Research Report
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KENTUCKY TRANSPORTATION CENTER

OPTIMIZATION AND STANDARDIZATION OF PAVEMENT MANAGEMENT PROCESSES

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Optimization and Standardization of Pavement Management Processes

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16. Abstract

This report addresses issues related to optimization and standardization of current pavement management processes in Kentucky. Historical pavement management records were analyzed, which indicates that standardization is necessary in future pavement management decisions. Based on data patterns from Kentucky's interstate and parkway systems, two distress threshold values and three stages of pavement distress development were defined in this research.

Also, staged survival models were developed in this research to predict the duration of a pavement in each stage. These duration models can assist the agency in optimizing design strategies and conducting life-cycle cost analysis.

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CHAPTER 1 INTRODUCTION

Pavement management continues to be a major effort for the Kentucky Transportation Cabinet. The Pavement Management Branch evaluates the condition of all pavements that are state-maintained. Pavements are evaluated to determine conditions and to identify the needed improvements. These evaluations typically include visual surveys, ride quality measurements, rut measurements, and some measure of the remaining structural life of the pavement.

Questions have arisen about dealing with the consistency of evaluations and the criteria of making rehabilitation decisions. When a pavement should be rehabilitated and what type of rehabilitation should be performed are questions that need to be answered.

1.1 Background and Significance of Work

To improve roadways that are in an unacceptable condition requires determination of the condition of roadway segments and selection of appropriate remedial treatments. These treatments should be based on sound engineering judgments, not arbitrary decisions. This will preserve the pavements in a manner that will provide the best benefit for the funding spent.

In order for the Transportation Cabinet to maintain the Commonwealth's pavements in a minimally acceptable condition of service, it is estimated that each year the Department needs $80 million for the Annual Resurfacing Program, $12 million for the State Primary Rehabilitation Program, and $34 million for the Rural Secondary Program. It is also estimated that 33.2% pavements on the Interstate system and 46.9% pavements on the Parkway system are in poor condition.

Depending on existing pavement types, preservations or rehabilitations may include several different treatments. For preservation of AC pavements, the typical treatment would be to apply a thin overlay to the existing pavement or mill and overlay the pavement surface. These treatments would generally improve serviceability and ride quality of the pavement. For rehabilitation of AC pavements, the typical treatment would be a thick overlay of from 2 – 5 inches. This would not only improve the serviceability of the pavement but would also improve the structural capacity.

For PCC pavements, preservation may include pavement repairs and diamond grinding. Rehabilitation strategies may include break and seat and thick AC overlay, AC overlay and saw and seal, or PCC Overlay.

The trigger values for making preservation and rehabilitation decisions have not been consistently selected. As a result, some pavement segments received treatments while they were still in fair condition, while other pavement segments did not get treated in time. Using consistent thresholds can help optimize resource allocation at the network level. To review the historical pavement condition thresholds, maintenance and rehabilitation data from Interstates and Parkways were analyzed in this research.

In addition, the effectiveness of various treatments has not been analyzed for each pavement type. This research project evaluated the major preservation or rehabilitation treatments currently being utilized and provided a measure for their effectiveness. The process for selection of preservation or rehabilitation treatments and the optimization of these treatments was reviewed to ensure that the best benefit may be achieved with the funding available.

1. 2 Goals and Objectives of the Study

The overall objective of this project was to develop an evaluation process for the utilization of various rehabilitation alternatives and treatments throughout the state. The application of this process by numerous individuals will insure uniform treatment of all pavement needs across the state. The following is an itemized list of the original objectives for this study.

1. Analyze the historical pavement preservation and rehabilitation records and determine the generally used decision criteria.

2. Determine the effectiveness of previous treatments. Evaluate the effectiveness and benefits of the various preservation and rehabilitation techniques; document what factors have led to successful applications.

3. Develop an evaluation process consisting of a decision tree that will include data collection and analysis, identification of needs and the treatment selections associated with those needs.

4. Evaluate the need for process improvements by determining what other data may need to be collected for improvements and by integration of past work.

5. Re-evaluate Objective Three based on findings in the other objectives.

The research data used in this study are from the Interstates and Parkways recorded in Kentucky's pavement management system. After reviewing the data, this research found that the types of treatments are very limited. Therefore, for the objective 2 and 3, this study concentrated on the most used treatments only.

CHAPTER 2 HISTORICAL THRESHOLDS OF PAVEMENT CONDITIONS BEFORE MAINTENANCE AND REHABILITATION

Before developing a uniform criteria for making pavement maintenance or rehabilitation decisions, this research first analyzed the historical records from Kentucky's pavement management system. A total of 13,988 data records from the 1970's to the year of 2000 were selected from the Kentucky's Interstate and Parkway systems. In addition, the published year books of *Condition of Pavements on Kentucky Highways* (KyTC, 2002, 2003) were used as supplementary sources. These data provide valuable information on pavement structures, traffic conditions, pavement age, and rehabilitation cycles. This chapter summarizes the findings from investigating the historical data, with emphasis on pavement conditions and pavement ages before maintenance or rehabilitation was scheduled.

The primary original types of pavements on Kentucky's Interstates and Parkways are asphalt concrete (AC) and plain jointed Portland cement concrete (PCC). Continuous reinforced concrete pavements were excluded from this study due to their limited numbers. The common maintenance or rehabilitation method for AC pavements is to apply an AC overlay with varying thickness. Usually the existing AC surface was milled before an overlay was placed. The application of an open-graded friction course (OGFC) was not considered as a maintenance or rehabilitation activity in this study, since its effect on improving pavement conditions is arguable. The primary maintenance or rehabilitation activities for PCC pavements are to apply AC overlays over PCC directly, apply AC overlays over fractured PCC, apply AC overlays over broken PCC, apply PCC overlays over existing PCC, grind PCC surface, seal, and patch. This research categorized these activities into the following groups: applying AC overlays over original AC pavements, applying AC overlays over fractured PCC, applying AC overlays over existing AC overlays, and repairing PCC pavements. Furthermore, Interstates and Parkways were treated separately. Historical information was summarized for these categories separately.

2.1 Rehabilitation Thresholds for Original AC Pavements

AC pavement conditions before their first rehabilitations were summarized (see Appendix I for selected pavement sections). A unique ID, SECTION, was used to represent road name, lane direction, start mile point and end mile point. For example, the section I24-4-26.55to29.13 represents a pavement section on I24, direction code 4 (westbound), from mile point 26.55 to 29.13. Three pavement condition indicators were analyzed: rideability index, conditions points, and rut depth. While most investigated pavement sections have rideability index (RI) data, all sections before 1980's do not have condition points data. The condition points on these sections were marked as missing. For records after 1980's, the missing values were estimated by the last observed condition points value plus the average increase of the last two years, or the average of the previous and the next year, whichever is applicable. The summary of the finding are shown in the following tables and figures.

2.1.1 Summary Statistics of RI, Rut Depth, Condition Points, and Age on Interstates

A total of 65 pavement sections (including both directions) on Interstate highways were identified. Table 2.1 shows the average RI, rut depth (in 1/16 inch), condition points, and ages of the original AC pavements before rehabilitations were scheduled.

		RI	Rut Depth (1/16 inch)	Con. Pts.	Surface Age
No. of Sections	Valid	65	49	49	65
	Missing	0	16	16	0
Average		3.52	5.84	35.75	9.99
Median		3.57	7.00	35.90	10.02
Std. Deviation		0..31	3.52	11.68	4.20
Minimum		2.66	.00	6.90	.24
Maximum		4.08	12.00	60.80	17.78
Percentiles	25	3.33	3.00	31.30	7.35
	50	3.57	7.00	35.90	10.02
	75	3.74	9.00	40.75	11.92

Table 2.1 Summary Statistics of RI, Rut Depth, Condition Points, and Age of Original AC Pavements before Rehabilitation on Interstates (All Pavement Sections)

For unknown reasons, overlays were applied to some sections immediately after the original construction (less than or around 1 year). Treating these sections as outliers and removing them from the analysis results in the statistics shown in Table 2.2.

		RI	Rut Depth (1/16 in)	Con. Pts.	Surface Age
No. of Sections	Valid	61	45	45	61
	Missing	0	16	16	0
Mean		3.51	6.31	38.07	10.59
Median		3.55	7.00	36.60	10.78
Std. Deviation		.31	3.26	8.98	3.57
Minimum		2.66	.00	23.80	4.79
Maximum		4.08	12.00	60.80	17.78
Percentiles	25	3.32	5.00	32.15	7.82
	50	3.55	7.00	36.60	10.78
	75	3.69	9.00	2.55	1.92

Table 2.2 Summary Statistics of RI, Rut Depth, Condition Points, and Age of Original AC Pavements before Rehabilitation on Interstates (After Outliers were Removed)

The average RI shown in Table 2.2 is 3.51. According to Research Report KTC-90-4, "Review and Analysis of Pavement Management Practices in Kentucky (Allen, 1990)", rideability should be rated as "good" if the rideability index falls between 3.0 and 3.9. Even the worst condition, RI 2.66, is within the range of "fair rideability." Therefore, the data shows that the rideability of AC pavements on Interstates was generally good before the first rehabilitation. The tables also show that the rutting conditions are moderate. The variations of RI and rutting are not large. However, the variations of condition points, with a standard deviation of 8.98, are quite large. Since condition points were based on visual evaluation, the types of pavement distresses cannot be identified. To examine the historical data in more detail, the distributions of the different parameters are plotted in the following figures.

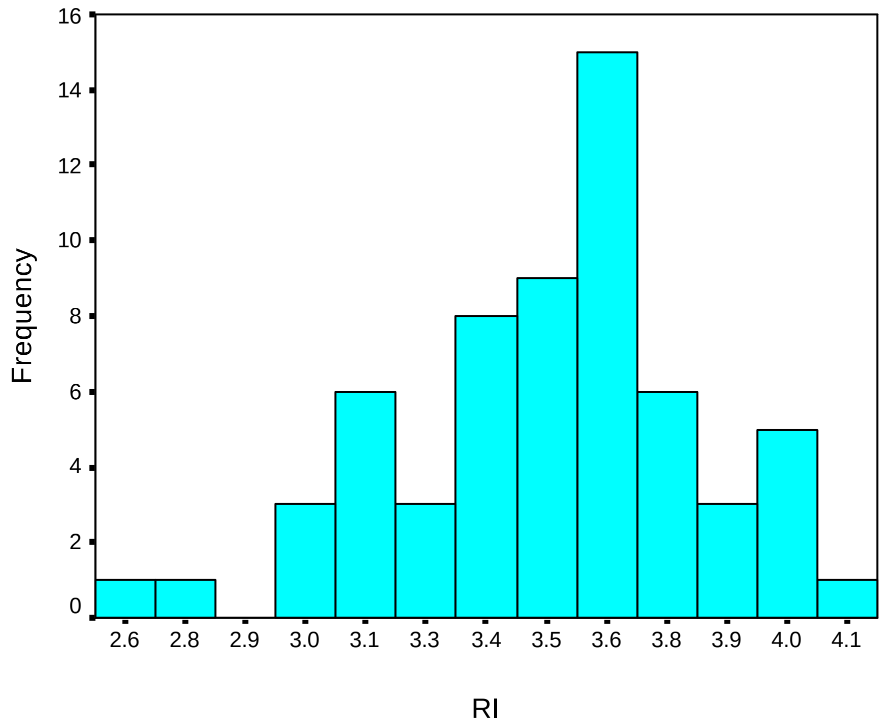

Figure 2.1 Distribution of RI before Rehabilitation of Original AC Pavements on Interstates

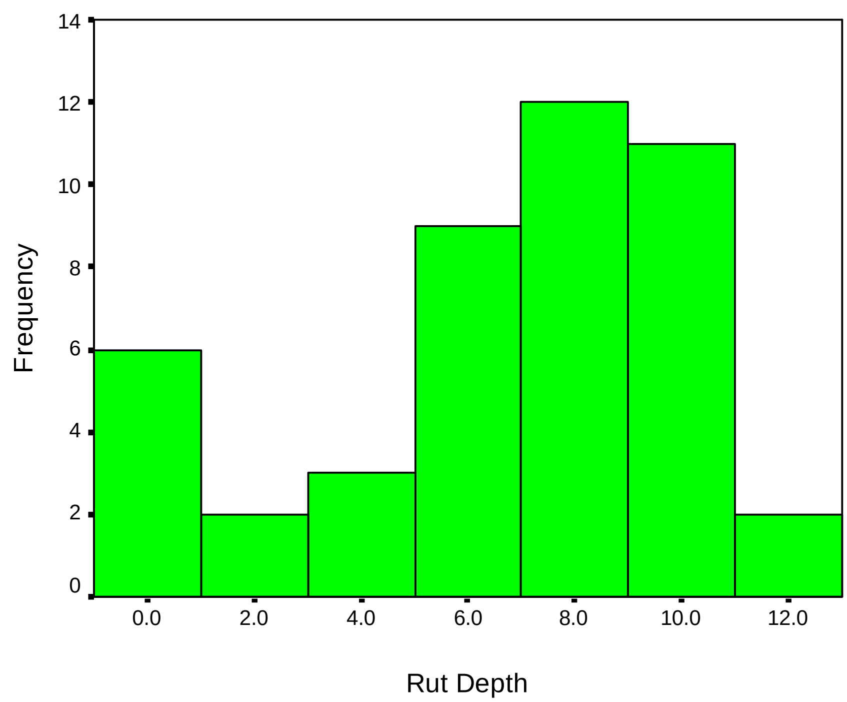

Figure 2.2 Distribution of Rut Depth before Rehabilitation of Original AC Pavements on Interstates

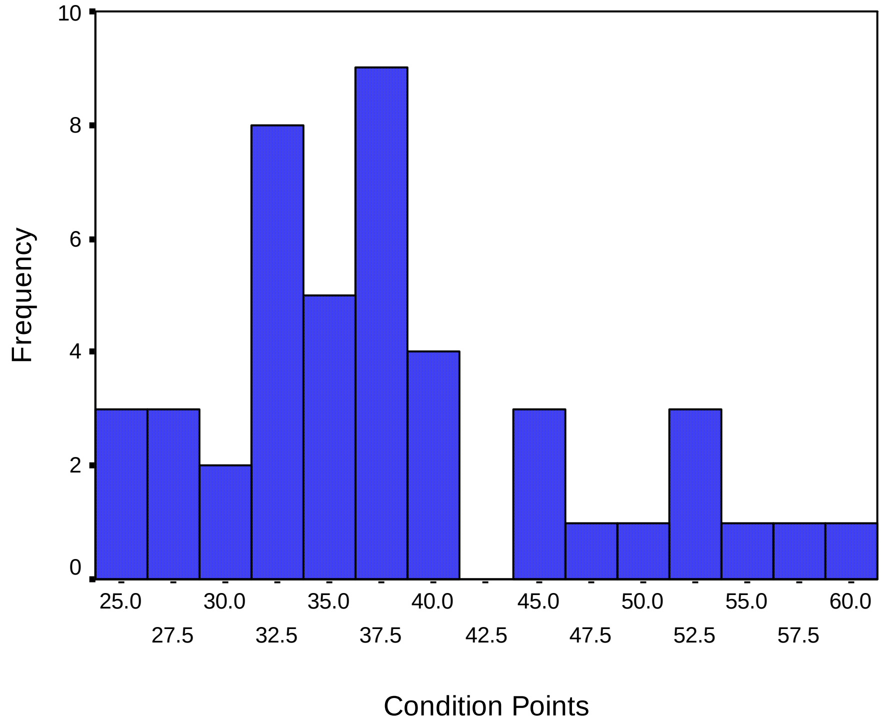

Figure 2.3 Distribution of Condition Points before Rehabilitation of Original AC Pavements on Interstates

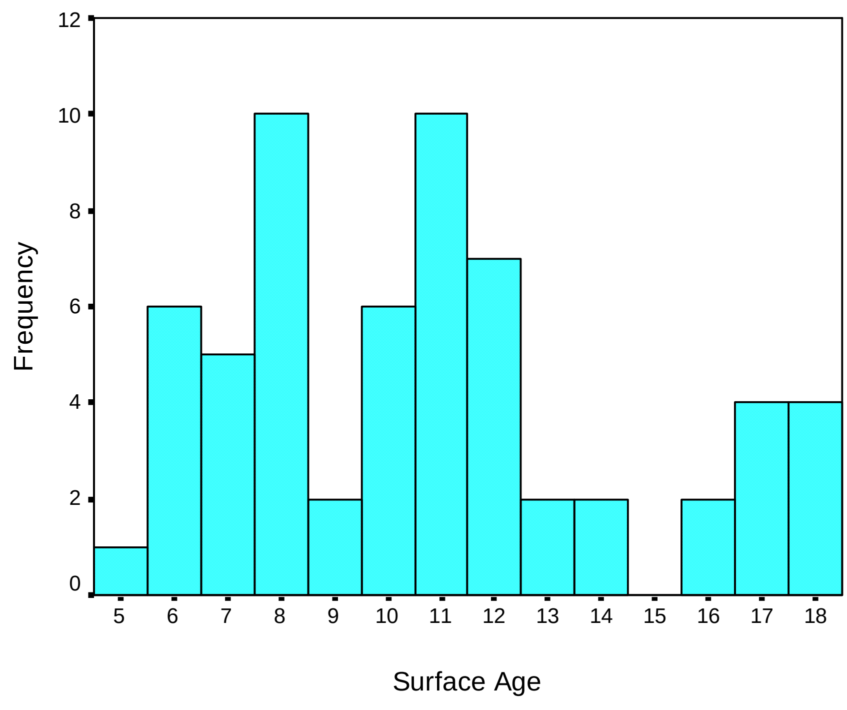

Figure 2.4 Distribution of Surface Age before Rehabilitation of Original AC Pavements on Interstates

The distribution plots reveal more information on the variations of historical trigger values. All the condition indicators show some variations; however, the largest variations are from pavement condition points and pavement ages, which suggests that standardization of rehabilitation trigger values is necessary.

2.1.2 Summary Statistics of RI, Rut Depth, Condition Points, and Age on Parkways

A total of 99 pavement sections (including both directions) on Parkways were identified. However, 16 sections from WN 9007 and LN 9008 were rehabilitated less than one year after the original construction. To remove possible bias caused by these sections, they are excluded from analysis. Table 2.3 shows the average RI, rut depth, condition points, and ages of the original AC pavements before rehabilitation on Parkways, after excluding the sections mentioned above.

		RI	Rut Depth	Con. Pts.	Surface Age
No. of Sections	Valid	83	38	38	83
	Missing	0	45	45	0
Mean		3.30	7.16	44.66	12.86
Median		3.39	7.00	45.30	13.90
Std. Deviation		.32	2.46	8.99	4.93
Minimum		2.49	2.00	27.90	3.75
Maximum		4.04	14.00	66.10	22.60
Percentiles	25	3.14	6.00	39.28	8.75
	50	3.39	7.00	45.30	13.90
	75	3.51	9.00	49.85	16.09

Table 2.3 Summary Statistics of RI, Rut Depth, Condition Points, and Age of Original AC Pavements on Parkways (After Outliers were Removed)

The average RI shown in Table 2.3 is 3.3, which indicates that the rideability of AC pavements on Parkways was also generally good before the first rehabilitation. Again, large variations in condition points and pavement ages can be noticed.

Comparing RI, Rut depth, condition points, and surface ages from Parkways with those from Interstates, it seems that the general conditions were allowed to be worse on Parkways.

The distributions of historical trigger values on Parkways were plotted from figure 2.5 to 2.8.

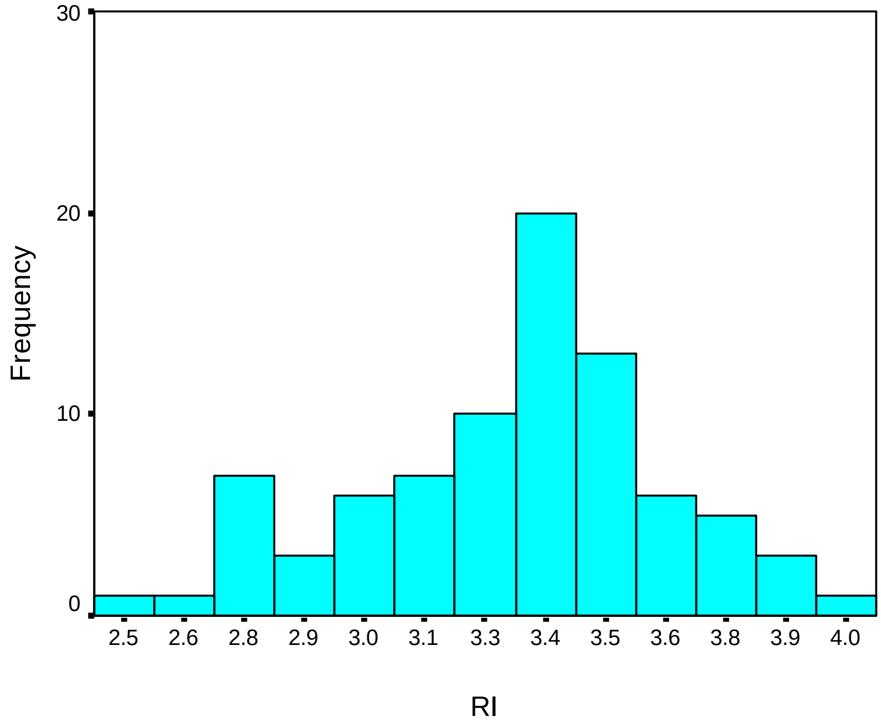

Figure 2.5 Distribution of RI before Rehabilitation of Original AC Pavements on Parkways

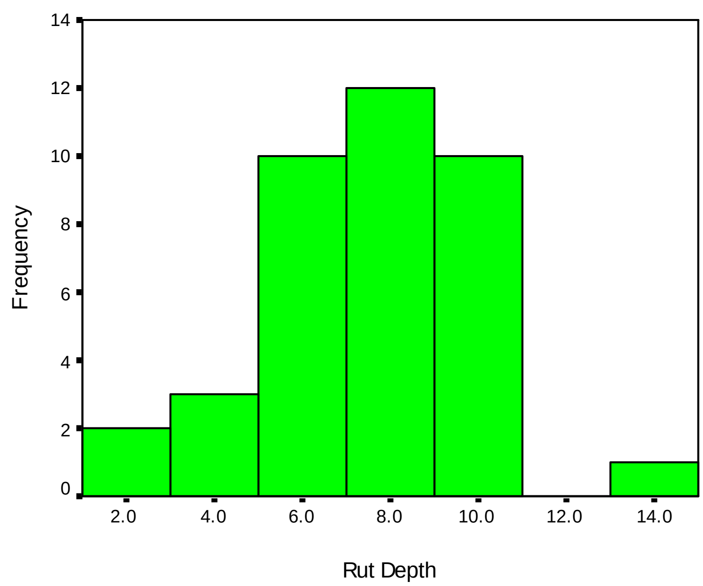

Figure 2.6 Distribution of Rut Depth before Rehabilitation of Original AC Pavements on Parkways

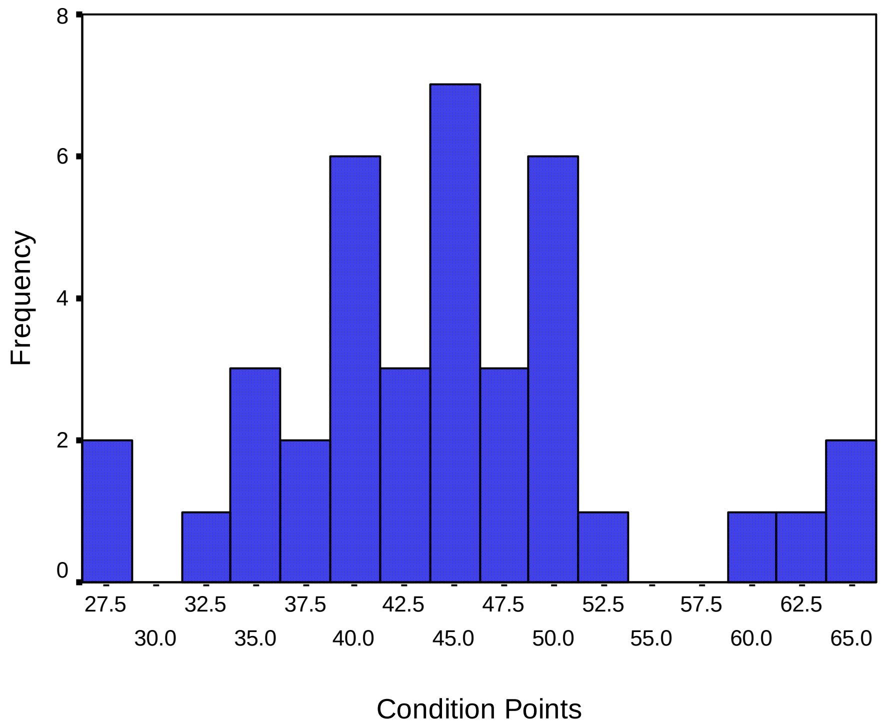

Figure 2.7 Distribution of Condition Points before Rehabilitation of Original AC Pavements on Parkways

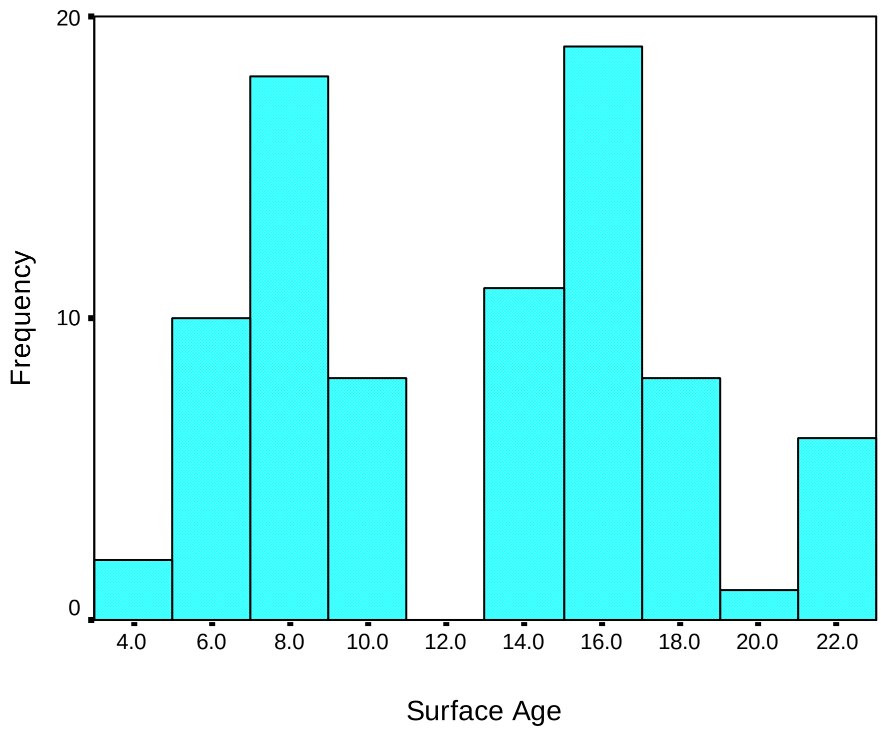

Figure 2.8 Distribution of Surface Age before Rehabilitation of Original AC Pavements on Parkways

These plots show large variations in all of the condition indicators, especially for rut depth and condition points. Although the thicknesses of original AC pavements on these Parkways are similar, the pavement ages before rehabilitation are quite different on most sections.

