# PREDICTING PAVEMENT PERFORMANCE FOR ESTABLISHING RESURFACING NEEDS AT THE NETWORK LEVEL PAVEMENT MANAGEMENT SYSTEM: PHASE I REPORT

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# CHAPTER 1. INTRODUCTION

Highway agencies are facing the enormous task of maintaining and rehabilitating highway networks. This requires processing a lot of information on the part of decision makers especially at the state level where the size of the highway network is substantial. Such information include:

1. The current condition of the highway network;
2. What highways are in need of repair; and
3. What kind of maintenance, rehabilitation and reconstruction measures should be applied.

With budget constraints, investment decisions affecting the highway network must be made that result in cost-effective use of available funds. The list of deficient highway segments will have to be prioritized since not all highways can be repaired with the limited funding. This calls for the development of a prioritization scheme that takes into account the different treatments that are available, as well as the funding levels for different highway subsystems, e.g., arterials, interstates, and turnpikes. The scheme must also allow for projects that have already been committed.

The impact of different treatments on the performance of highways and on the health of the network has to be investigated. In addition, decision makers need to evaluate the impact of different funding levels and the consequences of deferring maintenance and rehabilitation (M&R) treatments to justify funding requests to the state legislature and to solicit more funds. Since decisions are based in large measure on performance prediction models, a feedback loop is also necessary so that the accuracy of the models are periodically evaluated against new data and the models themselves updated as necessary.

These decision processes, complex as they are, require a methodical and systematic procedure for their accomplishment. Such a procedure can be provided through a pavement management system (PMS) with performance prediction models as its basis. Broadly defined, a PMS incorporates the body of systematic and organized procedures and activities for providing and maintaining pavements. These activities range from the initial planning and programming of investments to the design, construction, in-service monitoring, evaluation, maintenance and rehabilitation of pavements (1). Basic features of an implemented pavement management system are shown in Figure 1. As seen from the figure, pavement management operates at two levels - the network level and the project level. Activities at the network level are mainly the responsibility of district and state highway engineers and result in decisions covering large groups of projects or an entire state highway network. On the other hand, activities at the project level are concerned with more specific technical decisions for individual projects.

This study is concerned with network level pavement management systems. At this level, inventory data are used to assess network status and needs, and decisions are made on the schedule of resurfacing projects not only for the current program year but for future years as well. A framework for evaluating resurfacing needs is shown in Figure 2. In this framework, pavement performance is predicted on a segment-by-segment basis. The results are then aggregated to establish the number of deficient segments in the highway network. A list of resurfacing projects is selected in a way that results in the most cost-effective use of available funds. For this study, researchers formulated a prioritization scheme based on incremental benefit-cost analysis. This methodology, described later in this report, uses pavement life-cycle costs generated from performance prediction models.

## STUDY OBJECTIVES

The ultimate objective of this study is the development and implementation of a procedure for establishing resurfacing needs at the network level PMS. To satisfy this goal, performance prediction models suitable for network level implementation need to be developed. Consequently, the immediate objective in Phase I was to formulate functional forms of the performance models for the following distress types:

## FEATURES OF AN IMPLEMENTED PAVEMENT MANAGEMENT SYSTEM

**NETWORK**

- INVENTORY DATA BASE
- ASSESSMENT OF STATUS AND NEEDS
- PRIORITY PROGRAMS OF CAPITAL & MAINT. WORK
- FUNDING LEVEL EVALUATION

**PROJECT**

- DESIGN METHOD
  - TESTS, MODELS, CRITERIA
  - ECON. ANAL. & OPTIMIZATION
- CONSTR. CONTROL PROCED.
- MAINT. STANDARDS
- AS-BUILT & MAINT. DATA FILES

DOCUMENTATION OF METHODS AND PROCEDURES

Figure 1. Key features of an implemented pavement management system (2).

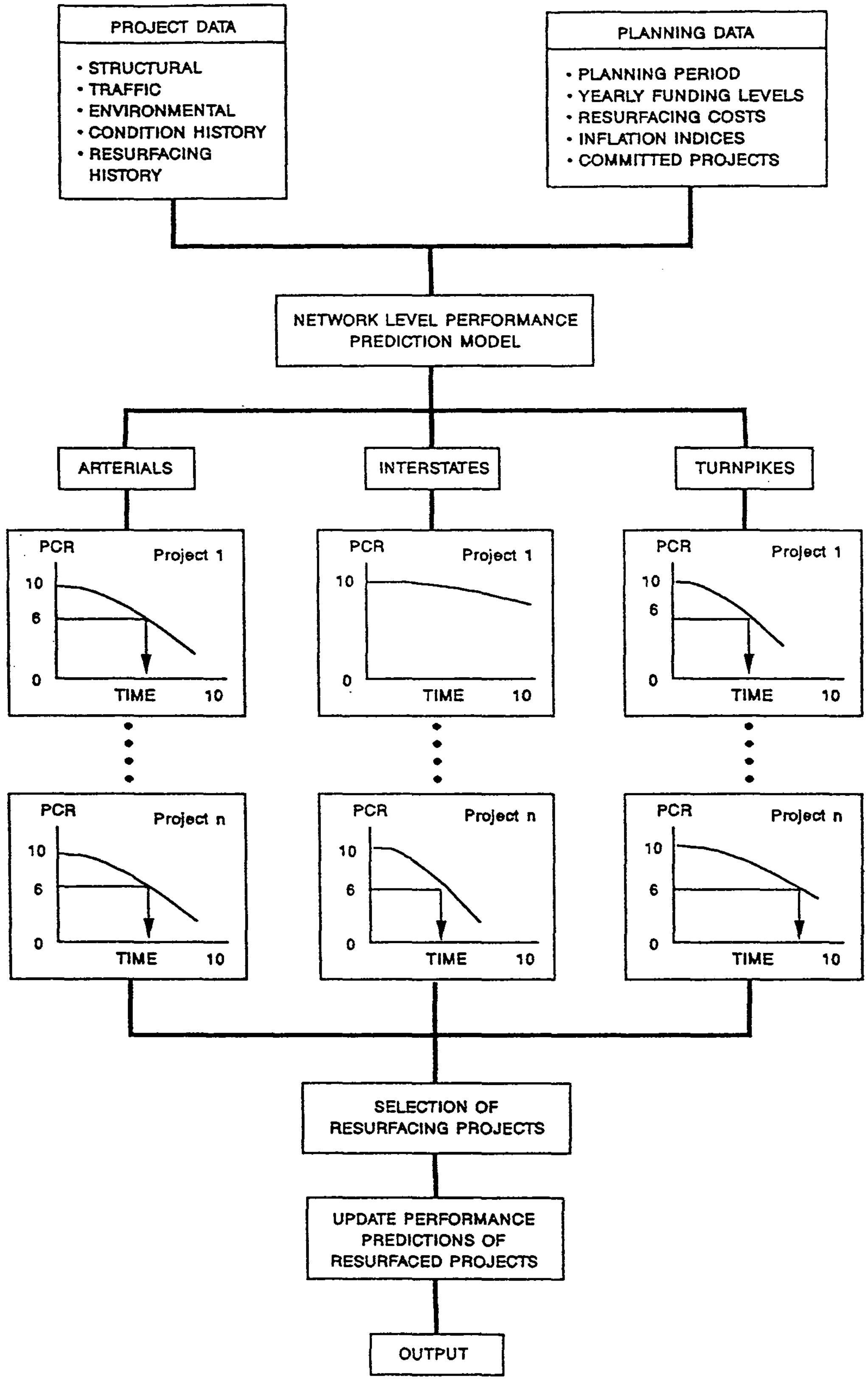


Figure 2. Framework for evaluating resurfacing needs at the network level PMS.

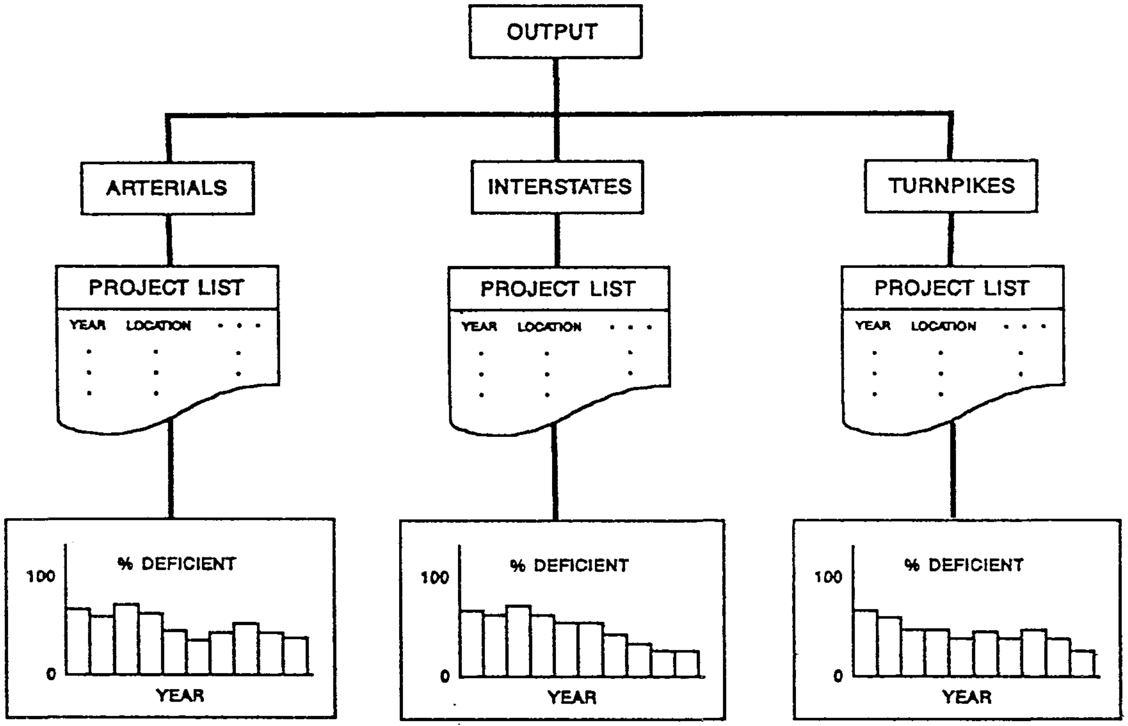


Figure 2. Framework for evaluating resurfacing needs at the network level PMS (continued).

1. Cracking;
2. Rutting; and
3. Serviceability loss.

Additional objectives were:

1. To establish a sample of Florida pavements from the Pavement Condition Survey (PCS) data base for the purpose of developing and verifying the performance models in Phase II;
2. To identify data requirements for model development and possible methods for obtaining the required information; and
3. To formulate a scheme for selecting resurfacing projects.

## SCOPE OF REPORT

This report presents the work accomplished during Phase I of the research study. Chapter 2 of the report describes the evaluation of the performance data from the PCS data base to identify the predominant distress types on Florida pavements and functional relationships for modeling the observed trends. Based on the results from this evaluation, functional forms of the prediction equations for cracking, rutting and serviceability loss were derived and are presented in Chapter 3. Data requirements for developing prediction equations for model parameters are then identified in Chapter 4. This is followed by a description of the proposed network level prioritization scheme in Chapter 5. Finally, Chapter 6 presents recommendations for completing the development of the project selection procedure in Phase II.

# CHAPTER 2. EXAMINATION OF PAVEMENT PERFORMANCE DATA

Researchers examined the PCS data provided by FDOT for the following purposes:

1. to identify the predominant distress types and thus establish the scope of the modeling effort;
2. to evaluate correlations between distresses to determine how to sample the PCS data for establishing a subset of highway segments for performance model development; and
3. to evaluate functional relationships for modeling the distress histories.

A description of the PCS data file is provided in Appendix A. Recognizing that the limits of a segment surveyed may vary over the years, researchers pre-processed the PCS data using a SAS program provided by FDOT. This program divides the network into distinct highway segments with milepost limits that are consistent over time. Researchers modified the program to divide the data by District and subsystem (interstate, arterial, turnpike, and toll).

The PCS data base provides pavement condition histories for the following distresses:

1. Cracking;
2. Rutting; and
3. Serviceability loss.

For each distress, highway segments are rated on a 0 to 10 scale with 10 indicating a pavement that shows no surface distress and 0, a pavement that is badly deteriorated. A Pavement Condition Rating (PCR) is determined for each segment as the lowest of the crack, rut and ride ratings for the given year of survey. A PCR of 6 indicates a deficient pavement.

Historical survey data are available as far back as 1976 but a number of changes in survey techniques and rating scales have taken place over the years. To make the ratings consistent, FDOT converted all scores to the current rating scale and provided the researchers with the updated version of the PCS data base.

## IDENTIFICATION OF PREDOMINANT DISTRESS TYPES

Researchers accomplished this task by identifying, from the PCS data base, the distresses that trigger the application of an overlay. For this purpose, a SAS program was written to search through the data base to determine the number of times each distress was the cause of an overlay. Appendix B presents an annotated listing of this program.

The program keeps count of the number of times each distress was equal to the PCR value at the end of a given life-cycle. This point in the performance history is defined as the time at which an overlay was placed or the time at which a significant increase in the condition rating was observed from the survey data. The application of an overlay was determined from the TYPE field (TYPE = 7) in the PCS data base. In addition, an increase in the crack rating of two or more points was assumed to indicate the application of an overlay. The delineation of life-cycles for any given segment was accomplished through a SAS program that uses these criteria. An annotated listing of this program is given in Appendix B.

The distress with a rating equal to the PCR at the end of a life-cycle is considered the controlling distress that caused the application of a treatment at that point in time. Based on the observation that overlays were placed even when PCR's were above 6, researchers conducted two different analyses, one for the full range of PCR values and another for PCR $\leq$ 6. Figures 3 through 10 show the results of the analyses. In these figures, the number of causes denote the sum, over the three distress types, of the occurrences at which a given distress triggered the application of an overlay. It is noted that more than one distress may have a rating equal to the PCR at the end of a life-cycle. In these cases, the relevant distresses were considered as equally contributing to the occurrence of an overlay.

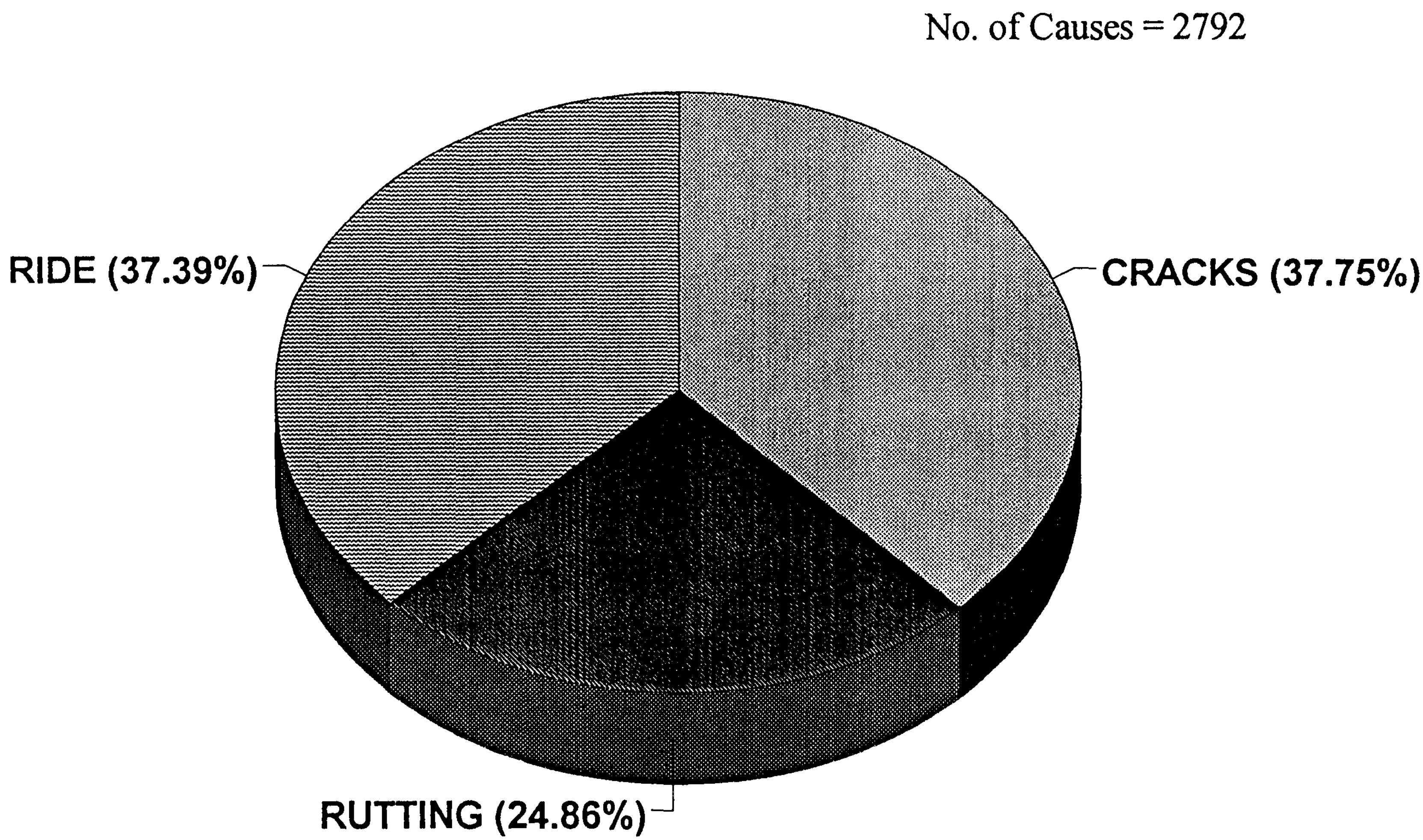


Figure 3. Chart showing the number of occurrences when a given distress triggers an overlay (Arterials).

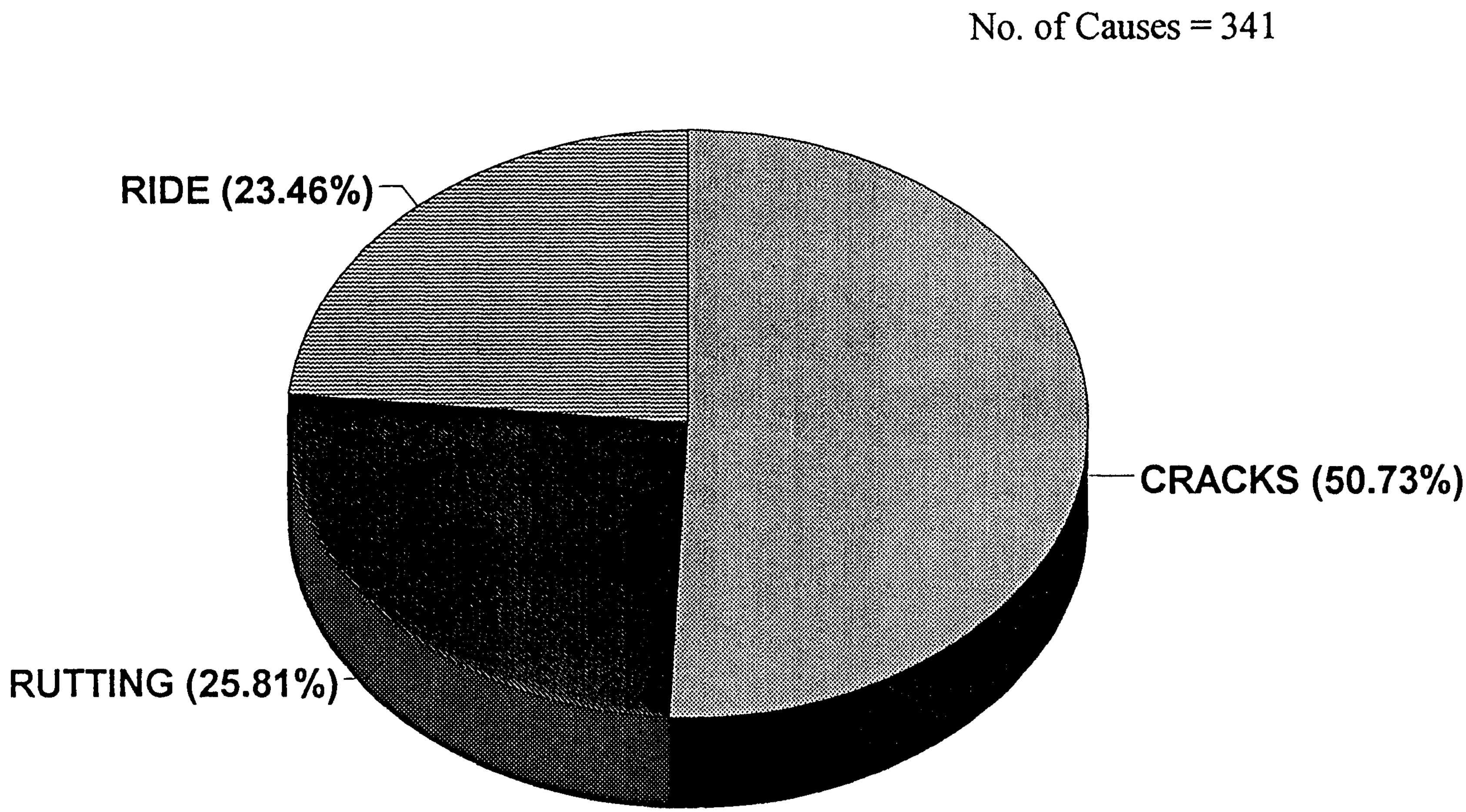


Figure 4. Chart showing the number of occurrences when a given distress triggers an overlay (Interstates).

