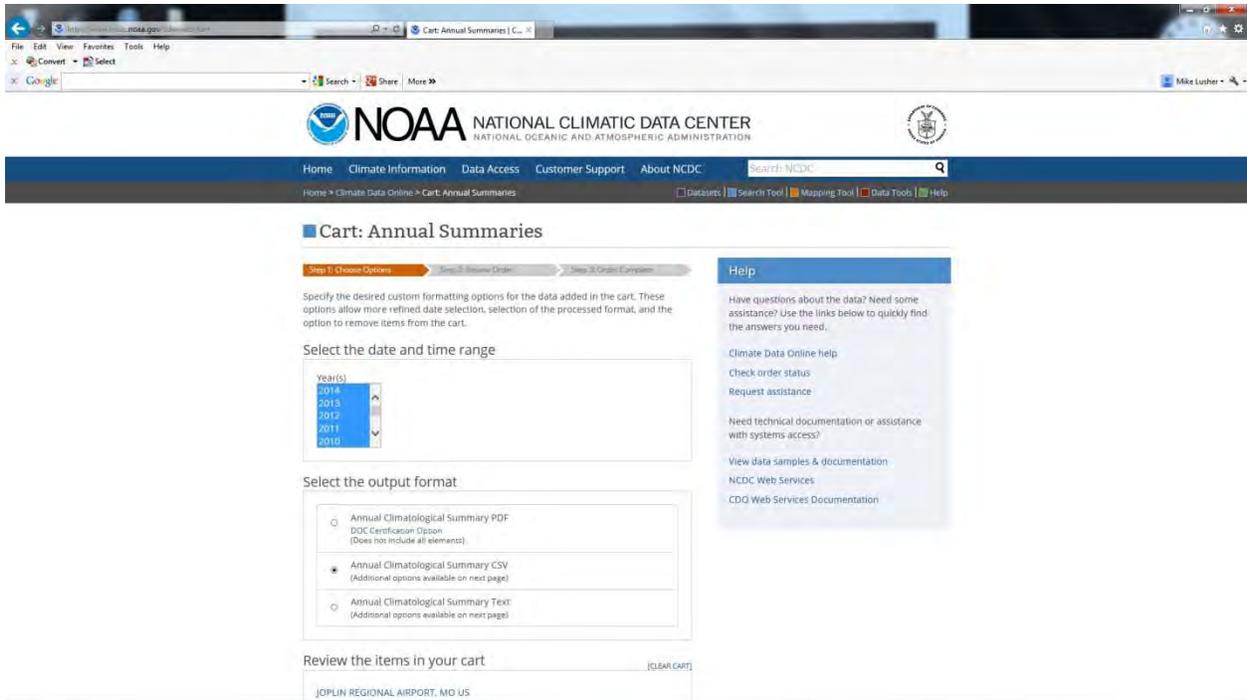


Fig. 3.17 – NCDC CDO Search Tool, requested data Output Format selection.

The image below shows the bottom half of the page view shown above.



Fig. 3.18 – NCDC CDO Search Tool, bottom half of page in Fig 3.17.

Click on the “Continue” button at the bottom of the page. The next page gives one “Custom Options” on the type of data requested for the selected stations. The image below shows that the default “Station Detail & Data Flag Options” is “Station Name” (see the check in the box to the left of the title).



Fig. 3.19 – NCDC CDO Search Tool, Custom Options output selection default page.

For this example, all six boxes were checked.



Fig. 3.20 – NCDC CDO Search Tool, Custom Options additional output selection.

Next, click on the “Continue” button (bottom right). The next screen will let one “Review Order.”



Fig. 3.21 – NCDC CDO Search Tool, Review Order screen.

The image below shows the bottom half of the page shown above. Enter and re-enter the e-mail address that the requested (in the shopping cart) data will be delivered. One can choose to have the website remember your e-mail address, or not. Click on “Submit Order.”

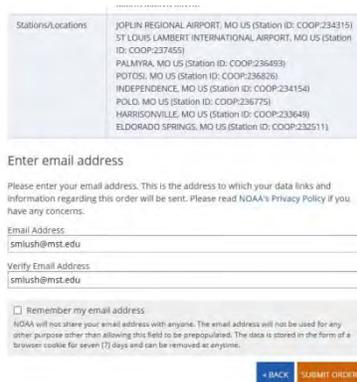


Fig. 3.22 – NCDC CDO Search Tool, bottom half of page in Fig. 3.21.

One the “Submit Order” is clicked, the next screen indicates “Request Submitted.”

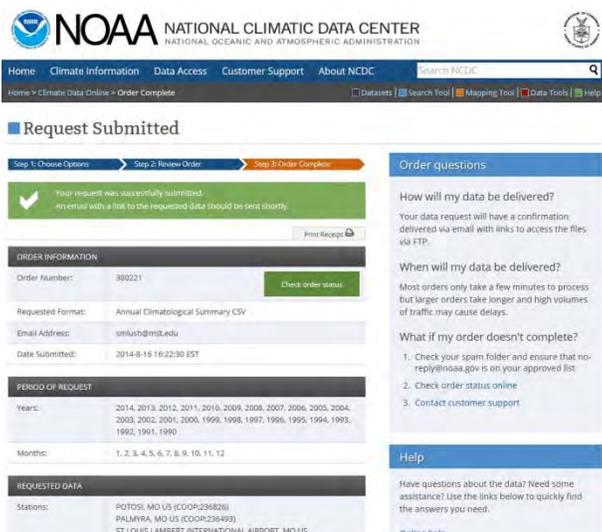


Fig. 3.23 – NCDC CDO Search Tool, Request Submitted confirmation.

The image below shows the bottom half of the page shown above.

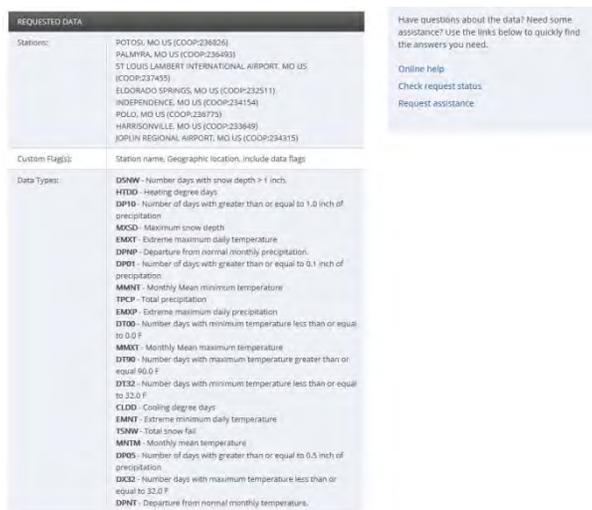


Fig. 3.24 – NCDC CDO Search Tool, bottom half of page in Fig. 3.33.

It usually does not take long for one to receive an e-mail confirming that the request was “submitted.”

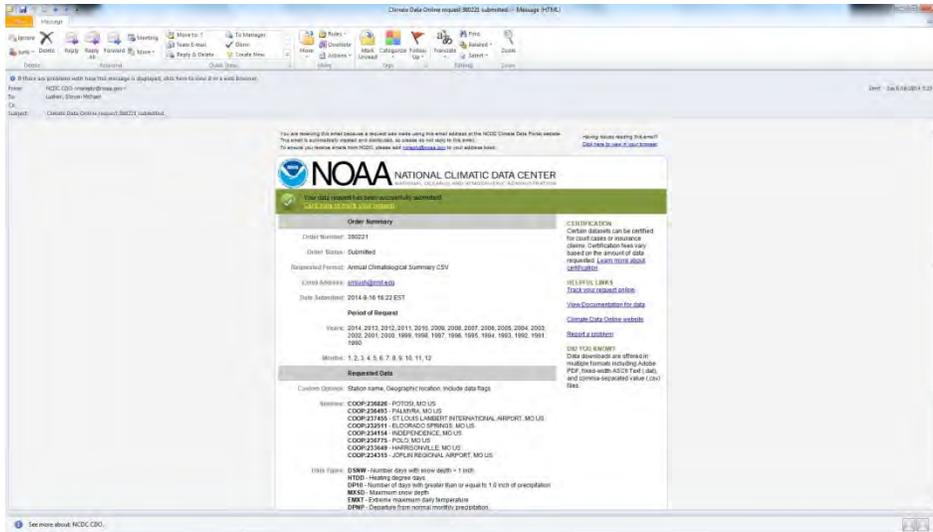


Fig. 3.25 – NCDC CDO data request submittal e-mail confirmation screenshot.

Depending on the size of the data request, the following e-mail will contain “download” links to access the data file. The image below shows the “Download Data” link and another link to “Download Documentation” (if desired-this is explanatory pdf or Word documents that describe the NCDC data, etc.).

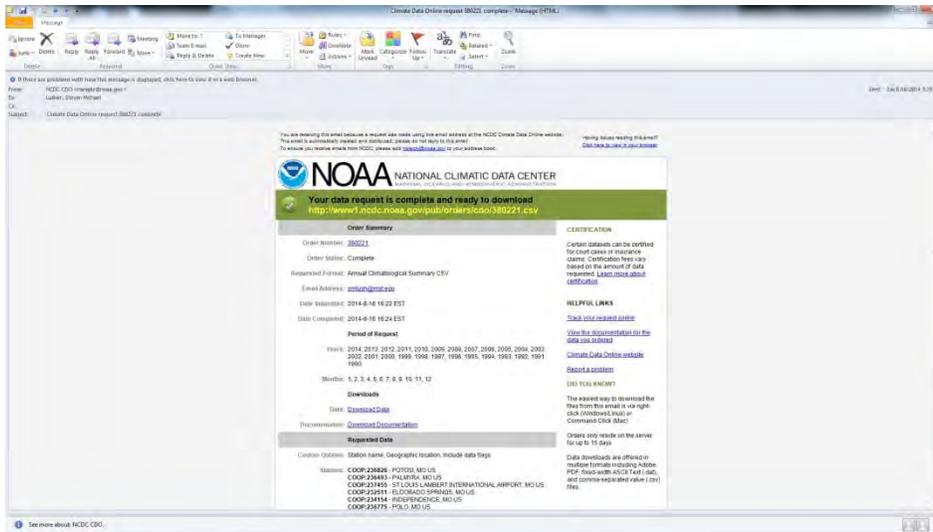
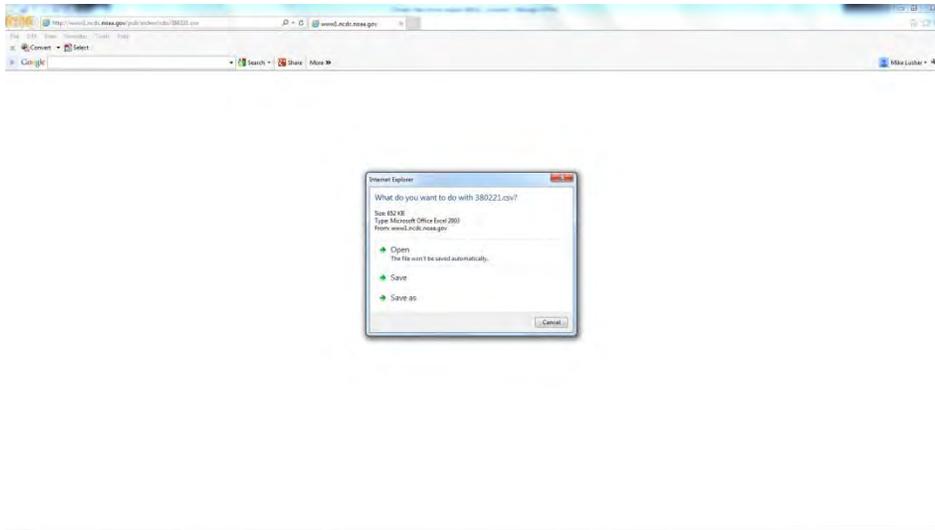


Fig. 3.26 – NCDC CDO data available (download links) e-mail screenshot.

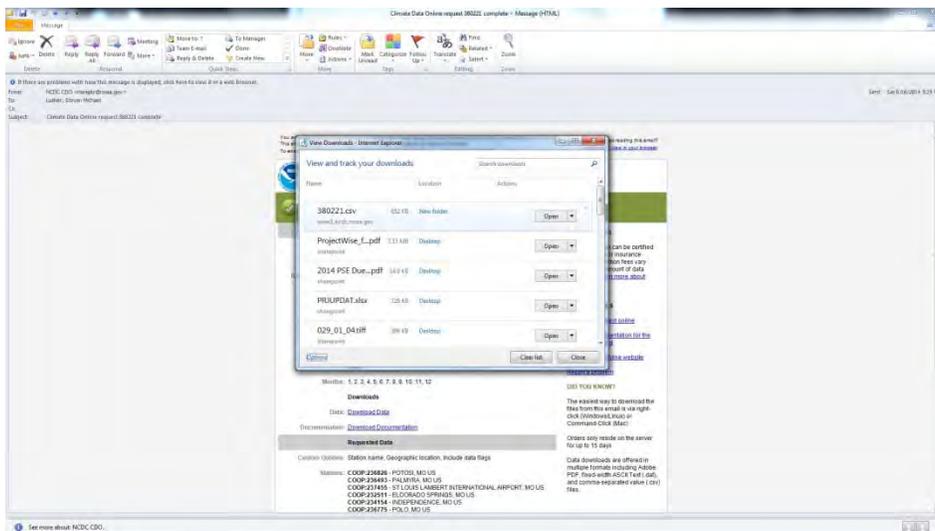
When one clicks on the “Download Data” link, your internet browser will open allowing for downloading capability. The next image shows what may happen, depending on your setting, if one uses Internet Explorer.





*Fig. 3.27 –Internet Explorer file download “save as” screenshot.*

For this example, the file was “Saved As” to a location of one’s choosing.



*Fig. 3.28 –Internet Explorer file download “complete” screenshot.*

Each downloaded file has its own unique filename. In this example, it is “380221.csv” and can be opened in Excel.

Details of the file contents will not be discussed here.

### **3.6 Miscellaneous MoDOT Pavement Data Sources**

There are other sources of pavement data available throughout MoDOT's divisions; unfortunately, many of these sources are difficult to access and all are difficult to implement within a pavement management framework.

#### **3.6.1 Coring Data**

Non-construction acceptance core data that is collected for project-scoping purposes is archived electronically in the specific project folder-of-interest by the Construction and Materials division.

#### **3.6.2 Non-Destructive Evaluation Data**

FWD data that is collected for project-specific purposes is archived electronically by the Construction and Materials division.

#### **3.6.3 Culverts and Other Construction**

Construction records for culverts and other assets often include incidental information regarding pavement cross-section. It would be beneficial to record this data and transmit it to the pavement group for potential decision making regarding future pavement treatments and for implementation into the pavement management database.

### **3.7 Summary and Conclusions**

Data sources for MoDOT's pavement management system are summarized in Table 3.1. The table describes the information presented in each data source, how to access each data source, and provides additional comments on the data sources as necessary.

Table 3.1 – Summary of Data Sources

Data Source	Description of Data	How to Access	Other Comments
ARAN Video	Still images of all roadways from the video records of MoDOT's ARAN van.	Link on TMS homepage.	
ARAN Inventory Tables	Raw IRI data; a record every 0.02 mile or about 105 feet. Other pavement data similar to that in the SS Pavement database is also available.	A pass-through query system within MoDOT Planning Division created Microsoft Access database files	A specialized process not generally available.
SS Pavement	Database of pavement data, including route information, pavement performance (IRI, condition index, cracking, rutting), and traffic.	Database files are available through MoDOT Planning Division. The files can be used with database software (e.g. Microsoft Access) for searching or with GIS software (e.g. ESRI ArcMap) for visualization.	Dynamic segmentation can result in log mile changes from year to year.
Rag Maps	Plan view of routes in a county with notes showing the extents and listing the general summary of projects and major maintenance along the route.	<a href="http://wwwi/intranet/tp/products/projecthistory/projecthistorymaps.htm">http://wwwi/intranet/tp/products/projecthistory/projecthistorymaps.htm</a>	History dates back to the 1920s and typically continues until the 1990s.
STIP Management	Database of projects completed through MoDOT's STIP. Projects can be searched by job number, route, district, and county.	Link on TMS homepage.	Project records on the STIP database often include construction plans.
Asphalt Summary Sheets	One set of asphalt summary sheets comprises a table of asphalt work for the table year. The table lists a project number, log miles, treatment type, and treatment history for each project.	Research team scanned all asphalt summary sheets and provided files to MoDOT.	
Concrete 2-AA Sheets	As-built summary sheets for concrete paving projects, including detailed information on the pavement (typical section, materials used and their source, subgrade, concrete mix proportions, reinforcement, joints, etc.)	Research team scanned all concrete 2-AA sheets and provided files to MoDOT.	

<b>Data Source</b>	<b>Description of Data</b>	<b>How to Access</b>	<b>Other Comments</b>
District Maintenance personnel	In-house pavement maintenance data such as surface treatment type, location, and date; e.g. chip seals, scrub seals, fog seals, as well as contract overlays	District pavement specialists and/or maintenance superintendents: electronic spreadsheets or personal interview	Collection of this type of data is still underway.
Traffic	AADT counts and commercial volume data are presented on ARAN page and in SS Pavement database. Additional traffic data is available through TR 50 reports.	See above for ARAN and SS Pavement info. TR 50 reports are generated on the TMS webpage. From the homepage, select reports link and then traffic reports.	Traffic data from ARAN was primary source for Task 1 collection efforts. There are directional differences in AADT for larger roads.
Subgrade	Project-specific data may be available (e.g. Concrete 2-AA sheets). Specific data related to subgrade can be found in Preliminary Geotechnical Reports. More general data can be found in the Geology & Soils Manual and updated files.	Preliminary Geotech Reports can be obtained from the Soils & Geology section. County soil surveys can be downloaded from <a href="http://websoilsurvey.nrcs.usda.gov/app/">http://websoilsurvey.nrcs.usda.gov/app/</a>	
Climate	Climate data is available through NOAA.	<a href="http://www.ncdc.noaa.gov/">http://www.ncdc.noaa.gov/</a>	
Pavement Cores	Pavement material and thickness	Archived electronically by Construction & Materials in project-specific files	
Non-Destructive Evaluation	FWD data	Archived electronically by Construction & Materials in project-specific files	
Other Construction Data	Construction of other assets (e.g. culverts) often results in incidental data about pavement cross-sections.	Data not collected at present	

## **4 PROCEDURE FOR PAVEMENT DATA RETRIEVAL AND RESULTS**

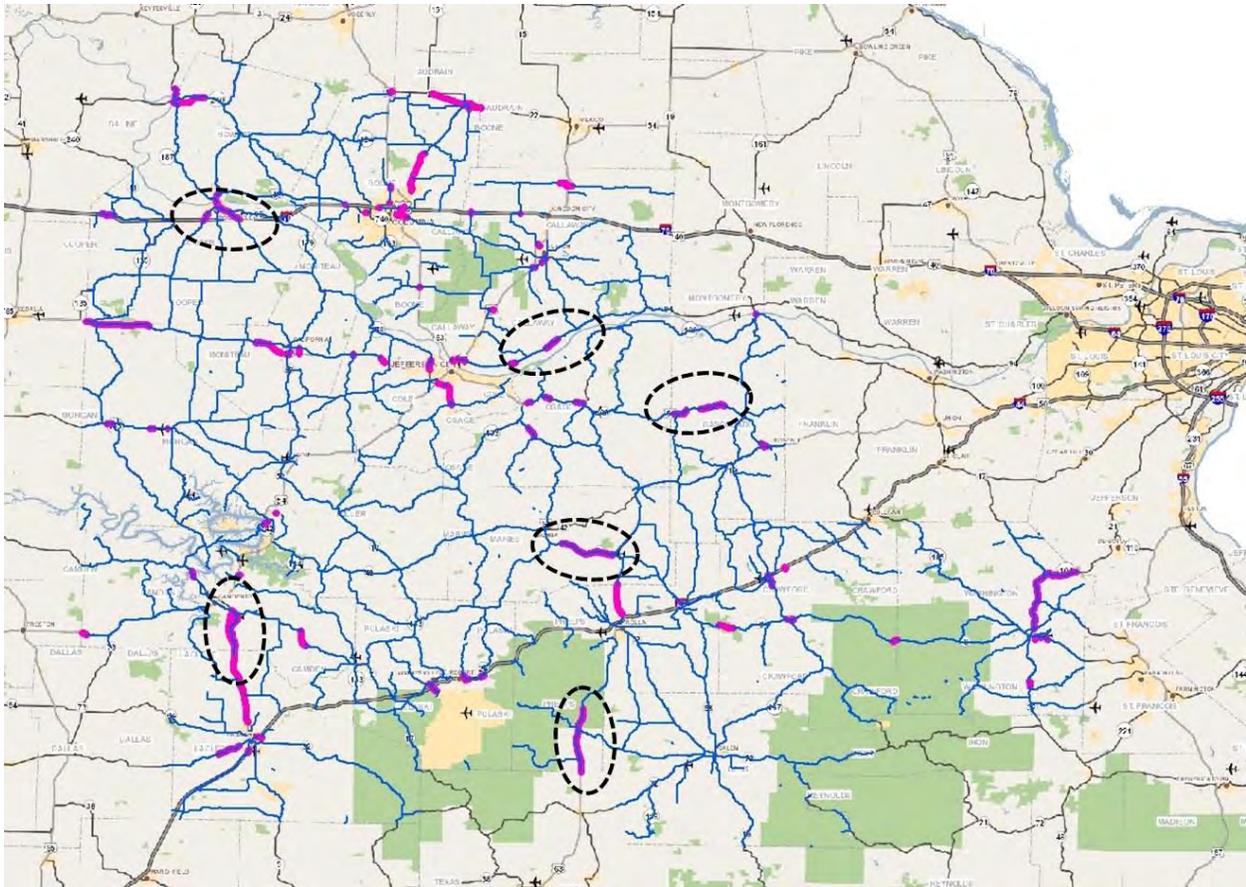
The data sources described in Chapter 3 were used to collect data for use in other tasks, primarily Tasks 2 and 5. Task 2 used the data collected from Task 1 to develop pavement family and treatment models. Task 5, in turn, used the Task 2 models to develop decision processes. This chapter describes the Task 1 data collection efforts and presents example results. The data were ultimately gathered into a spreadsheet termed “Pavement Family Model Working File”.

### **4.1 Procedure**

The procedure for mining pavement data from the MoDOT data sources described in Section 3 involved identifying candidate roadways, collecting raw data for those roadways, processing the data to improve its usefulness for subsequent tasks, and preparing it for presentation to the other tasks. These steps are described in further detail in the sections below.

#### **4.1.1 Select Roadway Segments**

Selection of roadway segments was conducted in close coordination with Task 2, which developed pavement family models. Pavement families were defined by pavement type (e.g. full-depth asphalt, concrete, or composite) and traffic level (for the full-depth asphalt family, there were four traffic levels based on AADT: less than 400, 400-750, 750-1700, 1700-3500). “Full-depth” was defined as an asphalt pavement with no concrete in the cross-section. Very few pavements were truly full-depth, but actually had some unbound granular base beneath the asphalt. Ten candidate routes for data collection were identified for each pavement family using ArcMap with SS Pavement data as shown in Fig. 4.1. At the suggestion of the MoDOT Research leadership, for most families, all routes were selected from the central district to serve as a model of how the rest of the state pavement system should eventually be brought into the PMS. Routes were selected from across the district, usually three north of the Missouri River and seven south of the Missouri River, to provide some geographic and subgrade variability.



*Fig. 4.1 – Example of using ArcMap to find study routes. Highlighted routes are composite pavement sections in the Central District with AADT less than 12,000 on a two-lane undivided roadway.*

After the potential routes were identified, they were screened with the ARAN viewer to delineate continuous and homogenous segments of at least 1 mile in length. Homogeneity was defined as having no change in surface type (e.g. overlays or chip seals, bridges, etc.) and no change in speed (speed limits, stop signs, etc.). The result of this step is 20 pavement segments per family, two in either direction along the 10 study routes.

#### **4.1.2 Extract Raw Data from ARAN Inventory and SS Pavement Databases**

Data for the 20 pavement segments were collected by querying the ARAN Inventory tables (for raw IRI, condition index, etc.) and SS Pavement (traffic data) databases using Microsoft Access. The query specified the travelway ID (based on route and direction) and logmiles identified from the previous step. The queried portion of the database was copied to a spreadsheet for further processing as described in the next step. The results copied to the spreadsheet include IRI, directional AADT, and commercial traffic volume, among other fields as described in more detail in Section 3.2.2.

### 4.1.3 Data Processing

Processing the data queried from the ARAN Inventory tables and SS Pavement involved verifying records and supplementing them with additional pavement history data. Pavement history was gathered from the sources described in Section 3.3:

- Rag maps were used to develop an initial summary of pavement history dating back to a road's initial construction.
- Asphalt Summary Sheets were consulted to supplement and confirm the rag map history. The summary sheets were consistent with rag map data and provided some supplementary information regarding pavement thickness.
- Similarly, Concrete-2AA sheets were consulted for concrete sections. All relevant details from the sheets were recorded.
- The STIP Management Database was searched to find plan sets from the last 20 years. Any relevant plan sets were saved and details related to pavement structure, like those from the example typical section of Fig. 4.2, were recorded. Often the typical sections encountered were less detailed, such as the example of Fig. 4.3.
- In regard to Maintenance information, researchers are currently making personal visits to various District Pavement Specialists and Maintenance Supervisors to review the information for each project section in order to 1) verify the data that the researchers have found (see above discussions), 2) add any treatments that were missing in the MoDOT central databases, and 3) review the pavement selection and maintenance planning procedures in-place at the district level. The data is either in spreadsheet form on personal computers, or in individual memories.

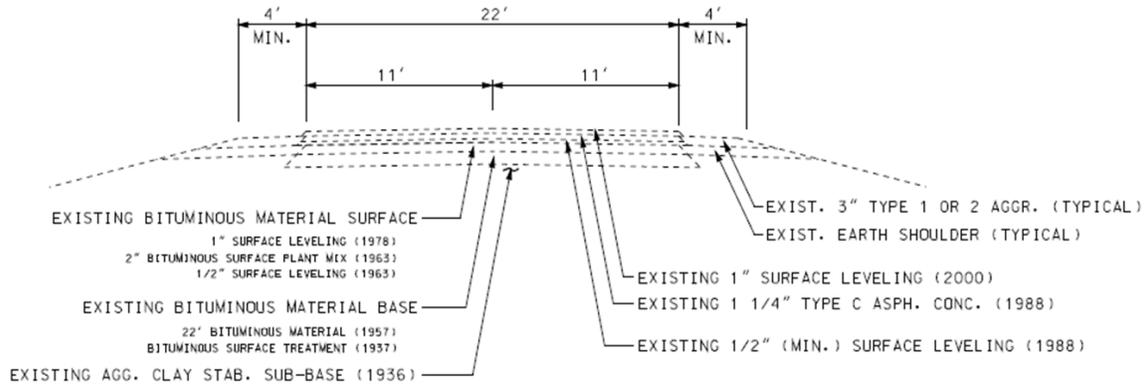


Fig. 4.2 – Example typical detail from project plans.

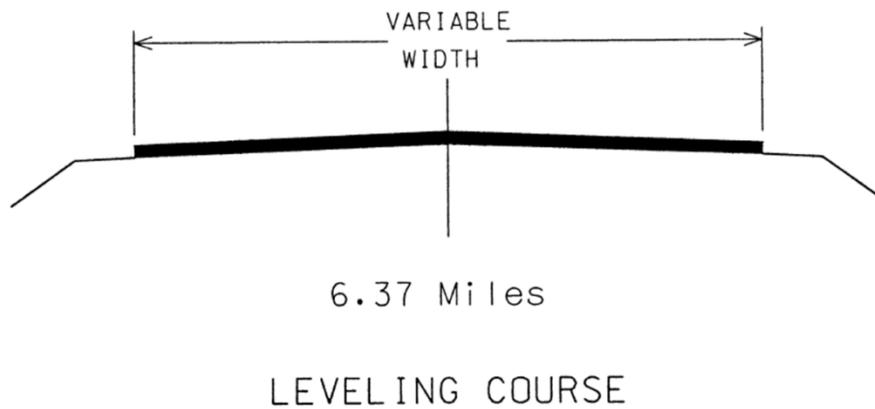


Fig. 4.3 – Example typical section with minimal detail.

Traffic data were also summarized and verified. SS Pavement includes fields (columns in spreadsheet) for directional AADT and commercial volume. These were verified along the route for the last five years using traffic data listed on the ARAN viewer site. A table of traffic counts from both SS Pavement and ARAN for the past five years was created, as in the example of Table 4.1. Typically, both data sources were consistent.



Table 4.1 – Example table of traffic counts

Year	Direction	ARAN		SS Pavement	
		AADT	ComVol-by-dir	AADT	ComVol-by-dir
2008	South	1711	147	1470	236
2009	South	1708	146	1708	146
2010	South	2177	278	2177	278
2011	South	2155	277	2155	277
2012	North	1833	241	2133	274
"Current"		1833	241		

Finally, a detailed review of all ARAN video records for each route was conducted. The review included all video records available with the TMS viewer; typically the review included about 10 years of data. For each year, detailed notes such as the example in Fig. 4.4 were recorded to note any observations related to pavement condition and/or surface changes.

ARAN NOTES

...

2007  
-Road in same condition as previous year, but showing significantly more wear.

2008  
-Small Intermittent patching, spaced every 20' (Pot holes, shoulder reinforcement, center filling) 1755-1785

-Northbound Patch at 175.0915 for 5' (Center of lane)  
-Northbound Patch at 175.1225 for 5' (Center of lane)  
-Northbound Patch at 175.1385 for 5' (Center of lane)  
-Southbound Patch at 175.1695 for 2' (edge Patch)

*...omitting 100 lines...*

-Northbound patch at 177.936 for 10' (median)  
-Northbound patch at 177.998 for 10' (Median)  
-Northbound patch at 178.013 for 10' (median)  
-Northbound patch (median)  
-178.029  
-178.06  
-178.076

Fig. 4.4 – Example of notes of observations from ARAN video records.

#### 4.1.4 Data Presentation

The results for each study route were compiled in the spreadsheet file originally extracted from the ARAN Inventory tables and SS Pavement. Pavement history was indicated in additional columns regarding treatment types and thicknesses, with color highlighting used to indicate changes. Traffic tables (e.g. Table 4.1) were added to each spreadsheet file, and graphics related to pavement history were also pasted into the spreadsheet file (e.g. Fig. 3.2, Fig. 4.2). Finally, a summary of ARAN notes was included in a textbox (e.g. Fig. 4.4) in the spreadsheet file.

## 4.2 Results

The procedure outlined in Section 4.1 was implemented for many families, most of which had 10 study routes. This section summarizes the work completed, references, and explains how the work has been communicated with other tasks from the Pavement Preservation Research program.

### 4.2.1 Summary of Study Routes

Table 4.2 shows the selected concrete/composite pavement sections for analysis. A range of AADT values indicates changes in traffic counts due to the travelway section encountering an intersection but without a reduction in travel speed. The SS Pavement query parameter was set to less than or equal to 12,000 AADT. The AADT range was increased from that used for asphalt sections (<400-3500) to garner more sections.

