IDENTIFICATION AND ASSESSMENT OF WASHINGTON STATE PAVEMENTS WITH SUPERIOR AND INFERIOR PERFORMANCE

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IDENTIFICATION AND ASSESSMENT OF WASHINGTON STATE PAVEMENTS WITH SUPERIOR AND INFERIOR PERFORMANCE

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16. ABSTRACT

The Washington State Pavement Management System (WSPMS) offers an organized methodology that WSDOT decision makers use to determine optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. It also helps improve decision-making efficiency, provide feedback on the consequences of decisions, and ensure the consistency of decisions made at different management levels within WSDOT.

Unfortunately, it is not possible, by simply scanning the WSPMS, to pinpoint reasons why pavement sections made of the same general surface materials and subjected to similar traffic and climatic conditions differ in performance. What the WSPMS can do is assist engineers in developing a candidate list of pavement sections with superior and inferior performance. Common characteristics that link multiple pavement sections are of particular interest, in part because they may reflect a common practice (e.g., nighttime construction) that leads to superior or inferior performance.

This study undertook various extensive analyses and comparisons to help illustrate common attributes of Washington state pavements with superior and inferior performance. The research also reviewed field performance data for Interstate 90 within the 1999 version of the WSPMS. The purpose was to examine all pavement segments on the 480 km of Interstate 90 within Washington state.

Reducing variability will allow WSDOT to produce more consistent pavement performance and will allow increasingly effective planning and forecasting. An almost certain byproduct of this increased planning effectiveness will be a more efficient allocation of available funding.

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EXECUTIVE SUMMARY

The Washington State Pavement Management System (WSPMS) offers an organized methodology that WSDOT decision makers use to determine optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. It also helps improve decision-making efficiency, provide feedback on the consequences of decisions, and ensure the consistency of decisions made at different management levels within WSDOT. A pavement management system helps answer the following three key questions:

- What pavement sections need some type of rehabilitation?
- What type and level of rehabilitation are needed?
- When is the optimum time to perform the needed rehabilitation?

While the WSPMS is designed to answer these three questions, managers often have a fourth key question:

- Why do some pavement sections, made of the same surface material and subjected to similar traffic and environmental conditions, perform in a superior or inferior manner?

The WSPMS is limited in its ability to directly answer this fourth question. It is not possible, by simply scanning the WSPMS, to pinpoint reasons why pavement sections made of the same general surface materials and subjected to similar traffic and climatic conditions differ in performance. What the WSPMS can do is assist engineers in developing a candidate list of pavement sections with superior and inferior performance. Common characteristics that link multiple pavement sections are of particular interest, in part because they may reflect a common practice (e.g., nighttime construction) that leads to superior or inferior performance.

Reducing variability will allow WSDOT to produce more consistent pavement performance and will allow increasingly effective planning and forecasting. An almost certain byproduct of this increased planning effectiveness will be a more efficient allocation of available funding.

Another benefit to WSDOT lies in understanding how other agencies design and manage pavements. This research effort incorporated specific pavement management practices and pavement performance results from the Gauteng Provincial Government of South Africa.

CONCLUSIONS

Interstate Highway Resurfacing Time

A comparison of Interstate highway resurfacing time (time from original construction to resurfacing or times between resurfacings) showed that WSDOT pavement performance is generally equal to that reported by states such as Minnesota and Illinois.

LTPP GPS Experiments

Results from LTPP GPS experiments revealed the following (based on two reports evaluated for the literature review and other studies):

<u>Jointed Plain Concrete Pavement</u>

- PCC slabs placed on asphalt treated bases perform best with respect to IRI.

- It is important to use dowel bars in JPCP transverse joints. This enhances long-term smoothness and decreases faulting. Use the largest dowel diameters possible. Thicker slabs are no substitute for dowels.
- Shorter joint spacings are preferred. Generally, this means a spacing between 3.8 to 4.6 m.
- Cold and/or wet climates in the U.S. result in rougher JPCP.

Asphalt Concrete Pavements

- Increased AC thickness decreases rutting, fatigue cracking, and roughness. This is not a "new" finding.
- Air voids in AC must be controlled. This too is not a new concept.

Relationship Performance Measure Analysis

The Relational Performance Measure Analysis showed the following:

- PSC is the best predictor of pavement service life for WSDOT pavements (in comparison to IRI and rutting).
- There was a high correlation between rutting and age for eastern Washington Interstate AC pavements. This suggests a systemic issue that merits further examination.
- A low correlation was found between PSC and IRI. This suggests that the WSPMS should continue to emphasize the use of PSC for identifying pavements for rehabilitation.

Superior WSDOT Pavements

- For the candidate pavement selection, 126 pavement sections were identified as superior performers. These fall into the following categories:

- New/Reconstructed AC, Interstate: 6
- New/Reconstructed AC, Non-Interstate: 11
- New/Reconstructed PCC, Interstate: 32
- New/Reconstructed PCC, Non-Interstate: 21
- Resurfaced AC, Interstate: 27
- Resurfaced AC, Non-Interstate: 19
- Resurfaced BST, Non-Interstate: 10

As expected, Interstate pavements with superior performance carried the highest ESALs—up to 2.5 million per year in the design lane (Resurfaced AC, Interstate category). In general, the minimum age of these pavements was at least 10 years (with two exceptions). As expected, the PCC pavements had the highest ages. When comparing AC to PCC pavements in the same highway category (Interstate or Non-Interstate), AC pavements were smoother (lower IRIs) but had more rut depth (or wear depth). Data collected on Interstate 90) showed that thick AC pavements have been in place, on average, longer than PCC pavements. However, the wearing courses for these AC pavements have been resurfaced more frequently. Finally, these data show that BST surfaced pavements can perform well (as measured by PSC, IRI, and rut depth) and under ESALs of up to 180,000 per year in the design lane.

- AC pavements with superior performance were nearly twice as old as the analysis group mean age for both western and eastern Washington.
- Annual design-lane ESAL levels for superior new/reconstructed non-Interstate AC pavements were generally 1.5 to 4 times higher than the analysis group mean.

