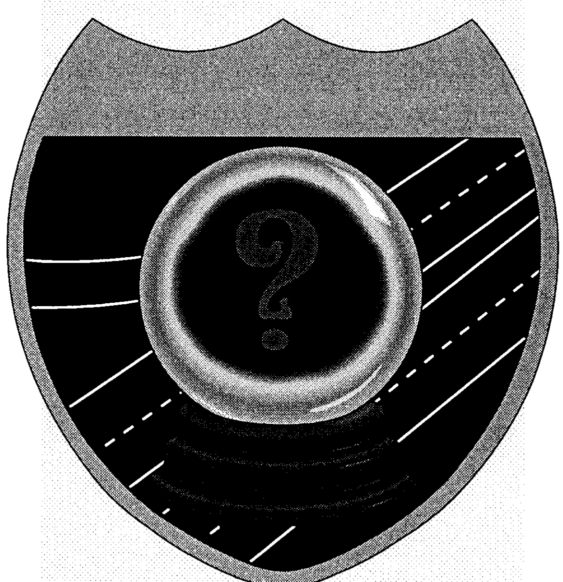
FINAL REPORT

THE DEVELOPMENT OF PERFORMANCE PREDICTION MODELS FOR VIRGINIA'S INTERSTATE HIGHWAY SYSTEM - VOLUME I: DATA BASE PREPARATION



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ABSTRACT

Performance prediction models are a key component of any well-designed pavement management system. In this study, data compiled from the condition surveys conducted annually on Virginia's pavement network were used to develop prediction models for modeling the interstate system. The study is being reported in two volumes.

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INTRODUCTION

Construction of new highways, including the interstate system, has been the primary focus of highway agencies since the 1950s. This emphasis has now changed. The nation's highway systems are basically complete, and it is not likely that future years will witness the construction of new roads.[1] The current challenge is to preserve and manage the existing system more efficiently. However, preserving and managing pavement is not a trivial task. Pavements are constantly deteriorating, and available funds for maintenance and rehabilitation are limited. This requires the adoption of strategies to make the best use of limited budgets. Pavement management systems (PMS) were developed as part of such strategies.

A PMS, as defined by the Federal Highway Administration (FHWA), is "a set of tools or methods that can assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition."[2] A properly designed PMS can save substantial funds for a state highway agency. In Arizona, for example, the state's PMS saved an estimated 40 million dollars between 1980 and 1985.[3]

Performance prediction models are a key component greatly enhancing the capabilities of a PMS. The ability to predict a pavement's future condition allows an agency to:

- predict when maintenance or rehabilitation will be needed for road sections;
- estimate the long-range funding requirements for preserving the system at a predefined condition level;
- analyze the effect of different funding levels; and
- perform life-cycle cost analyses for different strategies.[4,5]

However, the potential benefits of a PMS will always depend on its degree of sophistication and the analytical tools it possesses.

Types of Performance Prediction Models

In general, there are two types of performance prediction models, deterministic and probabilistic.[6] Deterministic models give a single value for the predicted pavement condition measure. They can either be purely empirical or mechanistic-empirical. Empirical models are developed by relating the pavement condition measure to one or more independent variables using regression analysis. For mechanistic-empirical models, the model form and the included variables are based on some theoretical knowledge of pavement behavior, and the coefficients are determined through regression.

Deterministic models can be developed to predict the structural or the functional performance of pavements. Structural performance models predict different pavement distress types or a composite index of pavement condition. Functional performance models, on the other hand, basically measure the ability of the pavement surface to serve the public in comfort and safety. The performance measures they predict include the present serviceability index (PSI), surface roughness and surface friction.

As opposed to deterministic models, probabilistic models give a range of values for the predicted measure along with their associated probabilities. They are based on the Markovian process. Since probabilistic models are based on the probability of a section moving from one condition to another, they can only be applied to network level pavement management activities. Deterministic models, on the other hand, can be used for both network and project level purposes.[7]

Data Required for Prediction Model Development

The basic requirement for any prediction model development process is an adequate and reliable data base,[8] since the models will only be as good as the data used in their development. There are two main approaches for securing the data required to develop prediction models. In the first approach, the data base is built from carefully observed and well-designed experiments. This may even entail the construction of special test tracks for model development. The AASHO Road Test in the late 1950s and the on-going SHRP/LTPP studies are typical examples of this approach, which requires enormous resources and nationwide dedication.[9]

The second approach, taken by this study, uses the existing data bases central to any state PMS. This approach is the more practical option. However, a number of challenges and problems must be resolved for model development to proceed. These problems generally fall under the following categories: (a) referencing and data base setup; (b) data quality; (c) missing structural and traffic data; and (d) a limited factor space.

Referencing and Data Base Setup

Frequently, different referencing and sectioning methods are adopted by different divisions within the same agency. For example, the beginning and ending points used to define traffic data collection sections rarely coincide with those for pavement condition surveys. This is one of the main reasons for the increased interest in using Geographic Information Systems (GIS) technology for PMS, since GIS capabilities will simplify merging the different files.[10] Until GIS technology is in place, however, model development will require algorithms and procedures to extract the required data and build a data base in an appropriate format.

Data Quality

Data obtained from a PMS database are subject to a number of potential recording and measurement errors. Human coding and keypunch errors are common. The subjective nature of pavement condition surveys and variability among raters make a true assessment of pavement condition impossible, especially if one considers that many survey methods require raters to collect data from a moving vehicle (windshield surveys). There are sometimes errors due to the failure to record major maintenance and rehabilitation efforts. A problem of that type was encountered during the development of prediction models for the North Dakota PMS.[11] In that study, unrecorded surface seals caused some sections to show an improvement in their condition over time. Any prediction model development using existing PMS data bases should be prepared for such data problems and limitations.

Missing Structural and Traffic Data

In many PMS data bases, reliable and complete information on pavement structure is not available. In a study to develop performance curves for Iowa DOT,[12] structural data were especially lacking in the non-interstate portion of the study. The same is unfortunately true with traffic data, where traffic loading information is often missing; in this study, for example.

Limited Factor Space

The *factor space* of a data base refers to the range and distribution of its variables or factors. As opposed to factorial experiments where the different levels of the factors are combined to form cells of observations, the factor space of an existing PMS data base is usually unbalanced, with the factors showing only a partial distribution.[7] The reason for such unbalanced factor space is that in-service pavements are *designed* pavements. If a high level of traffic loading is expected on a particular section, for example, adequate structural capacity will be provided to meet that level. This problem, which is sometimes referred to as the "on-the-diagonal performance problem,"[13] can lead to the exclusion of significant variables, and introduce bias in the developed models because of the limited range of the variables.[12] Extreme care is needed when attempting to model a data base of that type, as well as when extrapolating beyond the range of its data.[7]

PURPOSE AND SCOPE

In Virginia, a pavement performance model was developed by McGhee in 1984 from data collected on Interstate 81.[14] It related the pavement distress maintenance rating (DMR), which is a composite index of distress damage, to the cumulative equivalent single axle loads (ESALs). The model, however, is not currently being used, because the ESAL data upon which it was based are not now accessible from within the PMS. In addition, this model was developed when the Virginia Department of Transportation's (VDOT) pavement management system was still evolving and only limited condition data were available.

The condition surveys that have been conducted annually since the model was originally developed have resulted in a substantial amount of condition data. This information provides an opportunity to update and refine the current model. However, no serious effort has yet been made to analyze the information stored in the data base or to use it to refine the current prediction capabilities of the pavement management system.

The main objective of this research is to use such data to develop prediction models that can enhance the prediction capability of the system. The study was divided into two phases. This first phase has two objectives:

- Investigate the quality of the compiled data and identify its major problems and deficiencies.

- Develop methods and procedures to overcome some of the data problems, to make subsequent model development feasible.

The scope of the study was limited to the domain of deterministic models. The current unavailability of reliable historical roughness information in the PMS restricted the scope to the development of structural performance prediction models. Due to concerns about data quality and availability for primary roads, only Virginia's interstate highway system was considered.