*Table 4.2 – Concrete/composite sections for analysis*

Location				Current AADT
County	Travelway Designation/Name	Travel Direction	Beginning/Ending Logmile (current)	
Grundy	MO 6	East	70.9/76.2	1060 to 2324
St. Francois	MO 8	East	63.6/68.35	3019 to 6657
Lawrence	MO 174	East	4.05/6.25	1308
Cooper	RT M	South	0.06/3.97	184
Schuyler	US 63	South	13.7/15.8	2224 to 2381
Grundy	US 65	South	23.53/26.53	777 to 984
Butler	US 67	South	186.64/191.84	2203 to 2489
St. Francois	MO 32	East	242.2/244.3	890 to 1024
Cooper	MO 87	South	22.63/24.7	2074 to 2357
Monroe	US 24	East	160.1/162.8	843 to 1052
Pettis	US 50	East	173.4/176.7	2194 to 3737
Phelps	US 63	South	204.6/207.4	2609
Phelps	US 63	South	233/237.5	1732 to 2023

Table 4.3 shows the selected full-depth asphalt pavement sections for analysis. The AADT range was the one of the SS Pavement query parameters and was used to assign a particular section to a pavement family.

**Table 4.3 – Full-depth asphalt sections for analysis**

Location				AADT Range
County	Travelway Designation/Name	Travel Direction	Beginning/Ending Logmile (current)	
Washington	MO 21	South	60/66	1700 to 3500
Morgan	MO 52	East	129.1/137.1	
Laclede	MO 32	East	93.8/97.1	
Phelps	RT BB	East	4/11	
Pulaski	RT T	South	0.6/4.6	
Moniteau	MO 5	South	175/178.5	
Cole	RT C	East	28.1/33.1	
Boone	MO 124	East	27.2/31.2	
Callaway	RT F	East	6.7/8.8	
Gasconade	MO 28	East	57.7/63.7	
Washington	MO 47	South	91/96	
Gasconade	MO 19	South	107.8/111.2	
Pulaski	MO 17	South	31.7/35.2	
Camden	MO 7	South	134/138.6	
Cooper	MO 135	South	0.82/5.82	
Laclede	MO 64	East	41/46.9	
Boone	RT E	South	0/10	
Howard	MO 240	East	43.8/47.4	
Callaway	RT C	South	1.94/6.34	
Dent	MO 32	East	176.9/179.9	
Washington	MO 185	South	39.7/45.7	400 to 750
Osage	RT T	South	1.9/6.9	
Miller	MO 17	South	8.7/11.7	
Pulaski	MO 133	South	45.8/50.2	
Phelps	RT F	East	9.1/13.3	
Morgan	RT W	South	1.5/10.5	
Laclede	RT J	East	1.8/9.1	
Howard	MO 3	South	69.7/73.5	
Boone	RT N	South	0.2/5.6	
Callaway	RT B	East	3.3/6.7	
Osage	MO 133	South	6/12.4	
Crawford	RT M	South	1.1/5.9	
Dent	RT K	South	5.3/13.3	
Camden	RT J	South	4.1/8.1	
Cooper	RT J	East	6.7/15.5	
Howard	MO 87	South	5.4/10.4	
Cole	RT E	East	1.3/5.5	
Boone	RT HH	East	1.8/5.3	
Callaway	RT D	South	4.3/12.2	
Gasconade	RT Y	East	0.1/5.7	

#### **4.2.2 Coordination with Other Tasks**

Coordination between Tasks 1, 2, and 5 was relatively seamless because several of the various Task team members were on all three teams.

## 5 CONCLUSIONS AND RECOMMENDATIONS

This report has detailed the MoDOT, NOAA, and USDA data sources pertinent to pavement management and the data collection efforts undertaken to assist in development of MoDOT's pavement management system. Included in this chapter is a summary of these efforts and recommendations for improvements to the data collection methodology.

### 5.1 Pavement Data Sources

MoDOT data sources useful for the development of a pavement management system were described in Chapter 3. Table 3.1 summarized the data sources, how to access them, and important notes on their use.

### 5.2 Data Collection Procedure

The MoDOT pavement data sources were used to collect sufficient data for use by other tasks within the Pavement Preservation Research program, primarily by Task 2 (modeling of pavement families and treatments) and Task 5 (development of treatment triggers and decision methods). The procedure for collecting data involved identifying homogenous sections meeting the criteria for each family (i.e. pavement type and traffic level), querying databases to collect raw data, verifying the raw data and supplementing it with pavement history and ARAN video observational data, and preparing the data for presentation to other tasks. This procedure was sufficient for the Pavement Preservation Research program data needs, but it is rather labor intensive, and efficiency improvements would result in major time savings for an implemented pavement management system. Recommendations related to these efficiency improvements are presented below.

### 5.3 Completed Work

The following data sources have been successfully accessed. Included in the list is basic information about the data gathered from them.

- SS Pavement databases: Current (active) and Historic (1999 up to active)
  - Dynamically segmented records; i.e. pavement section lengths per record are variable
  - Data includes ARAN year, roadway name and travelway ID, locations (e.g. county, beginning and ending logmiles), roadway type and functional classifications, condition parameters (e.g. IRI, condition index, individual distress indices), traffic (AADT and commercial volume), most recent surface type and date
- ARAN databases: Survey (2000 to active, inclusive) and Historic (1988 to 1999, inclusive)
  - Raw ARAN data; i.e. each record represents approximately 0.02 miles (~105 feet) of pavement

- Data includes ARAN year, date that the data was collected (mm/dd/yyyy), roadway name and travelway ID, locations (e.g. county, beginning logmile), same condition parameters as SS Pavement
- Project History Maps, a.k.a. Ragmaps (MoDOT Intranet)
  - Construction history: location, date, type of pavement surface, project job numbers
- 2-AA Sheets and Asphalt Summaries (hard copy scans)
  - Historic as-built information
    - 2-AA sheets: concrete pavement projects; data can be very comprehensive and includes location (stationing), concrete mix design, structural thicknesses, base and subgrade information
    - Asphalt summaries: much of the data corresponds to that on the ragmaps; route, county, date construction completed, project job number and approximate location, existing base/subsurface (historic), surface being constructed (depending on the year, mix type and thickness, tons/mile, begin-end logs)
- Archived Project Plan Sheets (MoDOT Z-drive)
  - Project plan drawings in PDF file format: typical section drawings, geometries, quantities, etc.
- STIP Management (MoDOT Intranet: TMS)
  - An additional portal for finding more recently archived project plan files
- ARAN Viewer (MoDOT Intranet: TMS)
  - Primary method for visual verification of information already gathered, and determining if a treatment occurred that was not documented in databases
    - SS Pavement data can be accessed (back to and including 2003)
    - Most recent project plan drawings associated with section of interest may be available
- TR50 Reports (MoDOT Intranet: TMS)
  - Primarily traffic data (AADT and commercial)
- Historic State Highway Maps (MoDOT Intranet)
  - Annually published maps that indicate roadway surface type; can help determine when a pavement section was originally paved
- USDA county soils maps
  - County maps that indicate soil properties, extent, depth, and position
- NOAA climate data
  - Various types of precipitation and temperature data

## 5.4 Remaining Work

The following data sources have been *identified*, but *not fully accessed and/or utilized*. Included in the list is basic information about the data that is *hoped to be gathered* from them.

- Individualized working files (spreadsheets) created by district pavement specialists and maintenance supervisors have been and still are being investigated, specifically to verify and supplement (if needed) treatment data already collected for the project roadway sections
  - District pavement specialists have indicated that historical pavement data (e.g. new construction and maintenance activities), and future planning information (e.g. treatment types and when to be applied) based on that history is sometimes available on an individual basis
  - District maintenance supervisors have indicated that information similar to that collected/created by pavement specialists may be available on a more local maintenance jurisdiction basis
- dTIMS dBase files: select files from MoDOT’s previous pavement management system supplied by John Donahue
  - Low confidence data that includes route names, locations, traffic, and of greatest interest, structural information (e.g. base and surface thicknesses at a particular date, and material types)

## 5.5 Pavement Data Recommendations – “Ideal Situation”

The primary purpose of the project was to outline a *process* that would allow MoDOT to do more selective planning, better engineering, and more effective maintenance in order to minimize costs while maintaining adequate safety and performance of Missouri’s pavements. The project researchers envisioned developing a *user-friendly, single online portal* that would allow pavement engineers, district pavement specialists, and district maintenance supervisors to access *all data* pertinent to their particular tasks, *without leaving their desks or requesting special access methodology*.

In addition to all of the databases and other data sources outlined in section 5.3, the Pavement Tool (maintenance-oriented) should be incorporated into the single portal. The Tool could be improved by adding features such as the following, thereby allowing more input flexibility for district maintenance personnel:

- More treatment type choices and details (e.g. limestone or trap rock chips)
- Milling details such as depth of cut and transverse location of milling-machine passes
- Bituminous treatment thickness data whether input directly or estimated based on tonnage, design mix density, project width and length
- Specific bituminous mix types

It would be beneficial to pavement engineers to be able to access construction data from SiteManager through the single portal. Because material sampling and testing data collected during a project is entered into SiteManager, detailed information such as core data (as-built density and layer thickness,[especially if full-depth coring information is available as recommended elsewhere in this document]) and mix characteristics (which may raise red flags and prompt requests for more detailed data, such as coring), may help fine-tune the decisions made by planners on a future treatment selection for that project section. If the ProjectWise (engineering) application and the SAM II (maintenance costs) database supply valuable, pertinent capabilities, they, too, should be easily accessible through the single portal.

Developing and implementing the scenario outlined above will require considerable effort. Some of the details involved with improving the current system and processes that will continually update any future system are discussed below.

### **5.5.1 Immediate Improvements**

All of the MoDOT stakeholders should be called together to discuss their needs and expectations for going forward, and develop a plan for doing so. Stakeholders will probably include personnel from divisions of Design, Planning, Construction and Materials, and Maintenance at both the District and central levels. It is imperative that the stakeholders are quickly educated about the shortcomings of the current system, from all perspectives.

### **5.5.2 Short-term Improvements**

District pavement specialists that have been contacted have indicated that efforts are underway to find missing historical data in the various data repositories. These efforts should be moved up the priority list. Subsequently, existing data should be subjected to intense quality control inspections. One of the consequences of the Task 1 (and corresponding Task 2) activities has been identification of missing data, data entry errors, placeholder entries, redundancies and terminology inconsistencies across databases. The following is a list of some of those findings:

- Fields of interest in SS Pavement, etc., are incomplete; i.e. a significant amount of historical data needs to be recovered, checked for accuracy, and added to existing databases
- Some of the Surface Type and Surface Date records in SS pavement are not accurate in that they do not always reflect the traveled lane associated with a specific record. It was discovered that data in these fields sometimes actually referred to work recently performed on the shoulder or left/right turn lanes rather than the traveled way. Creating fields for more specific roadway features would be helpful.
- In some cases, the Surface Type recorded did not correlate with the distress indices for the same section of roadway. This may be connected to the previous bullet-point.
- SS Pavement location description errors; intersecting routes are shown in wrong counties



- SS Pavement irrational concrete surface type changes; PCN for many years then designated as PCR for 2010 and 2011
- The ARAN tables also contained some errors. For example, IRI values of 999 or entire ARAN years where the condition index or IRI was non-changing across the length of a roadway section.
- Although it may be impossible to rectify, the IRI values during the ARAN years of 1997 to 2001, inclusive were reportedly incorrect due to an algorithm error. This data was disregarded during modeling.
- In the ARAN tables, the driver and passenger IRI are recorded every 0.02 mile. It was found, fairly regularly, that errors in one or the other (usually the passenger IRI) existed which would have adversely skewed the average or raw (Unit) IRI value. The understanding is that mechanical issues in the ARAN van (e.g. bad accelerometers, calibration, etc.) were most likely the cause of this error.

## 5.6 Recommendations for Future Work

Regarding future data collection and storage, standardization of the various database fields and record entry descriptions (and codes) across *all* stakeholder departments would be extremely beneficial. The language and terminology used by the maintenance personnel should translate effortlessly with the pavement engineers, materials technicians, construction inspectors, etc.

Characterizing the structural configuration of existing roadways would be extremely helpful in improving the treatment selection process and the upgrading of performance models. It is evident that coring is the most reliable method for determining structural layer thickness, material makeup, and current condition. It is understood that this is an expensive recommendation, but it may be economically feasible to incorporate random coring during construction projects. For example, take one full-depth core (including sufficient subgrade) at some optimum frequency as part of the QC/QA process during projects involving Sections 401 and 403 mixes when cores are being cut anyway. The thing is that this full-depth coring would only have to be done once on any given section of Missouri's roadways. Once documented, those existing structures would remain as such unless significant rehabilitation/reconstruction occurred. Over time, a considerable amount of full-depth core data could be accumulated with a minimal amount of effort.

Any other activity that may lend itself to documenting the existing pavement structure characteristics should be considered. For example, culvert inspection and/or construction, or utility work may be conducive to evaluating the state of the pavement structure, eg. thickness and type of layers. Again, some sort of centralized documentation procedure would be necessary.

The technology exists at this time to augment the ARAN capabilities with more objective methods of evaluating different pavement distress measures; e.g. video-based evaluation and

analysis of crack severity and extent. Consideration of moving to this new technology should be in any plan going forward.

The issue of continuing to use logmiles has been ongoing. Fields for longitude and latitude are currently in the ARAN tables and partially populated. Adopting a GPS approach to locations of state assets should be in any future plan.

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## **APPENDIX 1A – SS PAVEMENT DATABASE DEFINITIONS**

This document defines fields used to populate the SS Pavement database. It was prepared by MoDOT.

**DATE CREATED:** 10/23/2002

**DATE MODIFIED:** 08/02/2011

## **SS\_PAVEMENT**

### ***Description***

Each SS\_PAVEMENT record represents pavement breaks on a Traffic Information Segment. A pavement break may be caused by a change in surface type, surface width, city limits, etc. This is one of the tables used to generate our yearly State of the System report.

<b><i>NAME</i></b>	<b><i>DESCRIPTION</i></b>
AADT	Annual Average Daily Traffic. The estimate of typical daily traffic on a road segment for all days of the week, Sunday through Saturday, over a period of one year.

ACCESS\_CAT\_NAME Describes the accessibility of a SS\_PAVEMENT route.

<b><i>NAME</i></b>	<b><i>DESCRIPTION</i></b>
FULL	FULL ACCESS CONTROL
LIMITED	PARTIAL ACCESS CONTROL
NONE	NO ACCESS CONTROL

ARAN\_YEAR Year the ARAN data was collected.

ARC\_ID\_BEGIN The unique identifier of the arc where the segment begins.

ARC\_ID\_END The unique identifier of the arc where the segment ends.

ARC\_REF\_BEGIN The direction on the arc where the segment begins.

ARC\_REF\_END The direction on the arc where the segment ends.

AREA\_DESG\_NAME The name of the area designation for this range.

<b><i>NAME</i></b>	<b><i>DESCRIPTION</i></b>
METROPOLITAN	OVER 200,000 POP.
RURAL	LESS THAN 5,000 POP.
UNDESIGNATED	UNDESIGNATED
URBAN	5,000 - 50,000 POP.
URBANIZED	OVER 50,000 - 200,000 POP.

AREA_ENGINEER	Name of the area engineer where the segment falls in.
AVERAGE_IRI	Average of driver and passenger wheel path (International Roughness Index)
BEG_CONTINUOUS_LOG	The begin continuous log unit defines the beginning of a travelway range or segment. Continuous log units increase throughout the entire length of the travelway and do not change when crossing county lines.
CENTERLINE	Centerline mileage for each ss_pavement record. Centerline mileage is calculated for travelways with directions of South and East.
CITY_ID	Unique identifier for a City.
CITY_NAME	The city in the City's official mailing address.
CNTL_BEG_CONT_LOG	The begin continuous log unit defines the beginning of a controlling travelway range or segment.
CNTL_END_CONT_LOG	The end continuous log unit defines the ending point of a controlling travelway range or segment.
CNTL_TW_DESG	Route designation for the controlling route.

<b>CODE</b>	<b>DESCRIPTION</b>	<b>HIERARCHY</b>
AL	ALTERNATE ROUTE	4
ALY	ALLEY	22
BU	BUSINESS	7
CO	CONNECTOR FOR WYE LEG	14
COE	CORP OF ENGINEERS	20
CRD	COUNTY ROAD	12
CST	CITY STREET	11
DOD	DEPARTMENT OF DEFENSE	21
FWS	FISH WILDLIFE SERVICE	19
IS	INTERSTATE	1
LP	LOOP (INTERSTATE ONLY)	6
MO	MISSOURI NUMBERED ROAD	3
NFS	NATIONAL FOREST SERVICE	17
NPS	NATIONAL PARKS SERVICE	18
OR	OUTER ROAD	10
PED	PEDESTRIAN	25
PK	PARK	26
PVT	PRIVATE	23
RA	REST AREA	15
RP	RAMP	13

RR	RAILROAD	24
RT	MISSOURI LETTERED ROUTE	5
RV	REVERSIBLE	9
SP	SPUR	8
US	US NUMBERED ROUTE	2
WS	WEIGHT STATION	16

CNTL\_TW\_DIRECTION      Direction of the controlling route.

CODE	DESCRIPTION
E	EAST
N	NORTH
S	SOUTH
W	WEST

CNTL\_TW\_ID              Unique route identifier for the controlling route.

CNTL\_TW\_NAME          Name of the controlling route.

CNTL\_TW\_OFFSET        Offset direction for the controlling route. It is used in conjunction with outer roads.

COMM\_VOL\_BY\_DIR        The total commercial volume for a specific travelway segment by directions.

CONDITION\_INDEX        The sum of distresses that apply to a pavement. For Asphalt it is the sum of F Cracking, F Patching, Raveling, and Rut Index. For Concrete, it is the sum of Joint Condition, C Cracking, C Patching, D Cracking, and Spalling.

COUNTY\_NAME            Official name of the county that the SS\_PAVEMENT record falls in. *Joins with COUNTY.*

COUNTY\_NUMBER         Unique identifier for the Counties within the state that the SS\_PAVEMENT record falls in.

CRACK\_INDEX\_FLEX        Rating assigned to the amount of cracking on asphaltic concrete.

CRACK\_INDEX\_RIGID      Rating assigned to amount of cracking on PCC (Portland Cement Concrete). Ratings are derived from a visual analysis of severity and extent with 0.0 (worst) to 5.0 (best).

DESG\_BYWAY\_CLS\_NM     Names and identifies a Designated Scenic Byway Classification.

DESG\_TRUCK\_RTE\_NM     Classification for the travelways for Federal or State designated truck routes.

DIRECTIONAL	Indicates the direction of the inventory route.
DISTRICT	The MoDOT District number that the SS_PAVEMENT record falls in.
DIVIDED_UNDIVIDED	Indicates if the travelway is divided or undivided. A divided travelway is a travelway with any type of barrier or four-foot or greater flush median.
END_CONTINUOUS_LOG	The end continuous log unit defines the ending point of a travelway range or segment.
FED_CLS_NFS	Federal System Classification name - 'National Forest System.'
FED_CLS_NHS	Federal System Classification name – 'National Highway System.'
FED_CLS_PRIORITY	Federal System Classification name – 'Congressional Priority.'
FED_CLS_STRAHCON	Federal System Classification name – 'Strategic Highway Network Connector.'
FED_CLS_STRAHNET	Federal System Classification name – 'Strategic Highway Network' that is assigned to truck routes.
FED_CLS_UNCLASS	Federal System Classification name - 'Intermodal Connector.'
FED_SYS_CLS_NAME	A unique identifier for the Federal System Classification.

<b>NAME</b>	<b>ABBR</b>	<b>DESCRIPTION</b>
CONGRESSIONAL PRIORITY	CHP	CONGRESSIONAL HIGH PRIORITY ROUTE
CORPS OF ENGINEER	CORP	CORPS OF ENGINEER
FEDERAL AID INTERSTATE	FAI	HISTORY – NOT ACTIVE
FEDERAL AID PRIMARY	FAP	HISTORY – NOT ACTIVE
FEDERAL AID SUPPLEMENTARY	FAS	HISTORY – NOT ACTIVE
FEDERAL AND URBAN	FAU	HISTORY – NOT ACTIVE
INTERMODAL CONNECTOR	IC	INTERMODAL CONNECTOR
NATIONAL FOREST SYSTEM	NFS	FOREST ROAD
NATIONAL HIGHWAY SYSTEM	NHS	NATIONAL HIGHWAY SYSTEM
STRAHNET	STR	STRATEGIC HIGHWAY NETWORK STRAHNET
CONNECTOR	STR-C	STRATEGIC HIGHWAY NETWORK CONNECTOR



FUNC\_CLASS\_NAME

This table names and describes the type of functional classification used to categorize a travelway.

### Rural

- 1 Interstate** – The interstate Highway System provides service for long distance trips. These trips may begin and end in Missouri, travel through Missouri, or begin or end in another state. All cities with a population of 50,000 or more, are served by an Interstate route. Interstate highway standards are such that speeds are high. Access is fully controlled on Interstates, which means entering and leaving the Interstate can only be done at an interchange.
- 2 Principal Arterial** – Principal Arterials serve long distance through trips within a state or from state to state. Together with the Interstate System they serve nearly all cities with a population of 5,000 or more. They also serve major recreational areas. These routes should be two-lane, limited access or fully controlled access divided highways. Provisions should be made to limit traffic interruptions on principal arterials.
- 6 Minor Arterial** – Minor Arterials serve moderate length trips within or between counties. They connect almost all the remaining cities with population over 1,000, and provide access to the Principal Arterial or Interstate Principal Arterials, most of the Minor Arterials are two-lane routes.
- 7 Major Collectors** – Major Collectors primarily serve trips within a county. They link the county seat and any larger towns, if not on an arterial, to the arterial system. In addition, the Major Collectors provide service to traffic generators of countywide importance, such as; consolidated schools, shipping points, other modes of transportation, important mining or agricultural areas, state parks and recreational areas.
- 8 Minor Collectors** – The Minor Collectors link the remaining communities and locally important traffic generators to a Major Collector or arterial route.
- 9 Local** – The local road system provides access to adjacent land along its entire length. Trips are relatively short and at low speeds. The Local functional classification accounts for all mileage not included in the collector or arterial systems.

## URBAN

- 11 Interstate** – The urban Interstate routes provide "cut through" the urban area or travel around the urban area on or near its perimeter. As with the rural Interstate System, these routes are fully access controlled to encounter as little traffic interruption as possible.
- 12 Other Freeway and Expressway** – These routes serve relatively long trips within an urban area. The speeds are not as fast as on the Interstate System but are generally high. Because the emphasis of the Other Freeway and Expressways is on traffic mobility, these routes should be fully or partially access controlled.
- 14 Other Principal Arterial** – The Other Principal Arterials provide relatively direct routes to major urban attractions, not on the Interstate or Other Freeway and Expressway system. These trips are also relatively long. The Other Principal Arterials also provide continuity to rural arterials, which intercept the urban boundary. Any direct access to adjacent land is purely incidental.
- 16 Minor Arterial** – The Minor Arterial system should connect and supplement the principal arterials and provide service to trips of moderate length at a lower degree of mobility than the principal arterials.
- 17 Collector** – The Collector channel traffic from residential, industrial, or commercial areas to the arterial system. Conversely, they channel traffic from the arterials into such areas. Because they provide a higher degree of land access than the arterial system, speeds are lower than on the arterials.
- 19 Local** – Local streets provide access to abutting land along their length, and to the collector and arterial systems. The local functional classification includes all urban mileage that is not on a higher system.

INTERCHANGE_ID	Unique identifier of the interchange if the SS_PAVEMENT record falls within an interchange.
INTERSECTION_NO	Unique identifier for a Travelway Intersection.
JOINT_INDEX_RIGID	Rating assigned to amount of joints on PCC (Portland Cement Concrete). Ratings are derived from a visual analysis of severity and extent, and a range from 0.0 (worst) to 5.0 (best).
LANE_COLLECTED	Visual lane number of the lane for which the ARAN data was collected.
LANE_MILES	The number of lane miles the project will cover.
LANE_WIDTH	Width in feet of individual driving lanes.
LAST_CHANGE_DATE	The date that the data was last changed in the system.
LAST_CHANGE_USER	The user ID of the individual who made the change to the data

LRPT	Long Range Planning Transportation. Values are 'NHS', 'OTHER Arterial', 'COLLECTOR' or 'NOS'.
MAJOR_MINOR	Major is established by functional class of Principal Arterial and above. The lower classes are considered "Minor".
MSHP_TROOP	Unique identifier for a HP Troop.
NUMBER_OF_LANES	Number of lanes per SS_PAVEMENT record.
OVERLAPPING_IND	Used to indicate if a route is controlling on an overlapping situation. Primary (P), Secondary (S), or Null.
PATCH_INDEX_FLEX	Rating assigned to the amount of patching on Asphaltic concrete.
PATCH_INDEX_RIGID	Rating assigned to the amount of patching on PCC (Portland Cement Concrete). Ratings are derived from a visual analysis of severity and extent, and a range from 0.0 (worst) to 5.0 (best).
PLANNING_ORG	Name of the planning organization that the SS_PAVEMENT record falls in.

<b>NAME</b>	<b>TYPE</b>
BOONSLICK REG PLAN COM	RPC
BOOTHEEL REG PLAN & ECON DEV	RPC
CAMPO MPO	MPO
CATSO MPO	MPO
EWGCC MPO	MPO
EWGCC RPC	RPC
GREEN HILL REG PLAN COMM	RPC
HARRY S. TRUMAN COORD COUN	RPC
JATSO MPO	MPO
KAYSINGER BASIN REG PLAN COMM	RPC
LAKE OZARK COUN OF LOCAL GOVT	RPC
MARC MPO	MPO
MARC RPC	RPC
MARK TWAIN REG COUN OF GOVT	RPC
MERAMEC REG PLAN COMM	RPC
MID-MO REG PLAN COMM	RPC
MO-KAN REGIONAL COUNCIL	RPC
NE MO REG PLAN COMM	RPC
NW MO REG COUN OF GOVTS	RPC
OTO MPO	MPO
OZARK FOOTHILLS REG PLAN COMM	RPC
PIONEER TRAILS REGIONAL COUN	RPC

SE REG PLAN & ECON DEV COMM	RPC
SJATSO	MPO
SO CENTRAL OZARK COUN OF GOVTS	RPC
SW MO ADVISORY COUN OF GOVTS	RPC

PLANNING\_ORG\_NO Unique identifier for a Planning Organization.

PLANNING\_ORG\_TYPE Type of planning organization such as MPO (Metropolitan Planning Organization) or RPC (Regional Planning Commission).

POS\_BEGIN The position on the arc where the segment begins. A percentage from 0 – 100.

POS\_END The position on the arc where the segment ends. A percentage from 0 – 100.

PRIOR\_COUNTY Previous county name.

PSR A 40-point scale representing overall pavement condition. PSR is developed from ratings of individual distresses and roughness, weighted and combined to form a single value.

RAVEL\_INDEX\_FLEX Rating assigned to the amount of raveling on asphaltic concrete.

ROADWAY\_TYPE\_NAME Name of the Roadway Type. *Joins with ROADWAY TYPE.*

<i>NAME</i>	<i>NUMBER OF LANES</i>
3 LANE SECTION	3 Lanes
5 LANE SECTION	5 Lanes
EXPRESSWAY	2 or More Lanes
FREEWAY	2 or More Lanes
MULTI-LANE	2 or More Lanes
ONE-WAY	1 or More Lanes
RAMP	1 or More Lanes
SUPER 2-LANE	2 Lanes
TWO-LANE	2 Lanes
SUPER 4 LANE (PASSING LANE 2+1)	2 or More Lanes

**Freeway:** A divided travelway with full control of access and two or more lanes for through traffic in each direction. All intersections are grade separated (interchanges).

**Expressway:** A divided travelway with limited/partial control of access and two or more lanes for through traffic in each direction. Intersections are normally at-grade, although isolated interchanges are possible.

**Multi-lane:** An undivided travelway with two or more lanes for through traffic in each direction. The access control can be either limited/partial or none.

**3 lane section:** An undivided travelway with one lane for through traffic in each direction and a Two-Way Left-Turn-Lane (TWLTL) as a median.

**5 Lane Section:** A travelway with two lanes for through traffic in each direction and a TWLTL as a median.

**Two-Lane:** An undivided travelway with one lane for through traffic in each direction and is not classified as a Super 2-Lane. May include three lane sections which the third lane maybe either a climbing lane or passing.

**Super 2-Lane:** A travelway with one lane for through traffic in each direction. Lane width is a minimum of 12 feet and has stabilized shoulders with a width greater than 8 feet. May include three lane sections which the third lane is a climbing lane.

**One-Way:** A travelway with one or more lanes for through traffic in one direction only.

**Ramp:** A travelway with limited/partial or no access control which allows movement from one travelway to another travelway. Ramps are usually found at interchanges; however, some at grad intersections may have ramps to reduce turning movements.

**Shared 4 Lane (passing lane 2 + 1):** A travelway with one lane for through traffic in each direction and an additional continuous lane that can be used for passing that will alternate between travelway directions (this does not include climbing lanes).

**RUT\_DEPTH** Displacement of material in a wheel path measured as the difference in elevation of both sides less the elevation of the displaced area with 0.0 (worst) to 5.0 (best).

**RUT\_INDEX** Number assigned to average rutting based on average rut depth.

SHOULDER\_TYPE                      Name of the type of material from which the shoulder is constructed.

<b>CODE</b>	<b>DESCRIPTION</b>
AC	ASPHALTIC CONCRETE
AG	AGGREGATE
BM	BITUMINOUS MAT
BRK	BRICK
CG	CURB AND GUTTER
ERT	EARTH
LC	ASPHALT LEVELING COURSE
MS	MICROSURFACING
OA	OIL AGGREGATE
PC	CONCRETE UNKNOWN REINFORCEMENT
PCN	CONCRETE NON-REINFORCED
PCR	CONCRETE REINFORCED
SLC	SUPERPAVE LEVELING COURSE
SM	STONE MASTIC
SP	SUPERPAVE
SA	SAND
SS	STABILIZED SHOULDERS
TYP1	TYPE 1 AGGREGATE
TYP2	TYPE 2 AGGREGATE
TYP3	TYPE 3 AGGREGATE
TYP4	TYPE 4 AGGREGATE
TYP5	TYPE 5 AGGREGATE
UTA	ULTRA THIN BONDED A
UTB	ULTRA THIN BONDED B
UTC	ULTRA THIN BONDED C

SHOULDER\_WIDTH                      The width of the shoulder surface measured in feet.

SPALL\_INDEX\_RIGID                      Rating assigned to amount of spalling on PCC (Portland Cement Concrete). Ratings are derived from a visual analysis of severity and extent, and range from 0.0 (worst) to 5.0 (best). Spalling is the loss of pieces of concrete pavement from the surface or along the edges of cracks and joints.

SS\_PAVEMENT\_ID                      Unique identifier for an SS\_PAVEMENT record.

STATE\_BRIDGE\_ID                      Unique identifier for State Bridges.