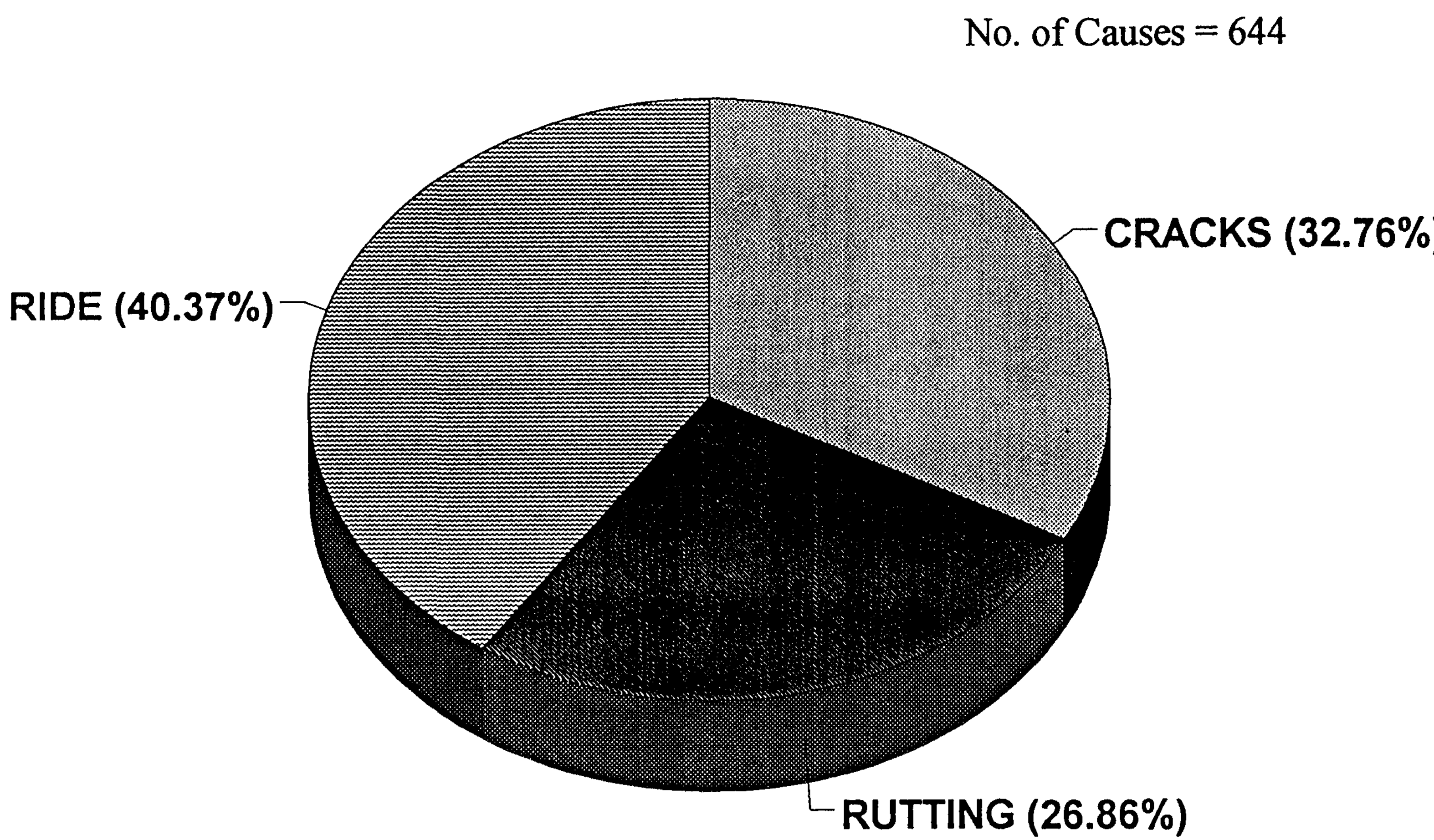


Figure 5. Chart showing the number of occurrences when a given distress triggers an overlay (Toll Roads).

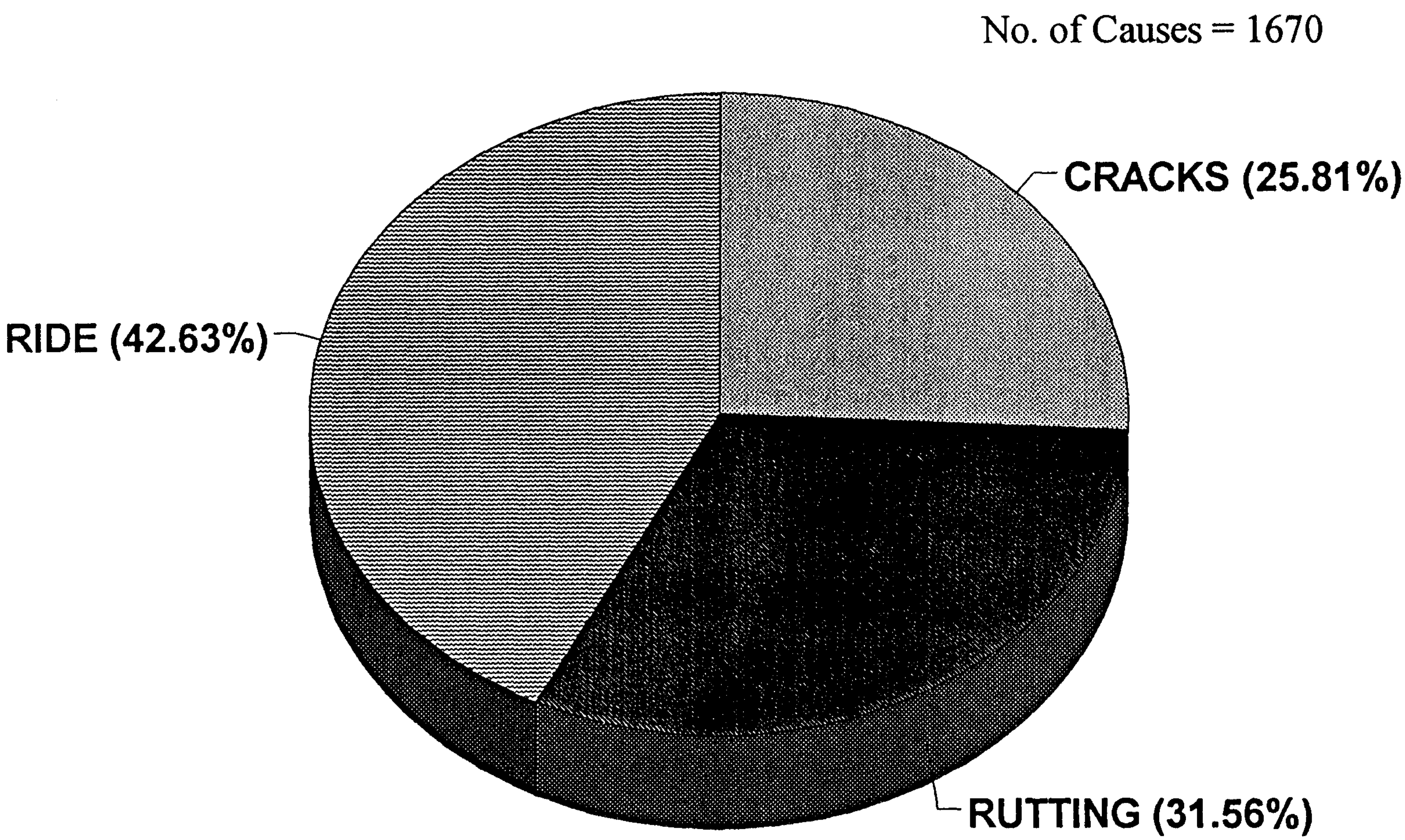


Figure 6. Chart showing the number of occurrences when a given distress triggers an overlay (Turnpikes).

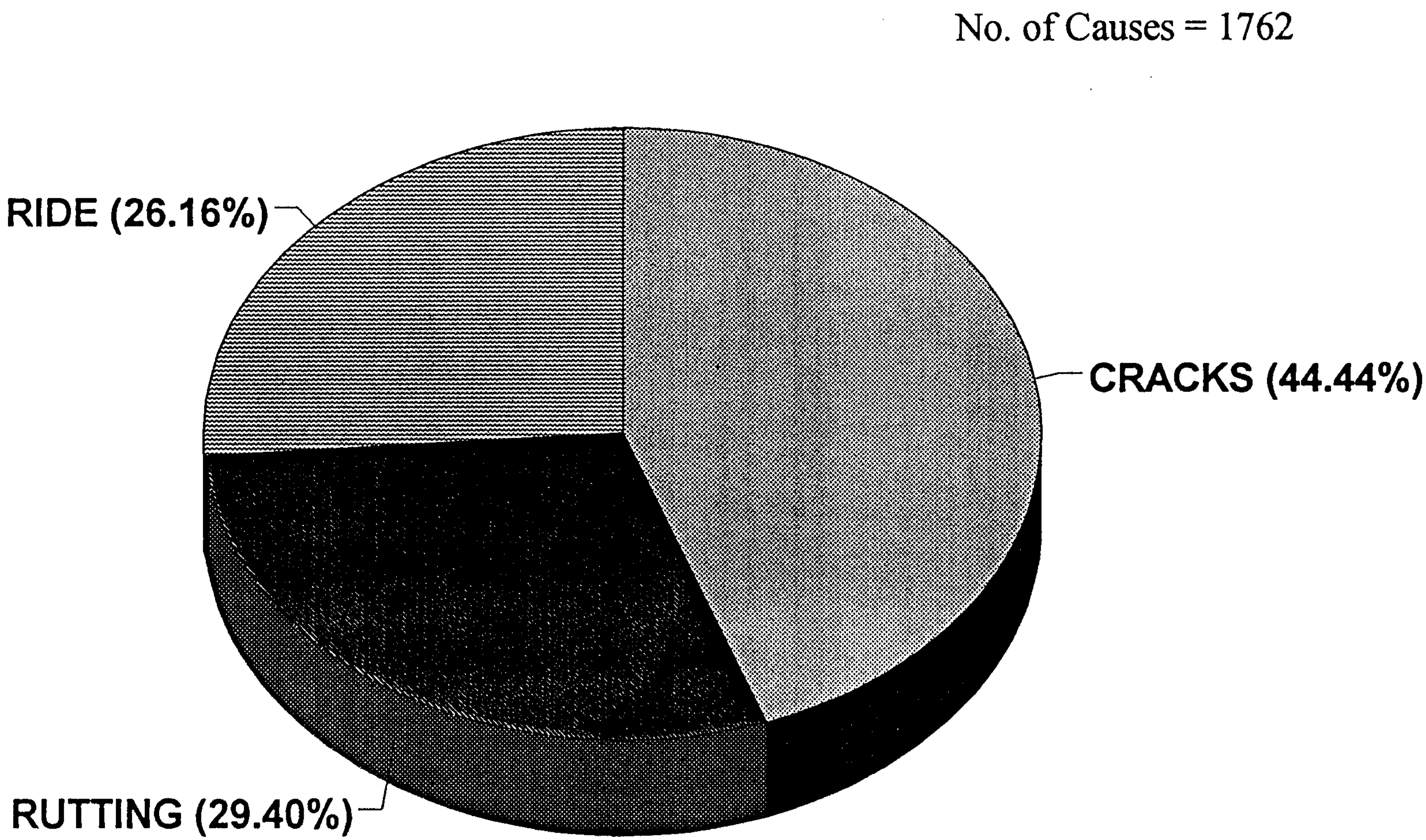


Figure 7. Chart showing the number of occurrences when a given distress triggers an overlay (Arterials; PCR at or below 6).

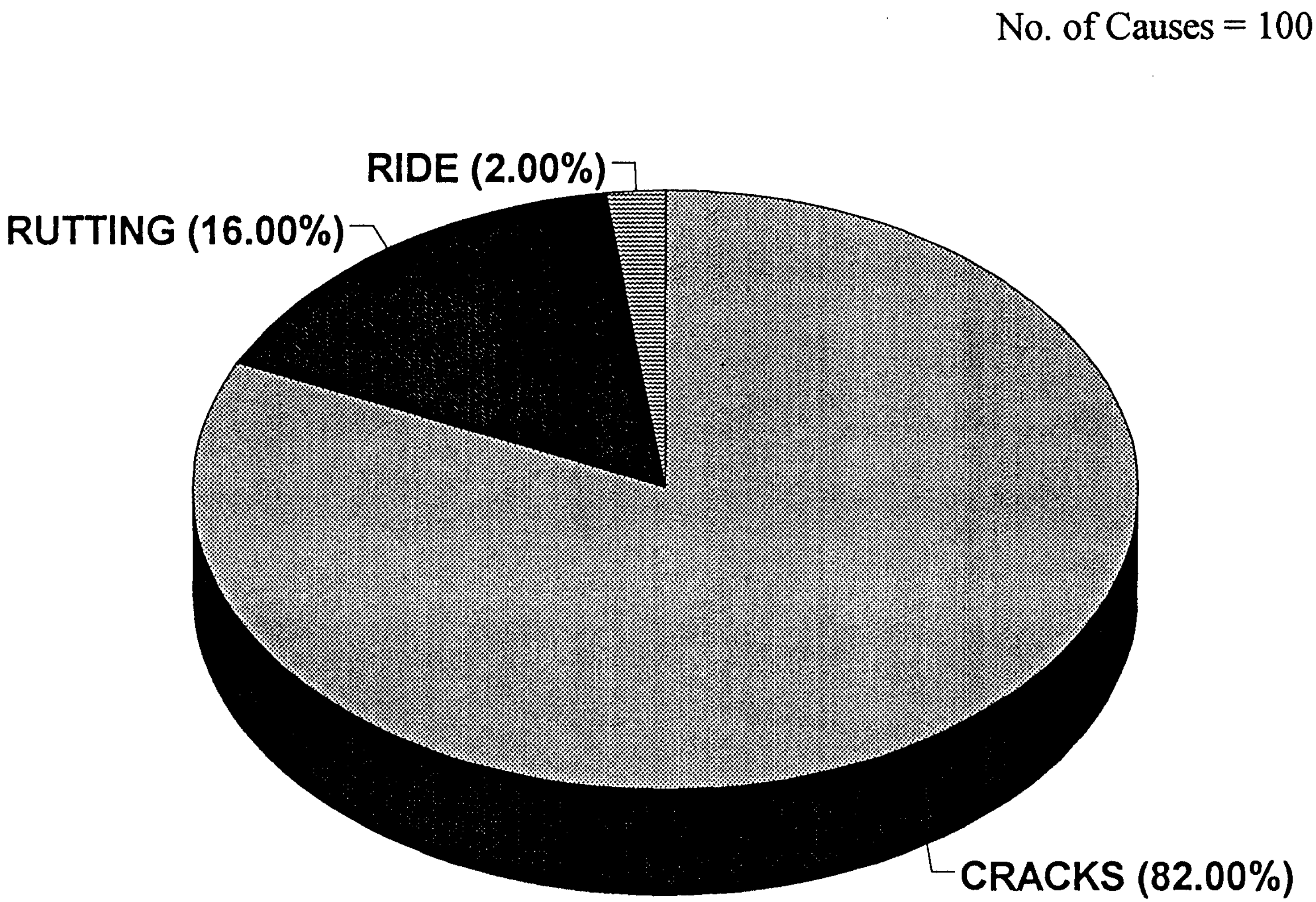


Figure 8. Chart showing the number of occurrences when a given distress triggers an overlay (Interstates, PCR at or below 6).

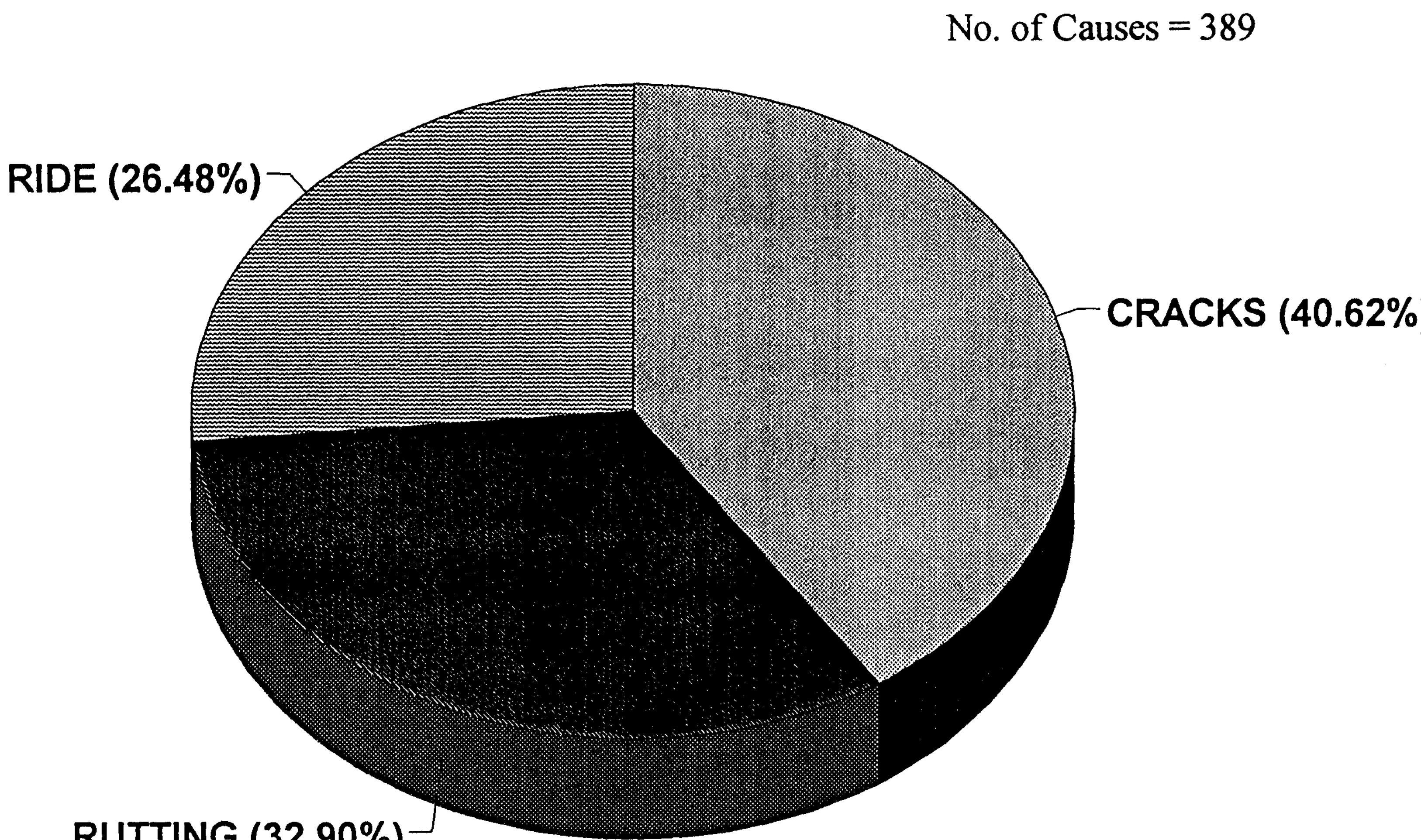


Figure 9. Chart showing the number of occurrences when a given distress triggers an overlay (Toll Roads; PCR at or below 6).

