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DEVELOPMENT of PAVEMENT PERFORMANCE ANALYSES AND PROCEDURES

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16. Abstract

A computerized method has been developed to conduct network optimization analysis. The analysis uses performance models along with life-cycle cost analysis to identify the most effective treatment to be applied for a specific section. Performance models were developed for the most common maintenance treatments: sand and chip seals, rehabilitation treatment; overlay, roadbed modification, and mill and overlay. The models were developed using actual pavement management data collected on field sections for the past 15 years. The life cycle cost analysis uses the present worth approach along with actual cost figures for initial and annual construction activities.

The individual treatments are used to create alternatives that can provide the acceptable performance level for a given pavement section over the entire analysis period of 20 years. The annual performance of pavement sections is modeled in terms of the present serviceability index (PSI). The most effective treatment alternative is selected based on the highest benefit cost ratio which is defined as the ratio of area under the PSI vs. time curve divided by the total cost of the alternative. Once the most effective alternative is selected for each pavement section, a summary of the annual expenditures is provided for the group of pavement sections that have been selected for analysis. The group of projects can be the entire network or a group of pavement sections that have been selected by the engineer.

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I. INTRODUCTION

Since 1917, the Nevada Department of Transportation (NDOT) has built and currently maintains 5,429 miles of highways and streets (1). There are an additional 46,458 miles of public roads in Nevada (33,010 miles of unimproved roads, and 13,448 miles of paved roads) which are maintained by county, city, and other governmental agencies. NDOT only maintains 12 percent of the highways and streets in the state. However, the condition of this 12 percent is extremely critical to the state and the national highway system since it carries 72 percent of all traffic and almost ninety percent of all heavy truck traffic (2).

NDOT spent $120 million during fiscal year 1998 for resurfacing, restoration, rehabilitation and reconstruction of 532 miles of highways. Another $12 million was spent on maintaining (pavement surface patching and sealing) highway pavements.

Construction costs have increased substantially in recent years. The Construction Price Index has increased eighty percent since 1977 (1). As a result, construction costs have almost doubled in the last 20 years. For example, one ton of bituminous concrete surfacing that cost $15.47 in 1977 cost $25.52 in 1991. The cost of replacing the pavement surface on the 5,429 miles of roadway built and maintained by NDOT alone would be in excess of $2.7 billion (2).

As noted above, Nevada has several thousands of miles of highways and streets which must be continually maintained in spite of the ever increasing construction costs. NDOT has established the preservation of the existing highway system as its number one priority.

In 1991, the U.S. Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA). Under this Act, State Highway Agencies (SHA) are required to develop and implement

a Pavement Management System (PMS). In addition, SHA's are required to conduct several analyses on the PMS data, including the following:

1. Condition Analysis. This includes ride, distress, rutting, and surface friction.

2. Performance Analysis. This includes pavement performance analysis and an estimate of the remaining service life.

3. Investment Analysis. This includes an estimate of network-level and project-level investment strategies.

4. Engineering Analysis. This includes the evaluation of design, construction, rehabilitation, materials, mix designs, and maintenance as they relate to the performance of pavements.

5. Feedback Analysis. This includes the use of the annual evaluation data to update the performance models.

NDOT implemented of a statewide PMS in 1980, which closely follows the ISTEA guidelines and satisfies requirement number 1 above. The NDOT experience with PMS has been very successful. Currently, NDOT is among the very few SHA's that have an implemented PMS. It has created the essential elements of a PMS and implemented the various tasks of data collection, data analysis, and decision-making processes.

In 1992-1993, NDOT sponsored a research project which developed performance models for pavement rehabilitation and maintenance treatments most commonly used in Nevada (3). The products of this research project satisfied requirements 2 and 4 of the ISTEA Act. In 1994, NDOT started a research project to develop analyses and procedures to satisfy requirements 3 and 5 of the ISTEA Act. This report summarizes the findings and recommendations of this research project.

I.1 Objectives

The overall objective of this study is to incorporate various data analysis procedures and decision-making processes into the NDOT pavement management system. The overall process must include the following critical steps:

- Pavement performance models
- Life-cycle cost analysis
- Optimization analysis

The pavement performance models represent the foundation for the entire effort. The life-cycle cost analysis combines the predicted pavement performance with the associated cost. Finally, the optimization analysis uses the results of the pavement performance prediction with those of the life-cycle cost analysis to recommend the most beneficial maintenance and rehabilitation action.

I.2 Results

The products resulted from this research effort include the following:

- Performance Models
- Life-cycle cost models
- Multi-year prioritization (network optimization)
- Analysis software

II. BACKGROUND

II.1 Pavement Performance Modeling

The increasing interest in pavement performance studies is a result of their representing the final link between theory and practice. As the pavement engineering profession strives for better design procedures and more enduring materials, the evaluation of the long-term pavement performance becomes a critical step for every agency. Predicting the actual performance of specific pavement sections under the combined action of traffic loading and environmental factors can provide valuable data to the various departments of a highway agency.

The pavement design engineer can use such data to check the validity of the design procedure and the appropriateness of the various assumptions that are made during the design process. The materials engineer can verify whether a given type of material is appropriate for the expected level of load and anticipated environmental conditions. As a result, design and construction practices may be altered in order to produce longer lasting pavements.

Pavement management engineers tend to gain the most from such studies. They are usually responsible for recommending various maintenance alternatives for specific applications. This is becoming an increasingly critical task since highway agencies at all levels (city, county and state) are generally operating under a limited budget which requires effective prioritization to provide the highest level of public service. Pavement management engineers are also responsible for setting up a Pavement Management System (PMS) and managing the collected data. Long-term pavement performance studies which develop performance models will help the engineers to evaluate the effectiveness of the PMS and determine the usefulness of the collected data.

The most common method of monitoring pavement performance is through field testing and surveys of actual road sections on a periodic basis. Pavement management systems are usually implemented for this purpose. Highway agencies have also been implementing highly effective quality control/assurance programs to measure materials properties considered to be critical to the long-term performance of the pavement. Development of pavement performance models which can tie the PMS data with materials properties is by far the most effective approach.

Attempts have been made over the last 30 years to develop models that can accurately predict the deterioration of highway pavements over time. In most cases the deterioration has been predicted by theoretical modeling and actual in-service pavement data were not used. In the cases where modeling was performed on in-service data, models were generally developed as a function of the pavement conditions alone - and environmental, materials and structural data were not included. Many of the pavement performance models that exist in the literature are very simple and include only some explanatory variables. The models generally do not account for common maintenance procedures and their effect on the pavement's rate of deterioration (4).

Theoretical modeling may produce deterioration rates which appear reasonable and can be extrapolated over a large range with few constraints. However, theoretical modeling suffers the major constraint of being dependent upon the expected theoretical behavior of the materials and the environment. This is acceptable when modeling materials with known properties and small expected deviations. Since pavement materials are much more variable than most other engineered materials, theoretical modeling has the tendency to produce unreasonable results. This method has been used primarily in the development of models focusing on individual damage or distress types. This is because individual distress modes can generally be simulated in the laboratory.

The most accurate method for developing pavement performance models is the use of a large number of test sections under tightly controlled conditions. The problem with this method is that it can be very costly and may not always allow for exact duplication of field data. This method has been successfully used for modeling a single type of rehabilitation procedure in a specific geographic location (5).

Therefore the most reasonable method for developing pavement performance models is the use of actual field performance data. Statistical modeling eliminates most of the before-mentioned problems but does add one major limitation. The model can only be used within the constraints of the in-service data from which it was developed.

II.1.a Pavement Performance Modeling in Arkansas, Iowa, Pennsylvania, and Washington

Four states (Arkansas, Iowa, Pennsylvania, and Washington) have developed pavement performance models based on information in their existing data bases (6). All four of these states have chosen to use functional performance indicators. This is partially because functional performance indicators allow the states to establish and incorporate life-cycle cost analysis into the models using their currently available data bases and existing PMS programs.

Arkansas used performance data to estimate a pavement's condition rating for the current year based on previous years' data. Components for pavement distress and ride are adjusted for traffic volumes. The pavement's condition rating is plotted against its age, on a yearly basis. From Arkansas' limited analysis it was concluded that even though the curves fit the data reasonably well, they would have to be revised to account for the effects of cumulative ESAL's.

Iowa considered a more elaborate model which addressed some of the more obvious

factors that could affect the performance of the overlay, such as thickness, aggregate durability, base and subgrade characteristics. Sites were selected and divided by service levels and pavement type (rigid and composite). The model did allow Iowa DOT to make some generalizations regarding material selection, but it also had several shortcomings. These included no allowance for maintenance and rehabilitation techniques, limited distribution of data points for loading and age, initial PSI's were all assumed to be constant, and only a few obvious variables that could affect the pavement performance were considered.

Pennsylvania generated performance curves from the roughness and traffic data for each of 22 monitored sites. The curves considered only rigid and composite pavement sections and while they do allow a reasonable prediction of PSI, the data considered were very limited.

Washington developed their curves based on the 5 years of data available in their data base. They considered a larger number of variables than the other three states which led their models to have good statistical correlations ($R^2 > .70$). In all of their models, age was determined to be the most significant independent variable. Other variables such as overlay type showed generalized trends, but were not as significant.

Aside from the individual limitations of each model, all four state's models shared the common limitation of being very generalized. In most cases this is because very few variables have been included in the final models. The model limitations can be attributed to the original data sets from which the models were developed; in most cases the data set included only a few specific test sections believed to be representative of the entire system.

The validity of the four state's models depend on the degree to which the pavement sections used in developing the regression equations are representative of the entire system.

Another limiting factor that most states have encountered is the limited amount of available data. Few states have enough data to develop models that can represent the entire life of the pavement. Five years of data may be adequate for developing equations for minor maintenance techniques, but falls short when considering a model for the life of a reconstruction job or a major overlay. Except Washington, the four states considered only one model, typically an overlay model. Washington's model accounted for any type of maintenance work. Most other models tend to ignore any maintenance work.

II.2 Life-Cycle Cost Analysis

The ISTEA act has forced all state highway agencies (SHA) to develop pavement management systems. The stage of development and degree of sophistication vary among the individual states. Several SHAs have the ability to perform LCCA, however, it is most commonly performed only at the project level for new construction to compare flexible versus rigid pavements. Pavement performance models are rarely available, and engineering judgement coupled with some historical data is typically used to predict performance and/or set rehabilitation and maintenance schedules. Maintenance cost data are available on a limited basis with questionable accuracy. User costs are not typically incorporated and salvage value may or may not be incorporated. Brief summaries are given below for the procedures used by some state DOTs.

II.2.a. Colorado DOT

The Colorado DOT uses LCCA at the stage of new construction to compare flexible versus rigid pavements and major rehabilitation projects. Pavement performance models are not used. Treatment performance lives are based on historical data and average daily traffic (ADT). For example if the ADT is less than 750 vehicles per day, a seal coat is said to last 3-7 years, and if the ADT is greater than 750 vehicles per day, it is said to last 1-4 years. The actual life used in the LCCA is up to the engineer. Fixed rehabilitation and maintenance schedules and costs are assigned based on the type of pavement. For example, a flexible pavement must receive a 2-inch overlay every 10 years and $600/lane-mile of maintenance each year, while a rigid pavement must receive a 2-inch flexible overlay at 20 years with joint sealing and 1 percent slab replacement, and $300/lane-mile of maintenance each year. User costs and salvage value are not incorporated into the analysis. The actual analysis is performed using computer software, either AASHTO's Darwin 2.0 or an in-house LCCA program. The LCCA employs the present worth economic method.

II.2.b. Wyoming DOT

The Wyoming DOT uses LCCA to compare projects after a committee in the Materials Division discusses and establishes alternatives. Typically two or three alternatives are selected for comparison. Pavement performance models are not used and performance lives are assumed based on recent experience. Fixed "occasional" maintenance schedules and costs are used in the analysis

along with user costs and salvage value. The present worth economic method is employed.

Colorado and Wyoming are typical examples of SHA's which do not have pavement performance models, use fixed rehabilitation and maintenance schedules, and have limited historical maintenance cost information.

II.2.c. Oregon DOT

A probabilistic approach of LCCA is used by the Oregon DOT as a basis for economic comparison of "large scale" construction projects (7). For each project alternative, initial designs are established along with their associated initial costs. Several rehabilitation strategies and costs are then developed for each initial design and each strategy is assigned a probability of occurrence in specific years. Figure 1 illustrates the concept for one initial design. A "P" in the figure represents the probability of selecting a possible rehabilitation strategy. At year i (node i), consideration is given to performing rehabilitation work. The probability of performing rehabilitation in year i is P_2 and the probability of not rehabilitating is P_1. Additionally, at year i (node k), three rehabilitation strategies are considered with probabilities P_{21}, P_{22}, and P_{23}. In year j (node j), two rehabilitation strategies are considered with probabilities of P_{11}, and P_{12}. The final probability for each strategy is obtained by multiplying the probabilities at relevant nodes. As an example, the final probability for strategy 1 is P_1 times P_{11}. The sum of the probabilities for the alternative must equal unity.

Annual costs are computed for each strategy and multiplied by the corresponding probability in order to obtain weighted annual costs, expressed as:

$$WACi = Pi * ACosti$$

Where:

WACi = weighted annual cost for strategy i

Pi = probability for strategy i

ACosti = annual cost for strategy i

Weighted annual costs are then cumulated to obtain an expressed equivalent annual cost (EEAC) for the alternative evaluated. The EEAC is computed as follows:

$$EEAC = Sum(WACi) \text{ for } i = 1 \text{ to } m$$

where:

m = total strategies in the analysis

The alternative with the lowest EEAC is selected as the most economical. Similar concepts can be applied if the present worth method of economic analysis is desired.

II.2.d. Alaska, Arizona, and Kansas DOT

Alaska, Arizona, and Kansas have all retained Woodward-Clyde Consultants to assist in the development of their pavement management systems, including LCCA. All three states have models used to predict pavement performance (statistical/mechanistic). Alaska has two models to estimate pavement performance and will be used as an example (8). There were four steps used in pavement performance predictions for Alaska:

1. To predict pavement performance as a function of traffic, material and environment,

2. To predict pavement performance in permafrost areas as a result of thaw settlement,

3. To integrate effects of traffic and thaw settlement to produce an estimate of their combined effects and,

4. To estimate the dispersion around the expected values of performance based on the reliability of prediction models.

Step 1

The following regression models were developed for areas where permafrost was insignificant:

a) transverse cracking as a function of: age and freezing index.

b) fatigue cracking as a function of: ESAL's and Benkelman Beam deflection.

c) roughness (Mays Road Meter data in inches per mile) as a function of: age, freezing index, number of transverse cracks, ESAL's, Benkelman Beam deflection, and percent fatigue cracking.

The basic approach in developing the traffic and environmental related performance factors was to first develop models for fatigue (alligator) and transverse cracking and then to combine those forms of distress to predict roughness. As can be seen from a, b, and c above, performance as a function of traffic, materials, and environment is characterized in terms of alligator cracking, transverse cracking, and finally roughness.

Step 2

A model was developed to predict roughness (Mays Meter Data) as a function of differential settlement due to thawing in areas where permafrost is significant.

Step 3

Roughness due to traffic and thaw settlement are added together to obtain a total expected roughness. If not in a permafrost area, the total roughness is simply due to traffic. At this point, both maintenance costs and user costs are estimated as a function of total roughness.

Step 4

Woodward-Clyde feels that exact prediction of future pavement performance is not possible, and that the dispersion around the best estimates of future performance is characterized by a coeficient of variation (COV). COV is the ratio of standard deviation to the mean. When regression modeling is performed, the coefficient of variation for each performance variable can be estimated from the standard error of estimate resulting from the lack-of-fit of data points from the mean value equation. COV's of 0.39 and 0.45 were obtained for the alligator cracking and roughness models, respectively. The thaw settlement model was not developed using regression analysis and therefore no COV was obtained for it. A constant COV of 0.45 was assumed for the total roughness based on the above discussion.

Attempts were made to model maintenance costs as a function of fatigue cracking, roughness and thaw settlement. Regression analysis was used to develop a relationship between roughness and maintenance costs and is represented in Figure 2. The R^2 was 0.20 for the model. Although the R^2 is poor, the model was still used. Fatigue cracking and thaw settlement could not be correlated to maintenance cost using regression analysis. A "general trend" was established to relate fatigue cracking to maintenance costs and "engineering judgement" was used to relate thaw settlement to maintenance cost. Based on the relationships just described, it was decided that maintenance costs would be estimated using the roughness model.

Road user costs are incorporated in Alaska's LCCA procedure. Both driver cost and vehicle operating costs are combined and termed excess road user costs. A relationship was developed to estimate excess road user costs as a function of Mays Meter data.

At this point models exist to predict roughness, fatigue cracking, maintenance costs, and road user costs. The coefficient of determination for the maintenance cost model is 0.20, and is not reported for any of the other models. It should be noted that only three to five years of data from a limited number of roadway sections were available/used to develop these models. There are obviously some uncertainties in using these prediction models, therefore the probabilistic theory is introduced into the modeling. One can estimate the probability that roughness or fatigue cracking would be equal to a specific value. Then for given values of fatigue cracking and roughness, maintenance and excess user costs could be estimated.

Continuous probability distributions of fatigue cracking and roughness at any given time were discretized into ten intervals, each having a probability of 0.10, and the median value for that interval was assumed to represent the interval. For a given variable X, the ten intervals and their representative values (medians) were as displayed in Table 1. X_p denotes the value of X such that the probability of being less than or equal to X_p is p. If X is normally distributed with mean = μ and standard deviation = σ, therefore COV = (σ/μ), then X_p may be calculated as:

$$X_p = \mu + k_p \sigma$$

where:

k_p = a value from normal probability tables corresponding to the cumulative probability of p.

The assumption was made that if a pavement performs better or worse than the average at

one time, it would continue to perform in the same manner at any other time. This is an arguable assumption. Based on this assumption, the performance values X_p at different time periods were connected to obtain a performance curve such that the probability of being less than or equal to the value on this curve at any given time would be p. A total of 10 different performance curves were thus defined, corresponding to ten values of p, for fatigue cracking and total roughness. The curves are shown schematically in Figure 3.

Maintenance cost and excess road user cost were then calculated for each performance curve, resulting in 10 cost figures for fatigue cracking and ten for total roughness. Averaging the ten values of cost for each distress at time t results in the expected cost at that time due to that distress. Therefore maintenance costs and user costs are established at each time t. Standard deviations of the costs are also calculated.

Figure 4 shows the maintenance policy used to estimate costs for fatigue cracking. The fatigue cracking model is used to estimate, with some uncertainty, that the amount of fatigue cracking will first reach 10 percent in the year t_1. Maintenance will then be performed theoretically reducing the amount of fatigue cracking to zero percent. At this point the fatigue cracking will continue to develop according to the initial prediction model (note the slope of the curve). When 10 percent cracking is reached again, in year t_2, maintenance will be performed theoretically reducing the amount of cracking to zero again. Maintenance cost is estimated as a function of the percent fatigue cracking in the year of maintenance. This process is repeated until time T, for which the comparisons of alternate designs are to be made (typically 15 to 20 years).

Expected maintenance cost due to fatigue cracking in the ith year (EMCF(i)) is given by:

$$EMCF(i) = \Sigma \{MCF(iFC_p)*P(FC_p)\}/10$$

where:

$MCF(iFC_p)$ = maintenance cost for fatigue cracking in the ith year if the performance FC_p is followed.

$P(FC_p)$ = probability of the performance curve FC_p.

Note the 10 in the denominator due to the 10 performance curves.

The present worth value of the total expected maintenance cost due to fatigue cracking (TMCF) for an analysis period of T years is calculated as:

$$TMCF = \Sigma\, \alpha_i\, EMCF(i) \quad \text{for } i=1 \text{ to } T$$

where:

α_i= present worth factor as a function of interest and inflation rates.

Expected maintenance cost due to total roughness is determined in a manner similar to that described for fatigue cracking. A limiting value of roughness is assumed to initiate maintenance and a reduction in roughness due to the maintenance is assumed. The required maintenance cost is a function of the percent reduction in roughness in the year when maintenance is performed.

Expected maintenance cost due to total roughness in the ith year (EMCR(i)) is given by:

$$EMCR(i) = \Sigma\, \{MCR(i,R_p) * P(R_p)\}/10$$

where:

$MCR(i,R_p)$ = maintenance cost for total roughness in the ith year if the performance R_p is followed.

$P(R_p)$ = probability of the performance curve R_p.

Note the 10 in the denominator due to the 10 performance curves.

The present worth value of the total expected maintenance cost due to total roughness (TMCR) for an analysis period of T years is calculated as:

$$TMCR = \Sigma\ \alpha_i\ EMRC(i) \text{ for } i=1 \text{ to } T$$

where:

α_i = present worth factor as a function of interest and inflation rates.

Expected user costs in the ith year (EUC(i)) are determined as a function of unit user cost in units of \$/inch of roughness/ESAL, total estimated roughness in a given year and the number of ESAL's for that year. An ESAL is an 18 kip equivalent single axle load. Expected user cost in the ith year (EUC(i)) is given by:

$$EUC(i) = \Sigma\ \{UC(i,R_p) * ESAL(i)\}/10$$

where:

$UC(i,R_p)$ = user cost in \$/ESAL in the ith year if the total roughness performance R_p is followed.

ESAL(i) = number of ESAL's in the ith year.

Note the 10 in the denominator due to the 10 performance curves.

The present worth value of the total expected user cost (TUC) for an analysis period of T years is calculated as:

$$TUC = \Sigma\ \alpha_i\ EUC(i) \text{ for } i=1 \text{ to } T$$

where:

α_i = present worth factor as a function of interest and inflation rates.

The present worth of the total expected costs (TEC) for a period of T years is the sum of the individual costs during the T year period and is expressed as:

$$TEC = I_0 + TMCF + TMCR + TUC + SV_T$$

where:

I_0 = initial construction cost in year zero.

SV_T = salvage value in year T.

The Woodward-Clyde Consultants methodology is very complex and it is doubtful that many of the personnel in the pavement community could thoroughly understand it, forcing the agencies to continuously rely on consultants to edit and update the system. Additionally it would be very difficult to explain at the legislative level. It seems as though the probabilistic theory is introduced due to a lack of confidence in pavement performance prediction models and maintenance cost information.

II.3 NDOT Pavement Management System (PMS)

Over the past 18 years, NDOT has implemented a Pavement Management System (PMS) in accordance with the ISTEA which monitors pavement conditions with time (9). The system was initiated in 1980 and provides yearly pavement condition data. The condition surveys are conducted on a mile-by-mile basis for the entire state-maintained system. Data are collected on cracking, rut depth, patching, surface condition, and ride. Additional data on traffic and accidents are collected for informational purposes only.

All these data are merged into a pavement conditions master file. Further analyses are conducted which generate seven performance indicators that are used to classify the pavement sections into one of four repair categories. These indicators include ride, rut depth, cracking, patching, bleeding, raveling, and the present serviceability index (PSI). The PSI used in NDOT's PMS between 1980 and 1994 was based on the PSI relationship that was developed during the AASHO Road Test experiment as follows:

$$PSI = 5.03 - 1.91 \log(1+SV) - 1.38\, RD^2 - 0.01\, (C+P)^{0.5}$$

Where:

SV= Slope variance (10^{-6})

RD= rut depth (in)

C= cracking area ($ft^2/1000ft^2$)

P= patching area ($ft^2/1000ft^2$)

In 1995, NDOT modified the PSI equation using the following relationship:

$$PSI = 5*e^{-0.0041*IRI} - 1.38RD^2 - 0.01(C+P)^{0.5}$$

Where:

IRI= international roughness index (in/mile)

RD= rut depth (in)

C= cracking area ($ft^2/1000ft^2$)

P= patching area ($ft^2/1000ft^2$)

The four repair categories are as follows:

a. Do Nothing

b. Maintenance

c. Overlay

d. Reconstruction

Distinctions among the categories are based on specific distress indicators and their severity. Points are assigned based on the severity and extent of each distress indicator and friction number (see Figure 5). The total summation of the points dictates the general repair category for a section of road. Figure 6 shows the breakdown of the point assignment system and respective repair categories.

The data analysis portion of the PMS produces a total of six reports. The DS-1 and DS-2 reports provide a distress summary by route, county, and milepost and a summary by district, route county, and milepost, respectively. The PD-1, PD-2, and PD-3 reports classify information on roadway miles which require maintenance, overlay, and reconstruction activities, respectively. The MS-1 report provides information on roadway miles requiring maintenance only, and it indicates a recommended repair strategy for each roadway mile. These reports provide information for: a) developing a periodic statewide status report indicating the effort necessary to maintain the entire state roadway system at a prescribed minimum service level; b) a database used to compare predicted and historic performance so strategies can be optimized; c) project prioritization; d) projecting costs and corrective actions and; e) aiding communications between districts, headquarters, and the Federal Highway Administration (FHWA).

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DEVELOPMENT of PAVEMENT PERFORMANCE ANALYSES AND PROCEDURES

August 2001

Prepared by Research Division
Nevada Department of Transportation
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16. Abstract

A computerized method has been developed to conduct network optimization analysis. The analysis uses performance models along with life-cycle cost analysis to identify the most effective treatment to be applied for a specific section. Performance models were developed for the most common maintenance treatments: sand and chip seals, rehabilitation treatment; overlay, roadbed modification, and mill and overlay. The models were developed using actual pavement management data collected on field sections for the past 15 years. The life cycle cost analysis uses the present worth approach along with actual cost figures for initial and annual construction activities.

The individual treatments are used to create alternatives that can provide the acceptable performance level for a given pavement section over the entire analysis period of 20 years. The annual performance of pavement sections is modeled in terms of the present serviceability index (PSI). The most effective treatment alternative is selected based on the highest benefit cost ratio which is defined as the ratio of area under the PSI vs. time curve divided by the total cost of the alternative. Once the most effective alternative is selected for each pavement section, a summary of the annual expenditures is provided for the group of pavement sections that have been selected for analysis. The group of projects can be the entire network or a group of pavement sections that have been selected by the engineer.

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I. INTRODUCTION

Since 1917, the Nevada Department of Transportation (NDOT) has built and currently maintains 5,429 miles of highways and streets (1). There are an additional 46,458 miles of public roads in Nevada (33,010 miles of unimproved roads, and 13,448 miles of paved roads) which are maintained by county, city, and other governmental agencies. NDOT only maintains 12 percent of the highways and streets in the state. However, the condition of this 12 percent is extremely critical to the state and the national highway system since it carries 72 percent of all traffic and almost ninety percent of all heavy truck traffic (2).

NDOT spent $120 million during fiscal year 1998 for resurfacing, restoration, rehabilitation and reconstruction of 532 miles of highways. Another $12 million was spent on maintaining (pavement surface patching and sealing) highway pavements.

Construction costs have increased substantially in recent years. The Construction Price Index has increased eighty percent since 1977 (1). As a result, construction costs have almost doubled in the last 20 years. For example, one ton of bituminous concrete surfacing that cost $15.47 in 1977 cost $25.52 in 1991. The cost of replacing the pavement surface on the 5,429 miles of roadway built and maintained by NDOT alone would be in excess of $2.7 billion (2).

As noted above, Nevada has several thousands of miles of highways and streets which must be continually maintained in spite of the ever increasing construction costs. NDOT has established the preservation of the existing highway system as its number one priority.

In 1991, the U.S. Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA). Under this Act, State Highway Agencies (SHA) are required to develop and implement

a Pavement Management System (PMS). In addition, SHA's are required to conduct several analyses on the PMS data, including the following:

1. Condition Analysis. This includes ride, distress, rutting, and surface friction.

2. Performance Analysis. This includes pavement performance analysis and an estimate of the remaining service life.

3. Investment Analysis. This includes an estimate of network-level and project-level investment strategies.

4. Engineering Analysis. This includes the evaluation of design, construction, rehabilitation, materials, mix designs, and maintenance as they relate to the performance of pavements.

5. Feedback Analysis. This includes the use of the annual evaluation data to update the performance models.

NDOT implemented of a statewide PMS in 1980, which closely follows the ISTEA guidelines and satisfies requirement number 1 above. The NDOT experience with PMS has been very successful. Currently, NDOT is among the very few SHA's that have an implemented PMS. It has created the essential elements of a PMS and implemented the various tasks of data collection, data analysis, and decision-making processes.

In 1992-1993, NDOT sponsored a research project which developed performance models for pavement rehabilitation and maintenance treatments most commonly used in Nevada (3). The products of this research project satisfied requirements 2 and 4 of the ISTEA Act. In 1994, NDOT started a research project to develop analyses and procedures to satisfy requirements 3 and 5 of the ISTEA Act. This report summarizes the findings and recommendations of this research project.

I.1 Objectives

The overall objective of this study is to incorporate various data analysis procedures and decision-making processes into the NDOT pavement management system. The overall process must include the following critical steps:

- Pavement performance models
- Life-cycle cost analysis
- Optimization analysis

The pavement performance models represent the foundation for the entire effort. The life-cycle cost analysis combines the predicted pavement performance with the associated cost. Finally, the optimization analysis uses the results of the pavement performance prediction with those of the life-cycle cost analysis to recommend the most beneficial maintenance and rehabilitation action.

I.2 Results

The products resulted from this research effort include the following:

- Performance Models
- Life-cycle cost models
- Multi-year prioritization (network optimization)
- Analysis software

II. BACKGROUND

II.1 Pavement Performance Modeling

The increasing interest in pavement performance studies is a result of their representing the final link between theory and practice. As the pavement engineering profession strives for better design procedures and more enduring materials, the evaluation of the long-term pavement performance becomes a critical step for every agency. Predicting the actual performance of specific pavement sections under the combined action of traffic loading and environmental factors can provide valuable data to the various departments of a highway agency.

The pavement design engineer can use such data to check the validity of the design procedure and the appropriateness of the various assumptions that are made during the design process. The materials engineer can verify whether a given type of material is appropriate for the expected level of load and anticipated environmental conditions. As a result, design and construction practices may be altered in order to produce longer lasting pavements.

Pavement management engineers tend to gain the most from such studies. They are usually responsible for recommending various maintenance alternatives for specific applications. This is becoming an increasingly critical task since highway agencies at all levels (city, county and state) are generally operating under a limited budget which requires effective prioritization to provide the highest level of public service. Pavement management engineers are also responsible for setting up a Pavement Management System (PMS) and managing the collected data. Long-term pavement performance studies which develop performance models will help the engineers to evaluate the effectiveness of the PMS and determine the usefulness of the collected data.

The most common method of monitoring pavement performance is through field testing and surveys of actual road sections on a periodic basis. Pavement management systems are usually implemented for this purpose. Highway agencies have also been implementing highly effective quality control/assurance programs to measure materials properties considered to be critical to the long-term performance of the pavement. Development of pavement performance models which can tie the PMS data with materials properties is by far the most effective approach.

Attempts have been made over the last 30 years to develop models that can accurately predict the deterioration of highway pavements over time. In most cases the deterioration has been predicted by theoretical modeling and actual in-service pavement data were not used. In the cases where modeling was performed on in-service data, models were generally developed as a function of the pavement conditions alone - and environmental, materials and structural data were not included. Many of the pavement performance models that exist in the literature are very simple and include only some explanatory variables. The models generally do not account for common maintenance procedures and their effect on the pavement's rate of deterioration (4).

Theoretical modeling may produce deterioration rates which appear reasonable and can be extrapolated over a large range with few constraints. However, theoretical modeling suffers the major constraint of being dependent upon the expected theoretical behavior of the materials and the environment. This is acceptable when modeling materials with known properties and small expected deviations. Since pavement materials are much more variable than most other engineered materials, theoretical modeling has the tendency to produce unreasonable results. This method has been used primarily in the development of models focusing on individual damage or distress types. This is because individual distress modes can generally be simulated in the laboratory.

The most accurate method for developing pavement performance models is the use of a large number of test sections under tightly controlled conditions. The problem with this method is that it can be very costly and may not always allow for exact duplication of field data. This method has been successfully used for modeling a single type of rehabilitation procedure in a specific geographic location (5).

Therefore the most reasonable method for developing pavement performance models is the use of actual field performance data. Statistical modeling eliminates most of the before-mentioned problems but does add one major limitation. The model can only be used within the constraints of the in-service data from which it was developed.

II.1.a Pavement Performance Modeling in Arkansas, Iowa, Pennsylvania, and Washington

Four states (Arkansas, Iowa, Pennsylvania, and Washington) have developed pavement performance models based on information in their existing data bases (6). All four of these states have chosen to use functional performance indicators. This is partially because functional performance indicators allow the states to establish and incorporate life-cycle cost analysis into the models using their currently available data bases and existing PMS programs.

Arkansas used performance data to estimate a pavement's condition rating for the current year based on previous years' data. Components for pavement distress and ride are adjusted for traffic volumes. The pavement's condition rating is plotted against its age, on a yearly basis. From Arkansas' limited analysis it was concluded that even though the curves fit the data reasonably well, they would have to be revised to account for the effects of cumulative ESAL's.

Iowa considered a more elaborate model which addressed some of the more obvious

factors that could affect the performance of the overlay, such as thickness, aggregate durability, base and subgrade characteristics. Sites were selected and divided by service levels and pavement type (rigid and composite). The model did allow Iowa DOT to make some generalizations regarding material selection, but it also had several shortcomings. These included no allowance for maintenance and rehabilitation techniques, limited distribution of data points for loading and age, initial PSI's were all assumed to be constant, and only a few obvious variables that could affect the pavement performance were considered.

Pennsylvania generated performance curves from the roughness and traffic data for each of 22 monitored sites. The curves considered only rigid and composite pavement sections and while they do allow a reasonable prediction of PSI, the data considered were very limited.

Washington developed their curves based on the 5 years of data available in their data base. They considered a larger number of variables than the other three states which led their models to have good statistical correlations ($R^2 > .70$). In all of their models, age was determined to be the most significant independent variable. Other variables such as overlay type showed generalized trends, but were not as significant.

Aside from the individual limitations of each model, all four state's models shared the common limitation of being very generalized. In most cases this is because very few variables have been included in the final models. The model limitations can be attributed to the original data sets from which the models were developed; in most cases the data set included only a few specific test sections believed to be representative of the entire system.

The validity of the four state's models depend on the degree to which the pavement sections used in developing the regression equations are representative of the entire system.

Another limiting factor that most states have encountered is the limited amount of available data. Few states have enough data to develop models that can represent the entire life of the pavement. Five years of data may be adequate for developing equations for minor maintenance techniques, but falls short when considering a model for the life of a reconstruction job or a major overlay. Except Washington, the four states considered only one model, typically an overlay model. Washington's model accounted for any type of maintenance work. Most other models tend to ignore any maintenance work.

II.2 Life-Cycle Cost Analysis

The ISTEA act has forced all state highway agencies (SHA) to develop pavement management systems. The stage of development and degree of sophistication vary among the individual states. Several SHAs have the ability to perform LCCA, however, it is most commonly performed only at the project level for new construction to compare flexible versus rigid pavements. Pavement performance models are rarely available, and engineering judgement coupled with some historical data is typically used to predict performance and/or set rehabilitation and maintenance schedules. Maintenance cost data are available on a limited basis with questionable accuracy. User costs are not typically incorporated and salvage value may or may not be incorporated. Brief summaries are given below for the procedures used by some state DOTs.

II.2.a. Colorado DOT

The Colorado DOT uses LCCA at the stage of new construction to compare flexible versus rigid pavements and major rehabilitation projects. Pavement performance models are not used. Treatment performance lives are based on historical data and average daily traffic (ADT). For example if the ADT is less than 750 vehicles per day, a seal coat is said to last 3-7 years, and if the ADT is greater than 750 vehicles per day, it is said to last 1-4 years. The actual life used in the LCCA is up to the engineer. Fixed rehabilitation and maintenance schedules and costs are assigned based on the type of pavement. For example, a flexible pavement must receive a 2-inch overlay every 10 years and $600/lane-mile of maintenance each year, while a rigid pavement must receive a 2-inch flexible overlay at 20 years with joint sealing and 1 percent slab replacement, and $300/lane-mile of maintenance each year. User costs and salvage value are not incorporated into the analysis. The actual analysis is performed using computer software, either AASHTO's Darwin 2.0 or an in-house LCCA program. The LCCA employs the present worth economic method.