STATE\_SYSTEM\_CLASS                      Describes how a travelway is classified by the Missouri Dept. of Transportation. Values are INTERSTATE, PRIMARY, SUPPLEMENTARY, or NOT ON SYSTEM.

SUBAREA\_LOCATION

SURFACE\_DATE                      Date that the pavement surface was laid.

SURFACE\_TYPE                      The name of the type of material from which the pavement surface is constructed.

<b>CODE</b>	<b>DESCRIPTION</b>
AC	ASPHALTIC CONCRETE
AG	AGGREGATE
BM	BITUMINOUS MAT
BRK	BRICK
CG	CURB AND GUTTER
ERT	EARTH
LC	ASPHALT LEVELING COURSE
MS	MICROSURFACING
OA	OIL AGGREGATE
PC	CONCRETE UNKNOWN REINFORCEMENT
PCN	CONCRETE NON-REINFORCED
PCR	CONCRETE REINFORCED
SLC	SUPERPAVE LEVELING COURSE
SM	STONE MASTIC
SP	SUPERPAVE
SA	SAND
SS	STABILIZED SHOULDERS
TYP1	TYPE 1 AGGREGATE
TYP2	TYPE 2 AGGREGATE
TYP3	TYPE 3 AGGREGATE
TYP4	TYPE 4 AGGREGATE
TYP5	TYPE 5 AGGREGATE
UTA	ULTRA THIN BONDED A
UTB	ULTRA THIN BONDED B
UTC	ULTRA THIN BONDED C

THROUGH\_LANES                      A lane that continues to the next segment without any right or left handed turns.

TMA\_NON\_TMA                      Transportation Management Area (area with population over 250,000 e.g. St. Louis or Kansas City).

TOTAL\_AADT                      The volume for both sides of a travelway added together (divided and undivided).

TRACKER\_CONDITION

TRAVELWAY\_DESG Describes the designation of the route that the SS\_PAVEMENT record resides on.

<b>CODE</b>	<b>DESCRIPTION</b>	<b>HIERARCHY</b>
AL	ALTERNATE ROUTE	4
ALY	ALLEY	22
BU	BUSINESS	7
CO	CONNECTOR FOR WYE LEG	14
COE	CORP OF ENGINEERS	20
CRD	COUNTY ROAD	12
CST	CITY STREET	11
DOD	DEPARTMENT OF DEFENSE	21
FWS	FISH WILDLIFE SERVICE	19
IS	INTERSTATE	1
LP	LOOP (INTERSTATE ONLY)	6
MO	MISSOURI NUMBERED ROAD	3
NFS	NATIONAL FOREST SERVICE	17
NPS	NATIONAL PARKS SERVICE	18
OR	OUTER ROAD	10
PED	PEDESTRIAN	25
PK	PARK	26
PVT	PRIVATE	23
RA	REST AREA	15
RP	RAMP	13
RR	RAILROAD	24
RT	MISSOURI LETTERED ROUTE	5
RV	REVERSIBLE	9
SP	SPUR	8
US	US NUMBERED ROUTE	2
WS	WEIGHT STATION	16

TRAVELWAY\_DIR The direction of the route that the SS\_PAVEMENT record resides on.

<b>CODE</b>	<b>DESCRIPTION</b>
E	EAST
N	NORTH
S	SOUTH
W	WEST

TRAVELWAY\_ID Unique sequence number for the route that each SS\_PAVEMENT record resides on.

TRAVELWAY\_NAME The name of the route that the SS\_PAVEMENT record resides on.



TRAVELWAY_OFST_DIR	Offset direction is used in conjunction with outer roads. If an outer road runs east/west, the offset will be north/south.
TRF_INFO_SEG_DESC	Describes the intersecting street of each traffic segment.
TRF_INFO_SEG_ID	Unique sequence number for the traffic segment that each SS_PAVEMENT resides on.
TRF_INFO_SEG_SEQ	Unique system generated identifier behind TRF_INFO_SEG_ID.
TW_ALIAS_NAME	A commonly used name for a given Travelway or section of travelway.

### **NAME**

1. GREAT RIVER ROAD
3. LEWIS AND CLARK TRAIL
7. ALEXANDER DONIPHAN MEMORIAL HIGHWAY
8. BRUCE R. WATKINS FREEWAY
9. CORPORAL M.E. WEBSTER MEMORIAL PARKWAY
10. GEORGE BRETT BRIDGE
11. GEORGE BRETT SUPER HIGHWAY
13. JAY B. DILLINGHAM FREEWAY
14. TOM WATSON PARKWAY
15. C.F. "RED" WHALEY FREEWAY
17. MARK TWAIN EXPRESSWAY
18. OZARK EXPRESSWAY
19. GENE TAYLOR HIGHWAY
20. PAYNE STEWART HIGHWAY
21. VETERAN'S BRIDGE
22. V.F.W. MEMORIAL HIGHWAY
23. BOB WARD HIGHWAY
24. KOREAN WAR MEMORIAL HIGHWAY
25. ROSA PARKS HIGHWAY
26. PEARL HARBOR MEMORIAL HIGHWAY
27. GEORGE WASHINGTON CARVER MEMORIAL HIGHWAY
28. KOREAN WAR VETERAN'S MEMORIAL HIGHWAY

29. BUTTERFIELD RANCH ROAD
30. AMERICAN LEGION MEMORIAL HIGHWAY
31. TROOPER CHARLES P. CORBIN MEMORIAL HIGHWAY
32. WILLIAM "BILL" LARK MEMORIAL HIGHWAY
33. TROOPER JIMMIE LINEGAR MEMORIAL HIGHWAY
34. CORPORAL BOBBIE J. HARPER MEMORIAL HIGHWAY
35. SHORT LINE SPUR HISTORICAL TRAIL
36. AVENUE OF THE SAINTS
37. SARGEANT ROBERT KIMBERLING MEMORIAL HIGHWAY
38. PONY EXPRESS BRIDGE
39. DAVID RICE ATCHISON MEMORIAL HIGHWAY
40. ZACH WHEAT MEMORIAL HIGHWAY
41. BABE ADAMS HIGHWAY
42. BRIGGS DRIVE
43. U.S. SUBMARINE VETERANS MEMORIAL HIGHWAY
44. WW II EXERCISE TIGER EXPRESSWAY
45. SMART MEMORIAL HIGHWAY
46. TROOPER WAYNE W. ALLMAN MEMORIAL BRIDGE
47. RICHARD L. HARRIMAN HIGHWAY
48. VETERANS MEMORIAL PARKWAY
49. CITY MARSHAL JOHN HENRY BRENDEL MEMORIAL HIGHWAY
50. CONGRESSMAN IKE SKELTON BRIDGE
51. HARRY DARBY MEMORIAL HIGHWAY
52. TROOPER ROSS S. CREACH MEMORIAL HIGHWAY
53. REX WHITTON EXPRESSWAY
54. TROOPER DENNIS H. MARRIOTT MEMORIAL HIGHWAY
55. SENATOR CHRISTOPHER S. BOND BRIDGE
56. HENRY SHAW OZARK CORRIDOR
57. BROWN-STINSON MEMORIAL BRIDGE
58. BERNARD F. DICKMAN BRIDGE
59. JOE R. NICHOLS OVERPASS

60. BLANCHETTE MEMORIAL BRIDGE
61. DISCOVERY BRIDGE
62. DANIEL BOONE EXPRESSWAY
63. LEWIS & CLARK BOULEVARD/EXPRESSWAY
64. MARK MCGWIRE HIGHWAY
65. GOVERNOR MEL CARNAHAN MEMORIAL BRIDGE
66. BUZZ WESTFALL MEMORIAL HIGHWAY
67. OFFICER SCOTT ARMSTRONG MEMORIAL HIGHWAY
68. CHIEF JERRY BUEHNE MEMORIAL ROAD
69. JOHNSON HIGHWAY
70. ALBERT E. BRUMLEY PARKWAY
71. CARVER PRAIRIE DRIVE
72. TROOPER RUSSELL HARPER MEMORIAL HIGHWAY
73. CONGRESSMAN MEL HANCOCK FREEWAY
74. JARRETT ROBERTSON MEMORIAL BRIDGE
76. ED BROWN BRIDGE
77. GLEN SHARP BRIDGE
78. RICK HARMON MEMORIAL HIGHWAY
79. EDWIN P. HUBBLE MEMORIAL HIGHWAY
80. LAURA INGALLS WILDER MEMORIAL HIGHWAY
81. JAMES GRASSHAM & ORVILLE WILLIAMS WALKWAY
82. SERGEANT RANDY SULLIVAN MEMORIAL HIGHWAY
83. TROOPER MIKE L. NEWTON MEMORIAL HIGHWAY
84. DANNY STAPLES BRIDGE
85. TROOPER KELLY L. POYNTER MEMORIAL HIGHWAY
86. TROOPER ROBERT KOLILIS MEMORIAL HIGHWAY
87. BILL EMERSON MEMORIAL BRIDGE
88. GOVENOR JOHN M. DALTON MEMORIAL HIGHWAY
89. SERGEANT RANDY SULLIVAN MEMORIAL HIGHWAY
91. TROOPER JAMES FROEMSDORF MEMORIAL HIGHWAY
92. THOMAS G. TUCKER, JR. MEMORIAL HIGHWAY
93. DEPUTY STEVEN R. ZIEGLER MEMORIAL HIGHWAY
94. TROOPER JESSE R. JENKINS MEMORIAL HIGHWAY
95. VETERANS MEMORIAL HIGHWAY
96. VETERANS MEMORIAL BRIDGE
97. INNERBELT EXPRESSWAY
98. AMERICAN VETERANS MEMORIAL HIGHWAY
99. KOREAN WAR VETERANS MEMORIAL FREEWAY
100. TROOPER MIKE L. NEWTON MEMORIAL BRIDGE
101. KOREAN WAR VETERANS ASSOCIATION MEMORIAL HIGHWAY
102. BOB WARD PARKWAY

TW\_CNTL\_STAT\_NAME Describes the status of a route.

<b>NAME</b>	<b>DESCRIPTION</b>
CONTINUOUS OPERATIONS RT	Priority routes defined for winter snow removal.
OPEN TO TRAFFIC	USED BY DRIVING PUBLIC

TW\_DSGN\_PVMT\_NAME Indicates the pavement design based on the number of trucks on the roadway. [Click here for codes](#)

<b>NAME</b>	<b>DESCRIPTION</b>
Heavy Duty	DESIGN MAN. CH. VI 6-03.1 (1)
Medium Duty	DESIGN MAN. CH. VI 6-03.1 (2)
Light Duty LA	>3,500 ADT
Light Duty LB	1,700-3,500 ADT
Light Duty LC	750 - 1,700 ADT
Light Duty LD	400 - 700
Light Duty LE	<400 ADT

TW\_LANE\_JOB\_NUMBER Unique identifier for the lane job.

TW\_OWNER\_ID Describes who owns the travelway.

<b>NAME</b>	<b>DESCRIPTION</b>
CITY	CITY
COUNTY	COUNTY
FEDERAL	FEDERAL
PRIVATE	PRIVATE
SPEC ROAD DIST	SPECIAL ROAD DISTRICT
STATE	STATE

TW\_SPEED\_LIMIT\_CD Speed Limit that the SS\_PAVEMENT record falls on.

<b>CODES</b>	<b>DESCRIPTION</b>
15	15 MPH
20	20 MPH
25	25 MPH
30	30 MPH
35	35 MPH
40	40 MPH
45	45 MPH
50	50 MPH
55	55 MPH

60	60 MPH
65	65 MPH
70	70 MPH
99	99 NOT STATED OR UNKNOWN

URBAN\_AREA\_NAME

Rural (area with population less than 5,000) Urban (area with population 5,000 – 50,000).

**NAME**

METROPOLITAN  
RURAL  
UNDESIGNATED  
URBAN  
URBANIZED

**DESCRIPTION**

OVER 200,000 POP.  
LESS THAN 5,000 POP.  
UNDESIGNATED  
5,000 - 50,000 POP.  
OVER 50,000 - 200,000 POP.

YEAR

Calendar year the data represents.

**APPENDIX B**  
**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**TASK 2 REPORT**  
**DEVELOPMENT OF PAVEMENT FAMILY MODELS**  
**AND**  
**PRESERVATION TREATMENT PERFORMANCE MODELS**

August 15, 2014

Prepared for the  
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The opinions, findings, and conclusions expressed in this publication are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard or regulation.

## EXECUTIVE SUMMARY

Pavement performance models describe the deterioration behavior of pavements. They are essential in a pavement management system if the goal is to make more objective, reliable, and cost-effective decisions regarding the timing and nature of pavement maintenance activities. The general objective of Task 2 is to develop performance models for a variety of pavement families and pavement preservation treatments used by the Missouri Department of Transportation (MoDOT).

Linear least-squares and non-linear iterative regression techniques have been used to evaluate models that predict the International Roughness Index (IRI), the pavement condition measure most widely used today. Modeling was also investigated for the 20-point Condition Index (CI). Although the CI has been recently replaced by the 10-point PASER rating system, a significant amount of CI data exists, simultaneous modeling efforts were minimal, and MoDOT may desire future development of correlations between the CI and PASER. And, there is insufficient PASER data for modeling purposes. Predictor variables shown to be significant in predicting IRI and CI are pavement surface age and commercial traffic volume. The investigation into climate, subgrade soil type, and pavement thickness as additional predictor variables is still underway.

## **AUTHOR ACKNOWLEDGEMENTS**

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## **1 INTRODUCTION**

Pavement performance models describe the deterioration behavior of pavements. They are essential in a pavement management system (PMS) if the goal is to make more objective, reliable, and cost-effective decisions regarding the timing and nature of pavement maintenance activities.

The purpose of a performance model is to predict pavement condition, primarily as a function of time. Models for pavement families (groups of pavements with similar characteristics and conditions) and preservation treatments are relied upon as tools in pavement management decision-making. For this reason, development of reliable pavement performance models is of the utmost importance in this project.

### **1.1 Objectives**

The primary objectives of Task 2 were to:

- Perform a literature review to determine how transportation agencies have approached pavement performance modeling
- Collaborate with the Missouri Department of Transportation (MoDOT) to obtain information needed to understand MoDOT's experience with performance modeling and expectations for any newly developed models
- Compile data collected by the Task 1 team into a usable format and generate pavement performance models and preservation treatment models

## **2 LITERATURE REVIEW**

The purpose of the literature review was to determine how transportation agencies have approached pavement performance modeling. Identification of the pavement condition parameters (the response or dependent variable) and model main effects (the predictor or independent variables) that are commonly utilized in pavement performance modeling, and the various model forms, was a necessary first step in formulating a strategy for developing MoDOT's models based on the types of data available.

The American Association of State Highway and Transportation Officials (AASHTO) published the second edition of its guide to pavement management in 2012. A 2011 draft of this document (Zimmerman et al. 2011) was the first reviewed for guidance on Task 2 work within the MoDOT Pavement Preservation Project. Chapter 5 of the AASHTO guide describes the types of data required for modeling, different approaches to modeling such as the type of pavement condition measures to be predicted, the various model types (probabilistic, Bayesian, deterministic, or expert-based) and forms (e.g. linear, power, logarithmic), the various applications of performance models (e.g. pavement family models, preservation treatment

models, or remaining service life), and the statistical requirements for any model that is considered.

The Bayesian and expert-based model types rely to some degree on subjective data which may be appropriate when empirical data is not readily available. That is not the case for this project task. The probabilistic approach does not predict a single pavement condition value but gives a likelihood or probability that a pavement will be in one of several condition states. This feature is advantageous in that it does account for pavement variability, but the model does not lend itself easily to implementation into pavement management software. The deterministic model is the most common model type for pavement performance modeling and is generated using regression analysis procedures.

Wolters and Zimmerman (2010) developed a recommended pavement performance modeling option for the Pennsylvania Department of Transportation (PennDOT). Their investigation included a 2009 survey of state agencies regarding current modeling practice, and summarized some of the key state survey results as case studies in developing PennDOT's recommended modeling option. Although the concept of individual roadway section models was discussed, the recommended modeling option was for creating an overall condition index for each pavement family in the PennDOT system, which would result in 37 models. The recommended model type was deterministic, but no specific model of any form was actually developed. The work of data collection and model building was left to PennDOT to pursue.

Donahue (2002) performed pavement performance modeling for various pavement families in the Missouri DOT highway system based on pavement type and functional classification. The linear model form was utilized with surface age ( $X_1$ ) as the only predictor variable (Eq. 2.1). However, several pavement condition measures were used as the response variable: IRI, condition score, ride score, present serviceability rating (PSR), and specific distress indices such as rut depth and cracking index.

$$Y = a + b(X_1) \tag{Eq. 2.1}$$

George (2000) authored a report about pavement family prediction models used by the Mississippi DOT's pavement management system (PMS). Model types utilized were mostly deterministic but some Bayesian modeling was generated. Deterministic models were of the general power form (Eq. 2.2). Predictor variables of significance were age, traffic, modified structural number (which reflects subgrade effects)/slab thickness, and overlay thickness. Predicted pavement condition parameters included IRI, a composite condition index (PCR or pavement condition rating), and various distress indices such as alligator cracking in asphalt pavements and punch-outs in continuously reinforced concrete pavements.

$$Y = a + b(X_1)^c (X_2)^d \dots \tag{Eq. 2.2}$$

Of particular interest in the George report was one of the predicted asphalt or composite pavement distresses: the 85<sup>th</sup> percentile rutting distress. A primary maintenance

trigger can be user discomfort (quality of the ride). The driving public does not usually wait until an entire stretch of roadway is bad before complaining; just a few deep ruts in a roadway can trigger phone calls to customer service. Therefore, a logical strategy would be to predict when really bad sections of a given length of roadway reach a certain distress threshold.

Khattak et al. (2009) issued a report addressing performance models used in the Louisiana DOT's PMS. Family and preservation treatment performance models were developed. Families were based on pavement type and functional classification. Preservation treatments modeled were chip seals, 2-inch overlays, and micro-surfacing. Model forms evaluated were polynomial, power, exponential, and logarithmic, with the general power form shown in Eq. 2.2 ultimately being utilized but the only predictor variable was surface age. Pavement condition measures to be predicted were IRI, rutting, various forms of cracking, and patching. Models were developed for the lower, middle, and upper 1/3 percentiles for select distresses, a concept also reported in the Mississippi study (George 2000).

Wang et al. (2012) did not develop performance models but instead investigated the effect of climate on various pavement preservation treatments applied to select asphalt sections in the Long-Term Pavement Performance (LTPP) program database. The pavement condition measure used to evaluate this effect was IRI. The researchers found that the effectiveness of the treatment procedures varied with climate to a significant degree. Precipitation (the number of days/year that precipitation was greater than 0.1 in. [2.5 mm]) and temperature (the number of days/year that the minimum air temperature was below 32° F [0°C]) were used together to define six climate zones. These zones were then used in a statistical analysis per pavement treatment to evaluate the change in IRI relative to control pavement sections.

The literature review included several more studies than those discussed above. Additionally, personal communication with state DOT personnel responsible for pavement management and modeling was performed via phone and e-mail. Based on the review and personal communications, the following characteristics were found to be predominant:

1. Deterministic model types are predominant with preference to the power and linear least-squares forms.
2. Pavement families are generally based on pavement type (typically 5 to 12 types).
3. The primary pavement condition measures are composite condition indices, individual distress indices, and IRI.
4. The primary significant predictor variables are surface age and traffic level with structure/treatment thickness and climate also showing some significance depending on the pavement condition measure of interest.



5. Model types were primarily the family-type; some states also had individual route/section models where possible.

6. Number of models: anywhere from 26 to thousands.

7. Minimum number of points per model curve: 4-9 for family models, 3-5 or more for section models.

8. Number of distress types where data was collected: 4-11

9. Homogeneous Section characteristics: up to 10 characteristics: pavement type, traffic (including % trucks), thickness, climate, subgrade, joint/reinforcement, age, maintenance applied, number of lanes, contract limits.

Table 2.1 shows a summary of five state DOT's salient information about their modeling systems (Colorado 2009; Colorado 2012; George 2000; Khattak et al. 2009; McGhee et al. 1991; South Dakota 2012).

**Table 2.1 – Summary of DOT’s pavement performance model systems**

<b>Items</b>	<b>Mississippi</b>	<b>Colorado</b>	<b>South Dakota</b>	<b>Louisiana</b>	<b>Virginia</b>
First Developed	1986	Late-1980’s	1977		Early 1980’s
Pavement Types	Original asphalt Overlaid asphalt Composite Jointed concrete CRC	Asphalt Composite Concrete Whitetopping	Asphalt: Full Depth Thick Thin-on-Strong Thin-on-Weak Composite Mesh-Rein. Concrete Thick Jointed w/dowels Thick Jointed w/o dowels Thin jointed CRCP Gravel Blotter	Asphalt Composite JCP CRC	Asphalt Composite JCP CRC JRC
Climates	1	4	1		
Families	5=pavement types	400=Combo of similar characteristics (like HS) Asphalt=240 Concrete=160	12 =pavement types		5=pavement types
Homogeneous Sections common characteristics	Const. contract limits Pavement type Thickness Joint/reinforced No. lanes %trucks Subgrade Age Maintenance applied Climate: constant	Pavement type Traffic Climate Thickness Same with Families	Not stated		“defined by surface mix”
Distress types/condition	Rutting alligator cracking	Trans. Cracking Long. Cracking	Rutting Transverse cracking	Long. crack Trans. crack	alligator cracking transverse

collected/used	transverse cracking block cracking longitudinal cracking reflection cracking edge cracking corner cracking D-cracking Spalling Faulting IRI ~PCR	Fatigue cracking Corner breaks IRI	Block cracking Fatigue cracking Patching D-cracking and ASR Spalling Faulting Corner cracking Joint seal Punchouts IRI	Fat. Crack Patching Rutting IRI	cracking Rutting Patching roughness
Distress severity/ extent	yes	yes	yes	yes	yes
Condition index	~PCR	5 " Distress Indices": Eg. Trans. Crack Index	Distress Indices: 6 for asphalt 6 for concrete Plus Composite Index	Long. crack Trans. crack Fat. Crack Patching Rutting IRI	NDR, LDR;CDR,CPR,SDR
Minimum No. points	4 for family More for site-specific	5 for site-specific 9 for Family 9 for Expert Default Curves			3 for site-specific
Model types	Family: 26 spread over 5 families Predict Distress & perf.	Site-specific if possible Family- if not 1 model per segment Predict Distress & perf.	168 spread over 12 Families	1 Per "control section" based on pavement type, functional class, distress index, percentile(3)	Default Site-specific Unclear as to use and predominance of these
Distress models	Asphalt: 4 distresses, 2 performance	Trans. Cracking Long. Cracking	Each pavement type(12)has a curve for each distress index+		Asphalt: 4:1 per rating type/

	Asphalt OL: same Composite: same JCP: 2 distress, 2 perf. CRCP: 2 distress, 2 perf.	Fatigue cracking Rutting IRI	1 comp index (so, distress & perf. curves)		treatment combo Both Composite: same JCP: 1: 1 per rating CRCP: 2: 1 per rating
No. treatments	Flex: 14 Rigid: 11	Up to 21-200	~50	Asphalt: 13 Composite:18 JCP:22 CRC:6	~14

From the literature review, it was decided to divide MoDOT's highway system into families based on pavement type and traffic level, with the possibility of further delineating/modifying families with "commercial vehicles" (truck traffic), climate, total thickness, and subgrade type.

### 3 INVESTIGATION

This chapter describes the strategy followed, to date, for generating pavement family and treatment performance models. Task 2 activities are still underway.

#### 3.1 Background

Pavement performance models can be thought of as a plot of a certain condition indicator, like IRI, versus pavement age or traffic. There are two basic kinds of models:

1. Individual section of a given route
2. Sections from more than one route that are similar and are grouped together. These are called Family models.

Individual section models are usually "cleaner" in looking at trends over time, and can be used to predict Remaining Service Life for that particular section. In practice, these types of models are difficult to produce because of a lack of years of data. Another issue is that there would be thousands of models that would have to be created for a state highway system. Family models overcome these difficulties. Also, Family models would give a broader evaluation of specific treatments in determination of their longevity. Thus, many DOTs concentrate primarily on producing Family models.

To model pavement behavior, one must be able to answer the basic salient question: why does one particular route exhibit a different pavement condition than another route at a given pavement age and physical location? Answers can be found by looking at the factors that are considered important by various pavement design methods. The following are the most significant factors:

1. Pavement type (eg. asphalt, concrete, composite)
2. Pavement design features (joint spacing, load transfer, etc)
3. Subgrade soil type and preparation
4. Drainage
5. Accumulated traffic, especially truck traffic
6. Pavement thickness
7. Base type
8. Initial condition (smoothness)
9. Maintenance activities

10. Climate
11. Treatment(s) material quality
12. Treatment construction process quality/weather issues

If one could gather all of this information about various routes/sections, and combine routes/sections that are similar in these respects, then this would give each family model a better chance of being statistically significant.

In choosing which of the above 12 factors to concentrate on in development of the Family models, decisions had to be made based on anticipated availability of data and how much actual variation there was in a given factor. In other words, if there was a very narrow variation in a given factor, than it was eliminated from further consideration.

In regard to development of Family models, many state DOT's use a factor to distinguish one type of road from another. In the MoDOT roadway system, there are six different methods that MoDOT uses to categorize its roadways. It was decided to go with MoDOT's "Design Pavement Name" as the way to categorize pavement because this method provides a way to delineate design features, such as drainage and base type, eg., Heavy Duty pavements provide internal drainage systems (design features and materials), and the systems are superior to the Medium Duty sections, which are superior to the Light Duty sections. The Pavement Names are delineated primarily by AADT and pavement type, and accounts for the Drainage and Base Type factors. This information is reasonably available.

Pavement types were divided into Full Depth Asphalt (which includes asphalt-over-granular base), Portland Cement Concrete Reinforced (PCR), Portland Cement Concrete Non-Reinforced (PCN), and Composite (asphalt over concrete). The PCR vs PCN distinction also includes the many changes in concrete pavement design that all occurred at the same time, such as joint spacing, traveled way lane width, use of tied concrete shoulder, etc. This information is reasonably available. Accumulated Truck Traffic is thought to be a major factor, but is not readily available. It was felt that the data could be produced with extra effort. Thickness may or may not be a major factor—it should be, but the nature of the data may cloud the importance of this factor. Subgrade type for the most part may not be variable enough across the state to be significant. This would have to be determined. The same can be said about Climate. Maintenance activities will be handled in several ways: first, when a concrete pavement gets overlaid, it is changed to a Composite type of family. Secondly, separate Treatment models will be created. Construction quality is not readily available, nor is treatment material quality.

### **3.2 MoDOT's Condition Scores**

Models that are currently being created include various measures of condition vs age. Most of the past available historical condition data is in the form of International Roughness Index (IRI)

and MoDOT's Pavement Serviceability Rating (PSR). The IRI is obtained from roughness measurements by devices in MoDOT's ARAN vans. The PSR is calculated by:

$$\text{PSR} = 2 * \text{Ride Index} + \text{Condition Score}$$

The Ride Index is developed from ARAN measured data, but is different from IRI data. The Condition Score is visually-based from ARAN surface video footage, and is either the Asphalt Condition Score or the Concrete Condition Score. The Scores are calculated as:

$$\text{Asphalt Condition Score} = [2 * \text{Cracking Index}] + [\text{Rutting Index}] + [(\text{Patching Index} + \text{Raveling Index})/2]$$

$$\text{Concrete Condition Score} = \text{Cracking Index} + \text{Joint Index} + \text{Spalling Index} + \text{Patching Index}$$

Each Condition Index is worth 0-5 points, with 5 being the best. The Ride Index is worth 10. Either Condition Score is also called the Condition Index, and has a maximum value of 20 points.

In 2009 MoDOT discontinued the use of PSR in favor of a rating similar to the 10-point PASER Rating. However, little PASER data is available in SS Pavement as of yet. Thus, models will be based on PSR or Condition Index (CI) and/or the individual Condition Indices.

### **3.3 Task 1 Data Reduction and Compilation**

The following steps describe the method for configuring the Task 1 supplemented data files into a form that allows for importation into statistical software for regression analyses.

1. Each Task 1 pavement section file receives the following treatment:
  - a. Remove Task 1 notes, plots, etc.
  - b. Create and populate "Assumed Last Treatment Date," "Surface Age," and "Unit IRI" columns. The Unit IRI is the average of the driver and passenger IRI (fields extracted from the ARAN Inventory tables during Task 1). Assumed Last Treatment Date column is in the day/month/year format and, ultimately, may be different than the "Last Treatment Date" determined by the Task 1 team. Surface Age (expressed in "years") is the difference between the date the ARAN data was collected (field labeled as DATE0) and the Assumed Last Treatment Date.
  - c. Task 1 Last Treatment Dates are double-checked if the Surface Age (or plots of the 20-point Condition Index (CI) as a function of DATE0) indicate that there may be a pavement treatment missing in the Task 1 data.
  - d. If the Task 1 Last Treatment Date is given as a year only (no month or day), July 31 is taken as the Assumed Last Treatment Date for that particular year (i.e. the approximate middle of the construction season). Other assumptions for

dd/mm/yyyy values may be made for logical reasons; e.g. missing ARAN Viewer years, missing surface treatments found and added, etc.

2. Double-check that irrational IRI or CI (e.g. IRI=999 or identical IRI and/or CI values through entire section length) were removed during the Task 1 ARAN table querying and retrieval.
3. Remove yearly data where driver and passenger IRI are extremely different; i.e. a potential error in IRI collection for that year/section. A quick method to determine a potential error in a particular year is to plot the driver IRI as a function of the passenger IRI and observe the amount of bias relative to a line of equality. Generally, the passenger IRI will be higher than the driver IRI. To look over several years, begin by averaging the driver IRI and the passenger IRI on a yearly basis then plot those yearly averages as two series: one for the driver side IRI and the other for the passenger side IRI. Potential errors in IRI collection will show up as large relative fluctuations in the two series from yearly trends. Fig. 3.1 shows an example of this latter method. In the Fig. 3.1 legend, SB = southbound, NB = northbound, PS = passenger side, and DR = driver side.
4. Combine all section files per pavement family into one worksheet called the "Pavement Family Model Working File" (PFMWF).
5. (Optional) Using the Step 4 file, create ¼ mile running average (4thRA) columns for the 20-point Condition Index (4thRACI) and IRI (4thRAIRI). Populate the 4thRA columns with running averages (13 consecutive rows of data; i.e. 13 rows x 0.02 miles/row ≈ 0.25 miles). Populate the 4thRACI column first (all years). This takes considerable time as the first and last 6 rows of yearly data are part of the 4thRA calculation, but there is no 4thRA value associated with those first and last 6 rows of data; this reduces the entire yearly dataset by 12 rows (records), 6 on each end of the section. Now populate the 4thRAIRI column by copying the entire 4thRACI column and pasting into the 4thRAIRI column. The last process in this step is to 1) copy and paste as "values," all of the 4thRA calculations, then 2) remove those 6 rows at the beginning and at the end of each year's worth of data.
6. Save the Step 4 (or Step 5, if performed) file as two separate files for importation into statistical software; one for IRI and one for CI. Remove appropriate data from each file based on the following criteria:
  - a. For IRI: remove all pre-1993 data (no IRI prior to 1993), and 1997-2001 data, inclusive (algorithm error)
  - b. For CI: remove 2010 and later data (PASER, a 10-point scale, replaced CI in 2010)
  - c. Extremely high Surface Ages; e.g. >15 years. These are pavements that either have not actually received any "total surface" treatment, or there are missing treatments in the data
7. Using the IRI file from Step 6, generate an Upper 25<sup>th</sup> Percentile IRI file for importation into statistical software. This involves sorting each year's records in descending order based on IRI, and deleting the bottom 75<sup>th</sup> percentile data.
8. To create treatment model files for importation into statistical software, simply subdivide pavement family files (e.g. Step 4, 6, or 7 files) into files with similar treatment types.