2.2 Rehabilitation Thresholds for the Original PCC Pavements

Appendix II shows the PCC pavement sections analyzed in this research. The missing condition points are processed the same way as the original AC pavements. The summary of pavement conditions and surface ages are shown in the following tables and figures.

2.2.1 Summary Statistics of RI, Condition Points, and Age on Interstates

A total of 132 pavement sections (including both directions) on Interstate highways were identified. Table 2.4 shows the average RI, condition points, and ages of the original PCC pavements before rehabilitations were scheduled.

It should be noted that the data contained in this table represents original Interstate PCC pavements which had been rehabilitated through 2000. There are some additional pavement sections still in service, most if not all of these are currently in need of rehabilitation. If it is assumed that these pavements are in need of rehabilitation and their data included in the analysis from Table 2.4, then the average age to first rehabilitation would be 25.5 instead of 21.13.

		RI	Con. Pts.	Surface Age
Number of Observations	Valid	130	114	132
	Missing	2	18	0
Mean		2.92	51.43	21.13
Median		2.89	54.25	20.80
Std. Deviation		.41	13.08	6.59
Minimum		2.05	22.30	2.98
Maximum		4.10	77.30	36.26
Percentiles	25	2.63	42.03	15.58
	50	2.86	54.25	20.80
	75	3.16	60.05	26.85

Table 2.4 Summary Statistics of Rehabilitation Trigger Values of RI, Condition Points, and Age for PCC Pavements on Interstates

The average RI shown in Table 2.4 is 2.92. According to research report KTC-90-4, “Review and Analysis of Pavement Management Practices in Kentucky”, the rideability should be rated as “fair”, which is lower than the average rideability of AC pavements. Nevertheless, no PCC pavements were found rehabilitated at “poor rideability (<2).” Conditions points on PCC pavements are also higher than those on AC pavements; and the pavement ages are greater. The distributions of the trigger values are plotted in the following figures.

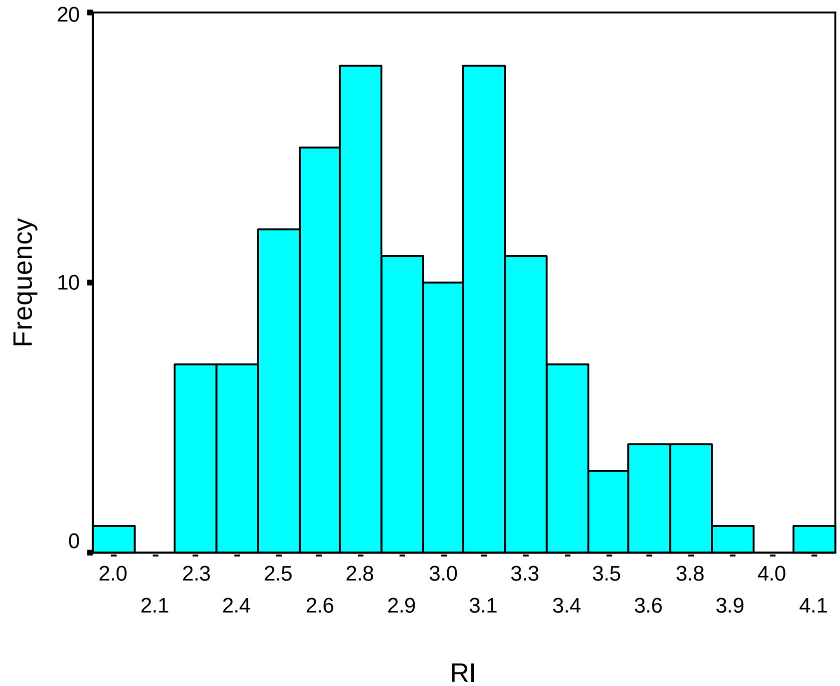

Figure 2.9 Distribution of RI before Rehabilitation of Original PCC Pavements on Interstates

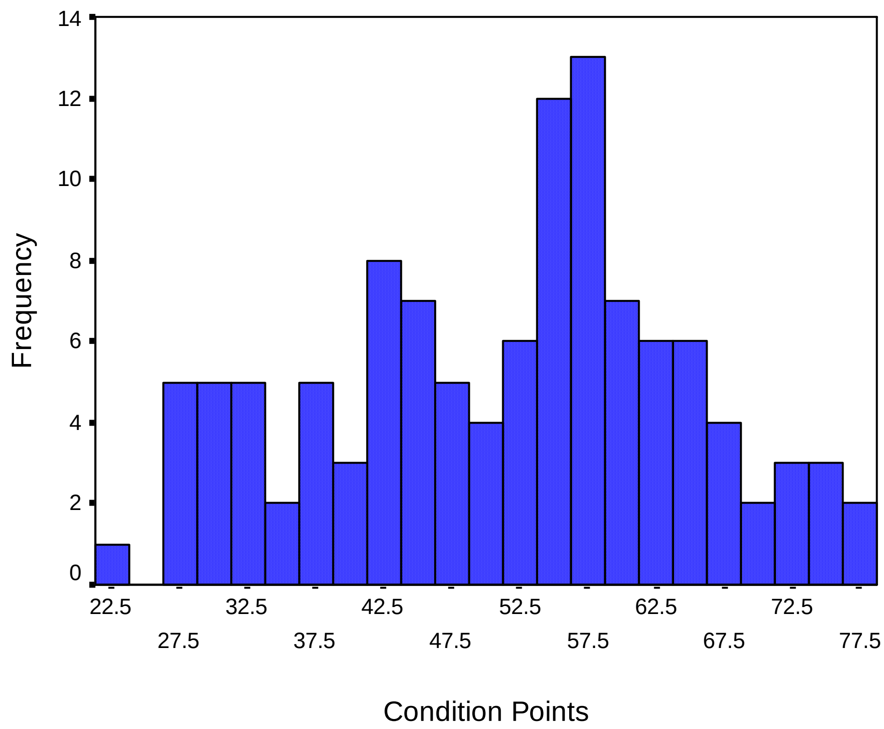

Figure 2.10 Distribution of Condition Points before Rehabilitation of Original PCC Pavements on Interstates

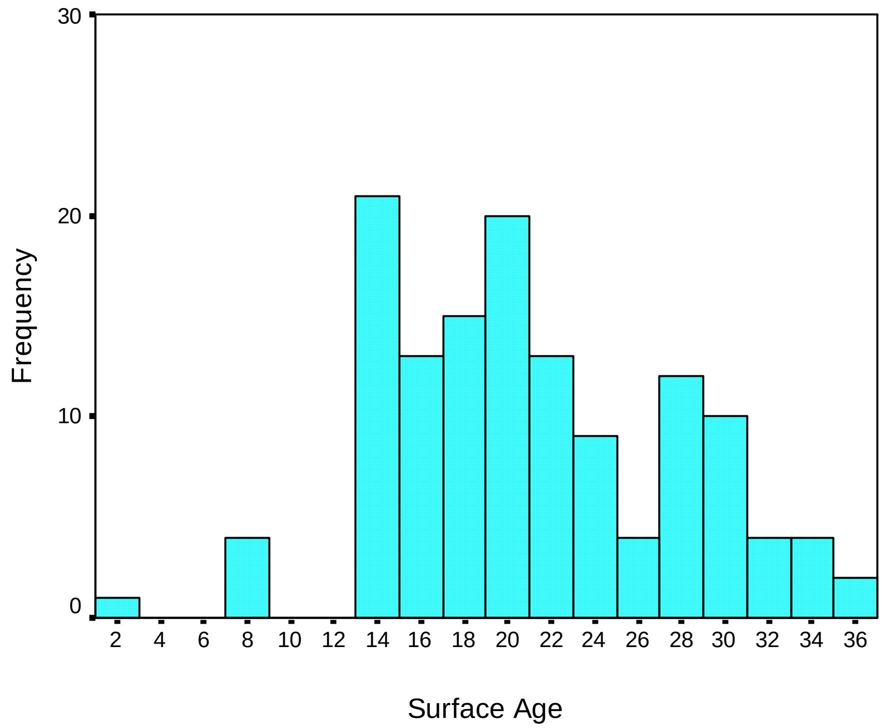

Figure 2.11 Distribution of Surface Ages before Rehabilitation of Original PCC Pavements on Interstates

Variations can be noted on all of the trigger values. The rideability on most pavement segments falls with the range between 2.3 to 3.9, while the condition points range from 27 to 77. For pavement ages, except for several outliers, most pavements are rehabilitated after 14 years. Some pavements last very long, up to 36 years.

2.2.2 Summary Statistics of RI, Condition Points, and Ages on Parkways

A total of 83 PCC pavement sections (including both directions) with rehabilitation records were identified on Parkways. Table 2.5 shows the average RI, condition points, and ages of the original PCC pavements before rehabilitation on Parkways.

The data contained in this table represents original Parkway PCC pavements which had been rehabilitated through 2000. Additional pavement sections are still in service, many if not all of these are currently in need of rehabilitation. If it is assumed that these pavements are in need of rehabilitation and their data included in the analysis from Table 2.5, then the average age to first rehabilitation would be 29.1 instead of 26.94

		RI	Con. Pts.	Surface Age
Number of Observations	Valid	83	80	83
	Missing	0	3	0
Mean		2.79	56.16	26.94
Median		2.86	57.45	26.03
Std. Deviation		.40	10.70	5.11
Minimum		1.72	25.00	16.92
Maximum		3.53	76.80	36.81
Percentiles	25	2.52	50.90	24.00
	50	2.86	57.45	26.03
	75	3.04	62.18	30.71

Table 2.5 Summary Statistics of RI, Condition Points, and Age of Original PCC Pavements on Parkways

The average RI shown in Table 2.5 is 2.78, which is less than RI on Interstates (2.92). Additionally, the condition points are larger and surface ages are greater. These again show that the general conditions were allowed to be worse on Parkways.

Large variations in condition points and pavement ages can also be noticed. The distributions of the different parameters are plotted in the following figures.

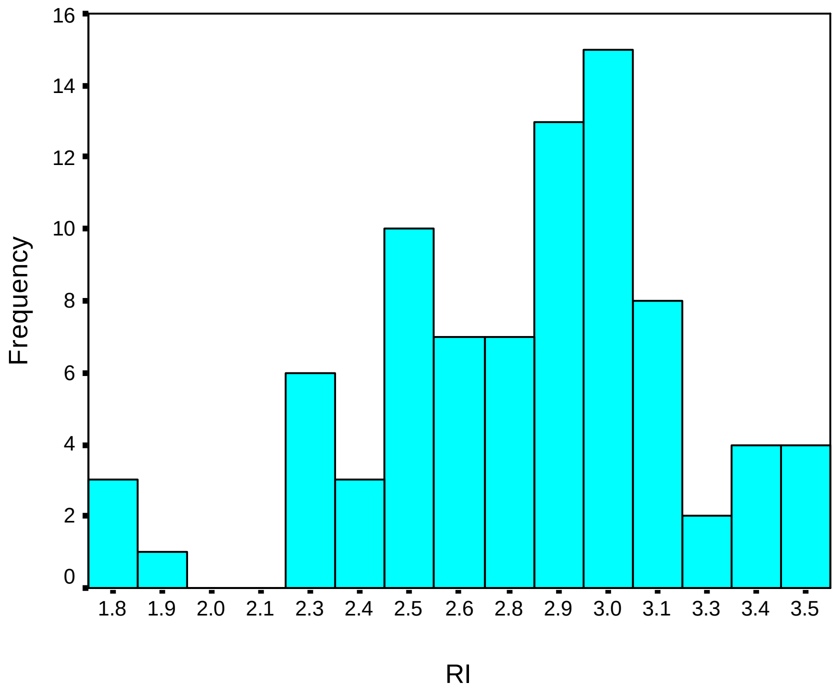

Figure 2.12 Distribution of RI before Rehabilitation of Original PCC Pavements on Parkways

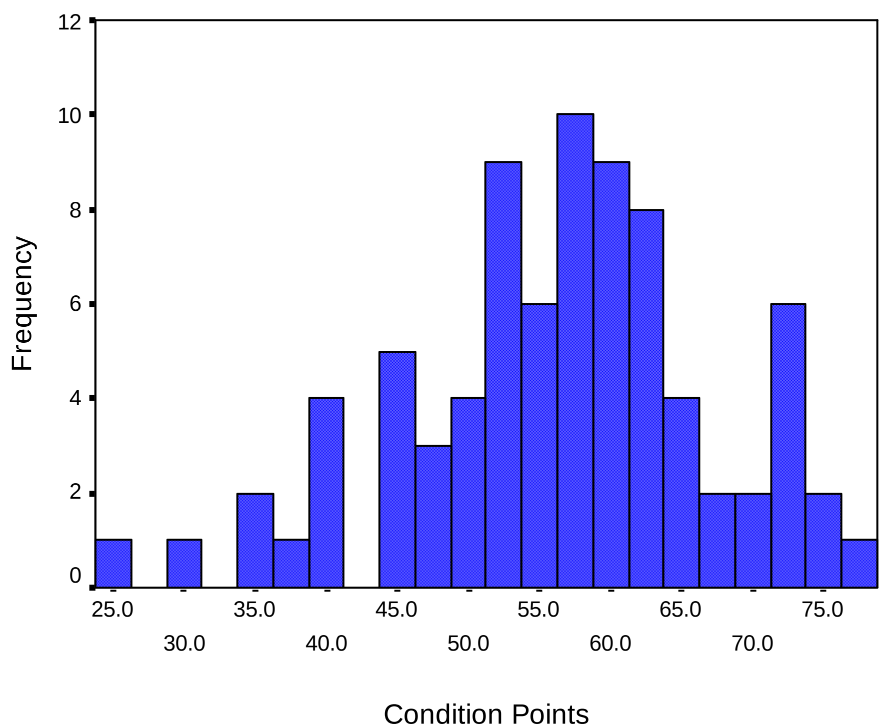

Figure 2.13 Distribution of Condition Points before Rehabilitation of Original PCC Pavements on Parkways

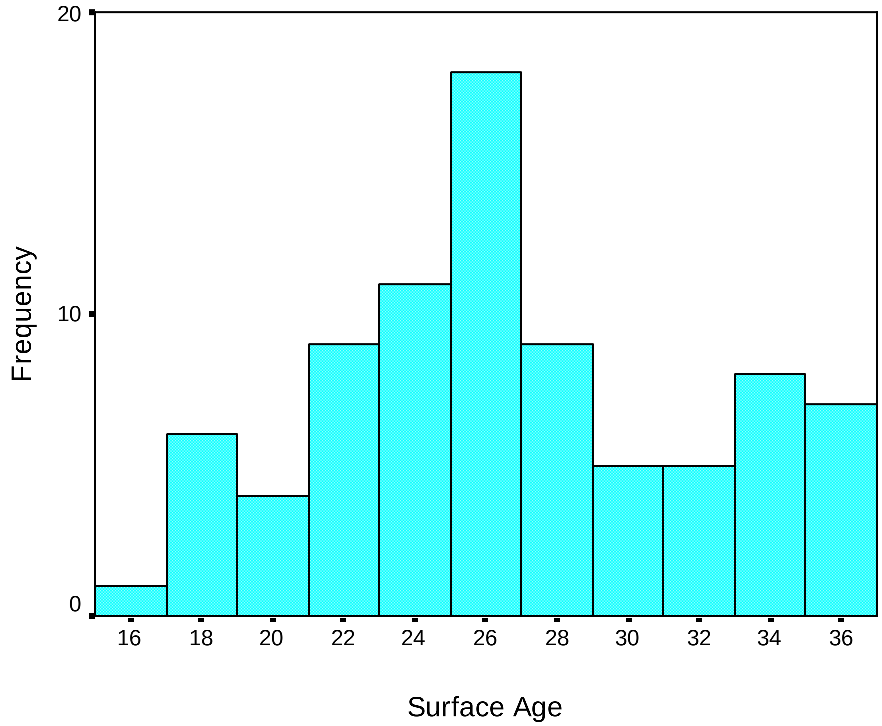

Figure 2.14 Distribution of Surface Age before Rehabilitation of Original PCC Pavements on Parkways

For the first time, the RI on Parkways falls into the “poor” rideability condition range, but rideability on most pavement segments is with the range between 2.3 to 3.5. The condition points from most of the sections range from 45 to 75 and all pavement ages are greater than 16 years. Except for several outliers, the conditions before rehabilitation of PCC pavements on Interstates show less variations than the other pavement types.

2.3 Rehabilitation Thresholds for AC Overlays

Pavement conditions of AC overlays with different thickness were analyzed in this research. Here the thresholds refer to the AC overlay conditions before they were replaced. These AC overlays could be constructed on original AC pavements or PCC pavements. Appendix III shows the pavement sections investigated in this research. The missing condition points were processed the same way as the original AC or PCC pavements. The summary of these conditions are shown in the following tables and figures.

2.3.1 Summary Statistics of RI, Rut Depth, Condition Points, and Age on Interstates

A total of 112 pavement sections (including both directions) of AC overlays with rehabilitation records on Interstates were identified. Table 2.6 shows the average RI, rut depth, condition points, and ages of the AC overlays before rehabilitations were scheduled.

		RI	Rut Depth	Con. Pts	Surface Age
No. of Sections	Valid	112	97	110	114
	Missing	2	17	4	0
Mean		3.72	5.76	29.96	9.64
Median		3.77	6.00	28.65	8.99
Std. Deviation		.27	2.36	8.02	2.62
Minimum		2.87	.00	16.80	3.72
Maximum		4.15	10.00	51.70	16.90
Percentiles	25	3.54	4.00	24.10	7.85
	50	3.77	6.00	28.65	8.99
	75	3.92	8.00	34.43	10.90

Table 2.6 Summary Statistics of RI, Rut Depth, Condition Points, and Age of AC Overlays on Interstates

The thresholds of RI, rut depth, and condition points are slightly better for overlays than for the original AC pavements. The mean surface age before rehabilitation is 9.64, which is less than the mean surface age of original AC pavements(10.59). However, considering that the pavement conditions on overlays were better when rehabilitations were applied and that the AC overlays are thinner than the original AC, the performance of AC overlays is remarkable.

The distributions of different values were plots in the following figures.