II.2.b. Wyoming DOT

The Wyoming DOT uses LCCA to compare projects after a committee in the Materials Division discusses and establishes alternatives. Typically two or three alternatives are selected for comparison. Pavement performance models are not used and performance lives are assumed based on recent experience. Fixed "occasional" maintenance schedules and costs are used in the analysis

along with user costs and salvage value. The present worth economic method is employed.

Colorado and Wyoming are typical examples of SHA's which do not have pavement performance models, use fixed rehabilitation and maintenance schedules, and have limited historical maintenance cost information.

II.2.c. Oregon DOT

A probabilistic approach of LCCA is used by the Oregon DOT as a basis for economic comparison of "large scale" construction projects (7). For each project alternative, initial designs are established along with their associated initial costs. Several rehabilitation strategies and costs are then developed for each initial design and each strategy is assigned a probability of occurrence in specific years. Figure 1 illustrates the concept for one initial design. A "P" in the figure represents the probability of selecting a possible rehabilitation strategy. At year i (node i), consideration is given to performing rehabilitation work. The probability of performing rehabilitation in year i is P_2 and the probability of not rehabilitating is P_1. Additionally, at year i (node k), three rehabilitation strategies are considered with probabilities P_{21}, P_{22}, and P_{23}. In year j (node j), two rehabilitation strategies are considered with probabilities of P_{11}, and P_{12}. The final probability for each strategy is obtained by multiplying the probabilities at relevant nodes. As an example, the final probability for strategy 1 is P_1 times P_{11}. The sum of the probabilities for the alternative must equal unity.

Annual costs are computed for each strategy and multiplied by the corresponding probability in order to obtain weighted annual costs, expressed as:

$$WACi = Pi * ACosti$$

Where:

WACi = weighted annual cost for strategy i

Pi = probability for strategy i

ACosti = annual cost for strategy i

Weighted annual costs are then cumulated to obtain an expressed equivalent annual cost (EEAC) for the alternative evaluated. The EEAC is computed as follows:

$$EEAC = Sum(WACi) \text{ for } i = 1 \text{ to } m$$

where:

m = total strategies in the analysis

The alternative with the lowest EEAC is selected as the most economical. Similar concepts can be applied if the present worth method of economic analysis is desired.

II.2.d. Alaska, Arizona, and Kansas DOT

Alaska, Arizona, and Kansas have all retained Woodward-Clyde Consultants to assist in the development of their pavement management systems, including LCCA. All three states have models used to predict pavement performance (statistical/mechanistic). Alaska has two models to estimate pavement performance and will be used as an example (8). There were four steps used in pavement performance predictions for Alaska:

1. To predict pavement performance as a function of traffic, material and environment,

2. To predict pavement performance in permafrost areas as a result of thaw settlement,

3. To integrate effects of traffic and thaw settlement to produce an estimate of their combined effects and,

4. To estimate the dispersion around the expected values of performance based on the reliability of prediction models.

Step 1

The following regression models were developed for areas where permafrost was insignificant:

a) transverse cracking as a function of: age and freezing index.

b) fatigue cracking as a function of: ESAL's and Benkelman Beam deflection.

c) roughness (Mays Road Meter data in inches per mile) as a function of: age, freezing index, number of transverse cracks, ESAL's, Benkelman Beam deflection, and percent fatigue cracking.

The basic approach in developing the traffic and environmental related performance factors was to first develop models for fatigue (alligator) and transverse cracking and then to combine those forms of distress to predict roughness. As can be seen from a, b, and c above, performance as a function of traffic, materials, and environment is characterized in terms of alligator cracking, transverse cracking, and finally roughness.

Step 2

A model was developed to predict roughness (Mays Meter Data) as a function of differential settlement due to thawing in areas where permafrost is significant.

Step 3

Roughness due to traffic and thaw settlement are added together to obtain a total expected roughness. If not in a permafrost area, the total roughness is simply due to traffic. At this point, both maintenance costs and user costs are estimated as a function of total roughness.

Step 4

Woodward-Clyde feels that exact prediction of future pavement performance is not possible, and that the dispersion around the best estimates of future performance is characterized by a coeficient of variation (COV). COV is the ratio of standard deviation to the mean. When regression modeling is performed, the coefficient of variation for each performance variable can be estimated from the standard error of estimate resulting from the lack-of-fit of data points from the mean value equation. COV's of 0.39 and 0.45 were obtained for the alligator cracking and roughness models, respectively. The thaw settlement model was not developed using regression analysis and therefore no COV was obtained for it. A constant COV of 0.45 was assumed for the total roughness based on the above discussion.

Attempts were made to model maintenance costs as a function of fatigue cracking, roughness and thaw settlement. Regression analysis was used to develop a relationship between roughness and maintenance costs and is represented in Figure 2. The R^2 was 0.20 for the model. Although the R^2 is poor, the model was still used. Fatigue cracking and thaw settlement could not be correlated to maintenance cost using regression analysis. A "general trend" was established to relate fatigue cracking to maintenance costs and "engineering judgement" was used to relate thaw settlement to maintenance cost. Based on the relationships just described, it was decided that maintenance costs would be estimated using the roughness model.

Road user costs are incorporated in Alaska's LCCA procedure. Both driver cost and vehicle operating costs are combined and termed excess road user costs. A relationship was developed to estimate excess road user costs as a function of Mays Meter data.

At this point models exist to predict roughness, fatigue cracking, maintenance costs, and road user costs. The coefficient of determination for the maintenance cost model is 0.20, and is not reported for any of the other models. It should be noted that only three to five years of data from a limited number of roadway sections were available/used to develop these models. There are obviously some uncertainties in using these prediction models, therefore the probabilistic theory is introduced into the modeling. One can estimate the probability that roughness or fatigue cracking would be equal to a specific value. Then for given values of fatigue cracking and roughness, maintenance and excess user costs could be estimated.

Continuous probability distributions of fatigue cracking and roughness at any given time were discretized into ten intervals, each having a probability of 0.10, and the median value for that interval was assumed to represent the interval. For a given variable X, the ten intervals and their representative values (medians) were as displayed in Table 1. X_p denotes the value of X such that the probability of being less than or equal to X_p is p. If X is normally distributed with mean = μ and standard deviation = σ, therefore COV = (σ/μ), then X_p may be calculated as:

$$X_p = \mu + k_p \sigma$$

where:

k_p = a value from normal probability tables corresponding to the cumulative probability of p.

The assumption was made that if a pavement performs better or worse than the average at

one time, it would continue to perform in the same manner at any other time. This is an arguable assumption. Based on this assumption, the performance values X_p at different time periods were connected to obtain a performance curve such that the probability of being less than or equal to the value on this curve at any given time would be p. A total of 10 different performance curves were thus defined, corresponding to ten values of p, for fatigue cracking and total roughness. The curves are shown schematically in Figure 3.

Maintenance cost and excess road user cost were then calculated for each performance curve, resulting in 10 cost figures for fatigue cracking and ten for total roughness. Averaging the ten values of cost for each distress at time t results in the expected cost at that time due to that distress. Therefore maintenance costs and user costs are established at each time t. Standard deviations of the costs are also calculated.

Figure 4 shows the maintenance policy used to estimate costs for fatigue cracking. The fatigue cracking model is used to estimate, with some uncertainty, that the amount of fatigue cracking will first reach 10 percent in the year t_1. Maintenance will then be performed theoretically reducing the amount of fatigue cracking to zero percent. At this point the fatigue cracking will continue to develop according to the initial prediction model (note the slope of the curve). When 10 percent cracking is reached again, in year t_2, maintenance will be performed theoretically reducing the amount of cracking to zero again. Maintenance cost is estimated as a function of the percent fatigue cracking in the year of maintenance. This process is repeated until time T, for which the comparisons of alternate designs are to be made (typically 15 to 20 years).

Expected maintenance cost due to fatigue cracking in the ith year (EMCF(i)) is given by:

$$EMCF(i) = \Sigma \{MCF(iFC_p)*P(FC_p)\}/10$$

where:

$MCF(iFC_p)$ = maintenance cost for fatigue cracking in the ith year if the performance FC_p is followed.

$P(FC_p)$ = probability of the performance curve FC_p.

Note the 10 in the denominator due to the 10 performance curves.

The present worth value of the total expected maintenance cost due to fatigue cracking (TMCF) for an analysis period of T years is calculated as:

$$TMCF = \Sigma\, \alpha_i\, EMCF(i) \quad \text{for } i=1 \text{ to } T$$

where:

α_i= present worth factor as a function of interest and inflation rates.

Expected maintenance cost due to total roughness is determined in a manner similar to that described for fatigue cracking. A limiting value of roughness is assumed to initiate maintenance and a reduction in roughness due to the maintenance is assumed. The required maintenance cost is a function of the percent reduction in roughness in the year when maintenance is performed.

Expected maintenance cost due to total roughness in the ith year (EMCR(i)) is given by:

$$EMCR(i) = \Sigma\, \{MCR(i,R_p) * P(R_p)\}/10$$

where:

$MCR(i,R_p)$ = maintenance cost for total roughness in the ith year if the performance R_p is followed.

$P(R_p)$ = probability of the performance curve R_p.

Note the 10 in the denominator due to the 10 performance curves.

The present worth value of the total expected maintenance cost due to total roughness (TMCR) for an analysis period of T years is calculated as:

$$TMCR = \Sigma\ \alpha_i\ EMRC(i) \text{ for } i=1 \text{ to } T$$

where:

α_i = present worth factor as a function of interest and inflation rates.

Expected user costs in the ith year (EUC(i)) are determined as a function of unit user cost in units of \$/inch of roughness/ESAL, total estimated roughness in a given year and the number of ESAL's for that year. An ESAL is an 18 kip equivalent single axle load. Expected user cost in the ith year (EUC(i)) is given by:

$$EUC(i) = \Sigma\ \{UC(i,R_p) * ESAL(i)\}/10$$

where:

$UC(i,R_p)$ = user cost in \$/ESAL in the ith year if the total roughness performance R_p is followed.

ESAL(i) = number of ESAL's in the ith year.

Note the 10 in the denominator due to the 10 performance curves.

The present worth value of the total expected user cost (TUC) for an analysis period of T years is calculated as:

$$TUC = \Sigma\ \alpha_i\ EUC(i) \text{ for } i=1 \text{ to } T$$

where:

α_i = present worth factor as a function of interest and inflation rates.

The present worth of the total expected costs (TEC) for a period of T years is the sum of the individual costs during the T year period and is expressed as:

$$TEC = I_0 + TMCF + TMCR + TUC + SV_T$$

where:

I_0 = initial construction cost in year zero.

SV_T = salvage value in year T.

The Woodward-Clyde Consultants methodology is very complex and it is doubtful that many of the personnel in the pavement community could thoroughly understand it, forcing the agencies to continuously rely on consultants to edit and update the system. Additionally it would be very difficult to explain at the legislative level. It seems as though the probabilistic theory is introduced due to a lack of confidence in pavement performance prediction models and maintenance cost information.

II.3 NDOT Pavement Management System (PMS)

Over the past 18 years, NDOT has implemented a Pavement Management System (PMS) in accordance with the ISTEA which monitors pavement conditions with time (9). The system was initiated in 1980 and provides yearly pavement condition data. The condition surveys are conducted on a mile-by-mile basis for the entire state-maintained system. Data are collected on cracking, rut depth, patching, surface condition, and ride. Additional data on traffic and accidents are collected for informational purposes only.

All these data are merged into a pavement conditions master file. Further analyses are conducted which generate seven performance indicators that are used to classify the pavement sections into one of four repair categories. These indicators include ride, rut depth, cracking, patching, bleeding, raveling, and the present serviceability index (PSI). The PSI used in NDOT's PMS between 1980 and 1994 was based on the PSI relationship that was developed during the AASHO Road Test experiment as follows:

$$PSI = 5.03 - 1.91 \log(1+SV) - 1.38\, RD^2 - 0.01\, (C+P)^{0.5}$$

Where:

SV= Slope variance (10^{-6})

RD= rut depth (in)

C= cracking area ($ft^2/1000ft^2$)

P= patching area ($ft^2/1000ft^2$)

In 1995, NDOT modified the PSI equation using the following relationship:

$$PSI = 5*e^{-0.0041*IRI} - 1.38RD^2 - 0.01(C+P)^{0.5}$$

Where:

IRI= international roughness index (in/mile)

RD= rut depth (in)

C= cracking area ($ft^2/1000ft^2$)

P= patching area ($ft^2/1000ft^2$)

The four repair categories are as follows:

a. Do Nothing

III. DEVELOPMENT OF PAVEMENT PERFORMANCE MODELS

Routine maintenance and rehabilitation activities must be conducted in a timely manner to maintain an acceptable level of the present serviceability index (PSI) for a given pavement section. The major difference between maintenance and rehabilitation activities is that maintenance does not show an initial increase in the current level of PSI and only helps in slowing down the rate of deterioration while rehabilitation does show an initial increase in the PSI level and may completely change the rate of deterioration. Figure 7 shows the difference between the two techniques.

For example, when applying a chip seal, which is a maintenance treatment, a significant immediate increase in PSI is not noticed because a chip seal does not reduce roughness, a major component of the PSI equation. However, applying a chip seal, reduces or eliminates water penetration through the surface, thereby slowing further deterioration of the entire pavement structure. On the other hand, applying a thick overlay, which is a rehabilitation technique, immediately increases the current PSI of the road as well as slowing the rate of deterioration.

Usually the cost of a maintenance alternative is less than the cost of a rehabilitation technique. Therefore, in order to optimize the available budget and satisfy the needs of the entire system, highway agencies including NDOT strive to determine a balance between the maintenance and rehabilitation activities.

NDOT uses several maintenance treatments as well as various rehabilitation techniques. The objective of this task was to identify the various maintenance treatments and rehabilitation techniques most commonly used by NDOT and develop performance models for these techniques.

The performance data of the selected projects will constitute the data base for the development of the performance models.

III.1 Selection of Maintenance and Rehabilitation Techniques

The primary goal of the selection process was to assure that the techniques to be modeled had been used often enough that they would provide a useful final product for NDOT. If a technique was used only on a limited basis, then the available performance data would be very limited and the developed model would not be extremely useful.

The initial selections were made based on several working meetings between the researchers and NDOT engineers from the Materials and Operations Analysis Divisions. These initial selections were then presented to the pavement management working committee, which has representatives from NDOT, FHWA, and the research team for final approval. The final list included two maintenance treatments and three rehabilitation techniques which NDOT uses on a regular basis.

Maintenance Techniques	Rehabilitation Techniques
	Flexible Overlays
Sand Seals	Roadbed Modifications
Chip Seals	Mill and Overlays

Several other techniques were proposed such as flexible overlays over rigid pavements, rigid overlays over rigid pavements, rigid overlays over flexible pavements, and recycling of flexible pavements. After reviewing these techniques with NDOT personnel, it was decided that these techniques have not been used often enough to develop a sufficient data base for analysis.

III.2 Selection of Projects

Once the final list of maintenance and rehabilitation techniques was established, the research concentrated on establishing guidelines for the selection of projects within each technique. In establishing the project selection guidelines, one must keep in mind the overall objective of the research. As mentioned earlier, the developed models should be used to predict the future performance of the selected techniques. These models will use statistical analyses of actual PMS, environmental, and materials data. Therefore, several minimum requirements must be satisfied to make the statistical analysis appropriate. The following criteria were selected as guidelines for project selection:

1. **Minimum Number of Replicates:** Since the models will be based on statistical analyses, there must be multiple sets of data which share a common basis. For example, there must be multiple projects which share the same geographical location for the same treatment type. For this purpose, the existing NDOT districts were used as various regions and replicate projects were selected within each district.

2. **Minimum Site Length:** When using actual field data, it is very important to select sites that are representative of the entire pavement section. Short projects may suffer from atypical data especially toward the beginning and end of a project. In addition, short sections may have been constructed in response to a localized condition and not as a normal construction project. Therefore, it was decided that a minimum site length of two miles must be maintained to eliminate any unusual or localized conditions.

3. **Availability of Traffic History:** Traffic loads are the most important factors

influencing the long-term performance of pavements. The traffic data can be expressed in many different formats, including vehicles per day, percent trucks, equivalent 18,000-pound single axle loads (ESAL), etc. It was decided that each project must have traffic loading data. Since any type of traffic data can be converted to the required format providing that the appropriate conversion factors exist, the criterion for traffic data consisted of the availability of both traffic volumes and the appropriate conversion factors.

4. **Availability of Materials Data:** The unique feature of this study is the inclusion of materials data into the performance models. Therefore, the availability of materials data was considered as a criterion for the selection of any project. It was anticipated that in some cases elaborate materials data would exist while in other cases the data would be limited.

5. **Availability of Structural Information:** It is well known that the performance of a treatment will depend on the quality of the supporting structure. For example, a flexible overlay will perform better on a structurally strong pavement than on a weak pavement. Therefore, the structural information criterion included the availability of information on the thickness and type of the supporting layers.

6. **Availability of PMS Data:** As mentioned earlier, the actual field performance data represent the backbone of this study. Such data are summarized in a PMS data base. Therefore, the availability of the PMS data for the selected project is a very important criterion and must always be satisfied, otherwise the project can not be selected for analysis.

The existing NDOT districts lines were used as regional boundaries. Projects were selected for maintenance and rehabilitation techniques within each district. The projects selection criteria were strictly followed with very few exceptions; some projects that were just under 2 miles long were accepted due to the limited number of available projects. The selected projects are summarized in Tables 2 through 6.

III.3 Data Collection

Three categories of data were of interest: Structural, environmental , and PMS. From each of these general categories, a list of factors that could possibly affect the performance life of the pavement system was derived. In order to be unbiased, the lists of factors were developed before any of the actual data sources were examined.

The lists were organized into standard data collection forms to expedite the collection process. The forms became known as "wish lists," as they contained all of the information the researchers hoped they could obtain. The forms were divided into four primary sections:

1. Project identification and information;
2. Specific material and construction information on the technique of interest;
3. Information desired from the PMS data base, including environmental data;
4. Information on any past construction techniques and materials used within the bounds of the current project.

Standardizing the data collection forms created more efficient collection and reduction of the large amount of information. Figure 8 is an example of the form used for the overlay

activity; standard forms used for other techniques may be found in Appendix A.

In summary, the following data were collected and used in the development of performance models:

8) **Materials data of activity being modeled:** These data include the types and percentages of asphalt binder and aggregates used in the maintenance or rehabilitation activity for which the performance model is being developed.

9) **Materials data of existing pavement layers:** These data include the types and percentages of asphalt binder and aggregates used in the layers underlaying the maintenance or rehabilitation activity for which the performance model is being developed.

10) **Structural data:** These data include the thickness of the various layers in the pavement structure including the thickness of the maintenance or rehabilitation activity that is being modeled. The structural number (SN) as defined by the AASHTO design guide was used to normalize the structural data among all of the pavement section. Reference 3 describes the method used to convert the layer thicknesses into SN values.

11) **Pavement performance data:** These data include the PSI, percent cracking, and average rut depth values as obtained from the NDOT PMS data base.

12) **Traffic data:** The equivalent single axle load (ESAL) was used as the traffic element. The average daily ESAL figures were obtained from the PMS data base and used to obtain the cumulative ESALs over the life of the maintenance or rehabilitation activity.

13) **Environmental data:** These data include maximum and minimum temperatures, number of freeze/thaw cycles, number of wet days, and annual precipitation.

The process of obtaining and standardizing all of the necessary data elements has been extensively described in reference 3.

III.4 Model Development

The model development task was a multifaceted operation that involved a great deal of testing as well as regression analysis. The purpose of the model development was to provide a conceptually simple method for examining the functional relationships among variables. The task was divided into the following processes: data review, regression analysis, equation review and tests of reasonableness, equation modification, additional regression analysis, and final model selection.

All of the statistical and regression analyses were performed using the SAS Programming Language. The SAS software is a combination of programs originally designed to perform statistical analyses of data, complex data management and provide a high-level programming language.

III.4.a. Data Review

As discussed earlier, numerous projects were selected under each of the maintenance and rehabilitation treatments. Each project encompasses several miles of a roadway. The NDOT's PMS measures pavement performance at individual mileposts. Therefore, the

performance data of each project includes multiple measurements depending on the number of mileposts within each project. The most appropriate way would be to average the data and use the mean value as representative measure of the project's performance. However, prior to averaging the data, it was necessary to identify data points which do not fit the general trend. These points are referred to as "outliers". The presence of these "outliers" has the tendency of influencing the evaluated average and therefore provide a skewed measure of the projects performance.

The Inter Quartile Range (IQR) analysis was used to identify the outliers which would then be deleted from the data set prior to the calculation of the average. This analysis consists of identifying the first and third quartiles which are defined as follow:

Q1 = the value below which 25 percent of the data falls

Q3 = the value below which 75 percent of the data falls

The IQR is then defined as:

$$IQR = Q3 - Q1$$

Using the Q1, Q3, and IQR, the upper and lower limits of acceptable data can be calculated as follows:

$$\text{Lower Limit (LL)} = Q1 - 1.5*IQR$$

$$\text{Upper Limit (UL)} = Q3 + 1.5*IQR$$

Outliers are identified as data points that do not fit within the LL and UL limits.

Using the IQR analysis all of the PMS data were reviewed and outliers were eliminated prior to the use of the data in the development of performance models.

III.4.b. Regression Analysis and Model Selection

Linear regression analyses were used to develop relationships between pavement performance indicators and project properties. As indicated earlier, the project properties include structural, materials, environmental, and traffic data which are specific to each project section. The following performance indicators were identified as possibilities for modeling puproses:

14) Surface cracking

15) Permanent deformation or rutting (RD)

16) Surface roughness (IRI)

17) Present serviceability index (PSI)

Several forms of performance models were considered for each of the four performance indicators. The models forms included the followings:

18) Models for each individual district

19) Models for all districts combined

20) Models including materials properties

21) Models excluding materials properties

Sixteen models were developed for each maintenance and rehabilitation treatment which makes the overall number of models that were evaluated close to 50. The following criteria were used to identify the models that will be included in the system analysis process.

1. Reasonable fit of the data as described by the R-squared value.

2. Minimum error in the estimated performance as described by the root

mean square error (RMSE)

3. Good stability of the model as described by the ability of the model to predict performance over a wide range of parameters.

The application of the first and second criteria have shown serious limitations of the models developed for cracking and rutting performance. The R-squared values for such models were always below 0.25 and the RMSE were very large which made the prediction ability of these models very poor. The models for roughness and PSI showed good prediction abilities as described by high R-squared values and low RMSE. However it was decided that the PSI models would be used since the PSI is largely dependent on ride and includes some effects of the rut depth and surface cracking.

The next step was to assess the need for individual district models and whether or not material properties should be included in the models. Appendix B shows all the performance models for the various combinations of individual districts, combined districts, and with/without materials properties. By looking at the models parameters and implementing the three criteria identified above, it was concluded that the models based on the combined districts with materials properties should be used. The inclusion of materials properties greatly improved the prediction capability of the models and reduced the error associated with the estimated performance. The combined districts models offer slightly better prediction capabilities but significantly improved the stability of the models over a wide range of input variables. The selected models are presented in Tables 7 through 11.

III.4.c. Definition of Variables

As can be seen from Tables 7 through 11, the models include a large number of variables which must be provided in order for the models to be executed. In order to keep track of these variables, the following list describes the individual parameters, their source, and their corresponding units.

AC: Type of binder used in first the structural layer below the flush, sand and chip seal projects, located in as-built plans, identified as a type.

AGGRATE: Aggregate spread rate for chip and sand seal projects, found in maintenance records, lbs/yd^2.

AGGSIZE: Maximum nominal aggregate size used in chip seal projects, found in maintenance records, 3/8" or 1/2".

BINDRATE: Binder application rate for flush, sand and chip seal projects, found in maintenance records, gal/yd^2.

Binder: Type of binder used in maintenance or rehabilitation projects, found in maintenance records or as built plans, identified as a type. This variable is not part of the actual equation but it is used to select the binder constant which is part of the actual equation.

THICK: Depth or thickness of overlay used in rehabilitation projects, located in as-built plans, inches.

ESAL: Cumulative value of annual Equivalent 18,000-pound Single Axle Loads. The ESAL value fro year zero of a road segment is the product of 365 times the daily equivalent 18,000-pound single axle loads shown in the D18-kip field of the PMS database. For subsequent years, a growth factor is applied to the previous year's value. The cumulative value is the sum of the values from year zero through the year of interest.

FRZ: The total number of freeze/thaw cycles that a pavement may experience over the course of one year, obtained from the weather section of the PMS data base, cycles per year (one freeze and one thaw are counted

as one cyle).

RBDEPTH: Depth of road bed modification in inches. Located in the as built plans.

MAXTEMP: Maximum average yearly temperature that a pavement section may experience, obtained from the weather section of the PMS data base, degrees Fahrenheit.

MINTEMP: Minimum average yearly temperature that a pavement section may experience, obtained from the weather section of the PMS data base, degrees Fahrenheit.

SN: Structural number prior to application of any rehabilitation or maintenance technique. For roadbed modification (RBM), this structural number is calculated at the top of the cement treated base (CTB).

WETDAY: The total number of wet days. Days that moisture was recorded, over the course of one year, obtained from the weather section of PMS data base, days per year.

YEAR: Service year of the project. The year of construction is represented by year zero.

S5,S10, S15: Indicate the application of surface treatments at 5, 10, or 15 years after initial construction, respectively.

III.4.d. Model Limitations

One major drawback of the use of statistical analysis in developing pavement performance models is that the PMS data base does not include a full factorial experiment. In other words, some unrealistic combinations which are needed to complete the factorial design may not exist in the actual PMS. For example the combination of a structurally weak pavement and high ESAL's may never exist in reality. However, it is still needed to complete the factorial design.

Since complete factorial designs do not exist in actual PMS data bases, the statistical relationships will be limited to applications which lie within the boundaries of realistic

combinations of variables. Therefore, the statistically based models should only be used with realistic variables and combinations of variables. If unrealistic values or combinations are used in the models, the output of the models may prove to be highly unreliable. For example, if the model is used to predict the performance of a pavement section with a low structural number that is subjected to very high ESAL's, the output of the model may be very unrealistic. This results from the fact that pavements with low structural numbers are not built to carry high ESAL's and vice versa.

IV. DEVELOPMENT OF LIFE-CYCLE COST ANALYSIS

The objective of this task was to develop a life-cycle analysis for each maintenance and rehabilitation technique, using performance histories developed by the performance models. These specific life-cycle cost analyses were combined together to develop a network optimization system. The completion of this task required the performance of the following four individual subtasks:

1) Selection of Analyses and Parameters
2) Establishment of Performance Periods
3) Selection of Cost Factors
4) State Highway Agencies Survey

IV.1 Selection of Analyses and Parameters

Life-cycle cost analysis (LCCA) can be defined as the economic assessment over the useful life, expressed in terms of discounted dollars. In pavement engineering, life-cycle cost refers to all costs involved with the construction, maintenance, rehabilitation and user impacts of a pavement over a given analysis period. A LCCA enables the pavement engineer to optimize expenditures of available funds by providing an economic assessment of alternate design/rehabilitation/maintenance strategies. When future rehabilitation alternatives coincide with anticipated needs during the pavement service life, pavement maintenance and rehabilitation costs are minimized. A LCCA will distinguish the most economical alternative over time.

LCCA involves the following five steps:

1. Any and all initial treatment alternatives must be identified.

2. An analysis period and treatment scheme for each alternative must be

determined.

3. The cost of each alternative and annual maintenance must be determined.

4. The treatment alternatives must be compared on an economic basis.

5. The best treatment scheme must be selected based on the LCCA.

IV.1.a. Economic Analysis Method

AASHTO prescribes that one of two methods of economic analysis be used; Present Worth (PW) or Equivalent Uniform Annual Cost (EUAC), with preference given to the PW method (10).

The Present Worth method involves the conversion of any present and future expenses to the basis of today's dollar. The present worth of a future expenditure is equivalent to the amount of money that would need to be invested now at a given compound interest rate for the original investment plus interest to equal the expected cost at the time it is required. The summation of present worth costs are then compared for each alternative. The present worth equation is expressed as:

$$PW = F(1/(1+i)^n)$$

where:

F = A future sum of money at the end of n years

i = Discount rate

n = Number of years

The Equivalent Uniform Annual Cost method requires the conversion of all present and

future expenditures to a uniform annual cost (11). EUAC reduces all costs to a common basis of a uniform annual cost for comparison. Recurring costs, such as annual maintenance, are already expressed as annual costs and need not be discounted. The equivalent uniform annual cost equation is expressed as:

$$EUAC = PW(i(1+i)^n)/((1+i)^n-1)$$

where:

PW = Present worth

i = Discount rate

n = Number of years

It was recommended that this research project uses the PW method of economic analysis since it is the method recommended by AASHTO and the most commonly used state highway agencies.

IV.1.b. Discount Rate

When performing a life-cycle cost analysis, a discount rate is required to compare costs occurring at different points in time. A discount rate reduces the impact of future costs on the analysis, reflecting the fact that there is a time value to money. Discount rate can be defined as the difference between the market interest rate and inflation, using constant dollars. Constant dollars refers to an expression of costs stated at price levels prevailing at a particular (constant) date in time, whereas current dollars is an expression of costs stated at price levels prevailing at the time the costs are incurred. AASHTO recommends the constant dollar approach, rather than

the use of inflated or current dollars for economic analysis, because it avoids the need for speculation about future inflation in arriving at the economic merit of the alternative.

Discount rate may affect the outcome of a LCCA because certain alternatives may be favored by higher or lower discount rates. Using a low discount rate will favor alternatives with high initial costs because future costs are included at little more than face value. When high discount rates are used, alternatives which span costs over a long period of time will be favored because future costs are discounted in relation to the initial cost. If alternatives require similar rehabilitation and maintenance costs, the discount rate will have little effect on the analysis and initial costs will have the greatest effect.

Choosing an appropriate discount rate is not always simple, because the difference between interest and inflation rates is not constant over time. This makes it impossible to select a unique discount rate that will always be appropriate over time. Because we cannot predict discount rates for extended periods of time, it would be conservative to select a discount rate between 3.5 and 5 percent, as the discount rate has been within this range for many years (12). A discount rate of 4 percent has been most commonly employed in pavement LCCA. Discount rate must always be kept constant when comparing alternatives.

It was recommended that this research project employs the discount rate into the LCCA as a variable which would allow the flexibility of changing it in the future.

IV.1.c. Analysis Period

In order to conduct network optimization, an analysis period must be selected. An analysis period may contain several rehabilitation and maintenance treatments with each treatment having

a unique performance period. Therefore, the combination of multiple rehabilitation and maintenance treatments along with their corresponding performance periods should cover the entire analysis period. Figure 11 shows a 20-year analysis period which includes an AC overlay followed by two sand seals and then followed by a second AC overlay.

In the past, pavements were typically designed and analyzed for a 20-year performance period, since the original Interstate Highway Act of 1956 required that traffic be considered through 1976. It is now recommended that consideration be given to 20 year or longer analysis periods, since these may be better suited to the evaluation of alternative long-term strategies based on LCCA. It is also emphasized that the analysis period should be extended to include at least one rehabilitation treatment. The 1986 AASHTO Guide for the Design of Pavement Structures gives the following general guidelines for analysis periods for new construction:

Highway Class	Analysis Period (years)
High-Volume Urban	30 - 50
High-Volume Rural	20 - 50
Low-Volume Paved	15 - 25
Low-Volume Aggregate Surface	10 - 20

An analysis period of 25-40 years is recommended for NDOT's flexible pavements for new construction and 20 years maximum for rehabilitation.

When recommending the length of the analysis period, the following two issues should be considered: 1) Selecting an analysis period which represents the realistic life of asphalt mixtures, and 2) selecting an analysis period which ensures that one or two rehabilitation activities can be

included within the period. A 20-year analysis period would satisfy both issues: a) asphalt mixtures could experience severe aging and disintegration problems after 20 years and b) with the 20-year period at least one or maybe two overlay may be implemented.

IV.2 Establishment of Performance Periods

The performance period of a maintenance or a rehabilitation technique represents the length of time that the treatment would last prior to reaching an unacceptable level of service. In this case the PSI is used as the performance indicator. Therefore, the performance period will be the length of time between the time the treatment is applied and when the PSI reaches an unacceptable level on a scale of 0 to 5.0. This unacceptable serviceability is commonly referred to as the terminal PSI. NDOT uses the following critical values:

Flexible Pavements	Terminal PSI
Interstate, national highway system, and other routes with average daily traffic (ADT) > 750	2.5
All other routes with ADT < 750	2.0

The most important step in this analysis is to define the performance period for each maintenance and rehabilitation technique. The performance models will be used for this purpose. These models will generate a performance curve similar to the one shown in Figure 9 for each maintenance or rehabilitation technique used in Nevada (2 maintenance and 3 rehabilitation techniques can be modeled).

In addition to using the performance models, this task will perform a reality check for the

recommended performance periods. These reality checks are necessary because the actual performance period of the pavement would normally include other factors which can not be considered through the performance models. These factors include traffic accidents, high maintenance costs, specific site failures, etc. In addition, some roads sections were not maintained or rehabilitated at the time when their level of service dropped to the critical level due to budget constraints. Therefore, the reality checks were developed to provide guidance to the engineer in interpreting all the external factors which could not be handled through the performance models. These checks consisted of normal performance period for each maintenance and rehabilitation technique. Table 12 summarizes the performance periods used in the NDOT system. An extensive review of the process by which these performance periods were established has been presented in reference 13.

IV.3 Selection of Cost Factors

Cost factors are the costs associated with the LCCA that cover the full life cycle from initial design through the end of a performance period. There are several costs which must be considered in a life-cycle cost analysis for the comparison of rehabilitation and maintenance treatments. These costs include: first costs, annual maintenance costs, road user costs, and salvage value. The objective of this subtask was to identify these costs for use in the LCCA.

IV.3.a. First Costs

First costs include both the initial and construction costs which are related to the design and construction of the rehabilitation or maintenance treatment. Initial costs include the costs of

site investigation, traffic analysis, pavement and material design, and preparation of the final plans and specifications for the project.

First costs for the five common rehabilitation and maintenance (the same treatments that performance models were developed for) were obtained from NDOT's Operations Analysis Division. The first costs were given in units of dollars per square yard. All unit costs are on a statewide basis, in other words there is one price for each treatment for all districts. Table 13 summarize the rehabilitation and maintenance first costs as obtained from NDOT.

IV.3.b. Annual Maintenance Costs

The cost of annual maintenance after the application of a rehabilitation or maintenance treatment may significantly affect the life-cycle cost of that treatment. A treatment may appear inexpensive based on initial cost, but if excessive annual maintenance costs are required after placement of the treatment, the life cycle-cost of the treatment will not be favorable. NDOT's Maintenance Manual prescribes 10 maintenance activities (14). The maintenance activity numbers and their descriptions are listed in Table 14. One activity was added to the 10 NDOT activities and it was coded as activity 101.11. The data contained several instances where a flush, sand, or a chip seal was applied to only a small portion of a mile. Therefore activity 101.11 was established as a general seal activity to include flush, sand, and chip seals which covered less than 2500 square yards.

Maintenance data for all the projects that were used in the development of the performance curves were obtained from the Operations Analysis Division of NDOT. The data supplied included: project number, system and route, from and to mileposts, from and to dates, PSI,

maintenance activity number, units and costs for each maintenance activity performed on each mile of pavement. The first item that had to be addressed was to update the historical cost data into 1994 dollars. Because the data were obtained from 1981 to the present and maintenance costs have changed over that time period due to increased material and labor costs, it was necessary to bring all of the costs to a common time frame (1994). The construction cost index method was used to update the earlier costs to today's costs. The construction cost index method produces a current estimated cost based on the cost at the time it was incurred and an index which is based on actual historical price trends (15). The following equation was used:

$$C_c = C_o*(I_c/I_o)$$

where: C_c = Current estimated cost

C_o = Cost at other time "0"

I_c = Current index number

I_o = Index number at other time "0"

The index numbers employed were obtained from *Price Trends for Federal-Aid Highway Construction* as compiled by the Federal Highway Administration from reports by state transportation agencies (15)(1987 is the base year for this publication).