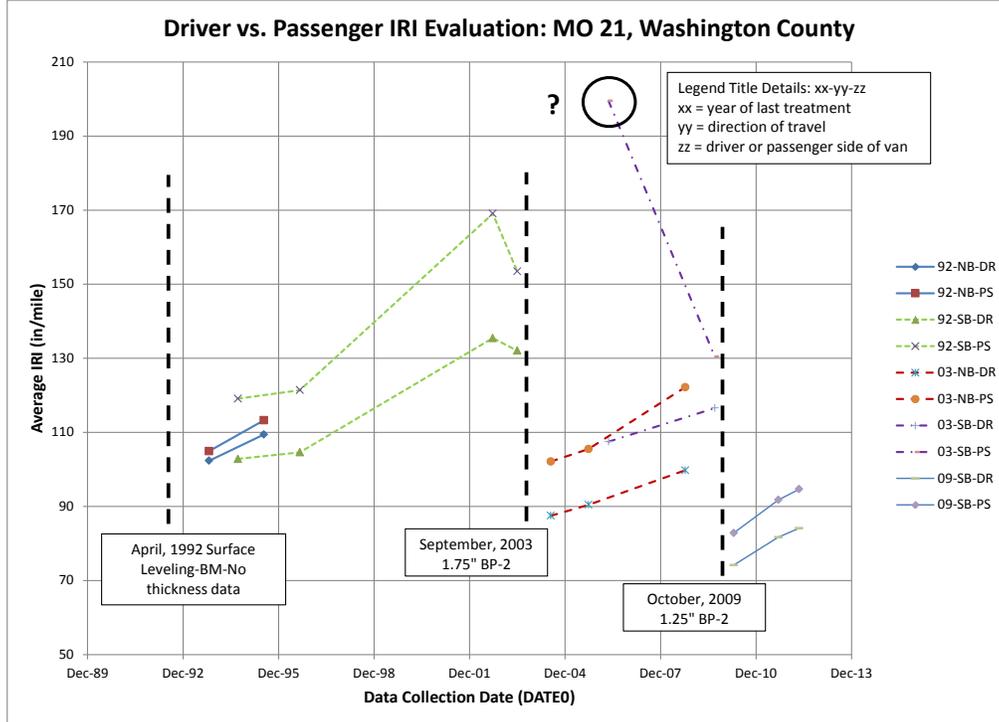


Fig. 3.1 – Example of driver vs. passenger IRI error check.

The creation of the ¼ mile running average (4thRA) data, Step 5 above, is *optional*. This is a data smoothing procedure that was performed originally because MoDOT personnel use the plotted 4thRAIRI as a function of logmile to better identify truly poor or failing areas of a particular pavement section. Fig. 3.2 shows the difference between plotting raw IRI (UnitIRI) and 4thRAIRI for the same pavement section. The section represented in Fig. 3.2 is the same as that in Fig. 3.1 and shows data for the year 2009.

In Fig. 3.2, the peaks shown in the raw (upper) data plot could be the result of debris in the traveled lane, such as driveway aggregate washed out onto the road after a rainstorm. By smoothing the data, one removes the effects of localized (~105 feet) phenomena and gains a more reliable indication of actual surface condition. In the 4thRAIRI (lower) data plot, it is clear that approximately ½ mile of the section between logmiles 60 and 61 has roughness issues (4thRAIRI greater than 140 inches/mile).



Fig. 3.2 – Example of raw IRI versus 4thRAIRI plotted as a function of logmile.

### 3.4 Pavement Performance Modeling

Based on the available data, deterministic models are the chosen type under development. Although still under way, modeling work has been performed that has guided and shaped the strategies for final model development. Presented in this section of the report is a portion of the preliminary work results.

#### 3.4.1 Rationale for Using Raw (Unit) Data, Not Smoothed Data, for Modeling

Although the procedure for creation of the 4thRA data was included in the file-creation steps above (Step 5, Section 3.1), and some of the plots/models to be presented in the following sections are based on the 4thRA data, the only statistical advantage in modeling the 4thRA data versus modeling the raw, non-smoothed data is an increase in the goodness-of-fit statistic, Rsquare ( $R^2$ ), due to the decreased relative variability. To illustrate this point, Fig. 3.3 shows the linear least-squares regression results for the UnitIRI data and the 4thRAIRI data derived from smoothing that same UnitIRI data, both as a function of surface age.

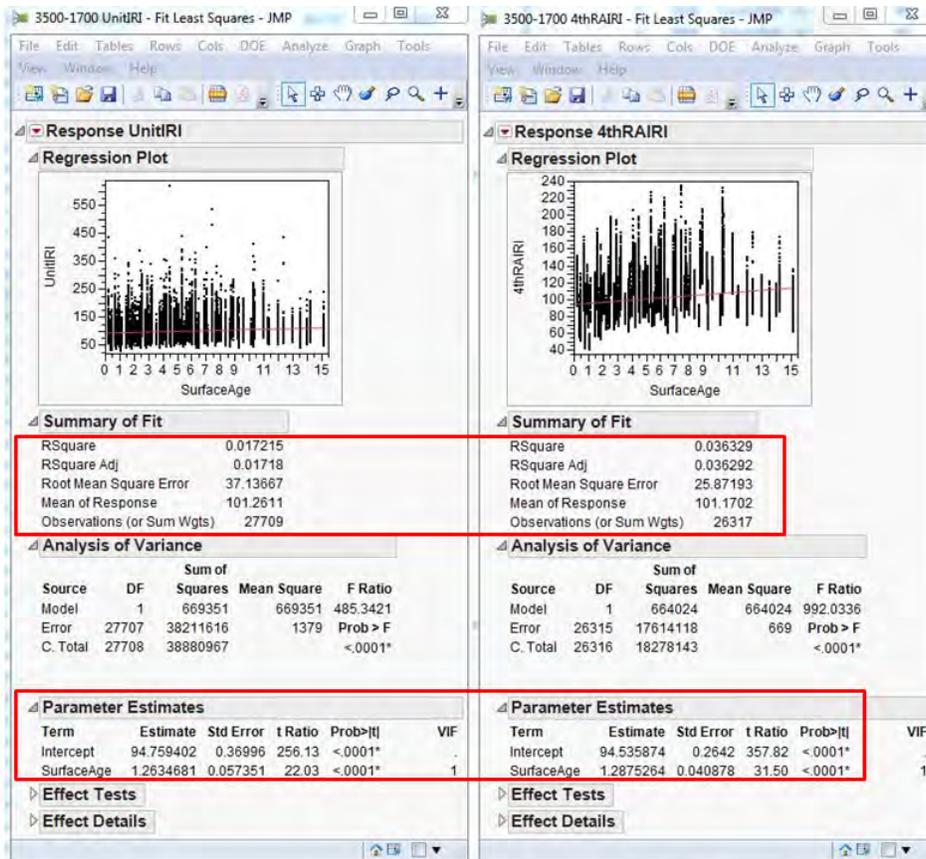


Fig. 3.3 – Comparison of UnitIRI (left) to 4thRAIRI (right) regression analyses.

The regression results of interest in Fig. 3.3 are highlighted in bold red boxes. The upper box shows the Summary of Fit statistics. The 4thRAIRI  $R^2$  is just over 100% higher than the UnitIRI  $R^2$ , which confirms the point discussed above. The number of 4thRAIRI observations are about 5% less than the number of UnitIRI observations and the reason for this was discussed in Step 5 of Section 3.1, above. Everything else being equal, fewer observations generally increases  $R^2$ . The mean UnitIRI and 4thRAIRI values are almost identical at 101.2611 and 101.1702, respectively.

But results of greater relevance are in the bottom red box of Fig. 3.3; the Parameter Estimates or the regression coefficients. The “Intercept” coefficient and the “Surface Age” (slope) coefficient for both analyses are almost identical, meaning the predictive models for both the UnitIRI and 4thRAIRI are almost identical. To check this claim, a plot of predicted UnitIRI and 4thRAIRI values based on the models shown in Fig. 3.3, is shown in Fig. 3.4. In addition to visually illustrating the similarity of the predicted values, a statistical comparison of the two groups of predicted values was performed using a one-tail, paired t-test and the results are included on the Fig. 3.4 plot.

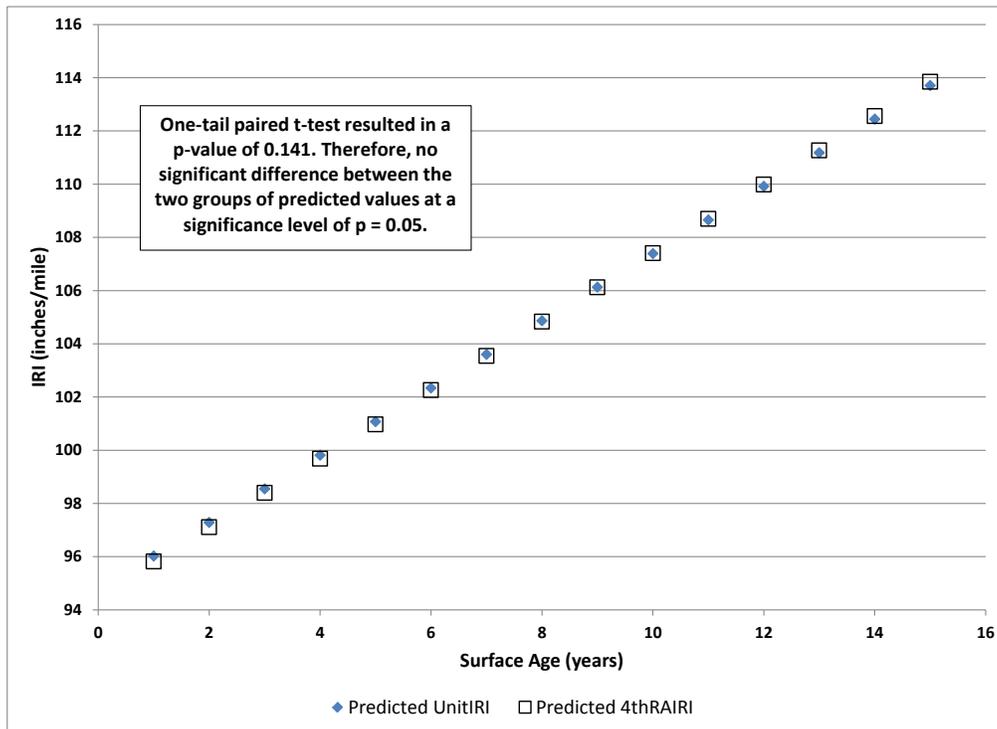


Fig. 3.4 – Plot and paired t-test result of predicted UnitIRI and 4thRAIRI values.

The one-tail, paired t-test showed that there is no significant difference in the two groups of predicted values at a significance level of  $p = 0.05$ . Therefore, based on the above analyses, the modeling yet to be performed for this project will use UnitIRI (or UnitCI) data as the response variable(s) because the difference between models created using the smoothed data versus the non-smoothed data is expected to be negligible.

### 3.4.2 Pavement Family Models

Modeling performed to date used data gathered from two pavement families. Both are characterized by two-lane, undivided, homogenous, full-depth asphalt pavement sections, but the AADT levels range from 1700 to 3500 for one family and 750 to 1700 for the second family. Each family contains 10 roadway sections (or 20 traveled lane sections totaling approximately 100 miles in length), each section from a different county in MoDOT's Central District. As discussed in the Task 1 report, it was the practice when selecting full-depth asphalt pavement sections to try and select one section each from the three Central District counties north of the Missouri River and distribute the remaining section selections as widely as possible from the counties south of the Missouri River.

The earliest analyses involved using the 1700 to 3500 AADT family data and modeling CI and IRI as functions of surface age only. Because there was only one predictor variable, a curve-fitting program called TableCurve 2D® was used. The program has 3556 built-in equations but only the simplest model forms (two regression coefficients) were considered during model comparisons. Figs 3.5 through 3.7 show plots of 4thRACI as a function of surface age, but different model forms are fit to the data. The shape of the fitted-curve and the goodness-of-fit statistics ( $r^2$ , in this software) help guide one to a decision regarding which model best represents the data and generates a fitted-curve that shows expected behavior over time.

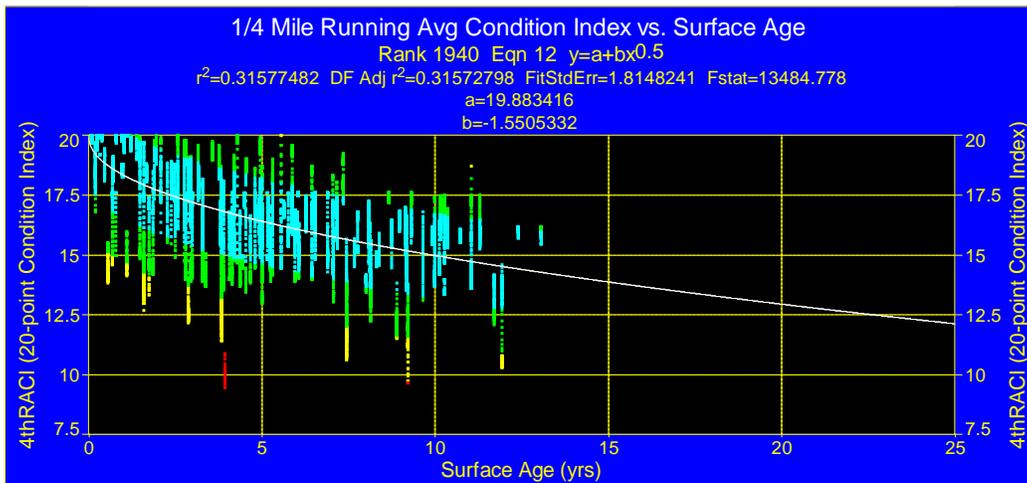


Fig. 3.5 – 4thRACI vs. Surface Age: decreasing response rate of change.

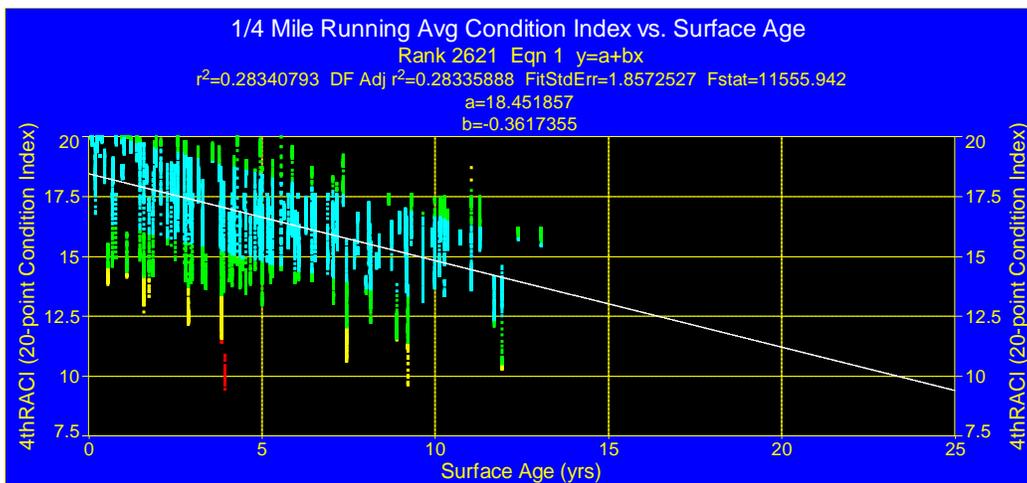


Fig. 3.6 – 4thRACI vs. Surface Age: constant response rate of change.

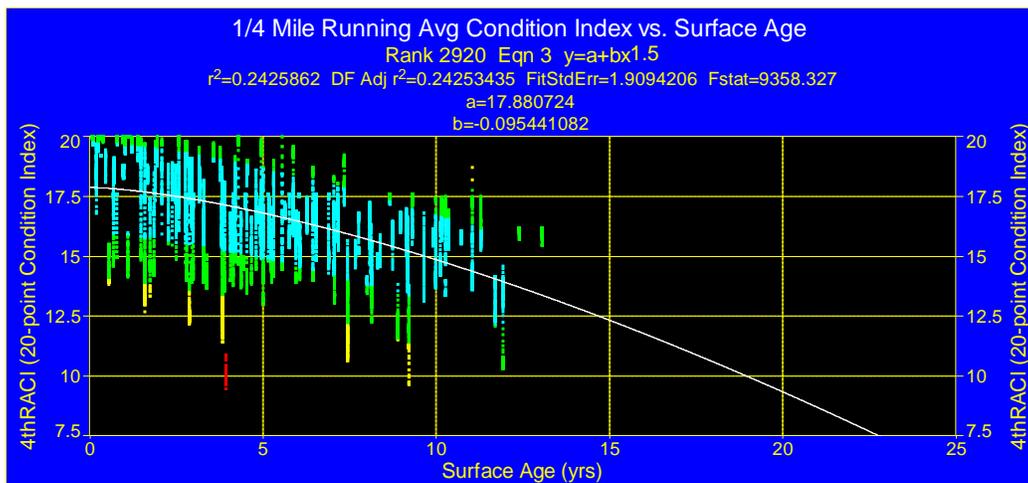


Fig. 3.7 – 4thRACI vs. Surface Age: increasing response rate of change.

The fitted-curve in Fig. 3.5 shows the best fit to the data ( $R^2 = 0.316$ ). However, the fitted-curve shows a decreasing rate of deteriorating pavement condition with surface age. Intuitively one might think that Fig. 3.7 shows the expected, or logical, long-term behavior; an increasing rate of deterioration with surface age. A large portion of the literature presents general deterioration curves that look like Fig. 3.7. However, this is not always the case. The differences in  $R^2$  values between the three curves are significant. Therefore, letting the actual data lead the way means the model in Fig. 3.5 is the best of the three in this case.

Figs 3.8 through 3.10 show plots of 4thRAIRI as a function of surface age. The same model forms used in Figs. 3.5 through 3.7 are fit to the data.

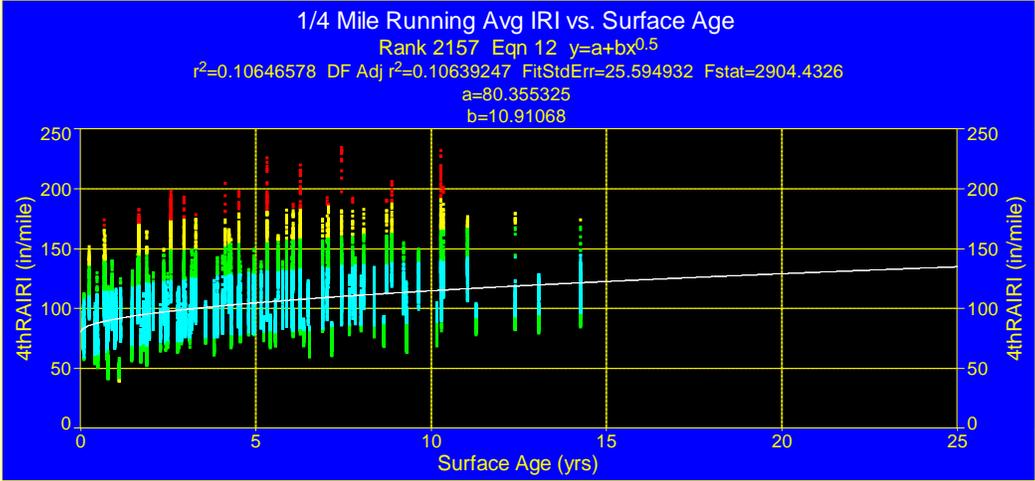


Fig. 3.8 – 4thRAIRI vs. Surface Age: decreasing response rate of change.

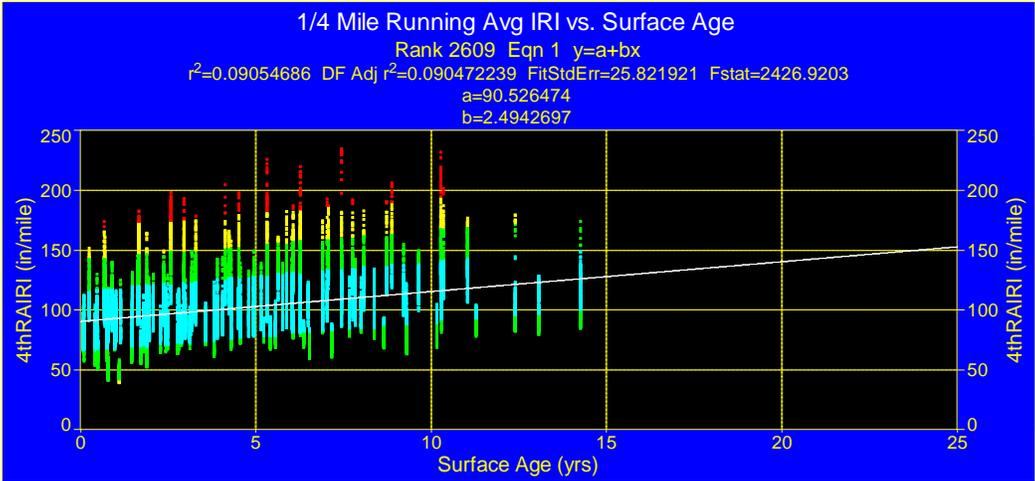


Fig. 3.9 – 4thRAIRI vs. Surface Age: constant response rate of change.

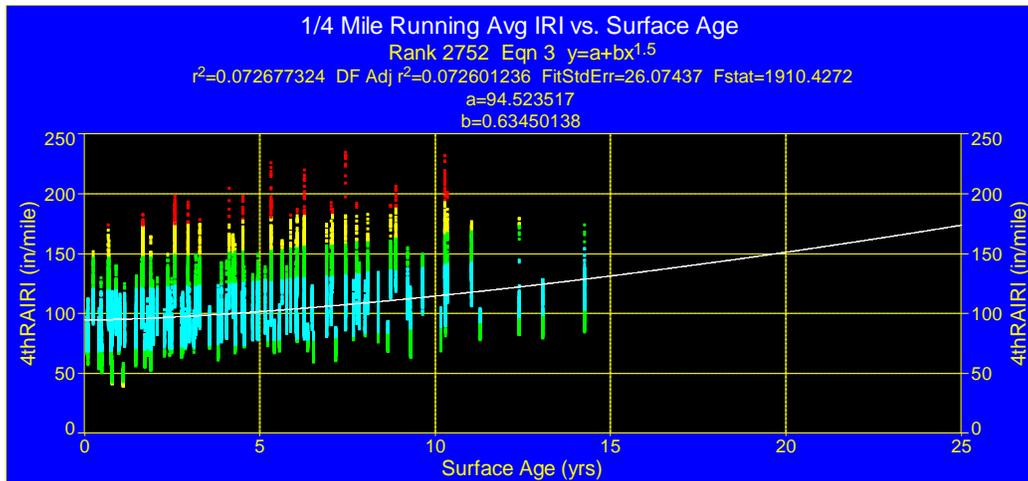


Fig. 3.10 – 4thRAIRI vs. Surface Age: increasing response rate of change.

Once again, the model that best fits the 4thRAIRI data ( $R^2 = 0.106$ ) is shown in Fig. 3.8 and demonstrates what some might consider counter-intuitive behavior; a decreasing rate of deteriorating ride (roughness) with surface age. Note that for 4thRAIRI and 4thRAIRI, the model that best fit the data for both of these responses did so as a function of the square root of surface age (i.e. TableCurve 2D Eqn 12).

Following Step 7 in Section 3.1, above, the 4thRAIRI data for the same pavement family discussed in this section was manipulated such that the upper 25<sup>th</sup> percentile of the data (the highest 25% of the 4thRAIRI values) was separated out for modeling purposes. Fig. 3.11 shows a plot of two linear least-squares fitted-curves: one fit to all of the 4thRAIRI data and another fit to the upper 25<sup>th</sup> percentile data. The single predictor variable is, again, surface age.



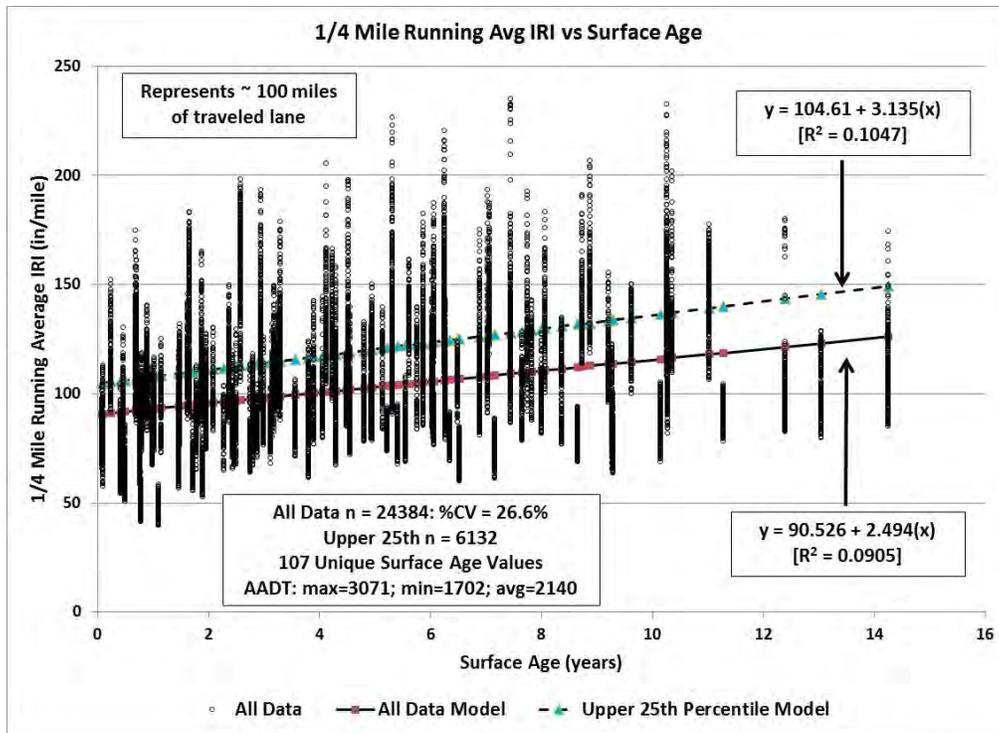


Fig. 3.11 – 4thRAIRI vs. Surface Age: all data and upper 25<sup>th</sup> percentile data.

The “All Data” fitted-curve regression coefficients and  $R^2$  values in Fig. 3.11 are the same as those in Fig. 3.9. The “Upper 25<sup>th</sup> Percentile” fitted-curve  $R^2$  is not much better than the All Data model. Since there is only about 25% of the number of observations in the Upper 25<sup>th</sup> Percentile dataset as there are in the All Data dataset, one might imagine that the  $R^2$  for the Upper 25<sup>th</sup> Percentile fitted-curve would be considerably higher than the All Data fitted-curve. However, there is a very high amount of variability in that upper 25<sup>th</sup> percentile data.

The same data was also modeled using Accumulated Commercial Traffic (vehicles). This traffic data is the mathematical product (i.e. the interaction) of Surface Age (years) and Current Commercial Volume by direction (vehicles/day). The Current Commercial Volume is daily directional truck traffic and was extracted from the Current SS Pavement database; i.e. it was the most recent commercial traffic data available. The Accumulated Commercial Traffic was calculated by multiplying the Current Commercial Volume by 365 such that the units would be vehicles/year, and the resulting units on the Accumulated Commercial Traffic would be rational.

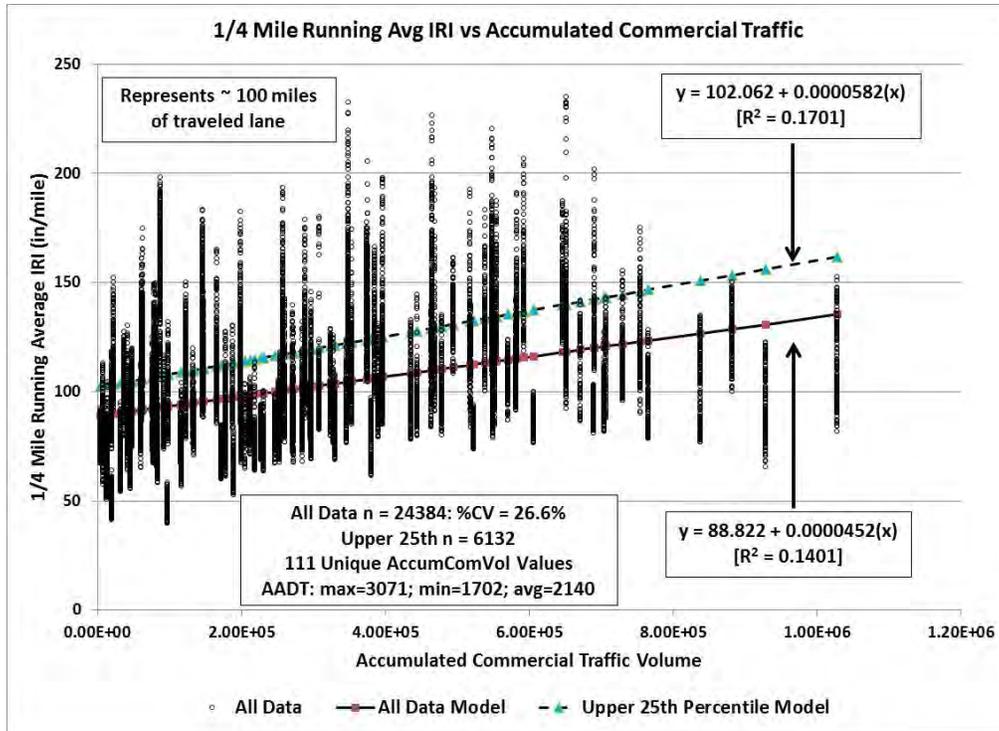


Fig. 3.12 – 4thRAIRI vs. Accumulated Commercial Traffic: all and upper 25<sup>th</sup> percentile data.

The major observation to make from Fig. 3.12 is the improvement in the  $R^2$  values for both datasets due to the different predictor variable. The fact that Accumulated Commercial Traffic is really the interaction between two variables for which data is available prompted the move toward multiple predictor variable models.

Because traffic proved to be a significant predictor, the thought was to combine data from the two pavement families (AADT from 750 to 3500) and investigate if one could successfully create multi-variate models across a wider range of AADT (and commercial traffic). Fig. 3.13 shows multiple regression output from this investigation.