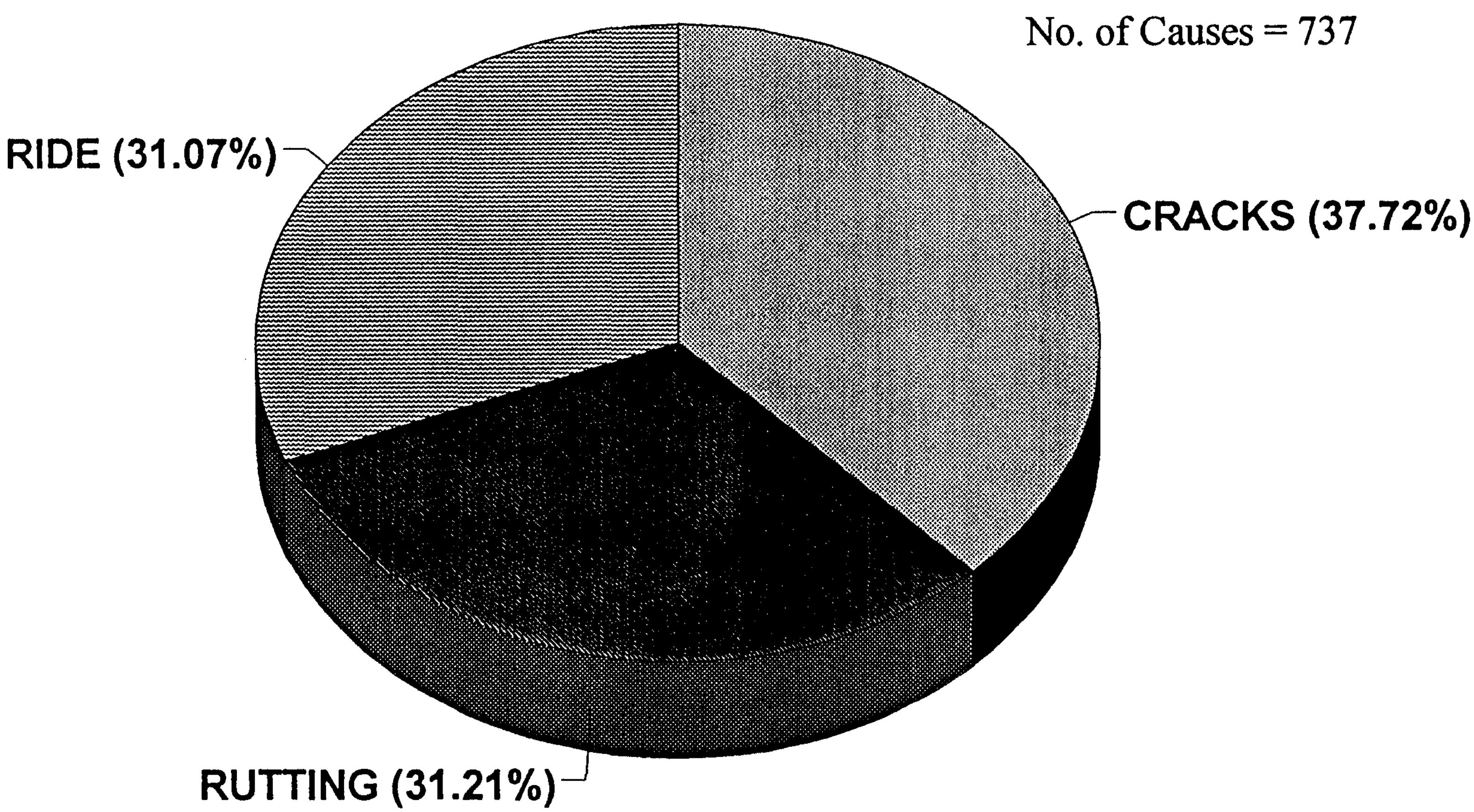


Figure 10. Chart showing the number of occurrences when a given distress triggers an overlay (Turnpikes; PCR at or below 6).

Examination of Figures 3 through 10 lead to the following findings:

1. The number of occurrences at which a given distress triggers an overlay is significant for all three distresses. Consequently, the modeling efforts must consider all three;
2. The survey data suggest that cracking triggers the application of an overlay for the majority of cases, particularly for Arterial and Interstate subsystems; and
3. The number of occurrences at which ride quality is the controlling distress is greater for PCR > 6 than for PCR ≤ 6, particularly for Interstate and Turnpike subsystems. The fact that a treatment is applied to improve the ride quality when the PCR is above 6 indicates the importance attached to ride quality for these subsystems.

## EVALUATION OF CORRELATIONS BETWEEN DISTRESSES

In addition to identifying the predominant distress types, researchers investigated the correlations between cracking, rutting and ride quality. This was done to determine whether independent samples of highway segments may be established for one or more distresses for the purpose of developing performance models. A SAS program to determine the correlations between distresses was written and is included in Appendix B.

Pairwise comparisons were made between cracking, rutting, and ride quality for the sample of highway segments included in this analysis. Figures 11 through 13 present cumulative frequency histograms of the correlation coefficients determined for highway segments in District 1. The data shown are similar to the results found for the other Districts.

Figures 11 through 13 show that about 34 percent of the sampled segments have correlation coefficients of 0.6 or more between any two distresses. This is considered a significant amount. Thus, the results of this evaluation suggest that, for the purpose of developing performance models from PCS data, it is inappropriate to establish independent samples of highway segments for any of the distresses

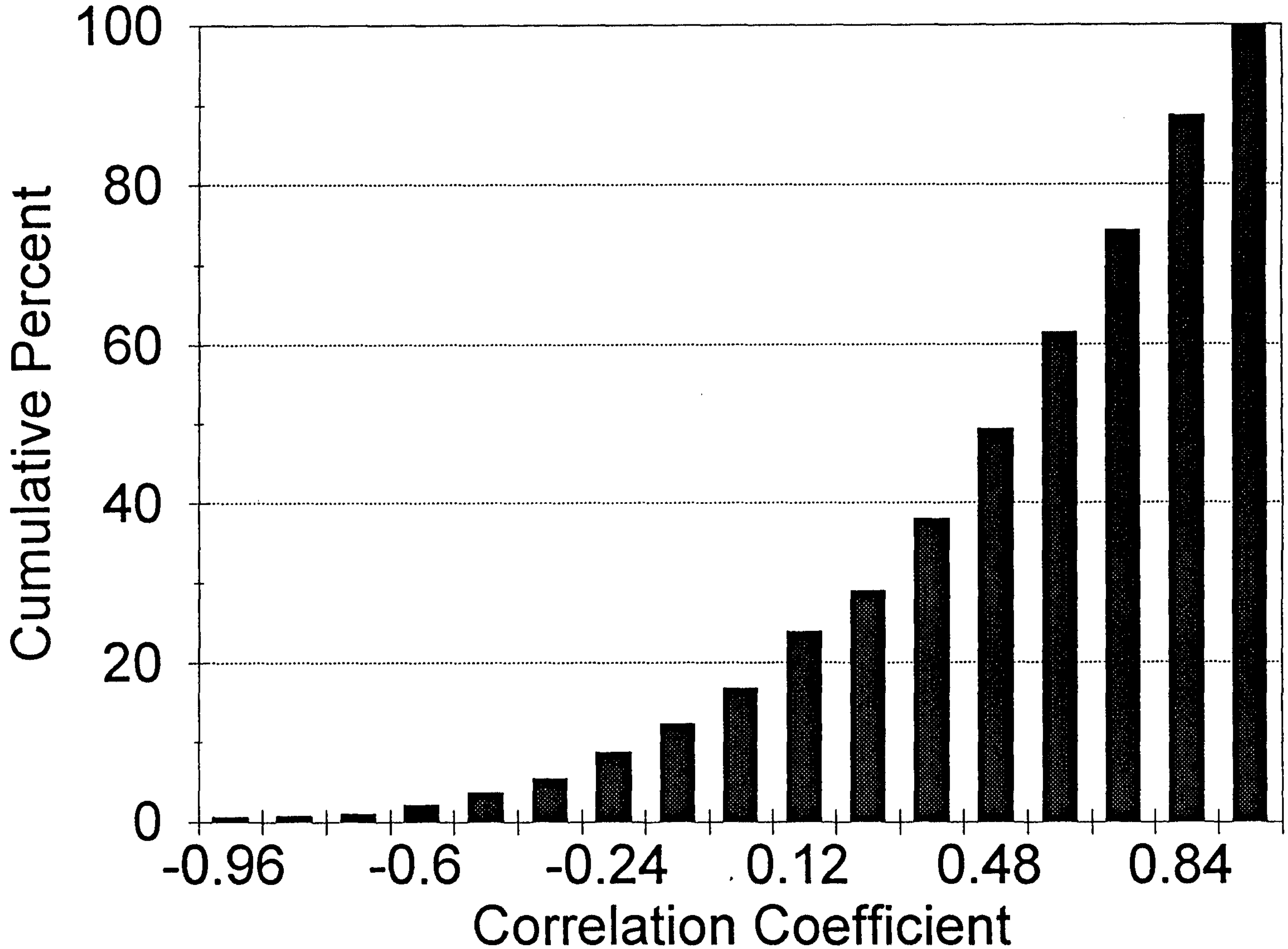


Figure 11. Cumulative distribution of correlation coefficients between cracking and rutting.

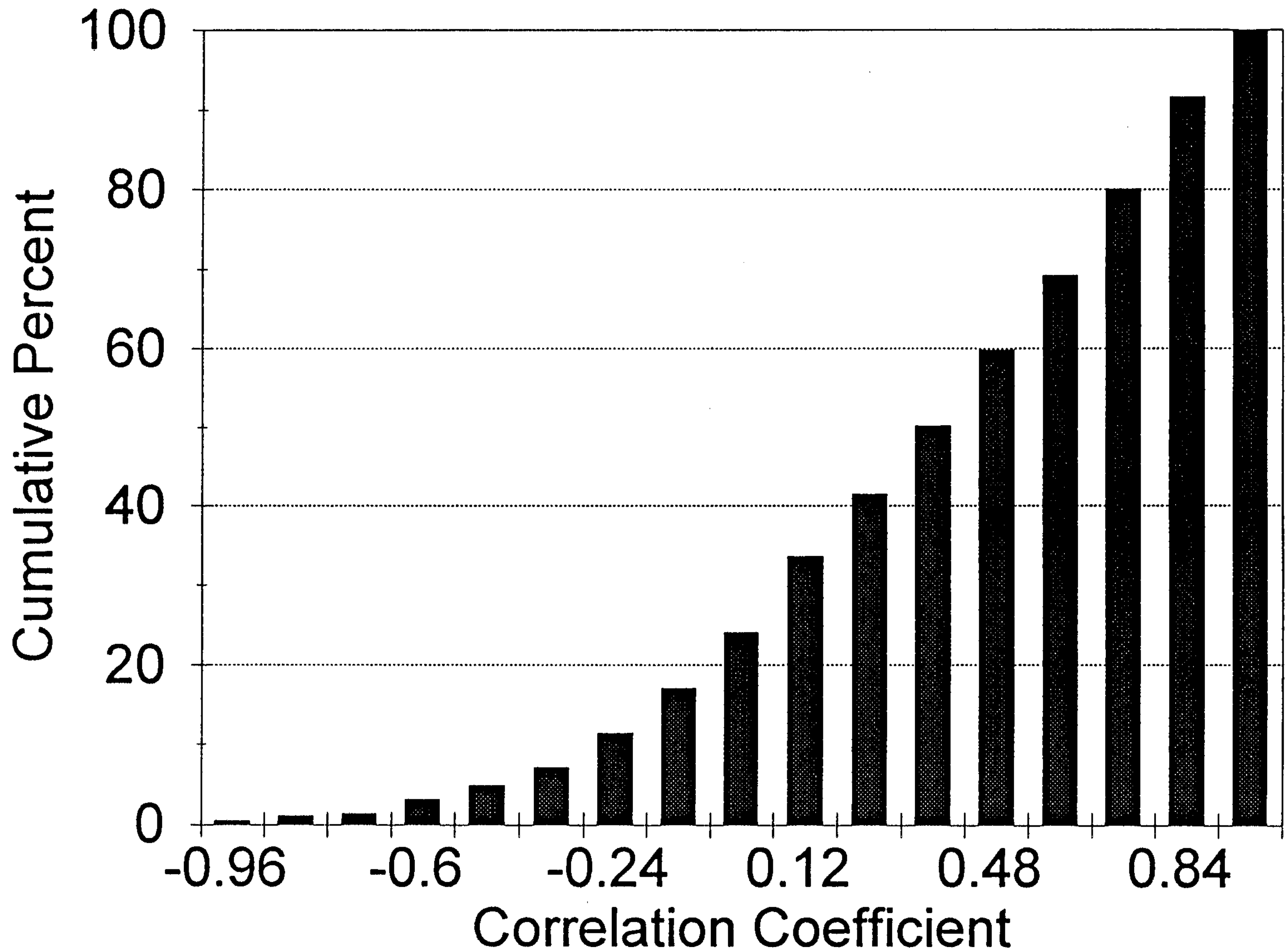


Figure 12. Cumulative distribution of correlation coefficients between rutting and ride quality.

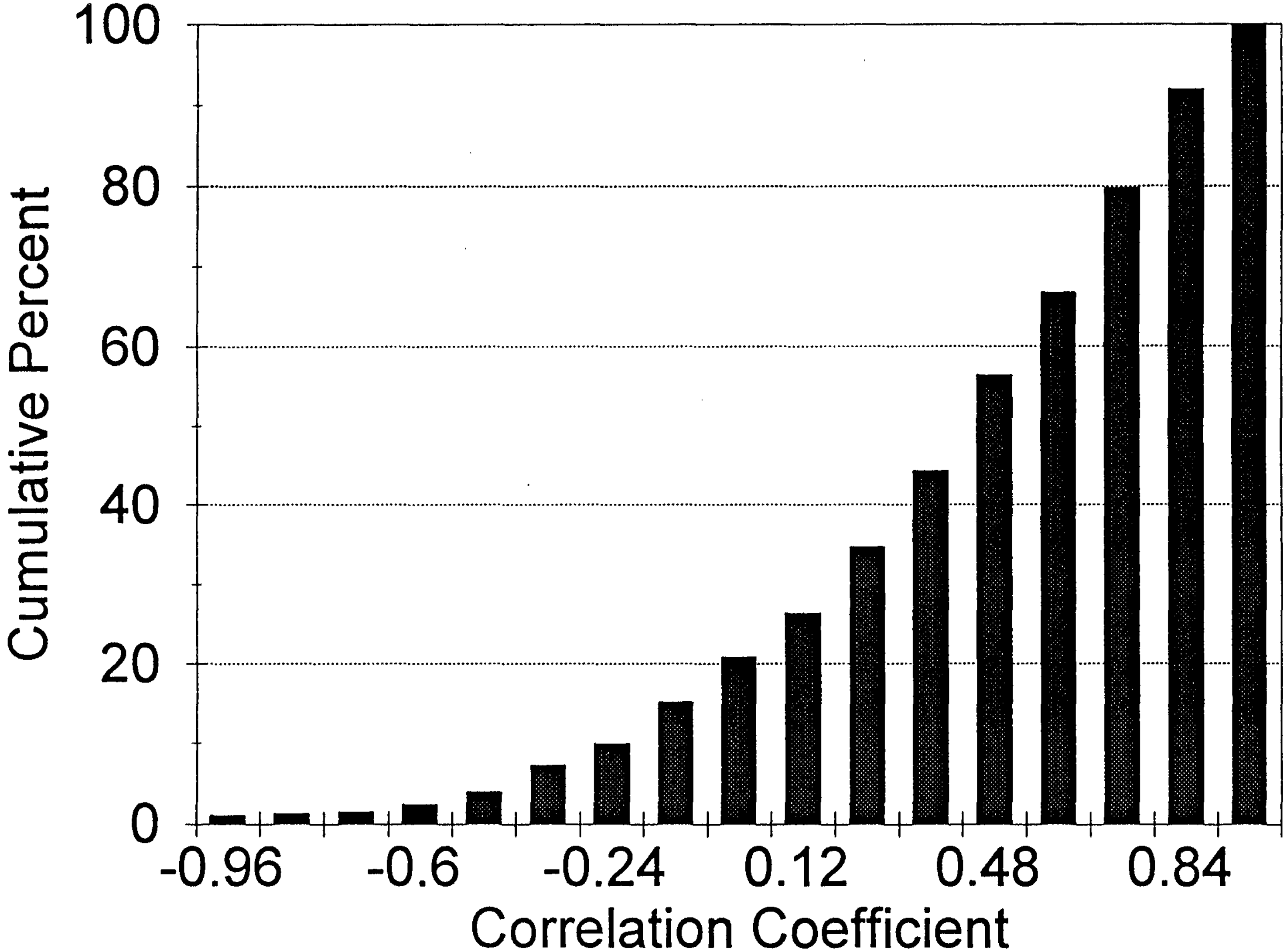


Figure 13. Cumulative distribution of correlation coefficients between cracking and ride quality.

considered. Instead, researchers should model corresponding distress histories for cracking, rutting and serviceability loss for any given segment.

## EVALUATION OF PERFORMANCE TRENDS

This task aims to identify functional relationships for modeling the distress histories in the PCS data base. Performance trends were assessed by visual examination of numerous plots of distress versus time. A preliminary modeling program was developed to examine the suitability of the sigmoidal curve to fit the observed trends of cracking, rutting and serviceability loss with time. This SAS program is listed in Appendix B.

The sigmoidal curve evaluated in this task is defined by the function:

$$Distress\ rating = \alpha \left[1 - e^{-\left(\frac{\rho}{Age}\right)^{\beta}}\right] \quad (1)$$

where $\alpha$, $\rho$, and $\beta$ are regression parameters. The parameter, $\alpha$, represents the rating at age zero. For cracking and rutting, this parameter was fixed to the maximum possible value of 10. For ride, it was fixed to 9, which is typical of new pavements. The sigmoidal function was fitted to the data for each life-cycle of a given highway segment.

Figures 14 through 16 illustrate typical results from the curve fitting. In general, this task established the suitability of the sigmoidal curve for modeling the observed performance trends in the PCS data base for all three distresses. Specific functional forms of the performance models for cracking, rutting and serviceability loss are derived in the next chapter based on this finding.