After updating the maintenance costs to the current year, relational plots were developed to determine general trends in annual maintenance costs. There were no distinguishable trends due to the high variability of the data. The data was further broken down by district and

rehabilitation or maintenance treatment. Again no distinguishable trends were observed due to the high variability of the data. There are many factors which could contribute to the variability in the data, including: geographical location, several climatic factors, asphalt cement and mixture properties, traffic, and even maintenance philosophy, to name a few. An example of different maintenance philosophies would be the engineer who fills the cracks as they first appear and the engineer who waits for the cracks to open up to the maximum allowable width under the Maintenance Management System (MMS) Manual of Instructions.

The overall objective was to develop a system by which annual maintenance costs could be established for each maintenance and rehabilitation technique with minimal variability. Several approaches were investigated, including the following:

1. Develop annual maintenance models which can predict annual maintenance costs as a function of PSI.

2. Develop a probability of occurrence and associated costs models which can predict the need for a certain type of annual maintenance and the associated cost in the years following a certain treatment.

3. Develop an overall maintenance cost system which predicts the total expenditures on a given treatment after the initial construction regardless of the type of annual maintenance being applied.

4. Develop a fixed period cumulative maintenance cost system which predicts the cumulative expenditures for a given treatment as a function of number of years after construction.

Reference 16 includes an extensive discussion of all four systems. The fourth system was the only one that showed a significant reduction in the variability of the annual maintenance costs. This system is described below.

Fixed Period Cumulative Maintenance Costs

As a final attempt to reduce the variability in the data, the fixed period cumulative annual maintenance costs were determined. The idea here was to cumulate the annual overall maintenance costs from year to year reducing the effect of cyclic maintenance on the overall cost variability. The data were sorted by district and rehabilitation or maintenance treatment. The total cost of all annual maintenance performed in each year following the application of a rehabilitation or maintenance treatment was determined for each project. These costs were then divided by the project length to obtain a cost per mile in each year. The cost per mile for each project was then divided by 7040 (one milex12 feet lane width =7040 yd^2) to obtain an overall annual maintenance cost per square yard for each project in each year. These costs were then cumulated from year to year for each project. For example, if a project received 0, 5, 0, 6, and 7 cents per square yard of maintenance in the first five years after a rehabilitation treatment, the cumulative maintenance costs would be 0, 5, 5, 11, and 18 cents per square yard in years 1 through 5 respectively. The cumulative cost for each project in each year was then summed and divided by the total number of projects in each year to determine the fixed period cumulative maintenance cost.

Additionally standard error and margin of error are evaluated. Standard error (σ_x) is a measure of the reliability of the mean (x), as an estimate of the mean probability distribution (μ). Standard error decreases in proportion to the square root of the number of observations; for example, it is necessary to quadruple the sample size in order to halve the standard deviation of the sampling distribution of the mean. Standard error may be represented as:

$$\sigma_x = (\sigma / n)$$

where:

σ = standard deviation of the probability distribution.

n = number of observations.

The margin of error is the range in which ninety-five percent of the maintenance costs will lay based on the mean. As an example, if a fixed period cumulative maintenance cost is 50 cents per square yard and the margin of error is 10 cents, then it may be stated that with 95 percent confidence, maintenance costs are between (50-10) = 40 and (50+10) = 60 cents, or simply, 50 cents +_ 10 cents. The margin of error is established by multiplying the standard error (σ_x) by the area (α) under a student t-distribution for a specified number of degrees of freedom. The number of degrees of freedom may be considered the same as the number of observations (n) in this case.

Using this approach, it was discovered that variability in maintenance costs goes down with time for a particular treatment until a point at which the variability starts to increase again, after which they may decrease again. Tables 15-19 summarize the average values of cumulative maintenance costs and their associated variability at various fixed periods for the maintenance and rehabilitation techniques. As previously mentioned, the cyclic nature of actual maintenance is the reason for this. The increase in variability usually occurs just beyond the average performance life of the treatment. This is reasonable because the number of projects which last longer than average obviously goes down and their associated maintenance costs typically go up, driving the standard error up. Based on this rational it is recommended that the fixed period cumulative maintenance cost be determined in a year in which variability is low for a particular treatment and that this cost be spread over the number of cumulated years. Variability is determined by inspecting the standard error relative to the mean, or simply what percentage of the mean the standard error is. The lower the percentage, the lower the variability.

For some maintenance and most rehabilitation treatments, there are two variability cycles. Therefore the cumulative maintenance cost at the end of the first cycle would be spread over the first cycle, and the cumulative maintenance costs for the second cycle would be spread over the second cycle. For example, for district 1 overlays the variability or error increases up to year 5, then drops in year 6 before increasing again in years 7 and 8, and finally drops again in year 10. The annual maintenance cost after applying an overlay in district 1 for the first six year would then be determined by dividing the mean cost for cumulative years 1 through 6 by six years ($0.453 per square yard divided by 6 years) = $0.0755 per square yard per year. Then for year 7 through 10 the annual maintenance cost would be [($0.523 - $0.453 per square yard) divided by 4 years)] = $0.018 per square yard per year. This requires that the first cycle maintenance costs be subtracted from the second cycle maintenance costs when performing LCCA, as described above.

The expected life of a treatment coupled with the periods in Tables 15 through 19 where the variability is relatively low will dictate the annual maintenance cost to employ. The following is a list of recommended cumulative years to be used for determining annual maintenance costs:

Treatment	Cumulative Year
Sand Seal District 1	4
Sand Seal District 2,3	3
Chip Seal District 1	5
Chip Seal District 2	3,6
Chip Seal District 3	3
AC Overlay District 1	6,10
AC Overlay District 2	6,9

AC Overlay District 3	5,10
Roadbed Modification District 1	3
Roadbed Modification District 2	6
Roadbed Modification District 3	6,8
Mill and Overlay Statewide	4,8

The variability in annual maintenance cost is significantly reduced when the cumulative approach is employed. It is also very useful when performing economic analysis where salvage value must be calculated, because only the cumulative maintenance cost up to the end of the analysis period need be included. It was recommended that this fixed period cumulative maintenance cost be employed for estimating annual maintenance costs.

IV.3.c. Road User Costs

Road user costs are associated with driving on the road. They consist of increase in travel time, increase in fuel consumption, increase in vehicle operation and maintenance costs, and accidents. It is very difficult to put monetary value on these items, especially accidents. Currently, there are models available for estimating traffic delay and user operating costs using the AASHTO guidelines. A traffic delay model was developed by Scrivner et al, and has been revised by others (17). This model basically aims to predict the length of delay as well as the number of vehicles delayed due to a construction project. Necessary input for the model includes: construction production rates, quantity of work to be done, average daily traffic, daily traffic distribution, traffic detour models, and traffic speed profiles. This information is not stored in

the PMS and would have to be gathered for each individual project. Obviously this model would require detailed study of each site prior to actual construction. This would be quite costly and therefore not worthwhile for most projects. Traffic delays, especially in urban areas, do need to be given serious consideration, however. Engineering judgement could play a significant role in this consideration. Employing several maintenance procedures over time, rather than overlaying, for instance, could reduce traffic delays and keep the motoring public happy.

Zaniewski developed an operating cost model for the FHWA (18). The model estimates operating costs based on a decrease in PSI. Zaniewski developed consumption rate tables for use with his model. His data are based on a five percent inflation rate, zero grade, and a fifty-five miles per hour operating speed. If Zaniewski's model were used, these tables would need to be continually updated to reflect current conditions. User input includes: detailed vehicle class distribution, initial PSI, terminal PSI, and PSI after completion of work. This model would also require detailed study of each site and would not be economically feasible for all projects.

Accident data is collected by the Department of Motor Vehicles (DMV) from respectable investigating agencies. Urban data is referenced by intersection and rural data is referenced by milepost. Rural data is sorted by computer, but urban data must be sorted by individual NDOT districts and summarized manually. Accidents that are directly related to or have the potential to be directly related to pavement condition are included in the PMS. Accidents that are potentially related to pavement condition include wet weather and pavement condition only. At the present time this data is only informational in the PMS, however, it can and does influence the prioritization and type of repair. At the present time NDOT is not collecting skid data on a defined basis and is not certain when or on what basis the skid data will be collected in the future.

Considering the extensive data requirements needed for the implementation of user costs and after consultation with NDOT's PMS Committee, it was recommended that user costs not be included in the LCCA.

IV.3.d. Salvage Value

Salvage value is the residual value of the pavement at the end of the performance period or its design life if they coincide. Salvage values may be positive or negative depending on the remaining life of the pavement at the end of the performance period. A situation in which a negative salvage value would be encountered would be when a roadway section has to be completely removed and replaced to be rehabilitated. This is a common scenario with rigid pavements. Salvage value must be expressed in terms of dollars.

There are three possible methods of determining salvage value. The economical analysis approach (PW or EUAC) employed in the analysis will dictate the method to be used. If PW analysis is used, a percentage of the initial construction cost should be applied for the salvage value. Fifty percent of the initial cost was most commonly cited for salvage value in the literature (7,8). If EUAC is employed, then the EUAC may be multiplied by the remaining life at the end of the analysis period to determine a salvage value. AASHTO recommends the use of PW analysis, which is the method most commonly found in the literature (10). The method used in the analysis to determine salvage value consists of multiplying the last construction or resurfacing cost applied to the section by the ratio of the unused expected life to the total expected life.

$$\text{Salvage Value} = C*(UL/TL)$$

where: C = Last rehabilitation or construction cost

UL = Unused life

TL = Total expected life

IV.4 State Highway Agencies Survey

The objective of this subtask was to gather information on what other states are currently using in the areas of prioritization, LCCA, and network optimization. Such investigation would provide guidance as to what really works in real life situations and will help to eliminate the processes which could not be implemented in the field.

As part of this subtask, letters were sent to all State Highway Agencies (SHA) in an attempt to determine what different agencies are using for Prioritization, Life-Cycle Cost Analysis, and Network Optimization schemes. Seventeen SHA's sent written responses. This was followed by telephone surveys with the SHA's that have not responded. Thirteen phone surveys were successfully collected, therefore a total of 30 agencies were surveyed. The findings concerning each of these items are discussed individually in the following section.

IV.4.a. Prioritization

The majority of the SHA's surveyed are prioritizing projects based on condition data accumulated annually and stored in their PMS databases. Agencies that don't prioritize on this basis either have not implemented a PMS or are using network optimization schemes. Table 20 indicates that a total of 28 SHA's out of 30 are presently employing prioritization process.

IV.4.b. Life-Cycle Cost Analysis

Twenty-three of the 30 (77%) agencies contacted are presently using LCCA in one form or another, however most are using it only on the project level. The majority of the agencies are performing their calculations by hand with a few exceptions who are using PC-based software (either commercial or developed in-house). For example, Colorado is using DARWIN 2.0 which was developed for the FHWA. Table 21 is a summary of the LCCA survey results. The agencies that are not using LCCA have implementation plans in the near future.

The majority of the agencies employing LCCA are using it to compare asphalt concrete with portland cement concrete alternatives for new roadway surfaces. Pavement performance models were not typically used in these analyses. Most states have fixed maintenance and rehabilitation strategies which are employed for the LCCA, based on historical data and engineering judgement. Oregon is using a probabilistic approach which is fairly simple, but probabilities are assigned to different repair strategies used which could be difficult to define/verify. Kansas uses the Markov principle in its LCCA.

IV.4.c. Economic Analysis

All agencies surveyed are using the present worth analysis method with the exception of two, which are using both the present worth and equivalent uniform annual cost methods.

IV.4.d. Analysis Period

Analysis periods ranged from 20 to 60 years. The majority of SHA's used 20 to 40 years which is in-line with AASHTO recommendations. A few states, like New York, use the longest

of all possible alternatives, all of which must include at least one rehabilitation. Pennsylvania uses 20 years for rehabilitation and maintenance of existing roadways and 40 years for new construction.

IV.4.e. Discount Rate

Discount rate, which is the difference between market interest rate and inflation, ranged from 3 to 7 percent. Sixty-two percent of the SHA's surveyed employed a rate of 4 percent. South Carolina starts with 4 percent and performs a sensitivity analysis on the LCCA using higher and lower rates to arrive at a final rate. Two agencies do not use discount rates, they use the construction price index to estimate the cost of future construction.

IV.4.f. User Costs

Only seven of the agencies are including user costs in their LCCA. Several states have attempted to include user costs, but found them difficult to quantify or that they commonly skewed the analysis. Some states felt they lacked the necessary database for calculation, but most indicated that user costs, when calculated, were generally high relative to the other costs involved. Washington and Maryland only include costs related to traffic delays. Pennsylvania includes user costs on high volume roads only, and Montana includes them in all initial analysis, but they are often dropped in the final analysis.

IV.4.g. Salvage Value

Salvage value is considered in LCCA by 62% of the SHA's surveyed. Some agencies

calculate salvage value as a percentage of the initial construction cost, while others applied EUAC times remaining life or the last rehabilitation cost times the ratio of remaining life to total life. Illinois and Indiana only consider salvage value when the existing roadway surface is recycled, and Arizona uses the condition of the roadway surface as a base for a salvage value. The longer the analysis period, the lower the salvage value will be using the PW analysis. For this reason Iowa doesn't consider salvage value because an analysis period of 50 to 60 years is used.

IV.4.h. Network Optimization

Seven of the SHA's surveyed claimed to be employing network optimization, and several are attempting to develop and implement it. The basis of the systems that are presently being used is fundamentally the same. A threshold roadway condition, for example minimum PSI, is established and the objective of the network optimization is to maintain the entire state roadway system at or above this threshold with a given budget. Some states allow a small percentage of low-volume roads to drop below the threshold in the optimization process.

V. OPTIMIZATION ANALYSIS

The objective of this task was to develop a system to prioritize the various rehabilitation or maintenance techniques and to recommend a technique which will provide the best performance at the lowest cost. This task provides the pavement engineer a system by which to compare the various rehabilitation alternatives (treatments or sequences). For example, the pavement engineer will be able to compare the performance and economic benefits generated by applying an overlay followed by a chip seal and followed by another overlay versus applying two consecutive chip seals followed by an overlay and then followed by two consecutive chip seals. Both of these schemes will lead to the same analysis period but each one will have different cost figures spanned over the entire period.

In order to develop a network optimization system, several factors must be established in addition to the performance models and the LCCA. These factors are discussed below.

V.1 Pavement Segments Data Base

In order for any agency to be able to conduct network optimization, it must have a full inventory of the current pavement network. The current NDOT PMS evaluates pavement performance based on milepost units. Conducting optimization by milepost units would present an overwhelming problem. This approach was found to be unrealistic and unpractical. Therefore, it was recommended that the NDOT pavement network be divided into pavement sections where each segment would be considered a unique project.

Following this recommendation it was decided to subdivide the pavement network based

on the following criteria:

- Pavement type
- Pavement classification
- Pavement structure

Following the above criteria, the entire NDOT pavement network was divided into 658 segments with each segment presenting close to uniform conditions. The segments were numbered using a combination of route numbers and numerical values while allowing for future expansion of the data base through the subdivision of existing segments due to changes in the conditions within the segments. For example, two consecutive segments on interstate 80 are numbered as IR080180 and IR080190. The reason the numerical numbering jumped from 180 to 190 is to allow for future insertion of a segment between the two segments.

Once the segment identification and numbering task was completed, a data base was established which provides all the necessary input parameters for the full analysis of each pavement segment. Figure 10 shows a typical section of the segment data base. The information included in this data base must be updated every year to reflect changes in the structural, environmental and performance data of the pavement segments.

V.2 Selecting the Best Action

The serviceability of any pavement section can be upgraded through rehabilitation or maintenance activities. The decision on whether to apply a rehabilitation or a maintenance action should be driven by the current serviceability of the pavement section along with the policy of the

agency. For example, if a pavement section has a current PSI level of 2.5, the section should be recommended for rehabilitation instead of maintenance. The engineer assigning the action should be very well aware of the fundamental differences that exist between rehabilitation and maintenance and where each type of action can provide the most benefit.

NDOT uses the PMS system along with the 3R committee to select the appropriate action to be taken for any pavement section. As discussed earlier, the NDOT PMS system combines the actual pavement conditions along with traffic, environment, accident, and previous maintenance activity data to come up with a recommended action. Using the PMS recommendations along with the observations of the 3R committee presents the best approach since it combines the actual performance data with the experience of the 3R committee personnel. The researchers believe that the current NDOT approach is an excellent one and decided to use it in the network optimization process.

V.3 Generating Alternative Designs

Identifying all potential alternatives that will satisfy design or rehabilitation requirements is a critical step in the network optimization process. For a proposed pavement project, there will be various alternatives to choose from including several combinations of rehabilitation and maintenance treatments. To an extent, the alternative choices will be dictated by the condition of the pavement surface (at least the first action).

An initial thorough understanding of the design parameters for the particular pavement being planned must be grasped, followed by identification of all possible alternatives using creative thinking or brainstorming. The objective here is to generate a range of possible solutions

to the problem.

It is expected that pavement engineers will be using this system to identify the best alternative to be used for a given highway segment. It should also be recognized that not all engineers share the same common believes when it comes to what type of treatment works best on a given class of road. Therefore, selecting multiple alternatives for the network optimization process must be flexible enough where individual engineers can input their personal experiences. The engineers must also be aware of the current agency's policy on maintenance and rehabilitation. For example, NDOT does not allow the use of chip seals and sand seals on interstate routes, therefore, selecting an alternative which uses these activities on interstate routes would be meaningless.

The network optimization system developed in this research recommends four default alternatives for each of maintenance and rehabilitation actions. The default alternatives were established based on the experience of the research team and discussions with NDOT personnel. Each of the alternatives however, can be modified by the engineer conducting the analysis. This option was provided to allow the maximum flexibility for the engineer to use their experience.

V.4 Optimization Process

The optimization process consists of selecting the best alternative for a given pavement section. This analysis relies on the various steps and processes that have been identified earlier, including: performance modeling, life-cycle cost analysis, selection of best action, and generating of alternative designs.

The optimization process is conducted on individual segments regardless of how many

sections are being selected at one time. The overall process consists of the following seven steps:

1) The engineer is requested to select the best repair to be taken on a given pavement section. This selection includes two options: maintenance or rehabilitation. The engineer should rely on the combined recommendations of the PMS and the 3R committee.

2) Once the repair is selected, the engineer is given the opportunity to look at the various data concerning the section that is being analyzed. These data include: weather, traffic, structural, and economic parameters. At this stage, the engineer can modify any data element or stay with the default values. It should be recognized that the default values represent the best estimate of these parameters that the researchers identified based on the most current section information.

3) After the engineer reviews and modifies whatever necessary in the input parameters list, he/she is given a chance to review the recommended alternatives. Again, the engineer is given the choice of accepting the recommended alternatives or modify them as he/she sees fit. A total of four alternatives are given for each action (i.e. maintenance or rehabilitation). The engineers does not have to activate all four alternatives. The total number of active alternatives can range between 1 an 4.

4) Once the engineer completes the selection of input parameters and the appropriate alternatives, the performance modeling process starts. This process uses the performance models to estimate the variation of the PSI as a function of the pavement age. The result of this analysis is a graphical relationship between the PSI and pavement age similar to the one shown in Figure 12.

5) The relationship between PSI and pavement age is then used to perform the LCCA. The LCCA uses the economic analysis identified in Chapter 4. The result of this analysis is a summary of the annual cost over the entire analysis period.

6) Using the PSI versus age and the cost summary, the optimization process evaluates the benefit-cost ratio for each alternative.

$$\text{Benefit-Cost Ratio} = \frac{\text{Area under the PSI versus age curve}}{\text{Total cost per square yard } (\$/yd^2)}$$

7) Using the benefit-cost ratio for each alternative, the optimization process selects the most desirable alternative as being the one generating the highest ratio.

V.5 Network Optimization Analysis

As mentioned above, the optimization process is conducted by executing steps 1 through 7 on every pavement section. Using this approach, the engineer can conduct a full network optimization analysis following any one of the following three options:

1. Project-Level Analysis
2. System Analysis
3. Complete Network Analysis

Each one of the above options offers a different method of conducting the network optimization process. The term "full analysis" in each of the processes means that performance modeling, LCCA, and benefit-cost ratio analyses will be conducted for each alternative.

V.5.a. Project-Level Analysis

This option allows the engineer to conduct full analysis for one pavement section at a time. It provides the highest flexibility in modifying input parameters, and changing alternatives. The engineer can conduct the analysis while changing any input parameter and selecting any combination of alternatives. The analysis generates a PSI versus age relationship, cost summary table, and a benefit-cost ratio for each alternative as shown in Figures 13 and 14. The engineer can use this data to decide on the best action to be taken for a given pavement section.

The project-level analysis is offered to the engineer to evaluate the impact of various parameters on the expected pavement performance. Using this analysis, the engineer can assess the significance of weather, traffic, materials, and structural parameters on the expected performance of a given maintenance or rehabilitation treatment.

Even though the project level analysis is provided to allow the utmost flexibility while analyzing individual pavement sections, this analysis can also be used to conduct complete network optimization. If the engineer elected to conduct network optimization using the project level analysis, he/she will have to assess each segment individually and manually combine the results to derive network optimization recommendations. The question becomes, why would the engineer elect to use the project level to optimize the network if it involves lots of manual work? The answer to this question is that the project-level analysis provides the utmost flexibility when analyzing individual pavement sections which can not be achieved in the more automated analyses (i.e., system analysis and complete network analysis). For example, in the case of the system-analysis process, the engineer can analyze numerous pavement sections at one time and generate summary recommendations concerning each individual section, however, the selection of some input parameters and the evaluated alternatives will have to be common for all the evaluated sections.

V.5.b. System Analysis

This option allows the engineer to conduct full analysis for a user-selected group of pavement sections. The objective of this analysis is to provide the engineer with an analysis tool to respond to the 3R committee recommendations without having to conduct the full analysis on each individual section. The process used in this system analysis can be summarized as follows:

1. The PMS and 3R committee recommendations are presented to the engineer.
2. The engineer identifies the pavement sections that are recommended for maintenance and the pavement sections that are recommended for rehabilitation.

3. The engineer selects the appropriate input parameters and the alternatives to be used for each group of projects. The majority of input parameters will be set on their default values while some limited parameters can be modified for each group of sections (refer to the software users manual for details on the various input options). The alternatives will then be selected by the engineer. The same set of alternatives will be evaluated for each group of sections (i.e. maintenance or rehabilitation). At this stage, the engineer can use the default set of alternatives or he/she can modify them as needed.

4. The result of this analysis will consist of a graphical relationship of PSI versus age and a cost summary table for each pavement section for the most effective alternative as shown in Figures 15 and 16. Figure 15 shows a typical graphical presentation where the PSI versus age relationship is presented for the most effective alternative. The difference between this figure and Figure 13 is that Figure 13 provides the engineer with the option of printing any one alternative while Figure 15 only prints the most effective alternative based on the benefit-cost ratio.

5. A cumulative cost summary table is also produced (Figure 16). This table presents a ranking of the pavement sections in terms of their benefit-cost ratios and the annual expenditures associated with the group of sections recommended for maintenance and those recommended for rehabilitation.

Using the above analysis along with the cumulative summary table, the engineer can optimize the network by recommending the projects with the highest ranking while at the same time matching the available budget with the projected cumulative cost. The summary also provides an indication as to how much expenditures are needed for maintenance and how much are needed for rehabilitation. Also the PSI versus age relationships for the individual sections provide the engineer with an expanded picture for the entire network.

V.5.c. Complete Network Analysis

This analysis option is a fully automated one with very limited flexibility. The objective of this option is to conduct analysis for the entire state pavement network. All 650^{+} sections are

analyzed at once and a cumulative cost summary table is presented for the entire network. The network sections are divided into the following three action categories.

- Annual routine maintenance
- Maintenance
- Rehabilitation

The criterion used to categorize the pavement sections is based on the current PSI level of the pavement section. The engineer is allowed to provide the threshold PSI levels which delineates the three action categories. The following values represent the default PSI threshold levels provided in the current analysis:

	PSI Upper Limit (PSI-UL)	PSI Lower Limit (PSI-LL)
Interstate Routes	4.1	3.5
U.S. Routes	4.0	3.0
State Routes	4.0	2.5

Where:

PSI > PSI-UL	Annual Routine Maintenance
PSI-LL < PSI < PSI-UL	Maintenance
PSI < PSI-LL	Rehabilitation

Once the PSI thresholds are provided, the segments data base is accessed and the pavement sections are classified into their respective action categories. Each category of pavement sections is then subjected to a full life-cycle cost analysis and the best sequence of treatments is selected

for each pavement section. Because it is difficult to assess the immediate impact of annual routine maintenance activities on the PSI, the pavement sections that are initially categorized into the annual routine maintenance category are subjected to five years of routine maintenance and then moved into the maintenance category.

The cumulative cost summary table is then produced for the entire network, ranking the sections based on their benefit-cost ratios and providing the cumulative cost for each year. Table 22 shows portions of the cumulative cost summary for the complete network analysis. The first part of the table shows the cost figures for years 0 through 5 for the pavement sections that were categorized into annual routine maintenance. As discussed earlier, these projects are scheduled for routine maintenance for the first five years and then moved into the maintenance category as shown under year 5. The activity shown for each project at year 5 represents the first activity of the most effective alternative for that project selected based on the benefit-cost ratio data. The second part of Table 22 shows the cost figures for years 0 through 2 for the pavement sections that were categorized into maintenance. The activity shown for each project at year 0 represents the first activity of the most effective alternative for that project selected based on the benefit-cost ratio data. Following year 0, these projects are then subjected to annual routine maintenance activities until such time that the second activity in the alternative kicks in for each project.

Using the complete network analysis, the engineer can establish the funding requirements for the entire network. It should be noted, however, that the funding requirements are based on the current state of the network and these requirements will change as the state of the network changes. In other words as the agency maintains and rehabilitates some sections, the state of the network would change from one year to another and therefore, the funds requirements, as

established through the complete network analysis, will change accordingly. One major advantage of the complete network analysis is that it provides the engineer with the opportunity to evaluate the impact of changing the pavement performance criterion (i.e., PSI threshold) on the required level of expenditures. For example, the engineer can change the PSI threshold used to separate between the maintenance and rehabilitation actions and evaluate its impact on the required level of funds.

VI. SUMMARY AND RECOMMENDATIONS

A computerized method has been develop to conduct network optimization analysis. The analysis uses pavement performance models generated based on NDOT's pavement performance data along with life-cycle cost analysis to identify the most effective treatment to be applied for a specific pavement section.

Using regression analyses, performance models were developed for the most common maintenance treatments: sand and chip seals, and rehabilitation treatments: overlay, roadbed modification, and mill and overlay. The models were developed using actual pavement management data collected on field sections for the past 15 years. All the available pavement sections for each of the maintenance and rehabilitation treatments were used in the development of performance models (a total of 319 projects). For each pavement section, the structural, materials, traffic, environmental, and condition data were collected and used in a statistical analysis to develop the performance models. The majority of the models resulted in high R^2 values which indicate a good fit of the field performance data.

The life-cycle cost analysis (LCCA) generates the total costs needed to construct a given alternative. An alternative is defined as a sequence of maintenance and/or rehabilitation treatments necessary to carry a pavement section for the 20-year analysis period above a desired level of performance. The LCCA uses the present worth approach to convert future expenditures into current dollars for comparing alternatives. The LCCA includes both initial construction and annual routine maintenance costs for the alternative selected on each pavement section. User costs are not included in the LCCA process but salvage values are considered.

In summary, the individual treatments are used to create alternatives that can provide the acceptable performance level for a given pavement section over the entire analysis period of 20 years. The performance of pavement sections is modeled in terms of the present serviceability index (PSI). The LCCA is used to generate the present cost for each alternative. The most effective alternative is selected based on the highest benefit-cost ratio which is defined as the ratio of the area under the PSI vs. age curve divided by the total cost of the alternative. Once the most effective alternative is selected for each pavement section, a summary of annual expenditures is provided for the group of pavement sections that have been selected for analysis. The group of projects can be the entire network or a group of pavement sections that have been selected by the engineer.

Based on the research conducted in this project, the following recommendations can be made:

- The roadbed modification model should be used with extreme caution. The performance models represent the best estimate of performance based on the PMS data that have been collected for the past 15 years. The majority of the models resulted in a good fit of the data, except for the roadbed modification model which showed a R^2 value lower than 50%. This lack of good fit for the roadbed modification activity is attributed to the low number of roadbed modification projects which went through their entire life cycle. In other words, most of the roadbed modification projects required more performance years than were available in NDOT's PMS.

- The inclusion of material properties made a significant difference in the ability of the developed models to fit the measured performance data. Therefore, it is recommended that NDOT keeps good records of materials properties to effectively model the performance of maintenance and rehabilitation activities. Also the combination of all districts into one statewide model for each treatment provide good stability of the model over a wide range of parameters.

- The LCCA process uses the fixed period cumulative annual routine maintenance costs. This method showed the least variability in the routine maintenance costs and should be updated routinely to reflect the actual costs for a given time period.

- The entire NDOT pavement network was divided into 658 pavement sections. The appropriate information for these sections have been summarized into a data base which is used to conduct the network optimization analysis. It is highly critical that this data base be kept up to date to reflect the current conditions of the entire network. If this data base is not kept up to date, the network optimization analysis will produce erroneous results.

- NDOT should use this system to conduct all levels of optimization: project analysis, systems analysis, and entire network. This system represents the best optimization analysis that can be conducted using the current PMS data. Future updates of the system should be considered at five-year intervals to incorporate new materials and new design techniques. Updates at shorter intervals are not recommended due to their ineffectiveness in capturing the true contribution of new materials, and new design techniques.

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Table 1. Discretized Continuous Probability Distributions.

Interval	Representative Value
$X_{0.9}$- $X_{1.0}$	$X_{0.95}$
$X_{0.8}$- $X_{0.9}$	$X_{0.85}$
$X_{0.7}$- $X_{0.8}$	$X_{0.75}$
$X_{0.6}$- $X_{0.7}$	$X_{0.65}$
$X_{0.5}$- $X_{0.6}$	$X_{0.55}$
$X_{0.4}$- $X_{0.5}$	$X_{0.45}$
$X_{0.3}$- $X_{0.4}$	$X_{0.35}$
$X_{0.2}$- $X_{0.3}$	$X_{0.25}$
$X_{0.1}$- $X_{0.2}$	$X_{0.15}$
$X_{0.0}$- $X_{0.1}$	$X_{0.05}$

Table 2. List of Projects Used in Developing the Sand Seal Performance Models.

Project	Contract	District	Route	County	Begin MilePost	End Milepost
SS 101	MTN CL14488	1	SR144	CL	0	3.32
SS 102	MTN CL16587	1	SR165	CL	0	1.1
SS 103	MTN CL16588	1	SR165	CL	0.5	11
SS 104	MTN CL16587	1	SR165	CL	1.1	1.75
SS 105	1987	1	SR573	CL	21.46	23.66
SS 106	1987	1	SR574	CL	21.46	23.41
SS 107	1989	1	SR610	CL	0	2.03
SS 108	1988	1	US006	NY	1.8	7.44
SS 109	1989	1	US006	NY	7.3	14.2
SS 109	1989	1	US006	NY	7.3	14.2
SS 110	1989	1	SR376	NY	15.3	25.03
SS 111	1988	1	US006	NY	1.8	7.44
SS 201	1991	2	SR427	LY	0	5.2
SS 202	1989	2	SR431	WA	0	8.14
SS 203	1988	2	SR431	WA	0	8.14
SS 204	1989	2	SR854	PE	0	4
SS 205	1989	2	SR341	WA	14.54	20.5
SS 205	1992	2	US050	CH	31.7	43.9
SS 206	1990	2	US050	CH	43.71	53.7
SS 206	1988	2	SR396	PE	13	28
SS 207	1987	2	SR398	PE	0	4.3
SS 208	1988	2	SR431	WA	0	8.14
SS 209	1988	2	SR342	ST	0	2.6
SS 210	1987	2	SR396	PE	0	13
SS 211	1990	2	SR397	PE	0	11.4
SS 212	1989	2	SR431	WA	20	24.53
SS 213	1990	2	SR839	CH	0	13.92
SS 214	1990	2	SR839	MI	74.82	78.97
SS 301	MTN HU8088	3	IR080	HU	17.4	29.5
SS 302	MTN LA8091	3	IR080	LA	15.19	26.97
SS 303	MTN HU14088	3	SR140	HU	60.3	65.58
SS 304	1987	3	SR790	HU	0	0.51
SS 305	1990	3	SR793	HU	0.7	5.14
SS 306	1990	3	SR793	HU	10.21	10.99
SS 307	1990	3	SR793	HU	5.14	10.21
SS 308	1991	3	US093	EL	102.8	112.8
SS 309	1991	3	US093A	EL	24.85	39.05
SS 310	1988	3	SR305	LA	98.2	109.18
SS 311	1988	3	IR080	HU	17.95	29.3
SS 311	1989	3	SR794	HU	14.62	17.1
SS 312	1987	3	SR306	EU	12.8	20.43

Table 3. List of Projects Used in Developing the Chip Seal Performance Models.

Project	Contract	Route	District	County	Begin Milepost	End Milepost
CS101	MTN CL17088	SR170	1	CL	2.32	8.3
CS102	MTN LN31988	SR319	1	LN	60	70.91
CS103	MTN CL60490	SR604	1	CL	12.84	28.5
CS104	MTN NY691A	US006	1	NY	112.1	118
CS104	MTN NY691A	US006	1	NY	112.1	118
CS105	MTN LN9393K	US093	1	LN	39.6	48.7
CS105	MTN LN9393A	US093	1	LN	39.6	48.7
CS106	MTN LN9393E	US093	1	LN	161	163
CS107	MTN LN9393C	US093	1	LN	168.2	162.87
CS108	MTN NY9591	US095	1	NY	58.75	72
CS109	MTN ES9589B	US095	1	ES	20	31.58
CS110	MTN MI9590D	US095	1	MI	25.55	28
CS113	1987	SR160	1	NY	22	26
CS114	1984	SR160	1	NY	22	34
CS115	1986	SR160	1	NY	6.3	11
CS116	1989	SR319	1	LN	51.5	59
CS117	1989	US093	1	LN	39.7	46.46
CS119	1989	US093	1	LN	55	64.66
CS120	1987	US093	1	CL	13.3	16.62
CS122	1986	US095	1	CL	106	111
CS123	1984	US095	1	NY	8.98	15
CS124	1984	US095	1	CL	124	130.14
CS125	1988	US095	1	NY	7	14.37
CS201	MTN CH71592	SR715	2	CH	1.34	2.14
CS202	MTN MI35995	US050	2	CH	31.6	31.9
CS203	MTN MI9589	US095	2	MI	40	49
CS203	MTN MI9589	US095	2	MI	40	49
CS204	MTN MI9590C	US095	2	MI	49	49.26
CS205	MTN LY95A90	US095A	2	LY	0	1.2

Table 3. List of Projects Used in Developing the Chip Seal Performance Models (Cont.).

Project	Contract	Route	District	County	Begin Milepost	End Milepost
CS206	MTN LY95A92	US095A	2	LY	1.3	12.46
CS207	MTN LY95A94	US095A	2	LY	39.3	41.4
CS208	MTN LY95A94B	US095A	2	LY	35.6	38
CS209	MTN LY95A94	US095A	2	LY	41.4	44.25
CS210	MTN LY95A94B	US095A	2	LY	31.3	33.4
CS211	MTN LY95A94B	US095A	2	LY	27.5	31.3
CS212	MTN LY95A94B	US095A	2	LY	25.6	33.4
CS213	MTN LY95A94B	US095A	2	LY	24.7	26.2
CS214	MTN LY95A89A	US095A	2	LY	47.08	49.95
CS215	MTN LY95A89A	US095A	2	LY	49.95	52.72
CS216	MTN LY95A89A	US095A	2	LY	52.72	55.54
CS217	MTN LY95A89A	US095A	2	LY	55.54	58.36
CS218	MTN DO39590	US395	2	DO	21	22.3
CS219	MTN WA39591B	US395	2	WA	36.03	38.46
CS220	MTN WA39592	US395	2	WA	31.8	34.8
CS222	1985	IR080	2	PE	26.21	37.68
CS223	2206	IR080	2	WA	41.7	4.11
CS224	2208	IR080	2	PE	37.7	43.55
CS225	2208	IR080	2	PE	12	16.47
CS226	1987	SR208	2	LY	20.04	25.84
CS227	1988	SR429	2	WA	3.5	7.38
CS228	1988	SR429	2	WA	1.51	3.5
CS229	1986	US050	2	LY	8.32	18.37
CS230	1986	US050	2	CH	16.04	20.66
CS231	1986	US050	2	CC	0.7	7.6
CS232	2147	US050	2	CH	70	100
CS233	1985	US095A	2	MI	0	5.92
CS234	1986	US395	2	DO	4.53	10
CS235	1986	US395	2	WA	1.03	9.15
CS301	MTN HU14090	SR140	3	HU	88	96
CS302	MTN EL22592	SR225	3	EL	38	54.9
CS303	MTN E	SR225	3	EL	48	54.37

Table 3. List of Projects Used in Developing the Chip Seal Performance Models (Cont.).

