Use of PMS Data For Performance Monitoring With Superpave As An Example

Volume 1

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FHWA Contract DTFH61-98-C-00075, B98C75-007

Battelle Subcontract 156421 - TRDI Project 001

FINAL REPORT

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1. EXECUTIVE SUMMARY

The objective of this project was to examine how existing pavement management data and materials related data in various state DOTs can be used to evaluate the performance of new materials and concepts and to validate new design methods. In particular, Superpave is used as an ideal example and is carefully examined. This study is not big enough or long enough to evaluate or validate Superpave per se. Rather we examine the process and obtain consensus on what data states would need to collect to adequately evaluate Superpave. Similar studies could be done for any other new design or materials concept such as the 2002 Pavement Design Guide. No evaluation or judgment is made about Superpave, rather the concepts and details of using pavement management and related data are clearly illustrated.

A second objective of the study is to determine what PMS data and other related data and factors the state DOTs collect on a common basis, which could be combined and used for multi-state data analysis. A third objective is to determine what can be done to make data from several state DOTs compatible and usable to others to the point that a common analysis could be made for the broader benefit of all state DOTs and thus the Federal Highway Administration.

The project team assembled to undertake this effort at the request of the FHWA provided the three components critical to the success of the project (i.e. knowledge of pavement management, Superpave materials, and state and AASHTO interaction).

FHWA and the team visited DOTs in Maryland, Indiana, Florida, Arizona and, at a later stage, Washington to discuss the aspects of their active pavement management system and the status of their use and record keeping for Superpave materials.

Very productive meetings were held in all states to cover introductions, outlining the aims and objectives of the project, and general discussions on the DOT organization. Details covered included pavement management systems, data collection methods and monitoring network pavement performance in each state. The main emphasis was on pavement evaluation, Superpave projects, actually constructed, and the requirements for linking materials and construction data with performance data in the PMS database.

One of the main challenges discovered in all the states visited is the absence of a convenient link between essential data on materials characteristics used in each project on the one hand and PMS data including performance data on the other. This is most often caused by the fact that the first group of data (information on design, testing, in-place properties, thickness, and QA data) is commonly stored in flat files, difficult to access and sometimes incomplete. Thus it became clear early in the project that a valid analysis of the performance of Superpave, or any other material or technique for that matter, can only be done when relevant data is available in electronic format. Performance data can only be linked to materials and construction data when use is made of a common locator reference.

The results of phase 1 of the study were presented and discussed during a project review meeting with the FHWA; at that meeting a phase 2 was added to test the concepts with a Pathfinder Study with the Maryland SHA. This additional study served as an example of how a DOT can identify and collect required data on Superpave and how much effort is needed to enter these into one or more electronic databases. As a next step these databases were loaded into a suitable "vehicle" for storage, inspection, linking, analysis and reporting purposes. In this example the "vehicle" used was a web-based system recently developed by the University of Washington.

This report describes the project, and after an introduction covers the following relevant topics:

- database requirements,
- ideal and actual characteristics of a PMS database,
- currently used and desirable DOT reporting techniques,
- concepts for linking various databases
- requirements for this linking process,
- actual findings in the five state DOTs visited in relation to these requirements,
- examples of Superpave performance curves based on data from these states,
- Phase 2, the pathfinder study in Maryland, and
- other examples of new materials, methods and techniques that could benefit from this linking concept as a result of improved monitoring possibilities.

The report ends with conclusions, findings and recommendations, which are summarized here for executive review

Summary Findings.

The project results show that it is possible for state DOTs to assemble a database that can be used to evaluate the performance of Superpave and other design- and new materials concepts. The project was not large or long enough to make a thorough evaluation, but it did determine the feasibility of the concept and its applicability among five states.

The many details and variables involved in a new methodology such as Superpave also requires recording data on design, construction, and performance for individual projects in addition to the ordinary PMS data. These details may extend normal pavement management activities in some states, but the results are well worth the effort. As the data are collected over five to ten years, results and updates of performance comparisons will provide substantial benefits and validation of the method. Each year the analysis of the growing database will produce definite results.

The key to linking databases for performance, materials and construction is to have precise and common location identification and date/time information. Only in this way can it be assured that the data are comparable. For example, in the case of multi-lane roadways involving bi-directional interstate highway lanes and frontage roads, the new material may be used in only one or two lanes or in one roadway direction. When the material is first placed, it is clear in everyone's memory, which is which, but four or five years later or after personal changes, when a long-term analysis is needed, this becomes more difficult. Unambiguous locations can be provided by GPS measurements and these are relatively economical and easy to use at the present time. However, they must be tied to traditional location identification information such as project number, mile point, lane, direction, date, etc.

In Washington State the University of Washington (UW) has, in close collaboration with the DOT, developed an approach which stores all relevant data for Superpave contracts on a web-based system. The performance, design and construction data can be organized, downloaded and analyzed with the method. This new development was possible because most of the relevant data on materials and construction in WSDOT were available in electronic format (mostly Excel files), and in addition a major effort was made by UW to link these data to performance measurements from the PMS. This system was modified successfully to store, inspect, analyze and report relationships of Superpave data supplied by Maryland as part of the Pathfinder study.

A major advantage of the website approach is that all data are available to all users as soon as data are entered. With proper equipment for electronic data entry, used in the field, it is possible to monitor construction projects quickly with "real time" QC/QA data which could be beneficial.

The Pathfinder study has shown that the collection of relevant data in materials and construction files, required for linking with performance data, is cumbersome and time consuming. In Maryland it took two man-months to collect data for 7 Superpave projects, and even then not all required data could be obtained.

Ideally all relevant data should be generated in electronic format from the start, but there is also a need for a proper and unbiased definition of required data before they can be used in a linking exercise.

The review of information and data, as well as interaction with five state DOTs visited, suggests that with manpower for data entry it is possible for a state DOT to develop a Superpave evaluation database. More than $100 million has been expended to date to develop the Superpave concept, yet no actual performance results exist. It is now essential to compare real Superpave performance to current asphalt practice in state DOTs to validate the value of Superpave. Each state can use pavement management and related data to evaluate Superpave, but it will be faster and more definitive if several states can work together to set up databases with the required data and combine their efforts to make the necessary performance evaluations. A group of 5 to 20 states with coordination among states can produce a large analysis joint database of lasting value.

Preparation of a good work plan for evaluating new concepts using PMS data and such tools as standard Pavement Evaluation Protocols will be useful for state DOTs to encourage them to set-up appropriate evaluation databases and procedures for any new pavement concept they undertake. Similar methods are applicable in many state DOTs.

The approach examined in this project for Superpave is applicable for other new concepts. Specifically, now is an ideal time to set up a plan showing how several state DOTs can record the proper data to evaluate the new 2002 Pavement Design Guide when it is adopted by AASHTO. It is important to define this plan before the new method goes into effect.

Acknowledgements

The authors gratefully acknowledge the funding and support of the FHWA, especially the contract representatives Ms. Sonya Hill and Mr. Frank Botelho.

The TRDI contract for this project was administered through Battelle in Columbus, Ohio, acting as the prime for FHWA. We would like to thank Ms. Tami Hannahs and Mr. W. Scott Versluis of Battelle for their interest and support.

We are very grateful for the help from the five state DOTs that participated in the study: Maryland, Florida, Indiana, Arizona and Washington State. The DOT and FHWA representatives of those states were very kind to meet with us individually, to share their knowledge of and experience with PMS and Superpave, and to send us data that we needed for this study.

For the pathfinder study special thanks are due to Messrs. Sam Miller, Larry Michael, Pete Stephanos and several co-workers of Maryland SHA for collecting and formatting the required data, and to Dr. Joe Mahoney and George White of the Civil and Environmental Engineering Department of the University of Washington for making their newly developed web-based system available and for modifying it to accommodate the data from Maryland SHA for the benefit of this study.

Staffing

The TRDI Project Team included Dr. W. Ronald Hudson, Project leader (pavement management), Prof. Carl L. Monismith (Superpave), Dr. Charles E. Dougan (States/AASHTO), and W. (Pim) Visser, Project Engineer/Coordinator.

2. INTRODUCTION

2.1. General

Pavement management is a powerful tool for use by state DOTs, cities, counties and other transportation agencies. Pavements make up more than 60% of the assets and asset value of a transportation agency. A good pavement management system [Haas 78, Haas 94] is valuable at both the network and the project level and when properly applied, can be used for various engineering analyses. All 50 state DOTs have a functioning pavement management system although some are more robust than others [TRDF 94]. Approximately one third of the states have very strong pavement management systems. One-third have active network level pavement management. The final third are in various stages of implementing and using a simple PMS. There is also strong emphasis on the use of Pavement Management in the AASHTO Joint Task Force on Pavements.

Since the main use of pavement management in many state DOTs is applied at the network level for planning, programming and budget distributions, the more detailed use of the data for project applications and engineering evaluation is sometimes neglected. The purpose of this study and this report is: to determine the status of pavement management systems and databases, to emphasize the benefits of recording and systematically enhancing the PMS and related data with needed information, and in general upgrading the quality standards for data collection to fulfill burgeoning engineering objectives in state DOTs. It is simply good business to evaluate various pavement structures, materials and new concepts using these pavement management databases. To accomplish this it is necessary to collect, process, store, retrieve, and analyze the required data. In doing this, it is essential to maintain good data quality as well as good data collection standards, within states and across state DOTs. With proper focus this can be done at minimum cost.

This report concerns itself not with the day-to-day application of a PMS, but with the use of pavement management and related data for engineering applications, particularly with respect to the evaluation of new design concepts and new materials. There are many examples of how state DOTs have used pavement management data for engineering [Falls 94, Haas 78, Haas 94, Hudson 68a, Hudson 98].

Currently, active FHWA Demonstration Project 108 B outlines in some detail engineering analyses that have been performed by Washington State DOT, Texas DOT, Kansas DOT, Wisconsin DOT, and others. In addition, Arizona DOT has recently completed a significant study in which their 15 years of pavement management data were used to analyze the benefits of pavement management [Hudson 98, Hudson 99]. This study also evaluates various maintenance and rehabilitation techniques used in ADOT and determines their respective lifecycle performance [Hudson 98].

Many different design concepts and new materials are considered and many are used by state DOTs every year. Field application of such concepts requires that pavement management data be obtained and used to evaluate the effectiveness of these new materials and systems. One such concept, Superpave, presents a unique opportunity to define relationships involving pavement management data and the opportunity to determine how pavement management databases can be enhanced to address new as well as specific existing applications. The new Superpave concept is being implemented in 20 or more state DOTs at present. [Cominsky 94, Kennedy 94, AASHTO 99a/b/c] This presents a unique opportunity to use pavement management and related data to make the evaluation of Superpave and future evaluations of new concepts in a professional cost-effective manner.

2.2. Objectives and Scope

The objective of this project is to examine how existing pavement management systems in various state DOTs can be used to evaluate the performance of new materials and to validate new design concepts. In particular, Superpave provides an ideal example and test case for examination. This study does not evaluate or validate Superpave per se, but examines what five states are doing and develops a consensus on what data is needed by a state DOT to adequately evaluate Superpave. The concepts can then be applied to any other new designs or materials concept in general. No evaluation or judgments are made, but the concepts and details are clearly illustrated.

The secondary objective of the project is to determine what common data and factors are present among the five state DOTs, which could be used for multi-state data analysis. A third objective is to determine what could be done to make data from several state DOTs more compatible to the point that a broader common analysis could be made for the benefit of all states and indeed for the nation.

The scope for this project, as established by the FHWA in 2000, reads:

> "*A good Pavement Management System (PMS) provides the performance data and feedback elements needed to define the life or performance of a pavement section. The better the quality of the data and the more sections available, the better the models will be. Performance of a material such as asphalt designed with Superpave has a large number of variables that make model studies difficult and unreliable when using single source data.*
>
> *This project will evaluate the availability of pavement performance data from existing pavement management systems, propose methods for referencing specific locations in the database, and construct plots from existing Superpave data in the systems. A second part of the project is to describe the data elements needed for evaluating Superpave performance, identify missing elements in each of the databases, and encourage the addition of these elements to the pavement management system in each state.*"

After the completion of the first phase of this project in May 2001, the project was continued with a "Pathfinder" study; the scope for this continuation is as follows:

"*Additional data elements for measuring pavement performance have been identified by TRDI and recommended to be linked with the pavement management database. Based on this recommendation, TRDI will return to Maryland and take information that is currently in flat files or any other inappropriate form and put it in electronic format. TRDI will then electronically link the databases (i.e. materials, PMS, construction, and quality control) in such a way that engineers can readily access the data from all the databases for the purpose of analyzing pavement performance at the network level for long enough periods of time so it can cover a complete life cycle.*

Specifically, TRDI will link the databases (materials, construction, QC and pavement management) as an example to show the states how this should be done. Only one state, Maryland, will be revisited and a report written to document the process".

2.3. Project Team, Methodology, Activities and Time Frame.

To undertake this effort a Project Team was assembled at the request of the Federal Highway Administration that provided and brought expertise in pavement management, in Superpave and asphaltic materials development, and in state and AASHTO interaction. These are the three components critical to the success of the project. The members of this project team and authors of this report were:

- Dr. W. Ronald Hudson, TRDI, Consultant, Project Leader;
- Dr. Charles Dougan, Connecticut Transportation Institute, Consultant;
- Prof. Carl. L. Monismith, University of California at Berkeley, Consultant; and
- Pim Visser, TRDI, Technical Support and Coordination.

The work has been conducted by Texas Research and Development Incorporated under a subcontract to Battelle Institute. In January 2000, the project team met with the Project Coordinator, Mr. Frank Botelho and the Task Force Manager, Ms. Sonya Hill of the FHWA Pavement Management/Asset Management Group to outline a proposed work plan and to initiate the work on the project. It was agreed at that time that state DOTs in Maryland, Indiana, and Florida would be contacted and visited by the project team to discuss the aspects of their active pavement management system and the status of their activities and their record keeping for Superpave. After the successful visits to these three states, it was agreed to add a fourth state, Arizona, to provide broader geographical coverage for the study and to evaluate the Superpave related activities of a mature pavement management system (ADOT has fifteen years of data) to round out the projects findings. At a later stage the DOT of Washington State was also added and visited. See Appendix B for visit reports to these five states.

Prior to the visits to these states the project team developed a list of questions and a candidate list of appropriate data that were needed for a Superpave evaluation and which hopefully could be collected in a face-to-face visit and through subsequent follow-up mailings. This list covers three areas:

1. General information about the Pavement Management System and the PMS database being used in each state;
2. Details of the Superpave Projects carried out and planned in each state;
3. Extent of availability of detailed Superpave information and performance data in each PMS database or in other databases.

This list of questions is given in Appendix A. It should be made clear that this was not a questionnaire to be filled out by state DOTs, nor did it intend to include every possible option of information to be discussed. Rather, it was mailed to the DOTs to provoke thought prior to the visit of the project team and to serve as a background for discussions in project meetings. In each case, the state DOT provided representatives from their material's group, as well as their pavement management staff, to meet with the project team. In some cases representatives of the research staff or associated research universities were included in the discussions since they had knowledge of various Superpave activities. Each state DOT was requested, where possible, to provide examples of their pavement management system output, a brief description of their pavement management data collection and data storage efforts, and if possible an example of their PMS database output. They were also requested to provide a copy of any electronic Superpave information available as well as to be prepared to discuss their Superpave data collection and storage efforts.

This report summarizes the information gained in these state DOT visits and explores the details that our professional experience shows to be necessary for performance monitoring and evaluation.

The staff of all five states are listed in detail in Appendix B. Our thanks to them for their support and cooperation.

From the observations made during the discussions with the state DOTs it became clear at an early stage during the project that a routine analysis of the performance of Superpave, or any other material or technique for that matter, can only be done effectively when the relevant data is made available in electronic format. That, in turn, led to the concept to recommend the use of a structure that is summarized in Figure 1 and discussed more fully in Section 6.2: the use of a PMS database and a Materials & Construction database, both electronic, with links to a Performance Analysis database, from which any desirable performance analysis could be performed.

During the TRB 2001 Conference on January 9, 2001, the Project Team presented a summary of their preliminary findings during an informal meeting at the Asphalt Institute Suite to several representatives of the FHWA, and members of the Superpave Lead-State Team. This meeting was organized by the FHWA and chaired by Mr. Frank Botelho, team leader for the Systems Management and Monitoring team in the Office of Asset Management... The main purpose of the meeting was to inform both the Asset Management and the Pavement Technology groups at FHWA and the representatives of the Superpave Lead-State Team about the outcome of our study. The Lead-State Team includes member states Florida, Indiana, Maryland, New York, Texas and Utah. This Team was planning to start a project to track the performance of Superpave, and consequently the findings of our study were very relevant and timely.