- Longitudinal, alligator, and transverse cracking were the dominant failure mechanisms, in order, for new/reconstructed flexible pavements with superior performance. There is a tendency for the dominant failure mode in resurfaced pavements to be similar to that in the underlying pavement structure.
- Analyses suggest that WSDOT thickness design practices are working well for the design of new AC and PCC pavements.

Inferior WSDOT Pavements

- For the candidate pavement selection, 78 pavement sections were identified as inferior performers. These fall into the following categories:
  - New/Reconstructed AC, Interstate: 12
  - New/Reconstructed AC, Non-Interstate: 21
  - Resurfaced AC, Interstate: 13
  - Resurfaced AC, Non-Interstate: 17
  - Resurfaced BST, Non-Interstate: 15
- In comparison to pavements with superior performance, pavements with inferior performance
  - were about two times younger
  - had PSCs of about three times lower
  - carried about two times fewer ESALs
  - had IRIs of about 14 percent larger
  - had about 40 percent greater rut depth.

- Alligator cracking, patching, and longitudinal cracking were the dominant failure mechanisms, in order, for new /reconstructed flexible pavements with inferior performance.
- An examination into inferior flexible pavements showed a tendency for the dominant failure mechanism of the underlying layer to propagate through to the pavement surface.

Comparison of Pavements with Superior and Inferior Performance

- In six of ten analysis group comparisons of total mean pavement depth showed that pavements with inferior performance were thicker than those with superior performance.
- Given that pavements with inferior performance are generally thicker than pavements with superior performance, and assuming that WSDOT properly designs layer thicknesses, the conclusion is that inferior performance is not design related.

Interstate 90 Performance

The field performance data for Interstate 90 were reviewed within the 1999 version of the WSPMS. The purpose was to examine <u>all</u> pavement segments on the 480 km of Interstate 90 within Washington State. Specifically, the pavement segments all fit into three categories (based on original construction): flexible, cement treated base with AC wearing course, and PCC pavements.

The implications of the performance assessment of Interstate 90 for WSDOT can be summarized as follows:

- Design Period: The structural sections for flexible and rigid pavements are all intact (no significant reconstruction to date) with most of the segments approaching 30 years of service. The design life assumption in the 2000 version of the WSDOT Pavement Guide (Volume 1, Section 2.1 Design Period) is that both pavement types can be structurally designed for 40 years. These data from Interstate 90 support that design assumption.
- Life Cycle Cost Analyses: The following statements/assumptions in the WSDOT Pavement Guide, Volume 1, Section 2.3 are supported:
  - use of an analysis period of 40 years
  - the expectation that AC resurfacing will occur following 10 to 15 years of service
  - grinding of PCC slabs following 20 years of service to restore smoothness.
- CTB Pavements: CTB pavements have not been constructed on the WSDOT route system since the 1960s. The data support that decision made long ago.
- Overall Performance: The WSDOT pavements, as represented by those on Interstate 90, generally fall into the LTPP "good" performance category (the other possibilities being "average" and "poor"). The IRI of the current wearing courses (AC and PCC) all fall into the "good" category. The PCC slabs are rougher than the AC surfaced pavements but have been in service more than twice as long.

RECOMMENDATIONS

During the time this study was conducted and, in part, as a result of the early study findings, it is recommended that WSDOT continue to emphasize the reduction of construction variability. Studies such as temperature differentials, the construction case studies, and others will all contribute to improvement in this area. Specific emphasis needs to be placed on improved training—for both WSDOT and contractor personnel. Early efforts to aid this process are already under way.

CHAPTER 1—INTRODUCTION

Pavement management, in a broad sense, encompasses all of the activities involved in the planning, design, construction, maintenance, and rehabilitation of the pavement inventory under the purview of an agency such as the Washington State Department of Transportation (WSDOT). The Washington State Pavement Management System (WSPMS) offers an organized methodology that WSDOT decision makers can use to determine optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. It also helps improve decision making efficiency, provide feedback on the consequences of decisions, and ensure the consistency of decisions made at different management levels within WSDOT. A pavement management system helps answer the following three key questions:

- What pavement sections need some type of rehabilitation?
- What type and level of rehabilitation are needed?
- When is the optimum time to perform the needed rehabilitation?

While the WSPMS is designed to answer these three questions, managers often have a fourth key question:

- Why do some pavement sections, made of the same surface material and subjected to similar traffic and environmental conditions, perform in a superior or inferior manner?

The WSPMS is limited in its ability to directly answer this fourth question. It is not possible, by simply scanning the WSPMS, to pinpoint reasons why pavement sections made of the same general surface materials and subjected to similar traffic and climatic conditions differ in performance. What the WSPMS can do is assist engineers in developing a candidate list of pavement sections with superior and inferior performance for further investigation. Detailed investigation into pavement characteristics that the WSPMS does not chronicle, such as construction practices, specific site characteristics, and level of routine maintenance, should shed some light on this subject. Any of these or other characteristics that affect performance are of interest. Common characteristics that link multiple pavement sections are of particular interest, in part because they may reflect a common practice (e.g., nighttime construction) that leads to superior or inferior performance.

Reducing variability will allow WSDOT to produce more consistent pavement performance and increase the effectiveness of planning and forecasting. An almost certain byproduct of this increased planning effectiveness is a more efficient allocation of available funding.

Another benefit to WSDOT lies in understanding how other agencies design and manage pavements. This research incorporated specific pavement management practices and pavement performance results from the Gauteng (pronounced "how" teng) Provincial Government of South Africa. This information provides insight into how pavements are designed in South Africa and, to the extent possible, supports a comparison of pavement performance between the Gauteng Province and Washington State.

1.1 PROBLEM STATEMENT

Previous investigation into the WSPMS has revealed pavement sections on the WSDOT state route (SR) system that appear to outperform or underperform other pavement sections constructed of similar materials and subjected to similar traffic and environmental conditions. The reasons for these differences in pavement performance are not always clear and need to be better defined.