Project	Contract	Route	District	County	Begin Milepost	End Milepost
CS304	MTN EL22592	SR225	3	EL	66.9	75.5
CS305	MTN EL22692	SR226	3	EL	17.6	39.02
CS306	MTN E..	SR227	3	EL	7	11.2
CS307	MTN E	SR227	3	EL	11.1	20.1
CS308	MTN EL22794	SR227	3	EL	13.7	20.1
CS309	MTN E	SR228	3	EL	19.95	33.7
CS310	MTN EL23292	SR232	3	EL	2.62	17.15
CS311	MTN NY31888	SR318	3	NY	0	18.58
CS312	MTN NY31895	SR318	3	NY	0	18.58
CS313	MTN WP5089A	US050	3	WP	0	3.1
CS314	MTN WP5087A	US050	3	WP	61.5	66.25
CS315	MTN WP9394B	US093	3	WP	56.55	59
CS316	MTN WP9393C	US093	3	WP	99.5	112.76
CS317	MTN EL9390A	US093	3	EL	112.8	120.5
CS318	MTN EL93A93B	US093A	3	EL	24.85	39
CS319	MTN HU9594A	US095	3	HU	22.09	32
CS320	1987	IR080	3	HU	36	42.19
CS321	1988	IR080	3	EL	43.9	51
CS322	1987	IR080	3	EL	95.2	102.79
CS323	1988	IR080	3	HU	29.51	33
CS324	1987	SR290	3	HU	0.63	4
CS325	1986	US006	3	WP	14.19	18.99
CS326	1987	US006	3	WP	1.8	8.37
CS327	2255	US050	3	EU	2.33	7
CS328	2255	US050	3	LA	35.59	40
CS329	1986	US093	3	WP	56.65	60.8
CS330	1986	US093	3	EL	77.34	83.2
CS331	1987	US093A	3	EL	9.03	12.38

Table 4. List of Projects Used in Developing the Flexible Overlay Performance Models.

Project	Contract	Route	District	County	Begin Milepost	End Milepost
OL101	1835	IR015	1	CL	26.11	34.86
OL102	1837	IR015	1	CL	50.12	66.73
OL103	1836	IR015	1	CL	76.65	95.53
OL104	2291	SR146	1	CL	0	10.08
OL105	1806	SR318	1	LN	4.7	20.91
OL106	1857	SR318	1	LN	20.91	43.23
OL107	1950	SR318	1	LN	43.12	49.42
OL108	2155	SR360	1	MI	0	23.24
OL109	1945	SR601	1	CL	0	3.17
OL110	1984	US093	1	CL	5.67	7.63
OL111	2162	US095	1	CL	11.1	12.03
OL112	2162	US095	1	CL	12.03	17.12
OL113	2162	US095	1	CL	17.52	19
OL114	2162	US095	1	CL	17.12	17.52
OL115	2056	US095	1	CL	26	35.41
OL116	2056	US095	1	CL	29.13	29.54
OL117	2056	US095	1	CL	28.54	29.13
OL118	2056	US095	1	CL	29.13	29.54
OL119	1988	US095	1	NY	56.23	72
OL120	1825	US095	1	ES	29.88	30.96
OL121	2282	US095	1	ES	85.7	94.2
OL122	2282	US095	1	ES	85.24	85.7
OL123	2140	US095	1	MI	1.74	3.01
OL124	2140	US095	1	MI	0.6	1.22
OL201	1868	IR080	2	PE	0	11.34
OL202	1851	IR080	2	PE	37.68	51.33
OL203	2150	SR427	2	LY	0.11	5.45
OL204	2261	US050	2	CC	12.97	15.22
OL205	2505	US095	2	MI	64.01	69.81
OL206	2505	US095	2	MI	62.54	64.01
OL207	1971	US095A	2	LY	44.24	54.49

Table 4. List of Projects Used in Developing the Flexible Overlay Performance Models (Cont.).

Project	Contract	Route	District	County	Begin Milepost	End Milepost
OL208	2562	US095A	2	LY	44.63	58.75
OL209	1971	US095A	2	LY	54.49	58.36
OL210	2135	US395	2	DO	22.86	23.25
OL301	2420	IR080	3	HU	28.42	29.38
OL302	2518	IR080	3	HU	36.3	40.6
OL303	2415	SR140	3	HU	0	14.94
OL304	2159	SR226	3	EL	17.42	39.02
OL305	2333	SR233	3	EL	22.72	34.17
OL306	2388	SR304	3	LA	6.42	6.71
OL307	2388	SR304	3	LA	5.79	5.82
OL308	2388	SR304	3	LA	5.82	6.42
OL309-	2388	SR304	3	LA	5.04	5.79
OL310	1950	SR318	3	NY	0	18.58
OL311	2314	SR487	3	WP	0	11.47
OL312	2314	SR488	3	WP	0	5.49
OL313	2141	SR766	3	EL	0.42	5.18
OL314	2141	SR766	3	EU	0	2.32
OL315	2315	SR789	3	HU	0	15.98
OL316	2466	SR789	3	HU	5.89	5.89
OL317	2330	US006	3	NY	117.99	132.02
OL318	2278	US006	3	WP	52.41	64.8
OL319	2428	US050	3	EU	37.42	38.14
OL320	2428	US050	3	EU	12.3	29.27
OL321	2307	US093	3	WP	112.76	116.69
OL322	2307	US093	3	EL	0	11.89
OL323	2190	US093A	3	EL	0	2
OL324	2190	US093A	3	WP	0	5.69
OL325	TN WP95A	US093A	3	WP	0	5.69
OL326	2518	US095	3	HU	22.09	31.7
OL125	1837	IR015	1	CL	51.12	66.73

Table 13. First Costs for the Selected Maintenance and Rehabilitation Activities.

Activity	First Cost ($/yd^2)
Maintenance	
Sand Seals	0.64
Chip Seals	1.36
Rehabilitation	
Overlay 2 inches	6.95
Overlay 3 inches	8.50
Overlay 4 inches	10.00
Overlay 5 inches	11.50
Overlay 6 inches	13.00
Mill and Overlay 2 inches	9.00
Mill and Overlay 3 inches	11.50
Mill and Overlay 4 inches	14.00
Mill and Overlay 5 inches	16.50
Roadbed Modification	13.95

Note: All rehabilitation activities include an open-graded wearing course.

Table 14. NDOT Maintenance Activities and Descriptions.

Activity	Description
101.01	Base and Surface Repair
101.02	Hand Patching
101.03	Machine Patching
101.04	Spot Seal
101.05	Sand Seal
101.06	Flush Seal
101.07	Crack Filling
101.08*	Heater Planing
101.09	Chip Seal
101.10	Cold Planing
101.11	General Seal
256.02	Maintenance Overlay

* Heater Planing (101.08) is no longer performed.

Table 15. Average Values of Sand Seal Cumulative Maintenance Costs and their Associated Variability at various Fixed-Periods.

District	Year	Mean Cost ($/yd²)	Standard Error	Margin of Error
1	1	.036	.025	.057
	1 – 2	.108	.035	.078
	1 – 3	.207	.055	.122
	1 – 4	.309	.065	.145
	1 – 5	.387	.066	.147
	1 – 6	.433	.092	.213
	1 – 7	.788	.341	.945
2	1	.127	.050	.105
	1 – 2	.209	.060	.127
	1 – 3	.260	.062	.129
	1 – 4	.372	.092	.195
	1 – 5	.466	.125	.282
	1 – 6	.452	.179	.461
3	1	.121	.060	.128
	1 – 2	.317	.078	.167
	1 – 3	.437	.085	.182
	1 – 4	.760	.220	.475
	1 – 5	1.051	.303	.667
	1 – 6	1.486	.550	1.415

Table 16. Average Values of Chip Seal Cumulative Maintenance Costs and their Associated Variability at various Fixed Periods.

District	Year	Mean Cost ($/yd²)	Standard Error	Margin of Error
1	1	.013	.009	.019
	1 - 2	.058	.044	.092
	1 - 3	.091	.047	.099
	1 - 4	.189	.069	.148
	1 - 5	.322	.095	.206
	1 - 6	.555	.207	.477
	1 - 7	.522	.255	.654
	1 - 8	.716	.317	.881
2	1	.034	.018	.038
	1 - 2	.133	.055	.115
	1 - 3	.366	.114	.240
	1 - 4	.493	.138	.292
	1 - 5	.590	.126	.271
	1 - 6	.577	.086	.198
	1 - 7	.783	.150	.367
	1 - 8	1.08	.212	.545
3	1	.262	.107	.231
	1 - 2	.580	.184	.397
	1 - 3	.793	.212	.458
	1 - 4	.989	.295	.643
	1 - 5	1.18	.416	.927
	1 - 6	1.67	.452	1.042

Table 17. Average Values of Flexible Overlay Cumulative Maintenance Costs and their Associated Variability at various Fixed Periods.

District	Year	Mean Cost ($/yd²)	Standard Error	Margin of Error
1	1	.016	.007	.016
	1 - 2	.046	.026	.059
	1 - 3	.125	.068	.155
	1 - 4	.284	.106	.240
	1 - 5	.342	.106	.240
	1 - 6	.453	.102	.230
	1 - 7	.587	.203	.480
	1 - 8	.559	.215	.525
	1 - 9	.523	.143	.368
	1 - 10	.525	.143	.368
2	1	.051	.027	.060
	1 - 2	.141	.077	.169
	1 - 3	.471	.240	.527
	1 - 4	.505	.236	.519
	1 - 5	.610	.225	.496
	1 - 6	.359	.131	.297
	1 - 7	.469	.148	.335
	1 - 8	.642	.178	.420
	1 - 9	.621	.142	.452
3	1	.004	.002	.005
	1 - 2	.081	.043	.092
	1 - 3	.216	.071	.152
	1 - 4	.376	.077	.165
	1 - 5	.475	.083	.179
	1 - 6	.519	.085	.183
	1 - 7	.795	.133	.290
	1 - 8	1.012	.131	.288
	1 - 9	1.190	.191	.431
	1 - 10	1.352	.213	.503

Table 18. Average Values of Roadbed Modification Cumulative Maintenance Costs and their Associated Variability at various Fixed Periods.

District	Year	Mean Cost ($/yd²)	Standard Error	Margin of Error
1	1	.044	.028	.065
	1 - 2	.141	.044	.102
	1 - 3	.208	.079	.182
	1 - 4	.235	.114	.269
	1 - 5	.292	.222	.616
	1 - 6	.469	.327	.908
	1 - 7	.145	.070	.223
2	1	.013	.010	.022
	1 - 2	.050	.030	.068
	1 - 3	.139	.072	.163
	1 - 4	.163	.071	.160
	1 - 5	.202	.096	.227
	1 - 6	.255	.110	.268
	1 - 7	.548	.196	.481
	1 - 8	.685	.322	.895
3	1	.039	.017	.036
	1 - 2	.097	.025	.053
	1 - 3	.141	.030	.064
	1 - 4	.201	.037	.079
	1 - 5	.324	.051	.108
	1 - 6	.305	.044	.096
	1 - 7	.483	.077	.174
	1 - 8	.773	.062	.143
	1 - 9	.719	.087	.243

Table 19. Average Values of Mill and Overlay Cumulative Maintenance Costs and their Associated Variability at various Fixed Periods.

District	Year	Mean Cost ($/yd²)	Standard Error	Margin of Error
Statewide	1	.019	.006	.013
	1 - 2	.078	.022	.046
	1 - 3	.190	.046	.096
	1 - 4	.219	.060	.126
	1 - 5	.253	.128	.285
	1 - 6	.345	.157	.361
	1 - 7	.511	.210	.485
	1 - 8	.548	.222	.513
	1 - 9	.222	.136	.350
	1 - 10	.101	.030	.084

Table 20. Prioritization, LCCA, and Network Optimization Survey Results

State	Prioritization		LCCA		Network Optimization	
	Yes	No	Yes	No	Yes	No
Alaska	X		X		X	
Arizona	X		X		X	X
Colorado	X		X			X
Connecticut	X		X			X
Florida	X		X		X	
Iowa	X		X			X
Idaho	X		X			X
Illinois	X		X			X
Indiana	X		X			X
Kansas	X		X		X	
Maryland	X		X			X
Michigan	X			X	X	
Minnesota	X		X		X	
Mississippi	X		X			X
Missouri	X		X			X
Montana	X		X	X		X
Nebraska	X			X		X
New Mexico	X			X		X
New York	X		X			X
Oklahoma	X		X		X	
Oregon	X		X			X
Pennsylvania	X		X			X
Puerto Rico		X		X		X
Rhode Island		X		X		X
South Carolina	X		X			X
Texas	X		X			X
Vermont	X			X		X
Virginia	X		X			X
Washington	X		X			X
Wyoming	X		X			X

State	User Costs		Salvage Value		Analysis		Discount Rate (%)	Analysis Period (years)
	Yes	No	Yes	No	PW	EUAC		
Alaska		X		X	X		7	25
Arizona		X	X		X		4	
Colorado		X		X	X		4	30
Connecticut		X		X	X		4	
Florida	X		X		X		7	
Iowa		X		X	X		3	50-60
Idaho			X		X		4	36
Illinois		X	X		X		3	
Indiana		X	X		X		4-6	varies
Kansas	X	X						
Maryland	X		X		X		4	
Michigan		X		X			const	40
Minnesota		X		X	X		4.5	35
Mississippi		X	X		X		4.5	35
Missouri		X		X	X		4	longest
Montana		X	X		X	X	const	
Nebraska		X		X				
New Mexico								
New York		X	X		X		4	30+
Oklahoma		X	X		X		4	20
Oregon		X	X		X		4	30
Pennsylvania	X		X		X	X	4	20-40
Puerto Rico								
Rhode Island								
South Carolina		X	X		X		varies	
Texas	X		X		X		7	30-40
Vermont								
Virginia		X	X		X			30
Washington	X		X		X		4	40
Wyoming	X			X	X		4	30

Table 22. Cumulative Cost Summary for some Routine Maintenance and Maintenance Projects Generated through the Complete Network Analysis.

Type : Routine Maintenance

Network Name : SUR | Date : 3/ 5/99

	Segment Number	Benefit / Cost Ratio	AltNum	ActName	Cost	CumCost
Year : 0						
	US095240	5.39	2	ARM	$23,684	$23,684
	US006070	4.65	2	ARM	$6,920	$30,604
	IR015100	4.55	1	ARM	$35,250	$65,855
	SR445080	3.53	2	ARM	$7,441	$73,296
	US095250	2.92	3	ARM	$14,712	$88,009
						$88,009
Year : 1						
	US095240	5.39	2	ARM	$22,773	$22,773
	US006070	4.65	2	ARM	$6,654	$29,427
	IR015100	4.55	1	ARM	$33,894	$63,322
	SR445080	3.53	2	ARM	$7,155	$70,477
	US095250	2.92	3	ARM	$14,146	$84,624
						$84,624
Year : 2						
	US095240	5.39	2	ARM	$21,897	$21,897
	US006070	4.65	2	ARM	$6,398	$28,295
	IR015100	4.55	1	ARM	$32,590	$60,886
	SR445080	3.53	2	ARM	$6,879	$67,766
	US095250	2.92	3	ARM	$13,602	$81,369
						$81,369
Year : 3						
	US095240	5.39	2	ARM	$21,055	$21,055
	US006070	4.65	2	ARM	$6,152	$27,207
	IR015100	4.55	1	ARM	$31,337	$58,545
	SR445080	3.53	2	ARM	$6,615	$65,160
	US095250	2.92	3	ARM	$13,079	$78,239
						$78,239
Year : 4						
	US095240	5.39	2	ARM	$20,245	$20,245
	US006070	4.65	2	ARM	$5,915	$26,161
	IR015100	4.55	1	ARM	$30,132	$56,293
	SR445080	3.53	2	ARM	$6,360	$62,654
	US095250	2.92	3	ARM	$12,576	$75,230
						$75,230
Year : 5						
	US095240	5.39	2	CS	$350,663	$350,663
	US006070	4.65	2	CS	$102,460	$453,123
	IR015100	4.55	1	2OL	$2,667,075	$3,120,198
	SR445080	3.53	2	CS	$110,172	$3,230,371
	US095250	2.92	3	CS	$217,826	$3,448,197
						$3,448,197

Table 22. Cumulative Cost Summary for some Routine Maintenance and Maintenance Projects Generated through the Complete Network Analysis (cont.).

Type : Maintenance

Network Name : SUR

Date : 3/ 5/99

Segment Number	Benefit / Cost Ratio	AltNum	ActName	Cost	CumCost
Year : 0					
US093140	4.10	1	SS	$135,168	$135,168
US093170	3.92	1	SS	$132,644	$267,812
US095230	3.84	1	SS	$130,842	$398,655
US006210	3.82	1	SS	$43,343	$441,999
US093370	3.81	1	SS	$200,138	$642,138
US095030	3.73	1	SS	$63,078	$705,216
US006060	3.56	1	SS	$65,601	$770,818
US95A070	3.47	1	SS	$130,932	$901,750
US095050	3.40	1	SS	$92,274	$994,025
US093500	3.28	1	SS	$97,951	$1,091,977
US093460	3.23	1	SS	$115,163	$1,207,140
US093480	3.14	1	SS	$85,155	$1,292,296
SR163020	3.10	2	CS	$129,828	$1,422,125
SR159020	3.10	2	CS	$123,892	$1,546,017
SR163050	3.10	2	CS	$153,190	$1,699,208
US095200	3.02	2	CS	$243,189	$1,942,397
SR228010	2.93	1	SS	$118,317	$2,060,714
US006200	2.93	1	SS	$33,701	$2,094,416
US093410	2.87	1	SS	$119,037	$2,213,454
IR080090	2.16	1	2OL	$2,078,461	$4,291,916
IR080170	2.00	1	2OL	$2,671,468	$6,963,384
IR015030	1.63	4	2OL	$1,679,208	$8,642,593
IR015110	1.59	1	2OL	$643,892	$9,286,486
IR015130	1.59	1	2OL	$3,695,042	$12,981,528
IR015140	1.59	1	2OL	$4,495,504	$17,477,032
IR015010	1.58	4	2OL	$3,199,891	$20,676,924
IR080190	1.57	4	2OL	$2,471,842	$23,148,766
IR080360	1.54	1	2OL	$1,806,421	$24,955,188
					$24,955,188
Year : 1					
US093140	4.10	1	ARM	$15,687	$15,687
US093170	3.92	1	ARM	$15,394	$31,082
US095230	3.84	1	ARM	$15,185	$46,268
US006210	3.82	1	ARM	$9,487	$55,756
US093370	3.81	1	ARM	$43,810	$99,566
US095030	3.73	1	ARM	$7,320	$106,887
US006060	3.56	1	ARM	$7,613	$114,501
US95A070	3.47	1	ARM	$17,049	$131,550
US095050	3.40	1	ARM	$10,709	$142,259
US093500	3.28	1	ARM	$21,441	$163,701
US093460	3.23	1	ARM	$25,209	$188,910

Table 22. Cumulative Cost Summary for some Routine Maintenance and Maintenance Projects Generated through the Complete Network Analysis (cont.).

Type : Maintenance

Network Name : SUR

Date : 3/ 5/99

Segment Number	Benefit / Cost Ratio	AltNum	ActName	Cost	CumCost
US093480	3.14	1	ARM	$18,640	$207,551
SR163050	3.10	2	ARM	$6,975	$214,526
SR159020	3.10	2	ARM	$5,641	$220,167
SR163020	3.10	2	ARM	$5,911	$226,078
US095200	3.02	2	ARM	$11,072	$237,151
SR228010	2.93	1	ARM	$25,899	$263,051
US006200	2.93	1	ARM	$7,377	$270,428
US093410	2.87	1	ARM	$26,057	$296,486
IR080090	2.16	1	ARM	$17,195	$313,682
IR080170	2.00	1	ARM	$22,102	$335,784
IR015030	1.63	4	ARM	$17,540	$353,324
IR015110	1.59	1	ARM	$6,725	$360,050
IR015140	1.59	1	ARM	$46,957	$407,007
IR015130	1.59	1	ARM	$38,596	$445,604
IR015010	1.58	4	ARM	$42,057	$487,661
IR080190	1.57	4	ARM	$32,488	$520,149
IR080360	1.54	1	ARM	$23,742	$543,892
					$543,892
Year : 2					
US093140	4.10	1	ARM	$15,084	$15,084
US093170	3.92	1	ARM	$14,802	$29,887
US095230	3.84	1	ARM	$14,601	$44,488
US006210	3.82	1	ARM	$9,123	$53,611
US093370	3.81	1	ARM	$42,125	$95,737
US095030	3.73	1	ARM	$7,039	$102,776
US006060	3.56	1	ARM	$7,320	$110,097
US95A070	3.47	1	ARM	$16,393	$126,490
US095050	3.40	1	ARM	$10,297	$136,788
US093500	3.28	1	ARM	$20,616	$157,405
US093460	3.23	1	ARM	$24,239	$181,645
US093480	3.14	1	ARM	$17,923	$199,568
SR159020	3.10	2	ARM	$5,424	$204,992
SR163020	3.10	2	ARM	$5,683	$210,676
SR163050	3.10	2	ARM	$6,706	$217,383
US095200	3.02	2	ARM	$10,646	$228,030
US006200	2.93	1	ARM	$7,093	$235,124
SR228010	2.93	1	ARM	$24,903	$260,027
US093410	2.87	1	ARM	$25,055	$285,082
IR080090	2.16	1	ARM	$16,534	$301,617
IR080170	2.00	1	ARM	$21,252	$322,869
IR015030	1.63	4	ARM	$16,865	$339,734
IR015140	1.59	1	ARM	$45,151	$384,886
IR015110	1.59	1	ARM	$6,467	$391,353
IR015130	1.59	1	ARM	$37,112	$428,465
IR015010	1.58	4	ARM	$40,439	$468,905
IR080190	1.57	4	ARM	$31,238	$500,144
IR080360	1.54	1	ARM	$22,829	$522,973
					$522,973

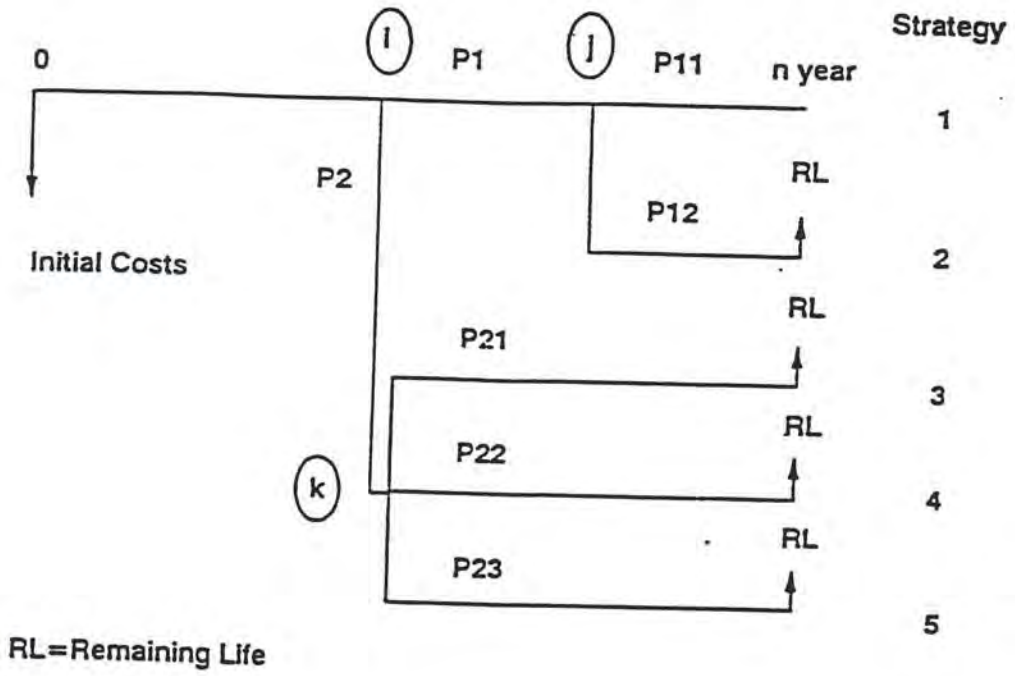


Figure 1. Illustration of the Probabilistic Approach Concept.

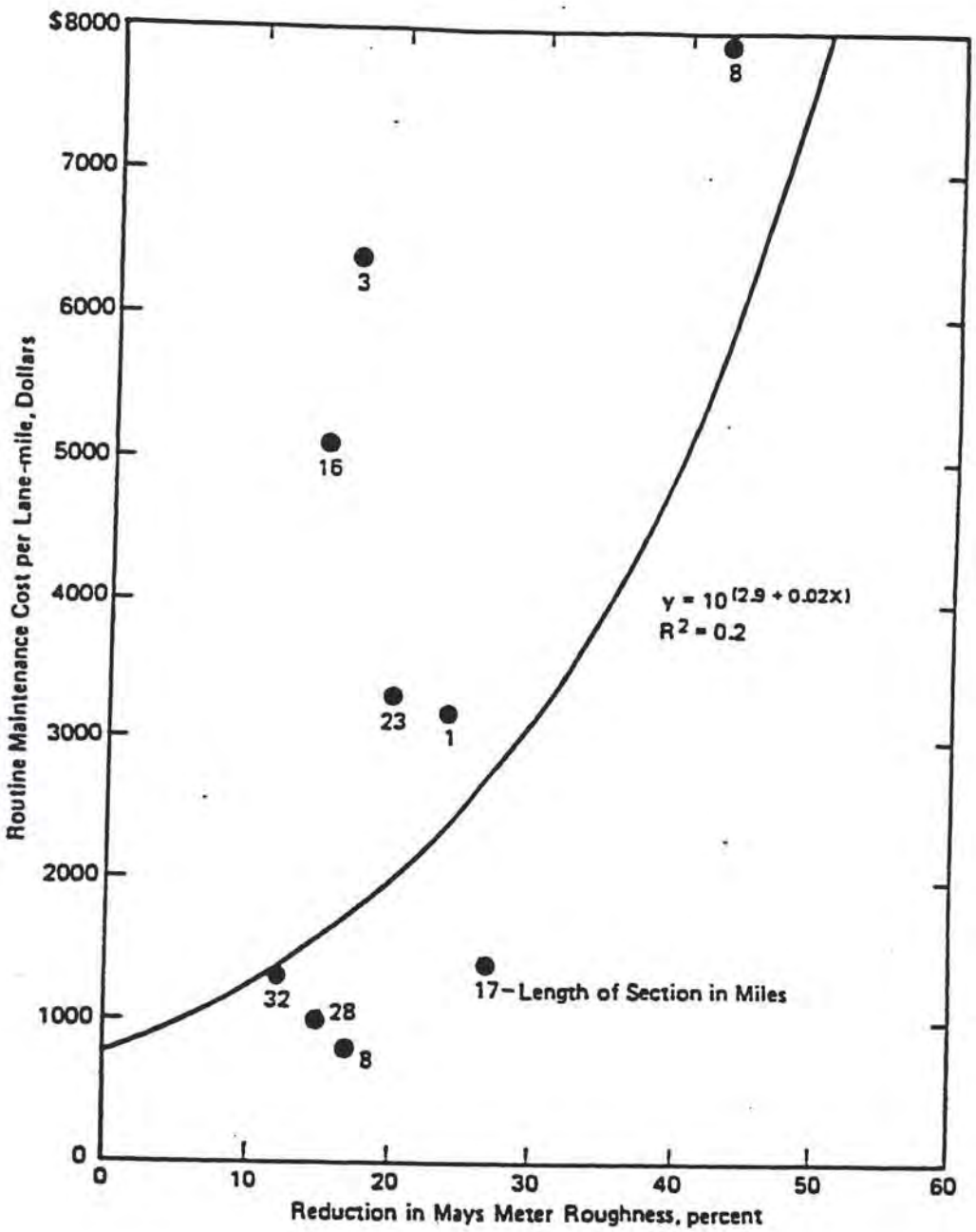


Figure 2. Relationship between Routine Maintenance Cost and Reduction in Roughness.

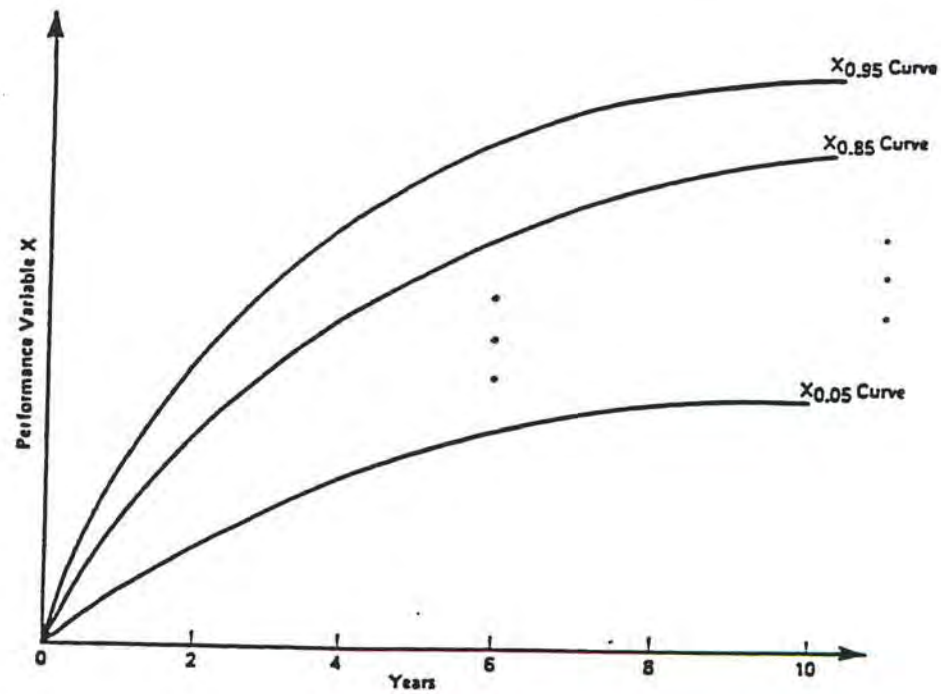


Figure 3. Treatment of Uncertainties in Performance Prediction.

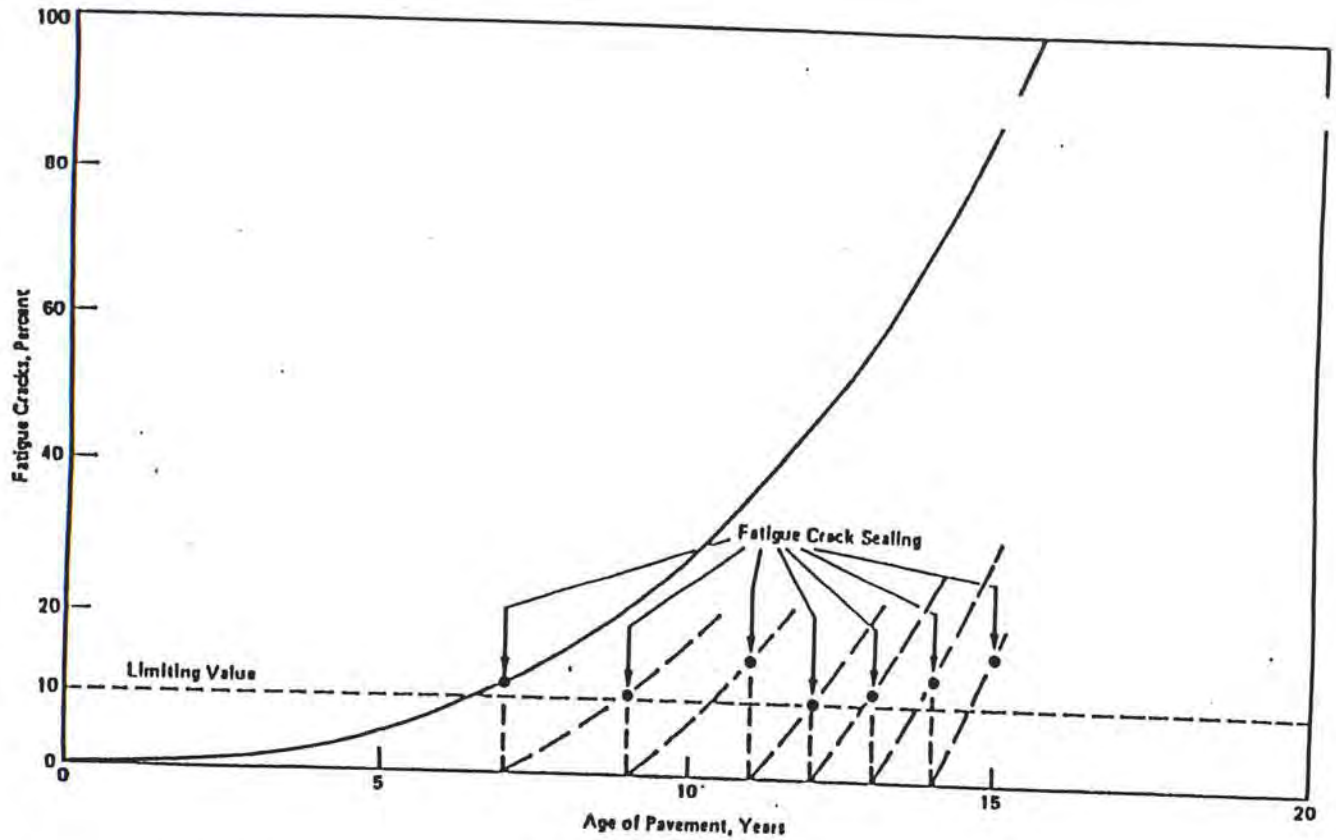


Figure 4. Fatigue-Cracking Sealing Policy.

FORMULAS AND DETERMINATION OF CATEGORY STATUS
FLEXIBLE PAVEMENT

TYPE	Interstate Only T.S.I. =2.5		Non-IR NHS, and STP w/ ADT >=750 T.S.I. =2.5		All Other Routes T.S.I. =2.0	
RIDE	IRI	PMS Points	IRI	PMS Points	IRI	PMS Points
	0 - 40	0	0 - 80	0	0 - 90	0
	41 - 70	100	81 - 100	100	91 - 130	100
	71 - 90	200	101-115	200	131 - 150	200
	91 - 105	300	116 - 130	300	151 - 170	300
	106 - 115	400	131 - 160	400	171 - 200	400
	> 115	500	> 160	500	> 200	500
RUT DEPTH	Average Rut Depth	PMS Points	Average Rut Depth	PMS Points	Average Rut Depth	PMS Points
	0 to .25"	0	0 to .25"	0	0 to .45"	0
	.26 to 1.00"	(675.7 x RD) - 168.9	.26 to 1.00"	(675.7 x RD) - 168.9	.46 to 1.19"	(675.7 x RD) - 304.1
	1.01 to 1.50"	(392.2 x RD) + 111.8	1.01 to 1.50"	(392.2 x RD) + 111.8	1.20 to 1.70"	(392.2 x RD) + 33.3
	above 1.50"	700	above 1.50"	700	above 1.70"	700
FATIGUE A & B BLOCK B & C	A = 1.50 x Extent B = 2.00 x Extent C = 1.00 x Extent D = 1.00 x Extent		A = 1.50 x Extent B = 2.00 x Extent C = 1.00 x Extent D = 1.00 x Extent		A = 1.00 x Extent B = 1.50 x Extent C = 0.50 x Extent D = 0.50 x Extent	
Non Wheelpath Linear TRANSVERSE BLOCK A	PMS Points = Extent x (LC Severity Factor) Where LC Severity Factor is determined from:		PMS Points = Extent x (LC Severity Factor) Where LC Severity Factor is determined from:		PMS Points = Extent x (LC Severity Factor) Where LC Severity Factor is determined from:	
	Crack Width	LC Severity Factor	Crack Width	LC Severity Factor	Crack Width	LC Severity Factor
	<1/4"	0.20	<1/4"	0.20	<1/4"	0.20
	≥ 1/4" ; ≤ 7/8"	0.8 x (crack width) + .80	> 1/4" ; < 7/8"	0.8 x (crack width) + .80	≥ 1/4" ; ≤ 7/8"	0.4 x (crack width) + .90
	>7/8"	1.50	>7/8"	1.50	>7/8"	1.25
PATCHING	0.5 x Extent		0.5 x Extent		0.25 x Extent	
BLEEDING	Picture No.	PMS Points	Picture No.	PMS Points	Picture No.	PMS Points
	14	0	14	0	14	0
	15	100	15	100	15	100
	16	250	16	250	16	250
RAVELING	Picture No.	PMS Points	Picture No.	PMS Points	Picture No.	PMS Points
	17	100	17	100	17	100
	18	250	18	250	18	250
	19	500	19	500	19	500
FRICTION	Friction Number	PMS Points	Friction Number	PMS Points	Friction Number	PMS Points
	2 to 20	400	2 to 20	400	2 to 20	400
	21 to 30	250	21 to 30	250	21 to 30	250
	31 to 36	100	31 to 36	100	31 to 36	100
	above 36	0	above 36	0	above 36	0

Figure 5. NDOT's PMS Points Assignment System.