METHODOLOGY

VDOT's existing PMS was first studied to identify major problems and deficiencies that challenged model development. Methods were then devised to resolve such problems and build the required data base. A number of computer programs were developed to process, merge and screen files obtained from the current system. Also, data items not accessible to the system were secured from external sources and added to the data base.

VDOT's PMS - An Overview

PMS Basic Modules

Pavement related information is currently stored in the pavement subsystem of VDOT's Highway and Traffic Records Information System (HTRIS), which is a huge mainframe data base. Data describing the different layers of the pavement structure, including information about any overlay or major maintenance activity performed, are stored in the *descriptive data module* of the system. Information on the condition of the different pavement sections in the state's network is stored in the *pavement rating module*. This information results from the condition surveys and testing procedures conducted by department personnel every year.[15]

PMS Referencing System

To locate the different sections, HTRIS uses a node-offset referencing method, where points along the highway system are identified by a node number plus an offset distance from that node. When a report is generated, the system converts the node-offset references to milepost references. The milepost referencing method resets the milepoint to zero at each maintenance jurisdiction boundary.[16]

VDOT's Current Pavement Condition Assessment Procedure

When this study was conducted, VDOT annually collected distress data on 100 percent of its interstate and primary systems. Data were collected using a windshield-type survey, where the rater rides over the pavement section to be surveyed and mentally averages the observed severity and frequency of the different distress types. These are then used to calculate the Distress Maintenance Rating (DMR) score for the surveyed section, which is a composite index reflecting the severity and frequency of the different types of distress.

The System's Sectioning Scheme

The two basic modules within the pavement subsystem use different dynamic sectioning schemes. The *descriptive data module*, which gives information about the structural layers, defines a new section whenever there is a change in the construction history. This yields sections with homogeneous structural characteristics. However, the number and length of these "construction" sections changes every year as the annual maintenance and rehabilitation activities introduce more variance into the network construction history. Eventually, this leads to a data base with a large number of short "construction" sections. Sections as short as 0.02 miles were identified during the data base compilation process.

The *pavement rating module* annually combines the short "construction" sections of the previous module to form condition survey or "DMR" sections, which are then rated during the annual surveys. To combine "construction" sections to form a "DMR" section, the sections should :

- have the same *surface* type,
- have their *surface* layers constructed at the same time, and
- have the same number of traffic lanes.

However, there is an additional requirement that the combined length of a condition survey section should not be less than 0.25 miles. The pavement management system has an algorithm to determine how to combine those sections that are shorter than the 0.25 miles, which may violate the above criteria.

Problems Challenging the Modeling Effort

VDOT's PMS sectioning scheme, and other data collection and storage attributes, posed a variety of problems that had to be addressed before the modeling effort could proceed.

1. A rated section can have significantly different underlying pavement structures, since condition survey sections are only required to have a common surface type. Consider the case of a portland cement concrete section adjacent to an asphaltic concrete (AC) section. The application of a common overlay on both sections will result in their being rated as a single section. Here two distinctly different pavement types, known to have different performance characteristics, are grouped together and assumed to have the same behavior.

2. A rated section can have different surface types constructed at different ages along its length, and still be considered one section and assigned a single condition rating, or DMR score. This is because no section can be less than 0.25 miles, leading to the grouping of significantly non-homogeneous "construction" sections. There is a practical rationale behind combining short sections. However, the alarming fact is that the current system

does not flag DMR sections combined of non-homogeneous "construction" sections. The inclusion of these sections in the analysis is likely to adversely affect the regression analysis results.

3. The rated sections change every year, from the ongoing maintenance and rehabilitation. For example, an overlay applied to only part of a section will cause it to be broken into two sections in subsequent years. In addition, the algorithm used to combine short segments together could cause slight changes in the beginning and ending points of a rated section from year to year, even if the segment was not overlaid or maintained. This is because yearly maintenance and rehabilitation activities cause the shorter sections to be recombined by the algorithm each year. The continuity in the data base is broken, and the ability to track the deterioration trends of specific road sections over the years is inhibited.

4. With all its data bases stored at the mainframe level, the pavement subsystem within HTRIS is rather "user unfriendly", with no intrinsic capability for custom data sorting or analysis.

5. The system has no on-line access for accurate traffic and classification data.

6. The system does not explicitly define whether the surveyed surface was the original surface or an overlay *at the time of the survey,* nor does it differentiate between overlaid flexible pavements and composite pavements.

7. Data within the *descriptive data module* are often incomplete. In general, detailed information can be found regarding the surface layer, but data for the sublayers are usually missing.

8. Coding errors, such as missing data from some fields and values that are obviously in error, are not uncommon.

Data Base Building Methodology Framework

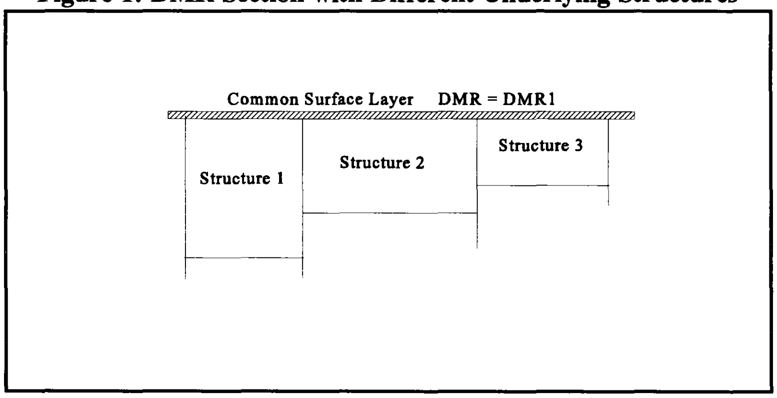
Ideally, pavement sections used in developing performance prediction models should be homogeneous with respect to attributes expected to affect the pavement condition. That is to say, their surface construction year, surface mix type, underlying structure, traffic volumes and number of lanes should all be uniform along the section length. Unfortunately, this was not the case in our situation, and a methodology was needed to address this issue.

The DMR score of a particular section represents the average condition of the whole section surveyed, since the rating team rides over the section and mentally averages the observed distress. Since the prediction models were intended to predict the pavement condition or DMR, it was decided to adopt the following basic approach:

Using the DMR section definition, other attributes affecting pavement deterioration, such as structural strength and traffic, are added to that section. The variation of these attributes along the length of the DMR section is then checked. If the variation is within acceptable limits (these acceptable limits are defined later in the report), a weighted average of that attribute is computed. If significant differences among the attribute values or among pavement types within a section are detected, the section is excluded from the analysis.

Once the DMR values are collected based on specific section definitions, it is no longer feasible to try to search for homogeneous subsections within the surveyed section, and to assume that the surveyed DMR value applies to that subsection. The pitfall in doing this is illustrated in Figure 1.

Figure 1. DMR Section with Different Underlying Structures



The figure shows a length of a pavement with a common surface, and three different underlying structures. Since it has a common surface, it is rated as a single section and given a single DMR score, DMR1. However, the three subsections have different structures, and each could be considered a homogeneous section by itself. To assume that the rate of change of the DMR value is uniform over the whole section, and assign each of these subsections the same DMR1 value despite their different structural capacity levels, would imply that the pavement condition deterioration is independent of the pavement strength. This is definitely not true.

Had the homogeneous subsections been identified before conducting the condition surveys, it would have been possible to rate these subsections independently. But once the pavement condition or DMR value is collected based on another section definition, it is no longer possible to determine what the DMR for the individual subsections might be.

With a basic approach defined, and considering the aforementioned problems, the framework for building the data base was conceived as four stages:

Task 1 : Acquire pavement condition or DMR data from HTRIS.
Task 2 : Add traffic volumes and classification data to the DMR sections.
Task 3 : Add layer data to the DMR sections.
Task 4 : Screen the data base for points to be included in the analysis.

The following sections describe the methodology's four stages and the computer programs that were developed for these tasks.