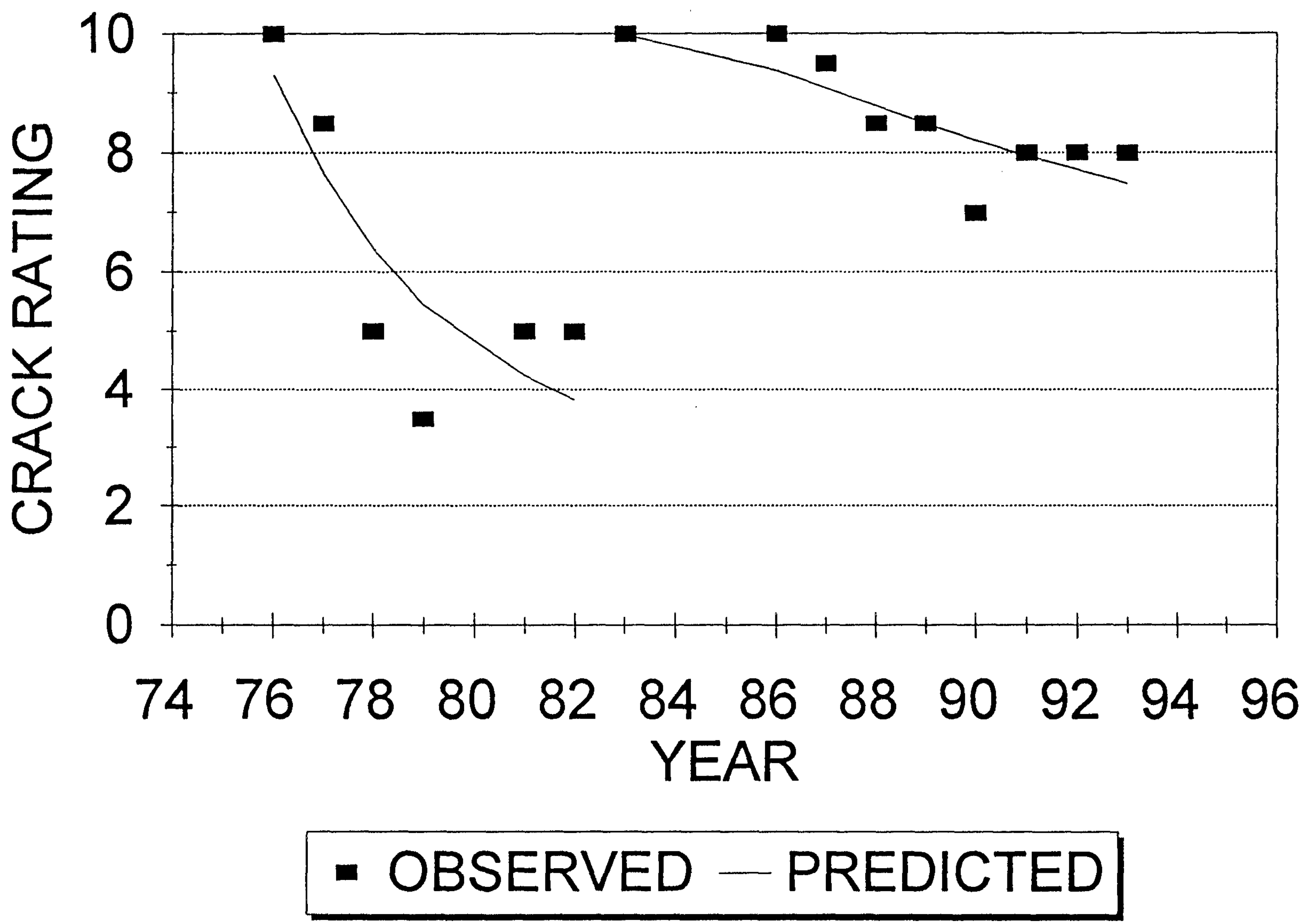


Figure 14. Plot showing the fit of the sigmoidal function to the observed crack data.

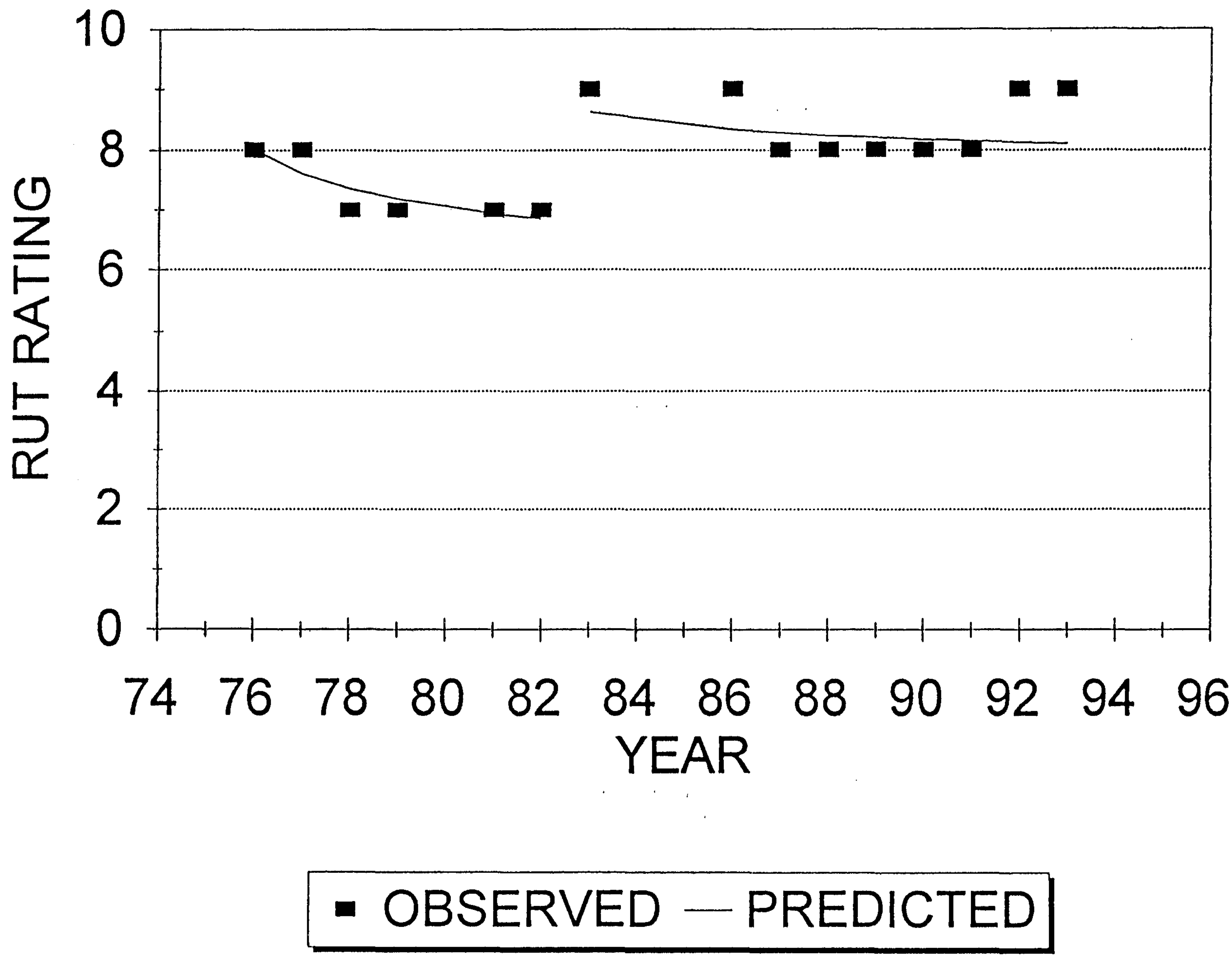


Figure 15. Plot showing the fit of the sigmoidal function to the observed rut data.

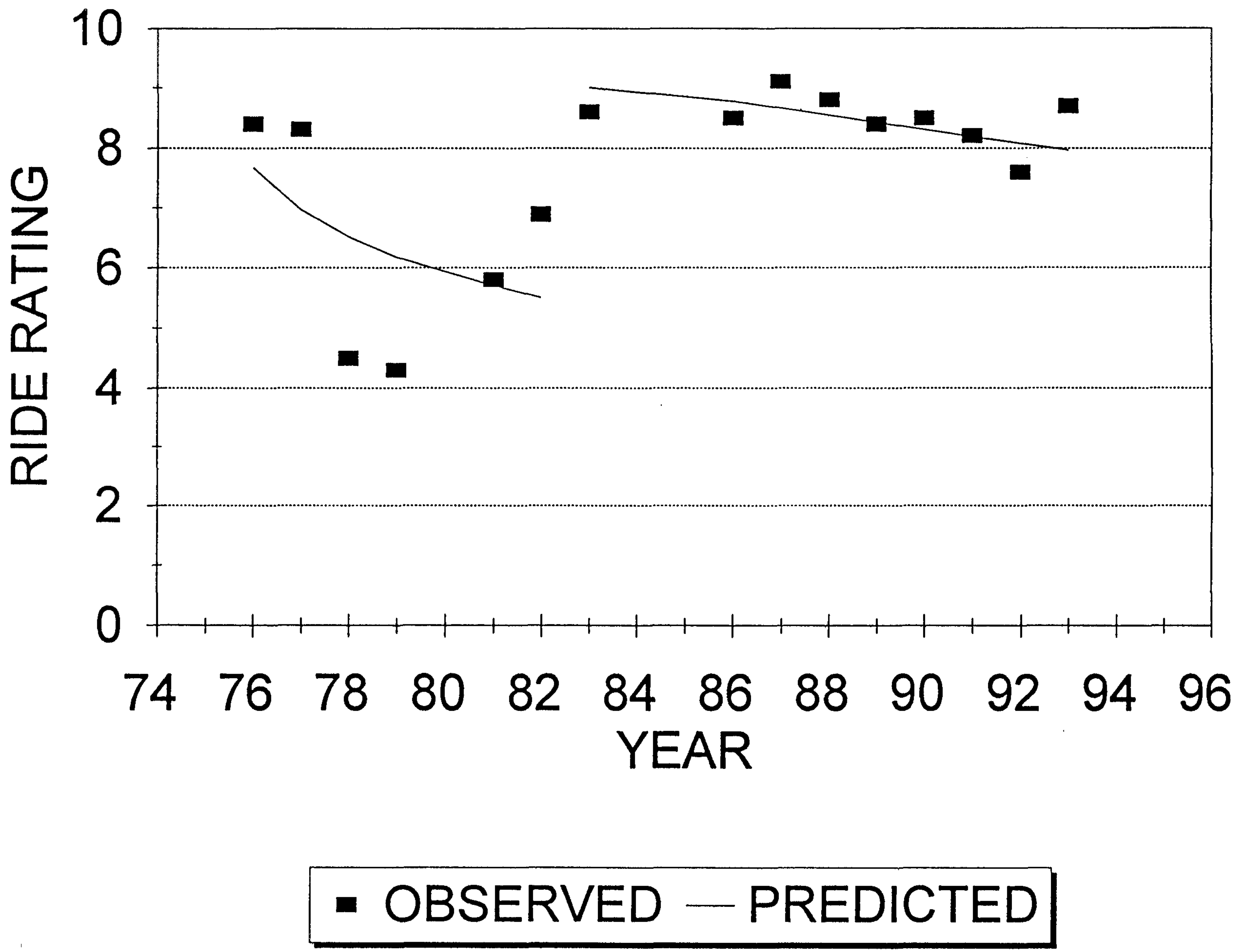


Figure 16. Plot showing the fit of the sigmoidal function to the observed ride quality data.

# CHAPTER 3. DEVELOPMENT OF FUNCTIONAL FORMS OF THE PERFORMANCE MODELS

Functional forms of the performance models for cracking, rutting and serviceability loss are derived in this chapter that are consistent with the sigmoidal or S-shaped nature of the observed PCS data. The equations presented are intended for predicting the performance of overlaid pavements and incorporate the effect of milling. An interesting feature of the models for rutting and serviceability loss is that the performance after an overlay is tied to the performance before the overlay. For the crack model, the predicted performance of the overlaid pavement is tied to the level of cracking before the overlay and to fracture properties of the asphalt concrete mix. A unique feature of the model is that it considers the distribution of crack depths in the existing pavement in predicting the performance of the overlay. The following sections present the performance models developed.

## CRACK MODEL

The old pavement underlying an overlay has areas that are cracked and areas that are uncracked (Figure 17). The damage to the overlay over the cracked areas will take place at a faster rate compared to the progression of damage over the uncracked areas. This is because of the weaker material in the cracked areas.

At any given point along the pavement, the crack depth will have reached some proportion of the existing surface layer thickness. If the crack depth is $d_c$ and the depth of the existing pavement is $d_1$, the relation between the two is:

$$d_c = d_1 \, p(x) \qquad (2)$$

where p(x) is the probability distribution function of the cracks. In areas of the existing pavement where the cracks have not yet reached the surface, the cracks, after placement of the overlay must propagate a distance, h, given by:

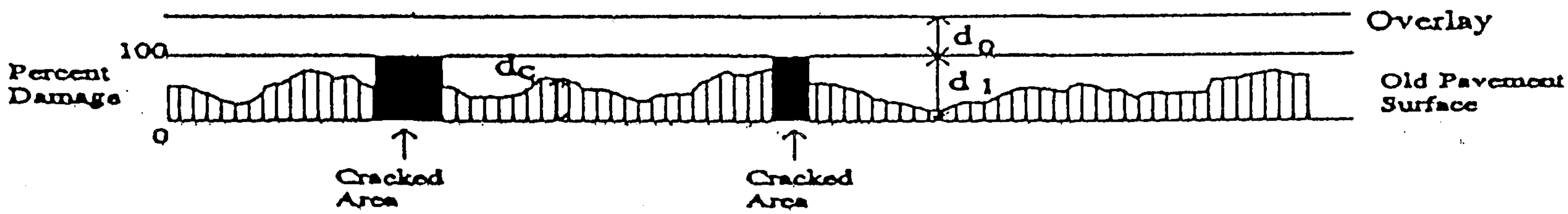


Figure 17. Variation in pavement condition at the time of overlay (3).

$$h = d_o + [1 - p(x)]\, d_1 \qquad (3)$$

where $d_o$ is the thickness of the overlay. In the cracked areas, the cracks will travel only through the overlay thickness. From principles of fracture mechanics, it can be shown that the number of load cycles to reach failure in the cracked areas, denoted by $N_{fc}$, is proportional to:

$$N_{fc} \ \alpha \ \left[ (d_o + d_1)^{1-\frac{n}{2}} - d_1^{\,1-\frac{n}{2}} \right] \frac{\sigma_{to}^2\, s}{E_o^{\frac{n}{2}}} \qquad (4)$$

where,

| | | |
|---|---|---|
| $\sigma_{to}$ | = | the tensile strength of the overlay mix |
| s | = | the speed of travel |
| $E_o$ | = | the elastic modulus of the overlay material |
| n | = | the fracture exponent of the overlay material |

In areas of the overlaid pavement where cracks have not yet propagated through the underlying old pavement, the number of load applications to reach failure, $N_{fu}$, is proportional to:

$$N_{fu} \ \alpha \ \left[ (d_o + d_1)^{1-\frac{n}{2}} - d_1^{\,1-\frac{n}{2}} \right] \frac{\sigma_{to}^2\, s}{E_o^{\frac{n}{2}}} + \left[ (1 - \bar{p}(x))\, d_1 \right]^{1-\frac{n}{2}} \frac{\sigma_{t1}^2\, s}{E_1^{\frac{n}{2}}} \qquad (5)$$

where,

$$\bar{p}(x) = \textit{the average value of } p(x) \approx \frac{(1 - c_r)}{2}$$

| | | |
|---|---|---|
| $c_r$ | = | the percent of surface area cracked at the time of overlay |

$E_1$ = elastic modulus of the underlying old pavement

$\sigma_{t1}$ = tensile strength of the old surface mix

Equation (5) assumes that the fracture exponent, n, is the same for both the old surface mix and the overlay material. If, in addition, the tensile strengths and the elastic moduli are assumed to be equal, the ratio, $N_{fc}/N_{fu}$, will then be equal to:

$$\frac{N_{fc}}{N_{fu}} = \frac{(d_o + d_1)^{1-\frac{n}{2}} - d_1^{1-\frac{n}{2}}}{(d_o + d_1)^{1-\frac{n}{2}} - d_1^{1-\frac{n}{2}} + \left[\left(\frac{1 + c_r}{2}\right) d_1\right]^{1-\frac{n}{2}}} = f_u \tag{6}$$

Dividing both the numerator and denominator of Eq.(6) by $d_o^{\left(1-\frac{n}{2}\right)}$, we get:

$$f_u = \frac{\left(1 + \frac{d_1}{d_o}\right)^{1-\frac{n}{2}} - \left(\frac{d_1}{d_o}\right)^{1-\frac{n}{2}}}{\left(1 + \frac{d_1}{d_o}\right)^{1-\frac{n}{2}} - \left(\frac{d_1}{d_o}\right)^{1-\frac{n}{2}}\left[1 - \left(\frac{1+c_r}{2}\right)^{1-\frac{n}{2}}\right]} \tag{7}$$

The area of cracking, c, that develops in the surface of the overlay is evaluated from:

$$c = c_r \int_{1}^{\infty} p(x_c)\, dx_c + (1 - c_r) \int_{f_u}^{\infty} p(x_u)\, dx_u \tag{8}$$

where $p(x_c)$ and $p(x_u)$ are the probability density functions of the distribution of crack depths in the cracked and uncracked areas respectively. If one assumes a Gumbel distribution, Eq.(8) is evaluated as:

$$c = 1 - c_r\, e^{-\left(\frac{\rho N_{fc}}{N}\right)^{\beta}} + c_r\, e^{-\left(\frac{\rho N_{fc}}{f_u N}\right)^{\beta}} - e^{-\left(\frac{\rho N_{fc}}{f_u N}\right)^{\beta}} \tag{9}$$

where,

| | | |
|---|---|---|
| N | = | the cumulative number of load repetitions since the overlay |
| $\rho,\beta$ | = | regression coefficients |

Equation (9) is the functional form of the performance model for cracking. For any given highway segment, the coefficients, $c_r$ and $f_u$, are known. The coefficient, $c_r$, is simply the cracked area at the time of overlay, and $f_u$ is evaluated from Eq.(7). Thus, the model may be fitted to the performance data for a given life-cycle to determine the regression coefficients, $\rho N_{fc}$ and $\beta$.

## RUT MODEL

Rutting is attributed to the accumulation of permanent deformations from repeated traffic loadings. Based on laboratory tests, the development of permanent strains in pavement materials follows a sigmoidal trend defined by the equation:

$$\varepsilon_p = \varepsilon_o\, e^{-\left(\frac{\rho}{N}\right)^{\beta}} \tag{10}$$

where,

| | | |
|---|---|---|
| $\varepsilon_p$ | = | permanent strain |
| N | = | cumulative load repetitions |
| $\varepsilon_o,\rho,\beta$ | = | material parameters determined from laboratory test data |

The fractional increase in permanent strain with load cycle is simply the ratio of permanent strain to the total strain for the given cycle where the total strain consists of elastic and plastic components. If it is assumed that the elastic strain, $\varepsilon_E$, is large in comparison to the increase of permanent strain with load repetition, the fractional increase of permanent strain, F(N), may be approximated by (4):

$$F(N) = \frac{1}{\varepsilon_E} \frac{\partial \varepsilon_p}{\partial N} \tag{11}$$

By substituting Eq.(10) into Eq.(11) and noting that the rut depth is simply the accumulation of permanent deformations produced by repetitive traffic loads, the following equation for predicting rut depth (RD) is obtained:

$$RD = \sum_{i=1}^{n} \varepsilon_{opi}\, e^{-\left(\frac{\rho_i}{N}\right)^{\beta_i}} (d_{i+1} - d_i)\, \varepsilon_{E\,i} \tag{12}$$

where, n, is the number of pavement layers and $d_i$ denotes the depth of the ith layer interface. If it is assumed that most of the rutting comes from the surface layer, the equation for rut depth reduces to:

$$RD = \varepsilon_{op1}\, e^{-\left(\frac{\rho_1}{N}\right)^{\beta_1}} d_1\, \varepsilon_{E1} \tag{13}$$

where $d_1$ denotes the thickness of the surface layer and all other symbols are as defined previously.

Equation (13) is used to derive the performance model for rutting. In the derivation, the total rut depth at a given load cycle, N, is assumed to consist of the rutting that comes from the old surface layer and the rutting attributed to the overlay. Equation (13) is used to evaluate the contributions of the overlay and the underlying layer to the total rut depth. The effect of milling is also considered.

The functional form of the performance model for rutting is given below:

$$RD = \varepsilon_{E_0}\varepsilon_{op_0}\, d_0\, e^{-\left(\frac{\rho_0}{N-N_0}\right)^{\beta_0}} + \varepsilon_{E_1}\, \varepsilon_{op_1} \left(d_1 - d_m\right) e^{-\left(\frac{\rho_1}{N}\right)^{\beta_1}} - \varepsilon_{E_1}\varepsilon_{op_1}\, d_1\, e^{-\left(\frac{\rho_1}{N_0}\right)^{\beta_1}} \tag{14}$$

where,

$d_o$ = depth of overlay

$d_1$ = depth of old pavement prior to milling

$d_m$ = depth of milling

$N_o$ = cumulative load cycles at time of overlay

and all other symbols are as defined previously.