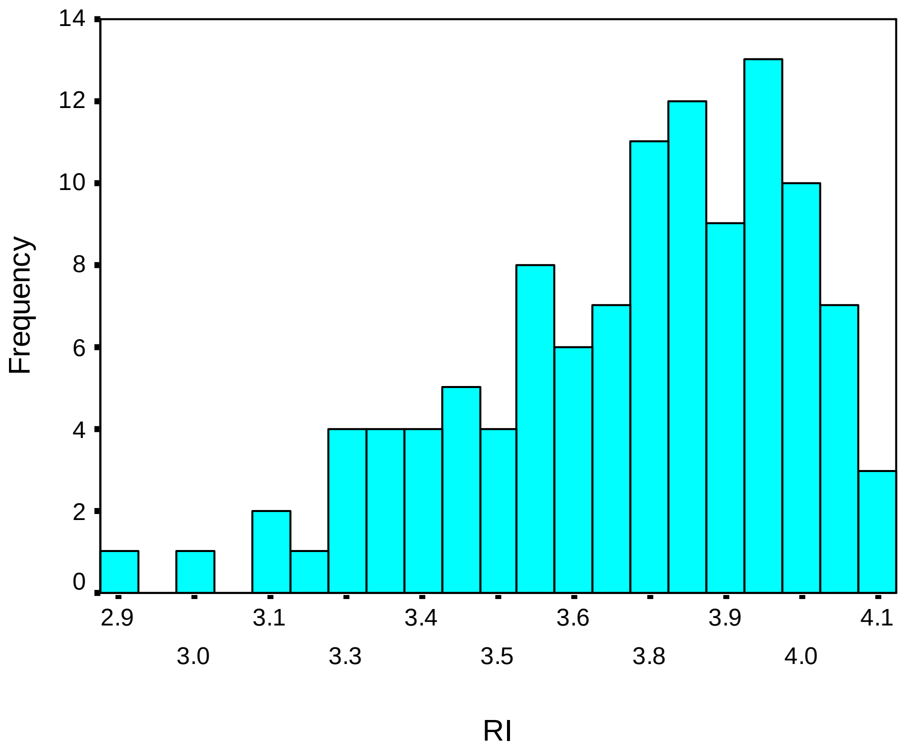

Figure 2.15 Distribution of RI before Rehabilitation of AC Overlays on Interstates

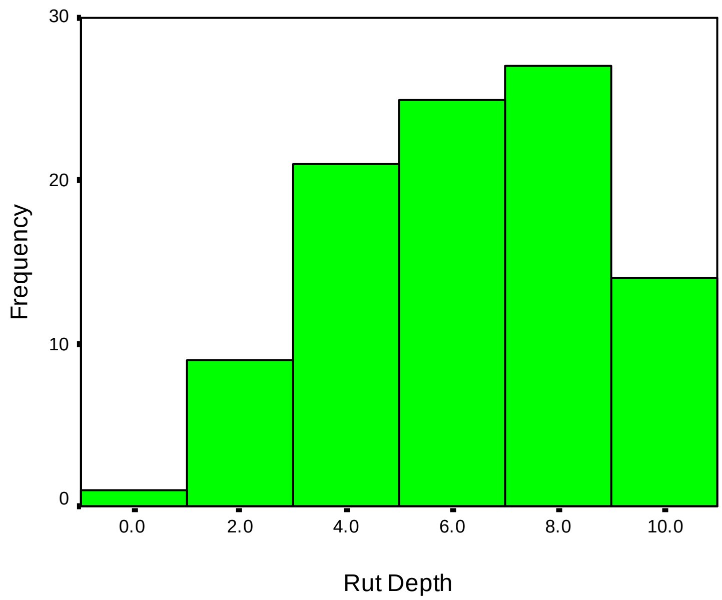

Figure 2.16 Distribution of Rut Depth before Rehabilitation of AC Overlays on Interstates

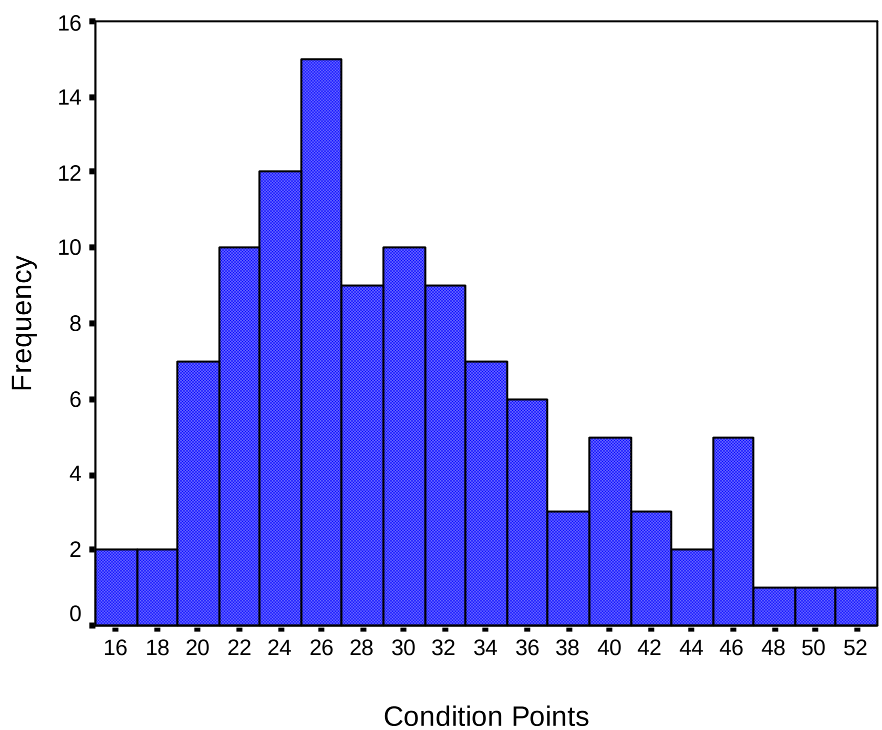

Figure 2.17 Distribution of Condition Points before Rehabilitation of AC Overlays on Interstates

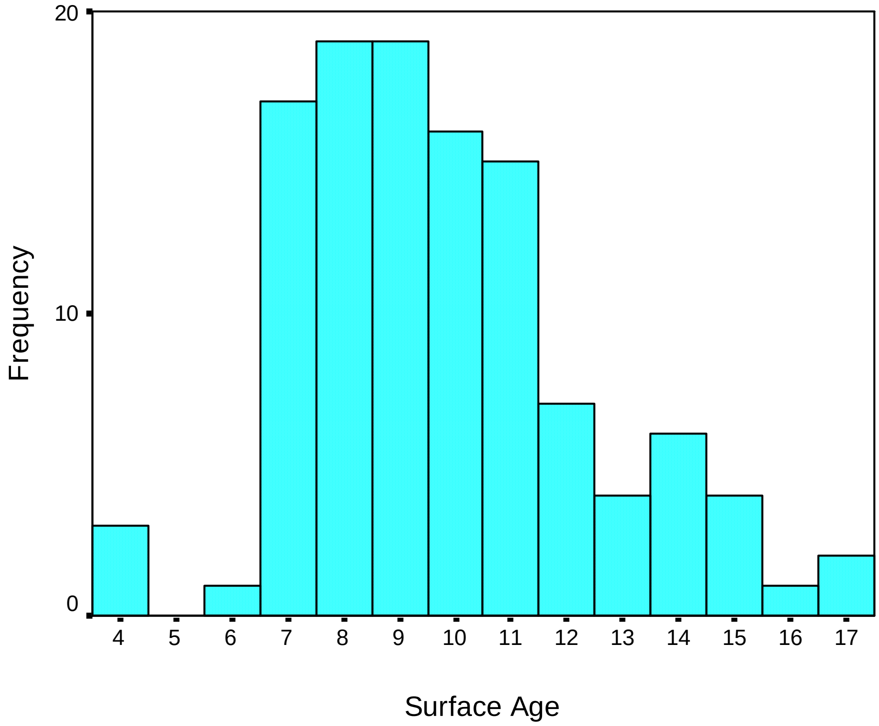

Figure 2.18 Distribution of Surface Age before Rehabilitation of AC Overlays on Interstates

Large variations of RI and condition points can be seen on these plots. The RI plot is skewed to the right, which indicates more pavement sections were rehabilitated in a better rideability condition. The condition points plot is skewed to the left, which indicates pavements with less distress. These plots show a tendency for AC overlays on Interstates to receive treatments at an early stage of deterioration.

2.3.2 Summary Statistics of RI, Rut Depth, Condition Points, and Ages on Parkways

A total of 114 pavement sections (including both directions) with rehabilitation on existing AC overlays on Parkways were identified. Table 2.7 shows the average RI, rut depth, condition points, and ages of the AC overlays before rehabilitations were scheduled.

		RI	Rut Depth	Con. Pts.	Surface Age
No. of Sections	Valid	114	112	114	114
	Missing	0	2	0	0
Mean		3.42	5.16	39.16	9.43
Median		3.44	5.00	38.20	9.01
Std. Deviation		.23	2.35	9.38	3.90
Minimum		2.49	.00	15.90	2.18
Maximum		4.07	12.00	80.30	19.00
Percentiles	25	3.28	3.00	32.48	6.64
	50	3.44	5.00	38.20	9.01
	75	3.58	6.75	44.15	12.63

Table 2.7 Summary Statistics of RI, Rutting, Condition Points, and Age of AC Overlays on Parkways

For overlays on Parkways, the thresholds of RI and condition points are slightly worse than those on Interstates. However, the performance of overlays on Parkways are also excellent. Even though overlays were rehabilitated in good condition, the average pavement life is 9.43. The distributions of different parameters are plotted in the following figures.

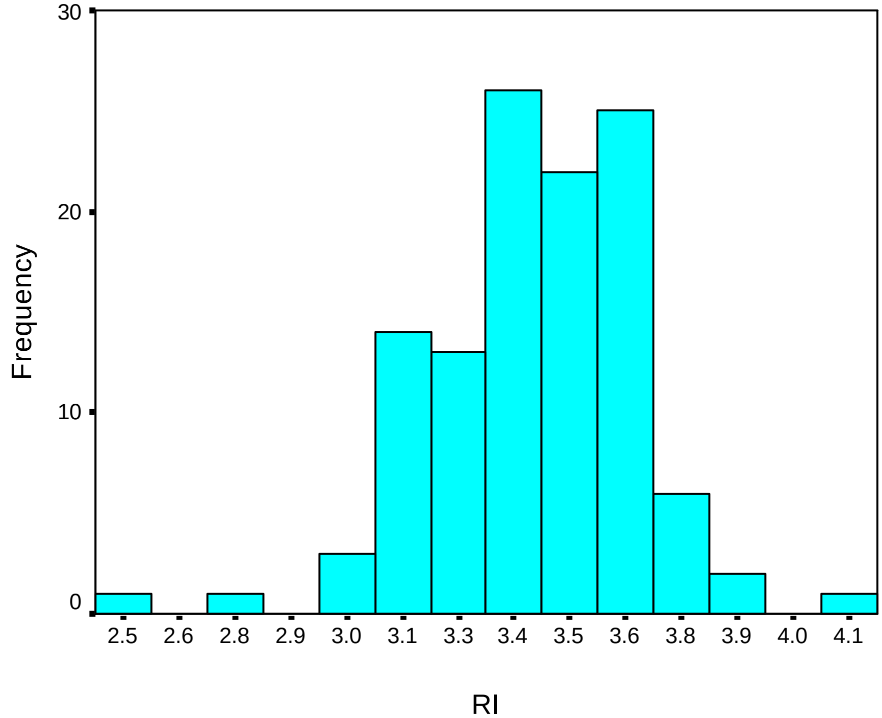

Figure 2.19 Distribution of RI before Rehabilitation of AC Overlays on Parkways

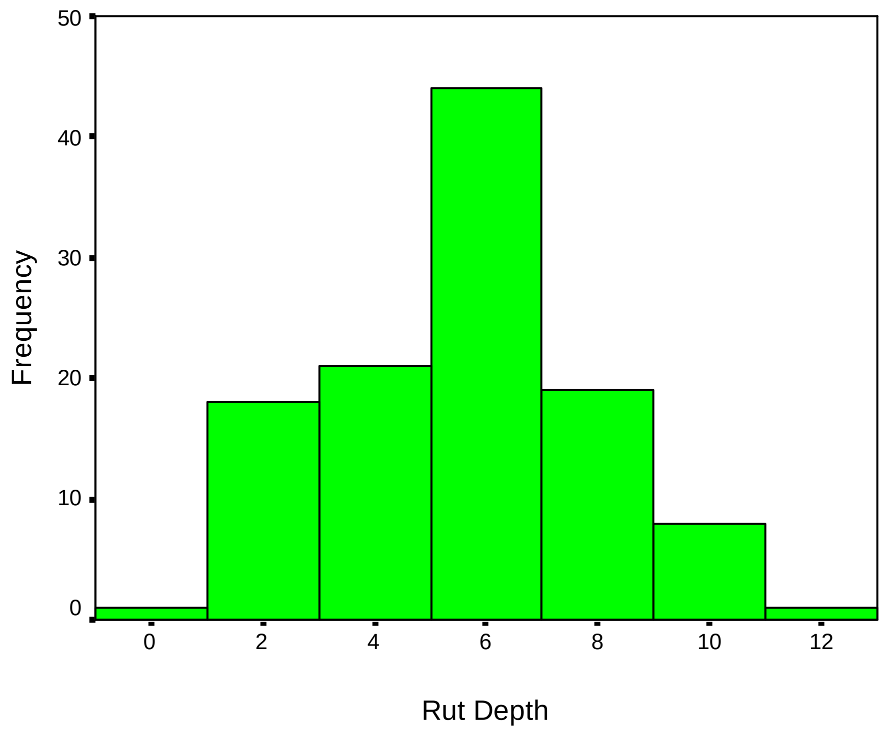

Figure 2.20 Distribution of Rut Depths before Rehabilitation of AC Overlays on Parkways

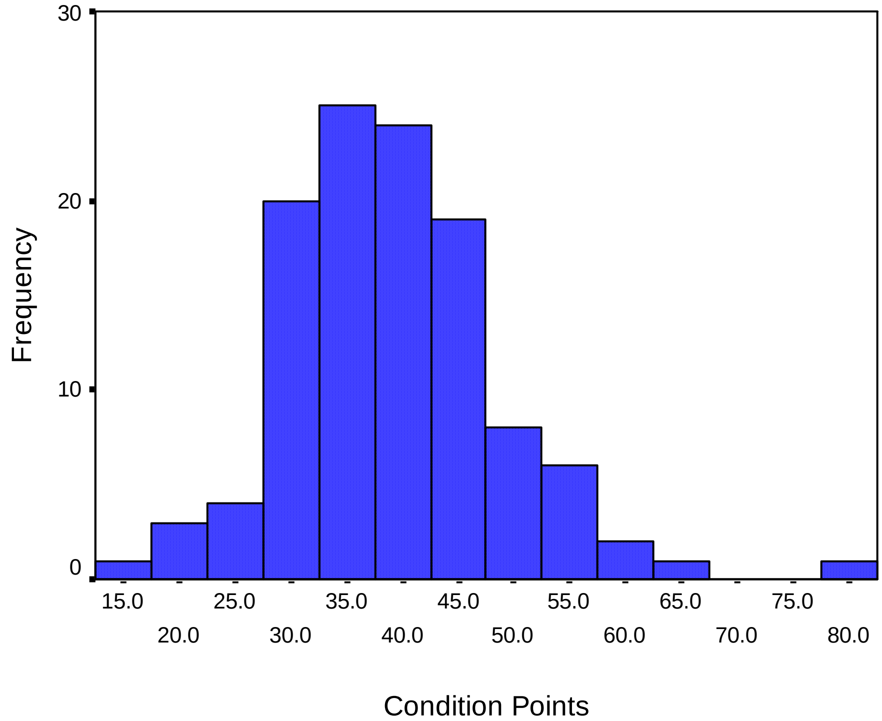

Figure 2.21 Distribution of Condition Points before Rehabilitation of AC Overlays on Parkways

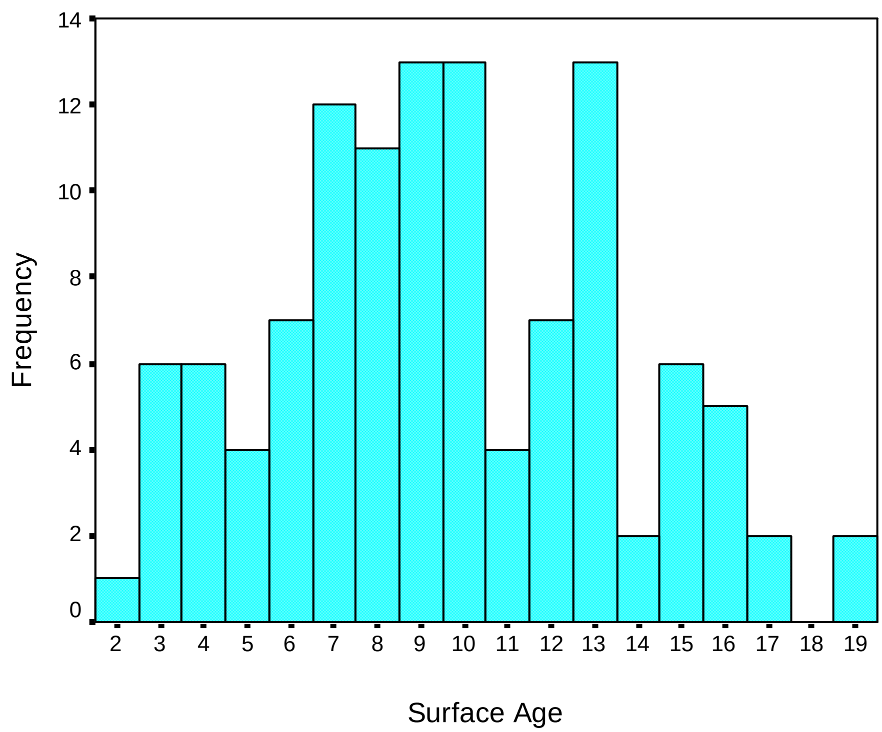

Figure 2.22 Distribution of Surface Age before Rehabilitation of AC Overlays on Parkways

Except for several outliers, the rideability is within the range between 3.0 and 3.9 and the condition points are within range between 15 and 65. Overlays have been rehabilitated at any age, according to Figure 2.22.

2.4 Thresholds for Grinding PCC Pavements

Although PCC preservation includes patching, replacing joint seals, and grinding, only PCC pavements with grinding were selected for analysis in this study. Additionally, because there are not many PCC maintenance records, PCC grinding on both Interstates and Parkways was summarized together. The sections investigated are listed on Appendix IV. Table 2.8 shows the average RI, condition points, and ages of PCC before grinding was applied.

		RI	Condition Points	Surface Age
No. of Sections	Valid	45	45	45
	Missing	0	0	0
Mean		2.56	44.48	17.70
Median		2.54	42.50	18.90
Std. Deviation		.39	10.17	11.49
Minimum		1.22	29.10	1.75
Maximum		3.20	67.10	36.27
Percentiles	25	2.38	35.95	9.76
	50	2.54	42.50	18.90
	75	2.79	51.80	27.76

Table 2.8 Summary Statistics of RI, Condition Points, and Age of PCC Pavements before Grinding

Reviewing rehabilitation records for PCC, it can be seen that the average RI on grinding sections is lower than RI on rehabilitation sections. Interestingly, the average condition points on grinding sections are smaller than those on rehabilitation sections. Grinding is more determined by rideability than by pavement distress.

The distributions of different parameters are plotted in the following figures.

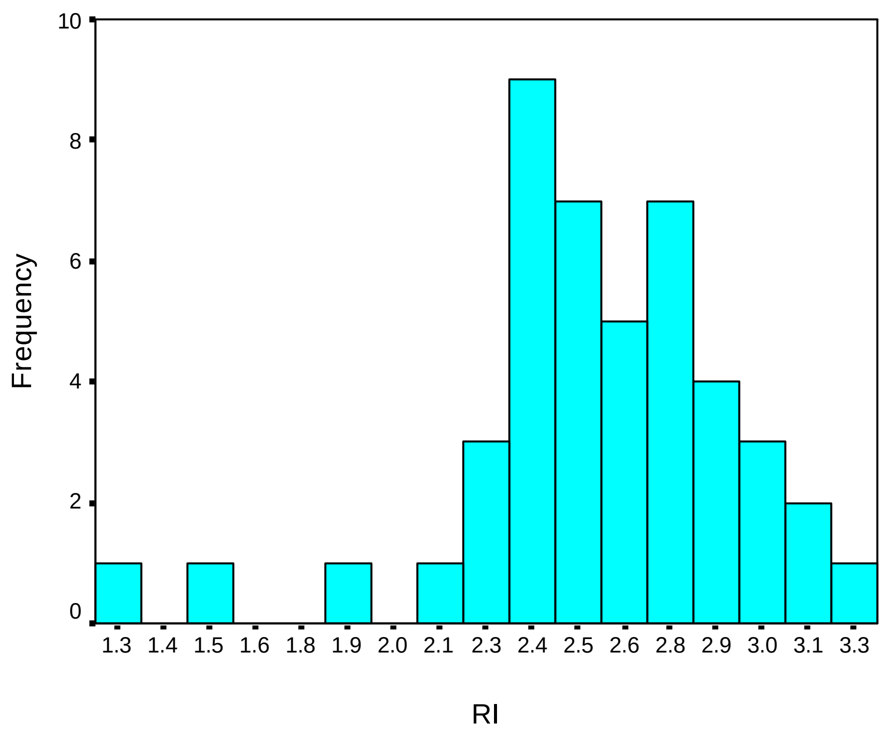

Figure 2.23 Distribution of RI before PCC Grinding

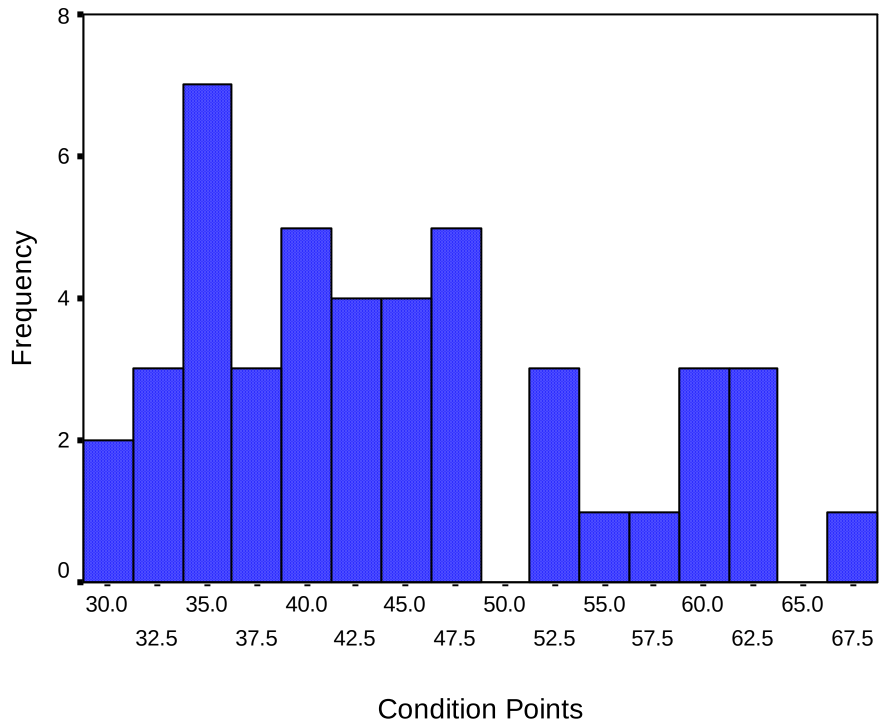

Figure 2.24 Distribution of Condition Points before PCC Grinding

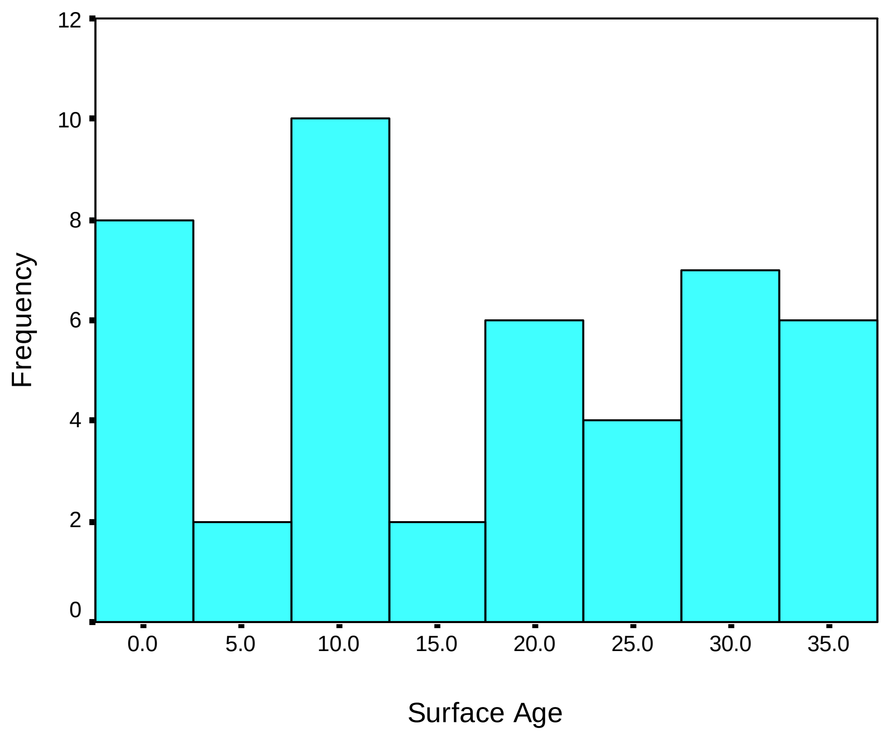

Figure 2.25 Distribution of Surface Age before PCC Grinding

The plots show that most sections were in fair or poor rideability conditions when grinding was applied. Condition points are more concentrated and lower than those on PCC sections for rehabilitation. Figure 2.25 shows that surface ages are very different for these sections. Some pavement sections were ground at a very early age.

2.5 Comparisons of Trigger Values of Different Treatments

The average pavement conditions and pavement ages when different treatments were applied are summarized in Table 2.9. The table reveals that, in general, Parkways have a lower standard for treatments than Interstates, and AC pavements have a higher standard for treatments than PCC pavements. The table also shows that the trigger values for different treatments are also different.

Maintenance or Rehabilitation Types	Interstate or Parkway	Average RI	Average Rut Depth (1/16 inch)	Average Condition Points	Surface Age
Resurfacing of Original AC	Interstate	3.51	6.31	38.07	10.59
	Parkway	3.30	7.16	44.66	12.86
Rehabilitation of Original PCC	Interstate	2.92	N/A	51.43	21.13
	Parkway	2.79	N/A	56.16	26.94
Resurfacing of AC Overlay	Interstate	3.72	5.76	29.96	9.64
	Parkway	3.42	5.16	39.16	9.43
PCC Grinding		2.56	N/A	44.48	17.70

Table 2.9 Average Pavement Conditions and Pavement Ages before Treatments

To compare the trigger values for the three types of resurfacing: rehabilitation of original AC, rehabilitation of original PCC, and rehabilitation of AC overlays, cumulative pavement conditions plots were constructed. Figure 2.26 shows the cumulative plot of RI for the three types of rehabilitation and Figure 2.27 shows the cumulative plot of the condition points.