Task 1 - Acquire Pavement Condition Data from HTRIS

When this study was conducted, the condition data stored in the HTRIS *pavement rating module* corresponded to distress data collected from annual surveys conducted in 1986, 1988, 1990, 1991, 1992, 1993 and 1994. Since the system had no intrinsic capability for data merging and manipulation, the data was downloaded from the mainframe to a PC, where it could be manipulated. The downloaded data were then imported into a number of spreadsheets, using a separate spreadsheet for each district in the state. Once in a spreadsheet format, it was possible to edit and organize the data as desired. This essentially involved two steps:

1. Within each maintenance jurisdiction, records corresponding to sections whose beginning and ending mileposts remained fairly consistent between the surveyed years were grouped together, and given a unique section identification number. A new number was assigned to a section whenever it was overlaid or maintained.

2. Records were then sorted by section number as the first sort key and section age as the second. This was done so the deterioration trend of individual sections over time could be checked.

The final product of this first task was a data base giving the DMR sections and their corresponding DMR scores for each district within the state, with the exception of Lynchburg and Northern Virginia (Lynchburg has virtually no interstate mileage; no Northern Virginia distress data were available from HTRIS). Appendix A, table A-1, is a sample from a data base for one district.

Task 2 - Add Traffic Volumes and Classification Data to the DMR Sections

Since HTRIS had no access to traffic volumes and classification data, it was necessary to compile this data from external sources. VDOT annually publishes tables giving the volumes and classification counts on the state's highway system. However, the vehicle categories used to classify traffic in these tables changed over the years. In addition, the tables referenced traffic sections only by a verbal description of their beginning and ending points; no mention was made of the corresponding mileposts.

Consequently, the first step in building the traffic data base was to determine the beginning and ending milepost points defining the traffic sections. This was done by referring to the graphic logs and locating the intersections in the tables. Then traffic volumes and classification data were manually entered into a number of spreadsheets. A separate spreadsheet was used for each district and each count year. Since the vehicle categories changed over the years, it was necessary to use three categories that could be estimated for the different years: (a) passenger cars, (b) single unit trucks, (c) tractor trailer and twin trucks.

The next step was to add the data to the DMR section files. In general, the beginning and end points of the traffic and DMR sections did not match, so traffic volumes were averaged along the length of the DMR section. In averaging, traffic volumes were weighed according to the ratio of the length of the DMR section subjected to a particular traffic volume relative to the total length of the section. For example, if we had a DMR section extending between mileposts 7.0 and 12.0, with a traffic volume of 10,000 vehicles/day between mileposts 4.0 and 9.0 and 12,000 vehicles/day between 9.0 and 15.0, the weighted average volume on the DMR section would be given as:

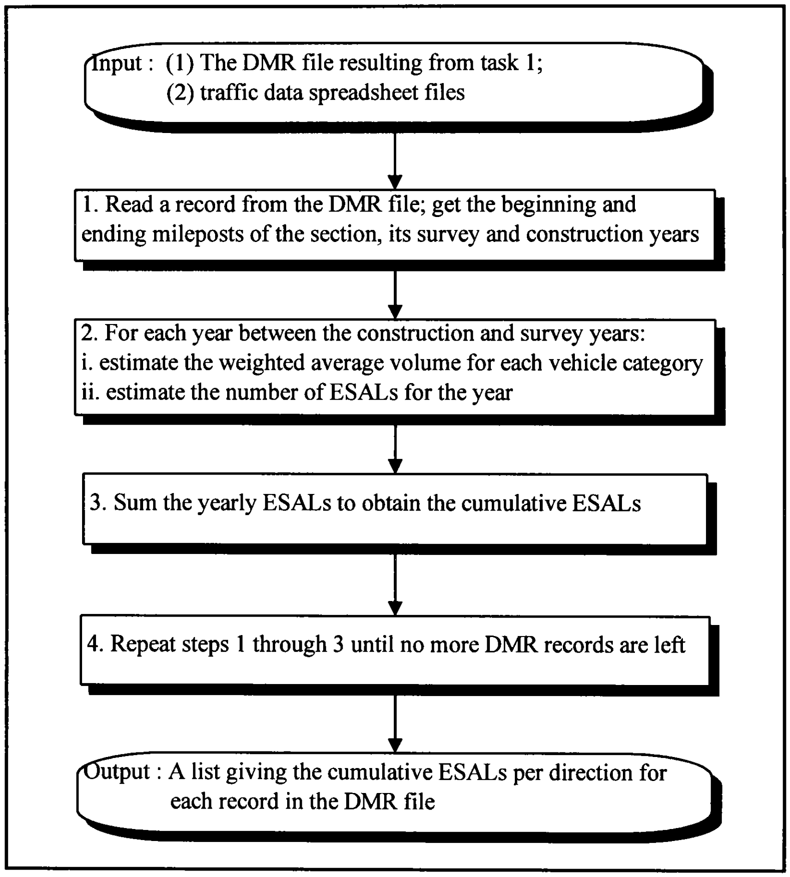
$$\frac{(9-7)}{(12-7)} .10{,}000 + \frac{(12-9)}{(12-7)} .12{,}000$$

A computer program, ***Program One***, was developed for this process. Since traffic loads are typically characterized by the cumulative number of 18-kips single axle loads (ESALs), this program also determined the number of the cumulative ESALs to which each rated section had been subjected from the time its surface was constructed to the time it was surveyed. The load equivalency factors used in estimating the ESALs, as obtained from the state's design engineer, were:

0.00 for passenger cars;
0.37 for single unit trucks;
1.28 for tractor trailers and twin trucks.

Figure 2 shows the basic tasks of this program. The output of this program was then merged with the DMR file prepared under task 1.

Figure 2. ***Program One*** **Basic Tasks**



Task 3 - Add Layer Data to the DMR Sections

Adding the layer data to the DMR sections entailed three main steps. First the layer data were downloaded from HTRIS; then the individual "construction" sections that were originally combined together to make up a DMR rating section were identified; and finally, each "construction" section was assigned to a major pavement type and the required structural parameters were estimated.

Step 1 - Data Download from HTRIS

Construction layer data stored within the *descriptive data module* of HTRIS were downloaded to the PC, and a computer program, ***Program Two***, was developed to extract the needed information from the downloaded files. This program also added the "time dimension" of the data base, an essential function explained below.

Records from the files downloaded from HTRIS gave the section's current structural layers. However, these did not always match the structure existing when the section was surveyed. To illustrate, consider the following example of an HTRIS record describing the layers of a pavement section :

Year	Mix Type	Thickness
93	L1	D1
86	L2	D2
...	...	...

However, when such section was rated, say in 1990, the top layer was actually L2 and not L1. This situation should be considered when joining the structural layer data to the DMR sections, so that only the layers that were in existence at the time of the survey are added. To achieve this, ***Program Two*** broke each record into subrecords for the individual layers and their associated construction years.

Step 2 - Identifying the "Construction" Sections Constituting Each DMR Section

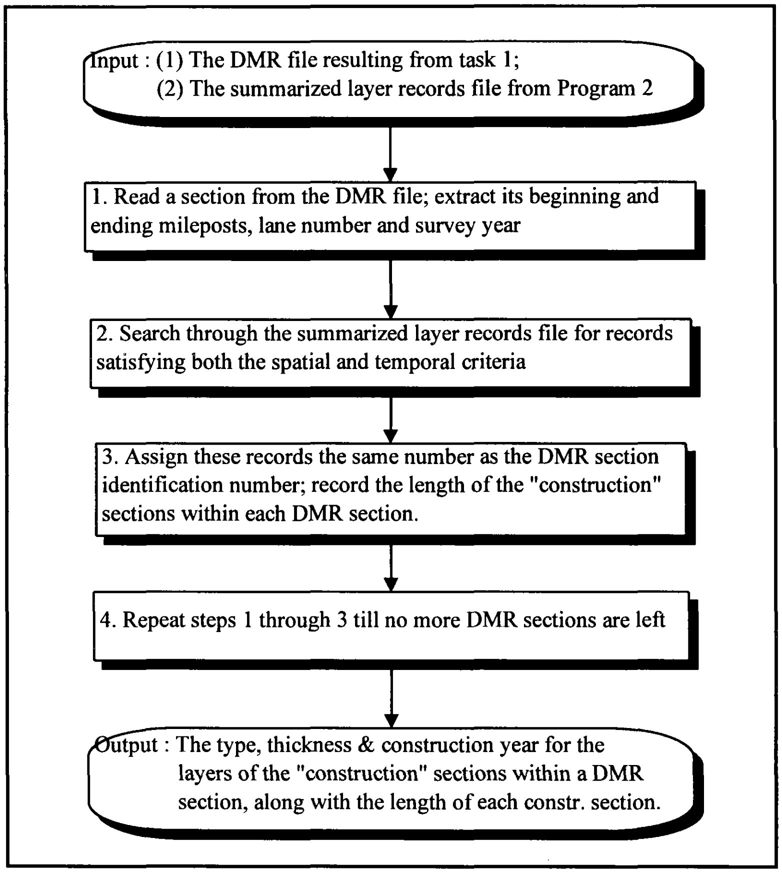
The next step was to identify the individual "construction" sections that were originally combined to make up a DMR rating section. ***Program Three***, shown in figure 3, was developed for this task. This program first accessed the DMR file to get the beginning and end points of the DMR section and the rating year. It then searched through the layer records, obtained from the output of the ***Program Two***, for records within the boundaries of the DMR section (spatial criterion), and constructed before the rating date for the DMR section (temporal criteria). These records were assigned the same identification number as the DMR section, and the length of each within the DMR section boundaries was estimated.