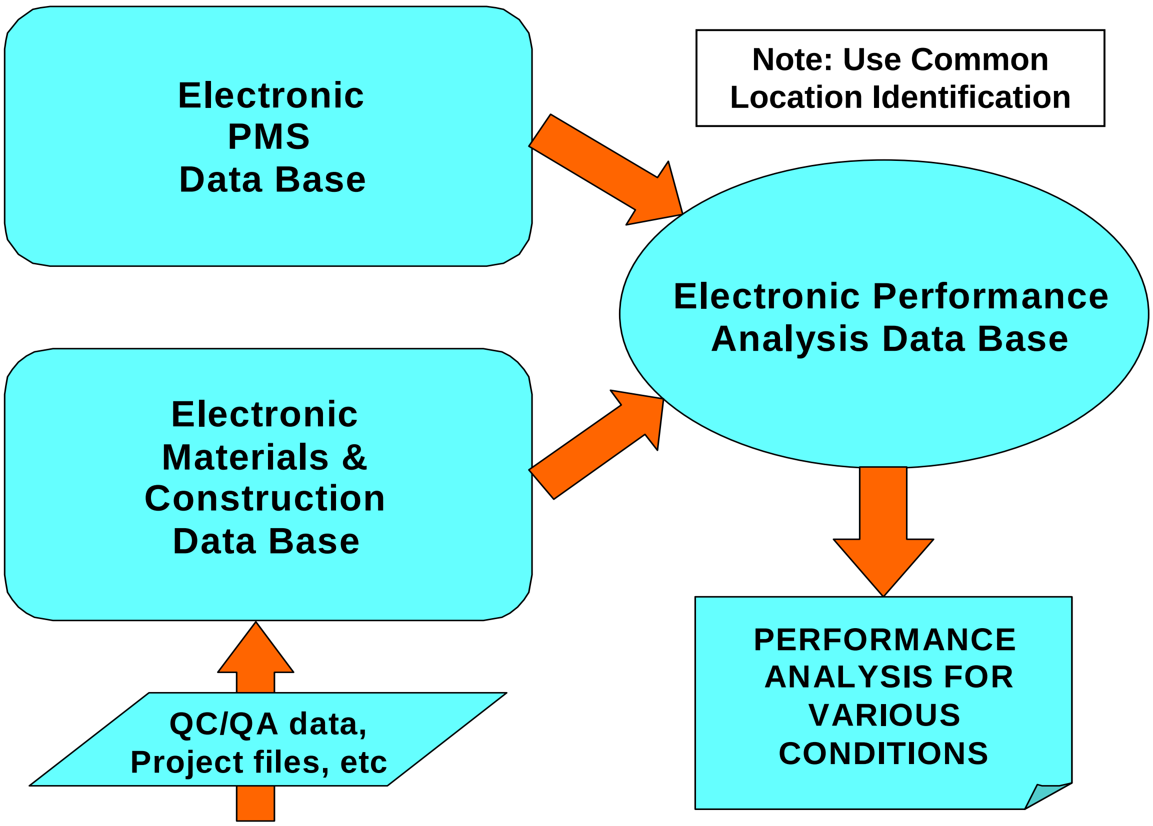

Figure 1. Links from PMS database and Materials & Construction database for performance evaluation.

On February 21, 2001, the project team presented the results of the study during a meeting with 13 representatives of the FHWA at their offices in Washington D.C. The project team handed out copies of the Executive Summary of the draft report, and of the slides presented at the meeting, to each participant. One copy of the draft report was handed to the Office of Asset Management. Although it had been agreed to also visit Washington State after this meeting, it was confirmed that the current meeting fulfilled the contractual obligation for a final project meeting, and that the results of the Washington visit would be reported in the Final report of this project. Some brief Notes about this meeting are given in Appendix E.

After the FHWA had granted a request from the Project Team to collect information from Washington State in view of their extensive experience with Superpave projects, Washington DOT (WSDOT) and the University of Washington were visited on April 25, 2001. During this visit the team learned about the recent development of a web-based data warehouse with an analysis and evaluation system that seemed suitable for our purpose of data linking. The main points discussed during the visits to Washington and the other four states are given in Appendix B.

TRDI submitted the final draft report of the first phase of the study, covering the above described activities, on May 31, 2001. The contents of that report have now been incorporated in the current final report.

On May 24, 2001, TRDI began the second phase of this project, the Pathfinder Study. The scope for this study is given in Section 2.2. Section 9 gives a description of all elements of phase 2.

The results of both phases of the study are presented in thirteen sections of this report in Volume 1, supplemented by Volume 2 with several appendices. A brief description of each section follows:

- After the Executive Summary in Section 1 and the Introduction in Section 2, Section 3 of the report defines database requirements in terms of detail, format, consistency and data integration and centralization for adequate performance monitoring and evaluation.

- Section 4 proposes a set of ideal characteristics of a PMS database and compares that to the actual characteristics of databases examined in several DOTs. Priority items are discussed and defined as well as details of accuracy and measurement uniformity.

- Section 5 describes the ideal reporting techniques for material properties and construction data and compares these in a broader sense to the actual situation as currently present in several DOTs.

- Section 6 discusses the concept for linking PMS and the Material and Construction databases for improved performance monitoring and evaluation. It also discusses the criticality of linking the materials data appropriately to the PMS database in terms of location, identification and future applications of GPS.

- Section 7 discusses specific requirements for the linking process for materials and construction data and the PMS database using Superpave as a particular example, involving a number of detailed material and construction elements.

- Section 8 describes in more detail the findings in five state DOTs as they relate to the background presented in the previous seven sections. This section also gives example Superpave performance curves for data obtained from these five states.

- Section 9 covers the second phase of the project, which includes the Pathfinder study.

- Section 10 describes other key areas, which could use PMS and related data in the performance monitoring of materials, techniques and designing concepts.

- Section 11 presents findings, conclusions and recommendations from this study.

- Section 12 contains references, and Section 13 covers acknowledgements. Volume 2 gives details in a number of appendices about the visits to five states (A & B), linking Superpave materials data to performance data (C), Superpave performance monitoring data received from the states (D), Notes about a major review meeting with the FHWA in Washington (E), a description of the two websites developed by the University of Washington and some images with Superpave data treatments (F), and Notes on Meetings during Phase 2 (G).

3. DATABASE REQUIREMENTS

3.1. General

If good pavement design methods are to be used and improved it is essential to provide engineers and technicians the ability to monitor the performance characteristics of various paving materials and methods. Pavements fail in several ways. For example rutting and cracking are related to structural failure; friction is needed to assure safety; smoothness is a substantial concern to the highway user. These pavement characteristics must be measured in some manner. Protocols to define these methods have been developed by AASHTO and ASTM. It is important that these or similar standards be employed by skilled technicians. In turn, this will permit the needed exchange and meaningful reporting of performance information, now and in the foreseeable future, to build a historical database.

Pavement performance is integrally tied to the composition of the pavement layers specified, as well as the placement methods employed. If either is improper then the pavement may fail prematurely. Therefore, it is imperative that such data be integrated into the database for future use and analysis. Modern electronic technology provides the capability to link design information with mix details, and subsequently with specific construction and placement data. In turn, the annual monitoring and testing including traffic data, can be linked and used by maintenance forces, designers and others to evaluate the effectiveness under traffic of specific design concepts, construction methods and materials.

This continuum of data can provide top executives with the data required to manage their highway networks. The data can be reported at several levels within a DOT to focus on the operational needs of the DOT. Specific conditions, unique to the DOT or an environmental region, can be documented and successful treatments selected.
In summary, the database should link design, materials, construction, loads (traffic) and performance data. These data should be managed and used to select and use the most cost-effective pavement materials and methods.

3.2. Classes of Data Required

One objective of pavement management is to coordinate all activities required for providing pavement structures in a cost-effective manner. These activities, for virtually all divisions of the highway agency, have impacts of varying degrees on a comprehensive pavement management system.

A comprehensive PMS uses data from a variety of sources. The classes of data needed include the following [Haas 91]:

- Section Description
- Performance Related Data

- Historic Related Data
- Policy Related Data
- Geometry Related Data
- Environment Related Data
- Cost Related Data

All but the policy and cost related data classes provide background information required for the analysis and modeling of pavement performance. In large state transportation departments, each class of data may be the responsibility of a different section. Hence, there is a need for effective coordination and cooperation. In smaller agencies, a staff of one or two engineers and technicians may handle these functions. However, it is always necessary to organize, acquire, and record the data in a systematic and accessible manner.

3.3. The Importance of Construction and Maintenance History Data

In order to fulfill its purpose, a PMS must follow through from planning, programming and design to implementation, including construction, maintenance and rehabilitation [Hudson 94].

Pavement data collected over time can also provide the basis for developing, updating and assessing pavement performance models used in planning and programming and in design [TRDI 97]. Data on the construction and maintenance of the pavement are essential to such model development. Pavement construction data include information on the as-built quality of the materials, such as concrete strength tests and asphalt concrete densities. All pavement maintenance activities that can affect the performance of the pavement such as crack sealing, patching, and surface seals should be recorded.

3.4. The Importance and Consistency of Pavement Evaluation Data

Performance related pavement evaluation is critical to PMS. Four key measures are used to characterize or define the condition of the pavement:

1. Roughness (as related to serviceability or ride comfort)
2. Surface distress
3. Deflection (as related to structural adequacy)
4. Surface friction (as related to safety)

These four performance measures, along with maintenance and user costs can be viewed as the "outputs" of the pavement, that is, they are the variables that can be measured to determine whether or not the pavement is behaving satisfactorily. These outputs are originally predicted at the design stage and then periodically evaluated during the life of the pavement. The service life of the pavement is reached when the measures reach a minimum (or maximum, depending on the measure) acceptable level.

Consistent and repeatable condition data are an essential requirement of evaluation. Some pavement evaluation schemes rely on the judgment and opinion of a human rater. While this provides useful insight into condition, such evaluations may lack uniformity and generally lose meaning over time as the attitude and ability of the rater changes and/or new personnel are added to the process. In order to reduce human error, evaluations should preferably be performed with automated systems. New equipment, which can objectively measure pavement distress, is becoming more widely accepted. Improvements in this automated distress evaluation technology have great potential to stabilize data consistency. But also these systems require a regular calibration of the instruments used.

The pavement evaluation and measurement protocol previously developed under FHWA auspices, and currently being reviewed for adoption by AASHTO, would provide excellent tools for use in data collection for performance evaluation [TRDI 00].

In conclusion, engineering evaluation of pavements requires a well-documented set of practices and procedures, consistent techniques, calibrated equipment plus good training.

3.5. Data Integration and Centralization

A good database is the foundation from which all pavement management and decision support is derived. The accuracy and completeness of required data is paramount to the success of the PMS. Therefore, it is vital that the PMS database be linked with databases from other functions in a “Data Warehouse” in order to access and use key information from all pertinent components of the agency.

Data must be integrated and accessible for a successful analysis of such data. In most cases the PMS database is centrally available in electronic format, but other related data such as material properties, construction information and QA/QC data may be stored separately in other locations, and not available in electronic format. This can lead to serious delays when such data are required for an engineering analysis.

One objective of a well-designed database is to catalog and index all available data throughout the agency and allow easy access by the PMS. It should allow users to analyze that data in any appropriate way to produce information for decision support both at the pavement management technical level and for strategic planning and management at the executive level within an overall asset management approach. Thus, it is important to distinguish the difference between data integration and systems integration. They are different layers in both pavement management and an overall asset management framework. We will therefore focus our discussions on how raw data can and should be integrated at the base level to feed information and decision support at the technical level. The output from the technical level in turn feeds asset management at the strategic level.

The following issues related to this subject will be discussed next:

- Integrated data;
- Integrated systems;

- Integration methods and tools;
- Analysis of database;
- Statistical analyses.

3.5.1. Integrated Data

Integrated data implies that raw data (with appropriate prescreening and cleansing) can be accessed and used by all authorized personnel throughout the agency who are responsible for any aspect of managing the pavement network. It is not necessary to create integration by putting all required data in one comprehensive database, because there are often problems in managing a very large database. A better approach is to have separate databases for various components, each managed by an owner who is responsible for its upkeep, placed on a centralized server and linked through referential keys for access by all potential users.

At the data integration level a precise definition of the data is of extreme importance. Take data on location as an example. The basis of a definition is some type of basic referencing and naming system to completely identify locations and interrelationships of each of the data relative to known points on the earth. For pavements a uniform method of linear referencing, relative to the centerline of the roadway, is needed for these features.

3.5.2. Linear Referencing System

The basis of a linear referencing system is location on the roadway. How that is defined by each agency varies widely throughout. NCHRP project 20-27(2) is focusing on the basic definition of linear referencing and provides a good foundation for agencies to build or improve on their existing referencing methodology [Opiela 97]. In general, the lowest level of referencing should be handled spatially in a two-dimensional x-y coordinate space. The technology for easily handling this type of special information is readily available through GIS (Geographical Information Systems) tools, which are readily available to be used with PMS and in the overall asset management function.

The basic location of each pavement feature is accurately positioned on an interactive map, which completely defines the roadway network and all features to be managed, relative to each other and their known locations on earth. The conversion to a specific linear referencing system suitable for referring to locations on a particular agency's roadway network becomes a matter of preference. NCHRP Research Results Digest Number 218 accurately describes several available and suitable methodologies for linear referencing, which can be accommodated and utilized by PMS and other roadway related assets [Opiela 97].

3.5.3. Integrated Systems

The primary concept associated with integrated systems is that shared information can maximize the availability of important information to decision makers. At the data integration level discussed above, the raw information is related and made suitably accessible throughout the agency for decision support analysis. At the systems integration level the user interface and reporting functions become the important components in sharing the results of the detailed analysis among various organizational units within an agency. As with the data at the data integration level, the flow of information is two-way. Pavement management receives reports and information packets from other management areas which affect their decisions and operations and the PMS provides results and information from its analysis to other management areas and to upper level administrators and decision makers responsible for dividing limited budgets among various asset categories owned by an agency.

System integration requires design and analysis of all aspects of system scope. Design of database interactions and relationships relative to the central linear referencing and features inventory as well as the other technical details within a component system and between other systems that manage other asset components is important. Good design based on a sound foundation of linear referencing is a key to success in providing for adequate exchange of data and information within the overall integrated systems concept.

3.5.4. Integration Methods and Tools

The tools for sharing integrated data across an organization must be carefully planned, designed, developed, and tested. The administrative procedures for accessing such data should be simple and straightforward but with adequate security to protect the valuable data. However, blocking access should not be considered security. "Read only" access should be provided to all. Security should involve data cleansing and changes. When the organization is spread over several locations a suitable network must be established. The linear referencing system discussed above acts to coordinate all information relative to location.

The integrated database should be made available on a server in a central location with strong technical support provided. For use over a wide area network, fast network lines are strongly recommended. Alternatively, architectures such as terminal emulation services, distributed databases covering only certain regions, replicated databases, or others can be used in a workable integration solution.

In most state agencies, database and system integration are controlled by or at least strongly influenced by a computer and information services division (ISD) or information technology (IT) department. These divisions typically provide the hardware infrastructure and the technical support structure required for such enterprise-wide systems to succeed. It is important for the owners of the PMS to establish a good working relationship with their ISD or IT function in order to evolve into an integrated system.

3.5.5. Analysis of Database and Data Mining

In some cases, the PMS database and the PMS-related databases may not be designed for engineering applications although they may have engineering data components. Sometimes an entire set of needed data items such as weather or traffic data may be missing. In such a situation, it is possible to use a surrogate variable, e.g.

"geography" as a substitute for "weather". When that proves to be useful and if "weather" shows to be significant, then it is possible to gather and add weather data and strengthen the analysis in subsequent years.

At other times there may be gaps in the database that must be filled. Certain key sections must contain all of the data items needed to analyze the trends being observed clearly. It may then be necessary to go back to the construction records, back to the traffic section, or wherever necessary to fill missing data elements in the database for subsequent analysis.

Data mining is the process of cross-referencing, querying, and interrelating an agency-wide database analytically in order to extract valuable information. Modern computer tools for querying and reporting from large databases are available to facilitate this process. However, such analyses also require a great deal of human thought and effort in experiment design, statistical analysis, review comparison, and revaluation of results.