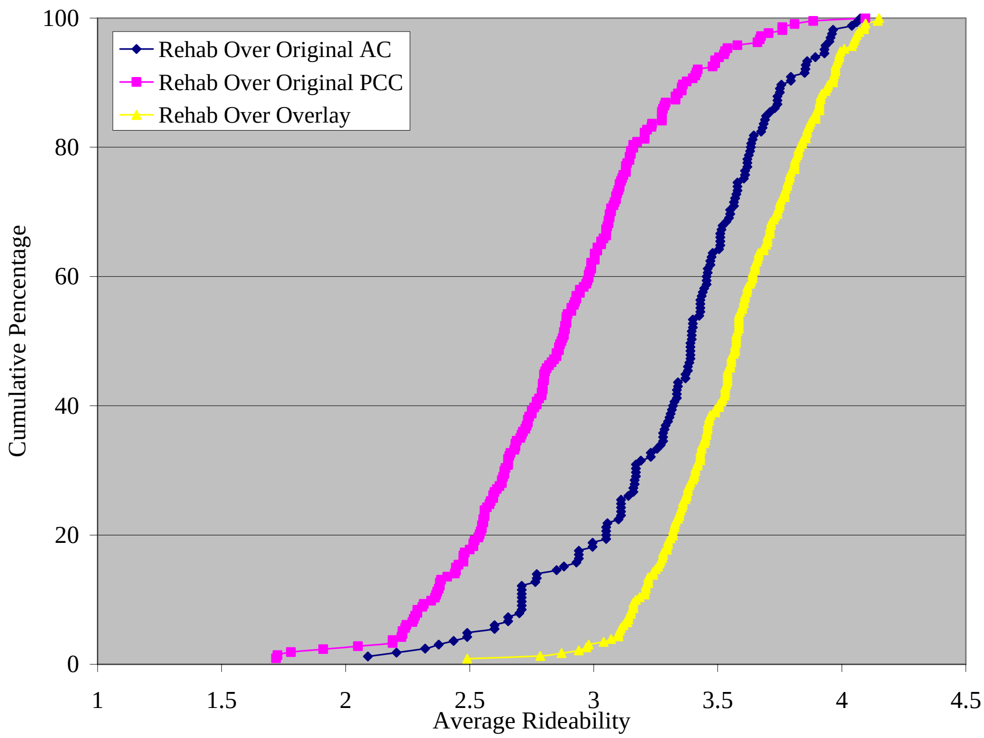

Figure 2.26 Cumulative Plot of RI Trigger Values for Three Rehabilitation Types

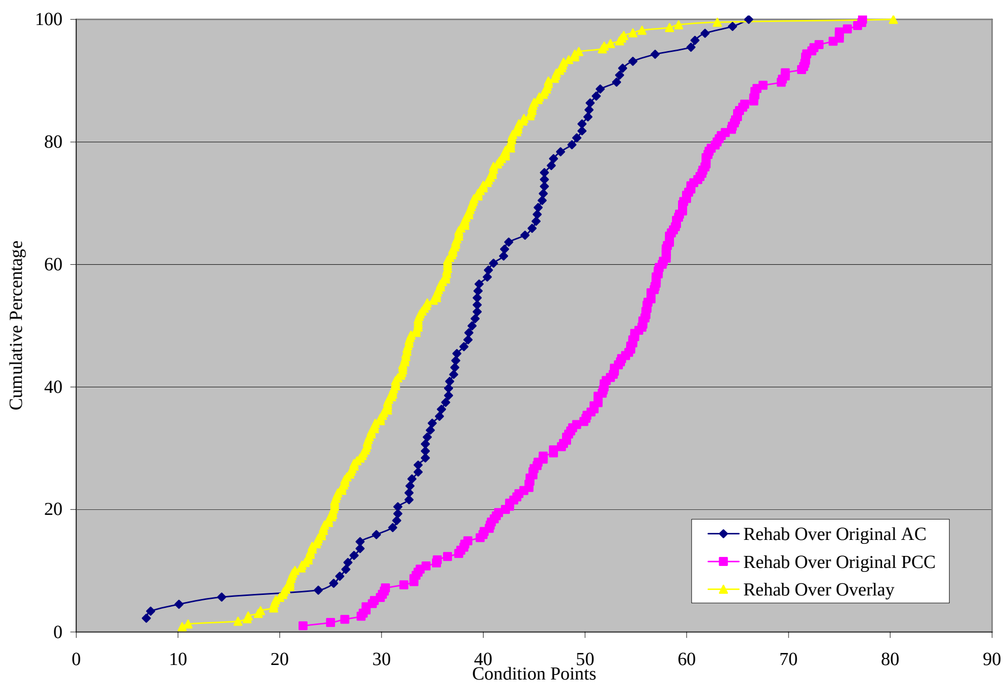

Figure 2.27 Cumulative Plot of Trigger Values of Condition Points for Three Rehabilitation Types

These plots indicate that sequence of standards for the three types of rehabilitation, from high to low, are rehabilitation over existing overlays, rehabilitation over original AC pavements, and rehabilitation over PCC pavements. However, the difference between the first two types of treatments is not large.

CHAPTER 3 STANDARDIZATION OF THRESHOLDS FOR PAVEMENT MAINTENANCE AND REHABILITATION

The historical records from Interstate and Parkway systems show large variations of pavement conditions before maintenance or rehabilitation was scheduled. Such variations may affect the selection of an effective treatment as well as the optimum allocation of limited resources. To assure that resources are assigned to the most needed pavement sections, a consistent decision process is needed. The first step of this process is to find appropriate thresholds of pavement conditions for maintenance or rehabilitation consideration.

3.1 Thresholds from Statistics of Historical Data

One approach to determine the thresholds is to use historical data that are summarized and analyzed in the previous chapter. The average value or a percentile can be used as a standard threshold. For example, the average RI value for PCC grinding is 2.56, which may be used as a candidate trigger value. If this standard is too low, the 75th percentile can also be considered, which is 2.79. Once a standard value is identified, no treatments will be applied to a pavement segment until its condition reaches the trigger value. Similarly, one can determine other trigger values by using the statistics in the pervious chapter.

The drawback of this method is that the selected trigger values are based on historical records only. The chosen trigger values do not reflect engineering or economic issues. Therefore, this study also attempted to address this issue from other aspects.

3.2 Other Criteria for Determining Thresholds

In general, three approaches were found by this research that can assist in making maintenance and rehabilitation decisions. The first one is based on the serviceability of the road, which is primarily affected by pavement roughness. The most well known serviceability concept is the pavement present serviceability rating (PSR) developed by the AASHO Road Test. Prior to the year of 1993, all pavement conditions were evaluated for the federal government using the PSR value (FHWA, 2002). After that, the international roughness index (IRI) was also reported. Table 3.11 was adapted from the FHWA report: "Status of the Nation's Highways, Bridges, and Transit: 2002 Conditions and Performance Report", which shows different roughness conditions with a corresponding subjective evaluation.

Pavement Condition Criteria (Old - New)

	IRI RATING		PSR RATING	
OLD CONDITION TERM CATEGORIES	INTERSTATE	OTHER	INTERSTATE	OTHER
Very Good	< 60	< 60	≥ 4.0	≥ 4.0
Good	60 to 94	60 to 94	3.5 to 3.9	3.5 to 3.9
Fair	95 to 119	95 to 170	3.1 to 3.4	2.6 to 3.4
Mediocre	120 to 170	171 to 220	2.6 to 3.0	2.1 to 2.5
Poor	> 170	> 220	≤ 2.5	≤ 2.0

	All Functional Classifications	
NEW RIDE QUALITY TERMS*	IRI RATING	PSR RATING
Good	< 95	≥ 3.5
Acceptable	≤ 170	≥ 2.5

* The threshold for "Acceptable" ride quality used in the 2002 Conditions and Performance Report is the 170 IRI value as set by the FHWA Performance Plan for the NHS. Some transportation agencies may use less stringent standards for lower functional classification highways to meet to be classified as "Acceptable".

Table 3.1 Subjective Evaluation of Pavement Conditions with Roughness and PSR values (from FHWA).

The current equation used in Kentucky that correlates RI to IRI is

IRI = 310 -64RI (IRI in inch/mile).

Comparing the “acceptable ” ride quality thresholds given in Table 3.1 with the historical pavement management records in Kentucky, for roughness only, this research found that the majority of pavement sections from Interstates and Parkways were treated in mediocre, fair, or good conditions.

Other researches have attempted to investigate the relationship between pavement conditions and the user’s perception of riding quality. A 5-year pooled fund project by Wisconsin DOT, Iowa DOT, and Minnesota DOT made an extensive survey of public perceptions of satisfaction and improvement policies on rural, two-lane highways (Kuemmel, et al., 2001). In phase III of the research, 150 pavement sections with various pavement types and conditions were selected. Subjects received $10 compensation for expenses incurred by their participation if they agreed to drive the segment and complete the second part of the phone survey within approximately one week. The survey was completed within 6 months and 2300 surveys were conducted. The research found that the IRI representing 70 percent of those indicating “satisfied” with rigid pavements was 1.94 (123 inch/mile) while the corresponding value for flexible pavements was 1.69 m/km (107 inch/mile). Another study sponsored by the Washington DOT recruited 56 subjects and let them drive over 40 predetermined highway test segments (Shafizadeh & Mannering, 2003). The pavement sections were located on I-5, I-90, I405, and SR-520 around the Seattle-Bellevue area. According to the study, the acceptable threshold corresponding to 80 percent of the participants was IRI 170 inch/mile or less, which verified the FHWA’s standard.

However, to use users’ perceptions to determine a threshold was affected by user’s driving experience, and probably the overall pavement conditions of certain areas. In addition, the effects of roughness on commercial trucks were often not reflected.

The second approach was to use cost analysis to determine the trigger values for maintenance and rehabilitation. The aim of choosing the trigger values as well as the maintenance or rehabilitation strategies is to minimize pavement’s overall life cycle cost, which includes agency’s cost and the user’s cost. From the agency’s standpoint, generally longer rehabilitation cycles can save money, but the associated higher roughness level increases the user cost. The user cost includes cost associated with normal operations and associated with work zones. The relationship between total cost, user's cost, agency's cost, and threshold conditions are shown in Figure 3.1.

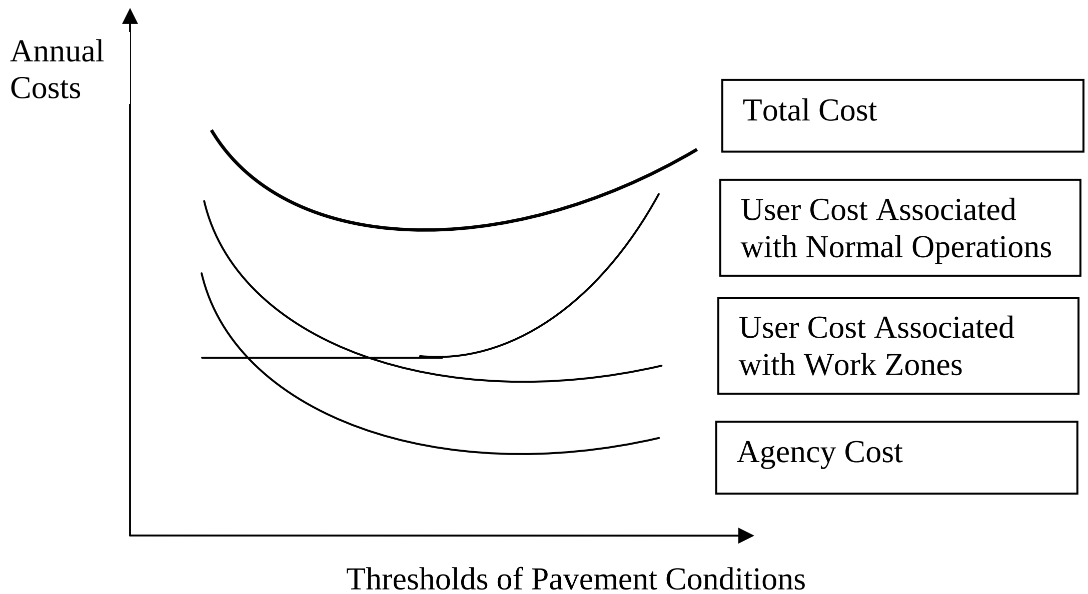

Figure 3.1 Life Cycle Cost and Thresholds of Pavement Conditions

However, to use this method, some reliable pavement performance models and cost models are required. First, a performance model is required that correlates rehabilitation cycles to threshold values and different treatments. The agency's cost can be determined from historical construction cost and the predicted rehabilitation cycles. The user cost associated with work zone road closure, for example, can be determined from the predicted rehabilitation cycles. However, the difficult part is the user cost associated with normal operations. How a slight change in pavement roughness affects user cost such as the increased wear of vehicles and slowdown of speed remains a question. For example, one model developed by the World Bank stated that there is no additional vehicle operating cost (VOC) before IRI equal to 170 inch/mile (The World Bank, 1997), while another model assumes an exponential relationship between IRI and vehicle operating cost (Dewan and Smith, 2002).

The third approach of determining thresholds aims to prolong pavement life before it reaches the end of service. Most of the activities for this purpose are categorized as maintenance or preservation in stead of rehabilitation. These activities include cracking filling or crack sealing, thin hot-mix asphalt overlays, diamond grinding, repair of PCC pavements, etc. Therefore, the determination of trigger values should be based on criteria for effective preservation instead of the criteria based on ride quality. To evaluate the timing for maintenance overlays, pavement distress and structural integrity play an important role in making decisions. For example, South Dakota DOT has used visual pavement distress surveys to assess the condition of its road network based on the procedures defined in the Distress Identification Manual for the Long-Term Pavement Performance Project (Zimmerman & Peshkin, 2003). A fatigue cracking index, from 0 to 5, is calculated based on the collected fatigue cracking data. If the fatigue cracking index drops from 5.0 to 3.5, the pavement becomes a candidate for the resurfacing program. Other agencies have also attempted to use structural condition indices based on test results from falling weight deflectometer (Zhang, et. al, 2003) to determine trigger values for resurfacing.

3.3 Analysis of Thresholds of Rehabilitation for Kentucky's Interstates and Parkways

The primary pavement types on Kentucky's Interstates and Parkways are plain jointed PCC and asphalt pavements. The corresponding maintenance options for PCC are replacing seals, patching, and grinding, while the primary rehabilitation option is an AC overlay over fractured PCC, although AC overlays over broken PCC, AC overlays on unbroken PCC, and PCC overlays were also occasionally applied. The primary recorded maintenance and rehabilitation option for AC is AC overlay over milled AC. In addition, stress absorbing remembrance interface (SAMI), open graded friction course (OGFC), and slurry were sometimes employed in resurfacing.

3.3.1 Thresholds of Rehabilitation and Maintenance on PCC Pavements

PCC rehabilitation and preservation activities are primarily scheduled to improve rideability, not to extend the structural capacity of existing PCC pavements. Therefore, a functional indicator like RI or IRI should be used as a reference for making decisions.

Using the equation that converts RI to IRI (IRI= 310 - 64RI), the historical IRI of PCC before rehabilitation can be obtained. Table 3.2 shows the percentiles of pavements with different IRIs and the corresponding descriptive conditions judged from the FHWA criteria. The table indicates that PCC pavements are often rehabilitated above the “unacceptable” condition. Furthermore, there are at least 25% of pavements rehabilitated in “fair” condition. If a same standard was applied, pavements still in fair condition may not be rehabilitated. Thus, the saved resource could be applied to other pavement segments or for new construction.

Percentiles	RI	IRI (in/mile)	Pavement Conditions
25	2.63	142	Mediocre (120<=IRI<=170)
50	2.86	127	Mediocre (120<=IRI<=170)
75	3.16	108	Fair (95<=IRI<=119)

Table 3.2 Historical PCC Rideabilty and Roughness Percentiles before Rehabilitation

Using the same criteria to check the percentiles of pavements scheduled for grinding, it shows that most grinding was scheduled when pavements were in “mediocre” condition.

Percentiles	RI	IRI (in/mile)	Pavement Conditions
25	2.38	158	Mediocre (120<=IRI<=170)
50	2.54	147	
75	2.79	131	

Table 3.3 Historical PCC Rideabilty and Roughness Percentiles before Grinding

To standardize the decision thresholds for PCC pavements, this study recommends no maintenance or rehabilitation is scheduled below IRI=120 (RI=2.97). This is the lower end of the "mediocre" pavement condition defined by the FHWA.

3.3.2 Thresholds and Timing of Preventative Resurfacing of AC pavements

According to the historical data, the majority of AC pavement sections were still in "fair" or "good" roughness conditions when overlays were constructed. These overlays can be seen as a preventative measurement to strengthen the existing pavement structures and to extend pavement lives. Another option would be to wait for pavements to continuously deteriorate until reaching an unacceptable level, and then make a major rehabilitation or reconstruction. Since no data were found to support the analysis of the second option, this research concentrated on the preventative resurfacing of AC pavements only.

Rehabilitation resurfacing usually refers to thick overlays, while preventative maintenance resurfacing refers to thin overlays. However, the research found that the existing pavement conditions were not significantly different for thin and thick overlays. Additionally, the thickness of historical AC overlays seems being continuously distributed; there is not a clear line of delineation between "thin" and "thick". Therefore, this research did not make a distinction between maintenance and rehabilitation for AC resurfacing.

Even though AC resurfacing on Kentucky's Interstates and Parkways is a preventative measure against deterioration, a standard trigger value would still be beneficial. The standard trigger value would optimize project prioritizations at the network level, and also timely protect pavement structures from rapid deterioration. The layered pavement system is used to protect weaker materials at the base and subgrade from heavy loads. Cracking, on the other hand, will increase surface layer deflections dramatically and increase water infiltration. If no treatment is applied in time, permanent damage will occur in the base and subgrade layer and reduce the pavement's structural integrity. However, application of overlays too early would not use the structural potential of existing pavements to the full extent and would cause a waste of resources.

3.3.2.1 Characteristics of Distress Development

Although the general trend of roughness development is linear, this is not the case for visually discernable distresses. Distresses usually do not appear at the very early age of pavements in service. Then, after numerous loading cycles, for certain types of distress like fatigue cracks, they appear and deteriorate rapidly. Figure 3.2 shows the distress and roughness change over time of a pavement section selected from the LTPP study (test section 510113). In Figure 3.2, fatigue cracking is represented by the cracking areas. More detailed information about identifying and measuring fatigue cracking can be found from the LTPP Distress Identification Manual (LTPP, 2003). Figure 3.2 is not the only type of distress development trend, some LTPP test sections will last longer at certain distress levels. However, for the majority of pavements, an abrupt increase of distress level is obvious. The distress and roughness trends from this test section also indicate that severe distress can be developed while roughness is still acceptable. Since the aim of preventative resurfacing is to extend pavement life by fully using the capacity of exiting structures, it is desirable to resurface before extensive cracking takes place along the wheel path. For the example shown in Figure 3.2, the test section may need thin resurfacing at the fatigue distress level of 15-25 square meters from the standpoint of effective preventative maintenance.

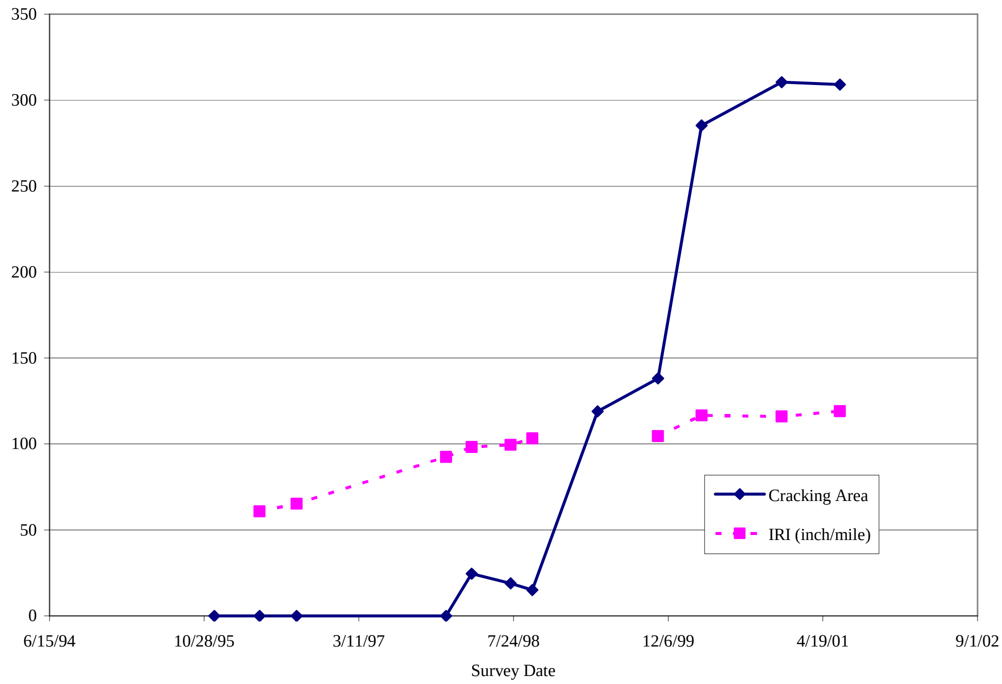

Figure 3.2 Distress and Roughness Development Pattern on One LTPP Test Sites (Test Section 510113)

In Kentucky, the distress level of a pavement is represented by a comprehensive index, condition points. Since condition points are assessed and combined from six elements, a clear trend like the fatigue cracking development on the LTPP test sections cannot always be observed. However, the change in condition points is not linear on most pavement sections. If a range of condition point values can be identified, and after the range the condition points increase faster than the other ranges, this range may be used as trigger values. This is because the purpose of preventative rehabilitation is to avoid accelerated deterioration. To find this range, this study examined the transition probability matrix of pavement condition points on pavement sections from Kentucky's Interstate and Parkway systems.

3.3.2.2 Transition Probability Matrix (TPM)

The transition probability matrix is often used in Markovian pavement performance prediction models, in which a discrete state vector is used to represent different pavement conditions and a transition probability matrix defines the probabilities of transition from one state of condition to another. The future condition state of a pavement at time i+1, S(i+1), is predicted from its current state S(i) multiplied by the transition probability matrix P. Table 3.4 shows an example of a simple transition probability matrix, in which P1,1 represents the transition probability from State i to State j.

Pavement Conditions		Good	Fair	Poor
		State: 1	State: 2	State: 3
	1	P1,1	P1,2	P1,3
	2	P2,1	P2,2	P2,3
	3	P3,1	P3,2	P3,3

Table 3.4 Example of Transition Probability Matrix

The objective of using transition probability matrix in this study is to review the transition probabilities at each distress levels. First, the numerical values of condition points were transformed to discrete state values. Then, the transition probabilities from one state to others were calculated. If the transition probability from one state to another worse state is high, the corresponding state, or the range of condition points, represents the appropriate distress levels for considering preventative resurfacing.

There are two assumptions about the transition probability matrix: time is homogeneous, where the same transition probability matrix applies at every state, and time is not homogeneous, where the stage effect is considered. Since this study concentrates on the distress level, in stead of making prediction models, the age effect is neglected. Several methods can be used to estimate the transition probability matrix, from experience or an expert's opinions to a mathematical method derived from historical data. When using the mathematical method, a simplification is often employed which assumes that the pavement condition cannot deteriorate more than one state. However, the distress data from both Kentucky's pavement management system and the LTPP data base show that the distress level can jump more than one state at the next survey period. To examine all the probabilities, the study did not use the simplification and estimated the transition probability matrix from its basic definition. Let n_i denote the number of pavement sections initially existed in state i and n_{ij} is the number of pavement sections in state j after one transition. The estimated transition probability is

$$\hat{P}_{i,i} = \frac{n_{i,j}}{n_i}.$$

This approach was used to estimate the transition probability matrices of two types of predominant resurfacing programs: AC over existing AC pavements and AC over fractured PCC pavements. Table 3.5 shows the estimated transition probability matrix for AC over existing AC pavements, while table 3.6 shows the TPM for AC over fractured PCC pavements.