1.2 OBJECTIVES

The following objectives shaped and focused this research effort:

- Gain a better understanding of why some similar pavement types, subjected to similar traffic and environmental conditions, provide superior or inferior performance. Determining common characteristics (e.g., construction practices, etc.) shared by a number of similar pavement sections may provide insights into what factors tend to enhance or degrade pavement performance along the WSDOT route system.
- Produce comprehensive summary statistics to provide WSDOT with the most current snapshot of the "state of the SR system."
- Perform a relational performance measure analysis to investigate the inter-relationship of the five performance measures used in this study to determine superior and inferior performance.
- Incorporate pavement management information and performance data from the Gauteng Provincial Government of South Africa. Use this information to gain insight into how pavements are designed in South Africa and, to the extent possible, to compare pavement performance between the Gauteng Province and Washington State.

- Assess the pavement performance of a complete corridor (Interstate 90) to provide further insights.
- Finally, organize and present all relevant information generated through this study in a format that promotes its comprehension and use.

1.3 STUDY DEVELOPMENT

The first phase in planning this study comprised developing techniques and processes consistent with a sound research methodology. The methodology was sound in that it was based on proven engineering and statistical theory and practices. It was also flexible enough to accommodate changes in direction and level of detail when needed.

Perhaps the greatest flexibility came from the fact that the study was partitioned into six phases, which allowed for overlap. In other words, multiple phases could be conducted simultaneously. Chapter 3 lists these six phases and explains in some detail the key aspects of each one.

The term "similar" describes pavement sections throughout this report. This term refers only to the following four broad distinctions:

1. whether the pavement section is located in the eastern or western half of the state
2. whether it is located on the WSDOT Interstate or non-Interstate system
3. whether it is a product of new/reconstruction or resurfacing
4. whether the surface (or wearing) course is made of asphalt concrete (AC), portland cement concrete (PCC), or a bituminous surface treatment (BST).

Comparing "similar" pavement sections on the basis of these four broad distinctions provided a fundamental basis for the analysis performed in this study. A more complete development of these topics is found in Chapter 3. Although not explicitly referred to, environmental and traffic conditions were considered directly by answering Questions 1 and 2 above. Washington State has very different climatic conditions in the eastern and western portions of the state, and the Interstate system has the highest traffic levels (expressed as Equivalent Single Axle Loads- ESALs). All of these factors affect pavement performance and deserve distinction. However, these broad distinctions leave ample room for identifying specific attributes of superior and inferior performing pavements. More specific distinctions that would likely shed light on why some pavements outperform or underperform other similar pavements include the following:

- pavement layer analysis
    - types
    - thicknesses
    - construction practices
- site specific characteristics
- other factors

Investigation into these and other factors was intended to help illustrate common attributes of pavements with superior and inferior performance. The comparison among "similar" pavements simply ensured that "apples" were compared only to "apples."

CHAPTER 2—LITERATURE REVIEW

Three of the key issues addressed by this study for WSDOT include the following:

- How are pavements performing in Washington State?
- What process was used to identify candidate pavement sections that are outperforming or underperforming other sections within their peer groups?
- Why have the selected candidate pavements performed in the superior or inferior manner displayed?

A review of the literature was undertaken to find studies that address similar issues with documented results. The primary reasons for identifying such studies were to compare research methodologies, to benefit from lessons learned, to share insights, and to provide meaningful comparisons.

2.1 LITERATURE SEARCH

A number of key on-line databases were accessed to search the literature. The most beneficial databases were the Transportation Research Information Services (TRIS) and University of California Library (MELVYL) databases.

2.2 RESULTS OF THE LITERATURE REVIEW

Topics such as pavement management, modeling pavement performance, and developing performance prediction equations are thoroughly documented in the literature. However, the literature provided limited practical results from studies similar to the focus and scale of this study for WSDOT. Discussions of how long pavements last and why they perform well or poorly is generally lacking. While no research closely resembled the research approach taken in this study, four studies are of value to this research. Each study is summarized below and compared to and contrasted with the current effort. The four studies are the following:

Study 1: Pavement Performance Analysis of the Illinois Interstate Highway System

Study 2: Performance of Asphalt Concrete Resurfacing of Jointed Reinforced Concrete Pavement on the Illinois Interstate Highway System

Study 3: Performance History and Prediction Modeling for Minnesota Pavements

Study 4: FHWA/SHRP Long-Term Pavement Performance

2.2.1 Study 1—Illinois Interstate Highway System

The Illinois Department of Transportation (IDOT) and the University of Illinois performed a joint study to analyze Interstate highway pavement performance, with a particular focus on comparing the performance of continuously reinforced concrete pavements (CRCP) and jointed reinforced concrete pavements (JRCP) (Dwiggins et al. 1989). The study considered pavements built between 1952 and 1987. Direct comparison of the study results to WSDOT performance trends is not possible because Washington State does not construct JRC or CRC pavements; Washington builds only jointed plain concrete pavements (JCP). However, discussion of this study gives some indication of the type of performance related research that has focused on the superior performance of pavements.

The IDOT study considered 5,195 center-line (CL) kilometers of roadway. The percentages of pavement types by thickness are shown in Table 2.1.

Table 2.1. Number of IDOT Pavement Sections by Type and Thickness.

Type of Pavement	Percentage of Total Mileage (5,195 CL km)			
	178 mm Thick	203 mm Thick	229 mm thick	254 mm Thick
CRCP	11%	35%	14%	6%
JRCP	—	—	—	34%

One of the primary concerns in the design of pavements involves specifying the number of traffic loads that the pavement section should accommodate during its design life (typically 20-40 years) before deteriorating to a point that rehabilitation is required. IDOT used the standard AASHTO 80 kN (or 18,000 lb.) Equivalent Single Axle Load (ESAL) to characterize traffic loads. The average annual ESAL applications in the design-lane in Illinois increased from about 300,000 to 1 million per year over the 30-year period from 1957 to 1987. The average compound annual growth rate of accumulated ESALs for this period was over 8 percent. The 20-year *design* ESALs for 203 mm CRCP was 4.8 million; however, the actual ESALs were approximately 12 million. Over half of the pavement mileage in the study was subjected to approximately 11 million design-lane ESALs.