The pavement management database and the related construction and materials databases generally contain a gold mine of information. That information is not perfect and may not be complete but it can and should be used.

3.5.6. Statistical Analyses

Performance data in PMS databases normally show a lot of scatter. Consequently, when carrying out an engineering analysis using such data, the results need proper scrutiny to assess whether they are statistically significant. Statistical analyses can help to quantify the significance of a conclusion or a trend. The reader is referred to professional textbooks, such as Statistics in Research [Ostle 74], Design of Experiments for Industrial Engineers [Anderson 82], and Practical Business Statistics [Siegel 90].

4. CHARACTERISTICS OF PMS DATABASES – IDEAL AND ACTUAL

Generally PMS databases reflect three levels of data collection: network, project and research. The most general and the most widely used is network level data collection which normally reflects three sublevels:

1. Minimum required
2. Very important data
3. Desirable data

In most cases state DOTs collect only the minimum required data and in some cases even less than is considered minimally required as discussed below.

The project level involves a much more detailed data collection effort and one, which is not currently collected for inclusion in a PMS. It involves detailed design and as-built data on individual pavement sections including thickness, material strengths, variability, stiffness and ultimately forensics analysis of pavement failures. These data vary with the type of project being considered, but will be presented here at two sublevels:

1. The minimum level required to be worthwhile for accurate project definition and
2. A more detailed desired level.

The third pavement management level involves research and evaluation and in some cases includes forensic information. To be most valuable the research level database will involve several sections or projects where the set of sections or projects combine to form a factorial or set of sections that can be compared for evaluation of material specifications, construction methods and design. All state DOTs have these kinds of data. It is used every time a new method is employed or a new construction procedure is tested. Unfortunately the data seldom get entered electronically into the organized pavement management database. Thus it seldom gets properly tied to the pavement management identification location. It is critical in the Superpave evaluation activities for example to set up this database in electronic format on a permanent basis. The Superpave example can also be expanded to other concepts by state DOTs as discussed later. The exact details of this research/evaluation database will depend on the individual studies.

4.1. Details of a Desirable Network Level Database

Most state DOTs currently maintain an electronic format PMS database. It is necessary to do so if pavement management is to function successfully. In this portion of the report, the desirable characteristics of a network level PMS database are compared to the characteristics of such network level databases found in the five states visited.

In any network level PMS database the roadway network must be divided into sections and subsections. A file is set up for each section or subsection with appropriate location identification information including beginning and end coordinates and mile points, direction, lane, roadway, and any other information which uniquely defines a section of roadway, preferably one lane wide and a finite distance long. Care must be taken to differentiate lanes and roadways, e.g. for interstate highways with frontage roads.

The physical characteristics of each section should be recorded including age of construction and/or subsequent reconstruction or overlay, type of pavement, surface or wearing course as a minimum. It is also desirable to store the thickness of individual layers, their age of construction, and as-constructed properties, including strength and stiffness. However, these last factors are seldom available in a network level database since the database is usually set after most of the pavements were constructed. Nevertheless, space should be provided in the network level database for layer properties, thickness, stiffness, and strength.

For typical network level activities such as ranking, prioritization, and optimization, one or more performance indicators is required. The first priority among these indicators is a serviceability or roughness index defining the quality of service that the pavement section is providing to the user. The history of this serviceability versus time provides a practical performance curve for each individual section.

A yearly record of distress or condition of each section is needed and can be used to define treatment options, projected costs, and predict it's serviceable life. The average surface friction of each section should also be collected to provide safety information. In most instances, surface friction is not collected network wide but is collected and stored in a separate database related to skid resistance.

The performance indicator measurements should be taken annually as a minimum. In some cases, these data should be taken more frequently. For example, when a new overlay is placed, it is desirable to measure the roughness and the distress prior to overlay and the roughness immediately after the overlay. In this way, the benefits of the overlay can be evaluated more effectively. If it's not possible to enter this before and after information in the network level database, it should be included in the project level database.

A measure of behavior, usually deflection measurements, is needed but is not commonly collected at the network level. In those cases where it is collected, it should be recorded electronically and keyed to the PMS database. A separate sub-file will be preferable to a sparsely filled network wide file. With modern, personal computers, it is easy to maintain an appropriate interface to move these data from one place to another as needed.

4.2. Network PMS Databases in Actual Practice

All PMS databases contain at least the following information: location of the pavement section (county, district, road nr., mile post, lane, direction), type of pavement, age, traffic (AADT, CESAL) and performance indicators for ride, cracking, rutting and friction, together with the year of testing. More sophisticated databases have additional data on the existing pavement (last rehab, project number, layer materials and thickness), environmental data (regional factor, climate) and more extensive performance data for patching, flushing and maintenance work. The majority of PMS databases, however, give little or no information on types of materials, layer thicknesses and construction details. Available traffic information is often unreliable. Nearly all databases differ in the way detailed data are recorded. Some agencies record AADT per direction, others take the average of two directions. The way AADT is divided over lanes can also differ. The direction can be recorded as a compass direction (N, S etc), or increasing/decreasing with mile posts (I or D). The distress data are normally converted into a performance index or rating, but the way this is done differs by state. The criteria used by states for judging the indicators also differ widely.

Table 1. Performance Indices used in Five States

	Ride	Rutting	Cracking
Maryland	IRI (inch/mile) Condition limits: Very Good, Good, Fair, Mediocre, Poor*)	Max depth for both wheel paths recorded in inch	Not reported
Indiana	IRI (inch/mile) Condition limits: Excellent, Good, Fair, Poor*)	Average depth in wheel paths recorded in inch. >0.25" is Poor	PCR includes all cracking types, Condition limits: Excellent, Good, Fair, Poor*)
Florida	IRI (inch/mile) Converted to RN with 0-10 scale (10 is best possible condition) *)	Average depth in both wheel paths, converted to 0-10 scale *)	Crack rating in & outside wheel path converted to 0-10 scale *)
Arizona	Roughness (inch/mile), Condition limits: Satisfactory, Tolerable, Objectionable*)	Average depth in both wheel paths, Limits: Low, Medium, High*)	% cracking of 1000 ft area at mile point, Limits: Low, Medium, High*)
Washington	IRI (in/mile or cm/km), Condition limits: Very Good, Good, Poor, Very Poor*)	PRC, average depth in both wheel paths, Limits: Very Good, Good, Poor, Very Poor*)	PSC includes all cracking types and patching, Limits: Very Good, Good, Poor, Very Poor*)

*) See also Section 8 for additional information on distress ratings in the five states.

Having reviewed the required and desirable network level database it is valuable to examine what performance data are actually being collected at the present time, and in what way these performance data are converted into a performance index or rating. In this process we have a sampling of information from five states, Maryland, Indiana, Florida, Arizona and Washington. Table 1 shows the performance indices for Ride, Rutting and Cracking that were reported in visits to these states. Additional information was obtained from their pavement management system and the hard copies of electronic files of data provided to the project team.

It can be seen from Table 1 that there is some diversity in the actual performance indices reported by state DOTs at the present time. The same is true for the definition of the condition limits. It must also be remembered that each state has individual needs within their agency, which will dictate their database characteristics. However, great benefit can accrue nationwide if the minimum desired network level data is recorded by every DOT. States are encouraged to review and modify their data collection efforts in this regard. It is also highly desirable that the data be collected uniformly nationwide. Currently AASHTO is evaluating data collection protocols, which would be very useful for this purpose [FHWA 97].

4.3. Desirable Project Level Database

Ideally, the detailed data from every project should be entered into the database as an individual pavement section, if possible on a subproject level. Individual subsections of the project with changing characteristics such as sub grade strength should be entered into the database. If it is not possible to enter the subsection data then the data should be entered for the entire project or section levels with the mean standard deviation and the number of individual data measurements used in the calculation.

The database should store both the design values and as-constructed values for parameters such as, thickness, strength, and stiffness of each of the individual layers. It is also desirable to enter information on material sources. It may not be feasible to enter details such as source of asphalt and detailed properties of the asphalt aggregate components within the mixture, but it is desirable to do so if possible.

The performance parameters for project level pavements will be obtained from the network level database. However, they should be entered on a subsection basis if possible and should include roughness or serviceability index, detailed condition surveys by distress type, deflection behavior including deflection basins and surface friction or skid resistance. All of these data should be on a subsection basis. Ideally the precise location of each lot should be recorded (mile point, lane#) so that the characteristics of that lot can be properly linked to its performance. Detailed traffic and load information should include vehicle classification, load axles, and axle distributions. It is desirable that all of these data be entered at key points along each section to provide geographical definition of variability within the section so that an analysis of the parameters and the performance variability within the section can be analyzed. A forensic analysis of any pavement failures, major maintenance, rehabilitation and/or reconstruction in the pavement section should be recorded in the project level database. The date when the section was opened to traffic is required mainly to check whether performance measurements during a certain year were done before or after the (re)construction.

It is possible to enter project level data on new sections or on sections that are being reconstructed or rehabilitated. When existing pavement sections are rehabilitated where no prior project level data are available in the pavement management database, then remedial data collection should be carried out for these sections. Representative coring with an adequate number of cores (e.g. a minimum of three cores for a short section and a minimum of three cores per mile for longer sections) should be carried out to obtain pavement thickness. Tests should be run on the cores to obtain pavement and sub grade properties, such as stiffness or strength. In the case of rehabilitation or restoration, detailed deflection data should also be obtained in the outside wheel path as a minimum. In the case of thickness it may be possible to estimate thickness using GPR (Ground Penetrating Radar). However, if GPR is used, then one core per mile should be taken, with a minimum of three cores per section to obtain calibration thicknesses for comparisons with the GPR data. When sections are rehabilitated or reconstructed, they should show historical data on the original construction dates and if possible, original plan details should be found and entered into the database at the time of reconstruction or rehabilitation, to make it available for future detailed analysis.

4.4. Actual Project Level Data Collection in Example States

The way data are collected, stored and analyzed varies from state to state, but in most cases the following four organizational groups are involved:

1. The Pavement Management group is responsible for the PMS database and its maintenance, for collecting performance data and for analyzing and interpreting the data in this database. This group is also largely responsible for the allocation of funds, since they provide data for projects that use various classifications of money (rehabilitation, maintenance, etc). Data on traffic loads and distribution are normally obtained from a separate Traffic group in the DOT, but they are often not available in a timely fashion. Data on distress, ride and friction are entered into the PMS database, data on deflection measurements are normally kept in a separate database for the benefit of the Pavement Design group. Data on maintenance activities are normally not recorded in a PMS. The date of carrying out performance measurements is recorded by year only, consequently it is unknown whether maintenance or rehabilitation work was done before or after the measurements.

2. The Pavement Design group is responsible for the design of new road pavements and for overlays and rehabilitation design. This group makes use of data supplied by PMS (performance, location, climate, traffic, age, etc), data from deflection or other structural testing (for existing pavement and/or sub grade), and data on materials to be used from the Materials and Testing group. With this last group there is often a lively exchange of information to arrive at the best possible choice of materials for a particular design.
   In some DOTs the design of new Portland cement concrete pavements is done by a different group, responsible for all concrete structures. The rehabilitation of these roads is normally the responsibility of the Pavement Design Group.

3. The Materials and Testing group is responsible for the selection, design and testing of all pavement materials. Most of the data used by this group are generated from laboratory and field testing, these tests are normally carried out prior to construction (on raw materials and for mix design), during construction

(check on mixes from plant and paver) and immediately after construction (mostly on cores). This group works closely together with the Construction group prior to and during the execution of the project.

4. The Construction group is responsible for the realization of the project. This group uses data from both the Pavement Design and the Materials and Testing group. An important part of the data is related to Quality Assurance (QA) and Quality Control (QC) requirements. QC testing is frequently contracted out to the contractor or an independent laboratory. In most cases the QA testing is done in-house by the Materials and Testing group. On-site density tests are carried out extensively, and in most cases cores are taken to check volumetric properties. These cores are hardly ever used to check actual layer thickness, consequently this important parameter is often neglected. A modern trend is to measure and record thermal images of the pavement prior to compaction to check cold spots and segregation. The date that the pavement is opened for traffic is often not recorded.

For the evaluation or monitoring of the performance of materials like Superpave it is imperative to have access to data generated by the four groups mentioned above. There are three main reasons why such data are often difficult to obtain:

a) Each of the groups described above has a clear, but different responsibility, and this is reflected in the way they generate and store their data.
b) The time lapse between initial planning for a project and the actual construction can be several years, and this puts an additional burden on keeping all relevant data organized and accessible.
c) In many cases major changes are incorporated, particularly for a longer time frame. These changes in design, materials or construction techniques are not always recorded in the documentation of all four groups, and this makes it more difficult to get accurate data after the project is completed.

There have been attempts by DOT's to develop a databank with project information, based on e.g. a survey questionnaire, but in practice it often appeared difficult to collect the data after the project was completed. There are a few exceptions, ADOT for instance has a reasonably updated project database, but even here not all relevant data needed for a proper evaluation is available.

4.5. Desirable Research Level Database Details

Currently the most neglected part in the pavement management database, is research level data. Each state DOT has many individual projects involving new materials and new concepts. In such cases, a lot of detailed measurements and design information is originally available. Often this information is recorded on laboratory worksheets or in individual project plans, specifications, and construction control records. However, in most cases these data are set aside and remain in these flat files without being transferred to a permanent electronic database. After several years it is seldom feasible to retrieve such information for subsequent analysis. Therefore, the over-riding role of the research database is to encourage everyone in the DOT, particularly in the materials and design sections, to provide detailed data on a project by project level for inclusion in an extension file that is coded directly with the pavement management section. It is recommended that the state DOT adopt a standard operating procedure for entering research data into the database within twelve months of the activity.

Typically, if a variable is being studied in a research project, that variable should be recorded in the research level database. However, any other variable that may have an impact on the project should also be recorded. In general, the research level database is more detailed than the network level or the project level database. For example, if a project is included as a part of a study of concrete properties then cement type, source, fineness, set time, water cement ratio, aggregate type, aggregate gradation, and angularity should be recorded. Both design properties and as-constructed properties and values are essential. It is essential to know what the designer hoped to obtain, but more importantly in every case it is important to know what actually was obtained, since that is what will govern the observed performance.

In this report, Superpave is the example under immediate consideration. The study has shown that the QC/QA module of the Superpave/AASHTOware data set [AASHTO 00], supplemented by information such as actual layer thickness and precise location identification, could be good vehicle to store and disseminate materials and construction data for Superpave applications. Unfortunately, AASHTO has recently decided to temporarily stop the distribution and support of that program. The recent efforts made by The University of Washington, in collaboration with Washington State DOT, where relevant data on Superpave projects, including performance data, is presented on an integrated website, is a most welcome and probably more suitable methodology. Details are given in Appendix F.

4.6. Actual Research Level Databases

Currently most state DOTs do not record research data in their PMS or a PMS related database because of lack of resources. It is not feasible to assume that project or research engineers who work full time in the design, construction and observation of projects or who have already completed those projects and have data available in hard copy, will have time to enter the data in a database. It is necessary to set up a data collection and processing activity, which will make the data available to the electronic database. The activity must include the pavement management section to ensure that the data are compatible in every way.

An important example of data that fit this category but which have never been properly used or entered into most state databases are the LTPP data. In many cases the state DOTs could take the individual LTPP sections and supplement them with measurements in their own state on other sections to make a broader applicable factorial, which could be analyzed for state benefits.

Little effort has been made in most state DOTs to store research level data in a form keyed to the pavement management database. There are many reasons for that, which is not relevant at this point. What is relevant is that state DOTs should be made aware of the benefits of keying such data to the PMS database. The value of research could be doubled if the data could be maintained permanently so that mistakes are not repeated.

Another major benefit of keying these data into the PMS database is that multiple states could share the data with each other. Electronic storage is critical to such databases. For example, if ten states stored their research data for 30 test sections each into their own PMS database, they could exchange data electronically among the states and a much broader database of 300 section could be analyzed. Most engineers do not fully understand the powerful analytical capabilities of large sample statistics. Even in the face of large variability, strong trends can be obtained when data sets can be combined into one large one.

It is important for data entered into the database, to make reasonable estimates of the traffic load history of each section. Even if weight data are not available, it is vital to make a timely estimate of equivalent single axle loads based on a reasonable evaluation of available load, traffic, and classification data. If attempts are made to reconstruct the data five to 15 years later, then the value of the estimates are degraded.

In summary the characteristics of the PMS database are extremely important. Great benefits can accrue to state DOTs if those data sets can be broadened to include project and research level data on a regular basis, and if the data can be combined among states for additional strength. Subsequent sections of this report will deal with Superpave data as a specific example and the importance of gathering these data while they are fresh.