A cursory investigation of the ***Program Three*** output revealed an additional problem with the system. For some sections, there were discrepancies between the *descriptive data module* and the *pavement rating module* regarding the construction year and surface mix type. Such discrepancies indicate that maintenance and rehabilitation activities are sometimes recorded in one module, but not in the other. This could lead to erroneous conclusions.

Step 3 - Categorizing Pavement Sections & Estimating Structural Parameters

Classifying the surveyed sections into the major pavement types was essential for performance prediction modeling, because different types are likely to have distinct performance characteristics, and because the parameters used to characterize pavement structural capacity differ according to pavement type. For flexible pavements, for example, the structural number developed in relation to the AASHO design equations is usually used, while for composite pavements, the thickness of the asphalt overlay is typically used.

Figure 3. ***Program Three*** **Basic Tasks**



The existing management system failed to explicitly differentiate between the different pavement types. It was necessary to use the compiled layer data to classify each "construction" section. ***Program Four*** was developed for this task. This program used the output of ***Program Three*** to categorize "construction" sections into the following groups:

1. flexible pavements with no overlay;
2. flexible pavements with overlay;
3. composite pavements with one overlay;
4. composite pavements with more than one overlay; and
5. other (which includes portland cement concrete pavements, slurry seals, black seals, and latex surfaces).

In the ideal situation, assigning a section to a certain classification should be easy; for example, an overlaid section can be differentiated from a section with no overlay by simply comparing the construction year for the top layer with that for the underlying layer. In our case, however, the classification process was complicated by the following factors:

1. Incomplete sublayer data was unfortunately the usual case in the layer file. For the majority of the structural sections, information was available for just the first one or two top layers of the section, which was sometimes inadequate to decide the classification.

2. A rehabilitation activity may involve applying an overlay in more than one layer, which means that the first two layers, as recorded by the system, would have the same date. Consequently, the fact that the first 2 layers have the same construction date does not mean that the top is an original surface, especially if data about the other sublayers are missing.

3. The layer file contained some coding errors that could lead to erroneous conclusions.

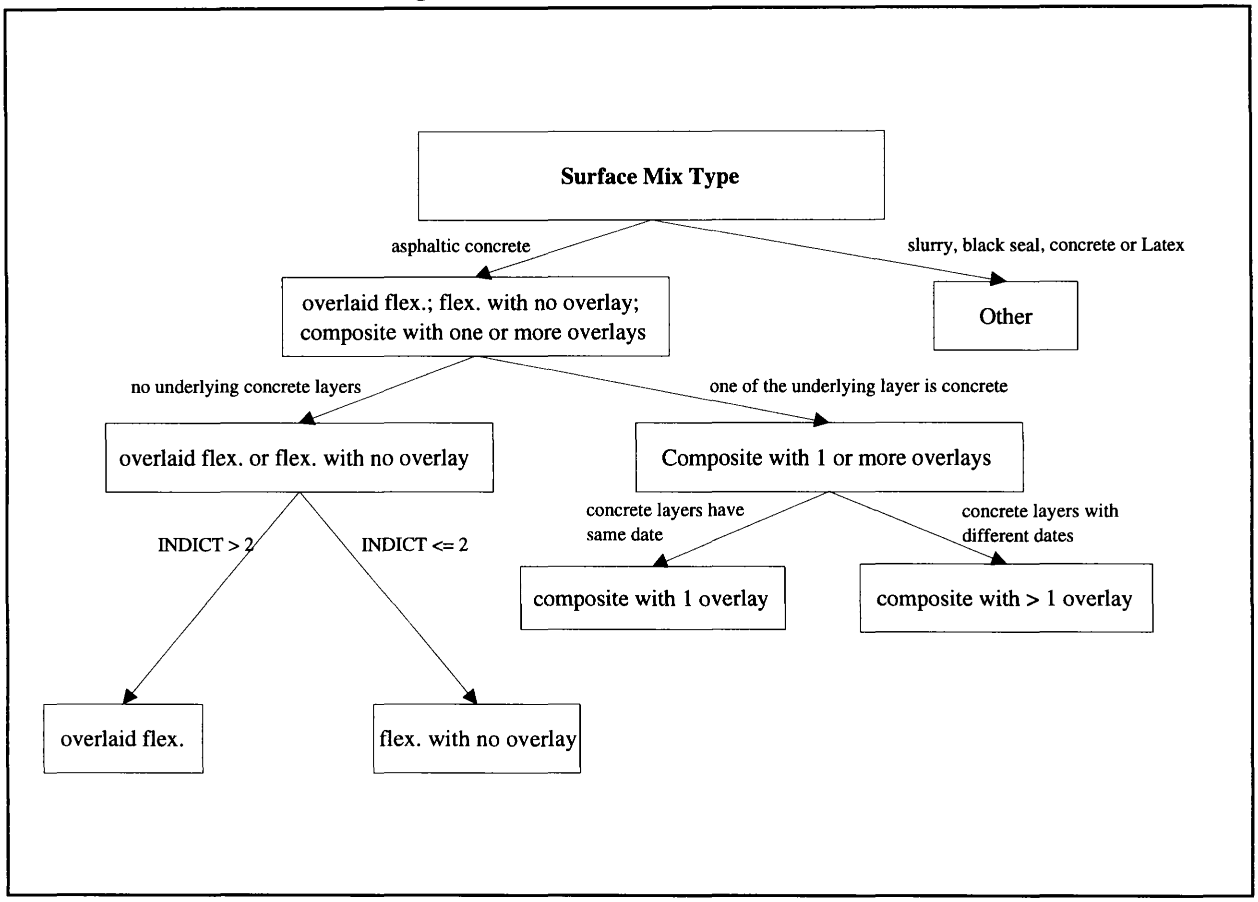
These issues had to be taken into consideration when coding the program.

The program had a series of IF-THEN classification rules. When classification was impossible because of missing data, the program returned a message of "NOT SURE", leaving the final decision to the researchers' judgement. The decision tree used by the program to arrive at a classification is shown in figure 4.

At the first level of the tree, the surface mix type was checked. This was followed by a search for any underlying portland cement concrete layer in order to distinguish between flexible and composite pavements. For a composite section, the final step was to check the construction date(s) of the asphaltic concrete layers to determine whether the section was composite with one overlay or more. For the flexible group, it was first necessary to calculate the difference between the construction year of the top layer and the construction year of any of the following layers: subgrade, subbase or aggregate base or more overlay, whichever is available. This difference (INDICT) was then used to differentiate between overlaid and non-overlaid pavements. Finally, if the available information was not sufficient to reach one of the final nodes of the decision tree,the message "NOT SURE" was returned. In such cases, reference was made once again to the graphic logs, to attempt to determine the nature of the underlying layers and decide on the section classification.