The IDOT pavements actually performed better than expected. The 1987 overall status of the Interstate highway pavements (all 3,228 center-line miles) reflected the following trends:

- Approximately 60 percent of the original mileage (dating back to 1952) remained in use.
- The average originally constructed pavement age was 19 years.
- The average cumulative pavement traffic loading since original construction was 16 million ESALs.

The indicators IDOT used to establish the useful life of pavements were age and number of applied ESALs before the first major rehabilitation. The distribution of age and applied ESALs to the first overlay was estimated by using a survival curve analysis called the product limit, or Kaplan-Meier method. The survival distribution estimates the percentage of sections overlaid versus age and applied ESALs. The results showed that the average service life of all pavement sections when 50 percent had been overlaid was 21 years. A similar curve in terms of ESALs showed that approximately 50 percent of the sections had been overlaid by the time 14 million ESALs had been applied. A majority of sections (80 percent or 2,582 center-line miles) were designed to receive less than 5 million ESALs during their design life. However, only about 5 percent of the 2,582 pavement miles had actually been overlaid by the time they had received 5 million ESALs. This indicated to IDOT a reliability of approximately 95 percent. Table 2.2 summarizes the study results and shows that thicker pavements generally perform better than thin pavements made of the same materials.

Table 2.2. Summary of Age and ESAL Results—Sound Pavements.

Pavement Type	Mean Life (yrs)*	Mean ESALs (millions)**	ESAL Design Ratio***
178 mm CRCP	17	8	4.0
203 mm CRCP	20	15	3.1
254 mm JRCP	22	13	2.7

* Mean age of pavements when 50% had been overlaid.
** Mean ESALs when 50% had been overlaid.
*** ESALs actually applied/Design ESALs.

IDOT concluded that JRCP and CRCP Interstate highway pavements in Illinois had performed "remarkably well." This conclusion was based upon the observation that a majority of pavement sections had accommodated up to four times the number of applied

ESALs that they were designed for and that only 5 percent of the sections had received an overlay by the time they had received the full number of design ESALs.

This study did a good job of summarizing results. The presentation of survivor curves was especially effective at illustrating the relationship of age and ESALs versus service life. However, in terms of relating to the WSDOT study, two observations are relevant. First, the authors made no attempt to explain why their pavement sections performed as they did. Perhaps the best performing sections had been subjected to the lowest traffic volumes or had better supporting (base and subgrade) materials. Second, the authors made no mention of what general condition the pavement sections were in at the time of rehabilitation. This is important because a roadway network that is allowed to deteriorate to a lower level will have a longer average service life and higher level of applied ESALs.

2.2.2 Study 2—Performance of AC Resurfacing over JRCP on the Illinois Interstate

This study was conducted on the survival of asphalt concrete (AC) overlays on the Illinois Interstate highway system (Hall et al. 1991). Data were obtained from the Illinois Pavement Feedback System (IPFS) database for 410 AC overlay construction sections placed on JRCP and CRCP sections between 1964 and 1989. The overlays ranged in thickness from 38 to 152 millimeters. Both in-service life and ESALs carried to the point of rehabilitation (or overlay) were analyzed through the use of survival curves. Only the survival of the 213 AC overlay sections of JRCP sections were reported. The study also made a point of comparing the performance of overlays of "D" cracked vs. non-"D" cracked (or sound) JRCP sections and discussed the underlying causes of overlay failure due to four failure mechanisms: reflection cracking, "D" cracking, rutting, and deterioration of AC patches. Again, direct comparison of the study results to WSDOT performance trends is not possible because Washington State does not construct JRC pavements. However, discussion of this study gives some indication of the type of performance related research that has focused on the superior performance of pavements.

Understanding the study results requires a description of each of the failure mechanisms listed. Durability, or "D" cracking, deterioration begins at the joints and cracks and progresses into the concrete slab. Reflection cracking generally occurs because of a strain concentration in the overlay caused by movement near joints or cracks in the existing PCC slab. The study suggests that in an AC overlay of JRCP, reflection cracks typically develop relatively soon after the overlay has been placed (often in less than a year). The report listed four mechanisms that cause rutting in AC: deformation of supporting layers, consolidation caused by insufficient compaction during construction, surface wear caused by studded tires and tire chains, and plastic deformation of the AC mix. Placement of full-depth AC patches and expansion joints in many JRCP and CRCP pavements before overlay often results in significant distress in the AC overlay.

Although this study sought to consider the effects of overlaying CRCP, at the time of the analysis, most of the AC overlays of CRCP were less than 7 years old, and only 6 percent had failed. Therefore, the researchers felt it was too early to draw any conclusions. However, at the same time, 25 percent of the thin AC overlays on non-D-cracked JRCP and 11 percent on D-cracked JRCP had failed. For thick AC overlays, the values were 31 percent and 12 percent, respectively, for non-D-cracked and D-cracked JRCP. These failure rates were considered sufficiently large to develop preliminary estimates of AC overlay survival distributions. Therefore, a discussion of study results was limited to JRCP sections. For the purpose of analysis, an overlay was considered to have failed either when a second overlay was placed or when cold milling was done. Table 2.3 shows the sample size of overlays by thickness, and Table 2.4 illustrates the resulting mean lives and accumulated ESALs of AC overlays over JRCP at the time of overlay.

Table 2.3. Sample Size of AC Overlays over JRCP.

AC Overlay Category	Non-"D" Cracked	"D" Cracked
Thin- 76 - 83 mm	81	72
Thick- 102 - 152 mm	35	25

Table 2.4. Mean Lives of AC Overlays over JRCP.

AC Overlay Category	AGE (years)		ESALs (millions)	
	Non-"D" Cracked	"D" Cracked	Non-"D" Cracked	"D" Cracked
Thin- 76 - 83 mm	11.9	7.3	18.4	6.3
Thick- 102 - 152 mm	16.4	14.5	45.4	14.7

Study conclusions included the following:

- Non-D-cracked JRCP provides a longer lasting, better performing base for AC overlays.
- Thicker overlays outperform thinner ones. Thick overlays last twice as long as thinner overlays on D-cracked JRCP. For overlays over non-D-cracked JRCP, thick overlays last 40 percent longer than thin overlays. Equally impressive are the relationships for ESALs.
- The performance of AC overlays for PCC pavements is strongly influenced by the condition of the overlaid PCC, i.e., the extent of deterioration present in

the original pavement and the type and amount of pre-overlay repair performed.