5. DOT REPORTING TECHNIQUES ON MATERIALS AND CONSTRUCTION, ACTUAL VERSUS IDEAL

5.1. Actual Situation

Current DOT practice is normally to plan, design, bid, and build projects. Included in these functions are the materials requirements and the QC/QA project acceptance requirements. Each function is treated as a separate entity, i.e., the design plans and specifications govern the project in a general fashion. Intermediate laboratory tests to develop project mix parameters are the “property” of the materials group, tied to the assigned project number. In a like manner, the day-to-day materials tests and QC/QA testing performed by construction inspectors are delegated to the project file, in the materials area and project office, or sometimes by the contractor. Usually duplicate materials testing data are provided to the project inspectors for payment and audit purposes. In most cases, data on materials, mix design, and construction details are recorded on paper, so this information is stored in flat files by different groups and is often difficult to access after the project is completed.

The pavement design plan for a particular rehabilitation project can normally be found in an inter-department communication, or memorandum, from the pavement design engineer to the Manager of Preliminary Engineering Studies Section, the project engineer or coordinator, or the design engineer. Such a memorandum is routinely copied to the materials engineer. In some cases, further correspondence follows between these parties with various revisions until a final design recommendation is made. In most cases this will be accompanied by one or more drawings with the cross-sections of the pavements in question. Apart from the design for the main pavement section, design details can be given for shoulders, ramps, overpasses, and temporary crossovers. This correspondence normally refers to the name of the road and the mile posts of the section, to a design number, and to a contract number. Often a project number is used also. Copies of these memoranda are filed at various different locations within a DOT. The time lapse between the first design memorandum and the final version can be from one to several years, since there can be long delays for a project between preliminary design and final construction.

Data on the laboratory mix design are developed by the materials group, they are tied to a design number and a project number. Most of the historic laboratory data are stored in flat files, and consequently are difficult to access. Currently there is a trend to make such data available in electronic format, either with the help of a commercial system such as LIM (Laboratory Information Management), or through custom made spreadsheets on a PC. In that way it is easier to analyze and to share the data, but the fact that such data are often still residing on a PC or a dedicated server makes it difficult for other interested parties in the DOT to access such data.

The routine testing data and the quality control and assurance data can come from several sources. There is a trend of increased testing by contractors or specialized consultants, although quality assurance is mostly still carried out by DOTs. Such data were usually made available in paper files until recently, when attempts were made to streamline data storage and transfer by using electronic systems. AASHTO introduced two programs for this purpose, Site Manager and BAMS (Bid Analysis and Monitoring System), but both have the limitation that they can not be integrated easily with other databases, such as PMS. Site Manager also has the drawback that it does not have any sort of filter or query capabilities.

Knowledge of and easy access to materials and construction data is essential if the long term performance of pavements is to be analyzed for constructive purposes. Such data should be linked by the uniform identifiers of date, project number, route and cumulative mileage to any follow-up performance data obtained after construction is completed. Routine measurements as well as specialized tests such as FWD should be tied together also by route and milepost to create a more complete picture of historical performance and expected performance trends by various classes of pavement. In this respect it should be stressed that records should be kept of all required data. Some DOTs do not measure as-laid thickness routinely, but this information is essential for analysis.

Arizona DOT has for several years maintained a separate electronic database for projects, which is called Projmod. This file contains the following information: Route, lane, direction, mileposts (begin and end), material category applied and its thickness (as designed, for up to six layers), project name, and date. The file does not give actual thickness and material properties (designed or actual), but it is a good start for any engineering analysis.

5.2. Ideal Situation

In the ideal situation all relevant materials, construction and performance data would be available in electronic format and a full integration and sharing of such data, as described in Section 3.5, could be realized. There would be major advantages if all required data are indeed entered electronically:

- Data entry would only have to be done once,
- Less room for mistakes,
- Available immediately,
- Corrective actions are possible in a timely manner,
- Automation possible (link to GPS during construction, field testing, etc)

The web-based system developed by the University of Washington in cooperation with Washington State DOT offers an excellent methodology for both data warehousing, inspection, linking and analysis. Details of this system and examples of its capabilities are given in Appendix F.

6. CONCEPTS FOR LINKING PMS AND MATERIALS AND CONSTRUCTION DATABASES TO PERFORMANCE EVALUATION

6.1 Current Situation

Typically, when engineers and analysts think of performing an evaluation or analysis, they think of the final data set needed to make the analysis, in other words they think of the "combined performance evaluation database". While that is the ultimate goal, it is not a feasible starting point, since such a database must be constructed from other available data sources first.

6.1.1. PMS Database

It's important to remember that the average PMS database is very large in terms of number of sections or subsections entered. In Arizona DOT, for example, there are more than 7,000 sections and in Texas there are more than 70,000 sections. On the other hand, for a particular performance evaluation module, the number of sections to be analyzed may range from a few to several hundreds at the most. Keeping this size differential in perspective should make it clear that it is impossible to put all the detailed materials data into the very large PMS database. Rather, separate databases for each individual purpose can be maintained or assembled and those linked to create the performance evaluation database or module. These facts are born out by the knowledge that early in the development of pavement management, it was thought that all project details could be assembled into a database. In each case the process bogged down. Only when states like Washington and Arizona [Kulkarni 82] started with the idea of keeping simple performance data at the network level, did pavement management move forward rapidly.

For the purposes of material evaluation and this project, reality starts where the states currently exist. Good PMS databases for network level use are simple and contain relatively few data elements because excessive detail can bog down the process. The data elements used in five states that were visited in this project are given in Section 8 and Appendix D.

In most PMS databases, information on cracking, roughness, and other performance measures, are stored in summary form such as, IRI or a cracking index of some sort. Some states use the serviceability index or a related pavement quality rating.

It is essential to define for states the elements of a minimum PMS database. However, that is not the goal of this project. The minimum PMS data expected for use in performance evaluation of Superpave, should be defined including a number of elements appropriately coming from PMS. Where that is not possible, it is suggested that they be collected as part of the auxiliary "materials database and construction database.” Subsequently, it would be desirable to move key elements into the broader PMS database.

Most pavement management databases do not include details about actual pavement thickness and material type below the surface layers. This is true in part because construction records were not readily available at the time when the pavement management system was implemented. Time and resources have not permitted coring and searching permanent record files to supply this missing data.

In those states where these type of data are missing from the PMS data file, it should be provided for selected sections in the materials database or data sub-files for performance evaluation.

Similarly, reliable traffic load data are often not available in the PMS database. For the present, it is recommended that the traffic data be obtained and entered into an analysis file. However, in some state DOTs a traffic data file is available and this information can be provided into the PMS database. In most cases, it is desirable that the traffic and load data element be added to the PMS database. Originally this element would contain data only for those sections being considered for evaluation of Superpave, other new design, or materials concept. As these data are collected and processed, it may become clearer to the DOT staff that it is important to add this information to the entire PMS process. If this is not possible, then a supplementary data element called the “Detailed Data” should be developed.

Depending on the materials or conditions begin evaluated, other classes of data not available in the PMS database may be needed. This may involve detailed climatic or history, structural evaluation such as repeated FWD measurements, and in the cases of some materials more detailed distress data related to the purpose of the material. For example, it may be necessary to evaluate rutting more extensively for certain types of mix designs than for others. Therefore, rutting or detailed cracking while combined as an index in the PMS database, should remain separate for those sections being evaluated for Superpave.

It will also be valuable if auxiliary short-term performance information such as, wheel track testing, Stabilometer values or other heavy vehicle simulator or other short-term estimators of performance could be restored in a permanent database. This will depend upon the testing resources available to the individual DOT and the information shown here is by way of example only, assuming a particular class of available information.

6.1.2. Materials and Construction Databases

As discussed in Section 4, much of the required data necessary for the performance monitoring of individual design and construction concepts exist in the materials and construction databases, not in the PMS database. Two major problems exist. The shear magnitude of the design and construction information exceeds anything that can be entered into a routine PMS database. Thus, the data, if stored, must be summarized on a statistical basis keyed to individual locations, including average value, standard deviation and number of samples. Probably more important is the fact that the data exist in a separate database obtained for a different purpose. First of all, the design data are probably not in a database, but on a set of hard copy files or hand written notes that define the design parameters and the mixed design characteristics obtained for the materials and the pavement structure for the individual section. Secondly, as-constructed pavement data exist in a separate construction file. In some cases, and hopefully in the future, this will exist in a file such as Site Manager or in another suitable electronic data subsystem. These will make the process somewhat easier, but it must be remembered that data collected for one purpose, often have limitations for a second purpose. The transposition of these data must be done carefully, effectively, and in a timely manner.

Another major problem with linking data is the source of the data, which may be some other section of the DOT, the files of a contractor, a materials testing company working for the contractor, or in a field materials laboratory. Other complications occur when field changes are initiated due to unexpected conditions such as weather, varied subsoil conditions, or existing condition of old pavements where rehabilitation or reconstruction is involved. This latter condition is further compromised and complicated when the section is to be built under existing traffic. Other complicating factors occur when the section is a widening of an existing pavement where drainage patterns are interrupted.

In these subsidiary data sets, the data may be keyed to local field identification and location, which must be transferred to a permanent mile point GPS location system. This must be done carefully with cross checking if it is to be useful. Data improperly located in an electronic data format are useless and have a negative impact since purportedly it represents conditions incorrectly. It is better to have missing data then bad data.

Only with special effort made at an early date will the linking of the data take place. There are many examples where important past research is not accessible for subsequent analysis and in fact the data have been effectively lost.

6.1.3. Summary of Main Needs

It is important in summary that the data from a materials and/or construction database be appropriately and effectively linked to the PMS database at an early date within the efforts of the history of the data. No major effort should be made to retrieve all possible project level or research level data for a twenty-year period. However, in many state DOTs it would be desirable to initiate a retrospective effort to enter such data for the past year and to setup the database so that the data could be effectively entered in the future. In this way, important data would not be lost. This is especially important for the Superpave study which serves as a primary example in this report. Superpave sections have been constructed for the past several years and because of the critical focus on this element nationwide, such data should still be available in most state DOTs and as soon as possible should be entered into an electronic database keyed to the PMS database.

6.2 *Concept for Linking Databases*

It is proposed to use the concept of linking two central electronic databases, one for Materials/Construction data and one for PMS data. Relevant data from these two databases should be made available and transferred electronically to a third Performance Analysis database, which should contain all required information. For the performance analysis, use can be made of a commercially available spreadsheet system (e.g. Excel or Lotus) that extracts relevant information and makes overviews, graphs, and reports. A possible structure for this methodology is given in Figure 2 below.

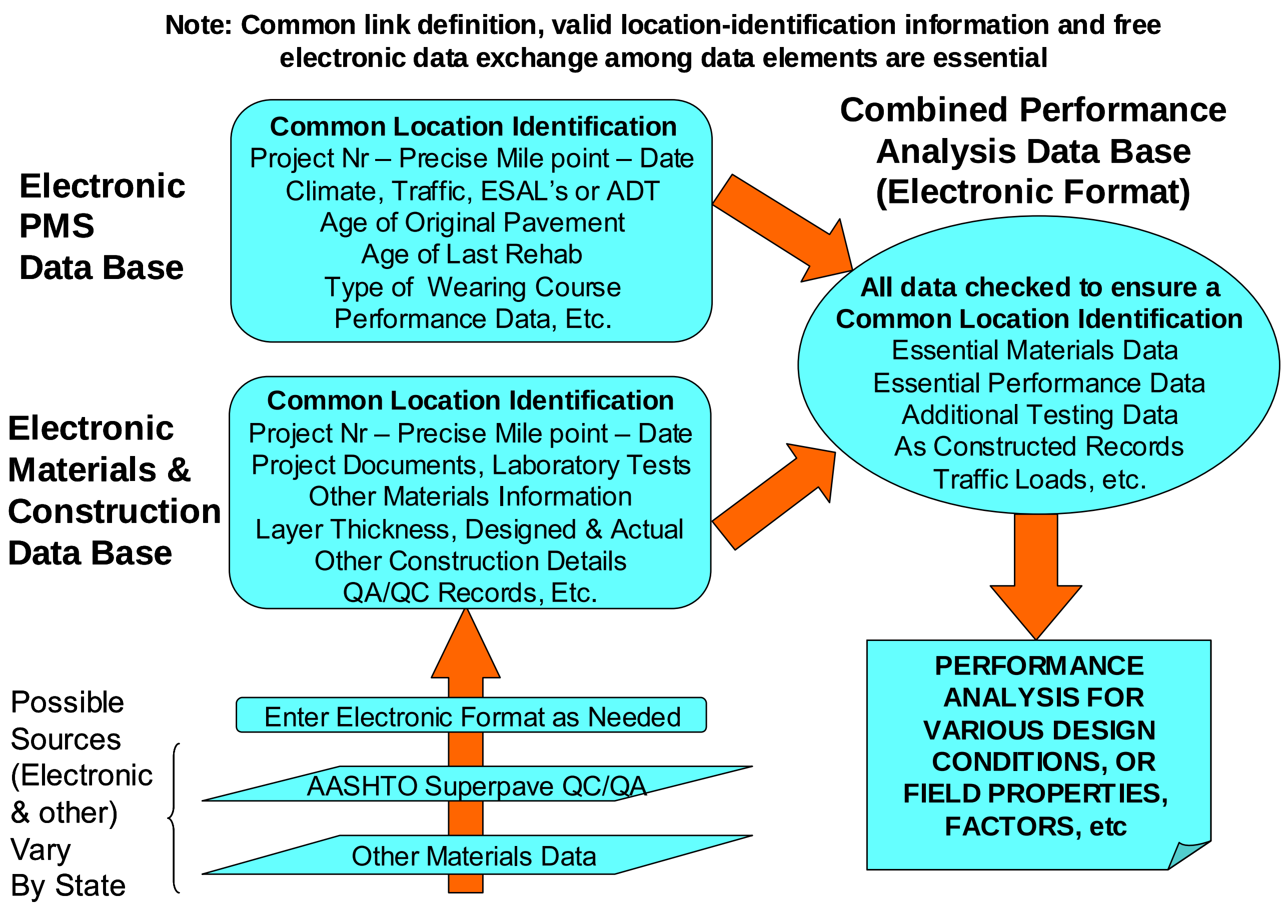

Figure 2. Example of a structure to link materials and construction data to PMS data

The key to linking databases, as shown in Figure 2, is to have precise unambiguous location identification and date/time information. Only in this way can it be assured that the data are comparable. For example, in the case of multi-lane roadways involving bi-directional interstate highway lanes and frontage roads, the new material may be used in only one or two lanes or in one roadway direction. This identification must be unambiguous over time. When the material is first placed, it is clear in everyone's memory, which is which, but four or five years later or after personal changes, when a long-term analysis is needed, this becomes more difficult. Unambiguous locations can be provided by GPS measurements and these are relatively economical at the present time. However, they must be tied to traditional location identification information such as project number, mile point, lane, direction, date, etc.

6.3. Practical Implementation of Data Linking

While the concept of data linking is relatively obvious to all, it became clear in this project, by visiting five DOTs, that additional resources and energy will be required to actually capture the information in usable form. As long as the data elements remain in paper files, field logbooks or other auxiliary locations, there will be a very difficult transition process.

The good news is that several states have already started to put materials and construction data in electronic format. An effort should be made in other states to transfer the data from hard copy files into electronic form quickly, soon after construction. This would introduce an additional check into the system and there is a good chance that the quality of data can be improved. With a properly designed system much of the detailed design, materials and construction data, only have to be entered into the system once. But this initial entry information should be done carefully and uniformly.

The new web-based database with analysis and evaluation capabilities as developed by the University of Washington, shows a lot of promise as a system for practical implementation of linking. Data can be entered with Excel, Access or comparable files. The University of Washington system offers a range of evaluation, analysis and reporting possibilities, but it is also possible to download the raw data and perform these analyses in another way at your own location. Appendix F gives further details.

Administratively it will be necessary to assign someone for data processing and storage. In computer parlance a “Data Administrator “ will be needed. If the data in each of the two or three subdata-elements remain independent of each other, there may be a gap in the compatibility of the data for future analysis. Rather than create a separate position or slot for this data administrator, it is likely that someone charged with data responsibility in materials, can start or Pavement Management should be responsible. If the Pavement Management Section is charged with the responsibility of evaluation and analysis, then the best place for data administration is PMS. However, this data administrator must be aware of the needs and workload imposed on the materials section or other sources for the detailed information. As in most other undertakings good relations and coordination between the sub-elements are required.