For a given highway segment, Eq.(14) may be fitted to the rut depth data to determine the coefficients of the model. Data for two life-cycles are needed. The data for the earlier life-cycle are used to determine the coefficients ($\varepsilon_{E1}\varepsilon_{op1}$), $\rho_1$ and $\beta_1$, while data for the succeeding life-cycle are used to determine corresponding coefficients for the overlaid pavement.

## SERVICEABILITY LOSS MODEL

Similar to the approach used for rutting, the serviceability loss is assumed to consist of contributions from the overlay and the underlying old surface layer. In the derivation, the sigmoidal function given by Eq.(1) was used to evaluate the components of serviceability loss. In the process, the following performance model was obtained:

$$p = p_1 - p_1\, e^{-\left(\frac{\rho_1}{N}\right)^{\beta_1}} + \left(p_o - p_t\right) - p_o\, e^{-\left(\frac{\rho_o}{N-N_o}\right)^{\beta_o}} \qquad (15)$$

where,

$p$ = Present Serviceability Index (PSI) at load cycle, N

$p_o$ = PSI immediately after the overlay

$p_1$ = initial PSI for the performance period before the overlay

$p_t$ = PSI just prior to the overlay

$N_o$ = cumulative load repetitions at the time of overlay

$\rho_1,\beta_1$ = model parameters defining the performance prior to the overlay

$\rho_o,\beta_o$ = model parameters defining the performance after the overlay

# CHAPTER 4. DATA REQUIREMENTS FOR PERFORMANCE MODEL DEVELOPMENT

While the PCS file will provide performance data for evaluating the parameters of the models presented in Chapter 3, other types of data are needed to complete the performance model development. For example, the thicknesses of the overlay and the underlying material, and the depth of milling are required to model cracking and rutting. In addition, other data are needed to develop prediction equations for the parameters determined.

In this chapter, a number of data items are identified that needs to be compiled to complete the development of the performance models presented previously. The chapter also suggests possible methods for acquiring the data. A preliminary sample of highway segments was established to guide the data collection effort. This is discussed in the following.

## HIGHWAY SEGMENTS SAMPLED

Due to the enormity of the PCS data file, researchers established a preliminary sample of highway segments with which to develop the performance prediction models. In developing the sample, the selection was first based on the availability of traffic data in the Roadway Characteristics Inventory (RCI) file. A SAS program was developed to merge the RCI data with the PCS data. This program is listed in Appendix B. Since the segment limits in both files are different, a linear interpolation scheme was used to estimate the ADT and percent trucks for highway segments in the PCS file. Table 1 illustrates the output from this program.

The preceding step identified the segments for which traffic data are available. The performance data for these segments were then plotted and visually inspected to select segments that have distinct second and third life cycles.

Table 1. Sample output from program which merges traffic data from RCI File with PCS Data.

| Obs | Roadway ID | Beginning milepost | Ending milepost | Roadway side | ADT | Percent trucks |
|---|---|---|---|---|---|---|
| 1 | 87004000 | 2.764 | 3.916 | L | 35299 | 0.60000 |
| 2 | 87004000 | 2.764 | 3.916 | R | 35299 | 0.60000 |
| 3 | 87270000 | 13.441 | 14.402 | L | 67946 | 7.69962 |
| 4 | 87270000 | 13.441 | 14.402 | R | 67946 | 7.69962 |
| 5 | 87270000 | 15.288 | 16.083 | L | 67747 | 7.69964 |
| 6 | 87270000 | 15.288 | 16.083 | R | 67747 | 7.69964 |
| 7 | 87270000 | 16.095 | 16.890 | L | 99195 | 7.69998 |
| 8 | 87270000 | 16.095 | 16.890 | R | 99195 | 7.69998 |

Consistent with the models derived in Chapter 3, the second cycle is intended for developing the crack prediction equations, while the second and third cycles are intended for modeling rutting and serviceability loss. The reason for selecting the second and third cycles is because the beginning of the first performance period cannot be determined from the PCS data. Based on the visual inspection, a preliminary list of highway segments for the performance modeling was established. This list is provided in Appendix C. Depending on the availability of data, the list shown may undergo further sub-sampling.

For toll roads, it was found that most of the data are found in District 5. Therefore, all toll road segments in District 5 are included in the preliminary sample. For turnpikes, the total number of segments is small enough to use all of the turnpike segments as test samples.

## LAYER THICKNESSES

A limited amount of layer thickness data is presently available. The Department is currently conducting a study with TTI to implement ground penetrating radar technology for non-destructive evaluation of layer thicknesses at highway speed. Consequently, it is expected that thickness data will become more available as this technology gets implemented and used.

A limited amount of thickness data from the radar study already exist that may satisfy some of the data needs. In addition, FDOT has initiated a program to compile pre-construction coring data which may provide base thicknesses for some of the sampled segments. An effort is also underway to use information from the asphalt pay-item history file to estimate asphalt thicknesses using information on the quantities of materials placed.

## TRAFFIC

As discussed previously, information on ADT and percent trucks in the RCI file were merged with the condition survey data in the PCS file. In the performance modeling, the ADT and percent trucks will be used to estimate the cumulative number of equivalent 18-kip single axle load repetitions. A factor will have to be applied to the estimates of cumulative traffic loading to account for growth of traffic over the years.

Recognizing that the performance models will be used at the network level PMS, growth factors currently used for planning purposes by the Department will probably be accurate enough for the modeling effort. From communication with FDOT, a growth factor of about 2 percent seems appropriate.

## PAVEMENT DEFLECTIONS

Surface deflections may be useful in explaining the variation in the model parameters determined for the sampled segments. The data may be used to establish a pavement structural index which will differentiate between the various segments. For example, deflection basin indices such as the surface curvature index (SCI) and the base curvature index (BCI) may be determined and used in a regression analysis to evaluate whether the indices help to explain the variation in one or more of the model parameters. Alternatively, layer moduli may be backcalculated from the measured deflections to generate other data that may be used to explain the variability in the parameters determined. For these analyses, the deflection data will have to be corrected to account for temperature effects. Consequently, environmental data appropriate to the area where a given highway segment is located will also be needed.

## MIXTURE PROPERTIES

The parameters of the models presented in Chapter 3 are likely to be influenced by the properties of the asphalt concrete mix. For this reason, it is important that mixture properties be compiled for the various asphalt mixtures used in Florida. These will include basic mixture properties such as gradation, asphalt content, and air voids, as well as fundamental material properties. An example of an important material property is the slope, m, of the creep compliance curve. From theory, the slope, m, significantly influences both cracking and rutting. In fact, the fracture exponent, n, appearing in the equations for predicting fatigue life of asphalt concrete mixtures, has been found to be directly related to the slope of the creep compliance curve (5,6).

# CHAPTER 5. ESTABLISHING RESURFACING PROJECTS

Chapter 3 presented functional forms of performance models for cracking, rutting and ride quality that are consistent with the observed pavement condition survey data from Florida. These models are required elements of a pavement management system and provide the means for identifying resurfacing needs and corresponding rehabilitation alternatives. In view of budgetary constraints, it is not possible to fix all segments that become deficient in any given year. Consequently, candidate projects must be prioritized in a way that considers their benefits and costs. Understanding this, an incremental benefit-cost (IBC) analysis scheme is proposed to establish resurfacing projects at the network level PMS. This technique looks at the ratio of the difference in benefits between two alternatives to the corresponding difference in costs. An alternative with a higher incremental benefit-cost ratio gets selected provided that its cost is within the available budget.

To implement the IBC technique, one has to evaluate the benefits of applying a given treatment to fix a deficient highway segment. A rational approach is to compare alternatives based on the predicted trends in pavement condition over time and to use these predictions to calculate life-cycle costs for the various alternatives. This approach has a number of advantages:

1. It allows comparison of pavements that fail at the same time. Consider, for example, two alternative treatments, A and B, and assume that the predicted trend in Present Serviceability Index (PSI) for each alternative is as shown in Figure 18. Assuming a terminal serviceability of $PSI_1$, the two alternatives would be characterized as providing the same level of performance. However, it is apparent that the levels of service for the two treatments are not necessarily equal since user and maintenance costs may be significantly different;

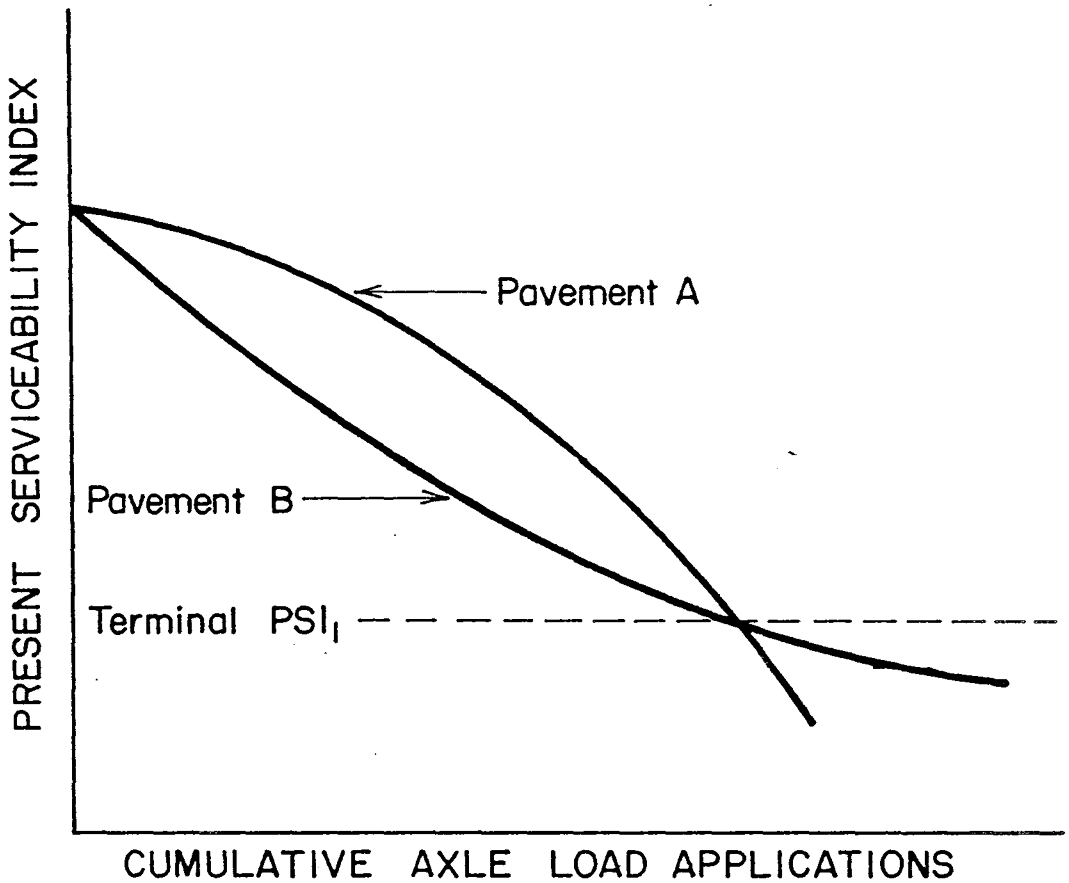


Figure 18. Conceptual serviceability histories for two different alternatives.

2. Similarly, evaluation of life-cycle costs allows comparison of alternatives that provide equal areas underneath the predicted performance curves;
3. Evaluation of life-cycle costs allows the pavement engineer to consider all costs associated with providing pavements and to minimize the cost to the taxpayers; and
4. The Federal PMS guidelines require states to use life-cycle cost analysis when evaluating program and project level investment decisions involving Federal funds.

In view of the above considerations, life-cycle costs form the basis for comparing alternatives in the proposed scheme for prioritizing resurfacing needs. Life-cycle costs include costs associated with initial construction (or reconstruction), routine maintenance, rehabilitation, user operation, user delay, and salvage value. Future costs are discounted according to a specified interest rate so that cost comparisons can be made on the basis of value at a particular point in time. Costs are considered over a designated analysis period which can vary in length depending on the specific conditions being analyzed.

The application of the IBC method in the proposed project selection scheme is explained with reference to Figure 19. In the proposed scheme, the user costs associated with various alternatives are evaluated and compared with the corresponding user cost for the do-nothing alternative (Figure 19b). Benefit is calculated as the difference in road user costs between a given alternative and the do-nothing alternative. In this way, marginal life-cycle user benefits are determined as illustrated in Figure 19c. The equivalent uniform annual user benefits are then calculated and used with the corresponding equivalent uniform annual agency costs to compare and prioritize the different alternatives using incremental benefit-cost analysis. The steps in this procedure are (7,8):

1. For each segment, maintenance and rehabilitation (M&R) alternatives are sorted in increasing order of equivalent uniform annual agency cost incurred from rehabilitation or reconstruction and any scheduled maintenance activities during the given planning period.

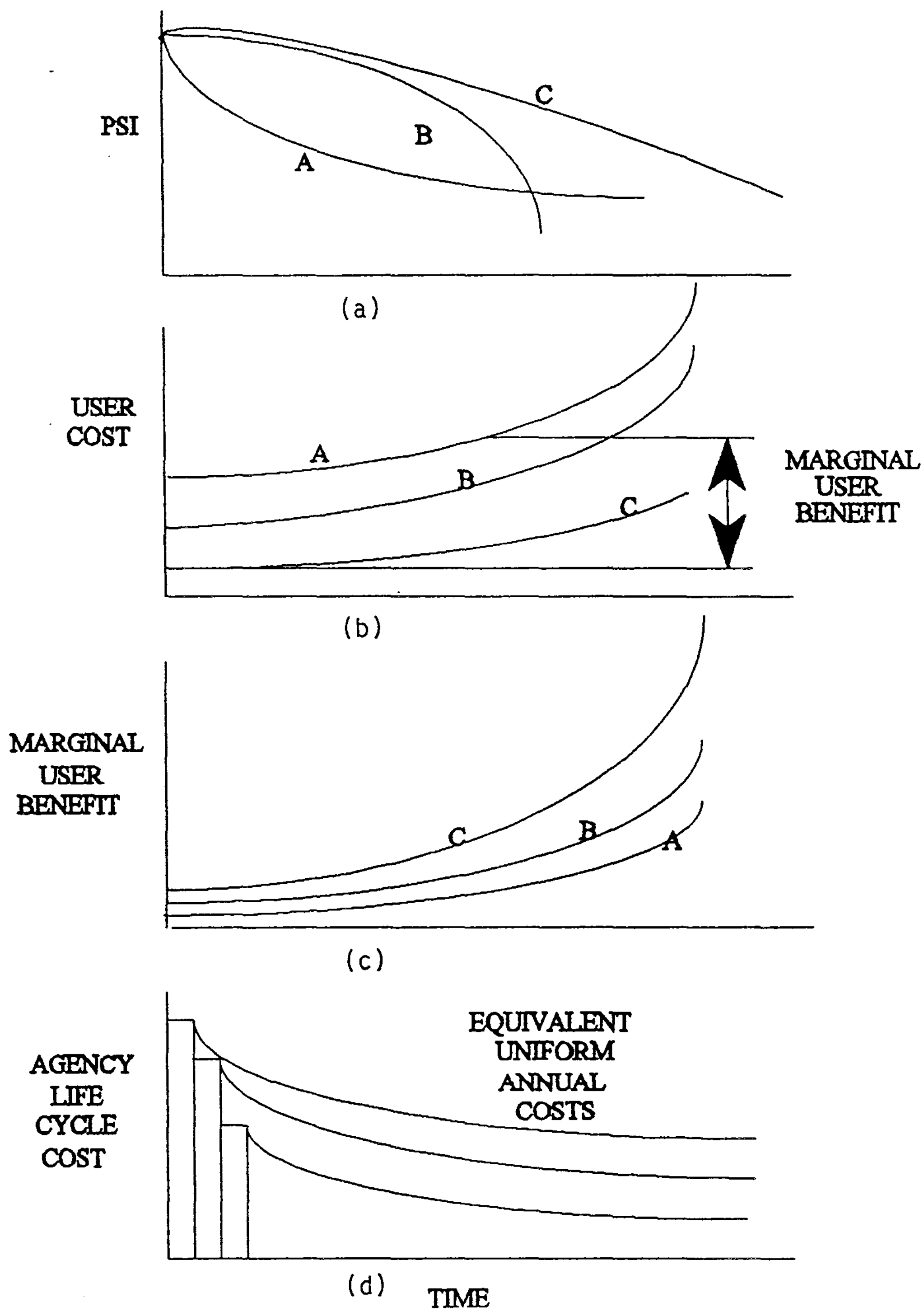


Figure 19. Proposed scheme for calculating incremental benefit-cost ratio.

2. The differences in user benefits ($\Delta B$) and agency costs ($\Delta C$) between two successive alternatives are calculated, and the incremental benefit-cost ratio, $\Delta B/\Delta C$, determined.
3. M&R alternatives with negative incremental benefit-cost ratios are removed from further analysis. A negative ratio means that the given alternative is not cost-effective since it provides less benefit and costs more than the previous treatment.
4. All M&R alternatives are arranged in descending order of the incremental benefit-cost ratio and a running sum of the initial cost of each alternative is computed until the available budget is exhausted. For any given segment, an alternative replaces another as the optimum if it provides a greater benefit.
5. The segments and corresponding treatments included within the running sum form the optimum list of projects for the funds available. The effect of a larger funding level is easily established by simply continuing with the running sum from Step 4 until the new budget level is reached.

It is seen that the IBC method is a simple but powerful tool for establishing the optimum list of projects for any given funding level. In fact, the effects of alternative funding levels are easily determined through simple arithmetic calculations and bookkeeping. For this reason, it is very much suited for implementation in a network-level PMS.

# CHAPTER 6. FUTURE WORK PLAN

During the course of the Phase I research, functional forms of the performance models for cracking, rutting and serviceability loss were derived that were consistent with the observed performance trends from the PCS data base. In addition, a framework for project programming based on incremental benefit-cost analysis was established. To complete the development of the procedure for identifying resurfacing needs and programming resurfacing projects at the network level PMS, a specific work plan for Phase II of the study is outlined and discussed in the following.

## TASK 1. ASSEMBLE DATA BASE FOR MODEL DEVELOPMENT

The objective of this task is to assemble data for the sample of Interstate, Arterial and Turnpike roadway segments selected for developing the performance prediction equations to be implemented in the network level PMS. These will include the traffic, environmental and pavement structural variables that were identified in Chapter 4. Data for accomplishing the model development are to be compiled in this task for as much of the segments included in the preliminary sample.

Data assembly actually started in Phase I. For example, information regarding ADT and percent trucks for the sampled segments have already been obtained using information from the RCI file. Researchers also have in-hand data on layer thicknesses from FDOT's pre-construction coring data base and from the on-going study to implement ground penetrating radar technology within the Department. The pre-construction coring data base will provide base thicknesses on specific roadway segments. Since layer thickness data are limited at this stage, an effort will be made in this task to fill in missing gaps by using data on tonnages of asphalt concrete placed during construction to obtain estimates of surface thicknesses from available records. These estimates will be checked against available coring information to assess their accuracy.

## TASK 2. ANALYZE DYNAFLECT DEFLECTION DATA

The purpose of this task is to establish a pavement structural index or indices for developing the performance prediction equations in Task 3. A number of approaches will be considered. Two of these, involving the evaluation of deflection basin indices, and the backcalculation of layer moduli, were already described in Chapter 4. In another approach, a structural indicator, such as the Structural Number, SN, or $Eh^3$ will be evaluated. The latter quantity is based on Odemark's theory where, E, is a composite pavement stiffness characterizing all layers above the subgrade, and h, is the total pavement thickness. For this purpose, a procedure for determining E and h from Dynaflect deflection measurements will have to be developed. This approach will require more effort but is an alternative that should be investigated if the other approaches prove unsuccessful. Should it become necessary, a large number of pavements will be evaluated in this task to determine relationships between $Eh^3$ and Dynaflect measurements. A factorial of pavement structures will be established consisting of various combinations of surface and subgrade moduli, surface thicknesses and depths to rigid layer. For each pavement structure, the surface displacements at the different Dynaflect sensor locations will be predicted using layered elastic theory. The data generated will then be used to develop relationships for determining $Eh^3$ from Dynaflect deflection measurements.