Once the classification was available, the second task of the program was to estimate the values of the appropriate parameters used to characterize the structural strength, as shown in figure 5. The parameters required differ according to the classification assigned to the section.

Figure 4. Decision Tree for Classification



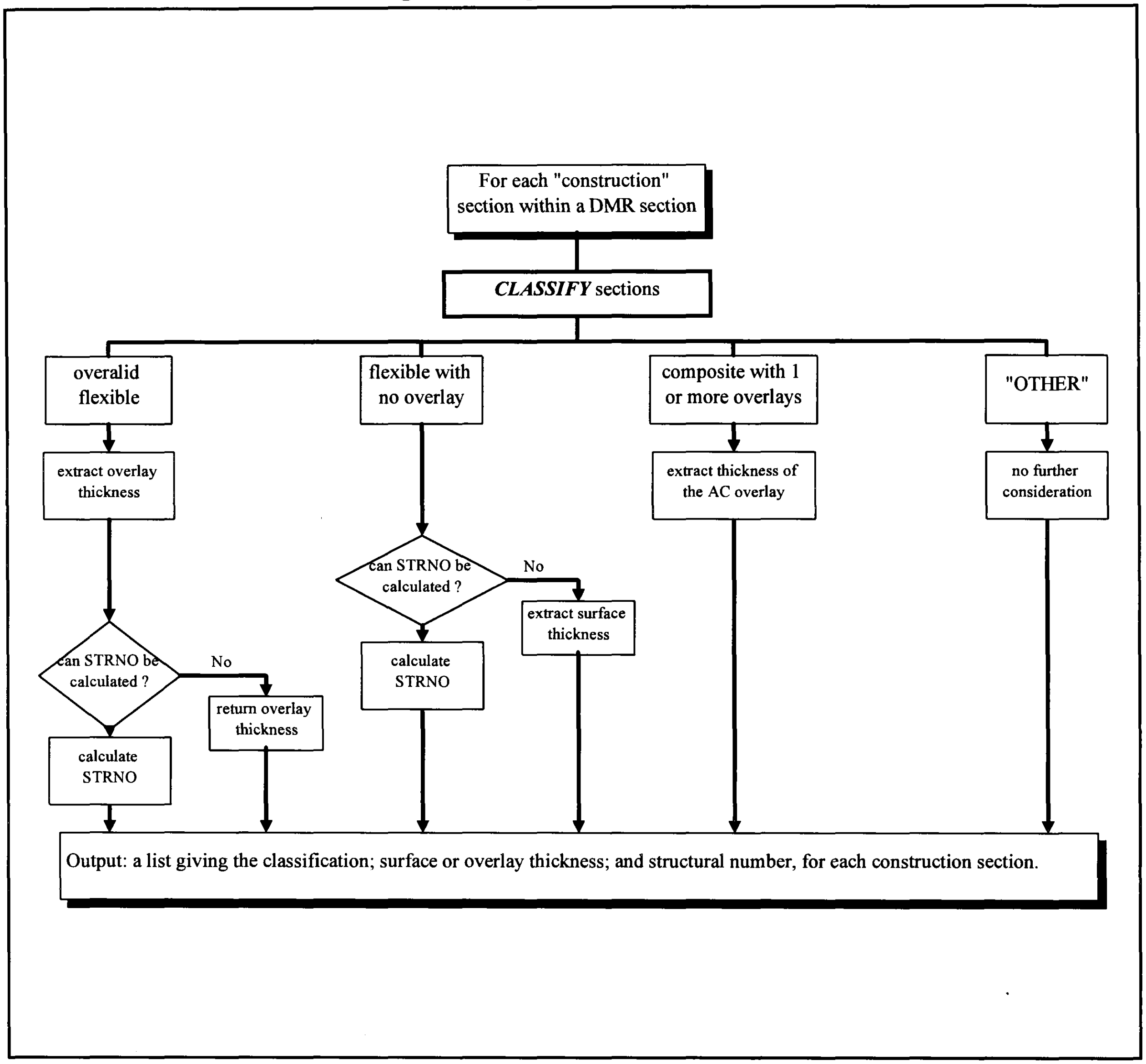
1. For flexible pavements with no overlays, the program estimated the structural number of the pavement structure. However, if the structural number could not be calculated because of missing sublayer data, the program returned the thickness of the surface layer.

2. *For overlaid flexible pavements,* the structural number and the thickness of the overlay were determined.

3. *For composite pavements,* the thickness of the last overlay was extracted.

In calculating the structural number, the layer coefficients currently used by VDOT were employed. These were 0.16 for soil cement; 0.14 for aggregate bases; and 0.40 for surface, intermediate or base asphaltic concrete layers.

Figure 5. ***Program Four*** **Basic Tasks**



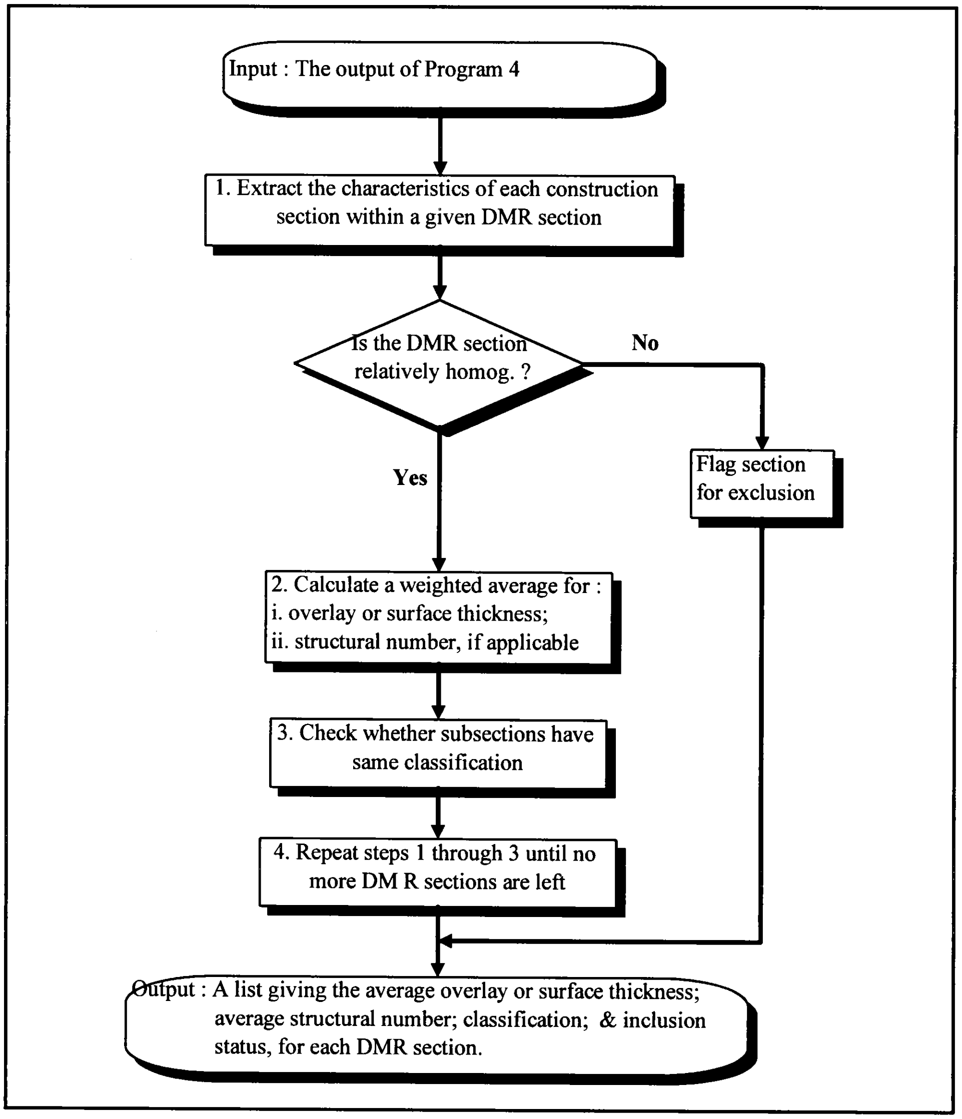
Task 4 - Screen for Points to be Included in the Analysis

This final task had two main phases. In the first phase, a computer program was developed to screen the data base for relatively homogeneous sections by comparing the characteristics of the individual "construction" sections that were combined to form a DMR section. This initial screening was then augmented by a manual screening procedure in the second phase.