From the TPM of AC resurfacing over existing AC pavements, one can see that if the condition points fall within the range between 29.5 and 34.5, the probability of remaining this range at the next period is only 0.41, and the probability of getting worse is 0.59. Additionally, after this range, the deterioration seems accelerated. Therefore, this range represents the initiation of accelerated deterioration and can be used as a threshold for resurfacing. The same conclusion can be reached from reviewing the TPM of AC resurfacing over fractured PCC pavements.

	Pavement Condition at the Next Period									
Initial Condition	<=9.5	>9.5,				>29.5, <=34.5	>34.5, <=39.5	>39.5, <=44.5	>44.5, <=49.5	>49.5
<=9.5	0.61	0.33	0.04	0.01	0	0	0	0	0	0
>9.5,<=14.5		0.52	0.40	0.07	0.01	0.01	0	0	0	0
>14.5,<=19.5			0.52	0.38	0.07	0.03	0	0	0	0
>19.5,<=24.5				0.48	0.46	0.05	0.02	0	0	0
>24.5,<=29.5					0.5	0.43	0.05	0.01	0.01	0
>29.5,<=34.5						0.41	0.47	0.06	0.04	0.01
>34.5,<=39.5							0.46	0.45	0.08	0.01
>39.5,<=44.5								0.39	0.43	0.18
>44.5,<=49.5									0.38	0.62

Table 3.5 Homogeneous Transition Probability Matrix for AC Overlays

	Pavement Condition at the Next Period									
Initial Condition	<=9.5	>9.5,				>29.5, <=34.5	>34.5, <=39.5	>39.5, <=44.5	>44.5, <=49.5	>49.5
<=9.5	0.69	0.27	0.03	0	0	0	0	0	0	0
>9.5,<=14.5		0.60	0.37	0.03	0	0	0	0	0	0
>14.5,<=19.5			0.59	0.36	0.05	0	0	0	0	0
>19.5,<=24.5				0.50	0.42	0.07	0.01	0	0	0
>24.5,<=29.5					0.51	0.39	0.06	0.01	0.04	0
>29.5,<=34.5						0.43	0.41	0.11	0.03	0.03
>34.5,<=39.5							0.31	0.50	0.17	0.03
>39.5,<=44.5								0.06	0.39	0.55
>44.5,<=49.5									0	1

Table 3.6 Homogeneous Transition Probability Matrix for AC Overlays over Fractured PCC

3.3.2.3 Change Patterns of Condition Points from Direct Plots

Another way to investigate the change pattern of condition points is to plot their average increase value at the next period. In the plot, the X axis represents the condition points of the current year, including all pavement sections, and the Y axis represents the average increase of the condition points of the next year. For example, the pair (31, 4) represents that the average increase of condition points is 4 for all pavement sections with a current condition point value 31. The average increase of conditions points at next periods are shown in Figure 3.3 and 3.4 for the two types of resurfacing, respectively.

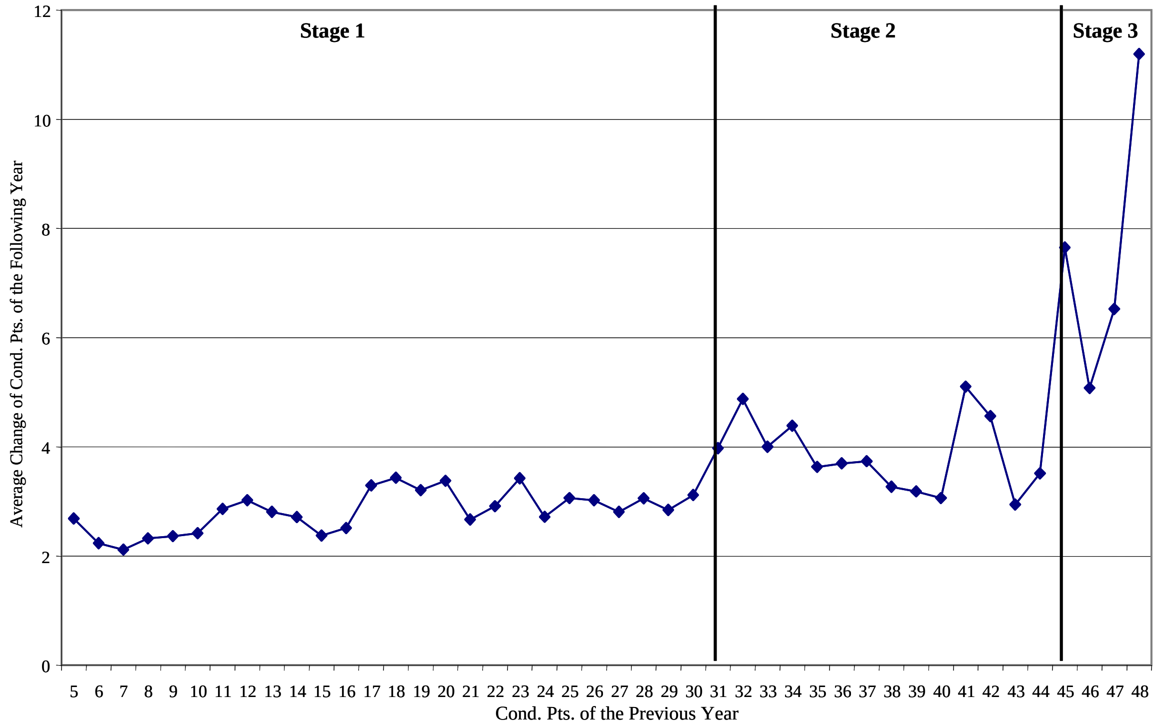

Figure 3.3 Condition Point Change Patterns on AC Overlays

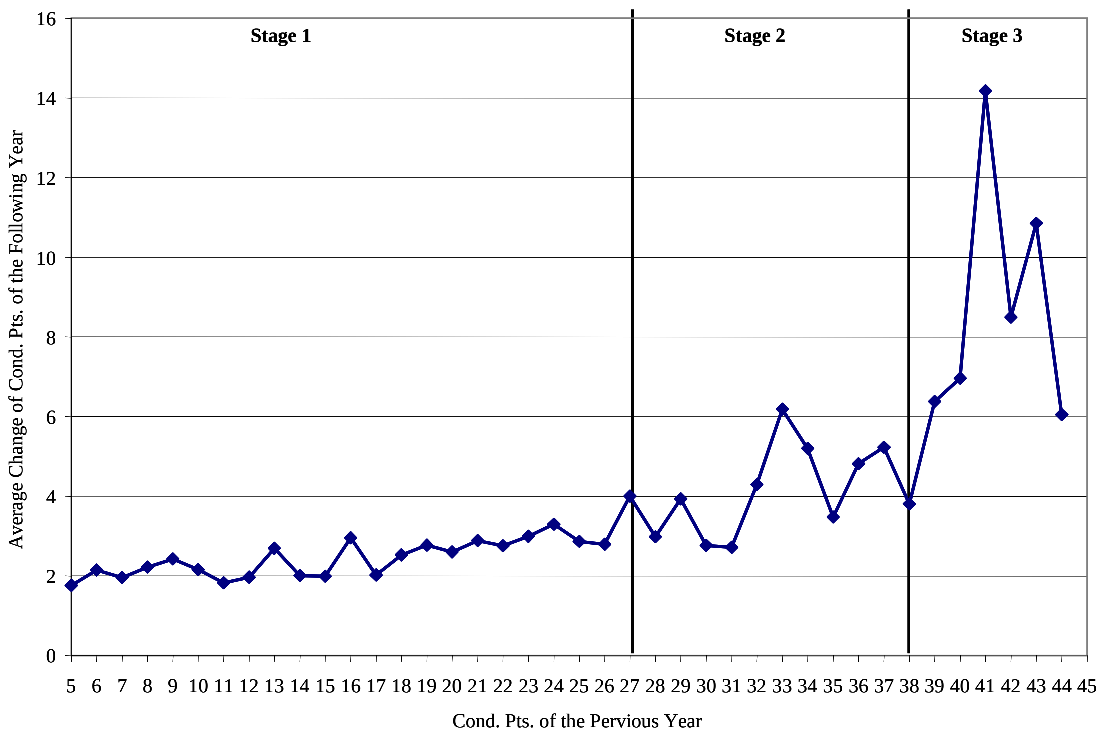

Figure 3.4 Condition Point Change Patterns on AC Pavements over Fractured PCC

This plot shows more interesting information on distress development patterns than the transition probability matrix. First, the plots show that the average increase of condition points is not linear for these two types of resurfacing programs. Both plots show a sudden increase in condition points after a particular value. Secondly, three stages of distress developments can be identified by the plots. At the first stage, the condition points increase at a slow rate. At the second stage, the condition points increase more rapidly. And at the third stage, the condition points increase dramatically. To effectively protect pavement structures, yet save limited resources, it is recommended that resurfacing be scheduled during the second stage. For AC overlays, this range corresponds to condition points between 31 and 44. For AC over Fracture PCC, this range corresponds to condition points between 27 and 38.

How long can a pavement section remain in Stage one and Stage two? The duration in Stage One can be used to predict rehabilitation cycles as well as analyze the effect of treatments (for example, different thickness). Due to limited resources, a pavement section may not receive treatments as soon as Stage Two starts. However, it must be treated before it enters Stage Three. If the duration in Stage Two can be estimated, then it provides a time window for the Department to schedule a resurfacing activity. This also helps the Department prioritize the resurfacing projects at the network level. For example, if the durations in Stage Two for two pavement sections are estimated to be the same, and the first project has been in Stage Two for one year and the second for three years, then the second project should be given higher priority.

CHAPTER 4 PAVEMENT CONDITION PREDICTION AND EVALUATION OF DIFFERENT TREATMENTS

4.1 Introduction

One of the key elements of a pavement management system is its performance or deterioration prediction models. A reliable prediction model can assist agencies in deciding the future needs for funding and making pavement preservation/rehabilitation plans. In recognizing the importance of prediction models, over the years, researchers have developed a number of models with different performance indicators, modeling techniques, and predictor variables. The performance indicators can be some sort of serviceability index, distress index, or a comprehensive index. The modeling techniques can be grouped into two major classes: empirical or mechanistic-empirical. Depending on the modeling techniques, the collected predictor variables can be mechanistic responses or general pavement performance influencing factors. Five classes of these influencing factors and their interactions are summarized by Haas (2001), which includes environment, structure, construction, maintenance, and traffic.

Why did this research attempt to develop new pavement performance deterioration models since a large number already exists? Three reasons make the performance models in this research necessary and also different from the existing models.

The first reason is the objectives of using these models. Since more and more present construction projects are not new construction, but resurfacing, the models in this research concentrate on asphalt concrete (AC) overlays. The second objective is to use the models to estimate pavement lives for projects with contractor’s warranties. To serve this purpose, a consistent failure thresholds need to be defined; and traffic, pavement resurfacing thickness, existing conditions before rehabilitation, and other possible influencing factors should be incorporated to accurately predict a warranty period. This model could then make adjustments on pavement service life based on the actual conditions.

The second reason is that the characteristics of the pavement management data in this research are different from those used in other models. In Kentucky, pavement management data from Interstates and Parkways are recorded from the early of 1960's. For the best protection of pavement structures, most resurfacing occurred before pavements deteriorated to an unacceptable level. And many of the resurfaced layers are thin overlays. This practice not only improves the riding quality of the pavements, but also avoids more expensive reconstructions or major rehabilitations. However, due to the variation in the historical resurfacing trigger values, if a unified critical condition threshold was chosen, in many occasions pavement sections were treated before this threshold. Therefore, one cannot decide when a pavement section would reach to failure condition if unattended.

The third reason is that the modeling technique used in this research is different. A staged survival model was used in this research to estimate the duration of pavements staying at different distress levels. More details on this modeling method can be found in the following discussions.

4.2 A Staged Survival Model

4.2.1 Patterns of Historical Distress Development

As shown in the previous chapter, three stages of pavement distress development can be identified. At the first stage, pavement distress increases at a slow rate. At the second stage, pavement distress increases at a moderate rate. At the third stage, pavement distress increases dramatically, suggesting structural failure of the pavement section. To protect the integrity of pavement structure as well as optimize the usage of resources, preventative resurfacing should be scheduled in the second stage.

4.2.2 Prediction Methods

The three stages can be treated as three condition states. The Markov process has been successfully used to predict pavement (Butt, et. al, 1987) or bridge condition states (Jiang, et. al, 1988). In a Markov process, discrete pavement condition states are defined according to different condition severity levels. After defining these conditions states, a transition probability matrix is developed to provide the probability of a pavement section changing from one condition state to another (usually the next severity level) in the next survey period.

Using the Markov process to predict pavement performance was attempted by this research. Pavement sections with similar traffic levels, AC thickness, and severity of pavement conditions before rehabilitation were put into one group and a transition probability matrix was developed for each group. However, the major challenge is the insufficient observations of pavement sections in some groups. Therefore, as an alternative, regression models were considered for each stage, since the models can use continuous predictor variables. The response variable of the regression models is the duration of a pavement staying at each of the first two stages. The first duration provides information on how long a pavement will stay in good condition without resurfacing. This piece of information can be used to estimate warranty periods. The second duration provides a time window for the Kentucky Transportation Cabinet: if a pavement condition enters the second stage, how long is the window opportunity for resurfacing before it starts to deteriorate dramatically.

The challenge of using a standard regression analysis is the existence of censored observations, which means the response variable, the failure time, is only partially observed. There are totally three censoring mechanisms: left, right, and interval. Since continuous records are available for test sections in the Kentucky's pavement management system, only right censoring is encountered. The right censoring is caused by the fact that some pavement sections were resurfaced before their conditions enter the second stage. For example, if a pavement section of age t was resurfaced with condition points less than the largest condition points for stage one, the only information it provides is that the section can last at least t years, but the exact duration in the stage one is unobserved. The censored data can be handled by survival models. Survival models also provide other advantages. In a standard regression, the error term is usually assumed to be normally distributed, while the survival model can choose a different probability distribution, which may be more realistic.

One stage survival analysis has been previously used in pavement performance modeling. The Highway Design and Maintenance Standards Study (HDM), initiated by the World Bank, employed survival analysis to predict the initiation of fatigue cracking in the HDM-III model (Paterson & Chesher, 1986) (Paterson, 1987). The AASHO road test data was reanalyzed by Prozzi and Madanat using survival analysis and the result indicated the survival model is more appealing than the original equation (2000). The methods were also used to investigate the performance of the Illinois freeway system (Gharaibeh, et. al, 1997).

Based on the patterns of pavement condition development and the censored pavement management data, this research developed staged survival models for the first two condition stages. Two predominant types of resurfacing programs were analyzed, which are AC overlays over existing AC pavements and AC overlays over fractured PCC pavements.

4.3 Estimation of the Survival Models

4.3.1 Semiparametric and Parametric Survival Models

Like the standard regression models, the survival models consist of a systematic component and an error component. The systematic component is used to assess how the measured and interested variables affect the response variables on the average. However, since not all of the variations can be captured by the systematic component, the unexplained variations are left for the error component, usually represented by a probabilistic distribution. The specification of a survival model requires choosing both the systematic and error components. Depending on the choice of the error component, the commonly used survival models can be categorized as semiparametric models and parametric models. If only the systematic component is of interest, one could use the semiparametric model, for instance, the proportional hazards model (Cox, 1972). If both the systematic and error components are concerned, as in the case of predicting failure time, one could use a parametric model. One family of parametric models, the accelerated failure time model, assumes the effect of covariates on the failure time is multiplicative. The accelerated failure time model can be expressed as:

$$T = T_0 e^{X\beta} \quad (1),$$

where T_0 is a time point from an baseline distribution (the error component), and X is a vector of covariates (an intercept and pavement performance influencing factors), and β is the coefficients of the covariates. For example, if T_0 is selected to be the median failure time of the baseline distribution, the expected median failure time of a subject with $e^{X\beta} = 5$ will be $5T_0$. In this research, the accelerated failure time models were employed.

4.3.2 Estimation of the Accelerated Failure Time Model

The accelerated failure time model in Equation 1 can be "linearized" by taking a log transformation, as shown in Equation 2:

$$Ln(T) = Ln(T_0) + X\beta = X\beta + \sigma\varepsilon^* \quad (2),$$

where σ is a scale parameter and ε^* is a random error term.

Although the transformed equation is akin to the ordinary linear model, due to the censored data and possible non normal distribution of the error term $Ln(T_0)$, the ordinary least square estimation cannot be used. In stead, the maximum likelihood estimation (MLE) method is used to estimate the unknown parameters.

Assuming the dependent variable y_i (for example, $Ln(T)$ in equation 2) is a function of θ and X_i, where θ is an unknown parameter to be estimated and y_i and X_i are observed data, the likelihood for the observation i can be expressed as $L_i = p(y_i \mid \theta, X_i)$. The likelihood function represents the conditional probability of observing y_i given θ and X_i. The maximum likelihood estimation procedure is to find the unknown parameter θ that maximizes the following likelihood function: $L = L_1 \times L_2 \times ... \times L_n$. Thus, the probability of observing all the response variables with the independent variables is the highest among all the possible parameter values.

For an observation in the survival analysis, if it is not censored (the failure time is observed), its likelihood function can be the probability density function of failure time $f(\beta, X_i)$. If an observation is right censored, since its failure time is unknown, one cannot use the probability density function. However, the right censored observation provides information that it can survive at least to certain time. This piece of information can be captured by the survival function $S(\beta, X_i)$. The survival function is defined by $S(T) = P(T > t)$, which is the probability that an individual does not fail within time *t*. By using the survival function, the right censored observations can also contribute to the likelihood function. Although left and interval censored observations were not encountered in this research, other likelihood functions can also be constructed for them. The likelihood function is usually transformed to the log-likelihood function for easier estimation, often using numerical methods.

4.4 Model Development

4.4.1 Exogenous Variables

As mentioned previously, survival models were developed for the two stages of the two types of resurfacing separately: AC over existing AC and AC over fractured PCC. For the first stage of the AC over existing AC pavements, the following predictor variables were initially selected: resurfacing thickness, existing thickness of dense graded aggregate base plus the thickness of fractured PCC (if applicable), pavement condition points before rehabilitation, annual average of the average daily traffic (ADT), Interstate or Parkways (as a categorical variable), and thickness of existing AC. Since some pavement sections may be resurfaced several times, besides using the existing AC thickness directly, the thickness of different layers constructed at different time was also weighted according to the following two equations:

$$\text{Existing AC1} = \sum_{i=1}^{n} \frac{\text{Thickness of Layer i}}{\text{Age of Layer i before Resurfacing}} \quad (3)$$

$$\text{Existing AC1} = \sum_{i=1}^{n} \frac{\text{Thickness of Layer i}}{\sqrt{\text{Age of Layer i before Resurfacing}}} \quad (4)$$

These two new variables and the unweighted thickness of existing AC were tried separately in regression.

For the second stage of AC resurfacing over the existing AC pavements, besides the variables used in stage one, pavement age at the end of stage one was also used.

For the first stage model of the AC resurfacing over fractured PCC, the following predictor variables were initially selected: resurfacing thickness, existing thickness of the dense graded aggregate base plus the thickness of fractured PCC, condition points of PCC pavements before fracture, the average value of ADT, and Interstate or Parkways (as a categorical variable).

For the second stage model of the AC resurfacing over fractured PCC, pavement age at the end of stage one and the other predictor variables from Stage One were used

4.4.2 Baseline Distribution of Failure Time

In using the parametric survival model, the baseline distribution of failure time *t* needs to be identified. Ideally, the baseline distribution should be decided by observed physical distress development patterns or by experiments. A commonly used baseline distribution for pavement cracking (Paterson, 1987) or pavement deterioration (Prozzi, et. al, 2000) is the Weibull distribution. In choosing an baseline distribution, people usually examine if the hazard function of this distribution is reasonable.

The term "hazard" refers to the risk of "failure" in an interval after time t, conditional on the subject having survived to time t. If the distribution is continuous, the hazard function can be expressed as

$$h(t) = \lim_{\Delta t \to 0} \frac{P(T < t + \Delta t \mid T \geq t)}{\Delta t} \text{(5).}$$

The shape of the hazard function for the exponential distribution is a horizontal straight line, which is often thought unrealistic because it means the probability of failure is irrelevant of pavement age. One argument of using the Weibull distribution is its hazard function could increase with age (Paterson, 1987). However, this may not be true for all the shapes of the Weibull hazard functions. In addition, depending on the shape factors, the hazard functions of other distributions may also increase over time. To avoid misspecifying the baseline distribution function, Lawless states that the current trend in employing the parametric survival model is to use a more general form of distribution (Lawless, 2002). However, if two models perform similarly, it is generally preferable to use a simpler model. The regression application in this research is the LIFEREG procedure in the SAS software. The supported baseline distributions are: Exponential, Weibull, Lognormal, Generalized Gamma, and Loglogistic. A model is said to be nested within another model if the first model is a special case of the second. For example, the exponential model is nested within both the Weibull and the Gamma models. The Weibull distribution and Lognormal distribution are nested within a Generalized Gamma distribution. The likelihood-ratio test can be used to compare the nested models. In addition, graphical methods can be used to compare the fitness of different models.

The technique in this research is to try different assumptions, and then select the appropriate distribution by using the likelihood-ratio test for comparing nested models and by using a graphical technique to check the fitness of all the models. The procedure is explained by developing the first stage model of AC resurfacing over AC pavements.

4.4.3 Model Selection Using the Duration of the First Stage of AC over Existing AC as an Example

For AC resurfacing over existing AC pavements, to estimate the duration of the first stage, different combinations of independent variables were attempted. Independent variables that are significant or marginally significant at the 5% significance level in most of the models were finally selected. The maximum likelihood values for different models are listed in the following table.

Model	Maximum Likelihood
Generalized Gamma	-95.9
Weibull	-96.4
Lognormal	-99.3
Exponential	-180.8
Loglogistic	-98.1

Table 4.1 Maximum Likelihood Values of Models with Different Distributions

Comparing the Exponential and the Weibull model, the likelihood-ratio Chi-square statistic is -2*(-180.8-(-96.4)) = 168.8 with one degree of freedom (the critical value is 3.84 at 5% significance level). Therefore, the Weibull model fits the model better than the Exponential model. Similarly, the likelihood ratio tests show that the Generalized gamma model fits the data better than the Lognormal model, but not better than the Weibull model.

The most frequently used graphic method to check the assumption of the distribution and the overall fitness of the model is to use the model-based estimate of the cumulative hazard function to form the Cox-Snell residuals $r_i = H(t_{i,} X_i, \hat{\beta})$ (Hosmer, 2000). If the model is good, the residuals should behave like a censored sample from an exponential distribution with parameter equal to one (Cox &Snell, 1968). The cumulative hazard function of the exponential distribution with parameter 1 is a straight line with a slope of 1. Therefore, if r_i's are plotted as X axis and a nonparametric cumulative hazard estimator of r_i with its censoring indicator is plotted as the Y axis, the plot should be approximately a straight line through the origin and with a slope of 1.

These graphs were plotted for various model assumptions, shown from Figure 4.1 to 4.5. The Kaplan-Meier estimator was used as the nonparametric estimate of the cumulative hazard r_i's. Information on Kaplan-Meier estimation can be found on any survival analysis reference book.