## TASK 3. DEVELOP PAVEMENT PERFORMANCE MODELS

The pavement condition data for different distresses will be fitted to the corresponding performance models developed for ride quality, rutting and cracking. The functional forms of these performance models were presented in Chapter 3. As may be observed, the models are defined by certain parameters which will be determined from regression analyses, for the sample of roadway segments established. Subsequently, prediction equations for these parameters will be developed that are functions of the characteristics of the various sampled segments. The data assembled in Tasks 1 and 2 will be used in developing the prediction equations for the model parameters.

## TASK 4. VERIFY PERFORMANCE PREDICTION EQUATIONS

The accuracy of the performance models shall be evaluated by comparing the predicted trends with the observed trends. This verification will be made using data that were not included in the development of the performance models. A sample of segments will be established for this purpose. As appropriate, the performance models shall be recalibrated based on the results of the verifications conducted.

## TASK 5. DEVELOP SAS PROGRAM FOR NETWORK LEVEL PROGRAMMING

A SAS program for network level programming of resurfacing needs will be developed in this task. The program will incorporate the performance models developed in Task 3 and the incremental benefit-cost procedure for project selection based on life-cycle costs. It is proposed to use the cost analysis program in **COMPAS**, developed in an earlier FDOT study (9,10) to determine agency and road user costs.

Task 5 will require close cooperation and coordination between the Department and TTI. The overall framework of the SAS program will be established initially in consultation with the Florida DOT. This framework will then be used to guide the programming work to be conducted. Since input data for the performance models will have to be obtained from various data files maintained by the Department, the assistance of FDOT is requested in developing the interfaces between the SAS program and the data files that must be accessed. It is also recognized that there are Department personnel who are proficient in the SAS programming language and their assistance in developing the various elements of the framework will be invaluable to this project. In this regard, the researchers can provide the Department with the necessary flow charts for programming of the performance models and/or the project selection algorithm in-house. By becoming involve in the programming work, the Department will gain an understanding of the software and will thus have the expertise to maintain the programs developed after completion of the study.

## TASK 6. SYSTEM IMPLEMENTATION

The purpose of this task is to assist the Department in implementing the network level PMS developed in Phase II. Assistance will be provided in compiling the data needed for implementing the system. Some of these, such as layer thicknesses, would have already been compiled for the sample of highway segments included in the performance model development and verification. The goal herein is to compile similar information for all the other highway segments to the extent possible, using available data within the Department.

A procedure will also be developed in this task for calibrating the performance equations as more data become available. It is recognized that the initial performance models will be based, in part, on estimates of the input variables used in developing the equations. Examples include layer thickness and traffic information, such as ADT, percent trucks, and truck factors for converting mixed traffic to equivalent 18-kip single axle load repetitions. The calibration procedure to be developed in this task will allow the Department to modify the performance equations as gaps in the data are filled and more accurate data become available.

The complete system will also be tested, as installed on FDOT's mainframe computer, to verify that it is working properly. This test may involve running the program to determine resurfacing needs for a selected District. Errors detected will be corrected jointly by TTI and FDOT.

## TASK 7. REPORT AND PROGRAM DOCUMENTATION

A report describing the development of the performance models and the procedure for network level programming of resurfacing needs will be prepared in this task. In addition, a user's guide to the SAS program will be provided.

## TASK 8. PROJECT PRESENTATION

A project presentation is proposed at the end of Phase II. In this meeting, the development of the network level PMS will be discussed and sample program applications will be made using data from a selected District. In this way, the benefits to be derived from implementing the computer program will be demonstrated. Possible future improvements to the system will also be identified.

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# APPENDIX A

# LIST OF DATA FILES PROVIDED BY FDOT

## PCS Files

| Field | Description |
|---|---|
| RDWYID | ID of roadway |
| YR | Year of survey |
| LANES | |
| DISTRICT | District code (1-7) |
| COUNTYDT | County code |
| SYSTEM | 1 = Arterial, 3 = Toll, 4 = Interstate, 5 = Turnpike |
| TYPE | 0 = exceptions not state maintained<br>1 = AC surface course<br>2 = surface treatment<br>3 = skin patch<br>4 = portland cement concrete<br>5 = new construction<br>6 = section defected with no ride<br>7 = new pavement (overlay)<br>8 = under construction<br>9 = state maintained exceptions or structures |
| BEG | Beginning milepost of inspected section |
| END | End milepost of inspected section |
| CRACKS | Crack rating of section |
| RIDE | Rating of ride quality for section |
| RUTTING | Rutting rating of section |
| PCR | PCR calculated as the minimum of the ratings for cracking, rutting, and ride. |
| RDWYSIDE | R,L = Divided highway<br>C = Composite (undivided) highway |
| PUMP | Pumping |
| DEFECT | |
| FAULT | Faulting |
| MANRUT | Average manual rut depth |
| REMARKS | |

## Asphalt Pay Item History

Library: CASAC
Dataset: CAS

| Field | Description |
| --- | --- |
| PAYITNO | Pay item number |
| PAYITDES | Pay item description |
| MEACODE | Unit of measure for pay item |
| PROJCODE | Project code |
| WPITEMNO | Work pay item number |
| LETDATE | Date of letting |
| PAYITUPR | Pay item unit price |
| JOBQUANT | Quantity of material used |
| DISTRICT | District code (1-7) |
| CONTYDOT | County code |
| AMOUNT | Amount paid |

## Historical Interstate Project Info

Library: INT
Dataset: INTR

| Field | Description |
|---|---|
| I | Interstate number |
| TYP | |
| FMP | Federal Mile Post |
| PROJCODE | Project Code |
| FAPIDNO | Federal Aid Program ID number |
| WPITEMNO | Work pay item number |
| LANES | Number of lanes |
| SURFACE | Surface type |
| SHLD | |
| TYPICAL | |
| RMILES | |
| PMILES | |
| LETDATE | Date of letting |
| LOWBID | Low bid received |
| CONTR | Contractor |
| OPEN | Date project opened |
| YEAR | Year project opened |
| FINLCOST | Final cost |
| BEGSECPT | |
| ENDSECPT | |
| RDWYID | Roadway ID |

## Dynaflect

Library: DYNA
Dataset: DYNA1, DYNA2, DYNA3

| Field | Description |
|---|---|
| SEQ | Sequence number |
| DISTRICT | District code (1-7) |
| COSEC | County section number |
| BEGSECPT | Beginning section milepost |
| YYMMDD | Date tested |
| LANE | Lane tested:<br>nbtl for north bound traffic lane<br>sbpl for south bound passing lane |
| SRNO | State road number |
| D1 | Dynaflect sensor 1 reading |
| D2 | Dynaflect sensor 2 reading |
| D3 | Dynaflect sensor 3 reading |
| D4 | Dynaflect sensor 4 reading |
| D5 | Dynaflect sensor 5 reading |
| CRKCL | Cracking: 1 = class 1 cracking<br>2 = class 2 cracking<br>3 = class 3 cracking |
| CRKTYP | Type of cracking: T = transverse<br>L = longitudinal<br>B = block<br>A = alligator<br>E = edge<br>P = patch |
| AIRTEMP | Air temperature |
| PAVTEMP | Pavement temperature |
| UNIT | Unit number |
| OPER | Operator initials |
| COND | Condition: R = rippling<br>S = severe rutting<br>H = high water table<br>I = intersection<br>D = depression/settlement<br>C = cypress head<br>PC = pavement change<br>CG = curb and gutter<br>W = water standing in ditch<br>G = gutter |

## Coring Averages

Library: PCR
Dataset: PCR

| Field | Description |
|---|---|
| WPITEMNO | WPA item number<br>1st digit is District<br>2nd and 3rd disgits are program component<br>4th to 7th digits are sequence numbers |
| LOCALNAM | Location name |
| LIMITSFM | WPA project begin milepost description |
| LIMITSTO | WPA project begin milepost |
| BEGSECPT | WPA project begin milepost |
| ENDSECPT | WPA project end milepost |
| RDWYID | County-section-subsection |
| RDWYSIDE | Side of roadway which WPA project is on |
| TYPSECT | Coring roadway section break number |
| BEGMIPT | Coring roadway section begin milepost |
| ENDMILPT | Coring roadway section end milepost |
| LENGTH | Coring roadway section break number |
| BMILPT | Actual coring roadway begin milepost |
| EMILPT | Actual coring roadway end milepost |
| RDWY | Actual coring roadway side |
| LANENMBR | Actual coring lane number:<br>L3 L2 L1 C R1 R2 R3 |
| PROJCODE | Project code |
| COREDATE | Coring date -- yyyymmdd |
| TYPEBASE | Base type |
| DISTRICT | District code (1-7) |
| COUNTY | County number |
| N1 | Total nonmissing number of pavement coring |
| N2 | Total nonmissing number of base coring |
| NOBS1 | Total number of pavement coring |
| NOBS2 | Total number of base coring |
| AVG1 | Average pavement coring thickness in mm |
| AVG2 | Average base coring depth in mm |
| STD1 | Standard deviation of pavement coring thickness |
| STD2 | Standard deviation of base coring depth |
| VAR1 | Mean deviation of pavement thickness calculated as STD1/AVG1 |
| VAR2 | Mean deviation of base depth calculated by STD2/AVG2 |

## RCI

Library: PCOND2
Dataset: RCI

| Field | Description |
| --- | --- |
| COUNTYDOT | Roadway identification number |
| RDWYID | FDOT county number |
| DISTRICT | FDOT district number |
| SECTSTAT | Section status code (only active 02, 06, 12) |
| UNIQSYS | Highway system code |
| RDWYSIDE | Roadway side:<br>R = right<br>L = left<br>C = composite |
| BEGSECPT | Begin milepost of characteristic |
| ENDSECPT | End milepost of characteristic |
| RDWYCHAR | Roadway characteristic variable name |
| FUNCLASS | Functional class code of highway |
| SECTADT | Section average daily traffic (two-way) |
| AVGTFACT | Average percent trucks |
| SURFNUM | Surface type code |
| SHLDTYPE | Outside shoulder type code |
| NOLANES | Number of through lanes |
| RCDVALUE | Roadway characteristic code value or numeric value |
| DECODESC | Roadway characteristic code value description |