Unlike Study 1, this study did not attempt to determine whether the cited performance values constituted superior or inferior performance. However, it did assess the underlying reasons for performance trends, which stemmed from distresses that existed in the PCC sections before they were overlaid.

2.2.3 Study 3—Performance History and Prediction Modeling for Minnesota Pavements

The Minnesota Department of Transportation (Mn/DOT) analyzed approximately 13,000 surface condition data records collected on the entire Minnesota state route (SR) pavement system between 1983 and 1991 (Lukanen et al. 1994). This was done for two reasons: to summarize performance trends to date, and to develop performance prediction equations (or models) to optimize future rehabilitation needs. Similar tasks were performed by WSDOT and documented (Kay et al 1993). Review of Study 3 is limited to pavement life performance trends. The development of prediction equations, although important, has limited application to the current WSDOT study.

The Mn/DOT study was similar to the WSDOT study in the following respects: (1) Mn/DOT had an extensive database dating back to 1967 (WSDOT's dates back to 1969), (2) the older Mn/DOT data (before 1983) was not as useful as newer data because of generally poorer distress survey techniques before 1984, and (3) pavements were grouped by functional class, roadway history (including layer type, material, thickness, etc.), condition ratings, traffic, and more. The distribution of pavement sections available for analysis is shown in Table 2.5.

Table 2.5. Number of Mn/DOT Pavement Sections Studied.

Group	PCC	AC	CRCP
Interstate	2,874	506	456
Principal Arterial	2,350	3,312	8
Minor Arterial	704	4,390	0
Collector	44	1,928	0

The Mn/DOT study suggested some important points about judging pavement age (or service life). Pavement service life is typically thought to imply the length of time a pavement could perform without losing bearing capacity, function, or safety. However, the life of a pavement can be extended by active maintenance or shortened by rehabilitation for reasons other than condition (e.g., staged construction). Therefore, actual pavement service life is not exclusively an indicator of structural or functional failure; it is, however, an indicator of overall management practice. Table 2.6 illustrates the resulting pavement survival performance trends. The data in Table 2.6 represent only pavements that have been rehabilitated, but they exclude sections that have been rehabilitated in the first four years of life. This removes most stage construction from influencing the pavement life, but it also eliminates early failure (or inferior pavement performance). The authors recognized that looking only at the pavements that had been overlaid or reconstructed did not take into account any of the pavements still in service (the survivors). Therefore, the data represented failed pavements only.

The Mn/DOT study also looked at pavement condition at the time of rehabilitation. The purpose was to provide information on how long a particular pavement type would last before rehabilitation was needed. They found that many pavements are overlaid or reconstructed before pavement condition dictates that

Table 2.6. Survival Service Life of Mn/DOT Pavements (years).

Pavement Type	Age Statistics (years)	Interstate	Principal Arterial	Minor Arterial	Collector
Concrete	lane miles	633	590	285	1
	mean	22.2	23.6	27.9	13.0
	median	23.0	24.0	28.0	0.0
	std dev	4.1	5.8	6.2	0.0
Bituminous over concrete (1st overlay)	lane miles	20	156	43	—
	mean	6.2	9.1	12.7	—
	median	6.0	6.5	12.0	—
	std dev	1.0	4.3	6.7	—
Bituminous over concrete (2nd overlay)	lane miles	12	12	21	—
	mean	9.0	9.8	9.4	—
	median	9.0	9.5	8.0	—
	std dev	2.1	2.2	2.9	—
Bituminous over aggregate base	lane miles	324	1,402	2,447	1,181
	mean	14.1	16.7	16.6	17.6
	median	17.0	16.0	17.0	17.0
	std dev	5.7	6.8	6.2	6.4
Bituminous full depth	lane miles	67	211	306	226
	mean	16.9	14.6	15.3	10.5
	median	18.0	12.0	16.0	9.0
	std dev	4.2	6.4	4.5	5.0
Bituminous over bituminous full-depth (1st overlay)	lane miles	186	557	1,465	552
	mean	13.0	15.6	16.4	15.1
	median	12.0	14.0	16.0	15.0
	std dev	4.6	6.0	5.1	4.5
Bituminous over bituminous full-depth (2nd overlay)	lane miles	48	61	116	65
	mean	9.3	7.1	10.8	15.0
	median	9.5	5.0	8.0	15.0
	std dev	2.8	3.1	5.7	3.0

Notes:

* Survival life refers to the length of time a pavement is in service before it is rehabilitated (i.e., resurfaced, reconstructed, etc.).

* The term "bituminous" is the same as "asphalt concrete."

rehabilitation is needed. To investigate this point in greater depth, Mn/DOT considered three primary condition indices:

- The last Present Serviceability Rating (PSR)—The PSR is a measure of ride quality originally developed from the AASHO road test. Values range from 0.0 to 5.0, with 5.0 representing a perfectly smooth ride.• Surface Condition Rating (SR)—The SR consists of a visual survey of pavement surface distresses. The range is from 0.0 to 4.0, with 4.0 representing a pavement free of any surface defects.
- Pavement Quality Index (PQI)—The PQI is a combination of the PSR and SR represented by the following equation: $PQI = (PSR * SR)^{0.5}$. The maximum PQI value, assuming a perfectly smooth road free from surface defects, is 4.47, i.e., $(5.0 * 4.0)^{0.5}$.

Some pavement sections were found to have been rehabilitated long before or after condition-based threshold limits had been met. Typical Mn/DOT threshold values for rehabilitation, based on the PQI, were 2.6 to 3.0. The range of PQI values represented in the data ranged from 1.2 to 3.8. Of the 516 lane-miles of pavements considered in the condition analysis, the approximate median PQI was 2.5. The approximate 25th and 75th percentile PQI values were 2.1 and 2.9, respectively. Pavements were found to have been rehabilitated in a wide range of conditions, leading to the conclusion that rehabilitation was occurring for reasons other than condition. Therefore, a fair evaluation of how long pavements last before needing rehabilitation based on condition was not possible.