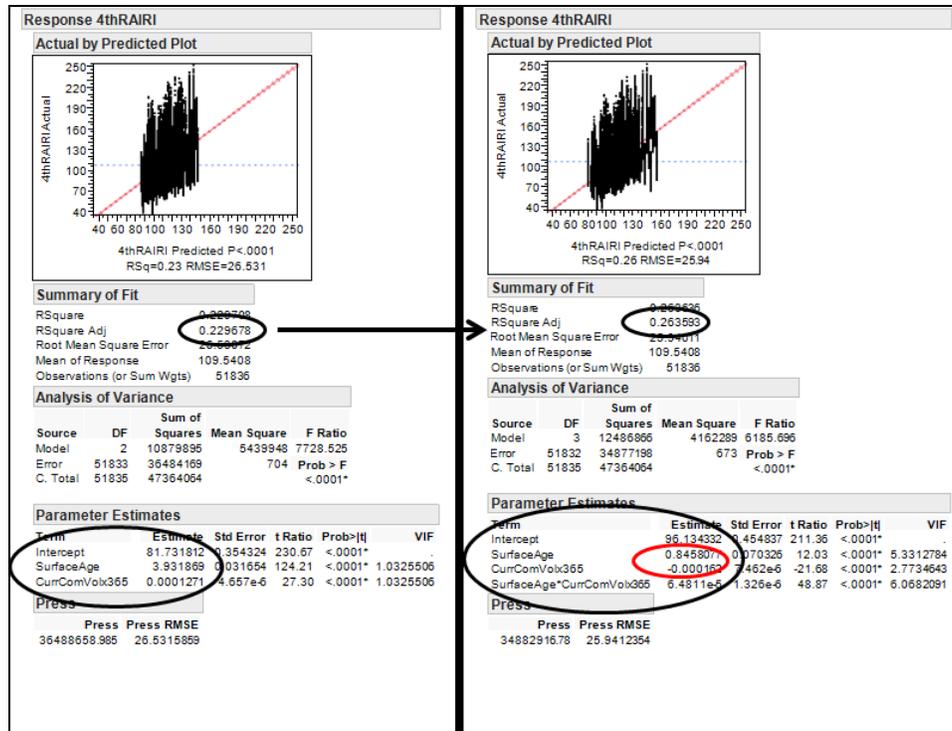


Fig. 3.13 – 4thRAIRI vs. Surface Age and Current Commercial Volume.

On the left side of Fig. 3.13 is the regression with just the two predictor variables, or main effects: Surface Age and Current Commercial Volume (times 365 days). Both of these terms are highly significant ( $p$ -values  $<0.0001$ ) and the  $R^2$  adjusted (adjusted for the number of predictor variables) is 0.230, a respectable value considering there are almost 52,000 observations. The output on the right side of Fig. 3.13 shows what happened when the interaction of the two main effects was added to the regression. All three terms are still highly significant and the  $R^2$  adjusted value increased by about 15%. The red oval around the parameter estimates in the right side output shows that the sign changed on the Current Commercial Volume regression coefficient. This phenomena is just one of many items to check when developing models. However, the reversal of signs on a main effect (e.g. Current Commercial Volume) when that main effect is involved in an interaction is not necessarily cause for concern.

The results of the exercise above is encouraging in that a wider range of traffic volume may be amenable to modeling, especially if other main effects are brought into the models; e.g. climate, pavement thickness, and/or subgrade type. Discussion of the investigation of these potential main effects is later in the report.

### 3.4.3 Preservation Treatment Models

The 1700 to 3500 AADT pavement family data was subdivided into the various preservation treatments that had been documented on the sections within that family. Figs. 3.14 through 3.17 show 4thRAIRI as a function of Surface Age for four different treatments: overlays of 1 in., 1¾ in., and 2¾ in., and chip seals.

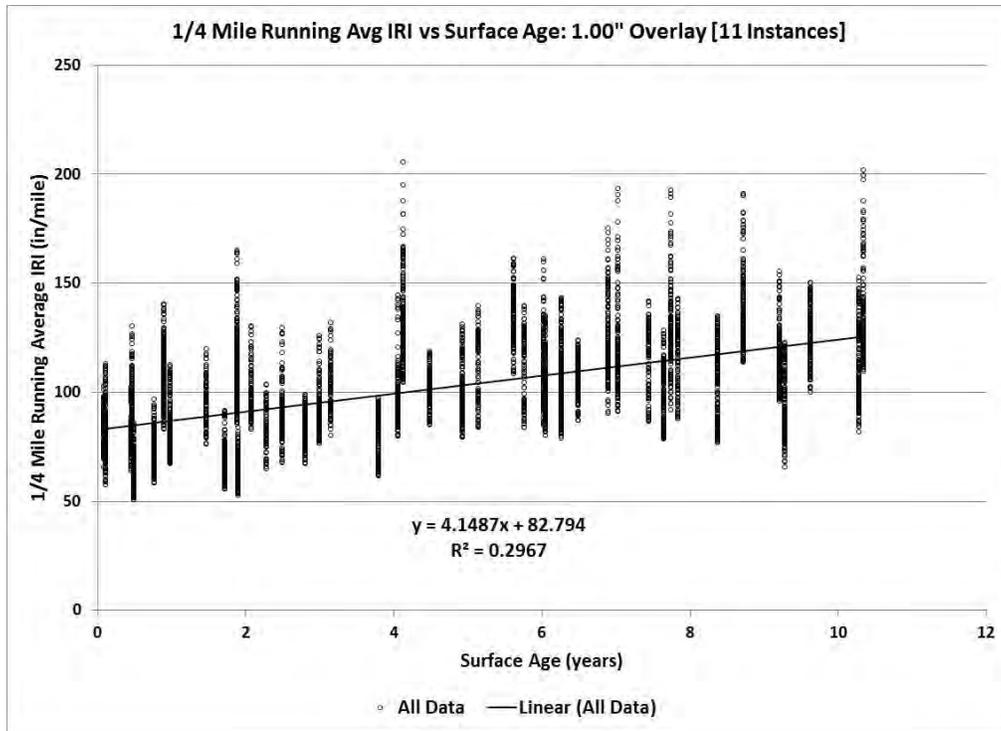


Fig. 3.14 – 4thRAIRI vs. Surface Age: 1 in. overlays.

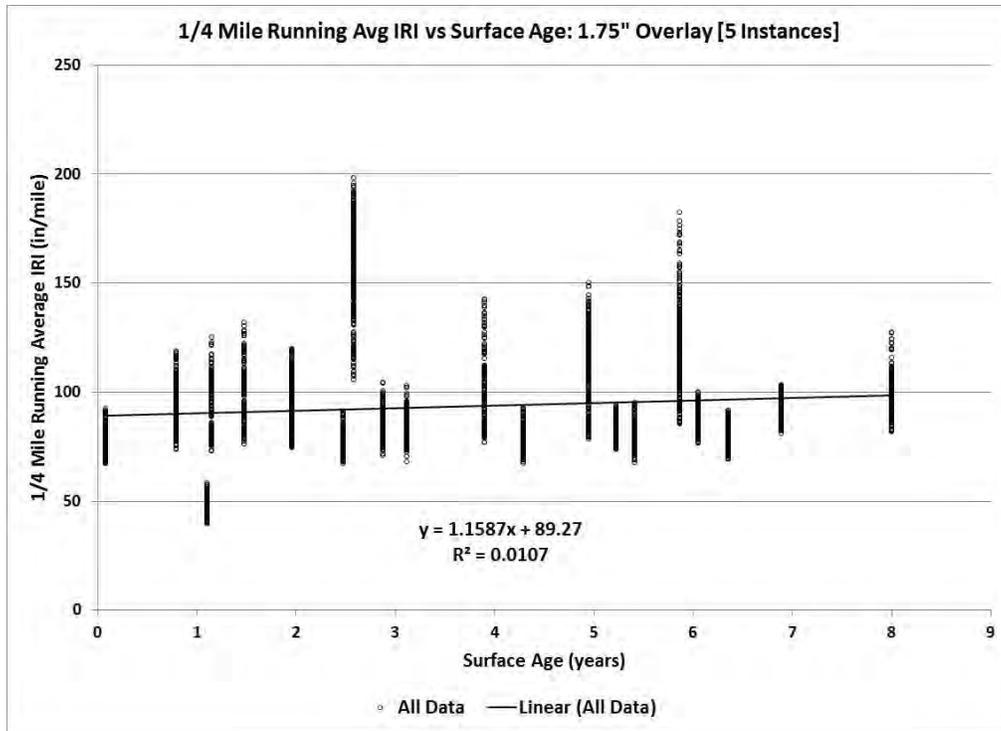


Fig. 3.15 – 4thRAIRI vs. Surface Age: 1¾ in. overlays.

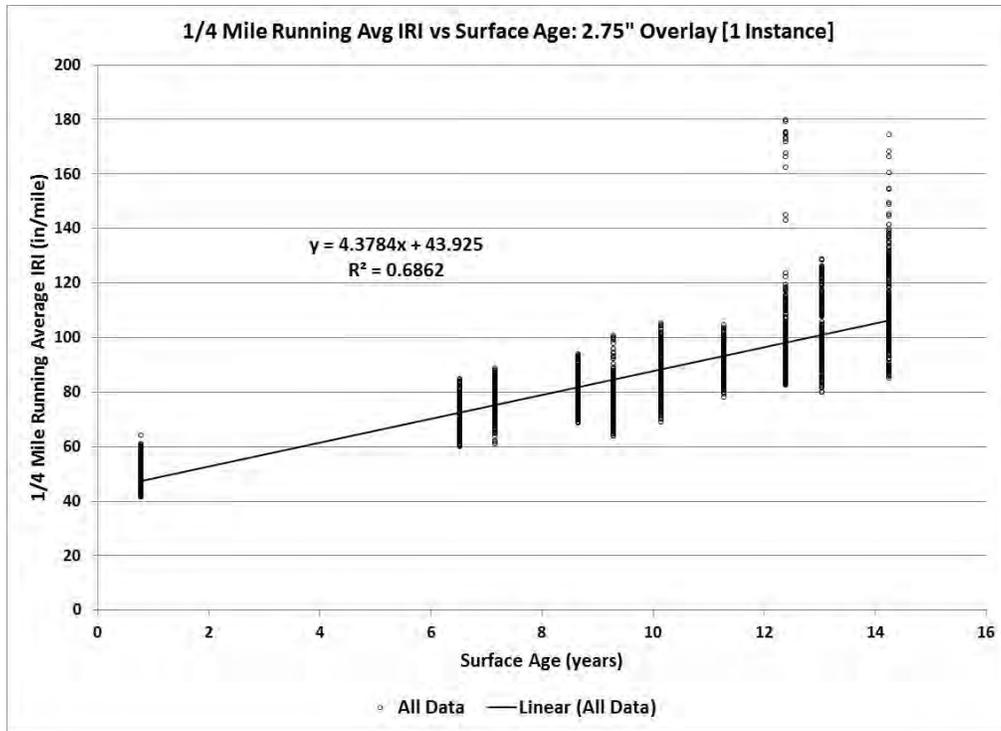


Fig. 3.16 – 4thRAIRI vs. Surface Age: 2¾ in. overlays.

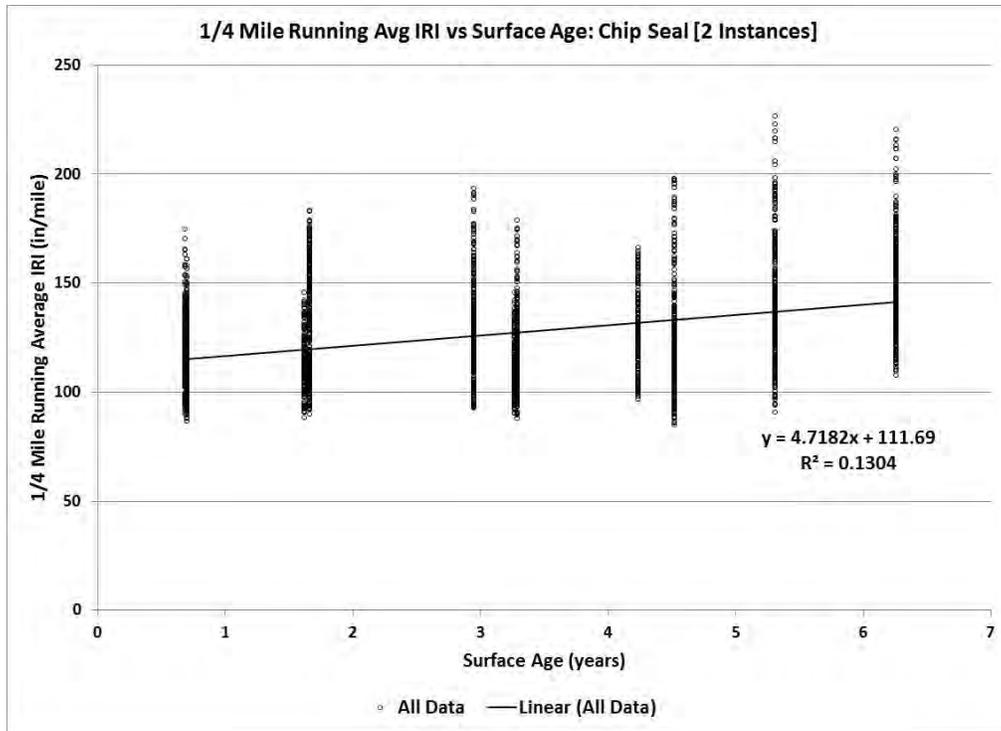


Fig. 3.17 – 4thRAIRI vs. Surface Age: chip seals.

The plots in Figs. 3.14 through 3.17 all show positive slopes for the fitted-curves, which is expected and welcomed. A flatter slope when the model is only a function of Surface Age is a desired property. Fig. 3.18, however, shows the effect that potentially invalid data is left in the modeling dataset.

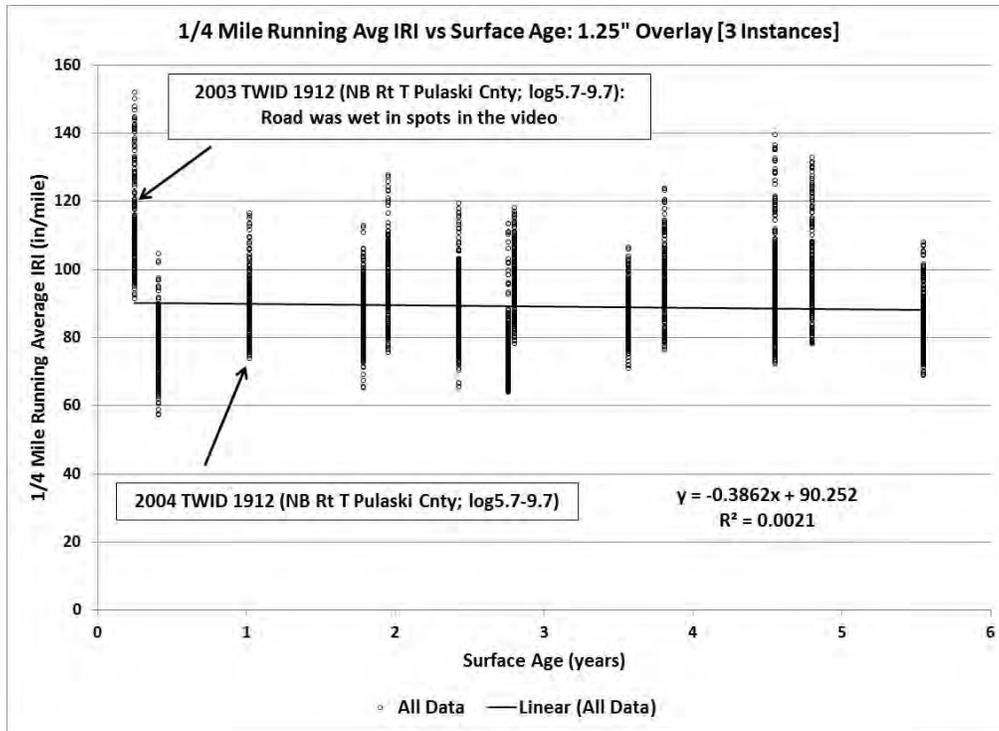


Fig. 3.18 – 4thRAIRI vs. Surface Age: 1¼ in. overlays with data anomaly.

The farthest left set of data in Fig. 3.18 (2003 TWID 1912 section data) is questionable as it is exerting severe leverage on the fitted-curve, causing a slightly negative slope, which is nonsensical. Fig. 3.19 shows what happens when that questionable 2003 data is removed from the curve-fitting.



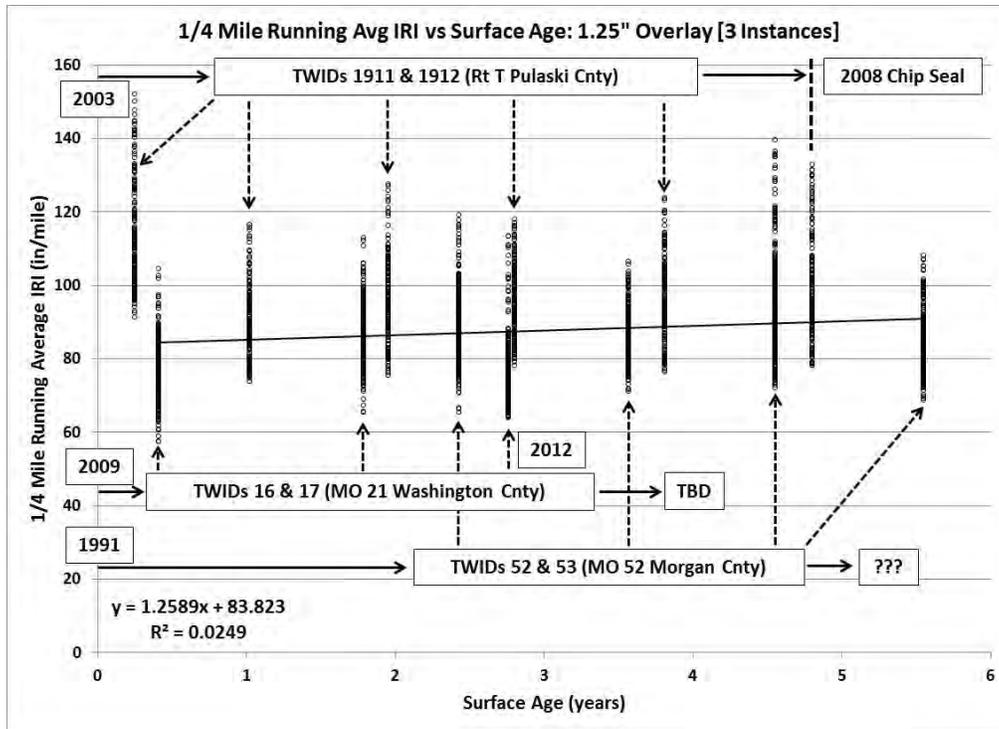


Fig. 3.19 – 4thRAIRI vs. Surface Age: 1¼ in. overlays with anomalous data removed.

Fig. 3.19 shows that removal of the 2003 anomalous data resulted in a positive slope for the fitted-curve. This shows the importance of diagnostic procedures to cull out invalid data prior to generating the models. There has been some additional information added to Fig. 3.19 indicating the three sections within the 1700 to 3500 AADT pavement family that had 1¼ in. overlays applied to them within the time period that data was available. Note that there is missing data regarding the status of the MO 21 and MO 52 sections in the out years.

Once the Pavement Family Model Working Files (as described in Step 4, Section 3.1) are compiled, subdividing them into the various preservation treatment files flows fairly quickly. As with the family models, multi-variate model forms will also be investigated for the treatment models.

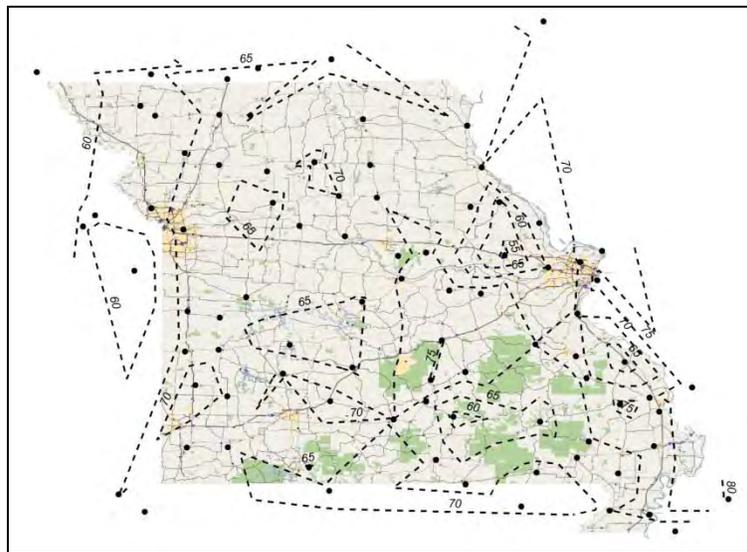
### 3.5 Other Potential Predictor Variable Data

Although pavement surface age and traffic (total and commercial) data have shown to be significant predictors for IRI and CI, investigations are ongoing to evaluate climate, subgrade type, and pavement thickness as additional predictor variables.

### 3.5.1 Climate Data

Wang, et al. (2012) indicated that two climate parameters correlate to the effectiveness of pavement preservation techniques better than other climate parameters: the number of days per year below freezing (DT32) and the number of wet days ( $\geq 0.1$  in. or 2.5 mm of precipitation) per year (DP01). Initially, a limited set of Long Term Pavement Performance (LTPP) data was used for the analyses in the referenced work. However, in an attempt to improve delineation of these two climate parameters across the state, a more extensive set of data from the National Climatic Data Center (NCDC) was obtained and used to create isolines for DP01 and DT32 and plot them onto the Missouri state map.

Data from weather stations across Missouri and adjacent states that was fairly recent and as complete as possible (i.e. continuously collected over time) was averaged and associated with the appropriate station. This resulted in data from 87 weather stations being used to create the isolines. The maximum, minimum, and average number of months used to create average DT32 and DP01 values for each weather station was 287, 227, and 276, respectively. Figs. 3.20, 3.21, and 3.22 show plots of DP01, DT32, and both isolines, respectively, on the state map.



*Fig. 3.20 – Number of wet days per year ( $>0.1$  in. precipitation) DP01 isolines.*

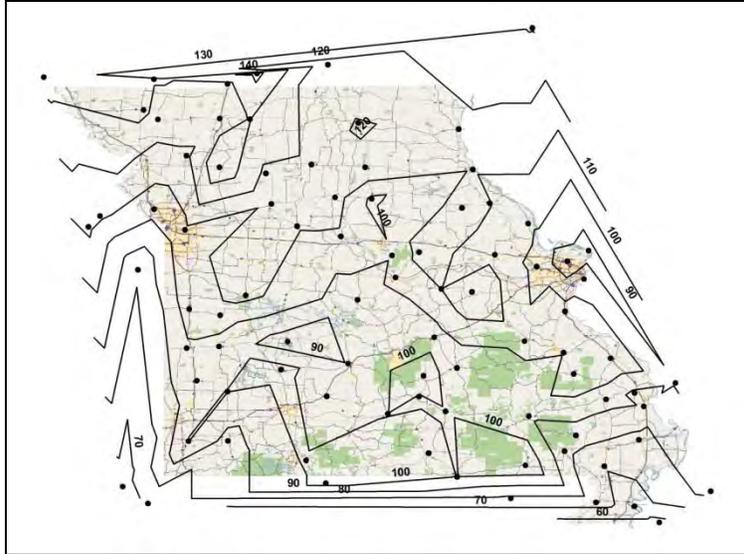


Fig. 3.21 – Number of days per year below freezing DT32 isolines.

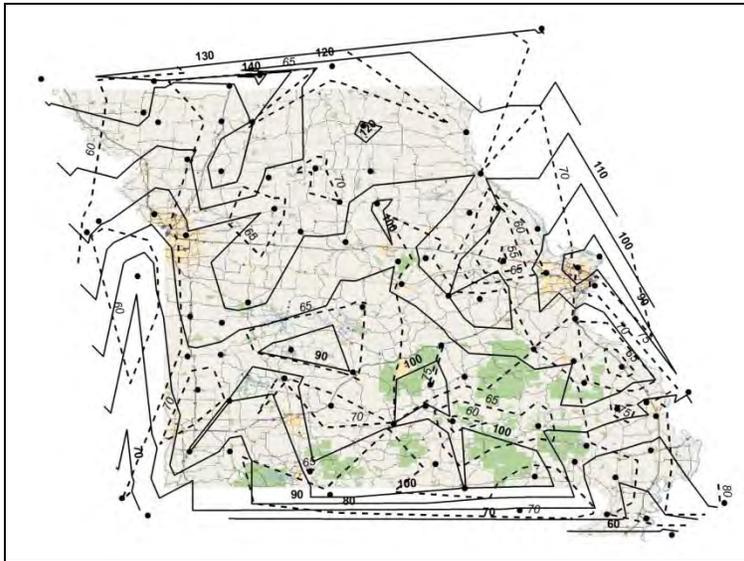


Fig. 3.22 – DP01 and DT32 isolines.

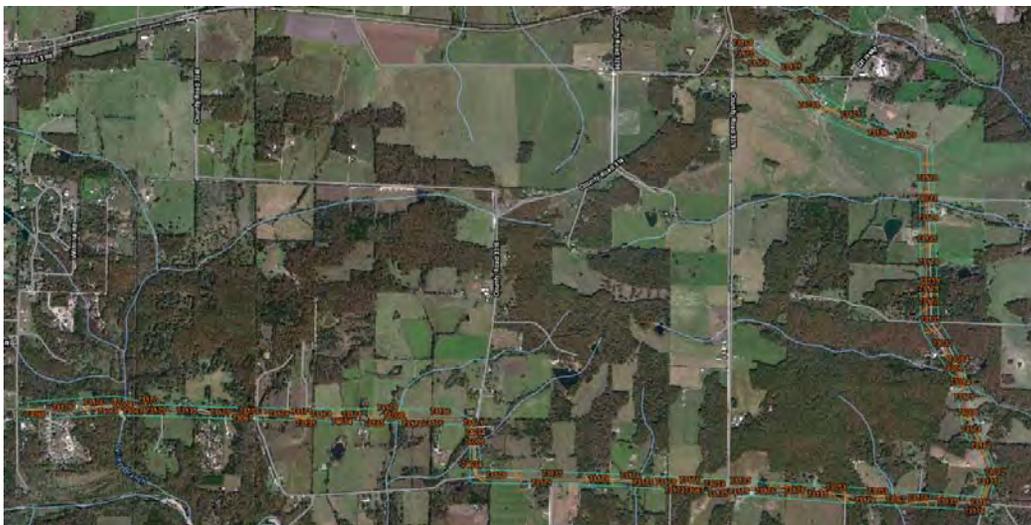
For modeling purposes, the intent is to estimate DP01 and DT32 for selected pavement sections and apply those values in the regression analyses. Whether or not these climate parameters prove to be significant predictors of performance will be determined as a result of the regressions. However, the better chance for DP01 and DT32 to show significance in predicting performance will be within the composite pavement analysis as the selected

pavement sections are spread across the entire state whereas the full-depth asphalt pavement sections are located in the Central District only.

### 3.5.2 Subgrade Soil Type

Investigation of subgrade soils underneath selected pavement sections is in its early stages. The hope is that, at the least, the pavement subgrade can be characterized as “bad” or “good.” Dummy or coded variables can be used as predictors in models in an “off” or “on” fashion. For pavement performance models, bad subgrades could be coded with a zero (0), and the good subgrades could be coded with a one (1). Therefore, the subgrade term in the model would drop out if the subgrade was bad but would contribute to changes in the response variable if the subgrade was good. Fig. 3.23 shows a pavement section that has been outlined as an area of interest using the USDA Web Soil Survey application.

(<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>).



*Fig. 3.23 – Outlined subgrade area of interest: RT BB, Phelps County.*

The numbers on the outlined area of interest indicate different soil map units. Each unit has many different soils properties associated with it in terms of area coverage and depth. The application is very flexible but there is difficulty in determining the correct soil properties or combination of properties that can be used to assign an overall condition to the entire pavement section. Soil swelling potential and/or freeze-thaw susceptibility are currently being investigated as criteria for subgrade condition classification. Details of subgrade data retrieval and manipulation is given in Appendix A.

### 3.5.3 Pavement Thickness Data

Pavement thickness data for pavements has been shown in the literature to be a significant performance predictor, depending on the application. In this study, the 2-AA sheets seem to hold promise as sources for thickness data related to the concrete and composite pavement sections. However, the full-depth asphalt pavement sections are lacking total thickness data. Many of the lower traffic volume roadways used to be county roads and the history of their development into state-maintained routes is incomplete. Many of the later year preservation treatment thicknesses can and have been verified through hard-copy and electronic documentation held by MoDOT. But obtaining total, cumulative thickness for the full-depth asphalt pavement sections selected for modeling may be unachievable.

There has been discussion with the MoDOT Pavement Team about ways to group the full-depth asphalt pavement families based on AADT with the assumption that roadways with AADT levels less than 750 are likely to be less than, say, 7 in. thick, and those roadways with AADT levels greater than 750 are likely to be greater than 7 in. thick. This may be the ultimate approach to adding thickness as a predictor variable in the models.

There are existing dBase files from MoDOT's original pavement management system that have been made available to the research team. Fig. 3.24 shows a screenshot of a portion of one of those spreadsheets that contains pavement structural data. However, MoDOT's Pavement Team members have warned that their confidence in this old data is not high.

A	B	C	D	E	G	L	M	N	U	V	W	X	Y	Z	AA	AB	AE	
TWAYDESG	TWAYNAME	TWAYDIR	BEGLOG	ENDLOG	YRLSTWRK	SURF	SURFTHK	SURFWTH	BASE	BASETHK	BASEYR	SUBBASE	SUBBASETHK	SUBBASEYR	SUBDRAIN	TRFSECID	TWAYID	
MO	21 S		59.77	66.46	1992	6	20	24	RS	8	1958			0	0	746949	16	
MO	21 S		66.46	66.6	1992	6	14	24	1	4	1932			0	0	746949	16	
MO	21 S		66.6	67.37	1988	R	8	24	3	4	1988			0	0	Y	746949	16
MO	21 S		67.37	67.41	1988	4	10.5	22	1	4	1932			0	0		746949	16
MO	21 S		67.41	67.84	1992	6	14	22	1	4	1932			0	0		746949	16
MO	21 S		67.84	69.38	1992	6	14	22	1	4	1932			0	0		746951	16
MO	21 S		69.38	69.42	1997	0	15.5	22	1	4	1932			0	0		746953	16
MO	21 S		69.42	70.25	1997	0	13.5	22	1	4	1932			0	0		746953	16
MO	21 S		70.25	71.56	1997	0	13.5	22	1	4	1932			0	0		750619	16
MO	21 S		71.56	71.97	1997	0	18	22	4	7	1987	1		4	1987		750619	16
MO	21 S		71.97	71.99	1997	0	12.5	22	1	4	1932			0	0		750619	16
MO	21 S		71.99	72.41	1997	0	12.5	22	1	4	1932			0	0		750619	16
MO	21 S		72.41	74.42	1997	0	10	22		0	0			0	0		750619	16
MO	21 S		74.42	74.5	1997	0	11.5	22		0	0			0	0		750619	16
MO	21 S		74.5	74.52	1996	9	9.5	22		0	0			0	0		750619	16
MO	21 S		74.52	74.71	1996	9	9.5	22		0	0			0	0		734221	16
MO	21 S		74.71	76.37	1996	9	9.5	22		0	0			0	0		750620	16
MO	21 S		76.37	80.82	1996	9	9.5	22		0	0			0	0		750621	16
MO	21 S		80.82	81.28	1996	9	9.5	22		0	0			0	0		734229	16

Fig. 3.24 – Pavement structural data in old PMS dBase file.