# APPENDIX B

# LIST OF SAS PROGRAMS DEVELOPED

```
*************************************************************
*                    PROGRAM CYCLES                         *
*       A program to define performance cycles for the      *
*       roadway segments in a PCS file.  FDOTPRJ.INCDSIX    *
*       is an arbitrary name for an input PCS dataset.      *
*       Results are output to FDOTPRJ.INCDSIX.              *
*       Since the research is still ongoing, this program   *
*       produces scratch files that are saved in the output *
*       to check the program.                               *
*************************************************************
;
libname fdotprj 'c:\fdotprj\prgsmpl';

data         fdotprj.incdsix(drop=typeflag firstyr prevtype prevcrks);
set          fdotprj.intsix;
by rdwyid beg end rdwyside;
retain typeflag cycle age1 firstyr prevtype prevcrks;
if first.rdwyside then do;
firstyr=yr;
typeflag=1;
cycle=1;
end;
else do;
if (type=7 and prevtype ne 7) or (prevcrks < 8.5 and cracks = 10) or ((cracks - prevcrks)
ge 2)
 then do;
firstyr=yr;
typeflag=typeflag+1;
end;
end;
prevcrks=cracks;
prevtype=type;
cycle=typeflag;
age1=yr-firstyr+1;
run;
```

```
**************************************************************
*           PROGRAM ADTMERGE                                 *
*      A program to combine average daily traffic            *
*      and percent data in the ADTRUCK dataset with          *
*      corresponding roadway segments in the list of         *
*      segments of a PCS dataset.                            *
*      The ADTRUCK is subsetted from the RCI dataset by      *
*      the ADTTRUCK program.                                 *
*      Refer to the listing of the ADTTRUCK program          *
*      for an explanation of ADTRUCK.                        *
*      FDOTPRJ.ARTSONE is an arbitrary name for a dataset    *
*      of a list of segments in a PCS file.                  *
*      FDOTPRJ.ARTSONE is created from                       *
*      FDOTPRJ.ARTDONE (a PCS dataset by the SEGCOUNT        *
*      program.                                              *
*      Since the research is still ongoing, this program     *
*      produces scratch files that are saved in the output   *
*      to check the program.                                 *
**************************************************************
;

libname fdotprj  'c:\fdotprj\prgsmpl';

**************************************************************
*      For each beginning mile post of each segment in       *
*      PCS determine the bounding segments in the            *
*      ADTRUCK dataset and linearly interpolate for the      *
*      ADT and number of trucks in the area between          *
*      the beginning of the segment in the ADTRUCK           *
*      dataset and the beginning of the segment in the       *
*      PCS dataset.                                          *
**************************************************************
;
proc sql;
create table fdotprj.begsec as
select
adtruck.begsecpt,adtruck.endsecpt,adtruck.rdwyid,artsone.rdwyside,artsone.beg,artsone.end,
adtruck.adt*(artsone.beg-adtruck.begsecpt)/(adtruck.endsecpt-adtruck.begsecpt) as begdiffa,
adtruck.notrucks*(artsone.beg-adtruck.begsecpt)/(adtruck.endsecpt-adtruck.begsecpt) as
begdifft
from fdotprj.adtruck,fdotprj.artsone
where adtruck.begsecpt<=artsone.beg
and adtruck.endsecpt>=artsone.beg
and adtruck.rdwyid=artsone.rdwyid;
```

```
proc sort data=fdotprj.begsec;
by rdwyid beg end rdwyside;
run;

data fdotprj.begsec;
set fdotprj.begsec;
by rdwyid beg end rdwyside;
if last.rdwyside then output;
run;

**********************************************************
*       For each ending mile post of each segment in       *
*       PCS determine the bounding segments in the         *
*       ADTRUCK dataset and linearly interpolate for       *
*       the ADT and number of trucks in the area           *
*       between the ending of the segment in the          *
*       ADTRUCK dataset and the beginning of the           *
*       segment in the PCS dataset.                        *
**********************************************************
;
proc sql;
create table fdotprj.endsec as
select
adtruck.begsecpt,adtruck.endsecpt,adtruck.rdwyid,artsone.rdwyside,artsone.beg,artsone.end,
adtruck.adt*(adtruck.endsecpt-artsone.end)/(adtruck.endsecpt-adtruck.begsecpt) as enddiffa,
adtruck.notrucks*(adtruck.endsecpt-artsone.end)/(adtruck.endsecpt-adtruck.begsecpt) as
enddifft
from fdotprj.adtruck,fdotprj.artsone
where adtruck.begsecpt<=artsone.end
and adtruck.endsecpt>=artsone.end
and adtruck.rdwyid=artsone.rdwyid;

proc sort data=fdotprj.endsec;
by rdwyid beg end rdwyside;
run;

data fdotprj.endsec;
set fdotprj.endsec;
by rdwyid beg end rdwyside;
if last.rdwyside then output;
run;
```

```
************************************************************
*       Add the ADT and number of trucks of the            *
*       bounding element                                   *
************************************************************
;
proc sql;
create table fdotprj.limsecs as
select
begsec.rdwyid,begsec.beg,begsec.end,begsec.rdwyside,begsec.begsecpt,endsec.endsecpt,
begsec.begdiffa,endsec.enddiffa,begsec.begdifft,endsec.enddifft
from fdotprj.begsec,fdotprj.endsec
where begsec.rdwyid=endsec.rdwyid
and   begsec.beg=endsec.beg
and begsec.end=endsec.end
and begsec.rdwyside=endsec.rdwyside;

proc sql;
create table fdotprj.adtadd as
select sum(adtruck.adt) as totadt,sum(adtruck.notrucks) as
tottruck,limsecs.rdwyid,limsecs.beg,limsecs.end,limsecs.rdwyside,
limsecs.begsecpt,limsecs.endsecpt
from fdotprj.adtruck,fdotprj.limsecs
where adtruck.begsecpt>=limsecs.begsecpt
and adtruck.endsecpt<=limsecs.endsecpt
and adtruck.rdwyid=limsecs.rdwyid
group by
limsecs.rdwyid,limsecs.beg,limsecs.end,limsecs.rdwyside,limsecs.begsecpt,limsecs.endsecpt;

************************************************************
*       Subtract the previously interpolated ADT and       *
*       number of trucks and calculate percent trucks      *
*       and output the results in ARADTONE.                *
*       FDOTPRJ.ARADTONE is an arbitrary name for the      *
*       output data set.                                   *
************************************************************
;
proc sql;
create table fdotprj.aradtone as
select limsecs.rdwyid,limsecs.beg,limsecs.end,limsecs.rdwyside,
int(adtadd.totadt-limsecs.begdiffa-limsecs.enddiffa) as adt,
100*(adtadd.tottruck-limsecs.begdifft-limsecs.enddifft)/
(adtadd.totadt-limsecs.begdiffa-limsecs.enddiffa) as ptrucks
from fdotprj.limsecs,fdotprj.adtadd
where adtadd.rdwyid=limsecs.rdwyid
```

```
and adtadd.beg=limsecs.beg
and adtadd.end=limsecs.end
and adtadd.rdwyside=limsecs.rdwyside
and adtadd.begsecpt=limsecs.begsecpt
and adtadd.endsecpt=limsecs.endsecpt;
quit;
```

```
*************************************************************
*                PROGRAM ADTTRUCK                           *
*       A program to extract the ADT and number of          *
*       trucks from the RCI file. FDOTPRJ.RCI is an         *
*       arbitrary name for a roadway condition index        *
*       dataset. FDOTPRJ.ADTRUCK is an arbitrary name       *
*       for the output dataset.                             *
*       Since the research is still ongoing, this program   *
*       produces scratch files that are saved in the output *
*       to check the program.                               *
*************************************************************
;
libname fdotprj  'c:\fdotprj\prgsmpl';

proc sql;
create table fdotprj.adtsecns as
select *
from fdotprj.rci
where rci.rdwychar eq 'SECTADT';

proc sql;
create table fdotprj.adtruck as
select adtsecns.*,rci.rcdvalue as trucks
from fdotprj.rci, fdotprj.adtsecns
where adtsecns.rdwyid=rci.rdwyid    and
     adtsecns.begsecpt=rci.begsecpt    and
     adtsecns.endsecpt=rci.endsecpt    and
     adtsecns.rdwyside=rci.rdwyside
and  rci.rdwychar='AVGTFACT';

data fdotprj.adtruck(drop=trucks rcdvalue decddesc);
set fdotprj.adtruck;
adt=input(rcdvalue,best30.);
notrucks=input(trucks,best30.);
run;
```

```
*****************************************************
*           PROGRAM CAUSE6                          *
*     A program to determine the count of the       *
*     different distresses that cause rehabilitation *
*     in a PCS file when the PCR values are less than *
*     or equal to 6.  FDOTPRJ.INCDSIX is an arbitrary *
*     name for an input PCS file.                   *
*     Since the research is still ongoing, this program *
*     produces scratch files that are saved in the output *
*     to check the program.                         *
*****************************************************
;
libname fdotprj 'C:\fdotprj\prgsmpl';

*****************************************************
*     If it is the end of the cycle and the PCR value *
*     is less than or 6, then find out which distress *
*     is equal to PCR and increase its counter by 1 *
*****************************************************
;
data fdotprj.cossix(keep=ccracks crutting cride);
set fdotprj.incdsix;
by rdwyid beg end rdwyside cycle;
if LAST.cycle AND PCR LE 6 then do;
if pcr=cracks then ccracks+1;
if pcr=rutting then crutting+1;
if pcr=ride then cride+1;
end;

*****************************************************
*     Combine results of count in one field for each *
*     type of distress                              *
*****************************************************
;
proc sql;
create table fdotprj.crcausix as
select max(ccracks)
from fdotprj.cossix;

proc sql;
create table fdotprj.rucausix as
select max(crutting)
from fdotprj.cossix;
```

```
proc sql;
create table fdotprj.ricausix as
select max(cride)
from fdotprj.cossix;

data fdotprj.caussix;
input distress $;
cards;
cracks
rutting
ride
;
run;

*****************************************************
*      Output results into dataset FDOTPRJ.CAUSESIX.      *
*      FDOTPRJ.CAUSESIX is an arbitrary name              *
*****************************************************
;
data fdotprj.causesix(keep= distress count);
set fdotprj.caussix;
if distress='cracks' then do;
set fdotprj.crcausix;
count=_temg001;
end;
if distress='rutting' then do;
set fdotprj.rucausix;
count=_temg001;
end;
if distress='ride' then do;
set fdotprj.ricausix;
count=_temg001;
end;
run;


options nodate nocenter nonumber formdlim=' ';

proc printto print='c:\fdotprj\prgsmpl\causes.txt' ;
proc print data=fdotprj.causesix noobs;
title;
run;
```

```
*************************************************************
*           PROGRAM CAUSES                                  *
*       A program to determine the count of the             *
*       different distresses that cause rehabilitation      *
*       in a PCS file for full range of PCR.                *
*       FDOTPRJ.INCDSIX is an arbitrary                     *
*       name for an input PCS file.                         *
*       Since the research is still ongoing, this program   *
*       produces scratch files that are saved in the output *
*       to check the program.                               *
*************************************************************
;
libname fdotprj 'C:\fdotprj\prgsmpl';

*************************************************************
*       If it is the end of the cycle and the PCR value     *
*       is less than or 6, then find out which distress     *
*       is equal to PCR and increase its counter by 1       *
*************************************************************
;
data fdotprj.cossix(keep=ccracks crutting cride);
set fdotprj.incdsix;
by rdwyid beg end rdwyside cycle;
if LAST.cycle then do;
if pcr=cracks then ccracks+1;
if pcr=rutting then crutting+1;
if pcr=ride then cride+1;
end;

*************************************************************
*       Combine results of count in one field for each      *
*       type of distress                                    *
*************************************************************
;
proc sql;
create table fdotprj.crcausix as
select max(ccracks)
from fdotprj.cossix;

proc sql;
create table fdotprj.rucausix as
select max(crutting)
from fdotprj.cossix;
```

```
proc sql;
create table fdotprj.ricausix as
select max(cride)
from fdotprj.cossix;

data fdotprj.caussix;
input distress $;
cards;
cracks
rutting
ride
;
run;

***********************************************************
*       Output results into dataset FDOTPRJ.CAUSESIX.       *
*       FDOTPRJ.CAUSESIX is an arbitrary name               *
***********************************************************
;
data fdotprj.causesix(keep= distress count);
set fdotprj.caussix;
if distress='cracks' then do;
set fdotprj.crcausix;
count=_temg001;
end;
if distress='rutting' then do;
set fdotprj.rucausix;
count=_temg001;
end;
if distress='ride' then do;
set fdotprj.ricausix;
count=_temg001;
end;
run;


options nodate nocenter nonumber formdlim=' ';

proc printto print='c:\fdotprj\prgsmpl\causes.txt' ;
proc print data=fdotprj.causesix noobs;
title;
run;
```

```
***********************************************************
*           PROGRAM CORR                                  *
*     A program to determine the correlations between     *
*     the different types of distresses in a PCS file     *
*     FDOTPRJ.INTSIX is an arbitrary name for an          *
*     input PCS dataset.                                  *
*     Since the research is still ongoing, this program   *
*     produces scratch files that are saved in the output *
*     to check the program.                               *
***********************************************************

libname fdotprj 'c:\fdotprj\prgsmpl';

***********************************************************
*     Perform correlation procedure                       *
*     and place output in FDOTPRJ.INTSIXC.                *
*     FDOTPRJ.INTSIXC is an arbitrary name for output     *
***********************************************************
proc corr data=fdotprj.intsix outp=fdotprj.intsixc;
by rdwyid beg end rdwyside;
var cracks ride rutting;
run;

***********************************************************
*     Plot correlation charts                             *
***********************************************************

proc printto print='c:\fdotprj\prgsmpl\incusix.txt';
options linesize=95 pagesize=32 date number pageno=1;
title;
footnote;
proc chart data=fdotprj.intsixc;
  vbar RUTTING /
    type=CPCT
    ;
    where
  _NAME_='CRACKS';
run;

proc printto print='c:\fdotprj\prgsmpl\incisix.txt';
options linesize=95 pagesize=32 date number pageno=1;
title;
footnote;
proc chart data=fdotprj.intsixc;
```

```
  vbar RIDE /
    type=CPCT
    ;
    where
  _NAME_='CRACKS';
run;

proc printto print='c:\fdotprj\prgsmpl\inuisix.txt';
options linesize=95 pagesize=32 date number pageno=1;
title;
footnote;
proc chart data=fdotprj.intsixc;
  vbar RUTTING /
    type=CPCT
    ;
    where
  _NAME_='RIDE';
run;
```

```
*********************************************************
*              PROGRAM CYCLES                           *
*     A program to define performance cycles for the    *
*     roadway segments in a PCS file.  FDOTPRJ.INCDSIX  *
*     is an arbitrary name for an input PCS dataset.    *
*     Results are output to FDOTPRJ.INCDSIX.            *
*     Since the research is still ongoing, this program *
*     produces scratch files that are saved in the output *
*     to check the program.                             *
*********************************************************
;
libname fdotprj 'c:\fdotprj\prgsmpl';

data        fdotprj.incdsix(drop=typeflag firstyr prevtype prevcrks);
set         fdotprj.intsix;
by rdwyid beg end rdwyside;
retain typeflag cycle age1 firstyr prevtype prevcrks;
if first.rdwyside then do;
firstyr=yr;
typeflag=1;
cycle=1;
end;
else do;
if (type=7 and prevtype ne 7) or (prevcrks < 8.5 and cracks = 10) or ((cracks - prevcrks)
ge 2)
 then do;
firstyr=yr;
typeflag=typeflag+1;
end;
end;
prevcrks=cracks;
prevtype=type;
cycle=typeflag;
age1=yr-firstyr+1;
run;
```

```
************************************************************
*               PROGRAM SEGCOUNT                           *
*     A program to list the segments in a PCS file         *
*     without the repetitions for each year of survey      *
*     FDOTPRJ.ARTSONE is an arbitrary name for an          *
*     input PCS dataset.                                   *
*     The results are output to FDOTPRJ.ARTSONE.           *
*     Since the research is still ongoing, this program    *
*     produces scratch files that are saved in the output  *
*     to check the program.                                *
************************************************************
;
libname fdotprj 'c:\fdotprj\prgsmpl';

proc sql;
create table fdotprj.artsone as
select rdwyid, beg, end, rdwyside, count(*) as count
from fdotprj.artdone
group by rdwyid, beg, end, rdwyside;
```

```
****************************************************************
*                   PROGRAM TRYMODEL                           *
*       A program to perform modeling of performance on        *
*       data in PCS files.  FDOTPRJ.INCDSIX is the input       *
*       and is an arbitrary name of a PCS dataset in which     *
*       the cycles have been by the program CYCLES.            *
*       Since the research is still ongoing, this program      *
*       produces scratch files that are saved in the output    *
*       to check the program.                                  *
****************************************************************
;
libname fdotprj 'c:\fdotprj\prgsmpl';

****************************************************************
*       Output files for plots of performance models for       *
*       cracking, rutting, ride, and PCR respectively          *
****************************************************************
;
filename crmdlsix 'c:\fdotprj\prgsmpl\crmdlsix.plt';
filename rumdlsix 'c:\fdotprj\prgsmpl\rumdlsix.plt';
filename rdmdlsix 'c:\fdotprj\prgsmpl\rimdlsix.plt';
filename pcmdlsix 'c:\fdotprj\prgsmpl\pcmdlsix.plt';


options linesize=75 pagesize=25 pageno=1;

****************************************************************
*       Perform non-linear regressin and output results in     *
*       FDOTPRJ.CRMDLSIX for crack modeling,                   *
*       FDOTPRJ.RUMDLSIX for rut modeling,                     *
*       FDOTPRJ.RIMDLSIX for ride modeling, and                *
*       FDOTPRJ.PCMDLSIX for PCR modeling.                     *
****************************************************************
;
proc nlin data=fdotprj.incdsix method=gauss;
parameters beta=1.1 rho=10;
model cracks=10-10*exp(-((rho/age1)**beta));
der.beta=-10*exp(-((rho/age1)**beta))*(-((rho/age1)**beta))*log(rho/age1);
der.rho=-10*exp(-((rho/age1)**beta))*(-beta*((rho/age1)**(beta-1)));
   output out=fdotprj.crmdlsix p=pcracks r=residual parms=beta rho;
by rdwyid beg end rdwyside cycle;
run;

proc plot data=fdotprj.crmdlsix;
```

```
plot pcracks*yr=cycle cracks*yr='o'/vaxis=0 to 10 by 1 overlay;
by rdwyid beg end rdwyside;
run;

proc printto print=rumdlsix new;
run;

proc nlin data=fdotprj.incdsix method=gauss;
parameters beta=1.1 rho=10;
model rutting=10-10*exp(-((rho/age1)**beta));
der.beta=-10*exp(-((rho/age1)**beta))*(-((rho/age1)**beta))*log(rho/age1);
der.rho=-10*exp(-((rho/age1)**beta))*(-beta*((rho/age1)**(beta-1)));
   output out=fdotprj.rumdlsix p=prutts r=residual parms=beta rho;
by rdwyid beg end rdwyside cycle;
run;

proc plot data=fdotprj.rumdlsix;
plot prutts*yr=cycle rutting*yr='o'/vaxis=0 to 10 by 1 overlay;
by rdwyid beg end rdwyside;
run;

proc printto print=rdmdlsix new;
run;

proc nlin data=fdotprj.incdsix method=gauss;
parameters beta=1.1 rho=10;
model ride=9-9*exp(-((rho/age1)**beta));
der.beta=-10*exp(-((rho/age1)**beta))*(-((rho/age1)**beta))*log(rho/age1);
der.rho=-10*exp(-((rho/age1)**beta))*(-beta*((rho/age1)**(beta-1)));
   output out=fdotprj.rimdlsix p=prides r=residual parms=beta rho;
by rdwyid beg end rdwyside cycle;
run;

proc plot data=fdotprj.rimdlsix;
plot prides*yr=cycle ride*yr='o'/vaxis=0 to 10 by 1 overlay;
by rdwyid beg end rdwyside;
run;

proc printto print=pcmdlsix new;
run;

proc nlin data=fdotprj.incdsix method=gauss;
parameters beta=1.1 rho=10 alpha=9;
model pcr=alpha-alpha*exp(-((rho/age1)**beta));
```

```
der.alpha=1-exp(-((rho/age1)**beta));
der.beta=-alpha*exp(-((rho/age1)**beta))*(-((rho/age1)**beta))*log(rho/age1);
der.rho=-alpha*exp(-((rho/age1)**beta))*(-beta*((rho/age1)**(beta-1)));
   output out=fdotprj.pcmdlsix p=ppcrs r=residual parms=alpha beta rho;
by rdwyid beg end rdwyside cycle;
run;

proc plot data=fdotprj.pcmdlsix;
plot ppcrs*yr=cycle pcr*yr='o'/vaxis=0 to 10 by 1 overlay;
by rdwyid beg end rdwyside;
run;

proc printto print=print;
run;
```

# APPENDIX C

# PRELIMINARY SAMPLE OF HIGHWAY SEGMENTS

Table C1. List of Test Segments for Arterials.

| Roadway ID | Beginning Milepost | Ending Milepost | Roadway Side |
|---|---|---|---|
| 1040000 | 0.184 | 0.682 | C |
| 1040000 | 0.994 | 1.47 | C |
| 3010000 | 8.456 | 11.535 | R |
| 3080000 | 24.767 | 28.43 | C |
| 3080000 | 38.631 | 39.492 | C |
| 4040000 | 0 | 5.077 | C |
| 4040000 | 14.167 | 14.701 | R |
| 4060000 | 0 | 4.23 | C |
| 5010000 | 3.02 | 3.99 | L |
| 5040000 | 4.782 | 12.529 | C |
| 6020000 | 0 | 3.26 | C |
| 7030000 | 0 | 1.518 | R |
| 9030000 | 14.293 | 15.3 | L |
| 9030000 | 15.3 | 16 | R |
| 9030001 | 0 | 0.58 | C |
| 9060000 | 17.32 | 17.878 | C |
| 9060000 | 25.544 | 27.2 | C |
| 12020000 | 17.662 | 18.305 | C |
| 12090000 | 0.085 | 0.97 | C |
| 13080000 | 4.007 | 4.545 | C |
| 16010000 | 4.146 | 5.41 | C |
| 16010101 | 0.303 | 0.947 | C |
| 16020000 | 4.593 | 5.15 | L |
| 16060000 | 9.779 | 10.474 | R |
| 16090000 | 18.161 | 18.962 | C |

| | | | |
|---|---|---|---|
| 16110000 | 17.567 | 18.481 | L |
| 16110000 | 17.567 | 18.481 | R |
| 16110000 | 25.594 | 27.175 | R |
| 16130000 | 11.9 | 12.485 | C |
| 16160000 | 0 | 0.635 | C |
| 16160000 | 0.971 | 2.494 | C |
| 16160000 | 2.707 | 6.1 | C |
| 16180000 | 3 | 5.859 | R |
| 16180000 | 15.652 | 16.55 | L |
| 16250000 | 25.438 | 26.125 | R |
| 17020000 | 1.953 | 2.7 | R |
| 17020000 | 5.444 | 6.087 | R |
| 17020000 | 9.081 | 9.986 | L |
| 17020000 | 12.6 | 13.2 | L |
| 17020000 | 14.4 | 15.184 | L |
| 17050000 | 2.317 | 6.343 | C |
| 17070000 | 4.389 | 5.246 | L |
| 17120000 | 1.199 | 2.107 | L |
| 91010000 | 3.122 | 4.666 | C |
| 91050000 | 0 | 2.105 | C |
| 26010000 | 11.639 | 12.539 | R |
| 26020000 | 17.362 | 19.057 | R |
| 26020000 | 22.779 | 23.44 | L |
| 26020000 | 24.218 | 25.22 | L |
| 26020000 | 25.3 | 25.78 | C |
| 26030000 | 0 | 6.75 | C |
| 26030000 | 6.75 | 8.1 | C |
| 26030000 | 24.181 | 25.799 | C |

| | | | |
|---|---|---|---|
| 26030000 | 25.799 | 26.418 | C |
| 26040000 | 0.04 | 1.04 | C |
| 26060000 | 0.422 | 2.126 | L |
| 26060000 | 2.168 | 2.861 | L |
| 26070000 | 8.414 | 9.76 | C |
| 26070000 | 9.76 | 10.57 | C |
| 26070000 | 10.57 | 12.087 | C |
| 26070000 | 14.778 | 15.639 | L |
| 26070000 | 15.842 | 16.829 | L |
| 26070000 | 17.641 | 18.785 | C |
| 26110000 | 3.185 | 3.722 | C |
| 26110000 | 3.722 | 7.179 | C |
| 27010000 | 0 | 5.05 | C |
| 27010000 | 9.341 | 9.984 | L |
| 28010000 | 5.294 | 7.271 | L |
| 28010000 | 5.294 | 7.271 | R |
| 28010000 | 8.934 | 9.803 | R |
| 28010000 | 10.02 | 14.405 | R |
| 28060000 | 0 | 0.455 | C |
| 29010000 | 8 | 8.452 | R |
| 29040000 | 1.293 | 2.804 | C |
| 29040000 | 3.007 | 4.139 | C |
| 29040000 | 4.205 | 4.788 | L |
| 29040000 | 4.205 | 4.788 | R |
| 29040000 | 4.863 | 10.819 | C |
| 29050000 | 0 | 7.219 | C |
| 29070000 | 0.248 | 1.086 | C |
| 29070000 | 1.09 | 2.508 | C |

| | | | |
|---|---|---|---|
| 29080000 | 0 | 1.18 | C |
| 30010000 | 0.498 | 0.976 | R |
| 30010000 | 7.023 | 7.68 | R |
| 30010000 | 17.82 | 23.45 | L |
| 30010000 | 17.82 | 23.45 | R |
| 30010000 | 23.649 | 26.955 | L |
| 30010000 | 23.649 | 26.955 | R |
| 31010000 | 0.114 | 1.185 | C |
| 31010000 | 1.725 | 7.532 | C |
| 31030000 | 12.52 | 13.142 | C |
| 32050000 | 0.471 | 1.353 | C |
| 32050000 | 12.273 | 13.322 | C |
| 33010000 | 1.61 | 4.593 | C |
| 33010000 | 4.63 | 13.285 | C |
| 33030000 | 0 | 7.326 | C |
| 34010000 | 8.8 | 16.63 | C |
| 34040000 | 7.605 | 11.724 | C |
| 34040000 | 12.737 | 18.56 | C |
| 34040000 | 18.75 | 19.623 | C |
| 34110000 | 18.13 | 19.255 | C |
| 34110000 | 19.361 | 20.479 | C |
| 35010000 | 21.377 | 22.068 | C |
| 35020000 | 0.199 | 7.97 | C |
| 35060000 | 13.632 | 14.925 | C |
| 35060000 | 14.925 | 20.222 | C |
| 37010000 | 5.415 | 5.936 | L |
| 37010000 | 5.415 | 5.936 | R |
| 37010000 | 12.642 | 13.123 | C |

| | | | |
|---|---|---|---|
| 37010000 | 14.696 | 21 | C |
| 37010000 | 21 | 26.152 | C |
| 37030000 | 0.305 | 8.551 | C |
| 37040000 | 0.672 | 7 | C |
| 37040000 | 7 | 12.802 | C |
| 37040000 | 21.125 | 23.665 | C |
| 37040000 | 31.504 | 32.407 | C |
| 38010000 | 0.453 | 1.649 | L |
| 38010000 | 1.657 | 2.913 | L |
| 38010000 | 3.225 | 7.792 | R |
| 38010000 | 7.813 | 9.304 | R |
| 38010000 | 9.55 | 15.996 | R |
| 38010000 | 16 | 16.739 | R |
| 38020000 | 0 | 1.279 | R |
| 38020000 | 1.288 | 1.784 | R |
| 38070000 | 10.203 | 10.93 | C |
| 38070000 | 10.941 | 11.853 | C |
| 39010000 | 4.264 | 4.834 | C |
| 39010000 | 5.096 | 9.817 | C |
| 39010000 | 9.854 | 13.951 | C |
| 39020000 | 0 | 2.265 | C |
| 71020000 | 12.66 | 14.01 | L |
| 71110000 | 15.195 | 20.378 | C |
| 71110000 | 20.397 | 21.213 | C |
| 71110000 | 21.497 | 22.488 | C |
| 72010000 | 1.988 | 2.482 | C |
| 72010000 | 20.073 | 20.67 | C |
| 72010000 | 20.977 | 21.722 | C |

| | | | |
|---|---|---|---|
| 72030000 | 0.55 | 2.505 | R |
| 72040000 | 7.536 | 9.572 | L |
| 72040000 | 7.536 | 9.572 | R |
| 72050000 | 4.29 | 6.621 | C |
| 72060000 | 2.448 | 8.721 | C |
| 72060000 | 8.818 | 10.318 | C |
| 72080000 | 5.314 | 6.198 | L |
| 72080000 | 6.198 | 7.83 | L |
| 72100000 | 15.491 | 18.021 | L |
| 72120000 | 21.243 | 21.716 | C |
| 72120000 | 23.138 | 24.266 | C |
| 72150000 | 8.161 | 11.183 | C |
| 72150000 | 11.183 | 13.582 | C |
| 72160000 | 9.775 | 11.849 | L |
| 72190000 | 4.174 | 4.822 | L |
| 72250000 | 4.156 | 4.791 | C |
| 74030000 | 15.615 | 16.098 | R |
| 74110000 | 0 | 2.811 | C |
| 74110000 | 2.814 | 4.807 | C |
| 74110000 | 5.224 | 5.693 | C |
| 76010000 | 29.474 | 30.365 | L |
| 76010000 | 29.474 | 30.365 | R |
| 76020000 | 7.836 | 8.4 | C |
| 76020000 | 8.45 | 10.814 | C |
| 76020000 | 12.055 | 17.264 | C |
| 76020000 | 20.675 | 21.127 | C |
| 76020000 | 21.18 | 21.869 | C |
| 76050000 | 23.757 | 24.548 | R |