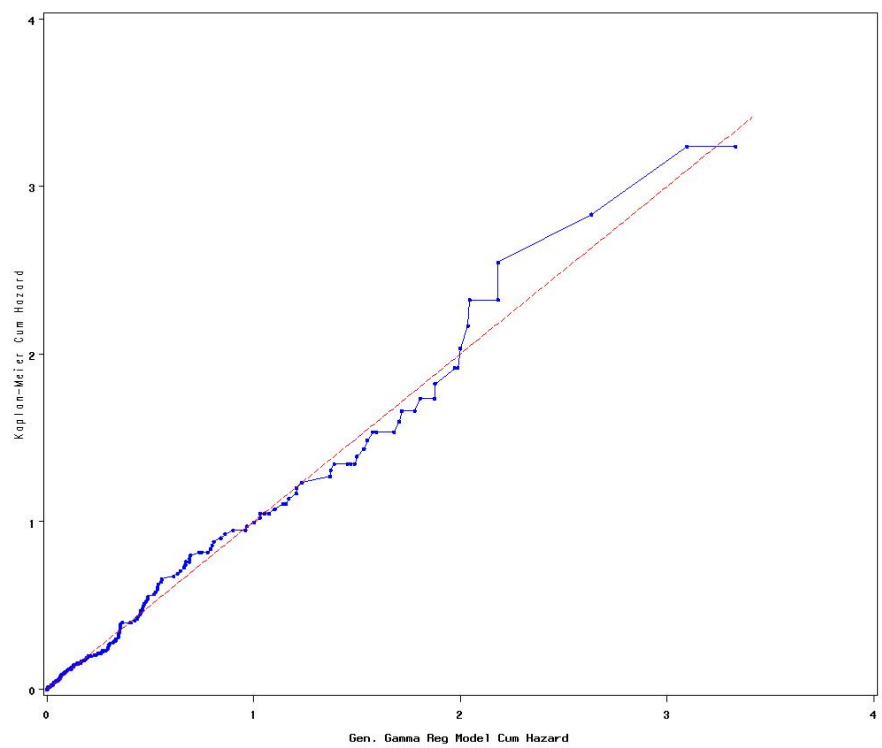

Figure 4.1 Graph of the Kaplan-Meier Estimate of the Cumulative Hazard Versus the Cox-Snell Residuals from the Generalized Gamma Distribution

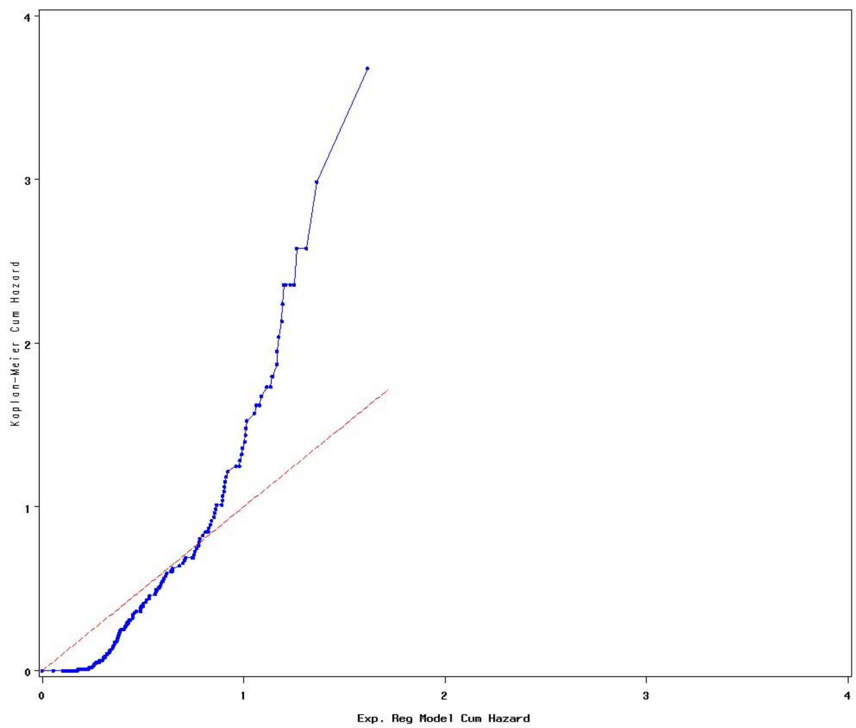

Figure 4.2 Graph of the Kaplan-Meier Estimate of the Cumulative Hazard Versus the Cox-Snell Residuals from the Exponential Distribution

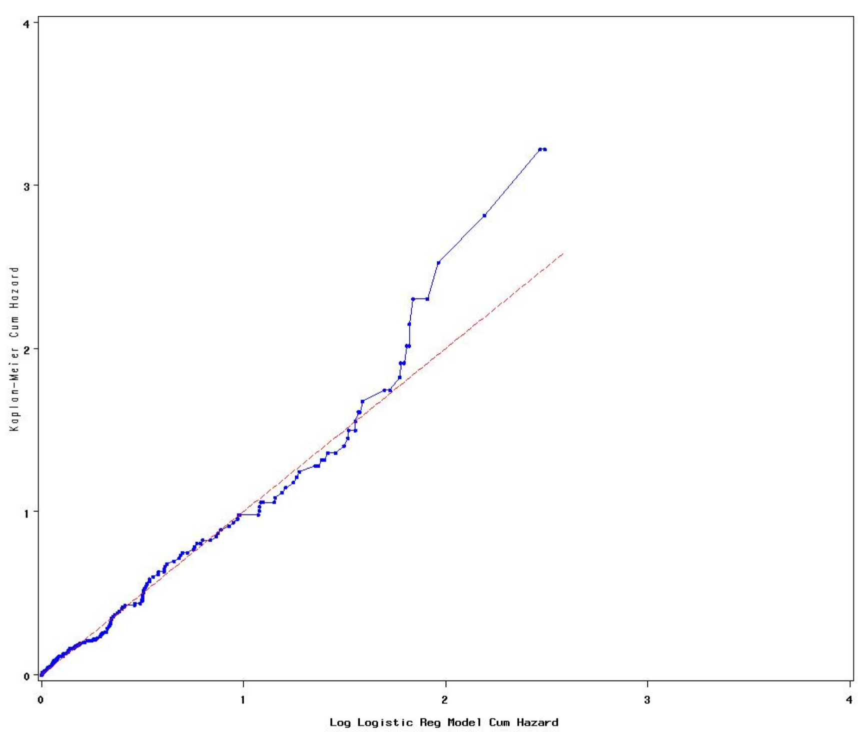

Figure 4.3 Graph of the Kaplan-Meier Estimate of the Cumulative Hazard Versus the Cox-Snell Residuals from the Log Logistic Distribution

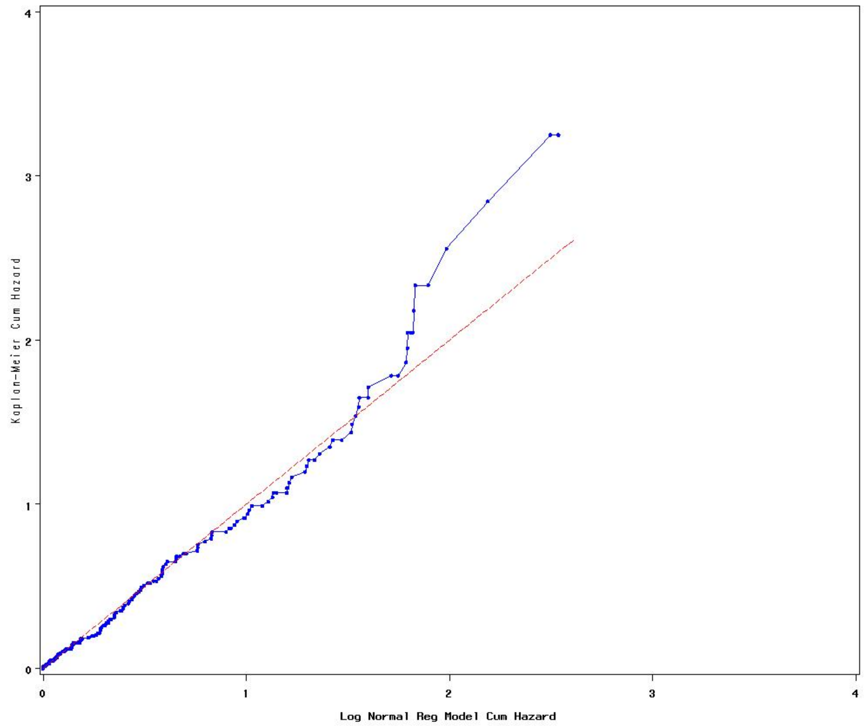

Figure 4.4 Graph of the Kaplan-Meier Estimate of the Cumulative Hazard Versus the Cox-Snell Residuals from the Log Normal Distribution.

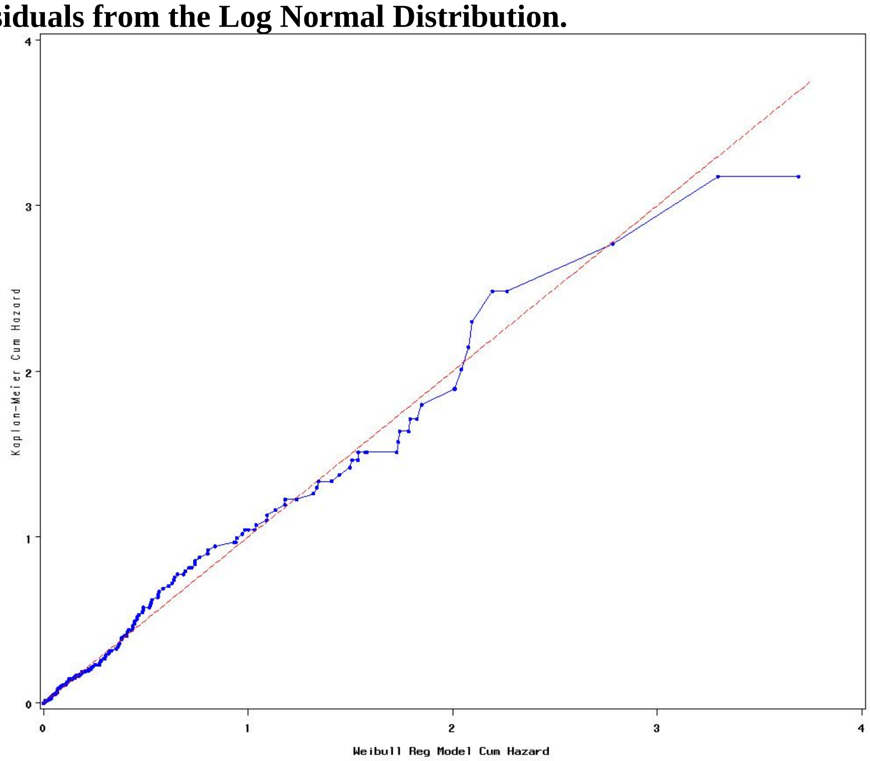

Figure 4.5 Graph of the Kaplan-Meier Estimate of the Cumulative Hazard Versus the Cox-Snell Residuals from the Weibull Distribution.

The plots indicate the Generalized Gamma and Weibull models fit the data better than the rest of the models. Since the Generalized Gamma and the Weibull models perform similarly and the Weibull model is a simpler form, the Weibull model is finally selected.

Table 4.2 lists the statistics for the Weibull model. Although resurfacing AC thickness is marginally insignificant at the 5% significance level, it was included in the final model since it improves the fitness of the overall model. In addition, this predictor variable is significant in the Generalized Gamma model, where the variation of residual is smaller.

Parameter	Meaning	Degree of Freedom	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept		1	2.4093	0.1511	254.33	<.0001
ResurfAc	Resurfacing AC thickness	1	0.0798	0.0466	2.93	0.0868
PreCondPts	Condition points before resurfacing	1	-0.0092	0.0035	6.88	0.0087
IP	Interstate or Parkway (1, interstates; 0 parkways)	1	0.2908	0.1078	7.28	0.007
Scale		1	0.2987	0.0212		
Weibull Shape		1	3.3484	0.2376		

Table 4.2 Statistics for the First Stage Model of AC Overlays over Existing AC

Same analysis procedures were conducted for the second stage of AC resurfacing over existing AC and the two stages of AC over fractured PCC. The research found that for the second stage of AC resurfacing over AC, the Weibull distribution is also an acceptable distribution. Table 4.3 lists the statistics of the parameter estimation for the second stage duration model.

Parameter	Meaning	Degree of Freedom	Estimate	Standard Err.	Chi-Square	Pr > ChiSq
Intercept		1	1.315	0.0947	192.83	<.0001
ResurfAc	Resurfacing AC thickness	1	0.1216	0.0489	6.17	0.013
AvgADT	Average ADT (in thousands)	1	-0.0188	0.0098	3.67	0.0553
Scale		1	0.3452	0.0307		
Weibull Shape		1	2.8967	0.258		

Table 4.3 Statistics for the Second Stage Model of AC Overlays over Existing AC

For the first stage model of AC over fractured PCC, the research found that the log-logistic distribution is the best of all options. Table 4.4 lists the statistics of the parameter estimation for the first stage of the duration model.

Parameter	Meaning	Degree of Freedom	Estimate	Standard Err.	Chi-Square	Pr > ChiSq
Intercept		1	1.7306	0.2423	51.04	<.0001
ResurfAc	Resurfacing AC thickness	1	0.0935	0.0287	10.59	0.0011
AvgADT	Average ADT (in thousands)	1	-0.0037	0.0019	3.93	0.0474
PreCondPts	Condition points before resurfacing	1	-0.0054	0.0028	3.62	0.0572
IP	Interstate or Parkway (1, interstates; 0 parkways)	1	0.5054	0.0722	48.94	<.0001
Scale		1	0.1575	0.0149		

Table 4.4 Statistics for the First Stage Model of AC Over Fracture PCC

For the second stage of AC over fractured PCC, the research found that the model based on the Generalized Gamma distribution best fits the data; however, the model using the Weibull distribution perform similarly. The Weibull distribution was finally selected for simplicity considerations. Table 4.5 lists the statistics of the parameter estimation for the second stage of the duration model.

Parameter	Meaning	Degree of Freedom	Estimate	Standard Err.	Chi-Square	Pr > ChiSq
Intercept		1	1.3096	0.0925	200.52	<.0001
AvgADT	Average ADT (in thousands)	1	-0.0058	0.0028	4.48	0.0342
Scale		1	0.3555	0.0405		
Weibull Shape		1	2.8127	0.3200		

Table 4.5 Statistics for the Second Stage Model of AC Over Fracture PCC

4.5 Application of the Estimated Models

The models can be used to predict the percentiles or other quartiles of duration for each stage of the two types of overlays. Only the prediction of median values was reported in this research, since it is was of the greatest interest. To estimate the other quartiles, one only needs to change the time T_0 in equation 1. Furthermore, to make the model easier to use, the median value of the underlining distribution is multiplied by the $e^{Intercept}$ to form a constant. Subjects with different independent variables are proportional to this constant.

The models used to predict the median values of durations for AC resurfacing over existing AC are shown in the Table 4.6.

AC Resurfacing Over Existing AC Pavements	
Stage 1	Stage 2
$T = 9.97e^{0.079 \operatorname{Re}surfAc - 0.0092 \operatorname{Pr}eCondPts + 0.29 IP}$	$3.28e^{0.122 \operatorname{Re}surfAc - 0.0188 AvgADT}$

Table 4.6 Equations for Predicting Median Survival Time of Stage One and Stage Two for AC Resurfacing Over Existing AC Pavements

The models used to predict the median values of duration for AC resurfacing over fractured PCC are shown in the Table 4.7.

AC Resurfacing Over Fractured PCC Pavements	
Stage 1	Stage 2
$T = 5.64e^{0.094\,\mathrm{Re}\,surfAc - 0.0037\,AvgADT - 0.0054\,\mathrm{Pr}\,eCondPts + 0.51\,IP}$	$T = 3.25e^{-0.0058\,AvgADT}$

Table 4.7 Equations for Predicting Median Survival Time of Stage One and Stage Two for AC Resurfacing Over Fractured PCC Pavements

Here is an example of how to use these models to predict the median values. For AC resurfacing over existing AC, if the AC overlay is 3 inches, the condition points before resurfacing is 34, and the pavement section is on Interstate, then the predicted duration in the first stage is

$$T = 9.97e^{0.079\times3-0.0092\times34+0.29} = 12 \text{ years.}$$

The predicted value means that for this particular pavement section, it is most likely to last 12 years during the first stage, i.e., before scheduling another overlay. Assume the average ADT is 10,000, then

$$T_2 = 3.28e^{0.122\times3-0.0188\times10} = 4 \text{ years.}$$

This means the pavement section will stay in stage 2 for approximately four years, which is the time window for the DOT to apply another overlay before the pavement condition deteriorates very rapidly.

The model can also be used to analyze the influence of different variables on pavement service life. For example, for the first stage of AC pavements over fractured PCC, an increase of one inch of AC thickness will result in a 1.1 time increase of pavement life (in stage one). On the other hand, the increase of one in condition points will result in the pavement life decreased by 0.5% on average. Other variables in the model can be explained similarly.

4.6 Limitation of the Models

The developed models are based on the historical data from the current Kentucky Pavement Management System. These models may not best reflect the relationship between pavement lives and influencing factors. The deficiency of the model is primarily due to the lack of some important data items. For example, the only traffic information used in the model is the average ADT. However, the cumulative Equivalent Single Axle Loads (ESALs), AADT, percent of trucks may provide more information. Additionally, the use of condition points as thresholds and predictor variables may not reflect the individual development pattern of certain major types of distresses.

CHAPTER 5 SUMMARY AND RECOMMENDATIONS

5.1 Summary and Conclusions

A comprehensive analysis of the historical pavement management data was conducted by this research. Thresholds of pavement rideability index, condition points, rut depth, and age before rehabilitation or maintenance were summarized. The historical data show large variations of these actual thresholds. This may impact the optimization of allocating resources and the effectiveness of treatments.

A literature review was conducted to determine the state of the art in determining a standard threshold for maintenance and rehabilitation. Thresholds based on serviceability, cost analysis, and preventative protection of existing pavement structures are summarized in this research. In Kentucky, PCC pavements are primarily maintained or rehabilitated based on rideability. Therefore, a uniform definition and usage of the critical roughness values are required in order to standardize the current pavement management practice. AC pavements are primarily resurfaced based on distress conditions. Therefore, the selection of thresholds should be based on protecting the integrity of pavement structures.

The trends of the AC pavement distress, represented by condition points, were analyzed using the historical data. The trend indicated that the development of condition points can be divided into three stages. At the first stage, the condition deteriorates slowly. At the second stage, the condition deteriorates moderately. At the third stage, the condition deteriorates very quickly.

Staged survival models were developed for the first two stages of two types of resurfacing programs: AC overlay over existing AC pavements and AC overlays over fractured PCC. The models can be used to predict the duration of a pavement in each stage. The models can also be used to check the effectiveness of treatments, i.e., the influence of AC thickness on pavement service life. Additionally, the models can help investigate the influence of other variables such as traffic, existing pavement conditions, etc., on pavement performance. The overall fit of the model is good.

5.2 Recommendation and Future Studies

It is recommended that the variation of criteria in deciding the critical pavement conditions for maintenance and rehabilitation consideration should be reduced in the future. For PCC pavements, maintenance and rehabilitation were historically based on roughness; therefore, a consistent roughness threshold should be used. One possible threshold is the pavement condition criteria (based on IRI) defined by the FHWA. For AC pavements, roughness is not a good indicator, since the majority of pavements were resurfaced when the roughness condition is still acceptable. Therefore, for AC pavements, maintenance and rehabilitation should be scheduled according to distress conditions.

The currently used distress indicator is the comprehensive distress index called condition points. The research found that the distress developments of AC resurfacing can be divided into three stages. It is recommended that rehabilitation should be scheduled during the second stage. The time window of the second stage is usually very short, which can be estimated by the survival models developed in this research.

Using the survival models developed in this research, a probabilistic life cycle cost analysis can be performed. The survival models provide the most likely failure time of a resurfaced AC pavement under the influence of treatments, traffic, previous conditions, etc. If needed, for each combination of performance influencing factors, a distinctive probabilistic distribution can be developed by the survival models.

Although Condition Points is a comprehensive indicator of the overall pavement conditions, to identify the specific types of distresses, find the causes of the distresses, and determine optimum strategies to address them, a more detailed recording of distress is required.

It is also recommended that more data items be included in the pavement management system, for example, the ESALs, traffic volume, percent of trucks, major material characteristics, and other pavement performance influencing factors. The additional information would help increase the accuracy of pavement performance prediction models as well as identify good and bad practices. It is recognized that some information was already available, probably in different sources. Therefore, continuous efforts should be made to integrate the relevant data from different sources.

Some of the recommendations mentioned above will be addressed in other research projects.

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Appendix A. Analyzed Original AC Pavement Sections

Appendix A. Analyzed Original AC Pavement Sections

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	INTERSTATE (I) OR PARKWAYS (P)	SURF_AGE
I24-2-1.07to4.41	3.45	7.00	36.60	recorded	I	13.77
I24-4-1.07to4.41	3.55	8.00	36.30	recorded	I	13.77
I24-2-4.41to7.36	3.58	7.00	36.70	recorded	I	10.78
I24-4-4.41to7.36	3.63	9.00	34.80	recorded	I	10.78
I24-2-7.36to11.03	3.70	7.00	35.90	recorded	I	10.78
I24-4-7.36to11.03	3.57	9.00	37.20	recorded	I	10.78
I24-2-13.8to16.27	3.94	12.00	33.00	recorded	I	10.78
I24-4-13.8to16.27	3.95	12.00	29.50	recorded	I	10.78
I24-2-16.27to22.04	3.96	7.00	25.90	recorded	I	7.03
I24-4-16.27to22.04	3.37	.00	53.40	recorded	I	4.79
I24-2-22.04to26.55	3.96	7.00	26.70	recorded	I	7.66
I24-4-22.04to26.55	3.93	8.00	27.30	recorded	I	7.66
I24-2-26.55to29.13	3.69	9.00	31.50	recorded	I	9.70
I24-4-26.55to29.13	3.74	9.00	26.50	recorded	I	9.70
I24-2-29.54to30.33	4.08	2.00	25.30	recorded	I	9.78
I24-4-29.54to30.33	4.06	.00	23.80	recorded	I	9.78
I24-2-30.33to33.66	3.61	7.00	38.10	recorded	I	10.02
I24-4-30.33to33.66	3.58	8.00	40.50	recorded	I	10.02
I24-2-33.98to39.5	3.64	9.00	35.70	estimated	I	6.74
I24-4-33.98to39.5	3.68	9.00	38.50	estimated	I	6.74
I24-2-39.5to41.6	3.54	10.00	39.20	estimated	I	6.15
I24-4-39.5to41.6	3.29	10.00	53.70	estimated	I	6.15
I24-2-41.6to45.13	3.65	9.00	34.50	estimated	I	6.15
I24-4-41.6to45.13	3.58	9.00	41.00	estimated	I	6.15
I64-2-89.48to94.23	3.17			missing	I	8.67
I64-4-89.48to94.23	3.11			missing	I	8.67
I64-2-94.23to101.73	3.34			missing	I	10.92
I64-4-94.23to101.73	3.11			missing	I	10.92
I64-2-101.73to112.3	3.17			missing	I	10.84
I64-4-101.73to112.3	3.00			missing	I	10.84
I64-2-146.1to148.66	3.40	4.00	33.60	recorded	I	11.92
I64-2-148.66to154.21	3.40	4.00	33.60	recorded	I	11.92
I64-4-146.1to154.21	3.11	6.00	44.10	recorded	I	11.92
I64-2-154.21to160.86	3.46	4.00	31.10	recorded	I	11.92
I64-4-154.21to160.86	3.28	6.00	38.60	recorded	I	11.92
I64-2-160.86to166.21	3.51	.00	45.30	recorded	I	13.00
I64-4-160.86to166.21	3.39	.00	46.90	recorded	I	13.00
I64-2-166.21to171.3	3.17	6.00	40.40	recorded	I	11.92
I64-4-166.21to171.3	3.43	6.00	31.60	recorded	I	11.92
I64-2-171.3to180.81	3.46	6.00	32.70	recorded	I	8.00
I64-4-171.3to180.81	3.57	6.00	31.60	recorded	I	8.00
I64-2-180.81to185.46	2.66	6.00	60.80	recorded	I	16.92
I64-4-180.81to185.46	3.00	6.00	49.20	recorded	I	16.92
I64-2-185.46to191.38	2.77	6.00	53.10	recorded	I	16.92
I64-4-185.46to191.38	3.06	8.00	46.00	recorded	I	16.92
I65-1-61.12to64.2	3.47	2.00	36.60	recorded	I	15.61