The top row (record) in the table, shown in Fig. 3.24 and highlighted in green, is one of the sections in the 1700 to 3500 AADT full-depth asphalt pavement family. Based on conversations with the MoDOT Pavement Team, in 1992 (YRLSTWRK), the surface type (SURF)

was coded as a number 6 (asphalt concrete), the surface thickness (SURFTHK) was 20 in., the surface width (SURFWTH) was 24 ft, and there was 8 in. (BASETHK) of rolled stone (RS) base (BASE) aggregate that had been placed in 1958 (BASEYR). This is the type of data needed to fully incorporate pavement thickness as a modeling parameter, provided it is accurate. The investigation into this matter is ongoing.

#### **4 RESULTS AND DISCUSSION**

There have been no final pavement performance models developed at this time. Pavement family definitions have been established and classified as two-lane, undivided, homogenous, pavement sections of varying pavement type and traffic level. Pavement types are full-depth asphalt, concrete, and composite (asphalt over concrete).

Four full-depth asphalt pavement families have been established based on four different ranges of AADT levels. The Task 1 team has delivered all files for the 40 sections (10 sections per family) located in the Central District to the Task 2 team. However, personal interviews with MoDOT maintenance superintendents is still underway to verify collected data and possibly augment the pavement section files with missing data.

Thirteen composite pavement sections have been selected from around the state because there were insufficient composite pavements at lower traffic levels in the Central District for modeling purposes. Note that the composite sections will also be used for concrete pavement modeling. Concrete pavement modeling will be performed using the thirteen sections up until the year that the first asphalt surface was applied to the existing concrete pavement, then composite pavement modeling will begin at that year. The Task 1 team has delivered all composite section files, but this data is also being checked during the maintenance superintendent personal interviews.

UnitIRI (raw IRI data), and UnitCI will be the primary response variables investigated during modeling. Surface age and commercial traffic level will certainly be two of the predictor variables investigated, with climate (precipitation and temperature), subgrade type, and pavement thickness also evaluated as potential additional predictors.

Model type will be deterministic and model forms examined will be, at a minimum, multi-variate linear least-squares, power, and logarithmic.

## **5 CONCLUSIONS AND RECOMMENDATIONS**

There are no conclusions or recommendations to make at this time.

### **5.1 Completed Work**

Two of the four full-depth asphalt, Pavement Family Model Working Files (PFMWFs) have been created and used in preliminary modeling investigations. Significant insight has been gained regarding modeling strategy, sources of error, and expected results.

### **5.2 Remaining Work**

There is much more work to be accomplished in Task 2. Once all of the maintenance data review is complete, the remaining PFMWFs will be generated and the preservation treatment model datasets will be created. 30% of the data in all files used for modeling will be randomly selected for model validation purposes, and pavement family and preservation treatment model selection will begin.

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**APPENDIX C**  
**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**TASK 3 REPORT**  
**PAVEMENT EVALUATION TOOLS-DATA COLLECTION METHODS**

August 15, 2014

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National University Transportation Center

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The opinions, findings, and conclusions expressed in this report are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## EXECUTIVE SUMMARY

The overarching goal of the MoDOT Pavement Preservation Research Program, Task 3: *Pavement Evaluation Tools – Data Collection Methods* was to identify and evaluate methods to rapidly obtain network-level and project-level information relevant to in situ pavement condition to enable pavement maintenance decisions. The focus of these efforts was to explore existing and new technologies that can be used to collect data and develop the knowledge, procedures, and techniques that will allow MoDOT to perform pavement evaluation. Application of these technologies will ultimately enable pavement maintenance decisions that minimize cost and maintain/improve pavement quality.

At the time of this report, a summary of the investigated methods is being compiled, and a comparative analysis is nearing completion. This report presents a summary of methods previously used by MoDOT to evaluate pavement condition, a summary of methods investigated to evaluate pavement and subsurface conditions, and a summary of the completed and ongoing work to date. Final results will be published at a later date. This study is sponsored by the Missouri Department of Transportation and the National University Transportation Center at the Missouri University of Science and Technology in Rolla, Missouri.

## **AUTHOR ACKNOWLEDGEMENTS**

The research reported herein was sponsored by the Missouri Department of Transportation (MoDOT) and the National University Transportation Center (NUTC) at the Missouri University of Science and Technology (Missouri S&T). The research was performed by Missouri S&T and the University of Missouri-Columbia (UMC). At Missouri S&T, the principal investigator was Neil Anderson, and the co-principal investigator was Lesley Sneed. The principal investigator at the University of Missouri was Brent Rosenblad. Major contributions to the project were made by Evgeniy Torgashov, Abdallah Dera, Adel Elkrry, Aleksey Khamzin, Dan Iffrig, Mengxing Li, Stanley Nwokebuihe, and Aleksandra Varnavina. The assistance of each of these individuals is gratefully acknowledged.

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# 1 INTRODUCTION

## 1.1 Objectives

The objective of Task 3 was to identify and evaluate methods to rapidly obtain network-level and project-level information relevant to in situ pavement condition to enable pavement maintenance decisions. The focus of these efforts was to explore existing and new technologies that can be used to collect data and to develop the knowledge, procedures, and techniques that will allow MoDOT to perform pavement evaluation. Application of these technologies will ultimately enable pavement maintenance decisions that minimize cost and maintain/improve pavement quality. Specific objectives included:

- Summarize state-of-the-art methods to collect pavement data (with focus on non-invasive imaging technologies);
- Compare and quantify pavement data collection methods in terms of applicability, relative ease, relative cost, and to identify potential improvements to current MoDOT data collection practices;
- Recommend methods that will be selected for site specific pavement condition assessments in Task 4.

## 1.2 Justification

To evaluate the condition of existing pavement, various in situ data must be collected and interpreted. The extent and level of data needed depends on the type of pavement condition data sought (distress, structural capacity, or surface characteristics) and influences the type of assessment conducted (network-level or project-level). Thus the objective of this task was to explore existing and new types of data to be collected either by ARAN during MoDOT's annual condition survey or as a separately deployed system to enable the cost-effective collection of high-quality wide-area information on pavement conditions and site-specific detailed engineering information on the pavement and its subsurface.

Data collection technologies that were the focus of this task are non-invasive techniques. Some of the methods investigated have been used successfully to determine pavement thickness, elastic moduli of different layers, and moisture content. Non-invasive techniques are particularly desirable for collecting pavement data because their implementation can minimize lane closures and traffic disruption, which in turn minimize public inconvenience. Additionally, the use of non-invasive imaging can limit the amount of destructive testing (e.g. cores) required. These aspects also result in increased safety during the data collection process. Data consistency throughout the state can also be improved if such techniques are included within the annual condition survey (ARAN). Interaction with MoDOT personnel will be critical to evaluate the feasibility, advantages, and disadvantages of each technology investigated.

Another value-added benefit to adopting certain non-invasive imaging techniques is that they can be used for other applications including quality assurance of new pavement construction, evaluation of pavement subsurface characteristics, or even condition assessment of bridge decks. For example, certain techniques such as GPR can be used to confirm as-built pavement thickness to assure proper construction, as well as locate regions of delamination or corroded reinforcing steel in concrete bridge deck.

### **1.3 Scope of Work**

The scope of work for this task was to collect and summarize techniques, especially non-invasive techniques, used by MoDOT and others to collect network-level and project-level data on pavement condition. These techniques were compared to evaluate the applicability and relative cost for various applications. This work also served to establish the assessment techniques and procedures evaluated in Task 4.

The scope of work included five subtasks, Sub-task 3A, Sub-task 3B, Sub-task 3C, Sub-task 3D, and Sub-task 3E. Each of these tasks is described below.

**Sub-task 3A:** This sub-task included examination of methods routinely used by MoDOT and identification of data that are collected during network-level and project-level pavement assessments. Methods and data collected both by internal abilities and subcontracted efforts were examined. MoDOT provided information on request regarding equipment and technologies used and types of data collected in-kind to support the research program.

**Sub-task 3B:** This sub-task included an extensive review of commercially available methods utilized by the industry to assess pavement condition. Techniques reviewed focused on non-invasive imaging techniques for the reasons described in the *Justification* section (Section 1.2).

**Sub-task 3C:** This sub-task included an extensive review of methods currently being researched and/or under development to assess pavement condition. Techniques reviewed focused on non-invasive imaging techniques for the reasons described in the *Justification* section (Section 1.2).

**Sub-task 3D:** A comparative analysis was conducted in this sub-task based on the methods identified and reviewed in Sub-tasks 3A, 3B and 3C. Evaluation of each technique's utility to MoDOT was the key focus of this analysis. A summary table was developed to describe each technology in terms of applicability to network-level or project-level data production, type of pavement condition data collected (distress, structural capacity, surface characteristics), data collection method (manual, automated, semi-automated), reliability / reproducibility, and other advantages / disadvantages / limitations. Another summary table was developed to describe and compare the planning and cost-related aspects of each technology such as crew size, cost per day, area per day, lane closure requirements, level of expertise in data acquisition / processing, etc.



**Sub-task 3E:** The final sub-task within Task 3 was to select the most appropriate methods to evaluate in Task 4 for use in site-specific pavement condition assessment. Procurement of equipment and testing of methods selected was also conducted in this sub-task. Equipment selected for assessment in Task 4 was tested on pavement sections near Rolla and Columbia, Missouri.

#### **1.4 Organization of Report**

At the time of this report, a summary of the investigated methods is being compiled (Sb-task 3C, Section 1.3), and a comparative analysis is nearing completion (Sub-task 3D, Section 1.3). This report presents a summary of the methods investigated (Section 2), and a summary of the completed and ongoing work to date (Section 3). Final results will be published at a later date.

## 2 PAVEMENT INVESTIGATION METHODS

### 2.1 Summary of Methods Investigated

The methods that were investigated in this task are summarized in Table 2.1.

**Table 2.1 - Pavement/subsurface data collection methods and applicability**

Method	Network-Level	Project-Level	Pavement	Subsurface
<b>Stress Wave Methods</b>				
Impact Echo (IE) using Portable Seismic Property Analyzer (PSPA)		x	x	
Mult-Channel Analyses of Surface Wave (MASW)		x	x	x
Conventional Refraction Seismic Surveying		x	x	x
Conventional Refraction Seismic Tomography Surveying		x	x	x
Refraction Microtremor (ReMi)		x	x	x
Ultrasonic Surface Wave (USW) using Portable Seismic Property Analyzer (PSPA)		x	x	
<b>Electrical and Electromagnetic Methods</b>				
Conventional Electrical Resistivity Tomography (ERT)		x		x
Electrical Resistivity Tomography Using OhmMapper		x		x
Frequency-Domain Ground Conductivity Control		x	x	x
Time-Domain Ground Conductivity Control		x		x
Frequency-Domain Metal Detectors		x	x	x
Time-Domain Metal Detectors		x	x	
Gravity Method		x		x
Magnetic Method		x	x	
<b>Infrared Methods</b>				
Infrared Thermography (IR)	x	x	x	
<b>Radar Methods</b>				
Air-Launched Ground Penetrating Radar (GPR)	x	x	x	
High-Frequency Ground Coupled Ground Penetrating Radar (GPR)		x	x	
Low- to Intermediate-Frequency Ground Coupled Ground Penetrating Radar (GPR)		x	x	x
<b>Deflection Methods</b>				
Falling Weight Deflectometer (FWD)	x	x	x	
Rolling Dynamic Deflectometer (RDD)		x	x	
Rolling Wheel Deflectometer (RWD)	x		x	

In the final version of this report, summary tables will be provided that describe each technology listed in Table 2.1. Another summary table will be developed to describe and compare the planning and cost-related aspects of each technology such as crew size, cost per day, area per day, lane closure requirements, level of expertise in data acquisition/processing, etc.

## **2.2 Summary of Methods Previously Used by MoDOT**

An electronic survey was conducted of the different MoDOT districts to determine which methods have been used to assess pavement condition. The survey period was 9/10/12 – 10/12/12. Results of the survey are summarized in Table 2.2.

**Table 2.2 - Methods used by MoDOT districts for pavement investigation - summary of 9/10/12-10/12/12 survey results**

District	Methods Used
Northeast (1 <sup>st</sup> Response)	GPR-Rarely ARAN-Yearly
Northeast (2 <sup>nd</sup> Response)	PSPA-Rarely FWD-Rarely RWD-Rarely Portable Deflectometer-Rarely ARAN-Monthly Self-Potential-Rarely GPR-Rarely Resistivity-Rarely Seismic Reflection-Rarely Seismic Refraction-Rarely Infrared Thermography
Northwest	Heavy Vehicle Simulator-Rarely ARAN-Yearly
Southeast	FWD-Rarely ARAN-Yearly
Southwest	FWD-Yearly RWD-Rarely ARAN-Yearly GPR-Rarely Covermeter (Profometer) To determine steel mesh depth for diamond grinding candidate
Kansas City	FWD-Rarely RWD-Rarely ARAN-Yearly GPR-Rarely Infrared Thermography-Rarely
St. Louis	ARAN-Rarely Time Domain Reflectometry-Yearly Metal Detectors-Monthly GPR-Rarely Resistivity-Rarely Magnetic-Rarely
Construction and Maintenance Division	FWD-Yearly Portable Deflectometer-Rarely ARAN-Monthly Metal Detectors-Yearly GPR-Rarely Magnetic-Rarely
(Unknown respondent)	ARAN-Yearly Nuclear Densimeter-Monthly GPR-Rarely Resistivity-Rarely

## 3 CONCLUDING REMARKS

### 3.1 Summary

This task was used to identify and evaluate methods to rapidly obtain network-level and project-level information relevant to in situ pavement condition to enable pavement maintenance decisions. The focus of these efforts was to explore existing and new technologies that can be used to collect data and develop the knowledge, procedures, and techniques that will allow MoDOT to perform pavement evaluation. These technologies will ultimately enable pavement maintenance decisions that minimize cost and maintain/improve pavement quality. Noninvasive imaging methods reviewed in this task are summarized in Table 2.1.

### 3.2 Work Status

This section summarizes the status of the work at the time of this report. Work completed is summarized in Section 3.2.1, and work currently underway is summarized in Section 3.2.2; Future work is summarized in Section 3.3. Subtasks are discussed in detail in Section 1.3.

#### 3.2.1 Work Completed

At the time of this report, Sub-tasks 3A, 3B, 3C, and 3E (Section 1.3) have been completed.

- **Sub-task 3A:** *Summarize methods routinely used by MoDOT to assess pavement condition:* all districts have been polled, and the information has been compiled (Table 2.2). Sub-task 3A is 100% complete.
- **Sub-task 3B:** *Summarize commercially-available methods to assess pavement condition:* commercially-available methods have been investigated and summarized (Table 2.1). Sub-task 3B is 100% complete.
- **Sub-task 3C:** *Summarize methods currently being researched:* methods currently being researched at the time of this report have been summarized and are undergoing final edits by the investigators. Sub-task 3C is 100% complete.
- **Sub-task 3E:** *Method selection for Task 4:* methods have been selected to carry out the project-level and network-level investigations conducted in Task 4. Procurement and testing of air-launched GPR equipment (GSSI Roadscan 2 System – twin 2GHz Horn antennae) and GPS unit (Trimble GeoXH) was completed. Mounting of the GPR unit to the front of a vehicle was designed and fabricated, and the GPR unit was tested before acquiring the data in Task 4. The GPR unit mounted to a vehicle is shown in Fig. 3.1. Sub-task 3E is 100% complete.



*Fig. 3.1–Photo of twin air-launched (horn) ground penetrating radar (GPR) antennae mounted to vehicle.*

### **3.2.2 Work Currently Underway**

At the time of this report, work is currently underway on Sub-task 3D (Section 1.3).

- **Sub-task 3D: Comparative analysis of methods investigated:** A comparative analysis of the methods investigated is nearing completion. Sub-task 4D is estimated to be 90% complete.

### **3.3 Final Report Content**

The final report for this task will present comparative summaries of available technologies that can be used to collect data on pavement condition. The summary will be used to provide guidance to MoDOT on network level or project level data collection. Technologies will be summarized in terms of applicability to network-level or project-level data production, types of pavement condition data collected (distress, structural capacity, surface characteristics), data collection method (manual, automated, semi-automated), and other advantages, disadvantages and limitations. Descriptions of each technology will also be provided, in addition to current and previous usage by MoDOT and its contractors. Another summary table will be developed to describe and compare the planning and cost-related aspects of each technology such as crew size, cost per day, area per day, lane closure requirements, level of expertise in data acquisition/processing, etc.

**APPENDIX D**  
**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**TASK 4 REPORT**  
**SITE SPECIFIC PAVEMENT CONDITION ASSESSMENT**

August 15, 2014

Prepared for the

National University Transportation Center  
at the Missouri University of Science & Technology

by

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The opinions, findings, and conclusions expressed in this report are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## EXECUTIVE SUMMARY

The overall objective of the MoDOT Pavement Preservation Research Program, Task 4: *Site Specific Pavement Condition Assessment*, was to thoroughly assess the cost-effectiveness and utility of selected non-invasive technologies as applicable to MoDOT roadways. The intent was to develop a guidance document focused on the utility and cost-effectiveness of project-applicable and network-applicable non-invasive imaging technologies. The optimal utilization of appropriate non-invasive imaging technologies will result in more accurate pavement assessments at significantly reduced costs. Assessment of the utility and cost-effectiveness of the tested network-applicable non-invasive imaging tools was based, in large part, on the analyses of data acquired along two designated roadways. Assessment of the utility and cost-effectiveness of the tested project-applicable non-invasive imaging tools was based, in large part, on the analyses of data acquired along eight designated roadways.

At the time of this report, all data have been collected from the network-level and project-level sites and processed, and data interpretation and analysis is nearing completion. This report presents an overview of the project-level and network-level sites investigated, and a summary of the completed and ongoing work to date. Final results will be published at a later date. This study is sponsored by the Missouri Department of Transportation and the National University Transportation Center at the Missouri University of Science and Technology in Rolla, Missouri.



## **AUTHOR ACKNOWLEDGEMENTS**

The research reported herein was sponsored by the Missouri Department of Transportation (MoDOT) and the National University Transportation Center (NUTC) at the Missouri University of Science and Technology (Missouri S&T). The research was performed by Missouri S&T and the University of Missouri-Columbia. At Missouri S&T, the principal investigator for this task (Task 4) was Lesley Sneed, and the technical lead was Neil Anderson. The co-principal investigator was Ronaldo Luna. The co-principal investigator at the University of Missouri-Columbia was Brent Rosenblad. Major contributions to the project were made by Evgeniy Torgashov, Brittany Coppedge, Adel Elkrry, Brandon Goodwin, Dan Iffrig, Aleksey Khamzin, Mengxing Li, Stanley Nwokebuihe, Aleksandra Varnavina, David Willey, and Brandon Wolk. The assistance of each of these individuals is gratefully acknowledged.

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# 1 INTRODUCTION

## 1.1 Objectives

The objective of Task 4 was to thoroughly assess the cost-effectiveness and utility of the non-invasive technologies identified in Task 3 (Table 1.1) as applicable to MoDOT roadways. The intent was to develop a guidance document focused on the utility and cost-effectiveness of project-applicable and network-applicable non-invasive imaging technologies. The optimal utilization of appropriate non-invasive imaging technologies will result in more accurate pavement assessments at significantly reduced costs. Specific objectives included:

- Assessment of the utility and cost-effectiveness of the tested network-applicable non-invasive imaging tools based, in large part, on the analyses of data acquired along two designated roadways;
- Assessment of the utility and cost-effectiveness of the tested project-applicable non-invasive imaging tools based, in large part, on the analyses of data acquired along eight designated roadways; and
- Development of a comprehensive guidance document including a matrix of which cost-effective site assessment technologies are applicable, how to employ them, and what site condition data can be obtained.

**Table 1.1 - Summary of non-invasive technologies assessed as part of Task 4**

<b>Non-invasive Imaging Technology</b>	<b>Tested on Project-level Roadways</b>	<b>Tested on Network-level Roadways</b>
Ultrasonic Surface Waves (USW)	Yes	No
Impact Echo (IE)	Yes	No
Ground-coupled Ground Penetrating Radar (GPR) (400 MHz and 1500 MHz)	Yes	No
Electrical Resistivity Tomography (ERT)	Yes	No
Multichannel Analyses of Surface Waves (MASW)	Yes	No
Falling Weight Deflectometer (FWD) and	Yes	No
Rolling Dynamic Deflectometer (RDD)	Yes	No
Air-launched Ground Penetrating Radar (GPR)	No	Yes

## 1.2 Justification

To rapidly and cost-effectively assess the condition of new and existing pavements, various non-invasive in situ data must be collected and interpreted. The extent and level of data needed depends on the type of pavement condition information sought (distress, structural capacity, or surface characteristics) and influences the type of assessment conducted (network-level or project-level).

As discussed in Section 1.1, the objective of Task 4 was to thoroughly assess, in part through network-level and project-level field studies, the non-invasive imaging technologies identified and selected in Task 3 as applicable to MoDOT roadways (Table 1.1). The intent was to develop a guidance document focused on the utility and cost-effectiveness of identified project-applicable and network-applicable non-invasive imaging technologies. The guidance document is focused on when, where, and how to use each tool. The data acquired during the comprehensive test phase of Task 4 were used to evaluate the utility, cost-effectiveness, user-friendliness, accuracy, reliability, reproducibility, and limitations of each technology.

The optimal utilization of appropriate non-invasive technologies will result in more accurate pavement assessments and significantly reduced costs. The tools that were tested in this study can be applied to new pavements for quality control and quality assurance purposes, and can also be used to assess existing pavements. The tools that were tested will generate reliable information about thicknesses, moisture content and elastic modulus of pavement. Information can also be generated about the thickness, elastic modulus, and moisture content of the soil.

### **1.3 Scope of Work**

The scope of work for this task was to select both network-level and project-level sites (Section 2.1) that are generally representative of the different pavement conditions within the state of Missouri. Comprehensive characterizations of these sites were then performed using the state-of-the-art non-invasive practices identified in Task 3 as applicable to MoDOT roadways. Core control was collected at each site for calibration and verification purposes.

The scope of work included five subtasks, Subtask 4A, Sub-task 4B, Sub-task 4C, Sub-task 4D, and Sub-task 4E. Each of these tasks is described below.

**Sub-task 4A:** This sub-task had four components. Components 1 and 2 were the selection of roadways suitable for the acquisition of the network-applicable and project-applicable non-invasive imaging data identified in Task 3, respectively, and the procurement of existing ground truth. Components 3 and 4 were the design of optimal field data acquisition procedures and the coring program. MoDOT was responsible for the acquisition of cores.

**Sub-task 4A.1:** This sub-task was the selection of the two 60 mile-long roadways along which demonstration network-applicable non-invasive imaging data were acquired.

**Sub-task 4A.2:** This sub-task was the selection of the eight 1000 foot-long roadways along which demonstration project-applicable non-invasive imaging data were acquired.

**Sub-task 4A.3:** This sub-task was the design of the field procedures (protocol and acquisition parameters) for the acquisition of the network-applicable non-invasive imaging data

set and the design of the supplemental coring program. Lane closures were not necessary for the acquisition of network-level non-invasive imaging data set.

**Sub-task 4A.4:** This sub-task was the design of the field procedures (protocol and acquisition parameters) for the acquisition of the project-applicable non-invasive data sets and the design of the supplemental coring program.

**Sub-task 4B:** This sub-task had four components. Components 1 and 2 were the scheduling of field work, including the acquisition of the non-invasive imaging data.

**Sub-task 4B.1:** This sub-task was the scheduling of the acquisition of the network-applicable non-invasive imaging data. Lane closures were not necessary.

**Sub-task 4B.2:** This sub-task was the scheduling of the acquisition of the project-applicable non-invasive data. As part of the project-level testing program, the project team collaborated with personnel from the University of Texas at Austin to utilize a Rolling Dynamic Deflectometer (RDD) to collect continuous profiles of pavement deflection.

**Sub-task 4B.3:** This sub-task was the acquisition of the network-applicable non-invasive imaging data.

**Sub-task 4B.4:** This sub-task was the acquisition of the project-applicable non-invasive data.

**Sub-task 4C:** This sub-task had four components. Components 1 and 2 were the processing of the acquired non-invasive data. Components 3 and 4 were the analyses of all available relevant ARAN data and available ground truth including core control, construction histories, maintenance histories, etc.

**Sub-task .C.1:** This sub-task was the processing of the network-applicable non-invasive data. This task involved the design and implementation of quality control and quality assurance procedures to ensure imaging data were correctly processed and accurately positioned.

**Sub-task 4C.2:** This sub-task was the processing of the project-applicable non-invasive data. This task involved the design and implementation of quality control and quality assurance procedures to ensure data were correctly processed and accurately positioned.

**Sub-task 4C.3:** This sub-task was the analyses of all available relevant ground truth including core control, construction histories, maintenance histories, etc., along the two 60 mile-long network-level roadways. It was anticipated that core control would be acquired at each site. These data were used to constrain the interpretation of the acquired network-applicable non-invasive imaging data and to verify the reasonableness of the same.

**Sub-task 4C.4:** This sub-task was the analyses of all available relevant ARAN data and ground truth including core control, construction histories, maintenance histories, etc., along the eight roadway segments on which project-applicable non-invasive imaging data were acquired. It was anticipated that core control would be acquired at each site. These data were to constrain the interpretation of the acquired project-applicable non-invasive imaging data and verify the reasonableness of the same.

**Sub-task 4D:** This sub-task was the interpretation of the non-invasive imaging data. The interpretation of each set of non-invasive data was constrained by ground truth and by the interpretations of all other acquired sets of non-invasive imaging data. The primary objective was to collect as much site condition information as possible.

**Sub-task 4D.1:** This sub-task was the interpretation of the network-applicable non-invasive imaging data. The interpretation of each set of non-invasive imaging data was constrained by ground truth. The primary objective was to collect as much site condition information as possible. It was anticipated that the output would include information about pavement thickness and base/subgrade moisture content. A secondary objective was to assess the accuracy of the interpretations and the various factors that affect the reliability of interpretations.

**Sub-task 4D.2:** This sub-task was the interpretation of the project-applicable non-invasive data. The interpretation of each set of non-invasive imaging data was constrained by ground truth and by the interpretations of all other acquired sets of non-invasive imaging data. The primary objective was to collect as much site condition information as possible. It was anticipated that the output would include information about pavement thickness, pavement/base/subgrade elastic moduli, base and subgrade moisture content, base thickness, subgrade clay content, depth to top of rock. A secondary objective was to assess the accuracy of the interpretations and the various factors that affect the reliability of the interpretations.

**Sub-task 4E:** This sub-task was the development of a comprehensive guidance document including a matrix on which site assessment technologies are applicable, where to employ them, when to employ them, how to employ them, and what site condition data can be obtained. Topics addressed include: parameters measured, optimum acquisition parameters, optimum processing parameters, sampling interval, crew size, equipment costs, software costs, vehicle requirements, estimated daily cost, volume of data acquired per day, ease of data acquisition, ease of data processing, ease of data interpretation, reproducibility of interpretations, reliability of interpretations and cost-effectiveness, and recommendations for improvements to current site investigation and testing practices that can help achieve cost savings for MoDOT projects. This information was intended to provide the basis and data to establish the value of different non-invasive imaging technologies in various conditions so that MoDOT can use the most effective means available to characterize future sites.



#### **1.4 Organization of Report**

At the time of this report, all data have been collected and processed, and data interpretation and analysis is nearing completion. This report presents an overview of the project-level and network-level sites investigated (Section 2), and a summary of the completed and ongoing work to date (Section 3). Final results will be published at a later date.

## 2 INVESTIGATION OF PROJECT- AND NETWORK-LEVEL ROADWAYS

### 2.1 Project- and Network-Level Roadways: Background Information

#### 2.1.1 Project-Level Sites: Background Information

The project-level sites and survey objectives were selected by the project team and MoDOT. Non-invasive imaging data and core control were acquired along eight project-level roadway sites. Each tested segment of project-level roadway was 1000 ft in length. Non-invasive imaging data were collected in one lane only. Lane closures were required. The eight project-level sites and survey objectives are listed below:

- **Project-level Site 1 (US 63).** Objectives: Estimate pavement thickness and assess roadway condition (Table 2.1)
- **Project-level Site 2 (US 54).** Objectives: Detect deep (>6 in.) stripping layer and assess roadway condition (Table 2.1).
- **Project-level Site 3 (Rte 179).** Objectives: Detect debonding and assess roadway condition (Table 2.1) .
- **Project-level Site 4 (Hwy AT).** Objectives: Detect shallow (<6 in.) stripping layer and assess roadway condition (Table 2.1) .
- **Project-level Site 5 (I-55 Pemiscot County):** Objective: Assess an unbonded concrete overlay (no flaws anticipated) (Table 2.1).
- **Project-level Site 6 (I-55 Perry County):** Objective: Assess an unbonded concrete overlay (no flaws anticipated) (Table 2.1).
- **Project-level Site 7 (Hwy U).** Objectives: Assess a poor-condition asphalt roadway (Table 2.1).
- **Project-level Site 8 (I-35).** Objective: Assess an unbonded concrete overlay (flaws are anticipated) (Table 2.1).

Fig. 2.1 shows the location of the project-level sites. In Table 2.1, the survey objectives of each of the eight project-level sites are presented.