Investigations into PSR improvement due to bituminous overlays and PSR improvement as a function of overlay thickness were also conducted. The initial hypothesis of the investigators was that thicker overlays should improve the PSR more than thin ones because of the potential benefit from multiple lifts (or layer applications). Results of the analysis showed, however, that the thickness of the overlay had little to do with improvement in PSR. The researchers ran a multiple linear regression, with surface rating before rehabilitation (SR_{before}) and overlay thickness as the two independent variables. There were 239 data records available for PSR before and after an overlay had been applied. The thickness of the overlays ranged from 25 to 203 mm. The resulting R^2 value was 0.02 (extremely low). This suggests that there was no substantial linear relationship between the overlay thickness and increase in PSR. The average PSR and SR values before rehabilitation were 3.34 and 3.72, respectively. Rehabilitation improved the average PSR value to 3.8. No specific conclusions were drawn as to the reasons the PSR improvement was not a function of overlay thickness.

Other conclusions from the condition analysis include the following:

- The improvement in PSR increased as the functional class decreased. In other words, Interstate had the lowest ΔPSR, followed by principal arterials and minor arterials, which had the highest ΔPSR. The authors did not suggest any explanations for these trends.
- The rate of PSR loss was greater for Interstate and higher-level functional class roadways. Interstate pavements generally lose their ride quality fastest, while collectors lose their ride quality the slowest.

- The loss of ride quality for concrete pavements was more dependent on the location in the state, as defined by district, than on traditional design factors of traffic and soil strength. This was attributed to distress types that are more prevalent in certain districts, such as "D" cracking.
- New construction bituminous pavements retained their ride quality better than overlaid bituminous pavements. Bituminous over aggregate base and bituminous full-depth pavements performed better than bituminous overlaid concrete.

2.2.4 Study 4—FHWA/SHRP Long-Term Pavement Performance

Two studies by Eltahan et al (1997) and Khazanovich (1998) attempted to identify common characteristics of LTPP AC and PCC pavements with good and poor performance. The basic approach for identifying such pavements was the same in both studies. Namely, they

- established performance criteria via a panel of experts
- used various analytical techniques to examine the characteristics of pavements with good and poor performance
- drew conclusions as to characteristics that influenced the observed performance.

This information was not available during the early stages of the WSDOT study.

The performance criteria developed by the panels are summarized in Table 2.7 (AC pavements) and Table 2.8 (jointed PCC pavements). Performance was quantified by good, average, or poor and pavement age. For AC pavements, criteria are shown for rutting, percentage of total cracked area, and IRI; for jointed PCC pavements, the criteria are faulting, percentage of cracked slabs, and IRI. The AC expert panel sorted pavement performance criteria into three highway categories: Interstate, non-Interstate, and overlaid pavements. Only one category was deemed necessary for PCC pavements.

Table 2.7 LTPP Developed Performance Criteria for AC Pavements Via Expert Panel

Age	Rutting (mm)			% Total Cracked Area			IRI (m/km)		
(years)	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor
Interstate									
0	0	0	0	0	0	0	<0.6	0.6-1.3	>1.3
5	<5	5-10	>10	0	0	0	<1.4	1.4-2.4	>2.4
10	<5	5-11	>11	0	0-2	>2	<1.7	1.7-2.8	>2.8
20	<5	5-12	>12	<5	5-10	>10	<2.0	2.0-3.2	>3.2
Non-Interstate									
0	0	0	0	0	0	0	<0.6	0.6-1.3	>1.3
5	<5	5-15	>15	0	0	0	<1.4	1.4-2.7	>2.7
10	<5	5-17	>17	0	1-4	>2	<1.7	1.7-3.2	>3.2
20	<5	5-18	>18	<7	7-19	>19	<2.0	2.0-3.7	>3.7
Overlays									
0	0	0	0	0	0	0	<0.8	0.8-1.6	>1.6
5	<5	5-10	>10	0	0	0	<1.4	1.4-2.7	>2.7
10	<5	5-12	>12	0	2-5	>5	<1.7	1.7-3.0	>3.0
20	<6	6-13	>13	<17	17-25	>25	<2.1	2.1-3.4	>3.4

Note: Values shown are after Eltahan et al (1997) Figures 1, 2, and 3.

Table 2.8 LTPP Developed Performance Criteria for Jointed PCC Pavements Via Expert Panel

Age	Faulting (mm)			% Cracked Slabs			IRI (m/km)		
(years)	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor
0	0	0	0	0	0	0	<0.7	0.7-1.2	>1.2
5	<1.4	1.4-2.8	>2.8	<1.2	1.2-2.7	>2.7	<1.0	1.0-1.8	>1.8
10	<1.7	1.7-3.4	>3.4	<2.2	2.2-5.0	>5.0	<1.2	1.2-2.2	>2.2
20	<2.0	2.0-4.0	>4.0	<5.0	5.0-10.0	>10.0	<1.8	1.8-3.2	>3.2

Note: Values shown are after Khazanovich et al (1998) Figures 1, 2, and 3.

Sections were drawn from the LTPP General Pavement Studies (GPS) experiments and included an examination of the 490 AC and 289 PCC sections.

The analytical techniques used to examine the LTPP AC pavements included sensitivity analyses and the hypothesis test comparisons of good and poor performing pavement populations (samples). On the basis of these analyses, a number of conclusions were drawn. Many of these only support well-known principles in pavement engineering and are not truly new information; however, a selection of the more "solid" conclusions follows (i.e., some conclusions were omitted because of uncertainty associated with causative effects):

- increased AC thickness decreases rutting, fatigue cracking, and roughness.
- air voids must be controlled; however, the air void data available via the LTPP database were obtained following substantial trafficking.