Ideally, the pavement management or asset management section within a DOT would recognize the multiple goals of a good pavement or asset management system: Network level, Project level and Research and Evaluation. In this case, recognition can be extended beyond Superpave analysis to other new concepts such as an evaluation of the results of using the AASHTO 2002 Guide, new concrete pavement technologies, etc.

In the specific case of Superpave, someone intensely interested in the performance of Superpave can become the data administrator and insure that the materials and auxiliary data are collected and then interfaced with the PMS database to obtain from that source the additional information needed for the ongoing analysis.

Since Superpave performance has a time history dimension to the data evaluation follow-up, the data required for analysis should be collected and evaluated as early as possible and the process should be continued on an annual basis for five to 10 years to better define the performance histories. We must remember from the AASHO Road Test [Hudson 68b] and other long term studies, that only abnormal failures are observed in the first two or three years. True performance based on long term observations, usually take a minimum of five years and more often 10 to15 years of observation. For true success, some administration unit should be charged with the data activities.

7. SPECIFIC REQUIREMENTS FOR LINKING DATABASES (WITH SUPERPAVE AS EXAMPLE)

7.1. General Requirements

1. All data must be available in electronic format in systems with search and filter capabilities. Most PMS databases conform to this requirement, but materials, design, testing, construction and QC/QA data are often stored in flat files.
2. The electronic evaluation system, linking the PMS database with the Materials/Construction/QC databases, should be manageable and user friendly, it is recommended that universal software be used so that the output can be easily reported, exchanged and compared;
3. Each database should have an “owner” who is responsible for the timely upkeep and the quality of data. These “owners” should work in an organizational structure that facilitates open communications among them.

7.2. Performance Evaluation Data

1. The performance evaluation data must be linked to the correct materials and construction data, using a common denominator such as project number and exact mile point (or GPS coordinates). This requires three checks:
   a. Check the exact location (mile point and lane) of the material in question. This will only be possible when records are kept of the placement of each batch or lot as produced by the hot mix plant;
   b. Check the exact location of the testing of in-place properties such as density/degree of compaction and thickness.
   c. Make sure that the location where performance data are collected does indeed correspond with the location of the material being studied.
2. Use the appropriate performance indicators for the distress or performance being studied. For Superpave this could mean comparisons of rutting, cracking, and/or ride quality when studying effects of mix or binder type, compaction effort, traffic loadings, temperature, age, types of specifications, etc. Other examples are given in Section 10.
3. Make sure that the performance indicators used are properly defined, standardized and consistently applied.

7.3. Environmental and Traffic Data

1. Incorporate relevant climate data (temperature, rainfall, etc);
2. Check proper drainage;
3. Make sure reliable information is used for actual traffic volume and loads.

7.4. Materials Data

1. Limit information for materials properties, design and testing to data that is essential to an individual DOT;
2. Make proper categorization of (Superpave) mix type, such as coarse or fine, binder type (grade bumping), etc;
3. Check whether mix design was done according to specifications and appropriate performance testing.

7.5. Construction and QC/QA Data

1. Information is required on total pavement structure, including subgrade, and actual layer thicknesses and strength;
2. Check that actual thicknesses conform to the pavement design specifications;
3. Check whether as-placed materials properties, including stiffness and degree of compaction conform to specifications.

7.6. Examples for Superpave Mix Performance Monitoring

Examples are given below of data from the PMS, Materials and Construction databases that are relevant for the monitoring of the performance of Superpave:

7.6.1. From PMS Database

1. Performance Data, such as ride (IRI, etc), rutting (identify contributing layer), cracking (fatigue, low temperature, reflective, etc), surface deterioration (raveling etc) and skid resistance;
2. Location (mile point, lane) and project number;
3. Traffic loadings (ESALS) and climate data;
4. Age of Superpave pavement.

7.6.2. From Materials Database

1. Asphalt/binder test data & PG classification (e.g. PG 64-22);
2. Aggregate test data, such as coarse and fine aggregate angularity (CAA, FAA) and gradation (coarse, fine, control points, restricted zone);
3. Other (sand equivalent, etc);
4. Laboratory mix test data, such as Gyratory test data, volumetric properties, water sensitivity test data and mix performance test data like Hveem “S” value, Marshall test, Rut test, Stiffness (E*, phase angle), creep test, repeated load test, shear test, axial load test, etc.

7.6.3. From Construction and QC/QA Data

1. Location, mile point, lane, and project number;
2. Asphalt mix composition as placed (grading, binder content and grade);
3. Voids content (VIM, VMA, VFA) and degree of compaction;
4. Actual layer thicknesses (e.g. from cores, or non destructive testing);
5. Other relevant construction information (rain, delays, etc).

7.6.4. Examples of Parameters to Investigate

The four examples given below illustrate how the process of linking the PMS data to the Materials database can be used to evaluate the Superpave mix technology, which includes the binder specification, aggregate requirements, volumetric mix design and accelerated performance tests of mixes if available.

1. Low temperature cracking: plot degree of transverse cracking as a function of time for different Superpave binder grades in different climates. These plots, together with an examination of field construction data, may indicate changed aging requirements in MP-1 binder specs;
2. Grade bumping: compare rut depth as a function of ESAL's for two grades, e.g. PG 64-22, and a grade bumped to PG 70-22. The latter is expected to show less influence of higher ESAL values.
3. Effect of fine aggregate angularity (FAA): check the observed rutting for several levels of increased FAA levels for similar traffic, environment and mix design.
4. Effect of aggregate gradation (coarse vs. fine) on roughness: Check roughness levels for three levels of traffic loading for two types of Superpave mixes, one with fine, and the other with coarse aggregate, and make sure that all other conditions are comparable. One would expect the coarse mix to show higher roughness values, this effect might increase with higher ESAL values.

These four examples are illustrated in more detail in Appendix C.

8. EXAMPLES OF PERFORMANCE PLOTS OF SUPERPAVE PROVIDED BY VARIOUS STATE DOTS

8.1. General

Although there were differences among the organizations and procedures of each DOT, they all shared a similar approach in reporting data for Superpave. All five pavement management systems could identify the location of Superpave sections, together with performance data for a few years (currently one to four years), but did not give any details on type of mix, as-constructed thickness, construction details, or any quality assurance (QA) or quality control (QC) data. It also was universal that materials, construction, and QA/QC data, which are crucial for a proper analysis of a material like Superpave, were kept in files in different sub-organizations, such as "Materials" and "Construction". In some DOTs the materials files were in electronic format, often existing of tailor made Excel files, but construction data were mostly stored in flat files. This practice makes it extremely time consuming to retrieve data from flat files in various locations, particularly when the project is several years old.

The state DOT's of Maryland, Indiana, Florida, Arizona and Washington have submitted data on several Superpave projects carried out in their states. TRDI has selected those projects with performance data for at least two years, and that selection resulted in a total of 30 projects: three from Florida, seven from Indiana, three from Arizona, 13 from Maryland and four from Washington. Some essential data for these 30 projects are given in Appendix D in two ways:

1. graphs for Ride, Rutting and Cracking with a summary of data, and
2. tables with more detailed information for these projects in each of the states.

Superpave has been used in these five states for hundreds of projects, some of them as early as 1995. TRDI collected information on a total of 56 projects, but 26 of these projects had inadequate data to link performance to materials properties for at least two consecutive years. These projects were either too recent, or their location was such that no performance measurements were available (e.g. in the left lane of a multilane highway, a short section between mile points, etc). For the selected projects some of the essential data were still missing as can be seen in Appendix D.

8.2. Superpave in Maryland

Maryland State Highway Administration (MDSHA) started designing and constructing Superpave mixes in 1995, and since 1998 virtually all asphalt mixes for new construction and rehabilitation use Superpave. The introduction of Superpave was facilitated by the fact that the previous asphalt mix compositions in Maryland were already similar to those in Superpave. As of 2000 there were almost 200 projects constructed using Superpave in Maryland.

MDSHA supplied data for 22 Superpave projects, constructed between 1995 and 2000. For 13 of these projects the performance data were available for at least two years, and data from these projects are shown in Appendix D. MDSHA provided the following summary for the 22 Superpave they furnished to us:

"The following data have been retrieved and are presented:

- *Project limits and location*
- *Date project was opened to traffic*
- *General comments on the pavement condition before the treatment was applied*
- *Design inputs – life of design and resilient modulus of subgrade*
- *Date of last major rehabilitation*
- *Pavement layer data – thickness, mix type, ESAL category, PG binder, tonnage*
- *Network level ride and friction data for past three years*

Additional information is available in project design and construction files. The following comments are provided with regard to these data:

- *The projects selected were among the oldest Superpave projects in MD to provide as many years of performance data as possible. Unfortunately, the approach to design these projects at the time was considerably different that the current approach. Many of the projects were designed years before construction and changed to Superpave mixes at the time of construction. As a result, little to no information is documented on the selection of the various Superpave mixes. However, all projects in MD that were designed after June, 1999 do include a very detailed approach to assessing existing conditions and selected appropriate designs (the attached projects were all designed prior to June, 1999).*
- *MDSHA has developed and implemented completely new pavement design guidelines that were implemented in the middle of 1999. These guidelines include very detailed condition surveys as well as updated design analysis procedures. More recent projects include more information on the design approach, distress quantities, repair quantities, effective structural condition and traffic data. These projects are no more than one year old and are available for consideration in this evaluation as well.*
- *Limited construction and materials details are included. Information such as time of year of construction, detailed mix properties and quality control data will certainly be of use in this evaluation. This information requires more effort to access."*

Two additional points about the Maryland projects are worth noting: They use a special wearing course of stone-matrix asphalt (SMA) extensively for major roads in Maryland. Consequently, in many cases Superpave mixes are not exposed to traffic. For this study MDSHA generally selected and provided project data where a Superpave mix was used as wearing course. Unfortunately no data for cracking were available for the Maryland projects.

Pavement evaluation ratings, and the criteria used with these ratings, are the following:

- IRI (International Roughness Index), expressed in accumulated inches per mile for two lanes into each direction. The criteria are Very good (<60 in/mi), Good (61-94 in/mi), Fair (95-119 in/mi for Interstates, 95-170 in/mi for other roads), Mediocre (120-170 in/mi for Interstates, 171-220 in/mi for other roads) and Poor (>170 in/mi for Interstates, >220 in/mi for other roads)
- Rutting, expressed as the maximum rut depth in inches in each section in both wheel paths, for two lanes into each direction, measured with the ARAN vehicle.

8.3. Superpave in Indiana

Superpave has been used since 1995, and from 1997 onwards all contracts over 4000 Mg of base or intermediate course or 2400 Mg (megagrams) of wearing course use Superpave. The INDOT staff tries to follow Superpave specifications without modifications. Mixes are designed in conformance with the Superpave method (code 401), but use is also made of a generic Superpave recipe (default design, code 402). Up to 15% of RAP (recycled asphalt pavement) is used on shoulders and in binder courses without a change in asphalt grade. RAP is not used in wearing courses by INDOT.

More than 100 Superpave projects have been carried out so far. A major effort would be required to convert all materials and construction information on these projects into electronic format, assuming that all data is still available. Our Project Team requested performance data for a limited number of sites, and INDOT personnel agreed to make the required information available in electronic format for seven projects with Superpave-designed mixes constructed since 1997. The mixes for these projects are designed in conformance with the Superpave method (code 401), not with a generic Superpave recipe (default design, code 402). The relevant data for these seven projects, and graphs with plots for ride, rutting and cracking are given in Appendix D.

The ride is expressed as IRI and measured in inches per mile. The following criteria are used: excellent (60-100), good (100-150), fair (150-200) and poor (>200).
Rutting is a measure of the average depth in the wheel paths, rutting above 0.25” is considered severe.

INDOT uses PCR (Pavement Condition Rating) as a measure of pavement surface distress. The PCR includes transverse, longitudinal and block cracking. The distresses are rated for severity and quantity, and “deduct points” are determined, which are subtracted from 100 to determine the PCR. The ratings for PCR are: excellent (100-90), good (90-80), fair (80-70) and poor (<70).

The plots for the performance indicators show a discontinuity between the years 1997 and 1998. There are two possible causes for these variations:

1. First, INDOT has serious reservations about the quality of these data, collected by a contractor in 1997. They therefore changed contractors to collect performance data in 1998 and 1999.
2. In addition the exact date of completion was difficult to establish for some of the projects. It is possible, therefore, that some of the performance data in 1997 were actually taken on the pavement prior to its rehabilitation and laying the Superpave.

8.4. Superpave in Florida

So far about 700 Superpave projects have been completed in Florida. Since 1998 all mix designs conform to Superpave criteria. It is normal practice for FDOT to apply a friction course as top layer for all mixes, including Superpave mixes used on Interstates. FDOT gave the Project Team a list with of 24 projects for the years 1997-2000, where the major structural component was a Superpave mix. Out of these 24, three projects could be selected based on two criteria:

1. At least two years of performance data must be available,
2. Performance, materials and construction data were available and relatively complete.

Details for these three projects are given in Appendix D.

The pavement distress is recorded as PMS data and expressed in crack, ride, and rut ratings. The tabular data also cover segment number, county, year of contract, direction, mile points, road number, rating year, age, WPA (Work Program Administrator) data, and contractor. Statistical information on the performance data is included in the PMS database.

The distress ratings, and the criteria used for these ratings, are the following:

- IRI (International Roughness Index), converted since 1991 into a Ride Rating, reported on a 0-10 scale to the nearest integer value, with 10 as best condition;
- Rutting, a measure of the average rut depth in both wheel paths, converted to a Rut Rating and reported on a 0-10 point scale to the nearest integer value, with 10 as best condition;
- Cracking, assessed as percent confined to wheelpaths (CW) and % outside of wheelpaths (CO), a crack rating is a combination of CW and CO, derived from established distress rating scales, and reported on a 0-10 point scale to the nearest integer value, with 10 as best condition. Crack type is reported as C=combination, B=block and A=alligator.

Segments having a Ride, Rut or Crack Rating of six or below are eligible for resurfacing.

Cracking is reported, but crack sealing is not done as a routine maintenance activity because experience in Florida suggests that sealing of cracks does not extend pavement life.

Material properties of the related Superpave mixes and traffic data can be accessed electronically (through a tie-in to bid files), and design thicknesses should be found in paper files. No information is readily available about actual thicknesses of the Superpave layers, but we were informed that these depend on the aggregate size, as a general rule for SP 9.5 mm, for SP 12.5 mm, and for SP 19 mm the thickness would be 1½"-2", 2"-3" and 3"-3½" respectively.

On average about 20% RAP (reclaimed asphalt pavement) is added to Superpave mixes (30% to Marshall mixes); about 60% of all Superpave projects in Florida contain RAP.

8.5. Superpave in Arizona

From 1993 until 1996 ADOT's Materials Group in cooperation with the FHWA designed and built a number of Superpave test sections. For the hot mix design use was made of the SHRP gyratory compactor. Towards the end of 1996 it was decided that ADOT would move from a test section phase to a pilot project phase of evaluation and implementation of the SHRP gyratory method of Superpave mix design.

ADOT has made an overview of 21 Superpave projects completed in 1997 and 1998 in various parts of Arizona. The total length of these projects is about 122 center line miles on Interstates and other main roads.

For each project the following information is recorded: Project Number, Tracs No., Project Name, Contractor, Year built, Mile points, ESAL's, Elevation, Design Air Temp., PG Grade, Mix Size, Gyratory compactor testing details, Surface Course, Overlay, and Mill/Replace. In all projects the final surface course consisted of ½" thick rubber-modified porous asphalt friction course (AR-ACFC).

ADOT's overview is very comprehensive, but does not contain as-laid layer thicknesses, nor any performance data. After checking with the ADOT PMS group it appeared that three projects could be identified with at least two years of performance data (data for the year 2000 were not yet entered into the PMS database). For the three projects with performance data, information about construction data was extracted from Pavement Design Summaries and from Superpave Project Tracking Survey Questionnaires (both in flat files, and not available for all projects). Details for these three projects are given in Appendix D.