**Table 2.1 - Background information about eight project-level sites (see Fig. 2.1)**

<b>Project Location</b>	<b>Survey Objective(s)</b>
US 63 Phelps County (Site 1)	Estimate pavement thickness and assess roadway condition
US 54 Camden County (Site 2)	Detect deep (>6 in.) stripping layer and assess roadway condition
Rte 179 Cole County (Site 3)	Detect debonding and assess roadway condition
HWY AT Franklin County (Site 4)	Detect shallow (<6 in.) stripping layer and assess roadway condition
I-55 Pemiscot County (Site 5)	Assess an unbonded concrete overlay (no flaws anticipated)
I-55 Perry County (Site 6)	Assess an unbonded concrete overlay (no flaws anticipated)
HWY U Dent County (Site 7)	Assess a poor-condition asphalt roadway
I-35 Jackson County (Site 8)	Assess an unbonded concrete overlay (flaws are anticipated)

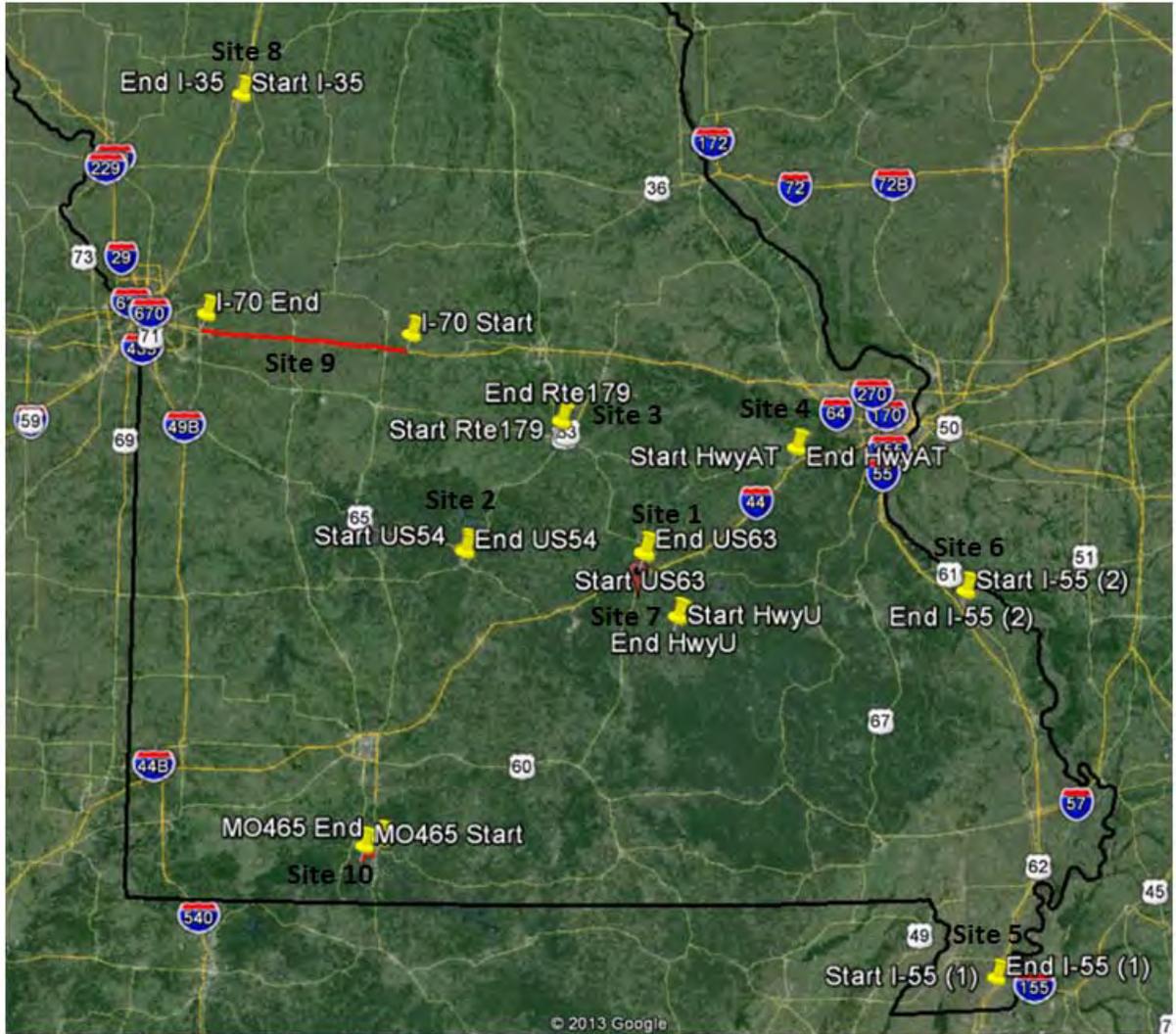


Fig. 2.1–Map showing locations of eight project-level sites and two network-level sites.

### 2.1.2 Network-Level Sites: Background Information

The network-level sites and survey objectives were selected by the project team and MoDOT. Non-invasive imaging data and core control were acquired along two network-level roadways. The two network-level sites and survey objectives are listed below:

- Network-level Site 9 (I-70). Objectives: Estimate pavement layer thicknesses and assess roadway condition (Fig. 2.2, Table 2.2).
- Network-level Site 10 (MO 465). Objectives: Estimate pavement layer thicknesses and assess roadway condition (Fig. 2.3, Table 2.2).

Fig. 2.2 and Fig. 2.3 show the locations of the network-level sites. In Table 2.2, survey objectives for both network-level investigations are presented.

**Table 2.2 - Background information about two network-level sites (see Figures 2.2 and 2.3)**

Project Location	Survey Objective(s)
I-70 MM84.2-MM20.8, driving lane, WB, survey extended across three counties (Jackson, Saline and Lafayette) (Site 9)	Estimate pavement layer thicknesses and assess roadway condition
MO 465 (between HWY 76 and US 65, both lanes, NB and SB) is located in Taney County (Site 10)	Estimate pavement layer thicknesses and assess roadway condition



*Fig. 2.2—Map showing network-level Site 9 (I-70). GPR data were acquired in the west-bound lane.*



*Fig. 2.3—Map showing network-level Site 10 (MO 465). GPR data were acquired in all four lanes (two north-bound; two south-bound).*

## **2.2 Methods of Investigations**

In an effort to demonstrate the cost-effectiveness and utility of the selected non-invasive imaging technologies, example test data were acquired using the following methods at eight project-level sites and along two network-level sites:

- High-frequency ground penetrating radar (GPR): network- (2.0 GHz, Fig. 2.4) and project-level (1.5 GHz, Fig. 2.5)
- Low-frequency (400 MHz) ground penetrating radar (GPR, Fig. 2.5): project-level only
- Impact echo (IE) (acquired using a portable seismic property analyzer, PSPA, Fig. 2.6): project-level only
- Ultrasonic surface wave (USW) (acquired using a portable seismic property analyzer, PSPA, Fig. 2.6): project-level only
- Electrical resistivity tomography (ERT, Fig. 2.7): project-level only
- Multichannel analysis of surface waves (MASW, Fig. 2.8): project-level only
- Falling weight deflectometer (FWD, Fig. 2.9): project-level only
- Rolling dynamic deflectometer (RDD): selected project-level sites

In addition to the non-invasive imaging technologies listed above, visual assessments were made of each project-level site. Additionally, cores were collected from each of the eight project-level sites and along two network-level sites.



*Fig. 2.4—Photo of high frequency (2.0 GHz) air-launched ground penetrating radar (GPR) mounted to vehicle.*



*Fig. 2.5—Photograph taken at Site 1 (US 63) showing operator, push-cart, high-frequency 1.5 GHz GPR antenna (in white plastic shell on pavement surface) and GSSI SIR-3000 control unit (top of cart). The low frequency 400 MHz data were acquired using the same set-up (low-frequency antenna was placed in white plastic shell). The acquired GPR data are displayed in real time on the control unit screen.*



*Fig. 2.6—Photograph of PSPA tool placed on pavement at project-level Site 1 (US 63 N). The PSPA tool is used to collect ultrasonic surface wave (USW) and impact echo (IE) data simultaneously.*



*Fig. 2.7—ERT data were acquired at each project-level site using an AGI SuperSting R8/IP resistivity system and a dipole-dipole array. Electrodes were spaced at 5 ft intervals. The intent was to image the subsurface to depths on the order of 40 ft. Photograph was taken at Site 1 (US 63).*



*Fig. 2.8—Active MASW data were acquired at each project-level site using a 24-channel engineering seismograph and 24 low-frequency (4.5 Hz) geophones spaced at 1.5 ft intervals. The intent was to image the subsurface to depths on the order of 40 ft. Photograph was taken at Site 1 (US 63).*



*Fig. 2.9—Photo of falling weight deflectometer (FWD) equipment. Photograph was taken at Site 1 (US 63).*





*Fig. 2.10—Photo of Rolling Dynamic Deflectometer (RDD) equipment. Photograph was taken at Site 8 (I-35).*

### 2.3 Summary of Investigation Dates and Weather Conditions

The dates and weather conditions for the geophysical field investigations and coring data acquisition for all the sites are presented in Table 2.3. Table 2.4 summarizes the RDD and FWD investigation dates and weather conditions.

**Table 2.3 - Summary of investigation dates and weather conditions of the pavement sites investigated**

Pavement Site	Date of Investigation	Weather Conditions	Coring Date	Weather Conditions
US 63 North of Rolla (Site 1)	10/29-30/2012	27-55° F, absence of rain	11/01/2012	51-68° F, absence of rain
US 63 (2 <sup>nd</sup> Survey) (Site 1)	02/13/2014	20-49° F, absence of rain	N/A	N/A
US 54 Camden County (Site 2)	11/12-13/2012	27-70° F, absence of rain	11/13/2012	21-54° F, absence of rain
MO 179 Jefferson City (Site 3)	12/03-05/2012	30-66° F, rain	12/05/2012	43-48° F, rain
HWY AT (Site 4)	07/25-26/2013	56-83° F, absence of rain	08/05/2013	67-91° F, absence of rain
I-55 Pemiscot County (Site 5)	07/31/2013	72-86° F, absence of rain	08/29/2013	72-94° F, absence of rain
I-55 Pemiscot County (2 <sup>nd</sup> Survey)	04/18/2014	50-73° F, absence of rain	N/A	N/A
I-55 Perry County (Site 6)	09/23/2013	45-75° F, absence of rain	09/24/2013	50-81° F, absence of rain
I-55 Perry County (2 <sup>nd</sup> Survey)	04/17/2014	39-68° F, absence of rain	N/A	N/A
HWY U (Site 7)	03/13-14/2013	25-67° F, absence of rain	03/14/2013	25-67° F, absence of rain
I-35 (Site 8)	08/06/2013	70-89° F, absence of rain	08/07/2013	71-90° F, absence of rain
I-70 WB (Site 9)	07/01/2013	61-83° F, absence of rain	04/08/2014	44-60° F, absence of rain
MO 465 Branson (Site 10)	09/19/2013	69-90° F, absence of rain	12/02/2013	41-64° F, absence of rain

**Table 2.4 Summary of RDD and FWD investigation dates and weather conditions of the pavement sites investigated**

<b>Pavement Site</b>	<b>Date of RDD Investigation</b>	<b>Weather Conditions</b>	<b>Date of FWD Investigation</b>	<b>Weather Conditions</b>
US 63 North of Rolla (Site 1)	12/11/2013	28-35° F, sunny	10/30/12	33-46° F, no rain
US 54 Camden County (Site 2)	11/19/2013	50-56° F, sunny	11/14/12	37-42° F, no rain
MO 179 Jefferson City (Site 3)	12/10/2013	36-38° F, sunny	12/4/2012	26-29° F, cloudy, rain
HWY AT (Site 4)	N/A	N/A	08/05/2013	71-74° F, no rain
I-55 Pemiscot County (Site 5)	12/12/2013	28-35° F, sunny	4/30/14	49-53° F, no rain
I-55 Perry County (Site 6)	N/A	N/A	09/24/2013	51-71° F, no rain
HWY U (Site 7)	N/A	N/A	05/2/2013	57-65° F, no rain
I-35 (Site 8)	11/18/2013	38-45° F, sunny	5/28/2014	84-87° F, no rain
I-35 Daviess County (RDD Only)	11/18/2013	42-45° F, sunny	N/A	N/A

## 3 CONCLUDING REMARKS

### 3.1 Summary

This task is used to assess the cost-effectiveness and utility of non-invasive technologies (Table 1.1) as applicable to MoDOT roadways by acquiring, processing, and interpreting non-invasive imaging data at selected project-level and network-level roadways. The non-invasive technologies utilized in this task were identified in Task 3. The optimal utilization of appropriate non-invasive imaging technologies will result in more accurate pavement assessments at significantly reduced costs.

### 3.2 Work Status

This section summarizes the status of the work at the time of this report. Work completed is summarized in Section 3.2.1, and work currently underway is summarized in Section 3.2.2; Subtasks are discussed in detail in Section 1.3.

#### 3.2.1 Work Completed

At the time of this report, Sub-tasks 4A, 4B, and 4C (Section 1.3) have been completed.

- **Sub-task 4A: *Site Selection*:** All eight project-level sites and both network-level sites have been identified. The project-level sites and network-level sites are presented in Section 2.2 and Section 2.3, respectively. Sub-task 4A is 100% complete.
- **Sub-task 4B: *Schedule and Acquisition*:** Acquisition of data at the project level and network sites has been completed. The project-level sites and network-level sites are presented in Section 2.2 and Section 2.3, respectively. Pavement core location selection and extraction has been completed. Sub-task 4B is 100% complete.
- **Sub-task 4C: *Processing*:** Processing of data at the project level and network sites has been completed. The project-level sites and network-level sites are presented in Section 2.2 and Section 2.3, respectively. Pavement core laboratory testing and logging has been completed. Sub-task 4C is 100% complete.

#### 3.2.2 Work Currently Underway

At the time of this report, work is currently underway on Sub-tasks 4D and 4E (Section 1.3). The following discussion contains details of the work currently underway for each of the five sub-tasks.

- **Sub-task 4D: *Interpretation and Analysis*:** Interpretation and analysis of the data for all eight project-level sites and both network-level sites is nearing completion. Sub-task 4D is estimated to be 90% complete.

- **Sub-task 4E: *Guidance Document*:** Work on the guidance document has been initiated. This sub-task is ongoing. Sub-task 4E is estimated to be 10% complete.

### **3.3 Final Report Content**

The final report for this task will present interpreted geophysical data acquired using each non-invasive imaging technology from each project-level and network-level site included in this project. The final report will also report information about pavement core control acquired at each project-level and network-level site. The effectiveness of each non-invasive imaging technology will be evaluated in terms of its ability to achieve the investigation survey objectives (Section 2.1). Finally, a guidance document (Section 3.2.1) will be developed in the Task 4, based on the findings from this work.

**APPENDIX E**  
**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**TASK 5 REPORT**  
**PAVEMENT TREATMENT TRIGGER TABLES/DECISION TREES**  
**and**  
**TREATMENT CANDIDATE SELECTION PROCESS**

August 15, 2014

Prepared for the

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The opinions, findings, and conclusions expressed in this report are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## EXECUTIVE SUMMARY

This research was performed by researchers from the Missouri University of Science and Technology and the University of Missouri-Columbia. This research was performed by the Missouri University of Science and Technology and the University of Missouri-Columbia. This research was performed by the Missouri University of Science and Technology and the University of Missouri-Columbia. The general objective of Task 5 is to provide a manual that the Missouri Department of Transportation (MoDOT) can use to select the most appropriate pavement treatment for a given roadway project. The selection procedure will include a benefit/cost assessment method. Salient to any pavement management system is the process of determining potential treatment options, and the subsequent selection of the final treatment choice. Task 5 thus entails the development of pavement treatment trigger tables/decision trees and the treatment candidate selection process.

Armed with the treatment tables and the selection process, MoDOT will be able to select appropriate treatments by use of treatment matrices showing the most appropriate applications for given specific site conditions and then be able to perform a benefit/cost analysis and/or economic lifecycle cost analysis for each candidate treatment. The idea in using the decision table/tree is to decide which optional treatments will be required to move the System Rating of a given road from “Poor” into “Good”, or in an extreme case, from “Poor-Unsafe” to “Poor-Safe”. The selection of the optimum treatment from the possible ones would be done in a network prioritization activity (not part of this research project).

This research project is currently underway, and the efforts to develop the treatment trigger tables is still in-progress. The input to the trigger tables could entail such factors as an overall condition indicator, smoothness, individual distress types-extent-severity (eg. surface defects, surface deformation, cracking, patches and potholes, wear, polishing, map cracking, D-cracking, pop-outs, scaling, spalling, shallow reinforcing, corner cracks, faulting), subgrade/base drainage, pavement type, history of treatment (including construction and material quality), and some measure of traffic, either actual ADT's or as a functional classification (e.g. interstate), and driving speed.

Table output would be one or more feasible potential appropriate treatments, which would consider pavement condition, traffic, climate (which affects construction timing and treatment performance), work zone duration (e.g. traffic control issues), time of year construction, construction quality risk, availability of quality contractors and quality materials, longevity of treatment, and availability of funding. Trigger tables/trees could include preservation treatments (chip seals, microsurfacing, slurry seals, ultrathin bonded asphalt wearing surface (UBAWS), crack sealing, crack filling, thin overlays, mill and fill, profile milling, hot in-place recycling, diamond grinding) and rehabilitation (structural hot mix asphalt (HMA)

overlays, bonded and unbonded concrete overlays, rubblizing/ break and seat, cold in-place recycling, full depth reclamation, load transfer retrofit and joint repair, partial/ full depth repair).



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# 1 INTRODUCTION

## 1.5 Report Organization

The following report is part of a research project on pavement preservation performed by the Missouri University of Science and Technology (Missouri S&T) and the University of Missouri-Columbia (UMC) on behalf of the Missouri Department of Transportation (MoDOT). The overall report consists of a Summary Report followed by six detailed technical reports. This report is one of the detailed reports: *Task 5 - Pavement Treatment Trigger Tables/Decision Trees and Treatment Candidate Selection Process*.

## 1.2 Background

In the Summary Report, a flow diagram of modified pavement management process flow chart (Fig. 1.1).

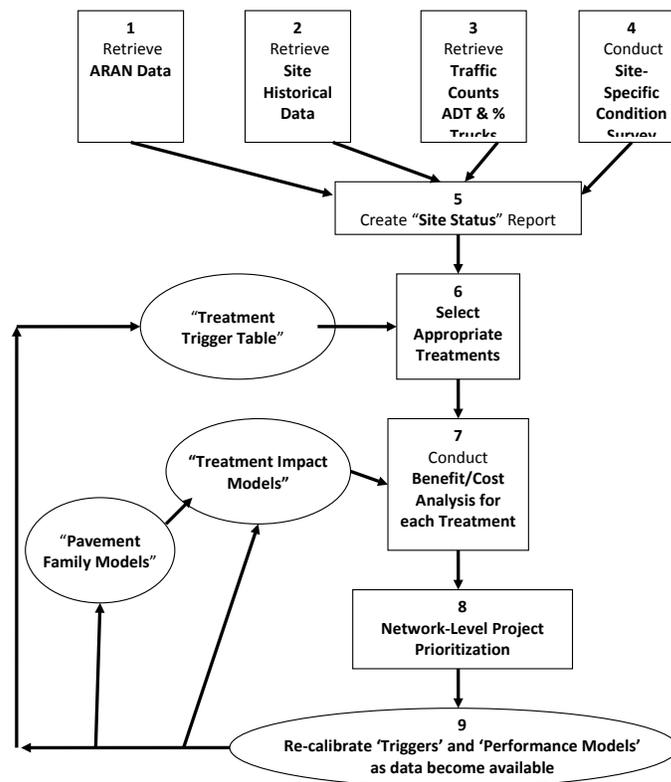


Fig. 1.1 – Procedural steps for implementing a modified pavement management process (after AASHTO 2011).

This information is taken from the updated AASHTO Guide to Pavement Management (AASHTO 2011) that MoDOT strongly recommended to the project team. Based on the AASHTO Guide, the following is the procedure that a MoDOT Pavement Specialist would use for implementing the *modified pavement management flowchart* (Fig. 1.1). The procedure would be followed for

a given proposed road maintenance/preservation/rehabilitation project. The word “retrieve” is used to emphasize that the data, models, and tables to be used would already exist:

- Step 1-Retrieve annual road condition survey (eg. ARAN) data
- Step 2- Retrieve site historical data: eg. materials, thicknesses, subgrade soil, drainage, weather, construction records
- Step 3- Retrieve traffic counts: Average Daily Traffic (ADT) and percentage trucks, or Average Daily Truck Traffic (ADTT)
- Step 4- Conduct a site-specific condition survey (visual, coring, non-destructive testing)
- Step 5- Combine information from steps 1 through 4 into a “Site Status”. Identify the roadway as a certain “Pavement Family” type (see Table 1.1)
- Step 6- With “Site Status”, enter appropriate “Treatment Trigger Table” and select several alternate treatments (Table 1.2) appropriate for the assigned Family
- Step 7- With the appropriate “Treatment Impact (Performance) Models,” conduct a benefit/cost or marginal cost effectiveness analysis for each potential treatment
- Step 8- Using the calculated cost effectiveness of all treatments and all projects, conduct a network-level (county, region or state-wide) project prioritization list. Project prioritization could be based on other considerations in addition to benefit/cost

**Table 1.1 – Potential definitions of Pavement Families in Missouri, i.e., types of pavements (two for flexible, one for composite, and six for rigid pavements)**

Flexible:
▪ < 7 in. Full-depth asphalt <sup>1</sup>
▪ ≥7 in. Full-depth asphalt <sup>1</sup>
Composite:
• Asphalt over concrete
Concrete:
▪ JPCP, 15 ft joint spacing
▪ JRCP, 61.5 ft joint spacing
▪ CRCP
▪ Bonded concrete overlay over concrete
▪ Unbonded concrete overlay over concrete
▪ Concrete over asphalt (whitetopping)

<sup>1</sup> may include nominal unbound granular base

<sup>2</sup>As Tasks 1 and 2 of the proposed program are completed, it is possible the number of Pavement Families could be more or less than the example shown here

**Table 1.2 – Example of pavement treatment types used in Missouri (not limited to MoDOT)**

<b>Pavement Treatment Types</b>
▪ Crack/joint sealing/filling
▪ Chip sealing, fog sealing, scrub sealing
▪ Micro-surfacing, onyx slurry sealing
▪ Thin HMA overlays: 1 ¾, 1 ¼ or 1-in.
▪ Unbonded Asphalt Wearing Surface (UBAWS)
▪ Structural overlays: 3 ¾, 3 ¼ or 2 ¾-in. thickness
▪ Mill & fill, mill & overlay (see above overlays)
▪ Asphalt Cold In-Place Recycling (CIR)
▪ Asphalt Hot In-place Recycling (HIR)
▪ Full Depth Reclamation (FDR)
▪ Diamond grinding
▪ Load transfer retrofit & joint repair
▪ Partial/ full depth repair

Thus, Task 5 was involved with creating the trigger tables used in step 6 and creating an analysis scheme for step 7.

**1.3 Objective**

The objective of Task 5 was to produce Trigger Tables/Decision Trees and the Treatment Candidate Selection Process.

**1.4 Scope of Work**

Task 5 involved the creation of Treatment Trigger Tables and a Treatment Candidate Selection Process. A procedure was to be furnished to select appropriate treatments (design) including a treatment matrix showing the most appropriate applications for given specific site conditions (Step 6 Fig. 1.1) and to perform a Benefit/Cost Analysis and/or Economic Lifecycle Cost Analysis (Step 7 Fig. 1.1) for each candidate treatment to ultimately recommend a specific treatment. (AASHTO 2011). The idea in using the table is to decide what optional treatments it will take to move the System Rating from Poor into Good, or in an extreme case, from Poor-Unsafe to Poor-Safe. Deliverables are: 1) Trigger tables/Decision Trees, and 2) benefit/cost methodology (roadway project specific). The sub-tasks are listed below:

9. Sub-task 5A: Procure laboratory equipment and AASHTOware Pavement ME Design software

10. Sub-task 5B: Conduct literature search
11. Sub-task 5C: Engage in discussions with MoDOT to obtain information about pavement types, treatment types, selection criteria, mixes, and past history
12. Sub-task 5D: Conduct treatment option analysis using AASHTOware and/or other software
13. Sub-task 5E: Conduct mixture testing and analysis
14. Sub-task 5F: Create a draft manual of treatment trigger tables and benefit/cost procedures
15. Sub-task 5G: Review the draft Task 5 manual and a final version is completed
8. Sub-task 5H: Provide training of MoDOT personnel in use of the product (trigger tables and benefit/cost calculations)

## 2 WORK STATUS

### 2.1 Work Completed

**Sub-task 5A:** *Procure laboratory equipment and AASHTOware software:*

Purchase or design and fabrication of the following has been completed: Asphalt Mixture Performance Tester (AMPT), Asphalt Pavement Analyzer (APA) Hamburg and digital upgrade, four conditioning ovens with support shelves, gyratory compactor mold spacers, gyratory compactor mold modification, core drill permanently mounted, core holding jig, and core holding saw jig. The AMPT compressor was replaced by the vendor. Sub-task 5A is 100% complete.

### 2.2 Work Currently Underway

At the time of this report, work is currently underway in sub-tasks 5B through 5G.

**Sub-task 5B:** *Conduct literature search*

The literature search has been initiated. Numerous publications have been identified, procured, and reviewed. Sub-task 5B is 50% complete.

**Sub-task 5C:** *Engage in discussions with MoDOT to obtain information about pavement types, treatment types, selection criteria, mixes, and past history.*

The Task 5 team has met with or has held telephone/email conversations with a number of MoDOT personnel from different divisions one-on-one in regard to choice of mix designs, pavement maintenance policies, lab equipment, and subgrade soils data: Construction and Materials (John Donahue, Joe Schroer, Jason Blomberg, Paul Denkler, Rob Massman, Jeff Huffman, Donna Hoeller, Leslie Wieberg, Mike Fritz, and Kevin McLain), Planning (Jay Whaley), and Maintenance (Mike Dunseth, Todd Miller, Jason Sommerer, Brad Brown, Jason Schafer,



Kenton Bohon, Charles Schroyer, and Joe Moore). From these discussions, decisions were made in choosing mix types to study in sub-task 5E. Sub-task 5C is 90% complete.

**Sub-task 5D:** *Conduct treatment option analysis using AASHTOware and/or other software*

The state's geologic areas/soil associations have been examined in a preliminary way leading to a first pass through the AASHTOware software for a variety of pavement scenarios, comparing different treatment designs. Also, MoDOT's AASHTOware local calibration constants have been applied to the software. It was noted that there are several bugs in the software and the software supplier has been notified.

Three BP-1 mixes have been evaluated via the AASHTOware software. Preliminary conclusions are that volumetrics seem to impact predicted performance the most, with the fatigue cracking prediction the most sensitive performance criteria. Sub-task 5D is 20% complete.

**Sub-task 5E:** *Conduct mixture testing and analysis*

In regard to pavement treatment evaluation, longevity of various treatments must be predicted. Two approaches are being followed in parallel. One approach, applicable to all treatment types from overlays to a variety of surface treatments, is to search the literature to garner other state DOTs' and other agencies' experiences with treatment longevity. The second approach, the subject of sub-task 5E, is to perform laboratory testing of HMA mix types to 1) provide input to the AASHTOware software for use in service life predictions (varying mix designs, thicknesses, base support, subgrade, climate, and traffic), and 2) compare AASHTOware predictions to results of performance testing such as APA rut depth, Hamburg Loaded Wheel rutting/stripping characteristics, and Tensile Strength Ratio (TSR). The second approach has been used successfully by other DOTs such as the Louisiana DOT.

Planning for the mix selection has been completed. The general approach is to narrow the scope of HMA mix types to be evaluated to those that would be used for maintenance on minor routes. After discussions with Paul Denkler, Jason Blomburg, and Joe Schroer, it was decided to eliminate Superpave and BP-3 mixes and concentrate on surface leveling (SL) and Bituminous Pavement (BP) mixes. Because SL and BP-2 mixes are virtually the same in many cases, the final experimental design called for BP-1 and SL mix types.

Two levels of quality (Good and Marginal) per mix type are being evaluated to give a range of behavior in the AASHTOware and performance testing. "Good" means high quality aggregate, proper volumetrics, proper binder content, proper dust/effective binder ratio, minimal deleterious materials content, and so forth. "Marginal" relates to these attributes being barely approved in design and possibly even worse as-produced. All mix designs approved by MoDOT's field office in 2011 of SL, BP-1, BP-2, and BB were examined as well as aggregate quality records. After discussions with Joe Schroer and one knowledgeable contractor, two aggregate sources (formations/ledges) were chosen. The Marginal aggregate source [Capitol

Quarries, Rolla quarry, Jefferson City Dolomite (JCD), ledges #9 through #1J (multiple fractions)] and the Good aggregate source [Capitol Quarries, Sullivan quarry, Potosi Dolomite, ledge #1,] (multiple fractions) have both been identified and sampled. Design of three BP-1 mixes (Good, Marginal (In-Spec), Marginal In-Tolerance (Out-of-Spec)) has been completed and testing begun.

The binder for all mixes was a PG64-22 (one supplier).

Table 2.1 contains the BP-1 mix characteristics and MoDOT specifications.

**Table 2.1 - BP-1 mix characteristics**

Parameter	BP-1	BP-1 Good	BP-1 Marginal, In-Spec	BP-1 Marginal, Out-Spec
	Specification	Design	Design	Design
Aggregate Formation		Potosi Dolomite	Jefferson City Dolomite	Jefferson City Dolomite
Aggregate:				
Absorption, %	4.5% max.	1.4-2.0	3.0-4.1	3.0-4.1
LAA	55 max.	26	30	30
Micro Deval		9.6	21.5	21.5
Gradation % Passing:				
¼ in.	100	100	100	100
½ in.	85-100	98	98	98
#4	50-70	53	53	53
#8	30-55	30	31	38
#30	10-30	16	13	23
#200	5-12	5.0	7.0	12.0
Mixture:				
Natural sand, %		9.4	23.0	21.0
Shale	2.0% max	0	2.0	2.0
Clay, dispersed	3.0% max.	0	3.0	3.0
Binder, %		5.9	6.1	5.8
Effective binder, %		4.6	4.5	4.1
Effective binder by volume, %		10.7	10.2	9.5
Dust/binder		1.1	1.6	3.0
Air voids, %	3.5	3.5	3.5	1.7
VMA	13.5	14.2	13.7	11.2
VFA	60-80	75.3	74.5	84.5
TSR	70 min.	86	28	23
Tolerance/Action Limit:				
Binder, %	±0.3			-0.3
Passing #8, %	±5.0/10.0			+7.0
Passing #200, %	±2.0/4.0			+5.0

As can be seen, the Potosi Dolomite mix would be considered a good material for asphalt mixtures: relatively low absorption, low LA abrasion, low Micro-Deval, no deleterious materials, modest minus #200, low natural sand content, meets volumetric requirements, moderate dust/effective binder ratio, and a relatively high effective binder content by volume. The Jefferson City dolomite in-specification mix met all requirements, but had inferior aggregate (high absorption, higher LA abrasion, high Micro-Deval), deleterious amounts of shale and clay dust at the maximum allowable by section 1004, high natural sand content, greater

dust/effective binder ratio, and lower effective binder content by volume. The Jefferson City dolomite in-tolerance out-of-specification mix was similar to the in-spec Jefferson City mix, but with several mix components allowed to stray as if during production: the dust was increased to the specification maximum allowable, the gradation became finer, the binder content was reduced, which led to lower (out-of specification) air voids and VMA, and a high dust/effective binder ratio.

The mixes were subjected to Hamburg Loaded Wheel and TSR testing. The results of the Hamburg testing for the Good, Marginal, and Marginal-out-of-specification mixes are shown in Figs. 2.1, 2.2, 2.3, and 2.4, respectively.