Phase 1 - Screening for Relatively Homogeneous Sections

With the traffic and layer data added to the DMR sections, it was now necessary to search for the relatively homogeneous sections to be included in the analysis. ***Program Five*** (Figure 6) was developed for this task.

Figure 6. *Program Five* Basic Structure



For each of the individual "construction" sections making up a DMR section, the program first read the values for six characteristics, from the output of ***Program Four***:

1. The surface layer construction year,
2. The surface layer mix type,
3. The surface thickness,
4. The pavement classification,
5. The structural number, if applicable, and
6. The number of lanes.

At first, the program checked two basic conditions, the violation of either of which directly led the program to exclude the section from the analysis. These were:

1. *The construction years of the individual sections did not differ by more than 2 years.* This was because the section condition, structure and cumulative ESALs would all be significantly different otherwise.

2. *The number of lanes of the individual sections was the same,* since the traffic loadings were unlikely to be constant in a DMR section with a different number of lanes along its length.

If the DMR section met the above two conditions, the program considered it relatively homogeneous, and proceeded to calculate the following for that section: (a) a weighted average for the thickness of the surface layer or overlay, and (b) a weighted average for the structural number, if applicable. Averaging was done similarly to the averaging of traffic volumes.

The program also checked to see whether the individual "construction" sections had the same pavement type or classification as given by ***Program Four***. If they did not, it gave a message that non-homogeneous classification was detected, but did not directly exclude the section. The reason was that in some cases, the performance of two different pavement types may not be significantly different; for instance, a composite section with one overlay and another with more than one overlay. Therefore, the decision in such cases was left to the manual screening stage.

The output of ***Program Five*** was then merged with the DMR file, resulting in the addition of the following four new attributes to each DMR section.

1. The weighted average for the overlay or surface layer thickness,
2. The weighted average for the structural number,
3. The section's classification or pavement type, and
4. A preliminary decision regarding whether the section is to be included in the analysis.

Phase 2 - Manual Screening

Manual screening of the data base was needed to consider other factors that were difficult to capture through computer coding and required human judgement. The procedure was as follows:

1. DMR sections with different values for their construction year and mix type (reported by the *pavement rating* and *data descriptive* modules) were identified. The DMR values along with their corresponding AGE values were checked to decide which of the two reports was the more credible. If a decision could still not be made based on these values, the section was excluded from the analysis.

2. The deterioration trend of each DMR section was checked to identify sections that exhibited appreciable improvements or fluctuations in condition over time. Improvement or fluctuation is sometimes attributed to a maintenance activity performed on the section but not recorded in the data base. To include such sections would adversely affect the accuracy of the developed models. However, in order not to bias the data, sections were only excluded if the improvement was obviously the result of unrecorded maintenance or rehabilitation activity, and not merely due to the subjective nature of the condition surveys. Whenever there was a doubt, the section was kept in the data base, to be detected by the robust regression techniques in the next stage of the study.

3. Finally, the characteristics of the DMR sections, flagged by ***Program Five*** as possessing different pavement types or classification along their lengths, were examined. The final decisions regarding their regarding their inclusion in the analysis were made after examining the types involved, as well as the reasonableness of the deterioration trend of the sections. Basically, if the difference in pavement classification detected was between a composite section with one overlay and another with more than one overlay, the section was not excluded.

RESULTS AND DISCUSSION

The results of the screening process are shown in Table 1, which gives the number of observation points that were excluded from each district data set, along with the reasons behind their exclusion. The percentages of excluded observation points are rather high. These points would have very likely distorted the subsequent regression analysis results had they not been detected and removed.

Table 1. Number of Records Excluded from Analysis, and Cause of Exclusion

District	Cause for Exclusion					Total no. of points excluded	Total no. of available points prior to exclusion
	Cause A	Cause B	Cause C	Cause D	Cause E		
Bristol	48	40	8	10	21	127	673
Salem	92	5	2	18	0	117	836
Richmond	236	13	72	15	14	350	1621
Suffolk	34	15	3	2	0	54	298
Fredricksburg	103	4	0	6	0	113	287
Culpeper	13	17	0	19	0	49	158
Staunton	143	8	47	62	41	301	1277

- Cause A: The individual "construction" sections making up the DMR section have different construction years or significantly different pavement types (classification).
- Cause B: Construction sections have different number of lanes.
- Cause C: Discrepancies in construction years reported by the pavement rating and descriptive data modules that could not be resolved through checking the deterioration trend.
- Cause D: Deterioration trend indicates a rehabilitation or maintenance activity not recorded.
- Cause E: Deterioration trend suggests that the section is nonhomogeneous, but no information about the section structure is available to confirm the suspicion.

With the four tasks completed, this phase of the study was accomplished. A sample of the final data base is given in Appendix B, table B-1, along with a legend for its different fields. A computer program was then developed to randomly select a 5% sample of the available data points. This sample data set was saved as a verifying set for checking the models' accuracy once they were developed.

CONCLUSIONS

Construction of the database for developing prediction models revealed a number of problems and deficiencies in the current data collection and storage system, as listed below.

1. The current system was incapable of custom data sorting and analysis.

2. Information in the system regarding the different layers in pavement structures was often incomplete. Generally, data were available for the surface layer, not for the underlying layers.

3. The system suffered from some coding errors, including missing data from some fields and values that were obviously wrong.

4. In some cases, there were discrepancies in the construction year and surface mix type between the two basic modules of the system. This indicated that maintenance and rehabilitation activities were sometimes recorded in one module, but not in the other.

5. The system did not explicitly indicate whether the condition survey was conducted on the original surface or an overlay, nor did it differentiate between overlaid flexible pavements and composite pavements.

6. The system had no on-line access to accurate traffic and classification count data.

7. Since survey sections needed only to have a common surface, regardless of the relative homogeneity of the underlying structures, there were a number of surveyed sections with significantly different underlying pavement types and structures.

8. Since a rated section could not be less than 0.25 miles, subsections with different surface types, construction years, or number of lanes were aggregated into single sections with significantly non-homogeneous characteristics. The inclusion of these sections in a regression analysis would adversely affect the accuracy of the models.

9. The ability to track the deterioration trends of individual sections was inhibited by the fact that the condition survey sections change every year, as annual maintenance and rehabilitation activities keep introducing more variance into the network construction history.

10. In some cases, maintenance or rehabilitation activities were not recorded in the data base.

RECOMMENDATIONS

Based on the conclusions of this phase of the study, the following enhancements to the existing system are recommended:

1. The system should be capable of data manipulation and modeling. This will eliminate the need for data export, whenever any analysis is required.

2. The system should explicitly distinguish between overlaid flexible pavements and composite pavements. A field should be added to clearly indicate the type of surface (i.e. original surface or overlay) on which the survey is being conducted. The current practice of recording the overlay as a surface layer should be avoided.

3. The system needs simple checking routines to ensure that coded values are within the reasonable limits, including integrity checks that guard against discrepancies (for example, between the construction year as recorded in the condition module and the descriptive module).

4. Efforts should be made to complete the layer information, if possible, and to provide the system with access to traffic volumes and classification data. This would allow the development of more theoretically-based prediction models.

5. The system should be able to identify pavement sections that are relatively homogeneous with respect to the different variables affecting deterioration. These sections could then be specifically rated, and used for prediction model development.

6. In defining sections for condition surveys, some consideration still should be given to the relative homogeneity of the underlying structures. At least, portland cement and flexible bases should be differentiated.

7. Condition sections, made up of non-homogeneous short sections combined to meet the 0.25 miles length criterion, should be clearly flagged by the system as unsuitable for the development of prediction models.