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	INTERSTATE (I) OR PARKWAYS (P)	SURF_AGE
I65-3-61.12to64.2	3.33	.00	32.80	recorded	I	15.61
I65-1-64.2to70.4	3.52	8.00	35.00	recorded	I	17.69
I65-3-64.2to70.4	3.47	.00	37.10	recorded	I	17.69
I65-1-70.4to76.1	3.32	7.00	54.70	recorded	I	17.78
I65-3-70.4to76.1	3.26	9.00	56.90	recorded	I	17.78
I65-1-90.58to93.69	3.63	.00	14.30	recorded	I	.24
I65-3-90.58to93.69	3.76	.00	10.10	recorded	I	.24
I65-1-93.69to95.12	3.85	2.00	7.30	recorded	I	1.24
I65-3-93.69to95.12	3.89	.00	6.90	recorded	I	1.24
I75-1-50.87to55.74	3.80			missing	I	7.88
I75-3-50.87to55.74	3.74			missing	I	7.88
I75-1-55.74to58.95	3.80			missing	I	7.88
I75-3-55.74to58.95	3.74			missing	I	7.88
I75-1-58.95to65.22	3.86			missing	I	6.41
I75-3-58.95to65.22	3.97			missing	I	6.41
I75-1-86.25to97.54	3.63			missing	I	7.92
I75-3-86.25to97.54	3.57			missing	I	7.75
I75-1-97.85to100.32	3.68			missing	I	6.75
I75-3-97.85to100.32	3.62			missing	I	6.75
WK9001-2-3.7to9.91	3.10	7.00	51.10	estimated	P	22.60
WK9001-4-3.7to9.91	3.38	8.00	45.20	recorded	P	21.70
WK9001-2-9.91to14.85	3.51			missing	P	6.00
WK9001-4-9.91to14.85	3.51			missing	P	6.00
WK9001-2-14.85to18.26	3.62			missing	P	5.75
WK9001-4-14.85to18.26	3.62			missing	P	5.75
WK9001-2-18.26to25.64	3.51			missing	P	5.75
WK9001-4-18.26to25.64	3.51			missing	P	5.75
WK9001-2-116.95to119.64	2.93			missing	P	15.98
WK9001-4-116.95to119.64	3.46			missing	P	15.98
WK9001-2-119.64to123.47	3.14			missing	P	15.98
WK9001-4-119.64to123.47	3.58			missing	P	15.98
WK9001-2-123.47to130.94	3.39			missing	P	15.82
WK9001-4-123.47to130.94	3.69			missing	P	15.81
WK9001-2-130.94to136.06	3.52			missing	P	15.98
WK9001-4-130.94to136.06	3.61			missing	P	15.98
BG9002-2-0to9.52	3.71			missing	P	13.90
BG9002-4-0to4.9	3.93			missing	P	13.90
BG9002-4-4.9to10.17	3.75			missing	P	13.90
BG9002-2-9.52to16.54	4.04			missing	P	13.90
BG9002-4-10.17to16.54	3.64			missing	P	13.90
BG9002-2-16.54to24.24	3.86			missing	P	13.90
BG9002-4-16.54to24.24	3.55			missing	P	13.90
BG9002-2-59.59to61.84	3.23	6.00	46.00	recorded	P	16.09
BG9002-4-59.59to61.84	3.40	6.00	39.40	recorded	P	16.09

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	INTERSTATE (I) OR PARKWAYS (P)	SURF_AGE
BG9002-2-62.04to71.13	3.23	6.00	46.00	recorded	P	16.09
BG9002-4-62.04to67	3.40	6.00	39.40	recorded	P	16.09
BG9002-4-67to71.13	3.40	6.00	39.40	recorded	P	16.09
PU9003-1-0to1.78	2.88	5.00	60.40	recorded	P	15.58
PU9003-3-0to1.78	2.85	6.00	66.10	recorded	P	15.58
PU9003-1-1.78to9.07	3.44	14.00	61.80	recorded	P	16.58
PU9003-3-1.78to9.07	3.34	4.00	64.50	recorded	P	18.61
PU9003-1-9.07to13.64	3.43	9.00	42.50	recorded	P	18.61
PU9003-3-9.07to13.64	3.27	8.00	47.60	recorded	P	18.61
PU9003-1-13.64to21.88	3.55	7.00	37.30	recorded	P	18.61
PU9003-3-13.64to21	3.31	8.00	46.70	recorded	P	18.61
PU9003-1-21.88to25.38	3.39			missing	P	3.75
PU9003-3-21to25.38	3.39			missing	P	3.75
PU9003-1-25.38to39.92	3.43	6.00	42.10	recorded	P	22.60
PU9003-3-25.38to39.92	3.40	6.00	50.30	recorded	P	19.68
PU9003-1-39.92to52.33	3.48	6.00	42.00	recorded	P	21.69
PU9003-3-39.92to52.33	3.48	7.00	45.40	recorded	P	21.69
DB9006-2-44.35to45.37	2.70	10.00	50.50	recorded	P	10.72
DB9006-4-44.35to45.37	3.11	10.00	39.50	recorded	P	10.72
DB9006-2-45.37to51.02	3.39	10.00	34.30	recorded	P	10.72
DB9006-4-45.37to51.02	3.43	7.00	27.90	recorded	P	10.72
DB9006-2-51.02to57.16	3.39	10.00	34.30	recorded	P	10.72
DB9006-4-51.02to57.16	3.43	7.00	27.90	recorded	P	10.72
DB9006-2-57.16to59.08	3.16	10.00	38.90	recorded	P	10.72
DB9006-4-57.16to59.08	3.19	7.00	32.70	recorded	P	10.72
WN9007-1-0to7.1	2.49			missing	P	.00
WN9007-3-0to7.1	2.38			missing	P	.00
WN9007-1-7.1to17.8	2.60			missing	P	.00
WN9007-3-7.1to17.8	2.44			missing	P	.00
WN9007-1-17.8to26.42	2.77			missing	P	.00
WN9007-3-17.8to26.42	2.77			missing	P	.00
WN9007-1-26.42to32.64	2.66			missing	P	.00
WN9007-3-26.42to32.64	2.71			missing	P	.00
LN9008-2-0to9.3	3.34			missing	P	.00
LN9008-4-0to8.17	3.11			missing	P	.00
LN9008-2-9.3to16	2.21			missing	P	.00
LN9008-4-8.17to16	2.09			missing	P	.00
LN9008-2-16to24.09	3.17			missing	P	.00
LN9008-4-16to24.09	3.34			missing	P	.00
LN9008-2-24.09to33.36	2.94			missing	P	.00
LN9008-4-24.09to33.36	2.32			missing	P	.00
LN9008-2-33.36to36.15	3.44			missing	P	5.94
LN9008-4-33.36to36.15	3.85			missing	P	5.93

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	INTERSTATE (I) OR PARKWAYS (P)	SURF_AGE
LN9008-2-36.15to43.02	3.46			missing	P	5.94
LN9008-4-36.15to43.02	3.75			missing	P	5.93
LN9008-2-43.02to48.08	3.34	3.00	49.70	recorded	P	13.79
LN9008-4-43.02to48.08	3.30	2.00	45.80	recorded	P	13.79
LN9008-2-48.08to53.89	3.16	3.00	50.40	recorded	P	14.82
LN9008-4-48.08to53.89	3.32	2.00	48.70	recorded	P	14.82
LN9008-2-62.5to71.34	3.73	8.00	37.40	recorded	P	18.58
LN9008-2-71.34to76.55	3.61	9.00	34.30	recorded	P	17.44
LN9008-4-71.34to76.55	3.46	9.00	39.60	recorded	P	21.51
LN9008-2-76.55to84.3	3.38	8.00	45.90	recorded	P	16.54
LN9008-4-76.55to84.3	3.31	8.00	44.80	recorded	P	17.44
LN9008-2-84.64to88.54	3.37	9.00	49.70	recorded	P	16.54
LN9008-4-84.64to88.54	3.29	9.00	51.50	recorded	P	16.54
KY9009-2-43.1to49.67	3.05			missing	P	8.75
KY9009-4-43.1to49.67	3.05			missing	P	8.75
KY9009-2-49.67to55.43	3.17			missing	P	8.75
KY9009-4-49.67to55.43	3.05			missing	P	8.75
KY9009-2-55.43to59.5	2.94			missing	P	8.75
KY9009-4-55.43to59.5	3.28			missing	P	8.75
KY9009-2-59.5to63.08	3.17			missing	P	8.75
KY9009-4-59.5to63.08	3.28			missing	P	8.75
KY9009-2-63.08to67.4	2.94			missing	P	8.75
KY9009-4-63.08to67.4	3.05			missing	P	8.75
KY9009-2-67.4to71.65	2.49			missing	P	8.75
KY9009-4-67.4to71.65	2.60			missing	P	8.75
KY9009-2-71.65to74.5	2.71			missing	P	8.75
KY9009-4-71.65to74.5	2.71			missing	P	8.75
KY9009-2-74.5to75.31	2.71			missing	P	8.75
KY9009-4-74.5to75.31	2.71			missing	P	8.75
KY9009-2-75.31to75.62	2.71			missing	P	8.75
KY9009-4-75.31to75.62	2.71			missing	P	8.75

Appendix B. Analyzed PCC Pavement Sections (Rehabilitation)

Appendix B. Analyzed PCC Pavement Sections (Rehabilitation)

SECTION	AVG_RI	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
BG9002-2-34.94to39.26	2.91	61.50	estimated	33.82	p
BG9002-2-39.26to41.79	2.44	66.70	estimated	20.64	p
BG9002-2-41.79to44.8	2.75	64.40	recorded	18.71	p
BG9002-2-44.8to47.69	2.83	62.20	recorded	18.71	p
BG9002-2-47.69to51.83	2.88	59.60	recorded	19.70	p
BG9002-2-56.28to59.59	2.36	59.00	estimated	33.33	p
BG9002-4-34.94to39.26	2.98	50.10	estimated	33.82	p
BG9002-4-39.26to41.79	2.52	71.30	estimated	20.64	p
BG9002-4-41.79to44.8	2.89	55.70	recorded	18.71	p
BG9002-4-44.8to47.69	2.99	54.70	recorded	18.71	p
BG9002-4-47.69to51.83	2.93	45.30	recorded	19.70	p
BG9002-4-51.83to56.28	2.48	62.10	recorded	28.67	p
BG9002-4-56.28to59.59	2.62	61.90	recorded	26.74	p
DB9006-2-28.4to31	2.82	44.60	both ri and cp estimated	24.00	p
DB9006-4-28.4to31	2.29	71.60	estimated	24.00	p
EB9004-1-10.7to12.13	3.03	56.10	recorded	25.78	p
EB9004-1-39.79to46.1	2.50	61.30	recorded	32.03	p
EB9004-1-53.11to61.85	2.46	61.10	estimated	16.92	p
EB9004-1-6.77to10.7	2.99	40.70	recorded	25.61	p
EB9004-1-61.85to65.39	1.73	76.80	recorded	17.95	p
EB9004-1-65.39to70.45	1.72	71.80	recorded	24.94	p
EB9004-3-10.7to16.5	3.08	25.00	recorded	25.78	p
EB9004-3-29.91to31.36	3.28		missing	26.03	p
EB9004-3-32.86to35.55	3.42		missing	26.03	p
EB9004-3-35.55to37.07	3.03		missing	27.03	p
EB9004-3-37.07to46.1	2.74	56.50	recorded	33.88	p
EB9004-3-53.11to61.85	2.45	75.00	estimated	21.93	p
EB9004-3-6.77to10.7	2.80	59.60	estimated	30.31	p
EB9004-3-61.85to65.39	2.28	69.70	recorded	17.95	p
EB9004-3-65.39to70.45	2.56	57.60	recorded	24.94	p
I264-2-20.7to22.61	3.07	29.30	recorded	13.93	i
I264-2-22.61to23.24	2.61	51.90	estimated	18.95	i
I264-4-20.7to22.61	2.93	38.20	recorded	13.93	i
I264-4-22.61to23.24	2.48	54.90	estimated	18.95	i
I265-1-23.36to25.35	2.54	64.80	recorded	26.85	i
I265-1-25.35to26.6	2.19	77.20	recorded	28.93	i
I265-3-23.36to25.35	2.38	66.90	recorded	26.84	i
I265-3-25.35to26.6	2.23	71.70	recorded	28.93	i
I64-2-112.3to117.83	2.64	57.00	estimated	30.84	i
I64-2-13.16to14.89	3.29	48.80	estimated	23.70	i
I64-2-134.75to138.4	2.39	64.50	recorded	27.83	i
I64-2-14.89to18.88	3.21	43.00	recorded	22.77	i
I64-2-18.88to25.09	2.05	69.70	estimated	21.69	i
I64-2-25.09to31.84	2.24	74.40	estimated	21.69	i
I64-2-31.84to38.18	2.75	65.20	estimated	20.86	i
I64-2-4.95to5.54	3.10	32.20	recorded	14.08	i

SECTION	AVG_RI	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
I64-2-43.33to47.74	3.16		missing	17.13	i
I64-2-47.74to53.11	3.76		missing	17.13	i
I64-2-5.54to8.18	3.38	29.10	recorded	14.72	i
I64-2-53.11to57.84	2.23	63.20	estimated	36.26	i
I64-2-64.96to71	2.67	66.60	recorded	20.80	i
I64-2-71to75.2	2.80	57.70	recorded	20.80	i
I64-2-82.32to85.38	2.71	56.50	recorded	33.54	i
I64-2-85.38to89.48	2.64	57.00	recorded	32.58	i
I64-4-112.3to117.83	2.68	54.00	estimated	30.84	i
I64-4-13.16to14.89	3.48	42.60	estimated	23.70	i
I64-4-134.75to138.4	2.55	62.80	recorded	27.91	i
I64-4-14.89to18.88	3.28	36.50	recorded	22.77	i
I64-4-18.88to25.09	2.56	54.70	recorded	20.85	i
I64-4-25.09to31.84	2.66	56.20	recorded	20.85	i
I64-4-31.84to38.18	2.66	55.30	estimated	20.01	i
I64-4-4.95to5.54	3.02	33.40	recorded	14.72	i
I64-4-43.33to47.74	3.12		missing	17.13	i
I64-4-47.74to53.11	3.76		missing	17.13	i
I64-4-5.54to8.18	3.16	28.20	recorded	14.72	i
I64-4-53.11to57.84	2.55	65.00	estimated	36.26	i
I64-4-64.96to71	2.65	59.20	recorded	20.80	i
I64-4-71to74.72	2.55	63.40	recorded	20.80	i
I64-4-82.32to85.38	2.74	56.90	recorded	33.56	i
I64-4-85.38to89.48	2.73	57.20	recorded	32.66	i
I65-1-12.81to21.92	4.10	22.30	recorded	15.95	i
I65-1-131.28to136.72	2.80		missing	7.99	i
I65-1-21.92to25.75	2.89	61.80	recorded	29.60	i
I65-1-25.75to33.18	2.72	67.50	recorded	29.60	i
I65-1-42.61to46.88	2.54	65.50	recorded	24.10	i
I65-1-46.88to49.65	3.13	56.00	recorded	24.70	i
I65-1-51.9to58.09	3.42	43.50	estimated	18.80	i
I65-1-58.09to61.12	2.37	75.00	both ri and cp estimated	31.00	i
I65-1-76.1to78.66	3.54	28.00	recorded	19.68	i
I65-1-78.66to85.59	3.21	40.00	recorded	23.52	i
I65-1-85.59to90.58	2.69	60.00	recorded	23.52	i
I65-3-12.81to21.92	3.89	28.50	recorded	15.95	i
I65-3-131.28to136.72	2.56		missing	7.99	i
I65-3-21.92to25.75	2.66	69.40	recorded	29.60	i
I65-3-25.75to33.18	3.01	57.00	recorded	29.60	i
I65-3-33.18to35.56	2.99	61.60	recorded	26.61	i
I65-3-42.61to46.88	2.38	75.80	recorded	24.10	i
I65-3-48.5to51.9	2.78	66.70	recorded	26.76	i
I65-3-51.9to58.09	3.68	35.50	recorded	18.79	i
I65-3-58.09to61.12	2.31	73.00	both ri and cp estimated	31.00	i
I65-3-76.1to78.66	3.40	30.40	recorded	19.68	i
I65-3-78.66to85.59	3.28	33.20	recorded	23.52	i
I65-3-85.59to90.58	3.13	41.50	recorded	23.52	i
I71-1-0to5.55	3.15	55.70	estimated	18.97	i

SECTION	AVG_RI	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
I71-1-21.55to28.17	3.15	43.30	recorded	14.05	i
I71-1-28.17to37.18	2.48	49.90	recorded	14.22	i
I71-1-43.94to56.67	2.29	77.30	recorded	15.55	i
I71-1-5.55to9.06	3.36	33.60	recorded	14.89	i
I71-1-56.67to61.77	2.56	50.60	recorded	13.67	i
I71-1-61.77to69.89	2.59	58.50	recorded	13.67	i
I71-1-69.89to77.72	2.76	59.60	recorded	15.54	i
I71-1-9.06to21.55	3.28	46.90	recorded	14.05	i
I71-3-0to5.55	3.33	48.20	estimated	18.97	i
I71-3-21.38to28.17	3.15	45.40	recorded	14.05	i
I71-3-28.17to31.1	2.57	52.10	recorded	14.22	i
I71-3-31.1to37.18	2.45	52.90	recorded	14.22	i
I71-3-43.94to56.67	2.37	71.70	recorded	15.54	i
I71-3-5.55to9.06	3.14	41.30	recorded	14.72	i
I71-3-56.67to61.77	3.07	48.60	recorded	13.67	i
I71-3-61.77to69.89	2.95	54.90	recorded	13.67	i
I71-3-69.89to77.72	2.86	59.70	recorded	15.54	i
I71-3-9.06to21.38	3.24	44.60	recorded	14.05	i
I75-1-100.32to105.36	3.06	48.40	estimated	33.56	i
I75-1-105.36to110.26	3.23	53.50	estimated	29.73	i
I75-1-111.82to117.8	3.81		missing	15.06	i
I75-1-117.8to122.25	2.79	42.20	estimated	27.71	i
I75-1-122.25to125.52	3.09	35.40	estimated	27.71	i
I75-1-125.52to133.98	2.88	47.70	estimated	28.54	i
I75-1-133.98to137.14	2.41	58.00	estimated	29.50	i
I75-1-137.14to138.78	3.07	45.90	recorded	19.83	i
I75-1-138.78to144.05	3.06	44.50	recorded	19.83	i
I75-1-144.05to154.47	2.84	60.40	recorded	19.59	i
I75-1-154.47to158.54	3.28	42.60	recorded	20.83	i
I75-1-158.54to166.26	3.05	45.00	recorded	21.59	i
I75-1-166.26to174.56	2.27		missing	15.67	i
I75-1-174.56to179.25	2.69		missing	15.87	i
I75-1-179.25to182.38	3.09		missing	17.81	i
I75-1-182.38to183.77	2.63		missing	2.98	i
I75-1-20.2to21.98	2.91	58.10	recorded	22.48	i
I75-1-21.98to23.2		30.30	recorded	15.39	i
I75-1-23.2to24.64	3.21		missing	17.46	i
I75-1-25.26to29.39	2.63	60.20	recorded	27.67	i
I75-1-33.2to41.4	3.67	33.20	recorded	8.32	i
I75-1-48.95to50.71	3.58	26.40	recorded	13.90	i
I75-1-65.22to70.2	3.18	44.50	recorded	18.86	i
I75-1-70.2to78	2.80	61.90	recorded	19.78	i
I75-1-78to83	3.01	53.60	estimated	21.65	i
I75-1-83to86.25	3.11		missing	21.65	i
I75-3-100.32to105.36	3.06	45.90	estimated	33.56	i
I75-3-105.36to110.26	2.80	52.90	estimated	30.76	i
I75-3-111.82to117.8	3.66		missing	15.06	i
I75-3-117.8to122.25	2.88	37.60	estimated	27.71	i

SECTION	AVG_RI	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
I75-3-122.25to125.52	2.87	40.60	estimated	27.71	i
I75-3-125.52to133.98	2.74	49.20	estimated	28.54	i
I75-3-133.98to137.14	2.32	58.00	estimated	29.50	i
I75-3-137.14to138.78	2.77	55.60	recorded	19.83	i
I75-3-138.78to143.23		54.50	estimated	21.17	i
I75-3-143.23to149.98	2.89	58.90	recorded	19.59	i
I75-3-149.98to154.47	3.02	56.10	recorded	19.59	i
I75-3-154.47to158.54	3.33	37.80	recorded	20.83	i
I75-3-158.54to166.26	2.60	55.90	recorded	21.59	i
I75-3-166.26to174.56	2.48		missing	15.67	i
I75-3-174.56to179.25	2.79		missing	15.87	i
I75-3-179.25to182.38	2.93		missing	17.81	i
I75-3-182.38to183.18	2.81	63.80	recorded	22.01	i
I75-3-25.26to29.39	2.71	56.80	recorded	27.67	i
I75-3-33.2to41.4	3.71	29.90	recorded	8.32	i
I75-3-48.95to50.71	3.53	28.50	recorded	13.90	i
I75-3-65.22to70.2	3.36	40.80	recorded	18.86	i
I75-3-70.2to78	2.92	58.00	recorded	19.78	i
I75-3-78to83	3.22	38.50	estimated	21.65	i
I75-3-83to86.25	3.11		missing	21.65	i
KY9000-2-0to3.64	2.99	51.70	recorded	36.81	p
KY9000-2-11.91to16.02	3.07	50.20	recorded	22.56	p
KY9000-2-16.02to19.15	3.53	30.10	recorded	25.61	p
KY9000-2-19.15to22.3	3.09	48.20	recorded	25.61	p
KY9000-2-22.3to27.37	3.51	34.40	recorded	24.65	p
KY9000-2-27.37to32.7	3.29	51.30	estimated	25.61	p
KY9000-2-3.64to11.91	3.04	44.90	recorded	22.56	p
KY9000-2-32.7to36	3.05	57.20	estimated	26.58	p
KY9000-2-36to39.51	3.12	52.80	recorded	26.58	p
KY9000-2-39.51to43.1	2.86	56.50	estimated	27.58	p
KY9000-4-0to3.64	2.60	72.30	recorded	36.81	p
KY9000-4-11.91to16.02	2.97	51.80	recorded	22.56	p
KY9000-4-16.02to19.15	3.41	38.10	recorded	25.61	p
KY9000-4-19.15to22.3	3.13	51.90	recorded	25.61	p
KY9000-4-22.3to27.37	3.36	40.10	recorded	24.65	p
KY9000-4-27.37to32.7	3.10	61.90	estimated	25.61	p
KY9000-4-3.64to11.91	3.05	51.30	recorded	22.56	p
KY9000-4-32.7to36	2.81	59.30	estimated	26.58	p
KY9000-4-36to39.51	3.15	46.90	recorded	26.58	p
KY9000-4-39.51to43.1	2.89	54.30	estimated	27.58	p
WK9001-2-100.25to103.97	2.85	58.70	recorded	33.64	p
WK9001-2-103.97to106.08	2.87	50.90	recorded	33.64	p
WK9001-2-106.08to107.75	2.38	60.00	estimated	28.74	p
WK9001-2-111.25to112.55	2.19	75.00	estimated	28.74	p
WK9001-2-114.8to116.95	2.73	58.30	recorded	26.81	p
WK9001-2-36.96to38.8	2.23	65.70	recorded	31.70	p
WK9001-2-38.8to42.8	2.52	59.00	recorded	32.60	p