| | | | |
|---|---|---|---|
| 76060000 | 0 | 1.395 | C |
| 76060000 | 1.395 | 5.919 | C |
| 76060000 | 5.933 | 6.668 | C |
| 76070000 | 0 | 7.155 | C |
| 76070000 | 7.18 | 7.781 | C |
| 76080000 | 0.368 | 0.972 | C |
| 76080000 | 0.991 | 5.701 | C |
| 76110000 | 0 | 1.278 | C |
| 76110000 | 12.299 | 14.3 | C |
| 76110000 | 14.3 | 15.65 | C |
| 76110000 | 15.706 | 16.889 | C |
| 76110000 | 20.595 | 21.245 | L |
| 78010000 | 1.058 | 2.035 | L |
| 78010000 | 1.058 | 2.035 | R |
| 78010000 | 2.382 | 5.132 | R |
| 78010000 | 5.993 | 7.308 | R |
| 78010000 | 7.421 | 8.675 | R |
| 78010027 | 1.404 | 2.177 | C |
| 78020000 | 14.482 | 15.454 | L |
| 78040000 | 15.996 | 16.687 | R |
| 78060000 | 6.311 | 7.979 | C |
| 78060000 | 7.979 | 9.465 | C |
| 26010000 | 11.639 | 12.539 | R |
| 34040000 | 12.737 | 18.56 | C |
| 38010000 | 3.225 | 7.792 | R |
| 38010000 | 9.55 | 15.996 | R |
| 71110000 | 21.497 | 22.488 | C |
| 72120000 | 21.243 | 21.716 | C |

| | | | |
|---|---|---|---|
| 72150000 | 8.161 | 11.183 | C |
| 74030000 | 15.615 | 16.098 | R |
| 76060000 | 0 | 1.395 | C |
| 78010000 | 1.058 | 2.035 | R |
| 78040000 | 15.996 | 16.687 | R |
| 46010000 | 16.076 | 16.791 | L |
| 46010000 | 16.076 | 16.791 | R |
| 46020000 | 6.332 | 7.088 | C |
| 46020003 | 0 | 2.463 | R |
| 46040000 | 0.01 | 1.12 | C |
| 46050000 | 23.458 | 25.877 | C |
| 46060000 | 0 | 0.743 | C |
| 46060000 | 0.743 | 1.743 | C |
| 46130000 | 1.243 | 2.303 | C |
| 48020000 | 13.034 | 13.513 | C |
| 49010000 | 12.389 | 13.049 | C |
| 49060000 | 13.252 | 17.702 | C |
| 50030000 | 1.252 | 4.516 | L |
| 50030000 | 1.252 | 4.516 | R |
| 50080000 | 12.937 | 13.643 | C |
| 51020000 | 23.529 | 24.62 | C |
| 52030000 | 1.763 | 2.587 | C |
| 52050000 | 6.725 | 14.401 | C |
| 53020000 | 0.685 | 1.501 | L |
| 53020000 | 13.068 | 15.586 | L |
| 53030000 | 16.24 | 17.22 | C |
| 53060000 | 0.335 | 8.016 | C |
| 54030000 | 4.925 | 6.246 | L |

| | | | |
|---|---|---|---|
| 55002000 | 4.732 | 5.406 | C |
| 55002000 | 7.03 | 7.866 | C |
| 55006000 | 0.13 | 0.828 | C |
| 55060000 | 7.11 | 7.759 | R |
| 55080000 | 3.43 | 4.987 | L |
| 55100000 | 1.475 | 2.005 | C |
| 56020000 | 21.153 | 23.139 | C |
| 56040000 | 0 | 0.469 | C |
| 56040000 | 1.02 | 3.15 | C |
| 56040000 | 25.8 | 26.45 | C |
| 57040000 | 4.65 | 5.621 | R |
| 57040000 | 13.117 | 13.977 | L |
| 58001000 | 0 | 0.555 | C |
| 58080000 | 25.394 | 29.104 | C |
| 59030000 | 0 | 0.91 | C |
| 59110000 | 0 | 1.15 | C |
| 60040000 | 0 | 2.091 | C |
| 61040000 | 2.331 | 11.2 | C |
| 61040000 | 11.2 | 12.49 | C |
| 61040000 | 18.943 | 19.4 | C |
| 61040000 | 19.466 | 19.974 | C |
| 61080000 | 25.01 | 25.668 | C |
| 61080000 | 28.022 | 29.811 | C |
| 86006000 | 2.142 | 2.921 | R |
| 86010000 | 0 | 0.461 | L |
| 86014000 | 1.351 | 1.808 | L |
| 86020000 | 0 | 0.513 | R |
| 86020000 | 0.513 | 1.002 | R |

| | | | |
|---|---|---|---|
| 86028000 | 5.094 | 6.02 | R |
| 86028000 | 7.455 | 8.08 | R |
| 86030000 | 4.226 | 5.364 | C |
| 86040000 | 3.328 | 3.847 | R |
| 86040000 | 16.004 | 16.706 | L |
| 86060000 | 0.498 | 3.503 | L |
| 86060000 | 19.535 | 27.355 | L |
| 86090000 | 5.308 | 5.91 | L |
| 86100000 | 2.27 | 2.726 | R |
| 86100000 | 6.454 | 7.656 | L |
| 86100000 | 6.454 | 7.656 | R |
| 86100000 | 10.536 | 11.266 | L |
| 86100000 | 10.536 | 11.266 | R |
| 86100000 | 11.65 | 13.073 | L |
| 86100000 | 17.823 | 19.526 | L |
| 86120000 | 0.29 | 1.954 | C |
| 86120000 | 4.818 | 6.08 | R |
| 86190000 | 2.64 | 3.5 | C |
| 86190000 | 3.669 | 5 | C |
| 86200000 | 0.516 | 1.472 | R |
| 86200000 | 1.472 | 2.337 | R |
| 88060000 | 8.528 | 9.008 | C |
| 88060000 | 11.493 | 12.147 | C |
| 88060000 | 13.147 | 14.082 | C |
| 88060000 | 15.129 | 21.661 | C |
| 88060000 | 29.693 | 30.644 | C |
| 88070000 | 8.1 | 8.692 | C |
| 89060000 | 1.3 | 1.756 | C |

| | | | |
|---|---|---|---|
| 93020000 | 7.006 | 7.831 | R |
| 93050000 | 3.812 | 5.741 | C |
| 93060000 | 5.135 | 7.382 | C |
| 93060000 | 9.007 | 9.838 | C |
| 93060000 | 9.838 | 10.56 | C |
| 93060000 | 24.944 | 26.638 | C |
| 93060000 | 27.025 | 27.984 | C |
| 93100000 | 6.103 | 11.904 | L |
| 93100000 | 12.025 | 12.503 | L |
| 93110000 | 4.977 | 9.771 | C |
| 93110000 | 10.4 | 13.492 | C |
| 93110000 | 13.7 | 15.625 | C |
| 93110000 | 15.813 | 17.934 | C |
| 93130000 | 3.29 | 4.28 | C |
| 93130000 | 5.653 | 6.667 | C |
| 93130000 | 9.384 | 10.1 | C |
| 93140000 | 13.888 | 19.35 | C |
| 93160000 | 0.144 | 5.515 | C |
| 93160000 | 19.265 | 21.782 | C |
| 93180000 | 2.367 | 3.53 | R |
| 93180000 | 7.518 | 8.637 | R |
| 93210000 | 4.39 | 4.93 | C |
| 93210000 | 4.972 | 5.548 | C |
| 93230000 | 0 | 2.183 | C |
| 93280000 | 4.111 | 4.725 | R |
| 93280000 | 4.725 | 5.555 | R |
| 94004000 | 1.565 | 2.157 | C |
| 94010000 | 0.875 | 3.094 | L |

| | | | |
|---|---|---|---|
| 94010000 | 0.875 | 3.094 | R |
| 94010000 | 5.688 | 8.225 | L |
| 94010000 | 8.225 | 10.599 | L |
| 94010000 | 8.225 | 10.599 | R |
| 94030000 | 16.403 | 17.212 | C |
| 94030000 | 17.264 | 20 | C |
| 94030000 | 22.61 | 23.897 | C |
| 94030000 | 23.897 | 24.74 | C |
| 94050000 | 1.504 | 2.45 | C |
| 94050000 | 2.45 | 5.584 | C |
| 94060000 | 2.67 | 3.708 | C |
| 94070000 | 19.697 | 20.9 | C |
| 94070000 | 20.985 | 21.671 | C |
| 11060000 | 14.15 | 14.982 | C |
| 11140000 | 0 | 4.697 | C |
| 11140000 | 6.261 | 7.113 | C |
| 11170000 | 11.975 | 12.442 | C |
| 11200000 | 11.15 | 11.772 | L |
| 11200000 | 12.362 | 13.091 | L |
| 11200000 | 13.87 | 14.37 | R |
| 11200000 | 15.515 | 16.145 | R |
| 11200000 | 16.676 | 17.365 | R |
| 11200000 | 23.895 | 27.37 | L |
| 11200000 | 32.674 | 33.71 | R |
| 11210000 | 0.475 | 1.3 | R |
| 11230000 | 0 | 0.594 | R |
| 18010000 | 14.755 | 15.611 | C |
| 18030000 | 10.256 | 10.725 | C |

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|---|---|---|---|
| 18030000 | 10.727 | 11.795 | C |
| 18070000 | 9.55 | 11.377 | C |
| 18120000 | 0 | 1.016 | R |
| 36002000 | 0.277 | 4.91 | R |
| 36030000 | 16.94 | 19.417 | L |
| 36030000 | 20.165 | 22.687 | R |
| 36070000 | 18.999 | 20.092 | L |
| 36090000 | 3.692 | 15.329 | C |
| 36100000 | 0 | 5.954 | C |
| 70010000 | 5.686 | 8.612 | L |
| 70020000 | 9.971 | 10.923 | L |
| 70030000 | 6.31 | 6.924 | R |
| 70050000 | 0 | 1.991 | C |
| 70100000 | 0.056 | 2.768 | C |
| 70100000 | 3.107 | 4.299 | C |
| 70120000 | 1.059 | 1.777 | C |
| 70150000 | 6.668 | 7.387 | C |
| 73010000 | 0 | 4.756 | R |
| 73010000 | 10.984 | 11.667 | L |
| 73010000 | 10.984 | 11.667 | R |
| 73010000 | 11.677 | 12.199 | L |
| 73010000 | 11.677 | 12.199 | R |
| 73030000 | 10.621 | 16.545 | C |
| 75040000 | 17.466 | 18.064 | C |
| 75050000 | 9.74 | 10.458 | C |
| 75060000 | 2.004 | 2.634 | C |
| 75060000 | 9.456 | 10.531 | R |
| 75060000 | 10.531 | 11.713 | R |

| | | | |
|---|---|---|---|
| 75060000 | 20.503 | 23.772 | R |
| 75060000 | 23.772 | 25.41 | R |
| 75190000 | 4.009 | 4.865 | L |
| 75190000 | 6.435 | 7.144 | L |
| 75220000 | 0.266 | 1.726 | L |
| 75220000 | 0.266 | 1.726 | R |
| 75270000 | 5.638 | 6.096 | R |
| 77080000 | 2.609 | 4.172 | L |
| 79010000 | 30.668 | 31.4 | L |
| 79030000 | 6.039 | 7.326 | R |
| 79030000 | 7.475 | 8.008 | L |
| 79050000 | 9.714 | 12.162 | C |
| 79050000 | 17.268 | 18.263 | C |
| 79050000 | 18.288 | 19.449 | C |
| 79070000 | 0 | 1.951 | C |
| 79070000 | 1.978 | 2.479 | C |
| 79080000 | 4.325 | 4.974 | L |
| 79100000 | 0 | 6.424 | C |
| 79120000 | 11.49 | 12 | C |
| 79120000 | 12.193 | 17.409 | C |
| 92030000 | 6.261 | 7.206 | L |
| 92090000 | 2.044 | 2.604 | R |
| 92090000 | 3.343 | 4.016 | R |
| 92090000 | 4.098 | 4.845 | L |
| 92090000 | 4.098 | 4.845 | R |
| 92090000 | 4.845 | 5.391 | L |
| 92090000 | 5.506 | 5.967 | L |
| 2050000 | 7.33 | 8.513 | C |

| | | | |
|---|---|---|---|
| 2050000 | 8.513 | 9.647 | C |
| 2050000 | 23.2 | 24.342 | C |
| 8010000 | 0 | 3.531 | C |
| 8010000 | 3.531 | 4.401 | C |
| 8010000 | 9.462 | 10.072 | C |
| 8010000 | 15.975 | 18.875 | C |
| 8050000 | 6.117 | 9.898 | C |
| 8050000 | 10.645 | 11.62 | C |
| 8050000 | 11.731 | 12.64 | C |
| 8060000 | 0 | 3.82 | C |
| 8070000 | 0 | 1.21 | C |
| 8080000 | 0.348 | 0.87 | C |
| 8080000 | 8.168 | 12.925 | C |
| 10010000 | 20.896 | 21.536 | R |
| 10010000 | 22.749 | 23.803 | L |
| 10020000 | 9.59 | 10.3 | C |
| 10030000 | 3.511 | 4.915 | L |
| 10040000 | 8.314 | 9.084 | C |
| 10060000 | 0.205 | 3.168 | R |
| 10060000 | 3.168 | 4.346 | L |
| 10060000 | 3.168 | 4.346 | R |
| 10060000 | 22.07 | 22.62 | L |
| 10060000 | 22.07 | 22.62 | R |
| 10060000 | 22.62 | 23.526 | L |
| 10060000 | 22.62 | 23.526 | R |
| 10060000 | 23.676 | 25.044 | L |
| 10060000 | 23.676 | 25.044 | R |
| 10110000 | 5.252 | 5.988 | L |

| | | | |
|---|---|---|---|
| 10110000 | 11.446 | 12.613 | R |
| 10130000 | 3.209 | 3.702 | L |
| 10160000 | 0.042 | 1.902 | L |
| 10200000 | 8.604 | 10.808 | C |
| 10210000 | 0 | 1.787 | C |
| 10210000 | 1.787 | 2.242 | C |
| 10210000 | 2.28 | 3.235 | C |
| 10210000 | 3.253 | 3.803 | C |
| 10210000 | 3.812 | 4.38 | C |
| 10260000 | 4.819 | 5.944 | C |
| 14030000 | 14.1 | 19.673 | L |
| 14030000 | 14.1 | 19.673 | R |
| 14050000 | 3.237 | 3.746 | C |
| 14050000 | 14.831 | 15.67 | R |
| 15010000 | 0.506 | 0.962 | C |
| 15060000 | 8.11 | 8.928 | R |
| 15070000 | 1.682 | 2.319 | C |
| 15090000 | 5.33 | 6.036 | R |
| 15150000 | 16.702 | 17.932 | R |
| 15150000 | 19.434 | 19.913 | L |
| 15150000 | 19.434 | 19.913 | R |
| 15230000 | 0 | 0.6 | L |
| 15240000 | 0.648 | 2.078 | R |
| 87001000 | 0 | 2.405 | L |
| 87001000 | 0 | 2.405 | R |
| 87002000 | 4.899 | 5.71 | C |
| 87020000 | 4.559 | 6.558 | L |
| 87027000 | 1.75 | 2.334 | R |

| | | | |
|---|---|---|---|
| 87037000 | 3.047 | 3.601 | R |
| 87037000 | 3.979 | 5.304 | L |
| 87060000 | 12.87 | 14.019 | L |
| 87062000 | 0.341 | 2.033 | C |
| 87090000 | 13.69 | 14.795 | C |
| 87090000 | 15.411 | 17.3 | C |
| 87110000 | 13.902 | 24.42 | C |
| 87120000 | 2.021 | 4.516 | L |
| 87150000 | 4.998 | 12.122 | C |
| 87150000 | 17.714 | 20.112 | C |
| 87160000 | 8.064 | 8.611 | L |
| 90060000 | 6.204 | 7.364 | C |
| 90060000 | 7.406 | 8.262 | C |
| 90060000 | 8.301 | 9.75 | C |

Table C2. List of Test Segments for Interstates.

| Roadway ID | Beginning Milepost | Ending Milepost | Roadway Side |
|---|---|---|---|
| 17075000 | 20.249 | 20.770 | L |
| 17075000 | 20.794 | 21.273 | L |
| 17075000 | 20.794 | 21.273 | R |
| 17075000 | 21.297 | 22.274 | L |
| 17075000 | 21.297 | 22.274 | R |
| 17075000 | 22.324 | 22.812 | L |
| 17075000 | 22.324 | 22.812 | R |
| 17075000 | 29.510 | 30.127 | R |
| 17075000 | 30.127 | 34.350 | R |
| 17075000 | 37.350 | 39.613 | R |
| 26260000 | 0.000 | 0.978 | L |
| 26260000 | 0.000 | 0.978 | R |
| 27090000 | 20.153 | 21.872 | L |
| 27090000 | 20.153 | 21.872 | R |
| 27090000 | 21.905 | 25.418 | R |
| 35090000 | 5.985 | 10.000 | R |
| 35090000 | 10.000 | 11.333 | R |
| 74170000 | 0.000 | 0.710 | L |
| 74170000 | 0.000 | 0.710 | R |
| 78080000 | 0.004 | 0.901 | L |
| 78080000 | 0.004 | 0.901 | R |
| 78080000 | 1.002 | 2.078 | L |
| 78080000 | 1.002 | 2.078 | R |
| 78080000 | 2.227 | 8.080 | L |
| 78080000 | 2.227 | 8.080 | R |

| | | | |
|---|---|---|---|
| 78080000 | 8.180 | 13.366 | L |
| 78080000 | 8.180 | 13.366 | R |
| 78080000 | 20.499 | 23.183 | R |
| 78080000 | 26.218 | 31.500 | R |
| 48270000 | 5.920 | 6.940 | L |
| 50001000 | 32.017 | 32.910 | R |
| 50001000 | 33.033 | 33.627 | R |
| 52002000 | 16.627 | 17.146 | L |
| 52002000 | 16.627 | 17.146 | R |
| 52002000 | 17.187 | 19.390 | L |
| 54001000 | 0.000 | 0.956 | L |
| 54001000 | 0.995 | 2.163 | L |
| 54001000 | 2.255 | 4.920 | L |
| 55320000 | 4.573 | 5.936 | R |
| 55320000 | 5.969 | 8.531 | R |
| 55320000 | 19.699 | 22.228 | R |
| 58002000 | 2.586 | 5.142 | L |
| 60002000 | 2.831 | 3.712 | L |
| 61001000 | 12.908 | 16.848 | R |
| 61001000 | 16.888 | 17.380 | R |
| 93220000 | 7.300 | 8.298 | L |
| 93220000 | 10.559 | 11.340 | L |
| 18130000 | 0.000 | 0.998 | L |
| 36210000 | 0.000 | 4.947 | L |
| 36210000 | 0.000 | 4.947 | R |
| 36210000 | 4.975 | 13.887 | L |
| 36210000 | 4.975 | 13.887 | R |
| 36210000 | 15.173 | 16.370 | L |

| | | | |
|---|---|---|---|
| 36210000 | 15.173 | 16.370 | R |
| 36210000 | 16.483 | 17.757 | L |
| 36210000 | 22.140 | 27.843 | L |
| 36210000 | 32.372 | 34.055 | R |
| 36210000 | 34.078 | 38.225 | R |
| 70225000 | 1.248 | 3.926 | R |
| 70225000 | 4.016 | 5.332 | L |
| 73001000 | 0.006 | 5.204 | R |
| 73001000 | 5.308 | 6.766 | L |
| 73001000 | 6.847 | 11.046 | L |
| 73001000 | 11.066 | 17.541 | L |
| 75280000 | 5.536 | 6.035 | L |
| 75280000 | 6.463 | 7.556 | L |
| 75280000 | 6.463 | 7.556 | R |
| 79002000 | 27.854 | 28.758 | L |
| 79002000 | 29.324 | 32.574 | L |
| 79002000 | 29.324 | 32.574 | R |
| 79002000 | 32.664 | 35.042 | L |
| 79002000 | 32.664 | 35.042 | R |
| 79002000 | 35.749 | 36.508 | L |
| 79002000 | 35.749 | 36.508 | R |
| 79002000 | 36.508 | 37.485 | L |
| 79002000 | 36.508 | 37.485 | R |
| 79002000 | 37.565 | 40.641 | L |
| 79110000 | 14.183 | 14.643 | R |