8. All maintenance or rehabilitation activity performed on a section should be recorded.

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Appendix A

A Sample of the Pavement Condition Spreadsheet File

Table A.1 A Sample of the DMR Spreadsheet File, Prepared under Task 1

(Part 1 / 2)

SN	ROUTEID	DR	LN	BEGMP	ENDMP	LENGTH	RATEDATE	SURDATE
13	IS-00081-N	N	0	0.58	1.16	0.58	01-86	06-76
14	IS-00081-N	N	0	0.58	1.16	0.58	04-88	09-87
14	IS-00081-N	N	0	0.58	1.16	0.58	01-90	09-87
14	IS-00081-N	N	0	0.58	1.16	0.58	01-91	09-87
14	IS-00081-N	N	0	0.58	1.16	0.58	01-92	09-87
14	IS-00081-N	N	0	0.58	1.16	0.58	02-93	09-87
14	IS-00081-N	N	0	0.58	1.16	0.58	12-93	09-87
15	IS-00081-N	N	0	1.64	3.40	1.76	01-86	06-76
15	IS-00081-N	N	0	1.64	3.40	1.76	04-88	06-76
16	IS-00081-N	N	0	1.64	3.40	1.76	01-90	10-88
16	IS-00081-N	N	0	1.64	3.40	1.76	01-91	10-88
16	IS-00081-N	N	0	1.64	3.40	1.76	01-92	10-88
16	IS-00081-N	N	0	1.64	3.40	1.76	02-93	10-88
17	IS-00081-N	N	0	1.64	7.64	6.00	12-93	10-88
18	IS-00081-N	N	0	3.40	3.70	0.30	02-93	10-88
19	IS-00081-N	N	0	3.70	4.06	0.36	01-86	06-76
19	IS-00081-N	N	0	3.70	4.06	0.36	04-88	06-76
20	IS-00081-N	N	0	3.70	4.06	0.36	01-90	10-88
20	IS-00081-N	N	0	3.70	4.06	0.36	01-91	10-88
20	IS-00081-N	N	0	3.70	4.06	0.36	01-92	10-88
20	IS-00081-N	N	0	3.70	4.06	0.36	02-93	10-88
21	IS-00081-N	N	0	4.06	4.60	0.54	02-93	10-88
22	IS-00081-N	N	0	4.60	5.76	1.16	01-86	06-76
23	IS-00081-N	N	0	4.60	5.30	0.70	04-88	06-76
24	IS-00081-N	N	0	4.60	5.30	0.70	01-90	10-88
24	IS-00081-N	N	0	4.60	5.30	0.70	01-91	10-88
24	IS-00081-N	N	0	4.60	5.30	0.70	01-92	10-88
24	IS-00081-N	N	0	4.60	5.30	0.70	02-93	10-88
25	IS-00081-N	N	0	5.55	5.76	0.21	01-90	10-88
25	IS-00081-N	N	0	5.55	5.76	0.21	01-91	10-88
25	IS-00081-N	N	0	5.55	5.76	0.21	01-92	10-88
25	IS-00081-N	N	0	5.55	5.76	0.21	02-93	10-88
26	IS-00081-N	N	0	5.76	6.08	0.32	02-93	10-88
27	IS-00081-N	N	0	6.08	7.20	1.12	01-86	06-76
27	IS-00081-N	N	0	6.08	7.20	1.12	04-88	06-76

SN:	DMR section identification number
ROUTID:	Route ID
DR:	Direction
LN:	Lane number
BEGMP:	Jurisdiction beginning milepost
ENDMP:	Jurisdiction end milepost
LENGTH:	Length of the DMR section
RATEDATE:	Rating date
SURDATE:	Construction date of the surface layer

Table A.1 *(continued)*

(Part 2 / 2)

MIXTYPE	RR	BEGNODE	OFFSET	ENDNODE	OFFSET1	DMR	AGE
S-8 (Popc)	0.9	50331	0.58	50331	1.16	77	9.583
I-2 (SPM)	1.0	50331	0.58	50331	1.16	94	0.583
I-2 (SPM)	1.0	50331	0.58	50331	1.16	100	2.333
I-2 (SPM)	1.0	50331	0.58	50331	1.16	94	3.333
I-2 (SPM)	1.0	50331	0.58	50331	1.16	97	4.333
I-2 (SPM)	1.0	50331	0.58	50331	1.16	94	5.417
I-2 (SPM)	0.9	50331	0.58	50331	1.16	91	6.250
S-8 (Popc)	0.9	50331	1.64	50331	3.40	71	9.583
S-8 (Popc)	0.9	50331	1.64	50331	3.40	84	11.833
S-5	1.0	50331	1.64	50331	3.40	98	1.250
S-5	1.0	50331	1.64	50331	3.40	87	2.250
S-5	1.0	50331	1.64	50331	3.40	91	3.250
S-5	1.0	50331	1.64	50331	3.40	88	4.333
S-5	0.9	50331	1.64	136442	0.20	74	5.167
S-5	1.0	50331	3.40	50331	3.70	89	4.333
S-8 (Popc)	0.9	50331	3.70	50331	4.06	74	9.583
S-8 (Popc)	0.9	50331	3.70	50331	4.06	85	11.833
S-5	1.0	50331	3.70	50331	4.06	100	1.250
S-5	1.0	50331	3.70	50331	4.06	96	2.250
S-5	1.0	50331	3.70	50331	4.06	95	3.250
S-5	1.0	50331	3.70	50331	4.06	94	4.333
S-5	1.0	50331	4.06	50331	4.60	79	4.333
S-8 (Popc)	0.9	50331	4.60	50331	5.76	76	9.583
S-8 (Popc)	0.9	50331	4.60	50331	5.30	84	11.833
S-5	1.0	50331	4.60	50331	5.30	100	1.250
S-5	1.0	50331	4.60	50331	5.30	92	2.250
S-5	1.0	50331	4.60	50331	5.30	97	3.250
S-5	1.0	50331	4.60	50331	5.30	79	4.333
S-5	1.0	50331	5.55	50331	5.76	100	1.250
S-5	1.0	50331	5.55	50331	5.76	94	2.250
S-5	1.0	50331	5.55	50331	5.76	95	3.250
S-5	1.0	50331	5.55	50331	5.76	87	4.333
S-5	1.0	50331	5.76	50331	6.08	89	4.333
S-8 (Popc)	0.9	50331	6.08	50331	7.20	73	9.583
S-8 (Popc)	0.9	50331	6.08	50331	7.20	79	11.833

MIXTYP: Surface mix type
RR: Ride rate
BEGNODE: Beginning node
OFFSET: Offset from the beginning node
ENDNODE: End node
OFFSET1: Offset from the end node
DMR: Distress maintenance rating (DMR)
AGE: Age of the section since construction or last overlay

Appendix B

A Sample of the Final Data Base

Table B.1 A Sample of the Data Base used for Prediction Model Development :

(Part 1 / 3)