NDOT PMS REPAIR CATEGORY ASSIGNMENT SYSTEM

REPAIR CATEGORY ASSIGNED	PMS POINTS TOTAL
Minor Maintenance	< 50
Maintenance	50 to 399
Overlay	400 to 699
Reconstruction	> 699

Figure 6. NDOT's Rehabilitation and Maintenance Assignment System.

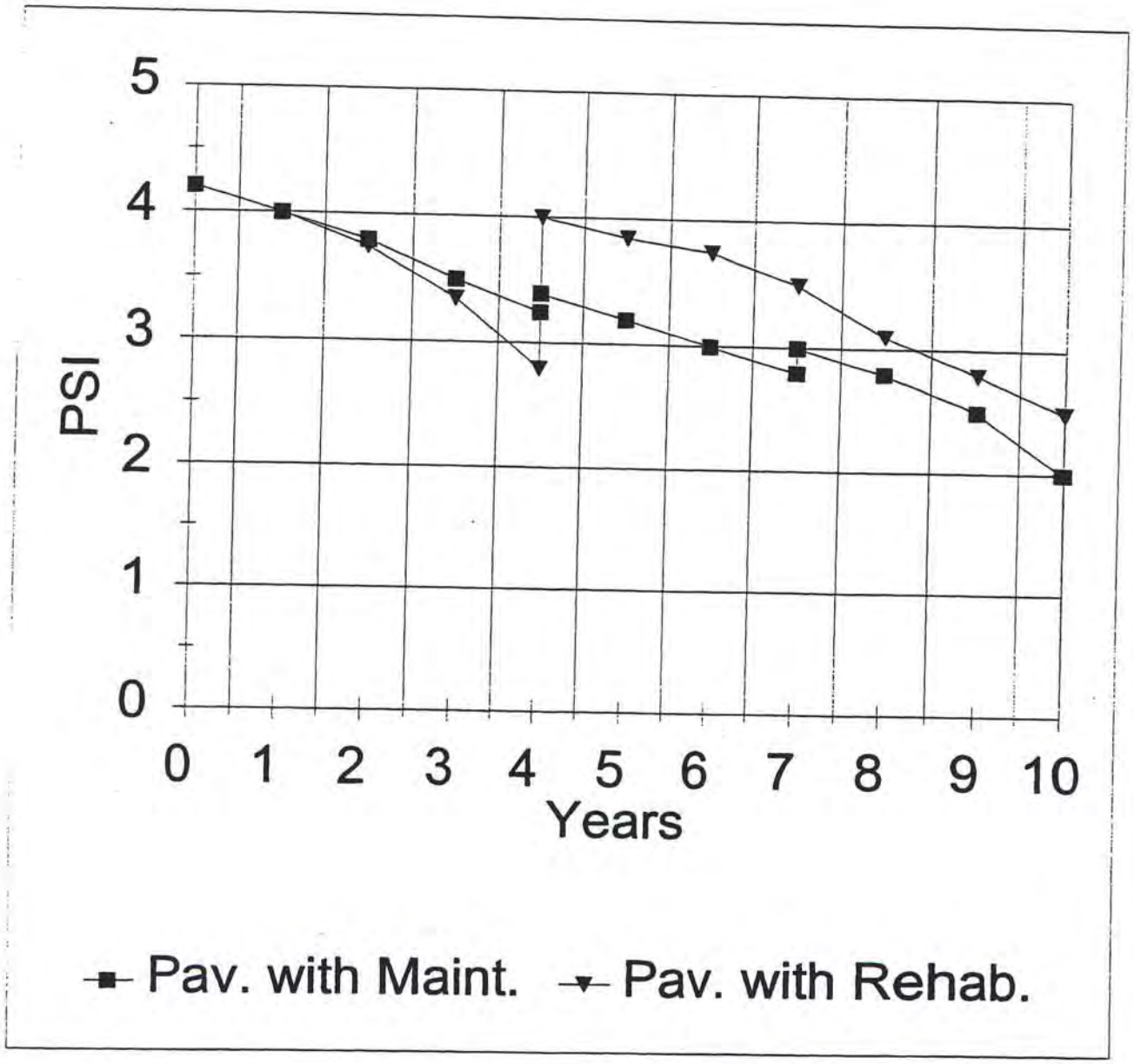


Figure 7. Typical PSI vs Pavement Age for Maintenance and Rehabilitation Activities.

PROJECT:_____

FLEXIBLE PAVEMENT OVERLAYS OVER FLEXIBLE PAVEMENTS

Date:__/__/__

Location:_____

Begining Milepost:_____.__ Ending Milepost:_____.__

MATERIALS / MIXTURES OF OVERLAY

Mix Type:_____ AC Grade:_____

% Fractured:_____ Viscosity/Temp:_____/_____

Penetration/Temp:_____/_____ Ductility/Temp:_____/_____

Sabilometer Value:_____

Mix Design Data:

Voids:_____ VMA:_____

Stability:_____ Mr/temp/moisture:____/____/____

%AC:_____ Field Density:_____

TRAFFIC HISTORY

-Traffic Composition By Classes (6-13) (as extensive as possible)

-ESALS will be used if LEF are site specific

PMS DATA

-PMS (Prior to Flexible Pavement Overlay & During Project Life)
-FWD (Prior to Flexible Pavement Overlay & During Project Life)

PMS:	Alligator cracking	Long. cracking
	Transv. cracking	Rut Depths
	Rideability (Roughness)	Slope Variance
	PSI	Raveling
	Flushing	Skid Number (normalized)

Figure 8. Standard Data Collection Form for Overlays.

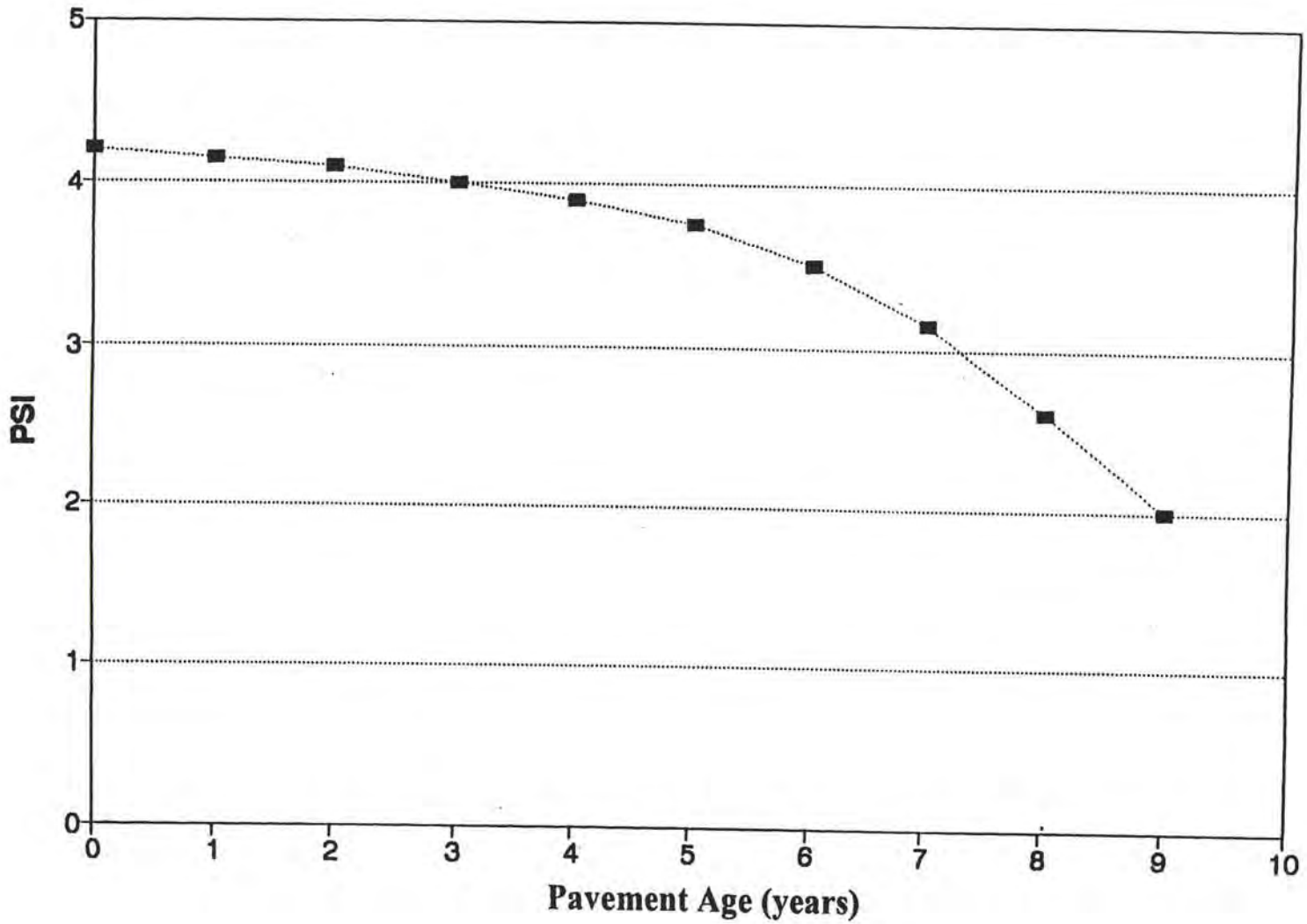


Figure 9. Typical Performance Curve Generated from NDOT's Performance Models.

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR140020	_DEFAULT	2.64	19,345	67	36	41	154	2.20	1	2	24	3	SR140	HU	14.94	21.4	3	4	2
SR140030	_DEFAULT	2.32	19,345	67	36	41	154	1.30	1	2	24	3	SR140	HU	21.4	26.5	3	4	2
SR140040	_DEFAULT	3.05	15,403	67	36	42	157	1.40	1	2	24	3	SR140	HU	26.5	56.1	3	4	2
SR140050	_DEFAULT	3.93	12,775	65	34	44	171	1.70	1	2	24	3	SR140	HU	56.1	65.58	3	4	2
SR140060	_DEFAULT	3.02	8,316	64	34	47	166	2.50	1	2	24	3	SR140	HU	65.58	75.34	3	4	2
SR144010	_DEFAULT	3.73	53,655	83	52	18	43	2.10	2	4	48	1	SR144	CL	0	2.68	3	4	2
SR146020	_DEFAULT	3.68	191,651	80	50	22	67	1.50	1	2	24	1	SR146	CL	0.39	11.34	3	4	2
SR146030	_DEFAULT	3.41	154,030	83	52	18	43	1.80	2	4	48	1	SR146	CL	11.34	14.37	3	4	2
SR146040	_DEFAULT	2.85	17,301	83	52	18	43	0.50	1	2	24	1	SR146	CL	14.37	18.16	3	4	2
SR147020	_DEFAULT	3.14	124,465	83	52	18	43	0.40	2	4	48	1	SR147	CL	27.8	29.43	3	4	2
SR147040	_DEFAULT	3.12	23,766	82	51	20	55	0.90	1	2	24	1	SR147	CL	34.58	42.04	3	4	2
SR156010	_DEFAULT	2.93	2,336	54	23	52	195	0.70	1	2	24	1	SR156	CL	0	5.07	3	4	2
SR156020	_DEFAULT	2.72	2,190	69	37	36	129	0.60	1	2	24	1	SR156	CL	5.07	17.57	3	4	2
SR157010	_DEFAULT	2.36	22,630	58	27	48	182	1.30	1	2	24	1	SR157	CL	0.33	3.03	3	4	2
SR157030	_DEFAULT	3.70	17,439	66	35	39	149	2.50	1	2	24	1	SR157	CL	3.41	12.18	3	4	2
SR157040	_DEFAULT	2.70	16,790	77	45	28	68	0.60	1	2	24	1	SR157	CL	12.18	20.58	3	4	2
SR157050	_DEFAULT	2.35	16,790	81	49	23	30	1.20	1	2	24	1	SR157	CL	20.58	21.14	3	4	2
SR158010	_DEFAULT	3.00	2,474	55	24	51	191	4.44	1	2	24	1	SR158	CL	0	8.86	3	4	2
SR159010	_DEFAULT	3.71	87,600	80	50	22	69	1.10	1	2	24	1	SR159	CL	0	10.55	3	4	2
SR159020	_DEFAULT	4.01	62,415	80	50	22	69	1.50	1	2	24	1	SR159	CL	10.55	17.02	3	4	2
SR159030	_DEFAULT	3.72	119,264	80	50	22	69	1.50	3	6	72	1	SR159	CL	22.82	26.1	3	4	2
SR159040	_DEFAULT	2.74	157,498	81	51	21	63	2.70	3	6	72	1	SR159	CL	26.4	28.46	3	4	2
SR160010	_DEFAULT	2.93	107,766	80	50	22	69	1.30	1	2	24	1	SR160	CL	0	2.27	3	4	2
SR160020	_DEFAULT	3.92	65,538	78	46	25	84	3.00	1	2	24	1	SR160	CL	2.27	11.08	3	4	2
SR160030	_DEFAULT	3.81	25,915	74	44	30	98	3.10	1	2	24	1	SR160	CL	11.08	14.3	3	4	2
SR160040	_DEFAULT	2.93	24,957	72	41	33	112	4.20	1	2	24	1	SR160	CL	14.3	21.78	3	4	2
SR160050	_DEFAULT	2.80	23,487	73	43	31	105	1.10	1	2	24	1	SR160	CL	21.78	44.62	3	4	2
SR160060	_DEFAULT	2.92	24,820	77	47	26	90	3.60	1	2	24	1	SR160	CL	44.62	46.85	3	4	2
SR160070	_DEFAULT	3.40	36,987	78	48	25	87	1.40	1	2	24	1	SR160	NY	0	6.49	3	4	2
SR160080	_DEFAULT	2.60	28,997	78	48	25	87	0.70	1	2	24	1	SR160	NY	6.49	14.55	3	4	2
SR160090	_DEFAULT	2.63	15,695	77	47	26	89	1.10	1	2	24	1	SR160	NY	14.55	33.57	3	4	2

Figure 10. NDOT Pavement Segments Database.