SECTION	AVG_RI	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
WK9001-2-42.8to45.95	2.28	63.00	recorded	30.71	p
WK9001-2-45.95to51	2.64	69.30	recorded	33.64	p
WK9001-2-51to55	1.91	66.60	estimated	35.39	p
WK9001-2-55to59.85	2.60	58.30	recorded	35.82	p
WK9001-2-65.72to71.97	2.98	39.70	recorded	21.67	p
WK9001-2-71.97to83.35	2.77	60.70	estimated	22.64	p
WK9001-2-83.35to90	3.34	33.80	recorded	24.77	p
WK9001-2-90to95.03	2.85	62.40	recorded	26.81	p
WK9001-4-100.25to103.97	2.80	58.00	estimated	24.76	p
WK9001-4-103.97to106.08	2.90	54.50	recorded	33.64	p
WK9001-4-106.08to109.05	2.52	64.70	recorded	27.67	p
WK9001-4-110.5to112.75	2.25	72.50	recorded	27.67	p
WK9001-4-114.8to116.95	2.95	60.40	estimated	28.75	p
WK9001-4-35.6to40.25	3.49	44.90	estimated	24.68	p
WK9001-4-40.25to42.8	3.11	47.90	estimated	24.68	p
WK9001-4-42.8to46.3	2.58	53.30	recorded	31.78	p
WK9001-4-46.3to51	2.69	50.90	recorded	32.68	p
WK9001-4-51to55	1.78	58.30	estimated	35.39	p
WK9001-4-55to59.85	3.01	41.10	recorded	36.10	p
WK9001-4-62.87to65.37	2.98	57.30	recorded	29.71	p
WK9001-4-65.72to71.97	2.89	51.30	recorded	21.66	p
WK9001-4-71.97to83.35	2.96	52.50	estimated	22.64	p
WK9001-4-83.35to90	3.49	44.00	recorded	24.76	p
WK9001-4-90to91	2.35	71.50	recorded	30.71	p
WK9001-4-91to95.03	2.56	65.00	both ri and cp estimated	35.39	p
WK9001-4-95.03to100.25	2.66	56.00	estimated	30.71	p

Appendix C. Analyzed AC Pavement Sections (AC Overlays)

Appendix C. Analyzed AC Pavement Sections (AC Overlays)

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
I24-2-1.07to4.41	3.57	7.00	33.60	recorded	10.18	i
I24-4-1.07to4.41	3.59	7.00	30.70	recorded	10.35	i
I24-2-7.36to11.03	3.31	8.00	26.10	estimated	8.64	i
I24-4-7.36to11.03	3.75	10.00	29.90	estimated	8.64	i
I24-2-11.03to13.8	3.77	9.00	23.60	recorded	8.95	i
I24-4-11.03to13.8	3.73	9.00	26.40	recorded	8.94	i
I24-2-16.27to22.04	3.83	10.00	28.80	recorded	6.50	i
I24-4-16.27to22.04	3.67	10.00	45.00	recorded	8.90	i
I24-2-22.04to26.55	3.92	10.00	25.20	recorded	8.19	i
I24-4-22.04to26.55	3.94	8.00	23.20	estimated	11.80	i
I24-2-26.55to29.13	3.78	3.00	11.00	recorded	1.90	i
I24-4-26.55to29.13	3.81	2.00	10.40	recorded	1.90	i
I24-2-30.33to33.66	3.71	5.00	26.60	estimated	7.64	i
I24-4-30.33to33.66	3.82	4.00	26.10	estimated	7.64	i
I24-2-33.98to39.5	3.70	9.00	35.60	estimated	11.64	i
I24-4-33.98to39.5	3.84	9.00	32.30	estimated	11.64	i
I24-2-39.5to41.6	3.80	9.00	27.30	recorded	6.94	i
I24-4-39.5to41.6	3.75	9.00	33.70	recorded	8.03	i
I24-2-41.6to45.13	3.76	.00	29.30	recorded	6.94	i
I24-4-41.6to45.13	3.82	9.00	27.10	recorded	8.03	i
I64-2-4.95to5.54	2.98		32.80	recorded	10.91	i
I64-4-4.95to5.54	3.43		25.10	recorded	9.99	i
I64-2-5.54to8.18	3.46		25.20	recorded	9.72	i
I64-4-5.54to8.18	3.41		24.80	recorded	9.72	i
I64-2-14.89to18.88	3.62	1.00	29.90	recorded	6.66	i
I64-2-43.33to47.74	3.30	6.00	38.60	estimated	7.18	i
I64-2-43.33to47.74	3.38	3.00	42.80	recorded	7.83	i
I64-4-43.33to47.74	3.27	5.00	33.40	estimated	7.18	i
I64-2-47.74to53.11	3.39	7.00	35.50	estimated	7.18	i
I64-4-47.74to53.11	3.35	8.00	37.60	estimated	7.18	i
I64-2-89.48to94.23	3.90	5.00	31.00	recorded	9.62	i
I64-4-89.48to94.23	3.86	5.00	23.00	recorded	9.62	i
I64-2-94.23to101.73	3.90	6.00	28.40	recorded	9.62	i
I64-4-94.23to101.73	3.90	5.00	24.30	recorded	9.62	i
I64-2-101.73to112.3	4.15	4.00	21.20	recorded	9.62	i
I64-2-101.73to112.3	3.70	5.00	28.70	recorded	9.87	i
I64-4-101.73to112.3	4.15	3.00	16.90	recorded	9.62	i
I64-4-101.73to112.3	3.94	5.00	29.00	recorded	10.71	i
I64-2-146.1to148.66	3.52	3.00	39.50	recorded	12.71	i
I64-2-160.86to166.21	3.62	8.00	45.50	recorded	12.71	i
I64-4-160.86to166.21	3.54	7.00	45.90	estimated	16.35	i
I64-2-166.21to171.3	3.46	6.00	45.40	recorded	16.90	i
I64-4-166.21to171.3	3.54	8.00	47.20	recorded	16.90	i
I64-2-180.81to185.46	3.77	4.00	29.40	estimated	7.68	i
I64-4-180.81to185.46	3.73	4.00	32.60	estimated	7.68	i
I64-2-185.46to191.38	3.81	5.00	30.60	estimated	7.68	i

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
I64-4-185.46to191.38	3.83	4.00	32.50	estimated	7.68	i
I65-1-12.81to21.92	3.35	5.00	40.40	recorded	10.69	i
I65-3-12.81to21.92	3.21	5.00	49.00	recorded	10.69	i
I65-1-61.12to64.2	3.97	8.00	22.50	recorded	8.02	i
I65-3-61.12to64.2	3.91	8.00	24.10	recorded	8.85	i
I65-1-64.2to70.4	4.09	7.00	21.10	recorded	8.02	i
I65-3-64.2to70.4	3.98	8.00	23.20	recorded	8.85	i
I65-1-70.4to76.1	4.06	6.00	19.40	recorded	7.86	i
I65-3-70.4to76.1	3.99	7.00	21.00	recorded	8.85	i
I65-1-76.1to78.66	3.97	4.00	20.40	recorded	7.94	i
I65-3-76.1to78.66	4.09	4.00	16.80	recorded	8.85	i
I65-1-78.66to85.59	3.98	4.00	20.00	recorded	8.02	i
I65-3-78.66to85.59	4.10	4.00	20.60	recorded	8.02	i
I65-1-85.59to90.58	3.98	4.00	21.30	recorded	8.02	i
I65-3-85.59to90.58	4.00	4.00	24.40	recorded	8.02	i
I65-3-95.12to97.54	3.55	8.00	35.80	recorded	5.92	i
I65-1-131.28to136.72	3.30		31.40	recorded	3.72	i
I65-1-131.28to136.72	3.28		39.70	recorded	6.69	i
I65-3-131.28to136.72	3.33		33.40	recorded	3.72	i
I65-3-131.28to136.72	3.24		43.30	recorded	6.69	i
I71-1-21.55to28.17	3.87	1.00	25.30	recorded	8.89	i
I71-3-21.38to28.17	3.75	2.00	36.00	recorded	8.91	i
I71-3-31.1to37.18	3.46	3.00	35.10	recorded	8.91	i
I71-1-69.89to77.72	3.58	3.00	40.70	recorded	14.92	i
I71-3-69.89to77.72	3.65	4.00	36.40	recorded	14.92	i
I75-1-0to0.48	3.51	4.00	19.50	recorded	8.75	i
I75-1-21.98to23.2	3.92	4.00	17.90	recorded	10.93	i
I75-1-23.2to24.64	3.70		22.80	recorded	6.98	i
I75-1-50.87to55.74	3.79	9.00	46.40	estimated	10.85	i
I75-1-50.87to55.74	3.91	2.00	25.40	recorded	8.99	i
I75-3-50.87to55.74	3.92	7.00	32.90	estimated	10.85	i
I75-3-50.87to55.74	3.86	2.00	25.50	recorded	8.99	i
I75-1-55.74to58.95	3.91	8.00	33.60	estimated	10.85	i
I75-1-55.74to58.95	3.99	2.00	18.10	recorded	8.99	i
I75-3-55.74to58.95	3.88	9.00	42.80	estimated	10.85	i
I75-3-55.74to58.95	3.97	2.00	25.70	recorded	8.99	i
I75-1-58.95to65.22	3.87	7.00	33.60	estimated	10.85	i
I75-1-58.95to65.22	4.05	2.00	21.00	recorded	8.99	i
I75-3-58.95to65.22	3.84	7.00	37.60	estimated	10.85	i
I75-3-58.95to65.22	4.01	2.00	27.90	recorded	8.99	i
I75-1-83to86.25	3.65		19.60	recorded	9.83	i
I75-3-83to86.25	3.74		22.20	recorded	9.83	i
I75-1-86.25to97.54	4.06	6.00	24.80	recorded	10.90	i
I75-1-86.25to97.54	3.26			missing	14.51	i
I75-3-86.25to97.54	3.99	7.00	28.60	recorded	10.90	i
I75-3-86.25to97.54	3.70			missing	13.59	i
I75-1-97.85to100.32	3.95	7.00	27.30	recorded	10.90	i
I75-1-97.85to100.32	3.86	7.00	22.80	recorded	11.83	i

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
I75-3-97.85to100.32	3.98	7.00	31.20	recorded	10.90	i
I75-3-97.85to100.32	3.79	6.00	20.30	recorded	11.83	i
I75-1-111.82to117.8	3.14	6.00	51.70	recorded	11.84	i
I75-3-111.82to117.8	3.15	6.00	44.90	recorded	11.83	i
I75-1-137.14to138.78	4.04	5.00	25.40	recorded	14.84	i
I75-3-137.14to138.78	4.05	4.00	26.40	recorded	14.43	i
I75-1-138.78to144.05	3.64	5.00	31.40	both ri and cp estimated	14.00	i
I75-3-138.78to143.23	3.53	4.00	30.10	estimated	13.59	i
I75-3-143.23to149.98	3.74	5.00	40.00	recorded	7.93	i
I75-1-154.47to158.54	3.78	5.00	26.90	estimated	12.59	i
I75-3-154.47to158.54	3.81	9.00	27.60	estimated	12.59	i
I75-1-166.26to174.56				missing	14.15	i
I75-3-166.26to174.56				missing	14.15	i
I75-1-174.56to179.25	3.97	8.00	24.10	recorded	6.53	i
I75-1-174.56to179.25	3.79	7.00	34.20	recorded	6.68	i
I75-3-174.56to179.25	3.91	8.00	22.10	recorded	6.53	i
I75-3-174.56to179.25	3.64	7.00	23.80	recorded	6.68	i
I75-1-182.38to183.77	2.87	5.00	41.40	recorded	4.26	i
I75-1-182.38to183.77	3.66		30.60	recorded	6.92	i
I75-3-182.38to183.18	3.53		29.00	recorded	6.92	i
I264-2-20.7to22.61	3.58	5.00	25.60	recorded	9.92	i
I264-4-20.7to22.61	3.59	5.00	24.30	recorded	9.92	i
KY9000-2-3.64to11.91	3.78	5.00	31.10	recorded	13.06	p
KY9000-4-3.64to11.91	3.59	8.00	38.30	recorded	13.06	p
KY9000-2-22.3to27.37	3.32	4.00	32.40	recorded	10.43	p
KY9000-4-22.3to27.37	3.35	4.00	32.10	recorded	10.43	p
KY9000-2-27.37to32.7	3.62	5.00	28.10	recorded	10.31	p
KY9000-4-27.37to32.7	3.54	5.00	31.10	recorded	10.31	p
WK9001-2-9.91to14.85	3.44	7.00	44.80	recorded	14.68	p
WK9001-4-9.91to14.85	3.33	6.00	41.80	recorded	14.68	p
WK9001-2-14.85to18.26	3.58	7.00	38.80	recorded	12.60	p
WK9001-2-14.85to18.26	3.57	3.00	23.00	recorded	2.78	p
WK9001-4-14.85to18.26	3.45	7.00	46.40	recorded	12.60	p
WK9001-4-14.85to18.26	3.12	3.00	37.20	recorded	2.78	p
WK9001-2-18.26to25.64	3.72	5.00	32.30	recorded	11.62	p
WK9001-4-18.26to25.64	3.60	6.00	43.40	recorded	11.61	p
WK9001-4-40.25to42.8	3.38	5.00	47.10	recorded	5.94	p
WK9001-2-116.95to119.64	3.41	6.00	36.50	recorded	4.70	p
WK9001-2-116.95to119.64	3.61	6.00	26.30	recorded	1.95	p
WK9001-4-116.95to119.64	3.72	4.00	32.70	recorded	.70	p
WK9001-2-119.64to123.47	3.59	6.00	44.00	recorded	7.70	p
WK9001-4-119.64to123.47	3.77	5.00	33.80	recorded	7.70	p
WK9001-2-123.47to130.94	3.55	6.00	47.00	recorded	9.79	p
WK9001-4-123.47to130.94	3.81	6.00	37.30	recorded	8.76	p

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
WK9001-2-130.94to136.06	3.61	6.00	37.60	recorded	9.79	p
WK9001-4-130.94to136.06	3.71	4.00	40.50	recorded	8.76	p
BG9002-2-0to9.52	3.56	4.00	43.40	recorded	7.70	p
BG9002-2-0to9.52	3.47	2.00	34.50	recorded	4.07	p
BG9002-4-0to4.9	3.51	3.00	39.50	recorded	7.70	p
BG9002-4-0to4.9	3.43	2.00	36.30	recorded	7.08	p
BG9002-4-4.9to10.17	3.49	3.00	42.90	recorded	7.70	p
BG9002-4-4.9to10.17	3.38	2.00	37.00	recorded	4.07	p
BG9002-2-9.52to16.54	3.57	3.00	38.20	recorded	7.70	p
BG9002-2-9.52to16.54	3.61	2.00	31.40	recorded	2.99	p
BG9002-4-10.17to16.54	3.57	3.00	37.40	recorded	7.70	p
BG9002-4-10.17to16.54	3.39	2.00	35.40	recorded	7.08	p
BG9002-2-16.54to24.24	3.67	3.00	32.10	recorded	7.70	p
BG9002-2-16.54to24.24	3.58	2.00	36.30	recorded	2.99	p
BG9002-4-16.54to24.24	3.43	2.00	42.20	recorded	7.70	p
BG9002-4-16.54to24.24	3.19	2.00	44.60	recorded	6.00	p
BG9002-2-39.26to41.79	3.53	4.00	43.90	recorded	5.94	p
BG9002-4-39.26to41.79	3.30	4.00	54.70	recorded	6.92	p
BG9002-2-41.79to44.8	3.41	1.00	42.70	recorded	7.94	p
BG9002-4-41.79to44.8	3.42	1.00	40.90	recorded	8.92	p
BG9002-2-44.8to47.69	3.11	2.00	53.80	recorded	9.99	p
BG9002-4-44.8to47.69	3.64	2.00	37.30	recorded	9.99	p
BG9002-2-47.69to51.83	3.47	5.00	47.90	recorded	8.83	p
BG9002-4-47.69to51.83	3.59	5.00	40.90	recorded	8.83	p
BG9002-2-59.59to61.84	2.79		39.10	recorded	12.75	p
BG9002-4-59.59to61.84	3.41	3.00	31.60	recorded	9.74	p
BG9002-2-62.04to71.13	3.07	2.00	38.90	recorded	11.75	p
BG9002-4-62.04to67	3.45	3.00	30.60	recorded	9.74	p
BG9002-4-67to71.13	3.44	3.00	31.90	recorded	8.69	p
PU9003-1-1.78to9.07	3.59	10.00	32.10	recorded	3.69	p
PU9003-1-1.78to9.07	3.69	9.00	28.60	recorded	4.68	p
PU9003-3-1.78to9.07	3.46	.00	38.20	recorded	7.92	p
PU9003-1-21.88to25.38	3.17	8.00	59.20	recorded	15.79	p
PU9003-1-21.88to25.38	3.56	3.00	34.40	recorded	3.61	p
PU9003-1-21.88to25.38	3.38	5.00	35.40	recorded	4.87	p
PU9003-3-21to25.38	3.33	5.00	36.70	recorded	5.79	p
PU9003-3-21to25.38	3.64	2.00	32.00	recorded	3.61	p
PU9003-3-21to25.38	3.36	6.00	42.70	recorded	4.87	p
EB9004-1-53.11to61.85	3.16		80.30	estimated	3.03	p
EB9004-1-61.85to65.39	3.14	7.00	53.40	recorded	6.78	p
DB9006-2-8.8to15	3.36	8.00	36.40	recorded	12.71	p
DB9006-4-8.8to15	3.28	9.00	42.20	recorded	12.71	p
DB9006-2-15to20.47	3.25	8.00	37.00	recorded	12.71	p

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
DB9006-4-15to20.47	3.11	9.00	44.80	recorded	12.71	p
DB9006-2-35.08to41.46	3.54	6.00	23.70	recorded	5.72	p
DB9006-2-35.08to41.46	3.37	6.00	32.50	recorded	9.58	p
DB9006-4-35.08to41.46	3.22	10.00	36.50	recorded	5.72	p
DB9006-4-35.08to41.46	3.15	12.00	47.80	recorded	8.61	p
DB9006-2-41.46to44.04	3.52	4.00	21.50	recorded	5.72	p
DB9006-4-41.46to44.04	3.40	8.00	27.00	recorded	2.18	p
DB9006-4-41.46to44.04	2.94	7.00	36.90	recorded	2.80	p
DB9006-4-41.46to44.04	3.32	6.00	28.20	recorded	3.66	p
DB9006-2-44.35to45.37	3.34	7.00	30.20	recorded	6.59	p
DB9006-4-44.35to45.37	3.21	9.00	36.50	recorded	6.59	p
DB9006-2-51.02to57.16	3.65	5.00	25.40	recorded	12.75	p
DB9006-4-51.02to57.16	3.54	4.00	30.60	recorded	12.75	p
DB9006-2-57.16to59.08	3.54	5.00	32.70	recorded	6.59	p
DB9006-4-57.16to59.08	2.97	10.00	63.00	recorded	6.59	p
WN9007-1-0to7.1	3.58	5.00	38.20	recorded	16.95	p
WN9007-3-0to7.1	3.61	5.00	37.80	recorded	16.95	p
WN9007-1-7.1to17.8	3.66	8.00	51.90	recorded	15.94	p
WN9007-3-7.1to17.8	3.56	6.00	47.50	recorded	15.94	p
WN9007-1-17.8to26.42	3.63	8.00	42.70	recorded	14.91	p
WN9007-3-17.8to26.42	3.60	7.00	43.50	recorded	14.91	p
WN9007-1-26.42to32.64	3.30	7.00	52.50	recorded	13.87	p
WN9007-3-26.42to32.64	3.21	9.00	58.30	recorded	13.86	p
LN9008-2-0to9.3	3.71	8.00	34.00	recorded	18.99	p
LN9008-4-0to8.17	3.69	7.00	33.60	recorded	19.00	p
LN9008-2-36.15to43.02	3.04	6.00	55.60	recorded	6.66	p
LN9008-2-36.15to43.02	3.27	6.00	44.70	estimated	11.00	p
LN9008-4-36.15to43.02	3.14	6.00	53.60	recorded	6.66	p
LN9008-4-36.15to43.02	3.46	5.00	38.70	estimated	11.00	p
KY9009-2-43.1to49.67	3.21	5.00	41.60	recorded	14.99	p
KY9009-4-43.1to49.67	3.22	4.00	38.60	recorded	14.99	p
KY9009-2-49.67to55.43	3.16	5.00	46.00	recorded	15.85	p
KY9009-4-49.67to55.43	3.22	4.00	39.00	recorded	15.85	p
KY9009-2-55.43to59.5	3.24	6.00	49.00	recorded	11.98	p
KY9009-4-55.43to59.5	3.42	6.00	40.00	recorded	11.98	p
KY9009-2-59.5to63.08	3.36	7.00	47.70	recorded	12.93	p
KY9009-4-59.5to63.08	3.45	6.00	41.00	recorded	12.93	p
KY9009-2-63.08to67.4	3.32	7.00	49.40	recorded	10.98	p
KY9009-4-63.08to67.4	3.47	5.00	32.40	recorded	10.98	p
KY9009-2-67.4to71.65	3.28	6.00	46.20	recorded	11.98	p
KY9009-4-67.4to71.65	3.49	5.00	35.80	recorded	11.98	p
KY9009-2-71.65to74.5	3.10	6.00	46.30	recorded	9.89	p
KY9009-4-71.65to74.5	3.59	6.00	28.50	recorded	9.89	p

SECTION	AVG_RI	RUTTING	CON_PTS	COMMENTS	SURF_AGE	INTERSTATE (I) OR PARKWAYS (P)
KY9009-2-74.5to75.31	3.10	6.00	42.20	recorded	9.01	p
KY9009-2-74.5to75.31	3.43	2.00	29.30	recorded	8.90	p
KY9009-4-74.5to75.31	2.49	6.00	48.40	recorded	9.01	p
KY9009-4-74.5to75.31	3.53	1.00	36.50	recorded	8.90	p
KY9009-2-75.31to75.62	3.16	6.00	41.00	recorded	9.01	p
KY9009-2-75.31to75.62	3.83	2.00	15.90	recorded	6.86	p
KY9009-4-75.31to75.62	3.86	6.00	21.00	recorded	9.01	p
KY9009-4-75.31to75.62	4.07	1.00	19.40	recorded	6.86	p

Appendix D. Analyzed PCC Pavement Sections (Rehabilitation)

Appendix D. Analyzed PCC Pavement Sections (Rehabilitation)

SECTION	RI	Condition Points	AGE
I64-2-0.65to3.19	2.54	39.60	2.02
I64-4-0.65to3.19	2.71	35.10	2.10
I64-2-81.03to82.32	2.48	44.00	14.83
I64-4-81.03to82.32	2.54	41.30	14.91
I65-1-97.54to101.98	2.37	33.90	2.46
I65-3-97.54to101.98	2.79	33.90	2.46
I75-1-110.26to111.82	2.38	52.00	11.83
I75-3-110.26to111.82	2.45	42.20	11.83
I75-1-184.7to186.95	2.72	39.40	1.75
I75-3-184.7to186.95	2.67	40.60	1.75
I264-2-0to0.46	2.50	34.10	2.07
I264-4-0to0.46	2.30	46.10	2.07
I275-5-0to1.05	2.83	29.10	3.86
I275-7-0to1.05	2.66	38.10	3.86
I275-5-73.55to75.38	2.41	45.30	9.76
I275-7-73.55to75.38	2.79	36.60	9.76
I471-1-0to1.74	2.65	39.80	10.66
I471-3-0to1.74	2.76	30.00	10.66
I471-1-1.74to3.2	2.33	43.00	10.57
I471-3-1.74to3.2	2.43	47.90	10.57
I471-1-3.2to4.75	1.22	47.20	9.99
I471-3-3.2to4.75	1.52	47.10	9.99
EB9004-1-16.5to22.48	2.93	36.00	27.76
EB9004-3-16.5to22.48	3.20	33.50	27.76
I75-1-0.48to3.68	2.43	61.10	36.27
I75-3-0to3.68	2.38	63.10	36.27
I75-1-3.68to10.54	2.26	59.30	33.43
I75-3-3.68to10.54	2.52	55.30	33.43
I75-1-10.54to15.45	2.39	58.00	32.51
I75-3-10.54to15.45	2.70	46.40	32.51
I75-1-15.45to20.2	2.16	62.30	31.09
I75-3-15.45to20.2	2.50	51.60	31.09
I75-3-20.2to25.26	2.21	67.10	31.09
I75-1-29.39to33.2	3.18	33.80	20.74
I75-3-29.39to33.2	2.69	35.90	20.74
I75-1-33.2to41.4	2.92	40.50	20.74
I75-3-33.2to41.4	2.88	36.60	20.74
I275-5-75.38to77.02	2.32	59.10	18.90
I275-7-75.38to77.02	1.86	62.30	18.90
EB9004-1-22.48to29.91	3.02	32.60	27.76
EB9004-3-22.48to29.91	3.10	32.40	27.76
WN9007-1-35.06to42.27	2.99	44.80	26.85
WN9007-3-35.06to42.27	3.01	42.50	26.85
WN9007-1-42.27to47.71	2.67	52.90	26.85
WN9007-3-42.27to47.71	2.68	48.30	26.85

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