SN	ROUTID	DR	LN	BEGMP	ENDMP	LENGTH	RATEDATE	SURDATE	MIXTYPE14
	IS-00064-E	E	0	24.27	26.07	1.80	02-91	05-90	SM-2C
14	IS-00064-E	E	0	24.27	26.07	1.80	01-92	05-90	SM-2C
14	IS-00064-E	E	0	24.27	26.07	1.80	02-93	05-90	SM-2C
15	IS-00064-E	E	0	26.07	28.37	2.30	01-94	05-90	RSM-2CRu
16	IS-00064-E	E	0	28.00	35.95	7.95	02-86	07-79	S-8(Popc)
16	IS-00064-E	E	0	28.00	35.95	7.95	04-88	07-79	S-8(Popc)
16	IS-00064-E	E	0	28.00	35.95	7.95	01-90	07-79	S-8(Popc)
16	IS-00064-E	E	0	28.37	35.95	7.58	02-91	07-79	S-8(Popc)
17	IS-00064-E	E	0	28.37	30.72	2.35	01-92	07-79	S-8(Popc)
18	IS-00064-E	E	0	31.00	35.95	4.95	01-92	07-79	S-8(Popc)
19	IS-00064-E	E	0	28.37	35.95	7.58	02-93	09-92	SM-2C
19	IS-00064-E	E	0	28.37	35.95	7.58	01-94	09-92	SM-2C
20	IS-00064-E	E	0	35.95	38.30	2.35	04-88	07-80	S-8(Popc)
20	IS-00064-E	E	0	35.95	38.30	2.35	02-86	07-80	S-8(Popc)
20	IS-00064-E	E	0	35.95	38.30	2.35	01-90	07-80	S-8(Popc)
20	IS-00064-E	E	0	35.95	38.30	2.35	02-91	07-80	S-8(Popc)
20	IS-00064-E	E	0	35.95	38.30	2.35	01-92	07-80	S-8(Popc)
20	IS-00064-E	E	0	35.95	38.30	2.35	02-93	07-80	S-8(Popc)
21	IS-00064-E	E	0	35.95	38.30	2.35	01-94	10-93	SM-2C
22	IS-00064-E	E	1	24.00	24.27	0.27	01-90	09-88	I-2(SPM)
22	IS-00064-E	E	1	24.00	24.27	0.27	02-91	09-88	I-2(SPM)
22	IS-00064-E	E	1	24.00	24.27	0.27	01-92	09-88	I-2(SPM)
22	IS-00064-E	E	1	24.00	24.27	0.27	02-93	09-88	I-2(SPM)
23	IS-00064-E	E	1	26.07	28.37	2.30	01-92	05-90	RSM-2CRu
23	IS-00064-E	E	1	26.07	28.37	2.30	02-93	05-90	RSM-2CRu
24	IS-00064-E	E	1	30.72	31.00	0.28	01-92	06-91	SM-2C

SN: DMR section identification number. The numbering scheme resets itself at each maintenance jurisdiction boundary.

ROUTID: Route ID.

DR: Direction; N,S, E and W.

LN: Lane number; this field gives the number of the lane being rated with a "1" for the outer or traffic lane. In the usual case, when the roadway section is rated as a whole, a "0" is encoded.

BEGMP: DMR section beginning milepost.

ENDMP: DMR section end milepost.

LENGTH: DMR section length in miles.

RATEDATE: Rating or inspection date.

SURDATE: Construction date of the DMR section surface layer or overlay.

MIXTYPE: DMR section surface layer or overlay mix type; codes used are those adopted by HTRIS.

Table B.1 *(continued)*

(Part 2 / 3)

RR	BEGNODE	OFFSET	ENDNODE	OFFSET1	DMR	AGE	STRNO	MIXTYP2
1.0	115587	0.06	700664	1.10	100	0.750	0.00	SM-2C
1.1	115587	0.06	700664	1.10	99	1.667	0.00	SM-2C
1.1	115587	0.06	700664	1.10	98	2.750	0.00	SM-2C
1.0	700664	1.10	115591	0.45	91	3.667	4.48	RSM-2
1.0	115591	0.08	115594	0.30	87	6.583	4.29	I-2
1.0	115591	0.08	115594	0.30	83	8.750	4.29	I-2
0.9	115591	0.08	115594	0.30	87	10.500	4.29	I-2
0.9	115591	0.45	115594	0.30	83	11.583	4.29	I-2
0.9	115591	0.45	115593	0.85	91	12.500	4.28	I-2
0.9	115593	1.13	115594	0.30	88	12.500	4.28	I-2
1.1	115591	0.45	115594	0.30	100	0.417	4.28	SM-2C
1.0	115591	0.45	115594	0.30	100	1.333	4.28	SM-2C
1.0	115594	0.30	115595	2.21	88	7.750	0.00	S-8
1.0	115594	0.30	115595	2.21	85	5.583	0.00	S-8
0.9	115594	0.30	115595	2.21	84	9.500	0.00	S-8
0.9	115594	0.30	115595	2.21	83	10.583	0.00	S-8
1.0	115594	0.30	115595	2.21	88	11.500	0.00	S-8
0.9	115594	0.30	115595	2.21	82	12.583	0.00	S-8
1.0	115594	0.30	115595	2.21	100	0.250	0.00	SM-2C
1.0	115586	0.14	115587	0.06	98	1.333	0.00	I-2
1.0	115586	0.14	115587	0.06	100	2.417	0.00	I-2
1.1	115586	0.14	115587	0.06	100	3.333	0.00	I-2
1.0	115586	0.14	115587	0.06	92	4.417	0.00	I-2
1.1	700664	1.10	115591	0.45	98	1.667	0.00	RSM-2
1.1	700664	1.10	115591	0.45	98	2.750	0.00	RSM-2
1.1	115593	0.85	115593	1.13	100	0.583	0.00	SM-2C

RR: Ride rate, the subjective measure of the surface smoothness (0.7 - 1.10).
BEGNODE: Beginning node for the DMR section
OFFSET: Offset distance from the beginning node in miles
ENDNODE: End node for the DMR section
OFFSET1: Offset distance from the end node in miles
DMR: Distress maintenance rating (DMR)
AGE: Age of the section since construction or last overlay
STRNO: DMR section structural number; a 0 in this field means that the value for the structural number is missing.
MIXTYP2: Surface layer or overlay mix type as determined from the Pavement Information Details report.

Table B.1 *(continued)* (Part 3 / 3)

DEPTH	CONYEAR	CODE	PERHOMG	DESCRP	NOL	ESALDIR	JURIS	DISTRICT
1.4	90	1	100	OVERLAY	2.0	166725	3	8
1.4	90	1	100	OVERLAY	2.0	387816	3	8
1.4	90	1	100	OVERLAY	2.0	670523	3	8
1.4	90	1	100	OVERLAY	2.0	877381	3	8
1.1	79	0	91	ORIGINAL	2.0	810166	3	8
1.1	79	0	91	ORIGINAL	2.0	1178083	3	8
1.1	79	0	91	ORIGINAL	2.0	1527719	3	8
1.1	79	0	91	ORIGINAL	2.0	1742169	3	8
1.1	79	0	100	ORIGINAL	2.0	1959612	3	8
1.1	79	0	100	ORIGINAL	2.0	1894589	3	8
2.0	92	1	100	OVERLAY	2.0	75709	3	8
2.0	92	1	100	OVERLAY	2.0	249807	3	8
0.0	80	1	100	OVERLAY	2.0	1074827	3	8
0.0	80	1	100	OVERLAY	2.0	711722	3	8
0.0	80	1	100	OVERLAY	2.0	1416899	3	8
0.0	80	1	100	OVERLAY	2.0	1630115	3	8
0.0	80	1	100	OVERLAY	2.0	1798137	3	8
0.0	80	1	100	OVERLAY	2.0	1985188	3	8
4.1	93	1	100	OVERLAY	2.0	46578	3	8
0.0	88	1	100	OVERLAY	2.0	279677	3	8
0.0	88	1	100	OVERLAY	2.0	518890	3	8
0.0	88	1	100	OVERLAY	2.0	739982	3	8
0.0	88	1	100	OVERLAY	2.0	1022689	3	8
0.0	90	1	100	OVERLAY	2.0	381872	3	8
0.0	90	1	100	OVERLAY	2.0	650273	3	8
0.0	91	1	100	OVERLAY	2.0	106486	3	8

DEPTH: DMR section surface layer or overlay thickness in inches.

CONYEAR: Surface layer or overlay construction year, as determined from the Pavement Information Details report.

CODE: Pavement classification code, defined as follows :
= 0, for flexible pavement sections with no overlay
= 1, for overlaid flexible pavement sections
= 3, for composite with 1 overlay sections
= 4, for composite with > 1 overlay sections
= 5, for sections to be excluded from the analysis
= 6, for sections belonging to the "OTHER" category.

PERHOMG: The ratio of the length of the longest portion within the DMR section with the same surface mix type, construction year and thickness to the total length of the section, expressed as a percentage.

DESCRP: A verbal description of the section classification and inclusion status.

NOL: Number of lanes; a 0 means that the DMR section has different number of lanes along its length.

ESALDIR: Cumulative ESALs per direction.

JURIS: Maintenance jurisdiction code; adopted codes used by HTRIS (1-99).

DISTRICT: District; adopted codes used by HTRIS (1-99).