Distress is recorded in ADOTs PMS for cracking, flushing, patching, rutting, friction and roughness in the right lanes only. For cracking, rutting and roughness the following is relevant:

- Cracking is measured through a visual survey of the first 83 ft at each mile post, covering roughly 1,000 sq. ft. and expressed as percentage of that area. The following criteria are used: Low (<10%), Medium (10-30%) and High (>30%).
- Rutting (measured since mid eighties with a four foot straight edge), determined from several short sections in the wheel path spread evenly over the entire mile after each mile post, averaged per section and expressed in accumulated inches. The following criteria are used: Low (<0.25 in), Medium (0.26-0.50 in) and High (>0.5 in).
- Ride is expressed as Roughness, measured after each mile post for the entire mile with a Mays Ride Meter, and since the mid nineties with a Profilometer, expressed in accumulated inches per mile. The following criteria are used: Satisfactory (<93 in/mi), Tolerable (94-142 in/mi) and Objectionable (>143 in/mi).

8.6. Superpave in Washington State

WSDOT began building Superpave projects in 1996, and since 1999 almost all their asphalt hot mixes are Superpave. Performance grade binder implementation started in 1999. In total some 40 Superpave projects have been completed so far, four projects were done in 1997, nine in 1998, 10 in 1999 and the remainder since then. Hot mix design uses all SHRP specifications and mix design techniques.

All materials and construction data are collected and stored in Excel files. The Civil and Environmental Engineering Department of the University of Washington (UW) has, in a joint effort with WSDOT and NCAT, recently developed a fully integrated website that contains relevant data of Superpave contracts, including performance data. This new development was possible because nearly all essential data on materials and construction are available electronically. In addition a major effort has been made to link these data to performance measurements from WSDOT's Pavement Management System (PMS). The data are available on a series of web pages (see Appendix F) from which they can be easily organized, downloaded and analyzed. Although this development is still in a pilot stage, it represents a major step in fulfilling the objectives of the project that is the subject of this report.

WSDOT has no experience yet with the AASHTO Superpave software, but it was stipulated by a UW representative that it should be possible to extract the information for the hot mix website equally well from that program.

The project team received an Excel file with details of 12 Superpave projects, including PMS performance data and materials/construction data. Of these projects, four contained performance data for at least two years. Details for these four projects are given in Appendix D.

Most Superpave mixes are based on a 12.5 mm grading and binders have been used ranging between PG 58-22 and PG 70-34.

The website with the hot mix database gives detailed project information for each contract. Currently the website shows the following data:

- Project information with location, dates of construction, total tonnage, and type of mix and binder,
- Mix Design information with details of gradation, binder content, voids, density, gyratory compactor results, TSR, Sand Equivalency, and performance test data for creep and Hveem stability,
- Construction details with lot number, date, gradation, binder content, voids, density, gyratory compactor results, and RAP %,
- Performance data for five years (before and after construction), PSC, rutting (PRC) and IRI and distress details. All performance data have been linked to materials and construction data.
- Various graphing windows for plotting several relevant data for the lot numbers in each project.

The weather conditions in Washington State can be harsh, and consequently extensive use is made of studded tires during the winter season. WSDOT experience shows that friction courses do not stand up to the abrasive action of studded tires, consequently the Superpave mixes are directly exposed to this wear. Experiments with wearing courses of stone mastic asphalt and/or gap graded mixes with larger size aggregates are being considered.

Performance data are collected on an annual or bi-annual basis in the outside lane (for a multi-lane highway) in two directions for the following parameters:

- Structural Condition, based on surface distress data (fatigue, longitudinal and transverse cracking, flushing, and patching) measured since 1999 with a Pavement Condition Van at highway speeds, using continuous video imaging of the pavement surface, ahead view, shoulder view, and vertical views. From these distresses a Pavement Structural Condition (PSC) is calculated on a scale from 0 to 100. The range 100-75 is Very Good, 75-50 is Good, 50-25 is Poor and below 25 is Very Poor.
- Rutting Condition, measured continuously in the wheel path with the help of lasers on a cross beam on the Pavement Condition Van, expressed in a Pavement Rutting Condition (PRC) and calculated in average rut (in mm) over the previous mile. The condition limits are: Very Good when < or = ¼", Good when > ¼" and < or =1/3", Poor when > 1/3" and < or = ½" and Very Poor when > ½".
- Roughness Condition defined by the International Roughness Index (IRI), measured continuously with laser sensors mounted on the Pavement Condition Van, expressed in accumulated inches per mile. The condition limits are: Very Good when < or = 95 in/mi, Good when > 95 and < or = 220 in/mi, Poor when > 220 and < or = 320 in/mi and Very Poor when > 320 in/m.

8.7. Examples of Performance Plots

Figures 3 through 5 give example curves of performance plots for ride, rutting and cracking for Superpave projects. One example for each performance indicator is presented. A set of all performance curves for the Superpave projects discussed in Section 8.2 – 8.6 are given in Appendix D.

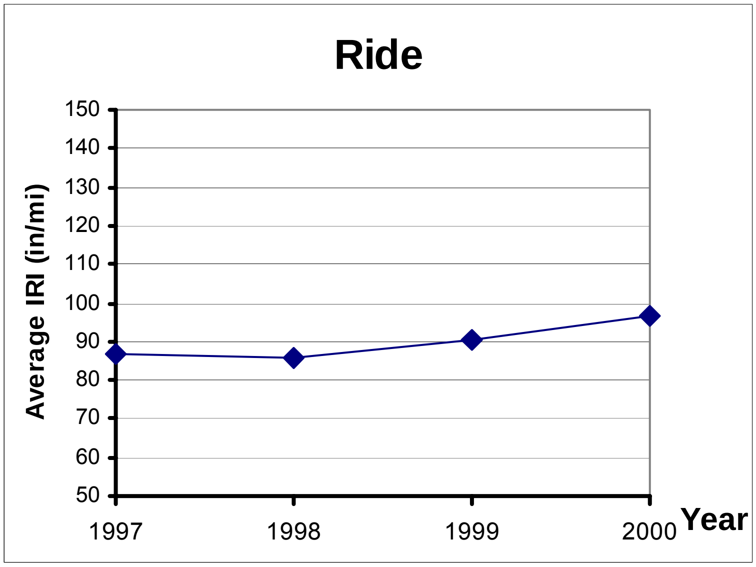

Figure 3. Example of performance curve for Ride

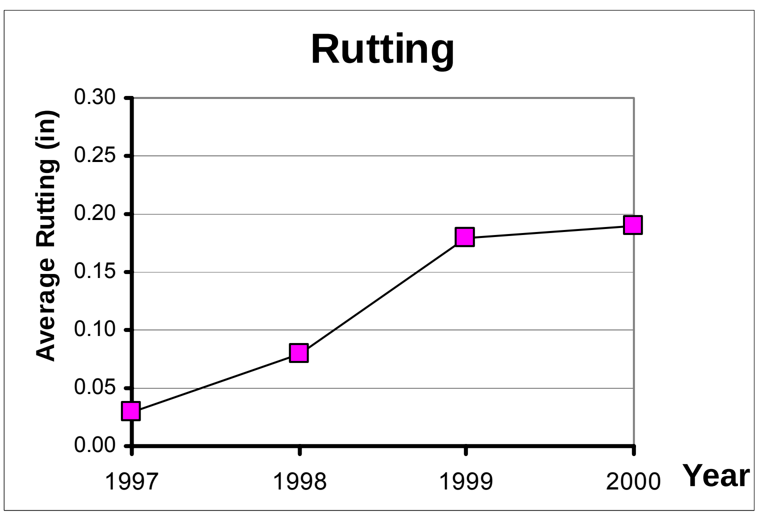

Figure 4. Example of performance curve for Rutting

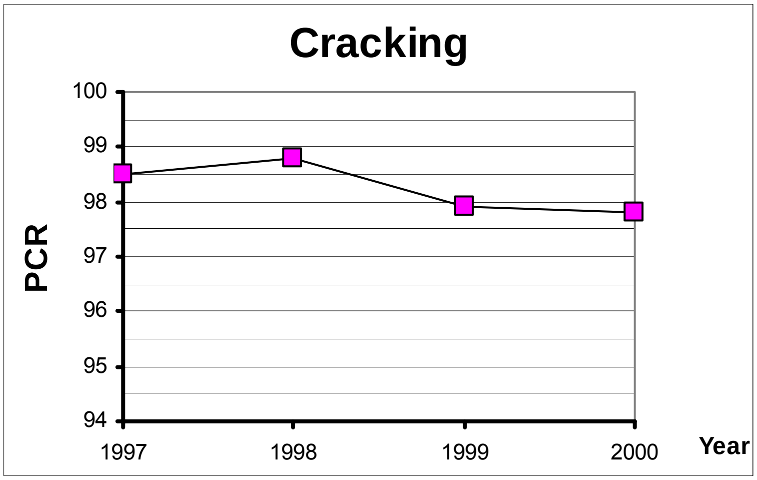

Figure 5. Example of performance curve for Cracking

These graphs are presented for illustration purposes only, it is not possible to draw any conclusions about the performance of Superpave. For a full analysis many more projects would be needed, each one with more complete data about traffic loading, actual thickness, existing pavement condition (pavement layers, subgrade, etc.), environmental conditions, etc.

9. PHASE 2 – PATHFINDER STUDY IN MARYLAND

9.1. General

The results of the study described in the previous sections were presented and discussed during a project review meeting with several FHWA representatives on February 21, 2001 in Washington DC. Notes of that meeting are given in Appendix E. A preliminary report "Use of PMS Data for Performance Monitoring with Superpave as an Example, Phase 1" was submitted to FHWA on May 30, 2001.

On August 21, 2001, TRDI received a Purchase Order to extend the study with the following statement of work:

> *"Additional data elements for measuring pavement performance have been identified by TRDI and recommended to be linked with the pavement management database. Based on this recommendation, TRDI will return to Maryland and take information that is currently in flat files or any other inappropriate form and put it in electronic format. TRDI will then electronically link the databases (i.e. materials, PMS, construction, and quality control) in such a way that engineers can readily access the data from all the databases for the purpose of analyzing pavement performance at the network level for long enough periods of time so it can cover a complete life cycle.*
>
> *Specifically, TRDI will return to Maryland to take data needed to track the performance of Superpave projects and move from flat files to an electronic format and then link the databases (materials, construction, QC and pavement management) as an example to show the states how this should be done. Only one state, Maryland, will be revisited and a report written to document the process".*

On August 27 and 28, 2001, the Project Team met with representatives of Maryland SHA to discuss the following:

1. Database to be used for linking performance/materials properties/construction details (mix design and testing, construction, performance, maintenance)
2. Amount of Data Transfer for Path Finder Study (period, types & number of projects)
3. Format of electronic database (AASHTO Superpave, Excel, Web-site)
4. Process of Data Linking (including analysis and reports)
5. Efficiency and Reliability of Data Collection, Transfer and Linking process (how much time and how much detail are needed)
6. Example(s) of actual analysis of Superpave performance (in final report)
7. Actual staff arrangements

A report about this meeting can be found in Appendix G-1.

On October 29, 2001, members of the Project Team had a follow-up meeting with representatives of the Office of Materials and Technology of the State Highway Administration of Maryland (MDSHA) at their office in Maryland. The following points were discussed:

1. The progress made so far in identifying data needed for analysis and evaluation purposes of materials and construction techniques, and the selection of data that are considered important for the project.
2. The progress made by Maryland SHA in using the web site approach for SMA mixes in cooperation with the University of Washington.
3. Agreement on action points.

MDSHA prepared a list with proposed data fields, data availability and comments for QC/QA data, Mix design information, Pavement design information, and Pavement Management data, together with a suggested list of reports that should cover the effects of various parameters on rutting, reflective cracking, ride quality and cracking. The Project Team proposed to add a few data fields in the areas of existing pavement structure, mix temperatures during spreading and compaction, performance data of laboratory- and actual mixes, and date when pavement section is opened to traffic. More detailed Notes about this meeting are given in Appendix G-2.

The PMS does not yet contain data on maintenance, but it was agreed that the linking system should provide for the inclusion of maintenance activities in the future.

The recommended data fields are given in Table 2, and Table 3 lists the types of analysis and evaluation that would be desirable.

Table 2 Recommended Data Fields to Include in Pilot Study

Key to Data Type Column: E=Electronic, PF=Project File (paper), N/A=Not available

Data Field	**Data Type**	**QC/QA**	**Mix Design**	**Pavem. Design**	**PMS**
AADT	E				√
Aggregate Consensus Properties	PF		√		
Aggregate Source	PF		√		
Aggregate Type	PF		√		
Ambient Temperature	PF	√			
Asphalt Content	E	√	√		
Asphalt Producer	E	√			
Binder Test Results	E		√		
Binder Type	E		√		
Compaction Level (N Design)	E		√		
Cracking Condition	E				√
Cumulative ESALs	PF			√	
Daily Paving Location (location of lots)	PF	√			
Date when pavement section was opened to traffic	N/A				
Density (field compaction) from cores & nuc gauge	E	√			
Density at N Max	PF		√		

Design Constraints	PF			√	
Design Life	PF			√	
Existing pavement layer thicknesses	PF			√	
Friction Condition	E				√
Gradation	E	√	√	√	
HMA Unit Price	PF	√			
Layer Type	E				✔
Load Spectra	N/A			√	
Location of Project	E				√
Longitudinal Joint Condition	N/A				√
Max Gravity	E	√	√		
Milling/Grinding Recommended	PF			√	
Mix Design Number	E	√			
Mix Pay Factor	E	√			
Mix Temperature prior to compaction	PF	√			
Mix Temperature after compaction	PF	√			
Mix Type	E		√		
No and Type of Layers Recommended	PF			√	
Patching Recommended	PF			√	
Pavement Type	E				√
Paver Type	PF	√			
Paving Contractor Name	PF	√			
Paving Time of Day (Day or Night)	PF	√			
Performance Test Results	N/A	√	√		
Pictures	N/A	√			
Pre-overlay Condition	PF			√	
QA Sample Location	PF	√			
RAP Quality	PF		√		
RAP Quantity	E		√		
Rating of Joint Construction	N/A	√			
Rating of Segregation	N/A	√			
Raveling Condition	N/A				√
Reflective Cracking Condition	N/A				√
Ride (profilograph results, profiler results in 2002)	PF	√			
Ride Condition	E				√
Ride Pay Factor	PF	√			
Rolling Pattern	N/A	√			
Rutting Condition	E				√
Section (open or closed, manholes, entrances)	PF			√	
Soil Strength	PF				√
Soil Type	E				√
Special Features (joint tape, saw seal, etc.)	PF	√			
Structural Capacity	PF				√
T-283	PF		√		
Thickness of new layer(s)	N/A	√			
Tonnage	PF	√			
Transfer Device (Y/N)	PF	√			
Type of Improvement Designed	PF			√	
Type of Rollers	PF	√			
Volumetrics	E	√	√		
Weather Conditions	PF	√			
Wedge and Level Recommended	PF			√	
Why Binder was Bumped	PF				√

Table 3. Analysis and Evaluation Reports

<table>
<tr>
<td>Effect of the following items on Rutting:
Mix Type (gradation and compaction level)
Fine Aggregate Angularity
As Built Density
Asphalt Content
Percent Passing #200 Sieve
Cumulative ESALs
Condition and Structure of Existing Pavement
Thickness</td>
<td>Effect of the following items on ride quality
Constructed Ride Quality
Use of Material Transfer Device
Condition of Underlying Pavement (ride and distress)
Mix Type (gradation and compaction level)
Reflective Cracking
Day or Night Paving</td>
</tr>
<tr>
<td>Effect of the following items on reflective cracking
Binder Type and Grade (use of polymer)
Type of Patch at Joint
Special Features (joint tape, etc.)
Thickness of Overlay
Asphalt Content
Condition of Underlying Pavement (load transfer%)</td>
<td>Effect of the following items on cracking
Constructed Density
Binder Type and Grade
Thickness of Overlay
Asphalt Content
Condition of Underlying Pavement
Mix Type (gradation and compaction level)</td>
</tr>
</table>

9.2. Collecting Data and Conversion to Electronic Format

In Maryland only the Superpave projects designed after June 1999 have sufficient data to make the performance analysis meaningful. MDSHA therefore selected 7 Superpave projects carried out since 1999, and made an effort to collect all available data listed in Table 2 from their QA/QC, Mix design, Pavement design and Pavement management records, and to import these data into an electronic database. Apart from the data that were not available (N/A in Table 2) they were unable to retrieve data on Aggregate Properties and on Binder Test Results. Other data, mostly those in paper files, were hard to retrieve. An overview of the sources of data and the difficulty to retrieve them, is given in Table 4. More details are given in Appendix G–4.6. For the seven Superpave projects it took 2 staff members about 4 weeks working full time to retrieve the data and to enter them into an electronic database. They used an Access database about 45 MB in size. Electronic data storage will in the future improve this process and speed it up considerably.