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR161010	DEFAULT	2.35	1,947	74	44	30	98	1.70	1	2	24	1	SR161	CL	0	6.9	3	4	2
SR161020	_DEFAULT	3.06	14,600	78	48	25	87	4.44	1	2	24	1	SR161	CL	6.9	7.34	3	4	2
SR163020	_DEFAULT	4.03	104,390	78	48	25	87	2.20	2	4	48	1	SR163	CL	0.11	3.5	3	4	2
SR163030	_DEFAULT	3.79	104,390	78	48	25	84	3.10	2	4	48	1	SR163	CL	3.5	9.4	3	4	2
SR163040	_DEFAULT	3.79	104,390	81	51	21	60	3.00	2	4	48	1	SR163	CL	9.4	12.4	3	4	2
SR163050	_DEFAULT	4.08	111,964	83	52	18	43	3.10	2	4	48	1	SR163	CL	12.4	16.4	3	4	2
IR015030	_DEFAULT	4.03	1,059,048	80	50	23	73	4.00	2	4	48	1	IR015	CL	26.28	34.86	3	4	2
IR015100	_DEFAULT	4.14	653,243	80	50	22	67	4.20	2	4	48	1	IR015	CL	50.15	66.73	3	4	2
IR015110	_DEFAULT	4.08	594,585	80	50	22	69	3.60	2	4	48	1	IR015	CL	66.73	70.02	3	4	2
IR015120	_DEFAULT	3.99	594,585	80	50	22	69	5.70	2	4	48	1	IR015	CL	70.02	76.65	3	4	2
IR015130	_DEFAULT	4.03	575,797	80	50	22	69	4.00	2	4	48	1	IR015	CL	76.65	95.53	3	4	2
IR015140	_DEFAULT	4.05	791,003	81	51	21	61	3.70	2	4	48	1	IR015	CL	95.53	118.5	3	4	2
IR015150	_DEFAULT	3.64	815,501	83	52	18	43	3.70	2	4	48	1	IR015	CL	118.5	123.79	3	4	2
IR080010	_DEFAULT	3.73	842,645	65	33	45	177	3.60	2	4	48	2	IR080	WA	0	12.48	3	4	2
IR080070	_DEFAULT	3.66	996,815	67	36	41	154	4.40	2	4	48	2	IR080	WA	41.49	44.5	3	4	2
IR080075	_DEFAULT	3.74	620,318	67	36	41	154	4.40	2	4	48	2	IR080	LY	0	5.84	3	4	2
IR080080	_DEFAULT	3.71	417,195	67	36	41	154	1.70	2	4	48	2	IR080	LY	5.84	16.1	3	4	2
IR080085	_DEFAULT	3.69	422,305	69	38	38	119	1.70	2	4	48	2	IR080	CH	0	2.21	3	4	2
IR080090	_DEFAULT	4.00	577,649	69	38	38	119	2.80	2	4	48	2	IR080	CH	2.21	12.83	3	4	2
IR080100	_DEFAULT	3.82	619,305	69	38	38	119	3.40	2	4	48	2	IR080	CH	12.83	22.47	3	4	2
IR080110	_DEFAULT	3.99	659,190	68	37	39	131	3.20	2	4	48	2	IR080	CH	22.47	27.7	3	4	2
IR080120	_DEFAULT	3.98	659,806	69	38	38	119	6.30	2	4	48	2	IR080	PE	0	16.47	3	4	2
IR080140	_DEFAULT	3.72	590,083	69	38	38	119	3.20	2	4	48	2	IR080	PE	16.95	18.56	3	4	2
IR080160	_DEFAULT	3.99	642,566	67	36	41	154	3.82	2	4	48	2	IR080	PE	26.21	37.68	3	4	2
IR080170	_DEFAULT	4.03	871,203	67	36	41	154	2.84	2	4	48	2	IR080	PE	37.68	51.33	3	4	2
IR080180	_DEFAULT	1.93	900,212	67	36	41	154	3.98	2	4	48	3	IR080	PE	51.33	62.46	3	4	2
IR080190	_DEFAULT	4.02	890,391	67	36	41	154	5.90	2	4	48	3	IR080	PE	62.46	75.09	3	4	2
IR080220	_DEFAULT	3.92	417,043	67	36	41	154	4.81	2	4	48	3	IR080	HU	17.95	29.51	3	4	2
IR080230	_DEFAULT	3.37	727,737	66	35	43	163	4.05	2	4	48	3	IR080	HU	29.51	48.42	3	4	2
IR080240	_DEFAULT	3.50	716,663	67	35	42	159	3.40	2	4	48	3	IR080	HU	48.42	54.86	3	4	2
IR080280	_DEFAULT	3.34	693,865	65	32	50	230	4.15	2	4	48	3	IR080	LA	15.89	26.98	3	4	2
IR080285	_DEFAULT	3.68	698,732	65	32	50	230	4.15	2	4	48	3	IR080	EU	0	2.88	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
IR080300	_DEFAULT	3.18	695,590	62	31	60	199	5.22	2	4	48	3	IR080	EU	15.73	25.77	3	4	2
IR080305	_DEFAULT	3.08	482,895	65	32	50	230	3.15	2	4	48	3	IR080	EL	0	1.12	3	4	2
IR080310	_DEFAULT	2.07	482,895	65	32	50	230	5.25	2	4	48	3	IR080	EL	1.12	7.5	3	4	2
IR080330	_DEFAULT	3.88	1,049,855	63	31	55	219	5.23	2	4	48	3	IR080	EL	11.09	26	3	4	2
IR080350	_DEFAULT	3.75	577,460	63	31	56	216	3.36	2	4	48	3	IR080	EL	31.85	43.56	3	4	2
IR080360	_DEFAULT	4.02	522,639	63	31	56	216	5.13	2	4	48	3	IR080	EL	43.56	52.79	3	4	2
IR080370	_DEFAULT	2.58	545,410	63	31	56	216	7.91	2	4	48	3	IR080	EL	52.79	62.09	3	4	2
IR080410	_DEFAULT	3.57	435,157	55	27	57	167	1.70	2	4	48	3	IR080	EL	83.32	91.28	3	4	2
IR080420	_DEFAULT	2.82	434,320	59	31	69	163	4.50	2	4	48	3	IR080	EL	91.28	102.79	3	4	2
IR080430	_DEFAULT	3.26	431,795	62	30	61	195	3.90	2	4	48	3	IR080	EL	102.79	117.68	3	4	2
SR028010	_DEFAULT	2.05	32,120	55	30	68	151	4.44	1	2	24	2	SR028	DO	0	1.23	3	4	2
SR028020	_DEFAULT	2.01	26,280	57	30	64	161	4.44	1	2	24	2	SR028	CC	0	3.95	3	4	2
SR028030	_DEFAULT	2.56	35,405	58	30	60	171	4.44	1	2	24	2	SR028	WA	0	8.13	3	4	2
SR028040	_DEFAULT	3.01	31,025	58	30	60	171	4.44	1	2	24	2	SR028	WA	8.13	10.99	3	4	2
SR088010	_DEFAULT	3.35	75,711	65	33	45	176	4.44	1	2	24	2	SR088	DO	0	7.3	3	4	2
SR088020	_DEFAULT	3.06	108,405	65	33	45	176	4.44	1	2	24	2	SR088	DO	7.3	8.18	3	4	2
SR115010	_DEFAULT	3.05	6,479	69	38	38	119	1.10	1	2	24	2	SR115	CH	0	4.02	3	4	2
SR116010	_DEFAULT	3.25	13,306	69	38	38	119	2.70	1	2	24	2	SR116	CH	0	10.49	3	4	2
SR117010	_DEFAULT	2.97	14,691	69	38	38	119	1.90	1	2	24	2	SR117	CH	0	4.23	3	4	2
SR117020	_DEFAULT	2.92	27,618	69	38	38	119	3.50	1	2	24	2	SR117	CH	4.23	6.95	3	4	2
SR118010	_DEFAULT	3.52	10,311	69	38	38	119	1.60	1	2	24	2	SR118	CH	0	3.48	3	4	2
SR119010	_DEFAULT	2.38	7,592	69	38	38	119	1.90	1	2	24	2	SR119	CH	0	4.14	3	4	2
SR120010	_DEFAULT	2.66	1,773	69	38	38	119	1.80	1	2	24	2	SR120	CH	0	6.26	3	4	2
SR121010	_DEFAULT	2.21	1,095	67	36	41	148	2.00	1	2	24	2	SR121	CH	0	14.3	3	4	2
SR121020	_DEFAULT	3.09	1,095	69	38	38	116	1.60	1	2	24	2	SR121	CH	14.3	26.95	3	4	2
SR140010	_DEFAULT	3.87	19,345	67	36	41	155	5.20	1	2	24	3	SR140	HU	0	14.94	3	4	2
SR163060	_DEFAULT	2.86	57,913	88	55	12	6	4.50	1	2	24	1	SR163	CL	16.4	19.13	3	4	2
SR164010	_DEFAULT	2.24	5,917	70	42	35	106	0.90	1	2	24	1	SR164	CL	0	18.6	3	4	2
SR165010	_DEFAULT	2.23	2,920	80	50	22	71	1.90	1	2	24	1	SR165	CL	0	6.77	3	4	2
SR165020	_DEFAULT	2.23	2,920	74	45	30	98	1.30	1	2	24	1	SR165	CL	6.77	10	3	4	2
SR168020	_DEFAULT	3.03	80,665	83	52	18	43	0.80	1	2	24	1	SR168	CL	0.1	1.72	3	4	2
SR168030	_DEFAULT	2.58	80,665	83	52	18	43	1.10	1	2	24	1	SR168	CL	1.72	2.52	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR168040	_DEFAULT	2.44	80,665	83	52	18	43	2.20	1	2	24	1	SR168	CL	2.52	3.26	3	4	2
SR168050	_DEFAULT	2.26	17,131	82	51	19	52	1.30	1	2	24	1	SR168	CL	3.26	18.64	3	4	2
SR168060	_DEFAULT	2.44	8,760	80	50	22	69	1.70	1	2	24	1	SR168	CL	18.64	23.82	3	4	2
SR169010	_DEFAULT	2.05	5,840	84	53	17	37	0.90	1	2	24	1	SR169	CL	5.82	9.37	3	4	2
SR169020	_DEFAULT	2.10	5,962	85	54	14	17	0.80	1	2	24	1	SR169	CL	9.37	12.08	3	4	2
SR169030	_DEFAULT	2.89	10,220	85	54	14	17	1.90	2	4	48	1	SR169	CL	12.08	13.84	3	4	2
SR169040	_DEFAULT	2.80	41,245	84	53	15	24	2.00	1	2	24	1	SR169	CL	13.84	24.06	3	4	2
SR169050	_DEFAULT	3.05	48,910	83	52	18	43	1.20	1	2	24	1	SR169	CL	24.06	24.18	3	4	2
SR170020	_DEFAULT	1.82	1,825	83	52	18	43	1.20	1	2	24	1	SR170	CL	0.73	2.56	3	4	2
SR170040	_DEFAULT	1.84	11,721	83	52	17	37	0.90	1	2	24	1	SR170	CL	2.73	11.22	3	4	2
SR170050	_DEFAULT	3.21	46,355	83	52	18	43	1.10	1	2	24	1	SR170	CL	11.22	11.98	3	4	2
SR206010	_DEFAULT	3.63	16,126	65	33	45	176	0.80	1	2	24	2	SR206	DO	0	11.74	3	4	2
SR206020	_DEFAULT	3.65	16,881	65	33	45	176	0.50	1	2	24	2	SR206	DO	11.74	15.38	3	4	2
SR207010	_DEFAULT	3.04	65,700	59	31	58	169	4.44	1	2	24	2	SR207	DO	0	11.32	3	4	2
SR208010	_DEFAULT	2.96	45,625	63	32	50	183	2.10	1	2	24	2	SR208	DO	0	8.78	3	4	2
SR208020	_DEFAULT	2.80	41,245	64	33	47	178	2.20	1	2	24	2	SR208	DO	8.78	11	3	4	2
SR208030	_DEFAULT	2.60	32,485	65	33	45	176	1.50	1	2	24	2	SR208	LY	0	1.1	3	4	2
SR208040	_DEFAULT	2.62	33,163	65	33	45	176	2.70	1	2	24	2	SR208	LY	1.1	8.3	3	4	2
SR208050	_DEFAULT	2.64	17,804	65	33	45	174	2.00	1	2	24	2	SR208	LY	8.3	16.71	3	4	2
SR208060	_DEFAULT	2.53	17,411	67	36	41	154	1.10	1	2	24	2	SR208	LY	16.71	26.78	3	4	2
SR208070	_DEFAULT	2.53	24,455	67	36	41	154	0.60	1	2	24	2	SR208	LY	26.82	27.83	3	4	2
SR221020	_DEFAULT	2.97	18,737	65	32	50	230	3.20	1	2	24	3	SR221	EL	1.45	4.17	3	4	2
SR221030	_DEFAULT	2.68	20,805	65	32	50	230	2.20	1	2	24	3	SR221	EL	4.17	4.43	3	4	2
SR223020	_DEFAULT	2.99	26,280	62	30	63	189	2.20	2	4	48	3	SR223	EL	74.85	75.98	3	4	2
SR223030	_DEFAULT	2.92	50,188	62	30	63	189	4.44	2	4	48	3	SR223	EL	75.98	76.38	3	4	2
SR225010	_DEFAULT	2.03	103,295	63	31	56	216	2.70	2	4	48	3	SR225	EL	27.34	27.66	3	4	2
SR225020	_DEFAULT	3.50	24,658	61	31	64	182	2.80	1	2	24	3	SR225	EL	29.54	38.11	3	4	2
SR225030	_DEFAULT	2.58	24,176	59	31	67	165	2.10	1	2	24	3	SR225	EL	38.11	54.51	3	4	2
SR225040	_DEFAULT	1.96	20,805	59	31	68	163	1.70	1	2	24	3	SR225	EL	54.41	66.88	3	4	2
SR225050	_DEFAULT	2.61	20,805	59	31	67	167	1.20	1	2	24	3	SR225	EL	66.88	76.95	3	4	2
SR225060	_DEFAULT	3.17	13,505	59	31	67	165	1.10	1	2	24	3	SR225	EL	76.95	87.77	3	4	2
SR225070	_DEFAULT	3.40	12,106	59	31	67	165	1.60	1	2	24	3	SR225	EL	93.1	93.91	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR225080	_DEFAULT	2.45	8,933	61	30	64	180	2.10	1	2	24	3	SR225	EL	94	112.78	3	4	2
SR225090	_DEFAULT	2.57	15,467	62	30	63	189	1.20	1	2	24	3	SR225	EL	112.78	127.54	3	4	2
SR226010	_DEFAULT	2.77	4,745	59	31	67	166	2.10	1	2	24	3	SR226	EL	0	17.42	3	4	2
SR226020	_DEFAULT	2.58	2,793	61	30	64	183	2.00	1	2	24	3	SR226	EL	17.42	39.02	3	4	2
SR227010	_DEFAULT	2.42	34,675	63	31	56	216	2.40	2	4	48	3	SR227	EL	0.54	1.47	3	4	2
SR227020	_DEFAULT	3.71	61,138	63	31	56	216	3.40	2	4	48	3	SR227	EL	1.47	6.88	3	4	2
SR227030	_DEFAULT	3.15	30,441	62	30	63	189	3.20	1	2	24	3	SR227	EL	6.88	11.5	3	4	2
SR227040	_DEFAULT	2.49	4,380	62	30	63	189	1.50	1	2	24	3	SR227	EL	11.5	20.1	3	4	2
SR228010	_DEFAULT	3.97	12,045	62	30	63	189	2.40	1	2	24	3	SR228	EL	6.87	20	3	4	2
SR228020	_DEFAULT	2.45	3,676	62	30	62	193	1.80	1	2	24	3	SR228	EL	20	33.7	3	4	2
SR229010	_DEFAULT	2.57	1,278	61	31	63	183	2.40	1	2	24	3	SR229	EL	0.02	35.38	3	4	2
SR229030	_DEFAULT	3.86	1,095	59	31	66	168	1.80	1	2	24	3	SR229	EL	35.87	50.32	3	4	2
SR230030	_DEFAULT	1.82	1,825	63	31	56	216	1.10	1	2	24	3	SR230	EL	0.82	1.8	3	4	2
SR230040	_DEFAULT	2.07	1,626	62	30	60	199	1.40	1	2	24	3	SR230	EL	1.8	12.64	3	4	2
SR230050	_DEFAULT	2.04	1,460	62	30	63	189	1.40	1	2	24	3	SR230	EL	12.64	12.89	3	4	2
SR231010	_DEFAULT	2.37	1,460	56	32	73	145	1.20	1	2	24	3	SR231	EL	0	11.17	3	4	2
SR231020	_DEFAULT	1.63	1,460	62	30	63	189	4.44	1	2	24	3	SR231	EL	11.17	14.75	3	4	2
SR232010	_DEFAULT	2.36	1,305	60	29	61	183	1.50	1	2	24	3	SR232	EL	2.62	17.15	3	4	2
SR233010	_DEFAULT	2.60	12,974	62	30	60	199	1.40	1	2	24	3	SR233	EL	0	22.7	3	4	2
SR233020	_DEFAULT	2.66	10,108	65	32	50	230	2.00	1	2	24	3	SR233	EL	22.7	34.17	3	4	2
SR264010	_DEFAULT	2.70	1,460	70	39	35	133	0.70	1	2	24	1	SR264	ES	0	8.2	3	4	2
SR264020	_DEFAULT	2.47	2,147	71	39	34	129	0.80	1	2	24	1	SR264	ES	8.2	25.15	3	4	2
SR265010	_DEFAULT	2.90	2,190	71	39	34	129	2.00	1	2	24	1	SR265	ES	0	9.82	3	4	2
SR265020	_DEFAULT	2.49	2,190	72	40	33	117	1.60	1	2	24	1	SR265	ES	9.82	20.86	3	4	2
SR266010	_DEFAULT	2.51	7,665	66	35	39	153	0.90	1	2	24	1	SR266	ES	0	9.72	3	4	2
SR266020	_DEFAULT	2.48	7,665	62	30	44	171	4.44	1	2	24	1	SR266	ES	9.72	17.8	3	4	2
SR266030	_DEFAULT	2.54	7,665	62	31	43	169	0.70	1	2	24	1	SR266	ES	17.8	25.66	3	4	2
SR266040	_DEFAULT	2.21	7,300	70	38	35	133	0.50	1	2	24	1	SR266	ES	25.66	40.34	3	4	2
SR267010	_DEFAULT	2.08	1,825	73	41	31	100	0.40	1	2	24	1	SR267	NY	0	12.07	3	4	2
SR267020	_DEFAULT	2.64	1,825	73	41	31	98	0.40	1	2	24	1	SR267	ES	0	9.35	3	4	2
SR278010	_DEFAULT	2.50	19,126	65	32	50	230	2.40	1	2	24	3	SR278	EL	0	4.84	3	4	2
SR278020	_DEFAULT	3.28	9,052	61	30	64	183	2.40	1	2	24	3	SR278	EU	0	20.23	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR278030	_DEFAULT	2.96	8,395	59	31	68	163	2.20	1	2	24	3	SR278	EU	20.23	35.33	3	4	2
SR278040	_DEFAULT	3.51	10,741	63	31	59	205	2.10	1	2	24	3	SR278	EU	35.33	62.47	3	4	2
SR278050	_DEFAULT	3.39	13,870	63	31	56	216	2.80	1	2	24	3	SR278	EU	62.47	75.07	3	4	2
SR278060	_DEFAULT	2.59	16,999	64	32	52	226	2.70	1	2	24	3	SR278	EU	75.07	82.65	3	4	2
SR278070	_DEFAULT	2.29	17,520	65	32	50	230	2.70	1	2	24	3	SR278	EU	82.65	82.73	3	4	2
SR289010	_DEFAULT	2.13	0	67	36	41	154	4.44	1	2	24	3	SR289	HU	1.43	4.02	3	4	2
SR289030	_DEFAULT	2.42	0	67	36	41	154	1.20	1	2	24	3	SR289	HU	7	7.53	3	4	2
SR289040	_DEFAULT	2.47	0	67	36	41	154	1.60	1	2	24	3	SR289	HU	7.53	9.42	3	4	2
SR289050	_DEFAULT	2.32	0	67	36	41	154	1.20	1	2	24	3	SR289	HU	9.42	10.09	3	4	2
SR289060	_DEFAULT	2.51	0	67	36	41	154	1.20	1	2	24	3	SR289	HU	10.09	11.19	3	4	2
SR289080	_DEFAULT	2.34	0	67	36	41	154	1.40	1	2	24	3	SR289	HU	11.95	12.29	3	4	2
SR289090	_DEFAULT	3.15	59,860	67	36	41	154	1.80	2	4	48	3	SR289	HU	12.98	14.68	3	4	2
SR289100	_DEFAULT	2.89	119,720	67	36	41	154	1.30	2	4	48	3	SR289	HU	14.68	15.1	3	4	2
SR289120	_DEFAULT	2.43	131,035	67	36	41	154	1.60	1	2	24	3	SR289	HU	15.63	17.31	3	4	2
SR290010	_DEFAULT	3.00	6,205	67	36	41	154	2.20	1	2	24	3	SR290	HU	0	10.05	3	4	2
SR290020	_DEFAULT	2.66	5,162	66	34	43	167	2.30	1	2	24	3	SR290	HU	10.05	17.94	3	4	2
SR290030	_DEFAULT	2.79	4,745	65	33	45	176	4.44	1	2	24	3	SR290	HU	17.94	21.05	3	4	2
SR293010	_DEFAULT	3.06	730	67	36	41	154	2.10	1	2	24	3	SR293	HU	0	4.3	3	4	2
SR293020	_DEFAULT	3.56	730	67	36	41	154	2.40	1	2	24	3	SR293	HU	4.3	5.15	3	4	2
SR293030	_DEFAULT	2.62	730	67	36	41	154	1.70	1	2	24	3	SR293	HU	5.15	12	3	4	2
SR293040	_DEFAULT	3.02	1,488	66	34	43	166	2.00	1	2	24	3	SR293	HU	12	23.99	3	4	2
SR304010	_DEFAULT	3.52	71,540	65	32	50	230	3.75	2	4	48	3	SR304	LA	5.04	6.71	3	4	2
SR304020	_DEFAULT	3.11	141,985	65	32	50	230	3.30	2	4	48	3	SR304	LA	6.71	7.11	3	4	2
SR304030	_DEFAULT	2.58	68,255	65	32	50	230	1.90	1	2	24	3	SR304	LA	7.11	8.2	3	4	2
SR305010	_DEFAULT	3.53	12,207	63	31	56	212	3.20	1	2	24	3	SR305	LA	30.8	93	3	4	2
SR305020	_DEFAULT	3.01	29,904	65	32	50	230	3.00	1	2	24	3	SR305	LA	93	106.76	3	4	2
SR305030	_DEFAULT	3.61	52,897	65	32	50	230	4.00	1	2	24	3	SR305	LA	106.76	118.53	3	4	2
SR306010	_DEFAULT	3.60	9,890	65	32	50	230	2.10	1	2	24	3	SR306	EU	0	20.43	3	4	2
SR306020	_DEFAULT	2.59	9,293	65	32	51	228	1.40	1	2	24	3	SR306	LA	0	12.34	3	4	2
SR317010	_DEFAULT	2.47	1,095	76	45	29	87	1.60	1	2	24	1	SR317	LN	37.1	45.53	3	4	2
SR317020	_DEFAULT	2.36	1,199	74	42	30	92	0.80	1	2	24	1	SR317	LN	45.53	58.59	3	4	2
SR318010	_DEFAULT	2.62	81,030	76	44	29	77	1.20	1	2	24	1	SR318	LN	0	4.7	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR318020	_DEFAULT	2.27	55,366	74	42	30	90	1.90	1	2	24	1	SR318	LN	4.7	20.91	3	4	2
SR318030	_DEFAULT	2.21	53,655	71	39	34	125	1.70	1	2	24	1	SR318	LN	20.91	43.21	3	4	2
SR318040	_DEFAULT	2.94	53,655	68	37	37	143	1.30	1	2	24	1	SR318	LN	43.21	48.79	3	4	2
SR318050	_DEFAULT	2.97	53,655	66	34	40	156	1.30	1	2	24	1	SR318	LN	48.79	49.42	3	4	2
SR318060	_DEFAULT	2.93	45,990	67	35	39	150	1.30	1	2	24	3	SR318	NY	0	18.54	3	4	2
SR318070	_DEFAULT	3.26	53,679	68	36	38	146	2.10	1	2	24	3	SR318	NY	18.54	33.47	3	4	2
SR318080	_DEFAULT	2.58	54,750	68	36	38	146	2.10	1	2	24	3	SR318	NY	33.47	38.77	3	4	2
SR318090	_DEFAULT	2.88	56,907	62	30	62	191	2.30	1	2	24	3	SR318	WP	0	11.89	3	4	2
SR318100	_DEFAULT	3.34	73,365	62	30	63	187	2.30	1	2	24	3	SR318	WP	11.89	22.57	3	4	2
SR319010	_DEFAULT	2.56	8,140	68	36	38	145	1.30	1	2	24	1	SR319	LN	50	60	3	4	2
SR319020	_DEFAULT	2.44	5,110	63	32	42	166	2.20	1	2	24	1	SR319	LN	60	70.91	3	4	2
SR320010	_DEFAULT	1.92	2,555	68	36	38	146	1.20	1	2	24	1	SR320	LN	0	4.77	3	4	2
SR320020	_DEFAULT	2.21	3,076	64	33	41	162	1.40	1	2	24	1	SR320	LN	4.77	10.67	3	4	2
SR321020	_DEFAULT	2.81	2,555	65	33	41	161	0.90	1	2	24	1	SR321	LN	0.11	2.37	3	4	2
SR321040	_DEFAULT	2.45	4,015	63	32	42	166	0.50	1	2	24	1	SR321	LN	2.75	3.84	3	4	2
SR321050	_DEFAULT	2.71	4,380	65	33	41	159	0.70	1	2	24	1	SR321	LN	3.84	5.11	3	4	2
SR322020	_DEFAULT	2.38	1,265	66	34	40	156	1.70	1	2	24	1	SR322	LN	0.78	15.07	3	4	2
SR322030	_DEFAULT	2.24	730	66	34	40	156	4.44	1	2	24	1	SR322	LN	15.07	18.58	3	4	2
SR338010	_DEFAULT	2.61	5,604	60	31	56	174	1.20	1	2	24	2	SR338	LY	0	30.89	3	4	2
SR339010	_DEFAULT	3.60	39,450	67	35	42	160	1.30	1	2	24	2	SR339	LY	0	11.52	3	4	2
SR340010	_DEFAULT	3.29	26,280	67	36	41	154	1.00	1	2	24	2	SR340	LY	0	1.08	3	4	2
SR341010	_DEFAULT	2.93	89,060	65	33	45	176	1.20	1	2	24	2	SR341	LY	0	2.81	3	4	2
SR341020	_DEFAULT	2.31	32,120	64	33	47	178	1.30	1	2	24	2	SR341	LY	2.81	5	3	4	2
SR341030	_DEFAULT	2.38	4,015	60	31	55	178	1.00	1	2	24	2	SR341	ST	5	8.03	3	4	2
SR341040	_DEFAULT	2.02	15,330	58	30	60	171	0.80	1	2	24	2	SR341	ST	8.03	9.01	3	4	2
SR341060	_DEFAULT	2.71	12,410	58	30	60	171	2.40	1	2	24	2	SR341	ST	9.22	10.33	3	4	2
SR341070	_DEFAULT	3.09	12,410	57	30	62	166	2.00	1	2	24	2	SR341	ST	10.33	15.83	3	4	2
SR341080	_DEFAULT	3.08	12,410	62	32	51	180	1.40	1	2	24	2	SR341	WA	15.83	20.45	3	4	2
SR341090	_DEFAULT	2.40	67,890	65	33	45	176	2.20	1	2	24	2	SR341	WA	21.89	22.14	3	4	2
SR342010	_DEFAULT	2.66	103,660	63	32	50	183	1.20	1	2	24	2	SR342	LY	0	2.95	3	4	2
SR342020	_DEFAULT	2.35	109,865	60	31	55	178	1.10	1	2	24	2	SR342	ST	0	2.95	3	4	2
SR359010	_DEFAULT	2.46	4,551	63	32	43	164	1.20	1	2	24	2	SR359	MI	0	32.9	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR360010	_DEFAULT	2.92	87,509	67	36	38	147	1.30	1	2	24	1	SR360	MI	0	23.24	3	4	2
SR361010	_DEFAULT	2.74	11,680	71	39	34	129	1.00	1	2	24	1	SR361	NY	0	7.67	3	4	2
SR361020	_DEFAULT	2.85	8,273	70	38	35	133	1.90	1	2	24	1	SR361	NY	7.67	24.96	3	4	2
SR361030	_DEFAULT	3.25	4,015	70	39	34	129	1.40	1	2	24	1	SR361	MI	0	7.67	3	4	2
SR361040	_DEFAULT	2.75	4,015	64	33	41	162	1.70	1	2	24	1	SR361	MI	7.67	14.42	3	4	2
SR361050	_DEFAULT	2.82	4,015	69	38	36	137	0.70	1	2	24	1	SR361	MI	14.42	22.2	3	4	2
SR361060	_DEFAULT	2.26	5,840	63	32	50	180	2.20	1	2	24	1	SR361	CH	0	15.69	3	4	2
SR362010	_DEFAULT	2.81	95,995	73	41	31	100	4.44	1	2	24	2	SR362	MI	1.32	10	3	4	2
SR372010	_DEFAULT	2.27	59,814	78	48	25	87	1.00	1	2	24	1	SR372	NY	0	7.77	3	4	2
SR373010	_DEFAULT	3.39	34,675	80	50	23	73	1.70	1	2	24	1	SR373	NY	0	16.3	3	4	2
SR374010	_DEFAULT	2.72	6,408	74	44	30	98	0.77	1	2	24	1	SR374	NY	0	8.84	3	4	2
SR375010	_DEFAULT	2.46	5,110	69	38	36	137	0.90	1	2	24	1	SR375	LN	0	24.61	3	4	2
SR375020	_DEFAULT	2.48	8,760	70	39	35	132	0.60	1	2	24	1	SR375	LN	24.61	40	3	4	2
SR375030	_DEFAULT	2.59	8,760	69	38	36	138	1.30	1	2	24	1	SR375	LN	40	45	3	4	2
SR375040	_DEFAULT	2.11	8,760	73	41	32	107	0.60	1	2	24	1	SR375	LN	45	49.05	3	4	2
SR375050	_DEFAULT	1.68	2,190	68	37	37	143	0.90	1	2	24	1	SR375	NY	0	13	3	4	2
SR375060	_DEFAULT	1.80	2,190	68	37	37	143	1.60	1	2	24	1	SR375	NY	13	15	3	4	2
SR375070	_DEFAULT	2.03	1,541	69	37	36	140	0.90	1	2	24	1	SR375	NY	15	24.73	3	4	2
SR375080	_DEFAULT	2.14	1,460	69	37	36	140	0.90	1	2	24	1	SR375	NY	24.73	49.36	3	4	2
SR376020	_DEFAULT	2.23	22,265	66	34	40	156	1.67	1	2	24	1	SR376	NY	0.31	4.9	3	4	2
SR376030	_DEFAULT	2.33	22,265	66	34	40	156	1.85	1	2	24	1	SR376	NY	4.9	12.64	3	4	2
SR376040	_DEFAULT	2.54	16,668	64	33	41	162	1.76	1	2	24	1	SR376	NY	12.64	36.75	3	4	2
SR376050	_DEFAULT	2.32	17,015	66	34	40	156	2.49	1	2	24	1	SR376	NY	36.75	48.27	3	4	2
SR376060	_DEFAULT	2.53	19,710	66	34	40	156	3.24	1	2	24	1	SR376	NY	48.27	54	3	4	2
SR376070	_DEFAULT	3.06	19,710	66	34	40	156	3.86	1	2	24	1	SR376	NY	54	81.75	3	4	2
SR376080	_DEFAULT	3.58	15,099	62	30	63	186	2.84	1	2	24	1	SR376	LA	0	18.06	3	4	2
SR377010	_DEFAULT	2.49	2,555	65	33	41	161	0.78	1	2	24	1	SR377	NY	0	4.13	3	4	2
SR377020	_DEFAULT	2.72	2,555	60	28	46	177	0.71	1	2	24	1	SR377	NY	4.13	6.6	3	4	2
SR378010	_DEFAULT	2.32	2,555	65	33	41	159	4.44	1	2	24	1	SR378	NY	0	2.71	3	4	2
SR379010	_DEFAULT	2.50	1,789	68	37	37	145	1.80	1	2	24	3	SR379	NY	0	19.53	3	4	2
SR396010	_DEFAULT	2.10	0	69	38	38	119	2.45	1	2	24	2	SR396	PE	0	16.81	3	4	2
SR396020	_DEFAULT	2.80	31,025	69	38	38	119	2.43	1	2	24	2	SR396	PE	16.81	17.71	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR396030	_DEFAULT	1.98	22,786	69	38	38	124	4.25	1	2	24	2	SR396	PE	17.71	22	3	4	2
SR396040	_DEFAULT	1.87	13,140	67	36	41	154	1.51	1	2	24	2	SR396	PE	24.38	25.7	3	4	2
SR396050	_DEFAULT	2.35	13,140	67	36	41	154	2.54	1	2	24	2	SR396	PE	25.7	28	3	4	2
SR397010	_DEFAULT	2.78	1,855	69	38	38	119	2.69	1	2	24	2	SR397	PE	0	11.84	3	4	2
SR398020	_DEFAULT	3.06	7,665	69	38	38	119	1.00	1	2	24	2	SR398	PE	0.71	2.72	3	4	2
SR398030	_DEFAULT	3.18	6,935	69	38	38	119	1.85	1	2	24	2	SR398	PE	2.72	4.51	3	4	2
SR399010	_DEFAULT	2.70	4,973	64	33	47	176	2.60	1	2	24	2	SR399	PE	1.3	17.23	3	4	2
SR399020	_DEFAULT	2.78	5,110	67	36	41	154	1.90	1	2	24	2	SR399	PE	17.23	19.49	3	4	2
SR400010	_DEFAULT	2.76	2,190	67	35	42	160	1.85	1	2	24	3	SR400	PE	0	16.45	3	4	2
SR425010	_DEFAULT	2.71	9,490	65	33	45	176	0.70	1	2	24	2	SR425	WA	1.85	2.84	3	4	2
SR425020	_DEFAULT	3.23	25,842	65	33	45	176	2.78	1	2	24	2	SR425	WA	2.84	6.21	3	4	2
SR427010	_DEFAULT	2.79	41,099	67	36	41	154	0.85	1	2	24	2	SR427	LY	0.11	5.45	3	4	2
SR427030	_DEFAULT	3.81	48,089	67	36	41	154	1.64	1	2	24	2	SR427	LY	5.76	9	3	4	2
SR428010	_DEFAULT	2.65	8,030	63	32	50	183	1.39	1	2	24	2	SR428	WA	0	0.43	3	4	2
SR429010	_DEFAULT	3.64	16,790	63	32	50	183	2.49	1	2	24	2	SR429	WA	0	7.38	3	4	2
SR431010	_DEFAULT	3.48	26,645	54	30	68	145	3.02	1	2	24	2	SR431	WA	0	8.13	3	4	2
SR431020	_DEFAULT	3.45	27,156	55	30	66	150	3.52	1	2	24	2	SR431	WA	8.13	18.75	3	4	2
SR431040	_DEFAULT	3.67	78,371	64	33	46	178	4.35	1	2	24	2	SR431	WA	18.86	24.57	3	4	2
SR443020	_DEFAULT	2.42	73,000	65	33	45	176	3.75	2	4	48	2	SR443	WA	1.15	3.59	3	4	2
SR445030	_DEFAULT	2.56	218,270	65	33	45	176	3.64	2	4	48	2	SR445	WA	2.34	2.42	3	4	2
SR445040	_DEFAULT	2.80	237,615	65	33	45	176	1.64	2	4	48	2	SR445	WA	2.42	3.07	3	4	2
SR445050	_DEFAULT	2.68	185,420	65	33	45	176	1.99	2	4	48	2	SR445	WA	3.07	4.12	3	4	2
SR445070	_DEFAULT	3.26	232,870	65	33	45	176	2.29	1	2	24	2	SR445	WA	4.33	4.52	3	4	2
SR445080	_DEFAULT	4.11	204,869	66	34	43	167	6.17	1	2	24	2	SR445	WA	4.52	11.52	3	4	2
SR445090	_DEFAULT	2.87	115,705	67	36	41	154	2.20	1	2	24	2	SR445	WA	11.52	20	3	4	2
SR445100	_DEFAULT	2.78	115,705	67	36	41	154	1.53	1	2	24	2	SR445	WA	20	25.9	3	4	2
SR445110	_DEFAULT	2.31	91,250	67	36	41	154	1.69	1	2	24	2	SR445	WA	25.9	29.27	3	4	2
SR445120	_DEFAULT	2.85	17,885	67	36	41	154	1.73	1	2	24	2	SR445	WA	29.27	32.36	3	4	2
SR445130	_DEFAULT	2.56	12,136	69	38	38	119	4.44	1	2	24	2	SR445	WA	32.36	43.98	3	4	2
SR446010	_DEFAULT	2.97	4,745	69	38	38	119	1.10	1	2	24	2	SR446	WA	0	13.16	3	4	2
SR447020	_DEFAULT	2.77	23,190	67	36	41	152	1.25	1	2	24	2	SR447	WA	0.42	16	3	4	2
SR447030	_DEFAULT	2.96	25,355	68	37	40	136	1.46	1	2	24	2	SR447	WA	16	74.72	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR487010	_DEFAULT	3.72	4,106	63	31	57	212	1.75	1	2	24	3	SR487	WP	0	11.47	3	4	2
SR488020	_DEFAULT	3.67	4,441	60	31	65	178	2.50	1	2	24	3	SR488	WP	0.72	5.49	3	4	2
SR490010	_DEFAULT	0.00	6,205	59	31	67	165	4.44	1	2	24	3	SR490	WP	0	8.39	3	4	2
SR511010	_DEFAULT	3.31	4,745	65	33	45	176	4.44	1	2	24	2	SR511	CC	0	0.81	3	4	2
SR512010	_DEFAULT	2.63	5,293	65	33	45	176	1.51	1	2	24	2	SR512	CC	1.37	2.15	3	4	2
SR513020	_DEFAULT	2.00	16,608	65	33	45	176	1.28	1	2	24	2	SR513	CC	0.12	0.86	3	4	2
SR513030	_DEFAULT	3.16	3,802	65	33	45	176	0.78	1	2	24	2	SR513	CC	0.86	4.46	3	4	2
SR516010	_DEFAULT	3.02	16,425	65	33	45	176	1.34	1	2	24	2	SR516	CC	0.44	2.44	3	4	2
SR518010	_DEFAULT	1.98	18,433	65	33	45	176	0.80	1	2	24	2	SR518	CC	0	1.04	3	4	2
SR520010	_DEFAULT	3.68	73,730	65	33	45	176	4.10	2	4	48	2	SR520	CC	0	1.23	3	4	2
SR525020	_DEFAULT	2.39	86,870	65	33	45	176	1.15	1	2	24	2	SR525	CC	2.36	3.08	3	4	2
SR535010	_DEFAULT	3.00	38,836	63	31	56	216	2.60	2	4	48	3	SR535	EL	22.02	27.06	3	4	2
SR535020	_DEFAULT	3.01	2,920	63	31	56	216	4.44	1	2	24	3	SR535	EL	27.27	33.07	3	4	2
SR535030	_DEFAULT	3.30	2,920	63	31	56	216	4.44	1	2	24	3	SR535	EL	33.07	34.4	3	4	2
SR535040	_DEFAULT	2.75	2,920	63	31	56	216	4.44	1	2	24	3	SR535	EL	34.4	35.42	3	4	2
SR562020	_DEFAULT	3.40	329,164	80	50	22	69	4.44	3	6	72	1	SR562	CL	25.35	33.71	3	4	2
SR562030	_DEFAULT	3.20	203,305	82	51	20	56	1.70	3	6	72	1	SR562	CL	33.71	34.72	3	4	2
SR573010	_DEFAULT	3.21	406,323	81	51	20	58	3.65	2	4	48	1	SR573	CL	21.46	30.86	3	4	2
SR573020	_DEFAULT	3.60	451,870	83	52	18	43	4.28	2	4	48	1	SR573	CL	30.86	32.22	3	4	2
SR574010	_DEFAULT	2.72	386,563	81	51	20	57	4.44	2	4	48	1	SR574	CL	21.46	30.06	3	4	2
SR574020	_DEFAULT	1.72	77,867	83	52	18	43	1.35	2	4	48	1	SR574	CL	30.06	31.81	3	4	2
SR578020	_DEFAULT	2.33	41,063	80	50	22	69	2.36	2	4	48	1	SR578	CL	26.9	27.66	3	4	2
SR579010	_DEFAULT	3.31	142,715	80	50	22	69	1.85	2	4	48	1	SR579	CL	25.17	26.95	3	4	2
SR579020	_DEFAULT	2.78	199,290	80	50	22	69	2.01	2	4	48	1	SR579	CL	26.95	27.16	3	4	2
SR579030	_DEFAULT	2.68	199,655	80	50	22	69	1.65	2	4	48	1	SR579	CL	27.16	27.51	3	4	2
SR589040	_DEFAULT	2.64	73,730	80	50	22	69	1.28	3	6	72	1	SR589	CL	21.46	23.33	3	4	2
SR589050	_DEFAULT	3.29	155,003	80	50	22	69	1.72	3	6	72	1	SR589	CL	23.33	25.36	3	4	2
SR589060	_DEFAULT	3.31	193,815	80	50	22	69	2.22	3	6	72	1	SR589	CL	25.36	25.56	3	4	2
SR589070	_DEFAULT	2.54	297,658	80	50	22	69	2.62	3	6	72	1	SR589	CL	25.56	26.45	3	4	2
SR589080	_DEFAULT	3.17	115,644	80	50	22	69	2.44	3	6	72	1	SR589	CL	26.59	31	3	4	2
SR592020	_DEFAULT	3.41	86,018	80	50	22	69	4.44	3	6	72	1	SR592	CL	21.46	24	3	4	2
SR592030	_DEFAULT	3.04	95,448	80	50	22	69	2.63	3	6	72	1	SR592	CL	25.09	25.98	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR592040	_DEFAULT	3.60	100,740	81	51	21	63	4.44	3	6	72	1	SR592	CL	25.98	28.47	3	4	2
SR592050	_DEFAULT	3.43	76,431	83	52	18	43	4.44	3	6	72	1	SR592	CL	28.47	31.38	3	4	2
SR593010	_DEFAULT	3.15	150,988	80	50	22	69	2.96	3	6	72	1	SR593	CL	21.46	24.81	3	4	2
SR593020	_DEFAULT	2.75	183,230	80	50	22	69	2.96	3	6	72	1	SR593	CL	24.81	25.37	3	4	2
SR593030	_DEFAULT	3.12	234,695	80	50	22	69	1.98	4	8	96	1	SR593	CL	25.37	26.67	3	4	2
SR593040	_DEFAULT	2.95	126,817	82	52	19	49	4.44	3	6	72	1	SR593	CL	26.67	32.35	3	4	2
SR595010	_DEFAULT	1.52	91,554	79	49	24	78	4.44	1	2	24	1	SR595	CL	32.42	37.77	3	4	2
SR595020	_DEFAULT	2.77	151,110	80	50	22	69	1.85	2	4	48	1	SR595	CL	37.77	38.88	3	4	2
SR595030	_DEFAULT	3.14	594,658	80	50	22	69	1.28	3	6	72	1	SR595	CL	40.94	43.19	3	4	2
SR596010	_DEFAULT	3.47	97,516	80	50	22	69	4.44	2	4	48	1	SR596	CL	37.88	42.88	3	4	2
SR596020	_DEFAULT	3.14	93,440	80	50	22	69	4.44	2	4	48	1	SR596	CL	42.88	43.08	3	4	2
SR596030	_DEFAULT	3.20	65,773	80	50	22	69	4.44	2	4	48	1	SR596	CL	43.08	47.02	3	4	2
SR599010	_DEFAULT	2.78	76,103	80	50	22	69	1.90	2	4	48	1	SR599	CL	3.11	5.02	3	4	2
SR599020	_DEFAULT	3.12	123,426	80	50	22	69	2.36	2	4	48	1	SR599	CL	5.02	12.56	3	4	2
SR601010	_DEFAULT	2.93	104,536	80	50	22	69	2.19	2	4	48	1	SR601	CL	0	3.17	3	4	2
SR602010	_DEFAULT	2.41	24,820	80	50	22	69	1.99	1	2	24	1	SR602	CL	0.18	0.45	3	4	2
SR604020	_DEFAULT	3.01	10,950	78	48	25	87	0.80	1	2	24	1	SR604	CL	12.84	13.1	3	4	2
SR604040	_DEFAULT	1.82	11,753	78	48	25	88	0.85	1	2	24	1	SR604	CL	13.13	28.55	3	4	2
SR604050	_DEFAULT	3.44	44,019	80	50	22	69	1.84	1	2	24	1	SR604	CL	28.55	35.65	3	4	2
SR604060	_DEFAULT	3.38	206,225	80	50	22	69	1.88	2	4	48	1	SR604	CL	35.65	36.26	3	4	2
SR604070	_DEFAULT	2.78	372,300	80	50	22	69	1.88	3	6	72	1	SR604	CL	36.26	37.69	3	4	2
SR604080	_DEFAULT	3.30	291,061	80	50	22	69	2.09	3	6	72	1	SR604	CL	37.69	41.61	3	4	2
SR604090	_DEFAULT	3.30	170,364	80	50	22	69	1.86	2	4	48	1	SR604	CL	41.61	44.46	3	4	2
SR604100	_DEFAULT	3.57	92,747	83	52	18	43	2.21	2	4	48	1	SR604	CL	44.51	50.75	3	4	2
SR604110	_DEFAULT	2.72	99,645	83	52	19	47	1.68	1	2	24	1	SR604	CL	50.75	56.61	3	4	2
SR604120	_DEFAULT	2.56	99,645	80	50	22	69	3.60	1	2	24	1	SR604	CL	56.61	57.58	3	4	2
SR604140	_DEFAULT	2.48	99,645	80	50	22	69	1.39	1	2	24	1	SR604	CL	57.9	58.59	3	4	2
SR604150	_DEFAULT	2.20	99,645	80	50	23	74	1.39	1	2	24	1	SR604	CL	58.59	62.18	3	4	2
SR604160	_DEFAULT	2.04	99,645	80	50	22	69	1.39	1	2	24	1	SR604	CL	62.18	65.85	3	4	2
SR604170	_DEFAULT	1.99	99,645	80	50	22	69	4.44	1	2	24	1	SR604	CL	65.85	69.68	3	4	2
SR605010	_DEFAULT	2.25	252,945	80	50	22	69	1.99	2	4	48	1	SR605	CL	1.57	3.04	3	4	2
SR605020	_DEFAULT	2.48	217,723	80	50	22	69	1.99	2	4	48	1	SR605	CL	3.04	4.54	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR607010	_DEFAULT	2.59	118,990	83	52	18	43	4.44	3	6	72	1	SR607	CL	40.95	44.58	3	4	2
SR607020	_DEFAULT	3.07	66,339	83	52	18	43	1.35	2	4	48	1	SR607	CL	44.58	46.17	3	4	2
SR610010	_DEFAULT	3.21	34,310	83	52	18	43	4.44	2	4	48	1	SR610	CL	1.03	2.03	3	4	2
SR612020	_DEFAULT	3.21	329,668	83	52	18	43	4.00	3	6	72	1	SR612	CL	38.74	44.01	3	4	2
SR612030	_DEFAULT	3.09	305,505	83	52	18	43	4.00	3	6	72	1	SR612	CL	44.01	44.53	3	4	2
SR647010	_DEFAULT	2.49	23,360	67	36	41	154	2.84	1	2	24	2	SR647	WA	6.54	8.47	3	4	2
SR647020	_DEFAULT	2.41	24,820	67	36	41	154	2.84	1	2	24	2	SR647	WA	8.47	11.13	3	4	2
SR647030	_DEFAULT	2.63	41,610	67	36	41	154	3.17	1	2	24	2	SR647	WA	11.13	11.36	3	4	2
SR647050	_DEFAULT	2.69	40,880	67	36	41	154	2.77	2	4	48	2	SR647	WA	11.72	12.75	3	4	2
SR647060	_DEFAULT	2.53	64,240	67	36	41	154	2.41	2	4	48	2	SR647	WA	12.75	14.95	3	4	2
SR647070	_DEFAULT	2.46	76,285	65	33	45	176	2.14	1	2	24	2	SR647	WA	14.95	15.84	3	4	2
SR647080	_DEFAULT	1.95	113,698	65	33	45	176	4.22	1	2	24	2	SR647	WA	15.84	16.22	3	4	2
SR648020	_DEFAULT	1.99	13,505	67	36	41	154	4.44	2	4	48	2	SR648	WA	0.31	0.71	3	4	2
SR648050	_DEFAULT	2.93	181,405	67	36	41	154	4.44	2	4	48	2	SR648	WA	2.75	3.26	3	4	2
SR648060	_DEFAULT	2.34	243,090	67	36	41	154	1.52	2	4	48	2	SR648	WA	3.26	3.37	3	4	2
SR648070	_DEFAULT	2.91	210,240	67	36	41	154	4.44	2	4	48	2	SR648	WA	3.37	5.18	3	4	2
SR648080	_DEFAULT	2.92	186,880	67	36	41	154	2.60	2	4	48	2	SR648	WA	5.18	5.34	3	4	2
SR650010	_DEFAULT	3.14	79,935	67	36	41	154	3.72	2	4	48	2	SR650	WA	1.85	4.75	3	4	2
SR650020	_DEFAULT	3.62	186,150	57	31	35	132	2.62	2	4	48	2	SR650	WA	4.75	8.13	3	4	2
SR650030	_DEFAULT	3.83	173,740	67	36	41	154	4.44	2	4	48	2	SR650	WA	8.13	8.28	3	4	2
SR651010	_DEFAULT	2.03	93,988	65	33	45	176	2.70	2	4	48	2	SR651	WA	0	1.4	3	4	2
SR651020	_DEFAULT	2.62	91,433	65	33	45	176	1.90	2	4	48	2	SR651	WA	4.1	5.46	3	4	2
SR651030	_DEFAULT	2.87	17,009	65	33	45	176	4.44	2	4	48	2	SR651	WA	6.02	10.33	3	4	2
SR653020	_DEFAULT	3.80	100,375	67	36	41	154	1.34	2	4	48	2	SR653	WA	0.64	0.92	3	4	2
SR653030	_DEFAULT	3.59	107,067	67	36	41	154	1.45	2	4	48	2	SR653	WA	0.92	1.32	3	4	2
SR657010	_DEFAULT	1.72	15,330	65	33	45	176	3.72	1	2	24	2	SR657	WA	0	0.18	3	4	2
SR660010	_DEFAULT	2.71	29,930	65	33	45	176	1.81	2	4	48	2	SR660	WA	3.93	5.12	3	4	2
SR663020	_DEFAULT	3.03	64,970	67	36	41	154	2.08	2	4	48	2	SR663	WA	0.44	1.25	3	4	2
SR663030	_DEFAULT	2.96	15,513	67	36	41	154	1.99	2	4	48	2	SR663	WA	1.25	2.49	3	4	2
SR667070	_DEFAULT	2.76	87,600	67	36	41	154	1.24	2	4	48	2	SR667	WA	22.54	23.46	3	4	2
SR667080	_DEFAULT	3.49	77,015	67	36	41	154	2.40	2	4	48	2	SR667	WA	23.46	26.76	3	4	2
SR705010	_DEFAULT	1.36	730	65	33	45	176	1.60	1	2	24	2	SR705	CC	2.94	3.37	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR705020	_DEFAULT	1.83	730	65	33	45	176	1.30	1	2	24	2	SR705	CC	3.37	4.38	3	4	2
SR705030	_DEFAULT	1.80	4,015	65	33	45	176	1.30	1	2	24	2	SR705	CC	4.38	4.6	3	4	2
SR715010	_DEFAULT	2.63	28,288	69	38	38	119	1.51	1	2	24	2	SR715	CH	0	2.11	3	4	2
SR718010	_DEFAULT	2.63	2,920	69	38	38	119	4.44	1	2	24	2	SR718	CH	0	1.86	3	4	2
SR718020	_DEFAULT	3.09	8,030	69	38	38	119	4.44	1	2	24	2	SR718	CH	1.86	2.94	3	4	2
SR720010	_DEFAULT	1.59	13,231	69	38	38	119	1.82	1	2	24	2	SR720	CH	0	3.03	3	4	2
SR722010	_DEFAULT	2.05	1,095	57	32	72	146	1.10	1	2	24	2	SR722	LA	0	6.11	3	4	2
SR722020	_DEFAULT	1.41	1,095	59	31	67	165	0.99	1	2	24	2	SR722	LA	6.11	12	3	4	2
SR722030	_DEFAULT	2.43	1,095	60	31	65	176	4.44	1	2	24	3	SR722	LA	12	41.5	3	4	2
SR722050	_DEFAULT	2.29	365	65	33	46	178	1.60	1	2	24	2	SR722	CH	0.2	4.17	3	4	2
SR722070	_DEFAULT	2.27	365	59	31	57	172	0.95	1	2	24	2	SR722	CH	4.6	16.62	3	4	2
SR723010	_DEFAULT	3.05	14,965	68	37	40	137	1.90	1	2	24	2	SR723	CH	0	2.01	3	4	2
SR726020	_DEFAULT	2.46	8,395	69	38	38	119	4.44	1	2	24	2	SR726	CH	0.83	1.87	3	4	2
SR739010	_DEFAULT	3.42	27,010	78	48	25	87	4.44	1	2	24	1	SR739	CL	0	0.23	3	4	2
SR756010	_DEFAULT	2.28	19,893	65	33	45	176	1.56	1	2	24	2	SR756	DO	0	3.89	3	4	2
SR757010	_DEFAULT	3.70	13,140	65	33	45	176	0.40	1	2	24	2	SR757	DO	0	3.19	3	4	2
SR759010	_DEFAULT	2.55	19,710	65	33	45	176	2.66	1	2	24	2	SR759	DO	0	1.01	3	4	2
SR759020	_DEFAULT	2.07	19,710	65	33	45	176	1.14	1	2	24	2	SR759	DO	1.01	1.25	3	4	2
SR760010	_DEFAULT	2.60	4,745	58	30	60	171	4.44	1	2	24	2	SR760	DO	0	0.61	3	4	2
SR766020	_DEFAULT	3.31	537,280	63	31	56	216	2.18	1	2	24	3	SR766	EU	0	6.31	3	4	2
SR766030	_DEFAULT	3.21	137,605	63	31	56	216	2.26	1	2	24	3	SR766	EL	0	5.2	3	4	2
SR767010	_DEFAULT	3.73	730	59	31	67	165	1.90	1	2	24	3	SR767	EL	37.18	39.1	3	4	2
SR773020	_DEFAULT	2.43	3,650	69	37	36	139	4.44	1	2	24	1	SR773	ES	25.8	35.86	3	4	2
SR780010	_DEFAULT	1.71	2,312	57	32	73	145	0.90	1	2	24	3	SR780	EU	0	2.27	3	4	2
SR789010	_DEFAULT	3.63	36,135	67	35	42	160	2.15	1	2	24	3	SR789	HU	0	15.98	3	4	2
SR790010	_DEFAULT	2.69	6,205	67	36	41	154	1.50	1	2	24	3	SR790	HU	0	0.51	3	4	2
SR794010	_DEFAULT	2.53	69,624	67	36	41	154	1.14	1	2	24	2	SR794	HU	14.62	17.1	3	4	2
SR806020	_DEFAULT	2.94	6,570	65	32	49	228	2.20	1	2	24	3	SR806	LA	0.23	5.81	3	4	2
SR822010	_DEFAULT	2.44	203,305	67	36	41	154	0.60	1	2	24	2	SR822	LY	0	0.14	3	4	2
SR823010	_DEFAULT	2.86	6,883	65	33	45	176	1.55	1	2	24	2	SR823	LY	0	7.57	3	4	2
SR824010	_DEFAULT	2.03	12,045	65	33	45	176	0.60	1	2	24	2	SR824	LY	0	1.53	3	4	2
SR824020	_DEFAULT	1.80	7,373	65	33	45	176	0.90	1	2	24	2	SR824	LY	1.53	5.66	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
SR825010	_DEFAULT	1.85	3,650	65	33	45	176	4.44	1	2	24	2	SR825	LY	0	0.41	3	4	2
SR827010	_DEFAULT	2.61	13,627	67	36	41	154	0.80	1	2	24	2	SR827	LY	0	5.8	3	4	2
SR828010	_DEFAULT	2.65	11,634	67	36	41	154	1.74	1	2	24	2	SR828	LY	0	7.75	3	4	2
SR839010	_DEFAULT	2.68	1,460	66	35	39	153	0.90	1	2	24	2	SR839	MI	74.82	78.97	3	4	2
SR839020	_DEFAULT	2.55	1,460	66	34	43	166	0.90	1	2	24	2	SR839	CH	0	13.92	3	4	2
SR844010	_DEFAULT	2.44	1,460	64	33	41	160	1.14	1	2	24	1	SR844	NY	0	12.32	3	4	2
SR854020	_DEFAULT	1.02	2,190	69	38	38	119	1.20	1	2	24	2	SR854	PE	0.59	1.59	3	4	2
SR854030	_DEFAULT	2.24	2,190	69	38	38	119	1.42	1	2	24	2	SR854	PE	1.59	3.59	3	4	2
SR854040	_DEFAULT	2.29	22,448	68	37	40	137	1.20	1	2	24	2	SR854	PE	3.59	4.12	3	4	2
SR856040	_DEFAULT	1.59	31,025	69	38	38	119	2.54	1	2	24	2	SR856	PE	0.88	1.01	3	4	2
SR856050	_DEFAULT	1.47	31,025	69	38	38	119	2.54	1	2	24	2	SR856	PE	1.01	1.6	3	4	2
SR859010	_DEFAULT	2.50	1,825	67	36	41	154	4.44	1	2	24	3	SR859	PE	0	0.33	3	4	2
SR860010	_DEFAULT	2.36	730	69	38	38	119	4.44	1	2	24	2	SR860	PE	0	1.88	3	4	2
SR878010	_DEFAULT	2.87	365	53	30	70	143	0.72	1	2	24	2	SR878	WA	0	1.34	3	4	2
SR880010	_DEFAULT	1.29	3,650	65	33	45	176	2.12	1	2	24	2	SR880	WA	0	0.57	3	4	2
SR892010	_DEFAULT	2.21	1,095	62	30	63	187	0.92	1	2	24	3	SR892	WP	0	29.99	3	4	2
SR892020	_DEFAULT	1.77	1,095	61	30	64	182	1.00	1	2	24	3	SR892	WP	29.99	35.92	3	4	2
SR893010	_DEFAULT	1.93	730	61	30	64	182	0.80	1	2	24	3	SR893	WP	0	14.58	3	4	2
SR893020	_DEFAULT	2.59	730	62	30	63	189	0.80	1	2	24	3	SR893	WP	14.58	19.77	3	4	2
SR893030	_DEFAULT	2.49	730	62	30	63	189	0.80	1	2	24	3	SR893	WP	19.77	29.19	3	4	2
SR893040	_DEFAULT	2.23	730	62	30	63	189	0.80	1	2	24	3	SR893	WP	29.19	31.19	3	4	2
SR893050	_DEFAULT	2.13	730	62	30	63	189	0.65	1	2	24	3	SR893	WP	32.19	39.75	3	4	2
SR894010	_DEFAULT	2.35	1,095	62	30	64	186	1.25	1	2	24	3	SR894	WP	0	8.5	3	4	2
SR894020	_DEFAULT	2.23	1,095	62	30	63	189	1.25	1	2	24	3	SR894	WP	8.5	12.57	3	4	2
SR895020	_DEFAULT	2.66	1,095	62	30	63	189	1.50	1	2	24	3	SR895	WP	0.32	1.15	3	4	2
SR895030	_DEFAULT	2.29	1,095	62	30	63	189	1.50	1	2	24	3	SR895	WP	1.15	1.48	3	4	2
US006010	_DEFAULT	3.44	48,271	62	31	43	168	2.84	1	2	24	1	US006	MI	0	12.29	3	4	2
US006020	_DEFAULT	3.37	5,434	70	38	35	134	2.46	1	2	24	1	US006	ES	0	18.73	3	4	2
US006030	_DEFAULT	3.10	5,110	71	39	34	129	1.20	1	2	24	1	US006	ES	18.73	19.01	3	4	2
US006040	_DEFAULT	2.31	82,229	71	39	34	129	2.28	1	2	24	1	US006	ES	19.01	26	3	4	2
US006050	_DEFAULT	3.14	89,039	71	39	34	129	2.05	1	2	24	1	US006	ES	26	43.95	3	4	2
US006060	_DEFAULT	4.08	80,665	71	39	34	129	2.66	1	2	24	1	US006	ES	43.95	51.23	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US006070	_DEFAULT	4.25	86,505	67	36	38	147	2.66	1	2	24	1	US006	ES	51.23	57.74	3	4	2
US006080	_DEFAULT	2.82	44,517	67	35	39	151	2.11	1	2	24	1	US006	NY	0.82	14	3	4	2
US006090	_DEFAULT	3.36	19,682	64	33	41	160	2.58	1	2	24	1	US006	NY	14	26	3	4	2
US006100	_DEFAULT	3.19	23,725	63	32	42	166	2.02	1	2	24	1	US006	NY	26	30.39	3	4	2
US006110	_DEFAULT	2.91	23,279	65	33	41	159	1.93	1	2	24	1	US006	NY	30.39	39.29	3	4	2
US006120	_DEFAULT	3.06	21,170	66	34	40	156	1.55	1	2	24	1	US006	NY	39.29	43	3	4	2
US006130	_DEFAULT	2.74	20,148	65	33	41	160	2.32	1	2	24	1	US006	NY	43	51.21	3	4	2
US006140	_DEFAULT	3.18	13,870	68	36	38	146	2.26	1	2	24	1	US006	NY	51.21	73.35	3	4	2
US006150	_DEFAULT	3.06	11,315	66	34	40	156	2.05	1	2	24	1	US006	NY	73.35	83.25	3	4	2
US006160	_DEFAULT	3.44	14,381	68	36	37	143	2.45	1	2	24	1	US006	NY	83.25	103.5	3	4	2
US006170	_DEFAULT	2.54	21,535	71	39	34	130	1.69	1	2	24	1	US006	NY	103.5	117.57	3	4	2
US006180	_DEFAULT	3.75	22,219	65	33	41	160	2.12	1	2	24	3	US006	NY	117.57	132.02	3	4	2
US006190	_DEFAULT	3.84	9,490	59	31	68	163	2.66	1	2	24	3	US006	WP	0	10.45	3	4	2
US006200	_DEFAULT	3.91	10,950	60	31	66	170	2.66	1	2	24	3	US006	WP	10.45	14.19	3	4	2
US006210	_DEFAULT	3.99	46,355	60	31	65	175	2.66	1	2	24	3	US006	WP	14.19	19	3	4	2
US006220	_DEFAULT	2.66	48,346	58	31	69	158	2.40	1	2	24	3	US006	WP	19	30.1	3	4	2
US006240	_DEFAULT	2.76	50,005	57	32	73	145	1.46	1	2	24	3	US006	WP	30.51	31.14	3	4	2
US006250	_DEFAULT	2.89	50,248	57	32	73	145	1.46	1	2	24	3	US006	WP	31.14	34	3	4	2
US006260	_DEFAULT	2.64	50,370	57	32	73	145	1.55	1	2	24	3	US006	WP	34	35.92	3	4	2
US006270	_DEFAULT	2.71	60,103	57	32	73	145	1.11	1	2	24	3	US006	WP	35.92	37.95	3	4	2
US006280	_DEFAULT	2.63	23,950	57	32	73	145	2.05	1	2	24	3	US006	WP	37.95	52.41	3	4	2
US006290	_DEFAULT	3.36	14,600	55	33	75	136	2.09	1	2	24	3	US006	WP	52.41	64.8	3	4	2
US006300	_DEFAULT	2.53	16,558	61	31	66	177	1.90	1	2	24	3	US006	WP	64.8	75.08	3	4	2
US006310	_DEFAULT	3.84	13,992	60	31	67	170	2.66	1	2	24	3	US006	WP	75.08	90.37	3	4	2
US006320	_DEFAULT	2.95	12,319	63	31	58	207	2.72	1	2	24	3	US006	WP	90.37	101.88	3	4	2
US050010	_DEFAULT	2.70	80,349	57	30	63	164	1.92	2	4	48	2	US050	DO	0	14.58	3	4	2
US050020	_DEFAULT	3.61	98,185	59	31	57	175	4.53	2	4	48	2	US050	CC	0	5.61	3	4	2
US050030	_DEFAULT	3.68	98,185	63	32	50	183	4.53	2	4	48	2	US050	CC	5.61	6.92	3	4	2
US050040	_DEFAULT	3.53	98,185	64	33	48	180	4.53	2	4	48	2	US050	CC	6.92	7.6	3	4	2
US050080	_DEFAULT	2.59	290,996	65	33	45	176	1.93	2	4	48	2	US050	CC	11.02	15.02	3	4	2
US050090	_DEFAULT	3.61	153,665	65	33	45	176	4.41	2	4	48	2	US050	CC	15.02	16.39	3	4	2
US050100	_DEFAULT	3.64	153,665	65	33	45	176	3.46	2	4	48	2	US050	CC	16.39	16.6	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US050110	_DEFAULT	3.57	126,777	65	33	45	176	4.84	2	4	48	2	US050	LY	0	2.55	3	4	2
US050120	_DEFAULT	3.87	95,630	66	35	42	161	4.29	2	4	48	2	US050	LY	2.55	8.1	3	4	2
US050130	_DEFAULT	3.35	121,180	67	36	41	154	2.87	2	4	48	2	US050	LY	8.1	9	3	4	2
US050140	_DEFAULT	2.52	104,187	67	36	41	154	2.80	1	2	24	2	US050	LY	9	18.86	3	4	2
US050150	_DEFAULT	2.41	68,852	67	36	41	154	2.99	1	2	24	2	US050	LY	18.86	29.43	3	4	2
US050160	_DEFAULT	1.71	31,755	67	36	41	154	2.84	1	2	24	2	US050	LY	29.43	32.1	3	4	2
US050170	_DEFAULT	1.71	31,755	67	36	41	154	2.84	1	2	24	2	US050	LY	32.1	35.36	3	4	2
US050175	_DEFAULT	3.19	32,485	67	36	41	154	2.75	1	2	24	2	US050	CH	0	11.53	3	4	2
US050180	_DEFAULT	3.29	179,717	68	37	40	137	2.84	2	4	48	2	US050	CH	11.53	19.4	3	4	2
US050190	_DEFAULT	2.74	136,328	69	38	38	119	2.46	2	4	48	2	US050	CH	19.4	20.64	3	4	2
US050200	_DEFAULT	2.18	171,915	69	38	38	119	1.46	1	2	24	2	US050	CH	20.64	21.14	3	4	2
US050210	_DEFAULT	2.96	60,184	69	38	38	119	2.84	1	2	24	2	US050	CH	21.14	30.03	3	4	2
US050220	_DEFAULT	2.63	31,558	69	38	38	122	2.55	1	2	24	2	US050	CH	30.03	43.71	3	4	2
US050230	_DEFAULT	2.66	35,362	67	36	41	157	2.05	1	2	24	2	US050	CH	43.71	60.05	3	4	2
US050240	_DEFAULT	1.82	30,478	66	34	43	167	2.72	1	2	24	2	US050	CH	60.05	70	3	4	2
US050250	_DEFAULT	2.37	17,897	62	32	51	179	1.43	1	2	24	2	US050	CH	70	100	3	4	2
US050260	_DEFAULT	2.50	17,520	60	31	55	179	1.78	1	2	24	2	US050	CH	100	106.88	3	4	2
US050270	_DEFAULT	2.40	17,586	59	31	67	165	2.89	1	2	24	3	US050	LA	0	22.27	3	4	2
US050290	_DEFAULT	2.22	18,980	59	31	67	165	0.87	1	2	24	3	US050	LA	22.85	23.41	3	4	2
US050300	_DEFAULT	3.26	13,505	59	31	67	165	1.83	1	2	24	3	US050	LA	23.41	24.08	3	4	2
US050310	_DEFAULT	3.29	15,695	55	32	74	138	2.84	1	2	24	3	US050	LA	24.08	33.63	3	4	2
US050320	_DEFAULT	2.79	14,036	61	31	66	177	3.39	1	2	24	3	US050	LA	33.63	44.23	3	4	2
US050330	_DEFAULT	3.63	13,505	59	31	67	167	3.54	1	2	24	3	US050	LA	44.23	47.68	3	4	2
US050335	_DEFAULT	3.86	14,235	62	30	63	189	2.67	1	2	24	3	US050	EU	0	12.3	3	4	2
US050340	_DEFAULT	3.62	18,685	61	30	64	184	2.47	1	2	24	3	US050	EU	12.3	38.14	3	4	2
US050350	_DEFAULT	2.03	11,680	57	32	73	145	2.30	1	2	24	3	US050	EU	38.14	40.74	3	4	2
US050360	_DEFAULT	2.05	11,880	58	32	72	150	1.27	1	2	24	3	US050	EU	40.74	47.38	3	4	2
US050365	_DEFAULT	2.20	10,585	62	30	63	189	2.12	1	2	24	3	US050	WP	0	3.15	3	4	2
US050370	_DEFAULT	2.34	10,001	61	31	65	177	1.60	1	2	24	3	US050	WP	3.15	13.6	3	4	2
US050380	_DEFAULT	2.27	9,855	59	31	68	163	1.70	1	2	24	3	US050	WP	13.6	22.78	3	4	2
US050390	_DEFAULT	2.22	9,855	57	32	73	145	2.45	1	2	24	3	US050	WP	22.78	25.28	3	4	2
US050400	_DEFAULT	3.54	9,855	57	32	73	145	2.91	1	2	24	3	US050	WP	25.28	33	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US050410	_DEFAULT	2.29	13,140	57	32	73	145	2.66	1	2	24	3	US050	WP	33	35.41	3	4	2
US050420	_DEFAULT	2.39	13,140	59	31	68	163	2.66	1	2	24	3	US050	WP	35.41	45.26	3	4	2
US050430	_DEFAULT	2.24	13,140	58	32	70	155	2.66	1	2	24	3	US050	WP	45.26	49.37	3	4	2
US050440	_DEFAULT	2.15	13,140	58	32	71	153	2.66	1	2	24	3	US050	WP	49.37	61.69	3	4	2
US050450	_DEFAULT	2.43	11,388	59	31	67	165	1.69	1	2	24	3	US050	WP	61.4	66.26	3	4	2
US050460	_DEFAULT	3.37	93,805	59	31	67	165	1.85	2	4	48	3	US050	WP	66.26	68.37	3	4	2
US093010	_DEFAULT	2.80	503,846	83	52	17	38	2.12	1	2	24	1	US093	CL	1.62	5.67	3	4	2
US093020	_DEFAULT	3.15	529,737	83	52	18	43	1.91	2	4	48	1	US093	CL	5.67	7.93	3	4	2
US093030	_DEFAULT	2.47	960,315	80	50	22	69	2.05	2	4	48	1	US093	CL	7.93	9.27	3	4	2
US093050	_DEFAULT	3.17	1,148,655	80	50	22	69	3.86	2	4	48	1	US093	CL	9.54	11.98	3	4	2
US093120	_DEFAULT	2.52	67,890	80	50	23	73	1.69	1	2	24	1	US093	CL	50.76	57.59	3	4	2
US093130	_DEFAULT	3.01	67,890	78	48	25	87	1.57	1	2	24	1	US093	CL	57.59	71.67	3	4	2
US093140	_DEFAULT	3.98	66,886	78	48	25	87	2.84	1	2	24	1	US093	CL	71.67	86.67	3	4	2
US093150	_DEFAULT	2.55	69,350	78	48	25	87	1.13	1	2	24	1	US093	LN	0	16.87	3	4	2
US093160	_DEFAULT	2.36	65,837	78	48	26	88	1.42	1	2	24	1	US093	LN	16.87	24.7	3	4	2
US093170	_DEFAULT	3.94	68,401	75	45	29	96	2.66	1	2	24	1	US093	LN	24.7	39.42	3	4	2
US093180	_DEFAULT	2.59	68,292	72	43	32	102	1.93	1	2	24	1	US093	LN	39.42	49.68	3	4	2
US093190	_DEFAULT	2.64	58,035	74	44	31	90	1.50	1	2	24	1	US093	LN	49.68	51.02	3	4	2
US093200	_DEFAULT	2.30	14,235	73	41	32	110	1.38	1	2	24	1	US093	LN	51.02	64.66	3	4	2
US093210	_DEFAULT	3.90	14,235	70	39	35	132	2.84	1	2	24	1	US093	LN	64.66	80.67	3	4	2
US093220	_DEFAULT	2.91	14,235	65	33	41	160	1.60	1	2	24	1	US093	LN	80.67	88.31	3	4	2
US093230	_DEFAULT	2.36	14,454	69	38	36	137	1.42	1	2	24	1	US093	LN	88.31	93.13	3	4	2
US093240	_DEFAULT	3.27	58,035	73	41	31	100	2.54	1	2	24	1	US093	LN	93.13	94.56	3	4	2
US093250	_DEFAULT	2.29	21,219	71	39	34	125	2.28	1	2	24	1	US093	LN	94.56	109.79	3	4	2
US093260	_DEFAULT	2.78	16,999	68	36	38	147	1.42	1	2	24	1	US093	LN	109.79	116.37	3	4	2
US093270	_DEFAULT	2.70	8,833	66	34	40	156	0.90	1	2	24	1	US093	LN	116.37	121.11	3	4	2
US093280	_DEFAULT	2.70	5,707	65	34	40	158	1.52	1	2	24	1	US093	LN	121.11	132	3	4	2
US093290	_DEFAULT	3.10	8,760	64	33	41	163	2.20	1	2	24	1	US093	LN	132	147.88	3	4	2
US093300	_DEFAULT	3.53	19,945	64	33	41	162	2.30	1	2	24	1	US093	LN	147.88	161.31	3	4	2
US093310	_DEFAULT	2.63	20,805	65	34	41	159	1.39	1	2	24	1	US093	LN	161.31	172.87	3	4	2
US093320	_DEFAULT	2.57	20,805	59	31	67	165	2.25	1	2	24	3	US093	WP	0	11	3	4	2
US093330	_DEFAULT	2.59	20,166	60	31	65	176	1.66	1	2	24	3	US093	WP	11	27.03	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US093340	_DEFAULT	2.88	111,225	59	31	67	165	1.97	1	2	24	3	US093	WP	53.45	64	3	4	2
US093350	_DEFAULT	3.67	126,290	59	31	67	165	2.22	1	2	24	3	US093	WP	64	67	3	4	2
US093360	_DEFAULT	3.21	43,983	59	31	67	165	1.40	1	2	24	3	US093	WP	67	76.35	3	4	2
US093370	_DEFAULT	3.91	44,895	59	31	67	165	2.66	1	2	24	3	US093	WP	76.35	98.56	3	4	2
US093380	_DEFAULT	2.82	46,258	61	30	64	183	2.66	1	2	24	3	US093	WP	98.56	112.76	3	4	2
US093390	_DEFAULT	3.47	32,850	62	30	63	189	2.86	1	2	24	3	US093	WP	112.76	116.69	3	4	2
US093395	_DEFAULT	3.55	36,500	62	30	63	189	2.84	1	2	24	3	US093	EL	0	11.89	3	4	2
US093400	_DEFAULT	3.89	36,500	62	30	63	189	2.84	1	2	24	3	US093	EL	11.89	30.79	3	4	2
US093410	_DEFAULT	3.99	36,500	62	30	63	189	2.80	1	2	24	3	US093	EL	30.79	44	3	4	2
US093420	_DEFAULT	3.72	35,405	62	30	63	189	2.81	1	2	24	3	US093	EL	44	54.6	3	4	2
US093430	_DEFAULT	3.88	36,961	62	30	63	189	2.70	1	2	24	3	US093	EL	54.6	73.78	3	4	2
US093440	_DEFAULT	3.56	44,165	62	30	63	189	2.60	1	2	24	3	US093	EL	73.78	74.13	3	4	2
US093450	_DEFAULT	3.53	160,600	62	30	63	189	4.40	1	2	24	3	US093	EL	74.13	83.22	3	4	2
US093460	_DEFAULT	3.95	160,600	61	30	65	178	2.80	1	2	24	3	US093	EL	83.22	96	3	4	2
US093470	_DEFAULT	3.78	160,600	62	30	63	189	3.80	1	2	24	3	US093	EL	96	102.8	3	4	2
US093480	_DEFAULT	3.99	160,600	62	30	63	187	2.80	1	2	24	3	US093	EL	102.8	112.25	3	4	2
US093490	_DEFAULT	3.80	150,572	63	31	59	203	2.80	1	2	24	3	US093	EL	112.25	131.01	3	4	2
US093500	_DEFAULT	3.99	123,204	63	31	56	216	2.80	1	2	24	3	US093	EL	131.01	141.88	3	4	2
US095010	_DEFAULT	2.99	292,081	78	48	25	87	3.00	1	2	24	1	US095	CL	0	9.5	3	4	2
US095020	_DEFAULT	3.29	349,670	77	47	26	90	1.40	1	2	24	1	US095	CL	9.5	19	3	4	2
US095030	_DEFAULT	4.05	217,019	75	45	29	96	3.40	1	2	24	1	US095	CL	19	26	3	4	2
US095040	_DEFAULT	3.72	194,910	76	46	28	93	1.50	1	2	24	1	US095	CL	26	35.41	3	4	2
US095050	_DEFAULT	3.93	194,910	79	49	23	74	2.00	1	2	24	1	US095	CL	35.41	45.65	3	4	2
US095060	_DEFAULT	3.82	252,580	83	52	18	43	2.50	1	2	24	1	US095	CL	46.63	55.12	3	4	2
US095170	_DEFAULT	3.62	1,160,578	80	50	22	69	2.50	3	6	72	1	US095	CL	77.03	81.27	3	4	2
US095190	_DEFAULT	3.72	999,370	80	50	22	69	1.70	2	4	48	1	US095	CL	81.38	86.65	3	4	2
US095200	_DEFAULT	3.92	364,726	78	48	25	87	2.30	2	4	48	1	US095	CL	86.65	93	3	4	2
US095210	_DEFAULT	2.61	224,110	81	49	23	30	2.70	2	4	48	1	US095	CL	95.15	96.01	3	4	2
US095220	_DEFAULT	2.42	171,368	78	46	26	53	2.70	2	4	48	1	US095	CL	99.82	113.74	3	4	2
US095230	_DEFAULT	3.93	109,135	78	46	26	53	3.30	2	4	48	1	US095	CL	113.74	121	3	4	2
US095240	_DEFAULT	4.25	80,665	77	45	28	65	2.40	2	4	48	1	US095	CL	121	132.14	3	4	2
US095250	_DEFAULT	4.13	80,665	75	45	29	96	2.80	2	4	48	1	US095	NY	0	6.92	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US095260	_DEFAULT	3.29	82,125	76	46	28	93	3.50	1	2	24	1	US095	NY	6.92	14.37	3	4	2
US095270	_DEFAULT	3.47	132,130	78	48	25	87	1.20	1	2	24	1	US095	NY	14.37	28.83	3	4	2
US095280	_DEFAULT	2.83	144,462	78	48	25	87	1.40	1	2	24	1	US095	NY	28.83	41	3	4	2
US095290	_DEFAULT	2.80	147,825	78	48	25	87	1.00	1	2	24	1	US095	NY	41.23	44.76	3	4	2
US095300	_DEFAULT	2.81	147,825	78	48	25	87	1.20	1	2	24	1	US095	NY	44.76	45.09	3	4	2
US095310	_DEFAULT	3.00	147,825	78	48	25	88	1.00	1	2	24	1	US095	NY	45.09	56.23	3	4	2
US095320	_DEFAULT	2.63	124,328	75	45	29	88	2.40	1	2	24	1	US095	NY	56.23	72	3	4	2
US095330	_DEFAULT	3.75	114,975	76	44	29	77	2.40	1	2	24	1	US095	NY	72	85.25	3	4	2
US095340	_DEFAULT	3.50	106,983	75	43	30	85	2.30	1	2	24	1	US095	NY	85.25	103.58	3	4	2
US095350	_DEFAULT	2.06	95,995	73	41	31	100	2.80	1	2	24	1	US095	NY	103.58	107.24	3	4	2
US095351	_DEFAULT	1.80	103,587	71	39	34	129	2.80	1	2	24	1	US095	ES	0	5.75	3	4	2
US095355	_DEFAULT	3.70	95,995	67	35	39	151	3.00	1	2	24	1	US095	ES	12	19.97	3	4	2
US095356	_DEFAULT	3.74	122,796	67	36	38	147	2.40	1	2	24	1	US095	ES	19.97	32.88	3	4	2
US095360	_DEFAULT	3.59	379,235	66	34	40	156	2.40	2	4	48	1	US095	ES	45	45.42	3	4	2
US095370	_DEFAULT	3.28	82,125	71	39	34	129	2.30	1	2	24	1	US095	ES	85.24	94.2	3	4	2
US095380	_DEFAULT	2.81	82,125	70	39	35	132	1.60	1	2	24	1	US095	ES	94.2	99.07	3	4	2
US095390	_DEFAULT	3.16	82,125	68	37	37	143	4.44	1	2	24	1	US095	ES	99.07	99.18	3	4	2
US095395	_DEFAULT	2.65	106,945	73	41	31	100	1.30	1	2	24	1	US095	MI	0	3.01	3	4	2
US095400	_DEFAULT	3.17	106,945	73	41	31	100	1.70	1	2	24	1	US095	MI	3.01	5.87	3	4	2
US095410	_DEFAULT	2.70	198,049	73	41	31	100	2.20	1	2	24	1	US095	MI	11.48	16.38	3	4	2
US095420	_DEFAULT	3.12	165,953	73	41	31	100	2.40	1	2	24	1	US095	MI	16.38	27.99	3	4	2
US095430	_DEFAULT	2.82	163,520	73	41	31	100	2.80	1	2	24	2	US095	MI	27.99	39.68	3	4	2
US095440	_DEFAULT	3.84	104,796	73	41	31	100	2.60	1	2	24	2	US095	MI	39.68	48.55	3	4	2
US095450	_DEFAULT	3.29	153,091	73	41	31	100	2.20	1	2	24	2	US095	MI	48.55	62.64	3	4	2
US095460	_DEFAULT	3.13	158,931	73	41	31	104	1.80	1	2	24	2	US095	MI	62.64	69.81	3	4	2
US095470	_DEFAULT	3.72	166,544	73	41	31	100	2.80	1	2	24	2	US095	MI	69.81	83.08	3	4	2
US095480	_DEFAULT	3.57	107,144	72	40	32	108	2.40	1	2	24	2	US095	MI	83.08	92.56	3	4	2
US095500	_DEFAULT	3.71	87,454	68	37	39	131	2.50	1	2	24	2	US095	CH	0	15.68	3	4	2
US095505	_DEFAULT	3.72	71,540	65	33	45	176	2.00	1	2	24	2	US095	LY	0	2.67	3	4	2
US095510	_DEFAULT	3.76	129,077	69	38	38	119	2.80	1	2	24	2	US095	CH	15.68	25.07	3	4	2
US095520	_DEFAULT	3.44	138,518	69	38	38	119	2.60	1	2	24	2	US095	CH	25.07	26.09	3	4	2
US095530	_DEFAULT	2.24	200,203	69	38	38	119	2.30	1	2	24	2	US095	CH	26.09	28.18	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US095540	_DEFAULT	2.72	69,131	69	38	38	119	2.00	1	2	24	2	US095	CH	28.18	58.89	3	4	2
US095550	_DEFAULT	3.33	183,473	67	36	41	154	2.90	1	2	24	3	US095	HU	0	10	3	4	2
US095560	_DEFAULT	3.40	130,427	67	36	41	154	2.10	1	2	24	3	US095	HU	10	12.67	3	4	2
US095570	_DEFAULT	3.33	110,595	67	36	41	154	2.10	1	2	24	3	US095	HU	12.67	13.31	3	4	2
US095580	_DEFAULT	3.42	110,595	67	36	41	154	2.10	1	2	24	3	US095	HU	13.31	22	3	4	2
US095590	_DEFAULT	2.89	105,011	65	34	44	172	3.10	1	2	24	3	US095	HU	22	31.7	3	4	2
US095600	_DEFAULT	3.07	86,036	67	36	42	157	2.70	1	2	24	3	US095	HU	31.7	45.57	3	4	2
US095610	_DEFAULT	3.50	83,220	67	36	41	154	2.70	1	2	24	3	US095	HU	45.57	60.31	3	4	2
US095620	_DEFAULT	3.34	100,610	67	36	41	154	2.80	1	2	24	3	US095	HU	60.31	73.79	3	4	2
US395010	_DEFAULT	3.58	90,155	63	32	50	183	2.80	1	2	24	2	US395	DO	0	12.04	3	4	2
US395020	_DEFAULT	3.14	98,550	64	32	48	181	2.10	1	2	24	2	US395	DO	12.04	18.73	3	4	2
US395030	_DEFAULT	3.38	188,340	65	33	45	176	4.40	1	2	24	2	US395	DO	18.73	20.63	3	4	2
US395040	_DEFAULT	3.28	299,483	65	33	45	176	1.80	2	4	48	2	US395	DO	20.63	22.3	3	4	2
US395060	_DEFAULT	3.42	260,161	65	33	45	176	3.30	2	4	48	2	US395	DO	22.86	34.17	3	4	2
US395070	_DEFAULT	3.19	317,550	65	33	45	176	1.90	2	4	48	2	US395	CC	0.24	0.56	3	4	2
US395100	_DEFAULT	3.56	227,030	65	33	45	176	3.30	2	4	48	2	US395	CC	4.77	7.7	3	4	2
US395130	_DEFAULT	3.82	201,063	65	33	45	176	3.30	2	4	48	2	US395	WA	0	7.03	3	4	2
US395140	_DEFAULT	3.30	260,063	65	33	45	176	1.00	2	4	48	2	US395	WA	7.03	9.43	3	4	2
US395150	_DEFAULT	3.60	256,413	65	33	45	176	3.90	2	4	48	2	US395	WA	11.64	15.49	3	4	2
US395160	_DEFAULT	3.24	291,818	65	33	45	176	3.10	3	6	72	2	US395	WA	15.49	19.7	3	4	2
US395170	_DEFAULT	3.28	102,930	65	33	45	176	4.00	3	6	72	2	US395	WA	19.7	20.33	3	4	2
US395180	_DEFAULT	2.85	122,275	65	33	45	176	3.80	2	4	48	2	US395	WA	20.33	23.31	3	4	2
US395190	_DEFAULT	1.92	116,800	65	33	45	176	2.60	2	4	48	2	US395	WA	23.31	23.91	3	4	2
US395200	_DEFAULT	1.60	129,940	65	33	45	176	2.30	2	4	48	2	US395	WA	23.91	26.64	3	4	2
US395210	_DEFAULT	2.35	43,070	65	33	45	176	2.50	2	4	48	2	US395	WA	26.64	27.69	3	4	2
US395240	_DEFAULT	3.05	150,818	65	33	45	176	2.10	2	4	48	2	US395	WA	38.46	42.18	3	4	2
US50A010	_DEFAULT	2.72	122,640	67	36	41	154	2.40	1	2	24	2	US050A	LY	70.41	78	3	4	2
US50A020	_DEFAULT	2.54	122,640	67	36	41	154	2.20	1	2	24	2	US050A	CH	0	3.06	3	4	2
US50A030	_DEFAULT	2.49	158,775	69	38	38	124	2.40	1	2	24	2	US050A	CH	3.06	9.29	3	4	2
US93A010	_DEFAULT	3.21	17,520	62	30	63	189	2.00	1	2	24	3	US093A	WP	0	5.59	3	4	2
US93A020	_DEFAULT	3.14	17,520	62	30	63	189	2.00	1	2	24	3	US093A	EL	0	2	3	4	2
US93A030	_DEFAULT	2.51	17,520	62	30	63	189	2.10	1	2	24	3	US093A	EL	2	9.1	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