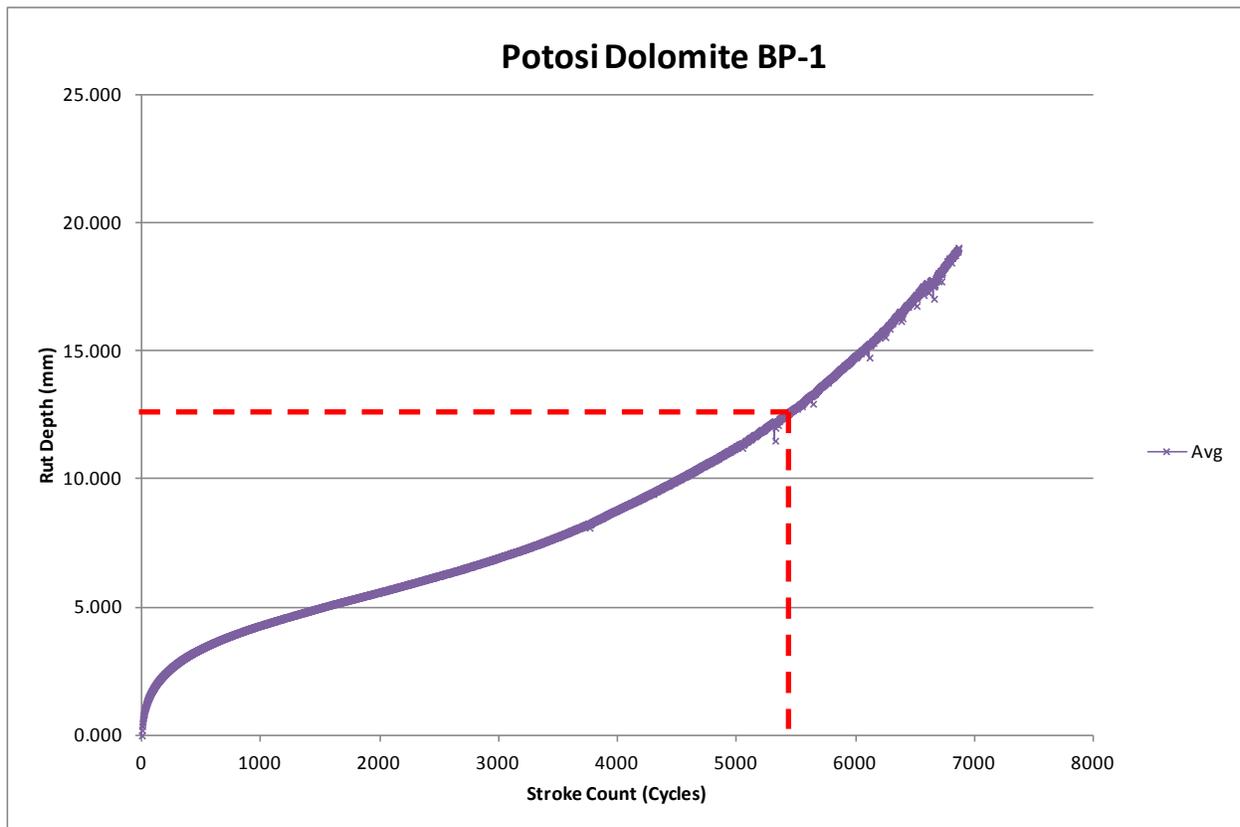


Fig. 2.1- Hamburg results for Potosi Dolomite mix, average of three curves.

Texas DOT (TXDOT) has had considerable experience with using Hamburg LWT results for mix approval, mix evaluation, and specification compliance. The Texas DOT criteria for limestone mixes with a non-modified binder PG 64-22 (similar to MoDOT's BP plant mixes) is equal to or less than 12.5 mm rutting at 5000 cycles. The Potosi mix met this requirement with about 5550 cycles at 12.5 mm rut depth. Very little stripping was observed by visual inspection (Fig. 2.2a). The TSR for the Potosi was 86, well over the MoDOT section 401 minimum requirement of 70. For the Jefferson City dolomite In-Spec mix, the Hamburg results showed about 3040 cycles at 12.5 mm, failing the Texas DOT threshold. The TSR was 28, badly failing MoDOT's section 401 specification. The visual exam showed a loss of matrix and considerable broken aggregate (Fig.

2.2b). As expected, the Jefferson City dolomite Out-of-Specification mix fared worse than the In-Specification mix: the Hamburg results resulted in about 2440 cycles at 12.5 mm, failing the Texas DOT threshold. The TSR was 23, badly failing MoDOT's section 401 specification. The visual exam showed a loss of matrix and considerable broken aggregate (Fig. 2.2.c).



Fig. 2.2.a- Potosi Dolomite    Fig. 2.2.b-JCD in-spec    Fig. 2.2.c- JCD out-of-spec

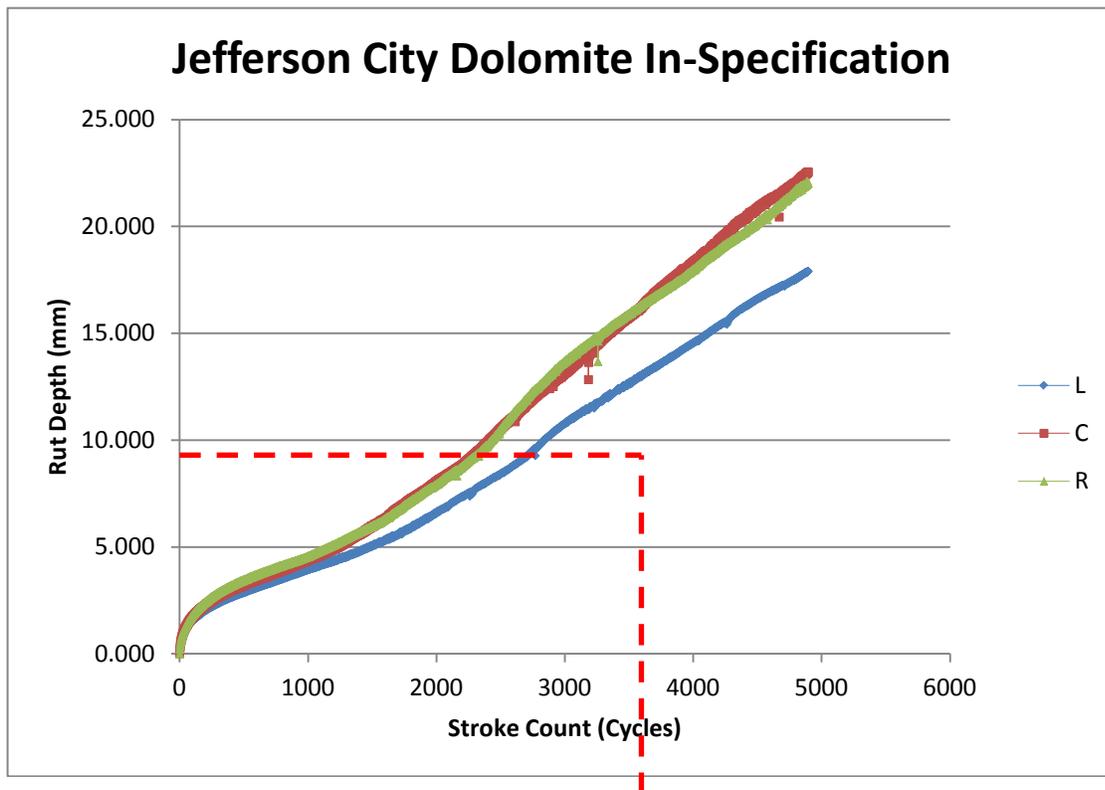


Fig. 2.3 – Hamburg results for Jefferson City Dolomite in-specification mix.

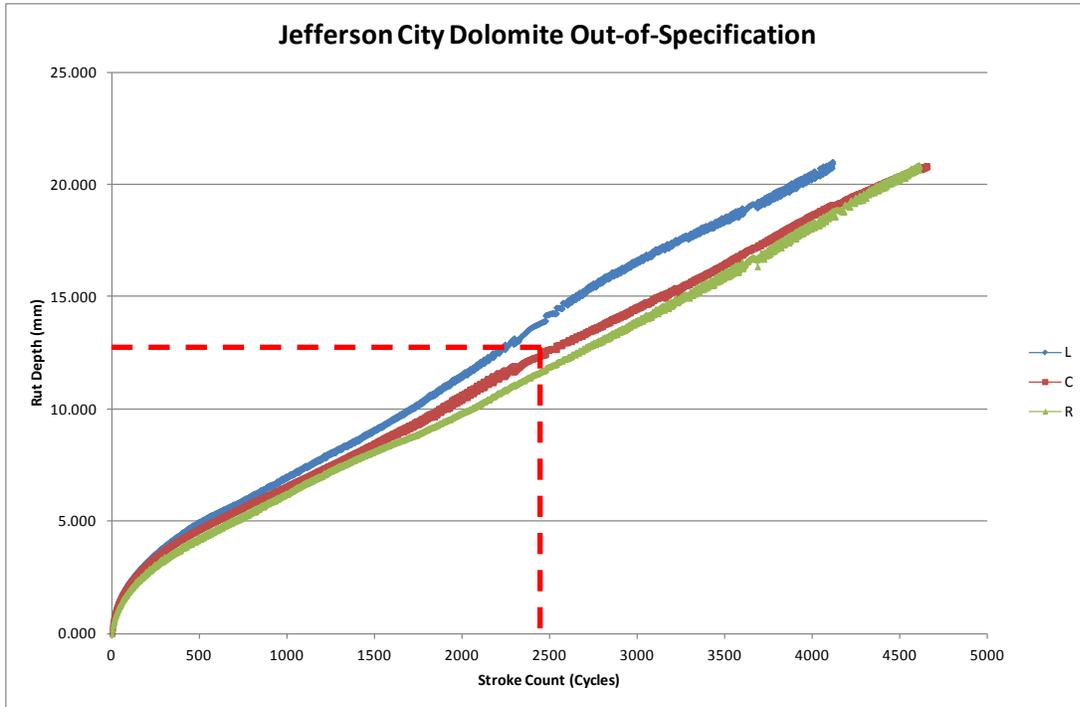


Fig. 2.4 – Hamburg results for Jefferson City Dolomite out-of-specification mix.

In Fig. 2.5 is shown the relationship of Hamburg cycles to 12.5 mm rut depth to TSR. As can be seen, in this preliminary data, there is a direct relationship, as expected.

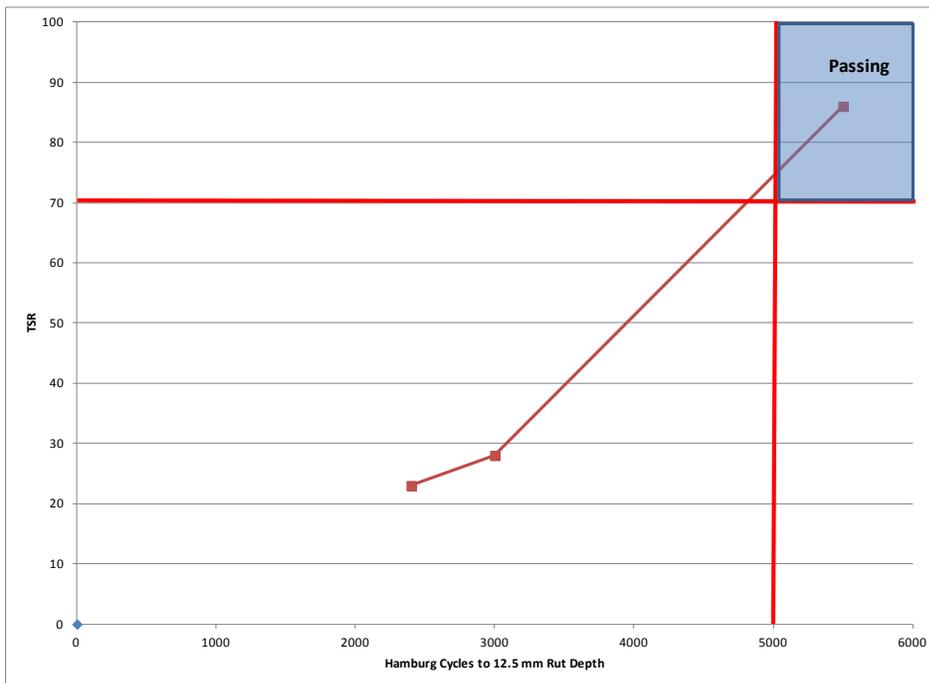


Fig. 2.5 - Relationship of Hamburg to TSR, all three mixes.

Sub-task 5E is 12% complete.

**Sub-task 5F:** *Create a draft manual of treatment trigger table/decision trees and benefit/cost procedures.*

Sub-task 5F is zero % complete.

**Sub-task 5G:** *MoDOT reviews the draft Task 5 manual and a final version is completed.*

Sub-task 5G is zero % complete.

**Sub-task 5H:** *Provides training of MoDOT personnel in use of the product (trigger tables and benefit/cost calculations).*

Sub-task 5H is zero % complete.

### **3 FINAL REPORT**

The final report for Task 5 will include laboratory testing results of SL and several mixes containing Recycled Asphalt Pavement (RAP), as well as the BP-1 mixes. AASHTOware analysis will be completed for prediction of service life, and a comparison made between the laboratory performance testing and the AASHTOware service life predictions. Trigger tables/decision trees will be developed based on a combination of the above service life predictions and the experience of other agencies. The report will also include a recommended method of a benefit/cost evaluation procedure.

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**APPENDIX F**  
**NUTC/MoDOT PAVEMENT PRESERVATION RESEARCH PROGRAM**  
**NUTC Project 00039112**

**TASK 6 REPORT**

**RE-CALIBRATION OF TRIGGERS AND PERFORMANCE MODELS**

August 15, 2014

Prepared for the

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at the Missouri University of Science & Technology

by

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The opinions, findings, and conclusions expressed in this report are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## EXECUTIVE SUMMARY

The research reported in this document was performed by researchers from the Missouri University of Science and Technology and the University of Missouri-Columbia (UMC). The objective of this task is to develop the concept and framework for a procedure to routinely re-calibrate and update the Trigger Tables and Treatment Performance Models. The scope of work for Task 6 includes a limited review of the recent pavement management systems literature for key elements for inclusion, strategies and procedures used to 'update' pavement performance (deterioration) models, and triggers for initiating a treatment evaluation. Because this is a relatively new process, the task will entail contacting and surveying several state DOT's that already have an updating process in place. The task will include interaction with MoDOT personnel in order to be sure that the proposed framework for the re-calibration procedure can incorporate what MoDOT already does to update triggers and performance models and is compatible with current practices in MoDOT. As the framework for the re-calibration process is developed, the draft framework will be prepared and shared with MoDOT for discussion and comments. A final document describing the framework will be submitted for the deliverable from Task 6. To reap full benefit from the overall pavement maintenance program, it will then be incumbent upon MoDOT personnel to adapt and implement the re-calibration framework in order to realize the full potential of the modified pavement management process.

## **AUTHOR ACKNOWLEDGEMENTS**

The research reported herein was sponsored by the Missouri Department of Transportation (MoDOT) and the National University Transportation Center (NUTC) at the Missouri University of Science and Technology (Missouri S&T). The principal investigator at UMC was Brent Rosenblad, and the co-principal investigator was Andy Boeckmann. The data collection efforts were greatly dependent on the cooperation of many MoDOT personnel, including Paul Denkler and Jay Whaley. The authors are greatly appreciative of this valuable cooperation.

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# 1 INTRODUCTION

Pavement maintenance treatment trigger tables and performance (pavement deterioration) models must represent the treatments being used by MoDOT and the conditions to which they are applied. As new treatments are adopted and additional pavement performance data become available it is essential to update and calibrate the performance models and treatment thresholds (triggers) in order to refine the decisions regarding which pavements to treat, what treatments are appropriate, when to perform the treatments and ultimately to save the greatest amount of money while maximizing pavement performance conditions. The objective of this task was to develop the concept and framework for a procedure to routinely update the pavement performance models and treatment thresholds (triggers).

This report comprises the final document describing the conceptual framework for updating the performance models and treatment thresholds. To reap full benefit from the overall pavement maintenance program, it is incumbent upon MoDOT to adapt and implement an updating framework in order to realize the full potential of the modified pavement management process.

## 1.1 Goal

The principal goal of the MoDOT Pavement Preservation Research Program, Task 6: *Re-Calibration of Triggers and Performance Models* was to provide a framework for updating the pavement management system developed in the other tasks.

## 1.2 Objectives

The primary objectives of this task were to:

- Summarize available literature regarding updating pavement management systems
- Identify existing updating procedures in place by other state agencies
- Describe any existing MoDOT procedures for incorporating new pavement information
- Develop a conceptual procedure for updating MoDOT's pavement management system

## 1.3 Scope of Work

The scope of work for Task 6 included a limited review of the recent pavement management systems literature for key elements for inclusion, strategies and procedures used to update pavement performance (deterioration) models and pavement treatment thresholds (triggers) for initiating a treatment evaluation. Because updating models and thresholds is a relatively new process, the task entailed identifying, contacting and surveying several state DOTs who already have an updating process in place. Task 6 also included interaction with MoDOT personnel to be sure the proposed framework for updating performance models and treatment thresholds is compatible with current MoDOT practices. The draft framework was shared with MoDOT for discussion and comments.



## **1.4 Organization of the Report**

Chapter 1 presents the goal, objectives, and scope of this task. Chapter 2 presents the results of a literature review related to updating pavement management systems. Chapter 3 summarizes a limited synthesis of updating procedures in place by other state agencies. Chapter 4 describes current MoDOT practice, and Chapter 5 presents a conceptual procedure for updating MoDOT's pavement management system.

## **2 BACKGROUND AND LITERATURE REVIEW**

Pavement performance modeling and establishing treatment action thresholds (treatment triggers) are not new concepts; however, the amount and types of performance monitoring data are rapidly expanding resulting in 'mega-data' concerning pavement performance. The issues have become: what data to collect, how frequently to collect it and how to most efficiently and effectively incorporate new data to update existing pavement management systems including performance models and treatment triggers. In the Pavement Preservation Research program, more robust pavement performance models have been developed and treatment thresholds (triggers) have been established. Literature applicable to 'updating' the performance models and treatment triggers has been reviewed and the most applicable information for updating the new (proposed) performance models and triggers is described in this chapter.

### **2.1 Development of Pavement Performance Curves for Individual Distress Indices in South Dakota Based on Expert Opinion**

The South Dakota Department of Transportation (SDDOT) and Deighton Associates Limited worked together to develop an improved pavement management system in the mid-1990s (Jackson et al., 1996). In order to develop the pavement performance curves SDDOT needed to establish pavement types, trigger indices for different pavement distresses, pavement performance curves for each distress, and composite curve combining distress types into one curve. Due to lack of historical information available SDDOT decided to ask for expert opinion to develop the pavement life for performance curves. The experts were asked to fill out a questionnaire focused on the life for a newly constructed flexible and rigid pavement types; pavement trigger levels and at what pavement distress would be required before a treatment is needed; and the performance life of different treatments. The responses from the questionnaire were compiled to establish trigger indices and pavement curves. SDDOT concluded the pavement curves were a reasonable estimate of pavement performance but they should be improved with more data as it becomes more available.

### **2.2 Calibration of Controlling Input Models for Pavement Management System**

The Oklahoma Department of Transportation (ODOT) conducted a study in 2013 to assess the performance of the current pavement performance curves (Lewis et al., 2013). ODOT is currently using a software program called Deighton Total Infrastructure Management System to develop maintenance and rehabilitation plans but the models need to be validated with data collected from historical data. Models have been developed for each of three pavement families: Asphalt, Concrete, and Composite. The pavement families are subdivided by traffic volume. In order to simplify the recalibration of the models, the authors summarized the curves in a spreadsheet by name and location of highway, volume of traffic, and pavement family. The spreadsheet can be used to help determine the most cost effective way of managing the roadways. The authors recommend updating the curves with new data as it become available.

### **2.3 Creating Mechanistic Based Performance Models in PMS**

Swan and Hein (2006) report that the difficulty with developing pavement performance curves which accurately reflect pavement deterioration is trying to predict future road conditions. The data collected to make the curves is usually based from historical or observed data. Use of historical data for future predictions is limited since the curves are only applicable for certain pavement types under given traffic volumes. If new pavements are used or new techniques are developed in roadway construction, new performance curves will need to be developed. The authors report the Mechanical Empirical Pavement Design Guide (MEPDG) can be used to predict pavement performance when there is a lack of historical data.

### **2.4 Modeling the Roughness Progression on Kansas Portland Cement Concrete (PCC) Pavements**

Felker et al. (2004) developed models of pavement roughness for Portland Cement Concrete (PCC) pavements for the Kansas Department of Transportation (KDOT). Roughness was quantified using the International Roughness Index (IRI). Pavement performance models were developed to predict the IRI with time using statistical techniques. In order for the pavement performance models to be accurate over time, the IRI values need to be input into the models regularly as to accurately represent the pavement performance. Long-term predictions are more difficult to predict due to variability from factors not considered in the IRI prediction model. One reason IRI values are difficult to predict is the roads frequently are treated in order to maintain a minimum IRI, and this treatment changes the model. The authors therefore recommend obtaining IRI values on a defined schedule so more data points can be input into the model before the pavement model no longer applies.

### **2.5 Summary**

The sources referenced in this chapter all acknowledge the importance of updating pavement performance models to ensure a reliable pavement management system. None of the sources specifically addressed a routine for updating models, but the work of Lewis et al. (2013) for ODOT shows that a spreadsheet tool for pavement management, while limited for database management purposes, provides some utility with respect to ease of updating models.

### **3 SYNTHESIS OF STATE DOT'S APPROACH TO UPDATING AND RECALIBRATING THEIR PERFORMANCE CURVES AND TREATMENT THRESHOLDS (TRIGGERS)**

Updating and re-calibration schemes for pavement performance models and treatment thresholds (triggers) are only in the early stages of development. As demonstrated in the previous chapter, the published literature on the topic is limited and departments of transportation are just beginning to implement updating procedures or are in the process of modifying their existing updating schemes. Thus, it became necessary to examine what state agencies have updating schemes and to contact them for their insight on which aspects for updating performance models and treatment thresholds are working best, any methods they have tried, and how their attempts have fared. The findings from several states with experience in updating their pavement performance models and treatment thresholds are presented in this section.

#### **3.1 Michigan DOT**

The Michigan Department of Transportation (MDOT) updated its Pavement Design and Selection Manual in 2012. MDOT uses a Life Cycle Cost Analysis (LCCA) for developing a plan to build and maintain the roadways. The LCCA is the managerial approach of looking at the entire cost of the roadway from building to maintaining the roadways for a given period of time. MDOT evaluates projects based on the Equivalent Uniform Annual Cost (EUAC) method when deciding on what type of roadway to build. EUAC is the method of taking the total cost of the project, building and maintenance, and averaging that cost over the entire life span of the project. MDOT also used a software package Construction Congestion Cost (CO3) for calculating the cost of delays due to construction. The building cost of the project is relatively easy to define because the project is bid out in the present so costs can be accounted for and predicted. The maintenance costs are more troublesome because the construction costs may increase or the processes for pavement management may change with time. MDOT uses past historical data for predicting when developing a treatment schedule for a project.

MDOT is responsible for updating the LCCA inputs every four years based on the newly updated system put in place in 2010. The update for the system includes a reevaluation of all the inputs into the system. Critical inputs include unit prices for construction and maintenance treatments, discount rates for the calculation of the EUAC, and pavement preservation strategies based on the performance of existing pavements and treatments. The unit prices will be based on the current building costs of the roadways and will be adjusted for future cost increases due to material prices. The construction and maintenance prices are to be derived from a qualified project list that contains prices from the previous 18 months and uses regional average unit prices. If there are no bids from the previous 18 months, the prices from the last 24 months may be used; if there are no prices available for a region, the state average may be used. The discount rate accounts for the time-value of money in a LCCA. Higher rates correspond to lower present value of future cash flow. MDOT's policy is to use the 30 year real discount rate, which is obtained from the Federal Office of Management and Budget Circular A-94. (A "real" discount rate, unlike a nominal one, does not include the effect of expected

inflation.) The maintenance cost for the life of the project is inflated using the Producer Price index.

The pavement preservation strategy is also to be updated every four years. MDOT’s strategies are presented in terms of remaining service life (RSL), and are based on distress models (deterioration curves) from “network/system wide historical averages.” An example pavement preservation strategy table for asphalt pavement is shown with the accompanying distress model in Fig. 3.1. The MDOT manual does not detail how the pavement preservation strategies will be updated, but it references the use of new data and “decisions ... based on engineering judgment.”

**PAVEMENT PRESERVATION STRATEGY**

Fix Type: New/Reconstruction HMA Pavement								
Activity	Approx. Age	Distress Index (Before)	Distress Index (After)	RSL (yrs) (Before fix)	Life (yrs) Extension	RSL (yrs) (After fix)	Cost per Lane-Mile	Time to Fix 1 Lane-Mile (In Days)
Initial Construction	0		0			14	Computed	
Prev. Maintenance	8	12	3	6	5	11	\$25,544*	0.48
Prev. Maintenance	12	9	4	7	3	10	\$36,757*	0.62
Prev. Maintenance	16	12	1	6	6	12	\$46,564*	0.90
Prev. Maintenance	20	7	1	8	5	13	\$27,350*	0.65
Rehabilitation or Reconstruction	33							

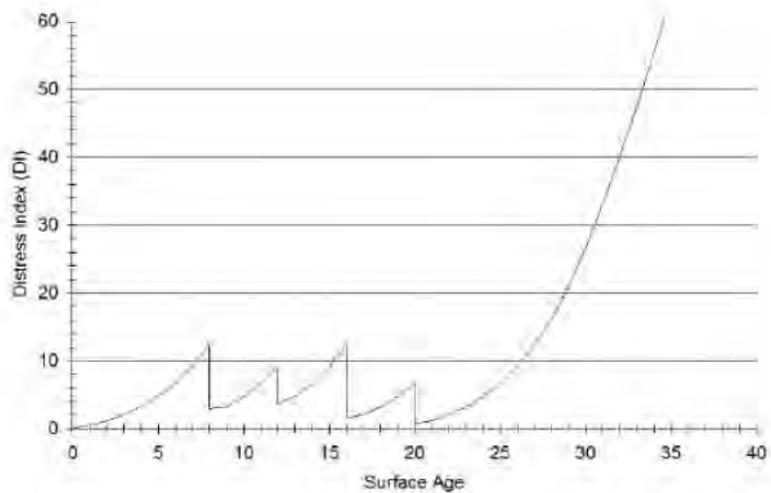


Fig. 3.1 – Example pavement preservation strategy and distress curve for asphalt pavement from MDOT (2013).

### **3.2 Kansas DOT**

KDOT is responsible for maintaining about 11,300 miles of roadway. Their pavement management system was described by Rick Miller, Pavement Management Engineer (personal communication, May 2014). Their pavement performance is evaluated by grouping the pavement as percent of miles of pavement in “good/fair/poor” condition for Interstate and Non-Interstate. The pavement conditions are further divided into performance based on the pavement type (concrete, asphalt, or composite). The roadway conditions are assigned a value of 1, 2, or 3, corresponding to good, fair, and poor, respectively. Distress State (DS) are given for three measures: roughness, rutting, and either transverse cracking (for asphalt) or joint distress (for concrete). These measures are then put together to represent the pavement condition; for instance, a roadway with a DS of 221 is considered level 2 “fair”. There is also a number in front of the distress states to indicate the type of previous maintenance work done on the pavement.

KDOT has been using this system since 1983. In order to predict pavement performance, KDOT uses a Markov process that uses the current distress state. This process starts by assuming some percentage of roads will deteriorate from good to fair or good to poor and the remaining roadway will stay at a good condition state. The percentages of roadway decreasing every year were based on a modified Delphi method in the mid 1980’s. The models were reviewed in the mid 1990’s and were rebuilt with historical data in 2001. The models developed give performance prediction for roughness, transverse cracking, joint distress, rutting, and faulting based on historical data. The models are occasionally checked to make sure they are predicting the pavement performance correctly but no changes have been made since 2003.

### **3.3 Virginia DOT**

The Virginia Department of Transportation (VDOT) uses two types of prediction models, site specific and default models. The site specific models must have a minimum of three historical performance measurements as well as rehabilitation history information. The pavement management system will verify that the models predict the correct pavement performance. Before a site specific model is approved the predicted maximum and minimum values from the model are compared to the historical data and must produce results within a specified range.

Default models are used for sections when there is not enough historical data or when the data available is not sufficient to produce accurate models. Default models are also used to predict future treatment for a section of pavement, and therefore default models are needed even when there is historical data for a given site.

The two main inputs into model development are historical data and the type and age of any rehabilitation. Windshield data are used to make the performance models along with performance indices and estimated age of the pavement. Data outliers, defined as representing non-typical performance of a given roadway category, are removed from the model.

VDOT implemented current performance models in 2007. The models were developed by Stantec Consulting Services and H.W. Lochner, Inc. (2007). The process for model

development is summarized above. VDOT's current practice is to use the Stantec models with a known pavement surface age to predict the RSL. The performance curves have not yet been updated since they were implemented. When the curves were implemented, VDOT's plan was to use them to predict the performance of new pavements, and then update the models as data became available during the life of the pavement.

### **3.4 Caltrans**

The California Department of Transportation (Caltrans) is currently updating its entire pavement management system including the software, condition rating system, and collection method. The collection segments are at 10-m intervals which has led Caltrans to use per-lane management segments. Caltrans used ground penetrating radar for structural and an annual pavement condition survey. Caltrans contracted Agile Assets to compile the data collected and develop software. The software developed, named "PaveM," was put into practice in August 2013. The models used by Caltrans still need to be established, then monitored and verified. After the models are developed, there is no set number of years before another update is made to the system. The previous pavement management process had remained in place since 1978.

#### **4 MODOT'S EXISTING UPDATING PROCESS**

MoDOT's current pavement management tool was developed by the department's planning division. The tool was described by Jay Whaley, MoDOT's transportation data systems coordinator, in a meeting with the research team held April 10, 2014. The GIS-based tool is updated annually to include a proposed schedule of treatment for all roads based on estimates of RSL. RSL estimates are based on IRI measurements (also updated annually) and the last treatment applied to each road. The pavement tool therefore does not consider the shape of the performance curve, only the time at which the performance is predicted to reach a threshold level. Mr. Whaley makes these predictions annually for each road, a significant undertaking made somewhat simpler by the assignment of similar expected lifespans for similar treatments within MoDOT's arsenal. The frequency of IRI measurements also makes the prediction undertaking less critical; another prediction will be made in the following year based on new IRI data (and not considering the previous year's data). Mr. Whaley also noted the predictions are easier for major routes since their traffic volumes are more consistent. He also noted the IRI trends are typically easy to predict for three to four years after treatment, after which the IRI typically increases more abruptly. The IRI consistency for the first three to four years and the department's current focus on maintenance efforts justify the RSL approach, which ignores pavement deterioration curves.



## **5 CONCEPT FOR UPDATING MODOT'S PAVEMENT PERFORMANCE MODELS AND PAVEMENT TREATMENT THRESHOLDS (TRIGGERS)**

A conceptual framework for updating the pavement management system is currently in development and will be finalized after results from other Pavement Thrust tasks are available.

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