Table 4. Degree of difficulty in collecting the data listed in Table 2

SUBJECT	SOURCE	DIFFICULTY TO RETRIEVE
Inventory Information	Design & Constr. Proj.Files	Medium
Daily Paving Information	Construction Project Files	Hard
Project Paving Information	Construction Project Files	Hard
Density QC and QA	QC/QA Database	Medium
Mix Design	QC/QA Database	Easy
Mix QC and QA	QC/QA Database	Easy
Aggregate Properties	MD AASHTOware Program	Unable
Binder Test Results	MD Binder Database	Unable
Ride QC and QA	Construction Project Files	Hard
Pavement Design&Recommend.	MD Pavement Design Files	Medium
Pavement Management Data	MD PMS Database	Easy (no cracking data yet)
Pre-Overlay Pavement Condition	MD Pavement Design Files	Medium
Pre-Overlay Pavement Layers	MD Construction History DB	Easy
Project Condition Ratings	None	Hard (collected in the field)
Pictures	None (not currently stored)	Hard

9.3. Setting up Database in modified UW Web-site System

As mentioned in Section 8.6. the University of Washington (UW), in cooperation with Washington State DOT and NCAT, recently developed a fully integrated website that contains relevant data of Superpave contracts, including performance data [White 02]. This new development was possible because nearly all essential data on materials and construction are available electronically. In addition a major effort has been made to link these data to performance measurements from WSDOT's Pavement Management System (PMS). The data is available on a website (see Appendix F) from which they can be easily organized, downloaded and analyzed.

In the initial phase of the study the Project Team considered the use of a modified version of the QC/QA module of the Superpave/AASHTOware data set [AASHTO 00] for collecting and storing the required Superpave data. After further review and knowledge of the University of Washington system, two reasons emerged to support why it proposed to use the web based system developed by UW for the Maryland Database with Superpave projects:

1. AASHTO recently decided to stop promoting and servicing their Superpave/AASHTOware data set package.
2. Several of the data fields listed in Table 2 are not included in this AASHTOware package.

Dr. Joe Mahoney and Mr. George White of the Civil & Environmental Engineering Department of UW offered their help in making their web-site system available for the seven Superpave projects from MDSHA. In order to do this George White undertook the following:

- Modify and extend the system to:
    - Accommodate all data fields given in Table 2

  - Extend the functionality of the system to include the analyses and plots listed in Table 3.
- Checking the MDSHA database and entering the data in the web-site system.

The total effort of George White for the above mentioned activities was about one man-month. Most of this effort went into the last point, clarifying the meaning and inter-relationship of the data, getting additional data, adjusting units, converting systems, etc.

UW received most of the data from MDSHA during the first half of December, 2001. On December 18, 2001, two members of the Project Team visited UW to discuss the possibilities for a life demo of the capabilities of the UW web-site system using the Maryland data during the TRB 2002 Conference. (A visit report is given in Appendix G-3). It appeared that MDSHA had forwarded a substantial database with complete data for most of the fields. Still, for 10 fields no data were available at all, and for several other fields there were insufficient data. Consequently no analysis could be done for cracking or other distresses, for the effects of mix temperature, the influence of the use of a MTV, the influence of day or night paving, the effect of different roller patterns or roller types, or the effects of actual versus designed layer thickness. It appeared that data with exact locations of lots and sub-lots were also missing, but it was agreed for one section only to divide the lots evenly over that section so that, for demonstration purposes only, the correlation between a lot and its performance could be shown. Another limitation of the data for the seven Superpave projects is that there are only one or two years of performance data, so it is difficult to create meaningful plots of performance over time. Some of the older Superpave projects do have several years of performance (see Appendix D), but these projects have insufficient data on materials and construction.

9.4. Demonstration of Capabilities of Web-site System of UW

The final presentation of the current project took place on January 15, 2002 at the TRB Conference in Washington DC. The purpose of the meeting was to give the FHWA and representatives of industry, universities, committees and state DOTs an overview of the progress made and a demonstration of the web-based evaluation system developed by the University of Washington. Representatives of the FHWA, TRB, AASHTO, Maryland SHA, Washington State DOT, NAPA, Asphalt Institute, NCAT, Battelle and the Universities of Maryland and Washington attended the meeting.

After a welcome and introduction by Carl Monismith, Pim Visser gave an overview of the project and of the progress made so far. He described the concept of linking materials and construction data to performance and distress measurements; the possibilities in case of an ideal situation of having all required data available in electronic format, and the limitations of the current situation where many data are either not available or difficult to access. He reviewed phase 2 of the project: the Pathfinder Study carried out with data from Maryland SHA, with as two main elements the actual collection of data, and their incorporation into the web based system developed by the University of Washington (UW). See also Appendix G-4.

Pete Stephanos described the efforts of MDSHA to collect the agreed set of data. For each data category he described the source of the data, and the level of difficulty to retrieve them. See also Appendix G-4.

Joe Mahoney introduced the development and capabilities of the HMA electronic web-based database and evaluation system, used by the State Pavement Technology Consortium of Texas, Minnesota, California and Washington on an experimental basis.

George White presented a "live" demonstration of the web-based evaluation system developed by him in cooperation with WSDOT and NCAT at the University of Washington. He showed two websites:
http://hotmix.ce.washington.edu/hma/ with the recent data from MD and http://hotmix.ce.washington.edu with data from WA, TX and MI. Since many data were still missing it was difficult to show well-defined plots, however most of the desired relationships were shown and the audience got a good idea of the capabilities of the system.
It was stressed that the demo should be judged on capabilities, rather than these interim results. Additional information about the websites, together with examples of web pages, is given in Appendix F.

The animated discussion after the meeting can be summarized as follows:

- It was clear that the system is very flexible, and that it is able to accommodate the different requirements of various agencies, but that there will be a need for some degree of consistency for data and the use of these data to make broader comparisons possible. One additional advantage of the system is that the information can be refreshed and updated at any moment, so it is possible to work on the basis of the latest available information. The use of "real time" QC/QA data during construction could be very beneficial.
- The FHWA is very interested to pursue the presented concepts, for instance by assisting with a Pooled Fund study in which various states can participate, but in the short term there is a lack of funds,
- Several representatives agreed that the concept would be a very useful tool to secure required pavement performance data for use in the AASHTO 2002 Pavement Design Guide and to evaluate the performance of pavements designed with this Guide,
- Industry representatives indicated their willingness to cooperate by promoting the use of data in electronic format. They considered it advantageous to have one complete set of data that could be used by all parties,
- MDSHA, WSDOT and UW want to continue with this system, independent of the possible start of a multi-state pooled fund study, but they are hoping for some contributions in the short term from some DOTs and/or the industry,
- All participants welcomed and approved of the concept, and it was realized that it is important now to capitalize on the considerable momentum that has been built up by the current promoters of the concept. Some mechanism should be set up and

funded quickly to continue the good work, and to widen the promotion to other states.

More details about this Special Meeting can be found in Appendix G-4.

10. OTHER EXAMPLES OF USING PMS DATA IN PERFORMANCE MONITORING

In Sections 7.6, 8 and 9 examples were provided illustrating how the linking of PMS and materials and construction data could be used to evaluate specific facets of Superpave technology. It is important to note that Superpave is only one example, although an important one, of what can be done with engineering analysis of PMS and related data. It was chosen as the primary example because the increasing use of this new technology for mix design and evaluation requires that performance information be obtained to test the performance of Superpave technology and whether modifications are necessary to enhance its usefulness.

The purpose of this section is to illustrate some other examples and to briefly point out the kinds of changes or additions that would be needed to PMS data collection procedures for a particular subset of pavement sections. For asphalt concrete (AC) pavements brief examples are given here for the performance and evaluation of pavement structures and overlays designed according to the forthcoming *AASHTO 2002 Guide*, and for the performance evaluation of porous friction courses, surface treatments, and asphalt treated permeable base (ATPB). For Portland cement concrete (PCC) pavements examples are given on the effect of aggregate type, the effect of maintenance procedures such as joint sealing and the effect of load transfer devices.

It must be emphasized that the basic PMS database with good location and referencing identification is critical to all of these evaluations. However, in each case a supplementary data set is required which depends upon the details of the materials, construction, or design techniques being evaluated. Each concept requires that some detailed materials or construction data be recorded for individual test sections and in some cases it is important that a small amount of additional performance information be recorded for these same sections. No modifications are needed to the basic data structure of the PMS database. However, additional sub-files keyed to the appropriate location identification should be set up with required query functions so that routine data may be extracted from the PMS database and assembled with the individual data subsets for analysis. Likewise, the data subsets can be imported into a PMS database for overall analysis as appropriate.

10.1. AASHTO Pavement Design Guide 2002

The proposed mechanistic-empirical 2002 *Pavement Design Guide* presents a unique opportunity for the use of PMS data. New mechanistic concepts will be employed that have not been tested. Work should be done in 2001 to set up plans for a database with nationwide potential to initialize data for sections designed according to the 2002 Guide. State DOTs can be encouraged to set up the required data set and start collecting data using standard data collection protocols. In this way a broad, dependable performance database could be built.

Linking of PMS and materials and construction databases will be essential to the successful application/implementation of the AASHTO 2002 Guide for pavement design and rehabilitation. Clear records should be made of design parameters, calculation, and predicted layer thickness and material properties. These should be followed with accurate records of asphalt thickness and properties.

To evaluate the performance models on which the 2002 Guide is based will also require a detailed materials database. Some of the elements of this database are:

- Material characteristics of the various components including subgrade, determined either in the laboratory and in-situ (e.g. by back calculation from FWD measurements) or both;
- QC/QA construction data for the various layers to assess both variability and reliability of design estimates and to assess as-built properties; and
- Other as-designed records.

To verify the models in the 2002 Guide, it will be important to ensure that good traffic/load data are recorded annually. Weigh-in-motion data will be desirable but as a minimum, good load spectrum and ESAL estimates must be recorded on an annual and seasonal basis. Annual performance measures should include distress, roughness and deflection data. The type and location of maintenance activities must also be recorded.

Comparisons of estimated and measured performance both as a function of traffic and environment will permit calibration and necessary modifications to be made to the performance models, thereby improving confidence of the transportation community in the use of the 2002 Guide.

10.2. Asphalt Pavement Examples

10.2.1. Porous Friction Courses

Porous friction courses of open – graded asphalt mix have been used for the last several years as a surfacing on both asphalt and concrete payments to carryout one or more of the following functions:

- Reduce the potential of hydroplaning, and consequently minimize loss of skid resistance at higher speeds;
- Reduce tire splash and spray, thus improving visibility to the road users; and,
- Reduce vehicle noise.

These purposes are fulfilled through increased pavement macro-texture and improved contact between tires and the pavement surface under conditions of heavy traffic and rainy weather. The function of the material depends upon the open pores created remaining open so that surface water will quickly drain, permitting the tires to continually contact the aggregate. The performance of such mixes is influenced by the composition of both the aggregate and the asphalt, the aggregate gradation, and by construction practices such as compaction, thickness, etc. There is no doubt that a properly placed porous course fulfills its goals. However, there is evidence that in a short time many porous friction courses fill up with debris and lose their effectiveness under road traffic.

Typically PMS performance indicators in the database include surface distress, ride quality and skid resistance. Additional indicators would need to be incorporated to study porous friction courses to measure noise levels and surface water permeability for the affected section. These additional data factors could be appended to a subsidiary data set keyed to pavement location since they will not routinely be collected on all PMS sections.

The materials database should include the following factors as a minimum:

1. Mix design, aggregate gradation, shape, and durability characteristics, both as-designed and as-constructed;
2. Asphalt/binder type and amount, both as-designed and as-constructed;
3. Density and void information as-constructed;
4. Layer thickness as-designed and as-constructed; and preferably,
5. Permeability measurements, both laboratory determined, and as-constructed.

As little as three or four years of these data combined with PMS data could be used to evaluate performance and could lead to a determination of the benefits and actual life of such porous friction courses. It could also lead to improvements in material selection and mix design procedures as well as construction practices, which would insure the desired functional performance of this type of free draining surface course.

10.2.2. Surface Treatments and Seal Coats

This category includes spray applications of asphalt covered by a single layer of aggregate to improve surface characteristics of the pavement structure. This type of construction encompasses fog seals (asphalt alone or a softening or recycling agent), chip seals, and slurry seals. Currently in the United States, application is limited to relatively lower volume roads and to maintenance of existing pavements under low and medium traffic volumes. In other countries such as New Zealand [Seal 87], Australia [AAPA 98], and South Africa [Emery 94] many miles of single and double surface treated roads are used to carry primary rural traffic.

Surface distress such as cracking and patching in a PMS database are obliterated when the surface is covered up with a layer of asphalt and stone chips or slurry seal. This creates a discontinuity in the PMS performance data. However, roughness data remain continuous and can be used for performance evaluation. For this type of pavement it is also necessary to add aggregate loss and bleeding as additional distress factors since they are important modes of failure.

The subsidiary materials and construction database for chip seals as an example, should include:

1. Details of existing surface before application (smoothness, degree of cracking, cracking and patching, presence of bleeding, or raveling, etc.);
2. Type of treatment, single or double application, etc;
3. Asphalt/binder data – emulsion or cutback, grade, modification if incorporated in binder;
4. Aggregate data – gradation, shape, polishing tendencies, adhesion characteristics;
5. Application rates for binder (gallons/yd^2) and aggregate (lbs/yd^2);
6. Construction control data, curing time prior to traffic;
7. Environmental data (temperature, possible rain fall or humidity during construction procedures); and,
8. Laboratory test data (e.g., wheel tracking or abrasion test results).

These data should be placed in a database (subset) for surface treatments to be studied, then keyed to the PMS database by location identifier. Performance evaluation would use both the PMS and the auxiliary database and should lead to improved chip seal performance predictions. In turn this will improve materials requirements and construction practices as well as add to the understanding of traffic conditions and surface conditions under which these procedures perform acceptably.

10.2.3. Asphalt Treated Permeable Bases (ATPB)

These mixes generally consist of a uniformly-graded relatively large size aggregate and a paving grade asphalt. They are usually placed in the pavement section directly beneath the HMA surfacing to intercept water entering from the pavement surface. An alternative application is to place this permeable material near the subgrade surface to intercept water, which might enter the pavement from subsurface sources. Some evidence suggests that ATPB may not be as effective as originally envisioned when it was adopted by many state DOTs to reduce the effect of surface water infiltration on pavement performance. The reduced effectiveness may result from lack of maintenance of the necessary side drains required for proper functioning of the drainage layer and/or infiltration of fines from the untreated base and subbase layers caused by heavy traffic and lack of a suitable filter layer.

Pavement performance data linked with materials data have the potential to define the efficacy of the use of the ATPB. In addition to the usual type of performance information obtained for the PMS database, data records relative to the performance of side drains are extremely important and must be recorded.

For the materials database, mix design and construction QC/QA data are important. In addition, special design features such as the use of filter fabrics or soil filters should be recorded as well as the location of the ATPB.

10.3. Example Uses of PMS Data for PCC Pavements

PMS data can also be used for performance evaluation of PCC pavements and various design and construction characteristics [Dossey 94, McCullough 95]. In most state DOTs PCC pavements make up a small but very important portion of the pavement network. For purposes of evaluation, a separate PCC PMS data set may be desirable and is often maintained because design factors, distress types, and maintenance methods are different from A/C pavements.

10.3.1. Continuously Reinforced Concrete Pavements

The first example relates to the performance of continuously reinforced concrete pavements (CRCP). Many states have banned the use of CRCP but the poor performance blamed for this situation may be due more to bad construction than to the pavement type itself. A nationwide study of PMS data might clarify this situation.

For this study, it would be necessary to pull PMS data records of pavement sections by pavement type and to identify CRCP sections and examine their performance life. Construction records would then need to be obtained for all performing sections for analysis and comparison. TXDOT, as one example, already has set up a performance analysis database, which is maintained for concrete pavements. Other state DOTs could do the same.

10.3.2. Effect of Aggregate Type

Based on work done in Texas [Dossey 94, McCullough 95] it is now widely believed that aggregate type and its coefficient of expansion can have a major effect on concrete pavement distress and performance. In Texas, pavement built with siliceous gravel aggregates show earlier failure than those with limestone aggregates.

In this study it would be necessary to examine the PMS database and define aggregate in some way perhaps by coring for direct observations. A direct comparison could then be made of pavement serviceability and distress history as a function of aggregate type and other variables [Hankins 91].