The limited number of conclusions suggests that the LTPP database will produce little in the way of useful, significant results from the GPS sections. However, the data do provide some "hints" at a major causative effect for good and poor performance—namely, construction. For example, data summarized for overlaid AC pavements showed that the overlays that performed well had a mean age of 6.3 years with a mean rut depth of 3.4 mm. Most factors such as pavement age at the time of overlay, pavement deflections (various parameters), climate effects, AC gradation, subgrade densities, and others did not reveal practical differences. The primary differences were total ESALs and AC air voids (the good performers had lower total ESALs by a factor of 3.5 and higher air voids (4.9 percent versus 2.0 percent)). The large difference in in-place air voids are unlikely to be due to poor mix designs (however, that cannot be ruled out).

Low air voids are more likely to be due to too high an as-constructed binder content, resulting in a relatively unstable mix (higher rutting potential). However, at this point, this is speculative. The LTPP GPS database offers little to assist in the examination of construction related issues.

The analytical techniques used to examine the LTPP jointed PCC pavements included various statistical hypothesis tests (t-test, F-test, Chi-Square test) that compared the means of groups with good and poor performance. Additionally, multivariate analyses were performed. This type of analysis allows the examination of the interrelationships among variables.

The conclusions drawn follow. They are presented in terms of IRI, joint faulting, and transverse slab cracking. First, conclusions relative to IRI:

- Climate
  - JPCP in the southwestern U.S.→smoother.
  - JPCP in colder climates→rougher.
  - JPCP in wet climates→rougher.
- Subgrade: JPCP constructed on coarse-graded subgrades→smoother.
- Design and construction features
  - Asphalt stabilized base: JPCP with asphalt stabilized base had significantly lower IRI than other base types.
  - Dowel bars: For pavements over 10 years old, doweled pavements were smoother than undoweled pavements (pavements younger than 10 years exhibited little difference in IRI—as should be expected).

- Initial as-construction smoothness: Lower initial IRI→lower IRI over time and traffic.

The JPCP conclusions drawn with respect to transverse joint faulting include the following:

- Climate: Higher annual precipitation and number of wet days→higher joint faulting for non-doweled JPCP (but not for doweled JPCP).
- Subgrade type: JPCP constructed on coarse-grained subgrade→less faulting.
- Slab thickness: No clear trend observed with respect to faulting and slab thickness (this is contrary to advice in the 1993 *AASHTO Pavement Guide* that recommends thicker slabs to combat faulting). A study done for WSDOT (Mahoney et al 1991) noted that a Caltrans experiment on Interstate 5 showed that thicker PCC slabs (290 mm (11.4 inches)) did not preclude joint faulting—in fact, the thicker slabs in the experiment exhibited some of the highest amounts of faulting following 17 years of service.
- Base type: Stabilized bases (as compared to granular bases) for both doweled and non-doweled pavements→less faulting.
- Dowel diameter: Larger diameter dowels→less faulting.
- Skewed transverse joints: Skewed transverse joints are vnot needed if doweled.
- Joint spacing: Shorter joint spacing→less faulting.
- Widened PCC slabs: Widened (by 0.6 m) PCC slabs→less faulting for non-doweled JPCP.

The JPCP conclusions drawn with respect to transverse slab cracking include the following:

- Climate: Higher thermal slab gradients→higher transverse cracking (Khazanovich (1998) noted that higher thermal gradients are experienced in the western states).
- Design and construction features
  - Base type and elastic modulus of the base course: JPCP with granular and AC bases→significantly lower percentage of transverse cracked slabs.
  - Slab thickness and transverse joint spacing: L/l ratio should be less than 6 (L/l<4: no reported slab transverse cracking, but few sections are in the database with L/l<4))

    where L = joint spacing, and
    l = radius of relative stiffness.

    To illustrate, a slab thickness = 250 mm, E_{pcc} = 28,000 MPa, and k = 100 pci.

L	L/l
3.8 m (12.5 ft.)	3.5
4.6 m (15.0 ft.)	4.2
6.6 m (21.5 ft.)	6.0

    Note: WSDOT has generally conformed to an L/l of 4.2 for design and construction of its JPCP pavements.
  - Widened slab: LTPP sections with widened slabs→no transverse cracking.
  - Construction: Early cracking→construction related.

CHAPTER 3—RESEARCH METHODOLOGY

This chapter outlines the approach taken to investigate the characteristics of pavements with superior and inferior performance on the WSDOT route system. The research methodology was divided into six phases:

Phase 1. Establish Analysis Groups (Chapter 3)

Phase 2. Establish Performance Measures (Chapter 3)

Phase 3. Generate Summary and Comparative Statistics (Chapters 5, 6)

Phase 4. Identify Candidate Pavement Sections (Chapter 7)

Phase 5. Develop and Analyze Detailed Pavement Section Data (Chapter 8)

Phase 6. Summarize Findings (Chapter 9)

Each of the six phases is described in the following sections.

3.1 PHASE 1. ESTABLISH ANALYSIS GROUPS

The complete WSDOT state route system comprises 13,500 center-line kilometers (km) of roadway, representing over 28,300 lane-km. The SR system is diverse in that the roadway consists of different types of pavement materials, varying levels of construction (e.g., new vs. rehabilitated), and numerous pavement types that are subjected to differing climatic conditions and traffic volumes. A brief discussion of these variables will provide a clear understanding of why specific analysis groups were developed.

3.1.1 Types of Pavements

Basically, all hard surfaced pavement types can be categorized into two groups, flexible and rigid. Flexible pavements are those surfaced with bituminous (asphalt) materials in the surface (or wearing) course. The surface course can either be in the form of a bituminous surface treatment (BST) or asphalt concrete (AC). A BST surface is generally used on lower traffic volume roads and AC surfaces on higher traffic volume roads. Rigid pavements are composed of a portland cement concrete (PCC) surface course and are typically "stiffer" than flexible pavements because of the inherently high stiffness properties of PCC. Performance characteristics for flexible and rigid pavements are quite different under similar traffic. (WSDOT 1995) These differences warrant unique analysis groups based on pavement type.