SEGMENT	FILE NAME	PSI	ANNUAL-ESAL	MAX-TEMP	MIN-TEMP	WET-DAYS	FRZ-THAW	SN	NO-LANES PER DIR	NO-LANES BOTH DIRECTION	WIDTH	DISTRICT	ROUTE	COUNTY	BEGIN MP	END MP	GROWTH RATE	DISCOUNT RATE	TERMINAL PSI
US93A040	_DEFAULT	2.60	17,520	62	30	63	189	2.50	1	2	24	3	US093A	EL	9.1	24.93	3	4	2
US93A050	_DEFAULT	3.04	17,520	62	30	61	198	2.10	1	2	24	3	US093A	EL	24.93	39	3	4	2
US93A060	_DEFAULT	3.55	20,336	66	33	49	226	1.80	1	2	24	3	US093A	EL	39	52.84	3	4	2
US93A070	_DEFAULT	2.98	21,900	67	34	46	217	2.30	1	2	24	3	US093A	EL	52.84	53.07	3	4	2
US95A010	_DEFAULT	2.56	28,032	73	41	31	100	2.70	1	2	24	2	US095A	MI	0	10.38	3	4	2
US95A030	_DEFAULT	2.54	40,789	66	35	43	165	2.70	1	2	24	2	US095A	LY	0.92	12.25	3	4	2
US95A040	_DEFAULT	3.05	33,580	67	36	41	154	2.60	1	2	24	2	US095A	LY	12.25	13.64	3	4	2
US95A050	_DEFAULT	2.68	67,492	67	36	41	154	3.28	1	2	24	2	US095A	LY	13.64	24.63	3	4	2
US95A060	_DEFAULT	3.28	63,510	66	35	42	162	3.20	1	2	24	2	US095A	LY	24.63	44.21	3	4	2
US95A070	_DEFAULT	4.05	82,627	66	35	43	164	2.59	1	2	24	2	US095A	LY	44.21	58.74	3	4	2
IR015010	_DEFAULT	4.06	920,637	78	48	25	88	3.50	2	4	48	3	IR015	EU	0	16.35	3	4	2
IR015010	_DEFAULT							3.50	2	4	48	3	IR015	EU	0	16.35	3	4	2
IR015120	_DEFAULT	3.99	594,585	80	50	22	69	5.70	2	4	48	1	IR015	CL	70.02	76.65	3	4	2
IR080010	_DEFAULT	3.73	842,645	65	33	45	177	3.60	2	4	48	2	IR080	WA	0	12.48	3	4	2
SR088020	_DEFAULT	3.06	108,405	65	33	45	176	4.44	1	2	24	2	SR088	DO	7.3	8.18	3	4	2
SR208030	_DEFAULT	2.60	32,485	65	33	45	176	1.50	1	2	24	2	SR208	LY	0	1.1	3	4	2
US050200	_DEFAULT	2.18	171,915	69	38	38	119	1.46	1	2	24	2	US050	CH	20.64	21.14	3	4	2
US093370	_DEFAULT	3.91	44,895	59	31	67	165	2.66	1	2	24	3	US093	WP	76.35	98.56	3	4	2
SR140050	_DEFAULT	3.93	12,775	65	34	44	171	1.70	1	2	24	3	SR140	HU	56.1	65.58	3	4	2

Figure 10. NDOT Pavement Segments Database (Continued).