10.3.3. Other Concrete Pavement Studies

Many other concrete pavement studies could also be made using the PMS database. The effect of joint and crack sealing could be examined by studying recorded maintenance history versus PMS distress history. The effect of load transfer could be examined by comparing roughness history for pavements with and without dowels or CTB bases.

Retrofitting of existing un-dowelled, plain, jointed concrete pavements with dowels (dowel-bar retrofit) is now underway in a number of states. The effectiveness of this technique on pavement performance can be accomplished in those states, e.g. Washington, with well established PMS databases.

These are just a few examples of the many possibilities to use this methodology. Apart from monitoring various materials for structural and functional treatments one might also consider the following categories:

- Different construction techniques for laying, compacting, recycling, etc.
- Different types of contracts with incentives, warranties, etc.
- Maintenance techniques, including preventive maintenance.

11. CONCLUSIONS, FINDINGS AND RECOMMENDATIONS

This section summarizes project findings, conclusions, and recommendations. The project was initiated with a team balanced in its understanding and experience in pavement management, the Superpave Design System, and interaction with AASHTO and state DOTs. An early meeting was held with the sponsors to discuss the various aspects of the project. As a result of this meeting a work plan was laid out and the states of Maryland, Indiana, Florida, Arizona and Washington were selected for visits. These states were selected because of their experience with pavement management and with Superpave.

The Project Team reported their findings to the FHWA, and as a result of this the project was extended with a Pathfinder Study in which Maryland SHA was asked to participate. This study was intended to serve as an example of how a DOT could identify and collect required data on Superpave and how much effort would be needed to enter these into one or more electronic database. As a next step these databases were loaded into a suitable "database" for storage, inspection, linking, analysis and reporting purposes. In this case, use was made successfully of a recently developed website of the University of Washington.

As a result of these visits, activities, analysis and interaction among the staff and sponsors, the following conclusions have been derived.

11.1 Conclusions

1. These project activities show that it is possible for state DOTs to assemble a database or a data warehouse that can be used to evaluate Superpave performance, other design, and new materials concepts. The emphasis in this project was not to completely evaluate Superpave, but to determine the feasibility of the concept and its applicability among several states.

2. Washington State DOT has, in collaboration with The University of Washington, developed an approach whereby relevant data for Superpave contracts are made available on a website. The performance, design and construction data can be organized, downloaded and analyzed. This new development was possible because nearly all their data on materials and construction are now available in electronic format (mostly Excel files), and in addition a major effort has been made to link these data to performance measurements from their PMS. The project is still in a test phase, but it looks promising, because it could be easily extended to other materials and techniques. For this project, and for the Pathfinder Study in particular, successful use was made of this new methodology, with the help of data supplied by Maryland SHA.

3. A major advantage of the website approach is that all data are available to all users as soon as they are entered. When the proper equipment for electronic data entry is

used in the field, it is possible to monitor construction projects instantly with “real time” QC/QA data which could be very beneficial.

4. The Pathfinder study has shown that the collection of relevant data in materials and construction files, required for linking with performance data, can be cumbersome and time consuming. In Maryland it took two man-months to collect data for 7 Superpave projects, and even then not all required data could be found and entered.

5. All relevant data should ideally be put into electronic format from the start, but there is also a need for a proper and unbiased definition of those data before they can be used in a linking exercise.

6. The many details and variables involved in a new broad-based approach such as Superpave requires recording detailed data on design, construction, and performance data for several individual projects for comparison. These details are beyond normal pavement management data activities, but can be added as a supplement and the results are well worth the effort. As the data are extended over five - ten years, analysis results and updates to the performance models can be substantial and the results highly beneficial.

7. The key to linking databases for performance, materials and construction is to have precise common location identification and date/time information. Only in this way can it be assured that the data are comparable. Unambiguous locations can be provided by GPS measurements and these are relatively economical at the present time. However, they must be tied to traditional location identification information such as project number, mile point, lane, direction, date, etc.

8. The best approach to using pavement management and related data to evaluate new design and material concepts such as Superpave, will involve several states setting up databases with the required detailed data and combining their efforts to make the necessary performance evaluations with a team of 5-25 states. This will require coordination among states, with possible FHWA and/or AASHTO support.

9. This review of information data, and support from these five state DOTs, suggests that an extended effort among several states in the field of evaluation of new concepts such as Superpave is warranted. In the specific case of Superpave more than $100 million has been expended to date and the comparison of actual to projected performance using the new specifications and methods essential to state DOTs to prove the concepts.

10. Preparation of a good conceptual work plan for evaluating new concepts using PMS data and such tools as standard Pavement Evaluation Protocols will be useful information for state DOTs to encourage them to set-up appropriate evaluation databases and procedures for any new pavement concept they undertake.

11. The approach examined in this project for evaluation Superpave is warranted for other new concepts and a project should be set up to outline a methodology for state DOT use.

11.2 Findings

The results of this project and the interaction with the five state DOTs supports the following findings:

1. All state DOTs contacted during this project showed a strong interest in using their pavement management data combined with materials and construction data to evaluate new concepts such as Superpave.
2. All five state DOTs visited in this project had adequate PMS data that can be used for a proposed Superpave evaluation.
3. At the present time, most of the states visited don't have an appropriate electronic format for other required materials and construction data needed for the evaluation analysis. However, these states have the data available in field files, which could be converted to electronic format with appropriate time and manpower effort. Most data required for proper analysis are available with the notable exception of the actually applied layer thickness.
4. Of the five state DOTs visited, only WSDOT and MDSHA currently have direct linkages between their materials & construction data and their PMS database for a number of Superpave projects. In every case the available personnel who could link these databases were submerged in their other duties. In some cases personnel cutbacks have limited the state's ability to do the necessary work and to assemble the necessary data. WSDOT and MDSHA were only able to utilize the website approach through the active participation and enthusiasm of staff at The University of Washington.
5. None of the states visited have precise unambiguous location identification and date/time information for their performance, materials and construction data. Performance data are only indicated with the year of the measurements so that it is not known if a major rehab during that year took place before or after the date of the measurements. The performance data in PMS are reported either as an average for an entire mile, or as an average for every tenth of a mile, and for a multi-lane road normally only the right lane is measured. In the construction files records are kept for materials, mix composition, density, etc; these data are linked to (a) certain charge(s) and lot(s) on the road, but it is not recorded where these lots are situated. Another difficulty in relating performance to location is the fact that many QC data are carried out randomly.
6. A review of possible data sources and formats shows that the web-based system developed by the University of Washington or a similar system, could be used to store, link and analyze all data needed for a Superpave evaluation.
7. All state DOTs have limited personnel in their PMS sections and generally the materials personnel are heavily involved in the design, supervision, QC/QA,

and/or laboratory testing of materials. In all cases, these personnel are capable of doing the necessary data collection, but their workload at the present time does not permit it. PMS personnel in general are also fully occupied with other duties.

8. All state DOTs visited in this project have an interest and a good potential for assembling the data needed for performance analysis of Superpave projects.
9. A well-designed, flexible, operational PMS, and electronic databases for materials and construction, are key elements in setting up operational performance analysis such as examined in this project. In cases of detailed evaluation of aspects of Superpave and/or other complex materials and design concepts, it may be necessary to set up extended PMS subfiles with additional performance measures such as detailed crack type in addition to a crack index typically currently used.

11.3 Recommendations

Based on the conclusions and findings of this study and discussions with the sponsors and the five state DOTs visited, the following recommendations are offered:

1. It is recommended that FHWA or some other oversight agency explore and undertake a more detailed effort to outline a generic database, which could be applied to develop a nationwide Superpave dataset. This dataset for 5 to 25 states would have broad capabilities for use in analysis of performance for various aspects of Superpave and other pavement concepts and materials.
2. The pavement evaluation and measurement protocols previously developed under FHWA auspices (and currently being reviewed for adoption by AASHTO) would provide excellent tools for use in data collection for performance evaluation.
3. State DOTs should be encouraged to strengthen their PMS analysis capabilities either with in-house staff or through consultants to use PMS data for engineering analysis. In some cases they should expand their PMS data collection in various subsystems to provide more detailed engineering information.
4. It is recommended that collection of data in electronic format be adopted by state DOTs as a means to assemble uniform detailed data collection and electronic storage for Superpave data for exchange and use in evaluation both within the state DOT and nationwide.
5. The main requirement for linking databases for performance, materials and construction is to use precise common location identification and date/time information. This identification must be unambiguous over time. Locators can be provided by GPS measurements that are relatively economical and easy to use at the present time. However, they must be tied to traditional location identification information such as project number, mile point, lane, direction, date, etc.

6. The integrated website approach developed by The University of Washington has great potential and warrants further consideration.
7. FHWA, AASHTO, other national agencies, Universities and the Industry should encourage the preparation of a national plan for use of PMS data for evaluation of Superpave. Each state can use pavement management and related data to evaluate Superpave, but it will be faster and more definitive if several states can work together to set up databases with the required data and combine their efforts to make the necessary performance evaluations. A multi-state effort with a group of 5 to 20 states with coordination among states, can produce a large analysis joint database of lasting value.
8. The same approach as indicated in the previous recommendation should be followed for other new materials and design concepts. It would particularly be valuable to outline a plan for future use in evaluating the proposed *2002 AASHTO Pavement Design Guide*, which is scheduled to have significant changes from past history but which has not yet been proven by field performance.
9. A number of rapid performance testers, such as the Georgia wheel tester, have been introduced for asphalt concrete surfaces. It is recommended that a database element be included in the pavement management database to store this type of data. While the ultimate goal of performance evaluation is long-term performance, it is essential to correlate rapid performance testing devices, heavy load vehicle simulators, and similar test track data into a permanent performance database.
10. It is important that data used for performance evaluation be accurately and uniformly collected. Every attempt should be made by state DOTs to continue to codify data collection standards. The data collection protocols developed under FHWA auspices is currently in the process of being finalized by AASHTO and should be adopted for this purpose as soon as practical.
11. It is simply good business practice to collect, process, store, retrieve, and analyze data from pavement management and related systems to evaluate new materials concepts, techniques and designs. This is clearly illustrated in this study and by many of the references cited in this report.

12. REFERENCES

[Anderson 82] "Design of Experiments for Industrial Engineers", Chapter XIII, Handbook of Industrial Engineering, John Wiley & sons, INC, NY, 1982.

[AAPA 98] "Sprayed Seal Basics", Information Booklet 1B-8, Australian Asphalt Pavement Association, Melbourne, Australia, 1998.

[AASHTO 99a] "Standard Specification for Superpave Volumetric Mix Design", AASHTO Designation MP 2-99, 1999.

[AASHTO 99b] "Standard Practice for Superpave Volumetric Design for HMA", AASHTO Designation PP 28-99, 1999.

[AASHTO 99c] "AASHTO Provisional Standards", AASHTO, Washington, DC, 1999.

[AASHTO 00] "AASHTO Superpave, An AASHTO ROADWare™ Family Product," AASHTO 2000 Software Release 2.1.2, August 5, 2000.

[Cominsky 94] Cominsky, R.J., G.A. Huber, T.W. Kennedy, and M. Anderson, "The Superpave Mix Design Manual for New Construction and Overlays," Strategic Highway Research Program, Report no. SHRP-A-407, Washington D.C., 1994.

[Dossey 94] Dossey, T., B.F. McCullough, and A. Dumas, "Effects of Aggregate Blends on the Properties of Portland Cement Concrete Pavements" Research Report 1244-8, Center for Transportation Research, The University of Texas at Austin, 1994.

[Emery 94] Emery, S.J., G.D. van Zijl, and R.M. vos, "Bituminous Surfacings for Low Volume Roads in Developing Areas", Proceedings, Vol. I, Conference on Asphalt Pavements for Southern Africa, Cape Town, SA, October 1994, pp II-75 to II-91.

[Falls 94] Falls, L.C., S. Khalil, W.R. Hudson, and R. Haas, "Long-Term Cost-Benefit Analysis of Pavement Management System Implementation," Third International Conference on Managing Pavements, Conference Proceedings 1, San Antonio, Texas, 1994, pp. 133-138.

[FHWA 97] "Development and Implementation of Pavement Performance Data Collection Protocols," FHWA contract no. DTFH61-95-C-00019, Final Report prepared by TRDI, May 1997.

[Haas 78] Haas, R.C.G., and W.R. Hudson, *Pavement Management Systems*, Krieger Publishing Company, Melbourne, Florida, 1978.

[Haas 91] Haas, Ralph: "Generically Based Data Needs and Priorities for Pavement Management," ASTM STP 1121, 1991.

[Haas 94] Haas, R., W.R. Hudson, and J.P. Zaniewski, *Modern Pavement Management*, Krieger Press, Malamar, Florida, 1994.

[Hankins 91] Hankins, K., Y.C. Suh, and B.F. McCullough, "Field Evaluations for Coarse Aggregate Types: Criteria for Test Sections," Research Report

1244-1, Center for Transportation Research, The University of Texas at Austin, 1991.

[Hudson 68a] Hudson, W. R., F. N. Finn, B.F. McCullough, K. Nair, and B.A. Vallerga, "Systems Approach to Pavement Systems Formulation, Performance Definition and Materials Characterization," Final Report, NCHRP Project 1-10, Materials Research and Development, Inc., March 1968.

[Hudson 68b] Hudson, W.R. and B.F. McCullough, "Translating AASHO Road Test Findings – Basic Properties of Pavement Components. Systems Formulation: Development of SAMP – An Operational Pavement Design System," Final Report, NCHRP Project 1-10, 1968.

[Hudson 94] Hudson, S.W., and W.R. Hudson, "Pavement Management Leads the Way for Overall Infrastructure Management," Transportation Research Board's Third International Conference on Managing Pavements, San Antonio, Texas, May 21-26, 1994.

[Hudson 98] Hudson, W.R., P. Visser, and L.O. Moser, "Benefit – Cost of Pavement Management in Arizona," TRDI project, Austin, Texas, December 1998.

[Hudson 99] Hudson, W.R., S.W. Hudson, W. Visser, and L.O. Moser, "Benefits Of Arizona DOT Pavement Management System After 16 Years Experience", Paper for CAPSA, South Africa, 1999.

[Hudson 01] Hudson, W.R., Hudson, S.W., Visser, W., , and Anderson, V., "Measurable Benefits Obtained from Pavement Management", paper presented at the Fifth International Conference on Managing Pavements, Seattle, Washington, 2001.

[Kennedy 94] Kennedy, T.W., G.A. Huber, E.T. Harrigan, R.J. Cominsky, C.S. Hughes, H. Von Quintus, and J.S. Moulthrop, "Superior Performing Asphalt Pavements (Superpave): The Product of the SHRP Asphalt Research Program," Strategic Highway Research Program, report no. SHRP-A-410, Washington D.C., 1994.

[Kulkarni 82] Kulkarni, R., K. Golabi, F. Finn, E. Alviti, L. Nazareth and G. Way, "Development of a Pavement Management system for the Arizona Department of Transportation," Fifth International Conference on the Structural Design of Asphalt Pavements, Volume II Proceedings, The Netherlands, August 1982.

[McCullough 95] McCullough, B.F., D.G. Zollinger, and T. Dossey, “Effect of Aggregate on Pavement Performance”, Research Report 1244-13F, Center for Transportation Research, The University of Texas at Austin, 1995.

[Opiela 97] Opiela, Kenneth S., “A Generic Data Model for Linear Referencing Systems,” Transportation Research Board, *Research Results Digest*, Number 218, (Findings of NCHRP Project 20-27(2)), September 1997.

[Ostle 74] Ostle, Bernard, “Statistics in Research”, The Iowa State University Press, 1974.

[Seal 87] “Seal Design Manual”, Ministry of Works and Development, Wellington, New Zealand, 1987.

[Siegel 90] Siegel, Andrew F., “Practical Business Statistics with StatPad”, Library of Congress Cataloging-in-Publication Data, 1990

[TRDF 94] “A Summary of Pavement Performance Data Collection and Processing Methods Used by State DOTs”, Final Report submitted to FHWA by TRDF, October 1994.

[TRDI 97] Texas Research and Development Inc., “Visual Modeler User’s Manual”, 1997.

[TRDI 00] Texas Research and Development Inc., “Pavement Management Analysis,” FHWA Demonstration Project No. 108-B, Contract DTFH61-C-00042, Participant’s Notebook, November 2000.

[White 02] White, G.C., Mahoney, J.P., Turkiyyah, G.M., Willoughby, K.A., and Brown, E.R., “Online Tools for Hot-Mix asphalt Monitoring”, paper presented at the 2002 TRB Conference.

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APPENDICES (Located in Vol. 2)

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