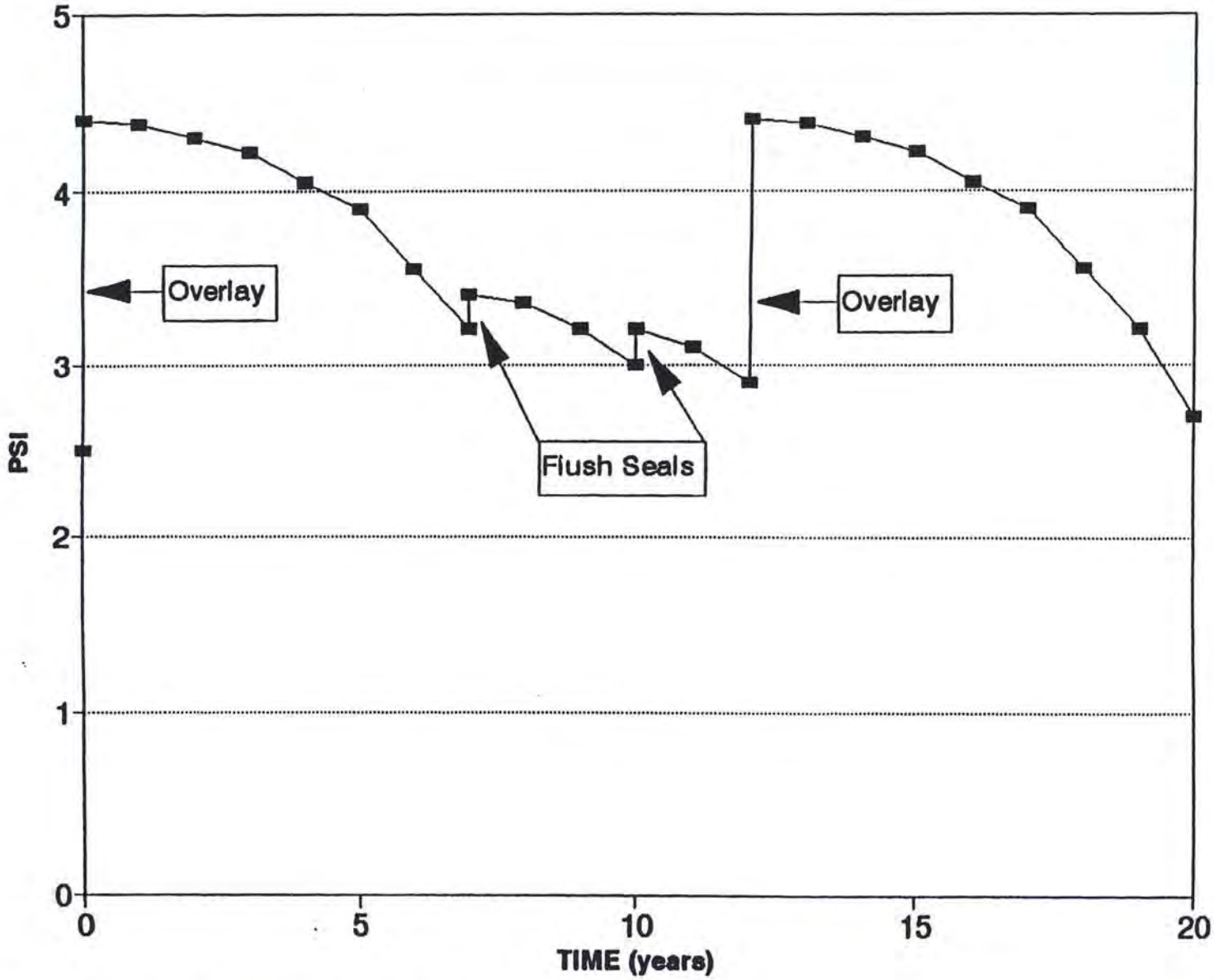


Figure 11. Typical Analysis Period for Flexible Pavements.

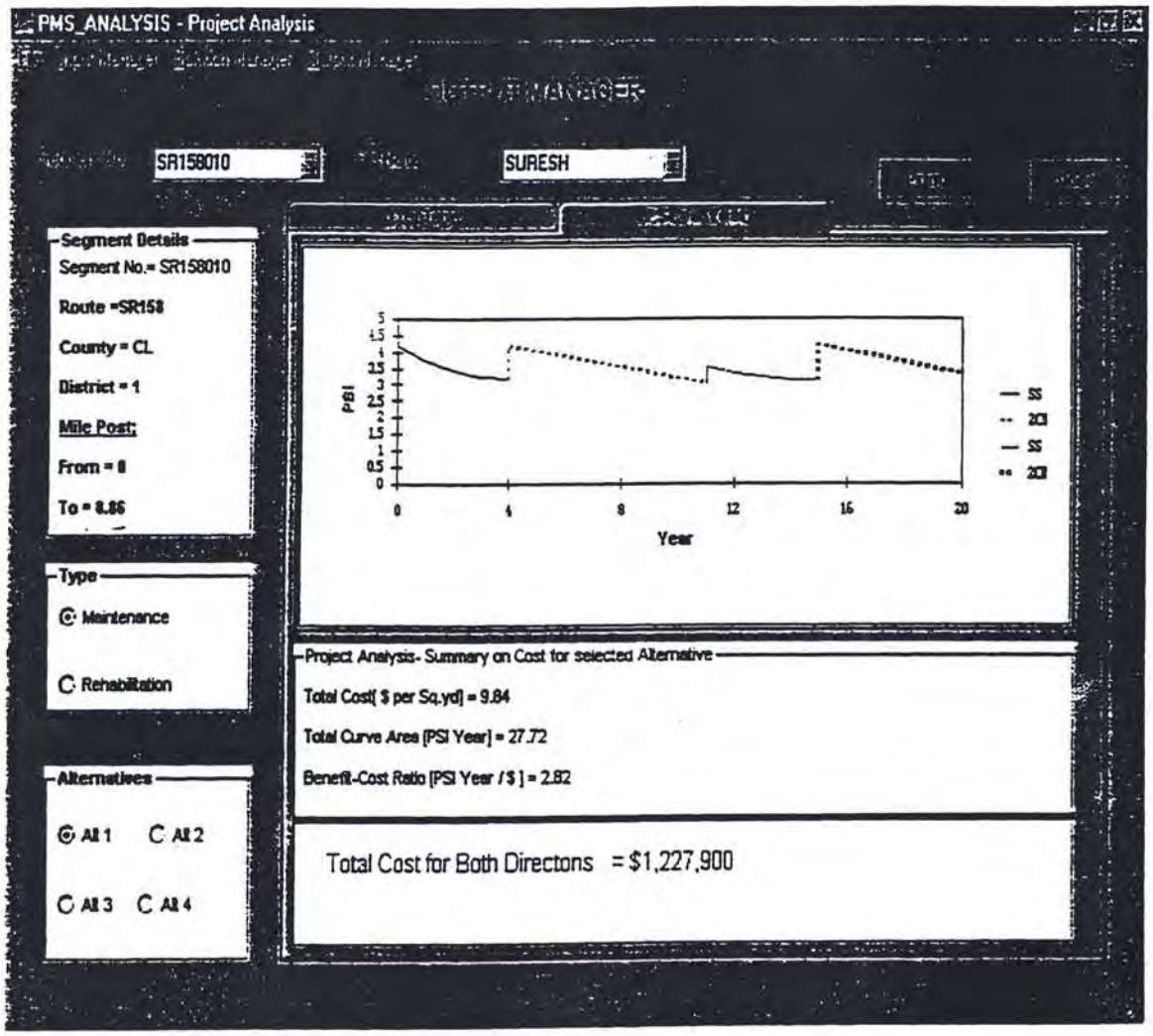


Figure 12. PSI Versus Age Function for one Alternative in the Project-Level Analysis.

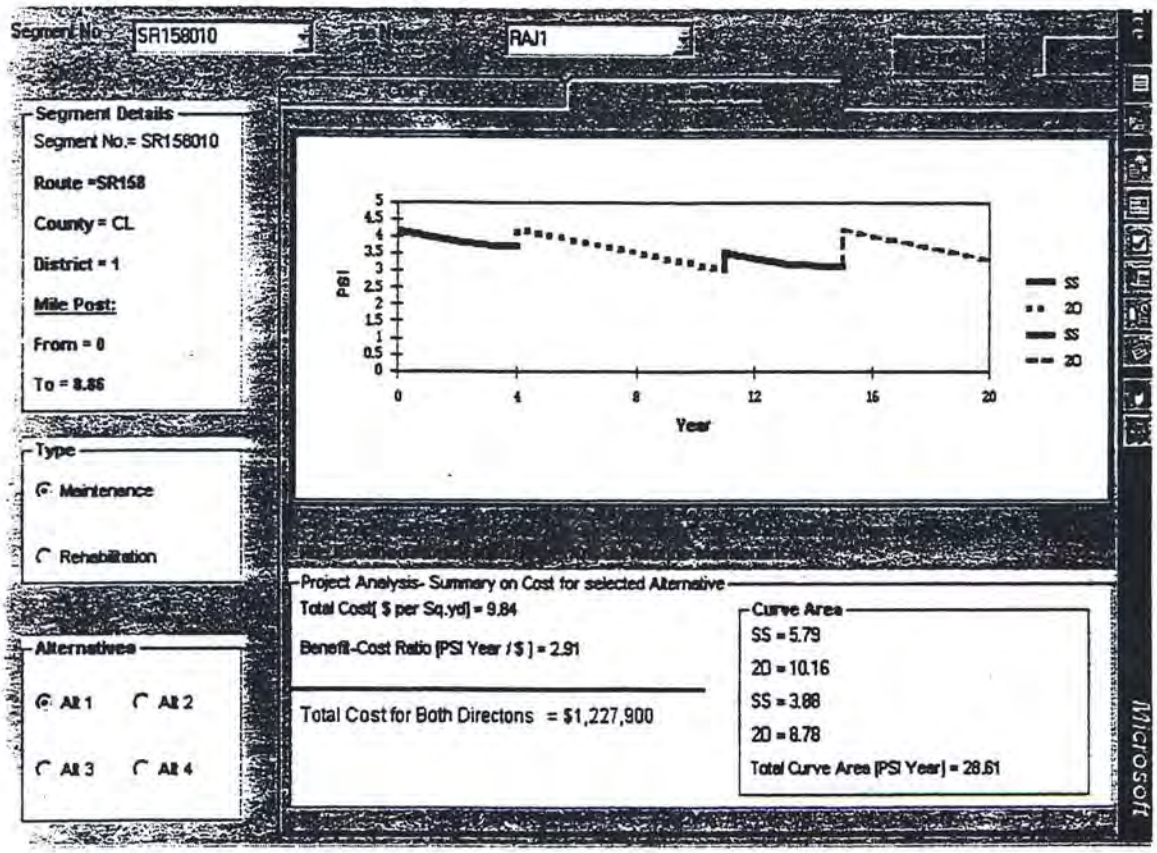


Figure 13. PSI-Age Relationship and Benefit-Cost Ratio Generated through the Project-Level Analysis.

Segment No: SR158010

Segment Details

Segment No.= SR158010

Route =SR158

County = CL

District = 1

Mile Post:

From = 0

To = 8.86

Type

Maintenance

Rehabilitation

Alternatives

Alt 1 Alt 2

Alt 3 Alt 4

Year	PSI	PWF	Treatment	Surface Area (sq. yd)	Cost ($/sq.yd)	PW($ /sq.yd)	PW($/)
00	4.20	1.0000	SS	124749	.640	.64	79,839
01	3.98	.9615	ARM	124749	.077	.07	9,266
02	3.83	.9246	ARM	124749	.077	.07	8,910
03	3.74	.8890	ARM	124749	.077	.07	8,567
04	4.20	.8548	20	124749	6.950	5.94	741,119
05	4.03	.8219	ARM	124749	.075	.06	7,741
06	3.86	.7903	ARM	124749	.075	.06	7,444
07	3.69	.7599	ARM	124749	.075	.06	7,157
08	3.53	.7307	ARM	124749	.075	.06	6,882
09	3.36	.7026	ARM	124749	.075	.05	6,617
10	3.19	.6756	ARM	124749	.075	.05	6,363
11	3.52	.6496	SS	124749	.640	.42	51,862
12	3.34	.6246	ARM	124749	.077	.05	6,019
13	3.21	.6006	ARM	124749	.077	.05	5,788
14	3.14	.5775	ARM	124749	.077	.04	5,565
15	4.20	.5553	20	124749	6.950	3.86	481,417
16	4.02	.5339	ARM	124749	.075	.04	5,029
17	3.84	.5134	ARM	124749	.075	.04	4,835
18	3.67	.4936	ARM	124749	.075	.04	4,649
19	3.49	.4746	ARM	124749	.075	.04	4,470
20	3.31	.4564	ARM	124749	.075	.03	4,298
20		.4564	Salvage Value	124749		-1.89	-235,929
					Total Cost($)	10	1,227,989

Figure 14. Cost Summary of a Maintenance Alternative over a 20-year Analysis Period Generated through the Project-Level Analysis.

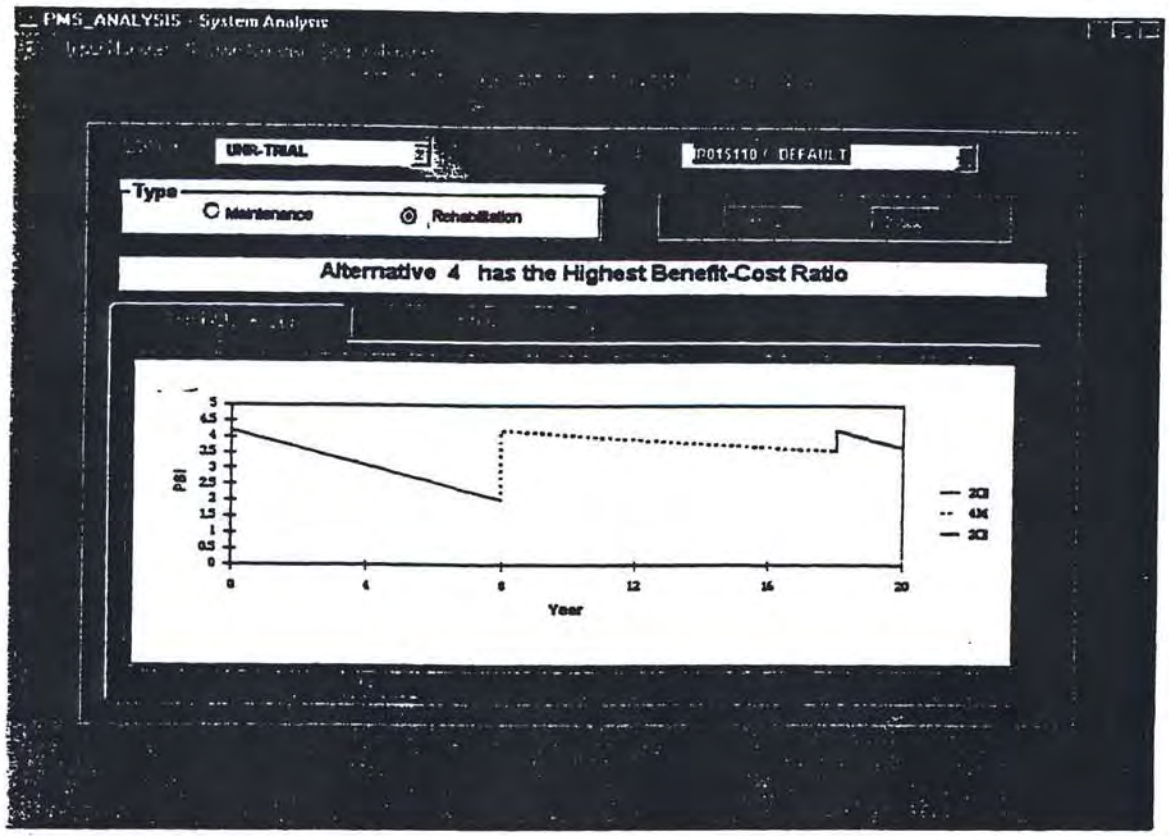


Figure 15. PSI Versus Age Function for the Most Effective Alternative in the System Analysis.

NDOT PAVEMENT MANAGEMENT SYSTEM ANALYSIS

SUMMARY REPORT - SYSTEM ANALYSIS

Network Name : TEST2 | Type : Maintenance | Date : 3/ 7/00

Segment Number	Benefit / Cost Ratio	AltNum	ActName	Cost	CumCost
Year : 0					
IR080010	1.16	1	2O	$2,442,485	$2,442,485
IR015100	1.08	4	2O	$3,244,904	$5,687,390
IR080420	0.99	4	2O	$2,252,645	$7,940,035
					$7,940,035
Year : 1					
IR080010	1.16	1	ARM	$20,207	$20,207
IR015100	1.08	4	ARM	$33,894	$54,102
IR080420	0.99	4	ARM	$29,607	$83,709
					$83,709
Year : 2					
IR080010	1.16	1	ARM	$19,430	$19,430
IR015100	1.08	4	ARM	$32,590	$52,021
IR080420	0.99	4	ARM	$28,468	$80,489
					$80,489
Year : 3					
IR080010	1.16	1	ARM	$18,683	$18,683
IR015100	1.08	4	ARM	$31,337	$50,020
IR080420	0.99	4	ARM	$27,373	$77,394
					$77,394
Year : 4					
IR080010	1.16	1	ARM	$17,964	$17,964
IR015100	1.08	4	ARM	$30,132	$48,096
IR080420	0.99	4	ARM	$26,320	$74,417
					$74,417
Year : 5					
IR080010	1.16	1	ARM	$17,273	$17,273
IR015100	1.08	4	ARM	$28,973	$46,246
IR080420	0.99	4	ARM	$25,308	$71,555
					$71,555
Year : 6					
IR080010	1.16	1	ARM	$16,609	$16,609
IR015100	1.08	4	ARM	$27,858	$44,468
IR080420	0.99	4	ARM	$44,827	$89,295
					$89,295
Year : 7					
IR080010	1.16	1	2O	$1,856,088	$1,856,088
IR015100	1.08	4	ARM	$6,386	$1,862,474

CS= Chip Seal, SS= Sand Seal, 2O= 2 inch Overlay, 2M= 2 inch Mill and Overlay, RBM= Roadbed Mod., ARM= Annual Routine Maint.

Figure 16. Cumulative Cost Summary for a Group of Pavement Sections Selected through the System Analysis Process.

APPENDIX A

Standard Data Collection Forms
for the
Selected Maintenance and Rehabilitation Activities

PROJECT:_____

CHIP SEALS OVER FLEXIBLE PAVEMENTS

Date:__/__/__

Location:_____

Begining Milepost:_____.__ Ending Milepost:_____.__

MATERIALS / MIXTURES OF CHIP SEAL

Binder Type:_____ Residue by Distillation:_____

Viscosity/Temp:_____/_____ L.A. Abr:_____

Penetration/Temp:_____/_____ Ductility/Temp:_____

Aggr Gradation:

3/4"-____	# 4-____
1/2"-____	# 16-____
3/8"-____	#200-____

Aggregate Rate (lb/yd2):_____ Binder Rate (gal/yd2):_____

Curing Time (hrs):_____ Cracks Sealed Prior to Construction: (Y / N)

TRAFFIC HISTORY

-Traffic Composition By Classes (6-13) (as extensive as possible)

-ESALS will be used if LEF are site specific

PMS DATA

-PMS (Prior to Chipseal & During Project Life)
-FWD (Prior to Chipseal & During Project Life)

PMS:	Alligator cracking	Long. cracking
	Transv. cracking	Rut Depths
	Rideability (Roughness)	Slope Variance
	PSI	Raveling
	Flushing	Skid Number (normalized)

PROJECT:_____

SAND SEALS OVER FLEXIBLE PAVEMENTS

Date:__/__/__

Location:_____

Begining Milepost:_____.__ Ending Milepost:_____.__

MATERIALS / MIXTURES OF CHIP SEAL

Binder Type:_____ Residue by Distillation:_____

Viscosity/Temp:_____/_____ L.A. Abr:_____

Penetration/Temp:_____/_____ Ductility/Temp:_____

Aggr Gradation:

1/2"-____ # 16-____
4-____ #200-____

Aggregate Rate (lb/yd2):_____ Binder Rate (gal/yd2):_____

Curing Time (hrs):_____ Cracks Sealed Prior to Construction: (Y / N)

TRAFFIC HISTORY

-Traffic Composition By Classes (6-13) (as extensive as possible)

-ESALS will be used if LEF are site specific

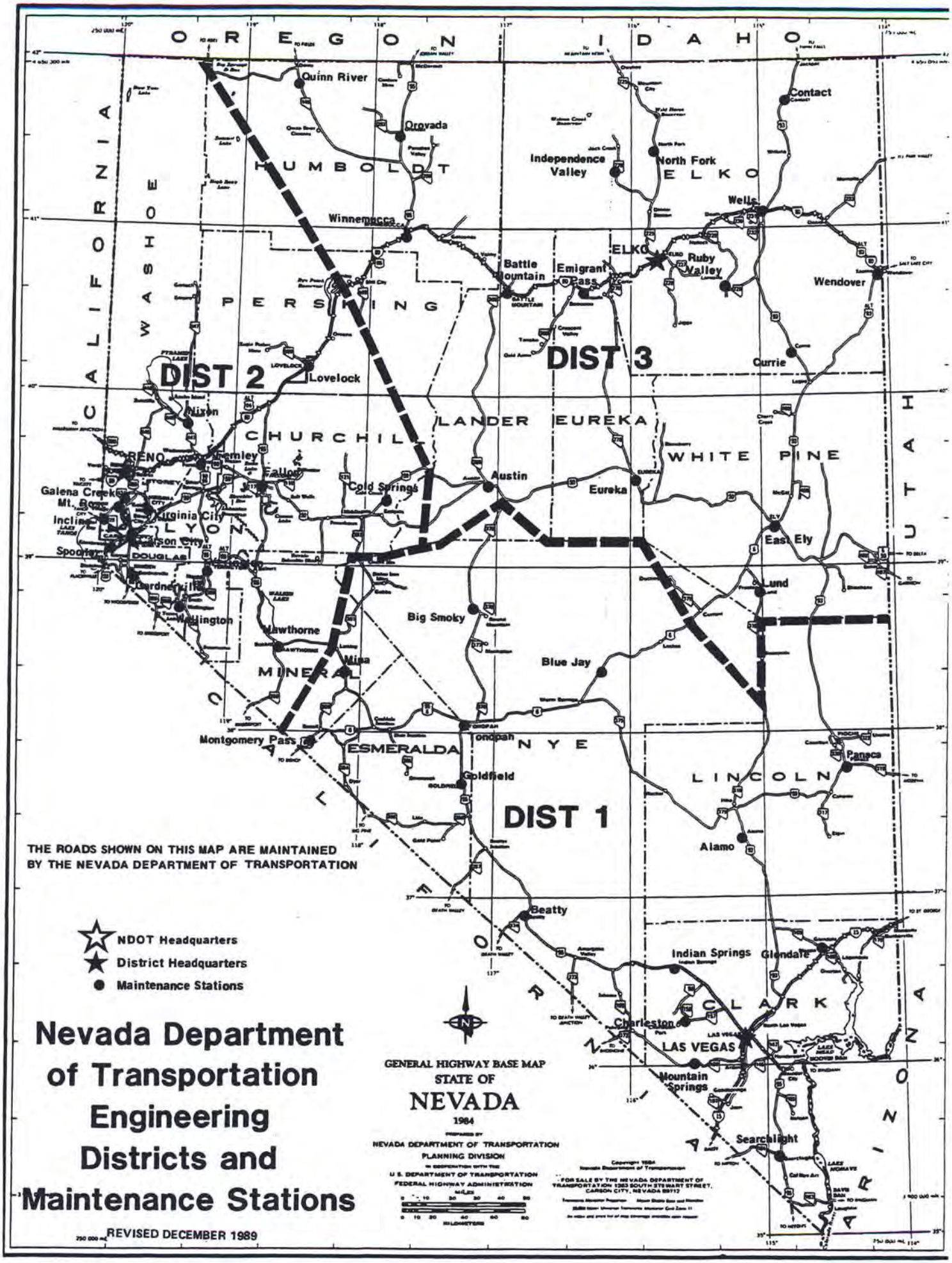
PMS DATA

-PMS (Prior to Sandseal & During Project Life)
-FWD (Prior to Sandseal & During Project Life)

PMS:	Alligator cracking	Long. cracking
	Transv. cracking	Rut Depths
	Rideability (Roughness)	Slope Variance
	PSI	Raveling
	Flushing	Skid Number (normalized)

APPENDIX B

Performance Models
Based on
Individual Districts and with/without Materials Properties


OREGON
IDAHO
CALIFORNIA
UTAH
ARIZONA
HUMBOLDT
ELKO
WASHOE
PERSHING
CHURCHILL
LANDER
EUREKA
WHITE PINE
LYON
DOUGLAS
MINERAL
ESMERALDA
NYE
LINCOLN
CLARK
DIST 1
DIST 2
DIST 3
Quinn River
Orovada
Winnemucca
Lovelock
Nixon
RENO
Sparks
Fernley
Fallon
Galena Creek
Mt. Rose
Incline
Virginia City
Carson City
Spooner
Gardnerville
Wellington
Hawthorne
Mina
Montgomery Pass
Tonopah
Goldfield
Beatty
Indian Springs
Glendale
Charleston Park
LAS VEGAS
Mountain Springs
Searchlight
Alamo
Pahrump
Lund
East Ely
Ely
Eureka
Austin
Cold Springs
Big Smoky
Blue Jay
Battle Mountain
Emigrant Pass
ELKO
Ruby Valley
Wells
Wendover
Currie
Independence Valley
North Fork
Contact
THE ROADS SHOWN ON THIS MAP ARE MAINTAINED BY THE NEVADA DEPARTMENT OF TRANSPORTATION
NDOT Headquarters
District Headquarters
Maintenance Stations
Nevada Department of Transportation Engineering Districts and Maintenance Stations
REVISED DECEMBER 1989
GENERAL HIGHWAY BASE MAP
STATE OF
NEVADA
1984
NEVADA DEPARTMENT OF TRANSPORTATION
PLANNING DIVISION
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
MILES
KILOMETERS

PERFORMANCE MODEL FOR SAND SEAL

DISTRICT-1 WITH MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 1.89294966+C1+0.00371322*ESAL -0.29025790*YEAR - 0.17444975*AGGRATE + 21.25454582*BINDERATE	60	0.91078	0.18402542

VARIABLES	DATA RANGE
ESAL	730 - 60,000
BINDRATE	0.3 - 0.35
YEAR	1 - 5
AGGRATE	18 - 35

BINDER TYPE	CONSTANT C1
ARA-B	-0.32136299
CRS-2	-1.2459893
LMCRS-2H	0.17461354
MC-800	1.18487802
SS1-H	0

PERFORMANCE MODEL FOR SAND SEAL

DISTRICT-1 WITHOUT MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 3.041393070 + 0.001799636*ESAL - 0.111491321*YEAR	60	0.036642	0.0024019

VARIABLES	DATA RANGE
ESAL	730 - 60,000
YEAR	1 - 6

PERFORMANCE MODEL FOR SAND SEAL

DISTRICT-2 WITH MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 5.832610167+C1+C2+ C3*ESAL-0.004502270*ESAL-0.021957410*MAXTEMP - 0.185507615*YEAR + 0.015914555 YEAR*YEAR + 0.023797295*AGGRATE - 2.802984444 * BINDRATE	91	0.9178	0.12233589

VARIABLES	DATA RANGE		
	IR	SR	US
ESAL	NA	630 - 37,000	19,000 - 23,000
AGGRATE	NA	0 - 21	11 - 16
BINDRATE	NA	0 - 0.25	0.13 - 0.16
MAX-TEMP	NA	53.89 - 69	66.6 - 68.8
YEAR	NA	1 - 6	1 - 5

BINDERTYPE	CONSTANT C1
CRS-1	-0.17575024
CSS-1	-0.25286774
MC-250	-0.509058914
SS-1H	0

ROUTE TYPE	CONSTANT C2	CONSTANT C3
SR	-1.043260693	0.00511794
US	0	0

PERFORMANCE MODEL FOR SAND SEAL

DISTRICT-2 WITHOUT MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 5.683014667+C1+C2*ESAL-0.000537265 * ESAL-0.025013065*MAXTEMP - 0.224691263*YEAR + 0.011671155* YEAR*YEAR	93	0.784193	0.19828681

VARIABLES	DATA RANGE
ESAL	630 - 37,000
MAX-TEMP	53.89 - 69.0
YEAR	1 - 6

ROUTE TYPE	CONSTANT C2	CONSTANT C3
SR	-1.164897433	0.005412593
US	0	0

PERFORMANCE MODEL FOR SAND SEAL

DISTRICT-3 WITH MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 2.11683120 + C1 + 0.00008272*ESAL - 0.11868113*YEAR - 0.29649766*AGGRATE + 28.39316746 * BINDRATE	59	0.784588	0.26820757

VARIABLES	DATA RANGE
ESAL	1,500 - 398,000
AGGRATE	5 - 22
BINDRATE	0.11 - 0.25
YEAR	1 - 7

BINDERTYPE	CONSTANT C1
MC-250	1.4423776
MC-70	1.0460999
MC-800	-2.86216662
SS-1H	0

PERFORMANCE MODEL FOR SAND SEAL

DISTRICT-3 WITHOUT MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 2.11683120 - 0.000082322*ESAL - 0.000054802*YEAR	59	0.010146	0.44974652

VARIABLES	DATA RANGE
ESAL	1,500 - 398,000
AGGRATE	5 - 22
BINDRATE	0.11 - 0.25
YEAR	1 - 7

PERFORMANCE MODEL FOR SAND SEAL

COMBINED DISTRICT WITHOUT MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 5.801135546 +C1 + C2*ESAL - 0.001284272*ESAL - 0.005774821*FRZ + 0.005078054*WETDAYS - 0.049108689*MINTEMP + 0.008663055*MAXTEMP - 0.309738877*YEAR + 0.030163370*YEAR*YEAR	212	0.628365	0.2910235

VARIABLES	RANGE		
	IR	SR	US
ESAL	39,000 - 785,000	630 - 37,000	17,000 - 60,000
WETDAY	18 - 77	18 - 68.1	37.4 - 59.87
FRZ	43 - 220	43 - 230	121.92 - 199.87
MINTEMP	32 - 41	29.7 - 52	30.5 - 37.8
MAXTEMP	54 - 69	53.9 - 83	62.6 - 68.8
YEAR	1 - 6	1 - 6	1 - 6

ROUTE-TYPE	CONSTANT C1	CONSTANT C2
IR	-1.078441595	0.00144644
SR	-1.012781909	0.004694621
US	0	0

Performance Model for Sand Seals, Combined Districts with Material Properties.

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 11.57521669 - C1 -C2 - C3*ESAL - 0.00169581*ESAL - 0.00713383*FRZ - 0.04377034*WETDAYS - 0.18374106*MINTEMP - 0.20451061*MAXTEMP - 0.29864042*YEAR - 0.03962666*AGGRATE - 3.35937311*BINDRATE - 0.02999933*YEAR*YEAR	210	0.838946	0.1993976

VARIABLES	RANGE		
	IR	SR	US
ESAL	39,000 - 785,000	630 - 37,000	16,800 - 50,000
WETDAY	18 - 77	18 - 68.1	37.4 - 59.9
FRZ	43 - 220	43 - 230	121.92 - 199.87
MINTEMP	32 - 41	29.67 - 52	30.5 - 37.8
MAXTEMP	54 - 69	53.9 - 83	62.5 - 68.8
YEAR	1 - 6	1 - 6	1 - 6
AGGRATE	5 - 22	0 - 35	9 - 32
BINDRATE	0.11 - 0.25	0 - 0.35	0.11 - 0.35

BINDERTYPE	CONSTANT C1
ARA-8	0.08224475
CRS-1	0.15540154
CRS-2	-1.29325436
CSS-1	0.19324833
LMCRS-2H	0.01761274
MC-250	-0.02638325
MC-70	0.78520057
MC-800	-0.36203267
SS-1H	0.36887149

ROUTE-TYPE	CONSTANT C2	CONSTANT C3
IR	-1.44219984	0.00183651
SR	-0.82721745	0.003177
US	0	0

PERFORMANCE MODEL FOR CHIP SEAL

DISTRICT -1 WITH MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 3.147994743 + C1 + C2 +C3 + C4*ESAL + C5*ESAL - 0.012276428*ESAL + 0.019825746*FRZ + 0.012457432*WETDAY + 0.159859392*MINTEMP - 0.133242309*MAXTEMP - 0.250269798*YEAR - 0.012961860*AGGRATE + 5.61294483*AGGRSIZE - 0.173928522*WETDAY*AGGRSIZE - 0.000019653*ESAL*FRZ + 0.021190962*YEAR*YEAR	162	0.909165	0.15771332

VARIABLES	RANGE	
	SR	US
ESAL	1,800 -10,000	12,000 - 64,000
WETDAY	25-38	31-33
FRZ	87-145	100-118
MINTEMP	37-48	40-43
MAXTEMP	68-78	71-73
YEAR	1-4	1-4
AGGRATE	25-33	26-33
AGGRSIZE	0.375	0.25-0.5

BINDER TYPE	CONSTANT C1
AC-20	-1.058768528
AR-2000	-0.597799712
CRS-2 / CRS-2H	-0.001543691
LMCRS--2	-.272336573
MC-800	0

AC TYPE	CONSTANTC2	CONSTANT C4
60-70	1.457010203	-0.010297865
MC-800	1.171105820	-0.010569265
SC-4	1.148716293	-0033786368
SC-800	0	0

ROUTE-TYPE	CONSTANT C3	CONSTANT C5
SR	-0.341258513	-0.002931995
US	0	0

NOTE: HERE CUMMULATIVE ESALs CONSIDERED

PERFORMANCE MODEL FOR CHIP SEAL

DISTRICT -1 WITHOUT MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= -0.2866419976 + C1 + C2*ESAL + 0.0042637881*ESAL + 0.0159829474*FRZ - 0.0040178783*WETDAY + 0.1761674080*MINTEMP - 0.0722898750*MAXTEMP - 0.2557877755*YEAR - 0.0000247775*ESAL*FRZ + 0.0197581190*YEAR*YEAR	164	0.336157	0.37120108

VARIABLES	RANGE	
	SR	US
ESAL	1,800 - 10,000	12,000 - 64,000
WETDAY	25-38	31-33
FRZ	87-145	100-118
MINTEMP	37-48	40-43
MAXTEMP	68-78	71-73
YEAR	1-4	1-4

ROUTE-TYPE	C1	C2
SR	-0.4352289081	0.0033347594
US	0	0

NOTE: HERE CUMMULATIVE ESALs CONSIDERED

PERFORMANCE MODEL FOR CHIP SEAL

DISTRICT -2 WITH MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 5.041206086 + C1 + C2 +C3 + C4*ESAL - 0.001118392*ESAL - 0.316603656*YEAR - 0.026009450*AGGRATE - 1.032299202*AGGRSIZE	113	0.882661	0.15036679

VARIABLES	RANGE		
	IR	SR	US
ESAL	375,000 - 779,000	2,200 - 4,200	19,000 - 797,000
YEAR	1-5	1-3	1-5
AGGRATE	22-35	24-33	20-29
AGGRSIZE	0.375-0.5	0.5	0.375-0.5

BINDER TYPE	CONSTANT C1
CRS-2 / CRS-2H	0.063188631
LMCRS--2	-0.154012634
MC 3000 W/LATEX	0

AC TYPE	CONSTANT C2	CONSTANT C4
120-150	-1.160775927	0.000985712
60-70	-0.522987194	0.000830234
85-100	0.091341991	-0.002311621
AR-2000	0.009611561	-0.002284621
AR-4000	-0.438959230	-0.001023685
MC-800	-1.062864750	-0.002225081

ROUTE-TYPE	CONSTANT C3
IR	0.232780393
SR	0.725247053
US	0

NOTE: HERE CUMMULATIVE ESALs CONSIDERED

PERFORMANCE MODEL FOR CHIP SEAL

DISTRICT-2 - WITHOUT MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 3.401448120 + C1 + 0.000173376*ESAL - 0.248879704*YEAR	119	0.371769	0.28695449

VARIABLES	RANGE		
	IR	SR	US
ESAL	375,000 - 779,000	2,200 - 4,200	19,000 - 797,000
YEAR	1-5	1-3	1-5

ROUTE-TYPE	CONSTANT C1
IR	-0.204695778
SR	-0.246991741
US	0

PERFORMANCE MODEL FOR CHIP SEAL

DISTRICT -3 WITH MATERIAL PROPERTIES

EQUATION	NO. OF OBS	R-SQUARE	ROOT MSE
PSI= 3.369544323 + C1 + C2*ESAL - 0.012304471*ESAL + 0.112049936*YEAR - 0.007420113*AGGRATE - 0.044498999*YEAR*YEAR	39	0.858463	0.1606254

VARIABLES	DATA RANGE
ESAL	17,000 - 163,000
YEAR	1-5
AGGRATE	20-38

AC TYPE	CONSTANT C1	CONSTANT C2
120-150	0.298971163	0.012608603
85-100	0.456789874	-0.003781586
AR-2000	0.264861060	0.010803372
AR-4000	0.02540637	0.011562479
SC-800	0	0

NOTE: HERE CUMMULATIVE ESALs CONSIDERED