3.1.2 Type of Construction

Most WSDOT pavement sections are categorized as new construction, reconstruction, or resurfacing. New construction is characterized by projects that have new roadway alignment. Reconstruction involves removing an old pavement section down to the base, subbase, or subgrade as needed and rebuilding the pavement on the same alignment. Often some old pavement materials are recycled and reused in the reconstructed section. The level of construction associated with reconstruction is generally comparable to new construction. Since WSDOT has few reconstructed pavement sections, new and reconstructed pavements were grouped and analyzed together. Resurfacing generally refers to an AC overlay but also encompasses BSTs. It involves the placement of a new surface course on top of the existing pavement structure. Often, the existing pavement is first subjected to grinding or some other process to better prepare the existing pavement to receive the new surface.

3.1.3 Climate Considerations

Climate and truck traffic are generally the two major causes of pavement deterioration. Washington State has two very different climates that affect pavement performance. Like all northern states, Washington is affected by ground freezing during the winter months, followed by thawing. The part of the state primarily affected by this process is east of the Cascade crest and therefore includes the North Central, South Central, and Eastern WSDOT regions. The mean annual rainfall for eastern Washington is about 380 mm, and the mean summer and winter temperatures are 21° C and -2° C, respectively. The mean annual rainfall for western Washington is about 990 mm, and the mean summer and winter temperatures are 18° C and 4° C, respectively. A detailed explanation of the freeze-thaw cycle is available (WSDOT 1995), but it is sufficient to note that the freezing process, in general, and freeze-thaw cycles have a critical climatic impact on WSDOT pavements. Understanding that these climatic impacts exist can help explain why similar pavements do not perform as well in the eastern part of the state and also why they should represent a unique analysis group.

3.1.4 Interstate vs. Entire State Route (SR) System

The primary reasons for analyzing the Interstate system separately from the rest of the SR system are that Interstate pavements tend to be thicker, and the Interstate system is subjected to higher traffic volumes (in terms of ESALs).

All of the Washington state routes are shown in Figure 3.1 for easy reference. In summary, categorizing the SR system into distinct analysis groups was necessary to maintain a delineation of pavement performance among similar pavements with similar structural, environmental, and in many cases operational characteristics. A tree diagram depicting the 18 analysis groups formed to generate the comparative statistics is shown in Figure 3.2.

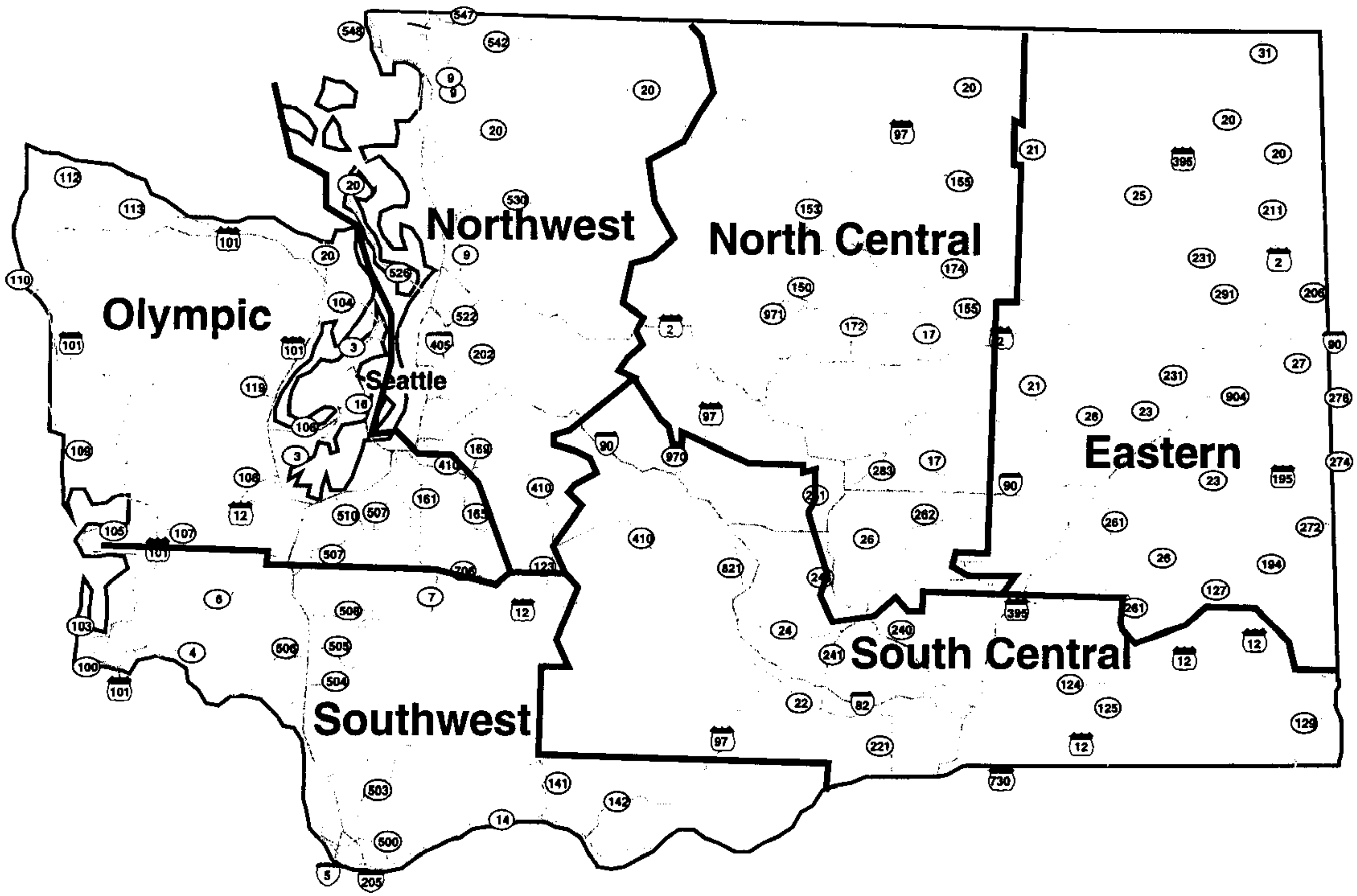


Figure 3.1. Washington State Route Location Map

3.2 PHASE 2. DETERMINE PERFORMANCE MEASURES

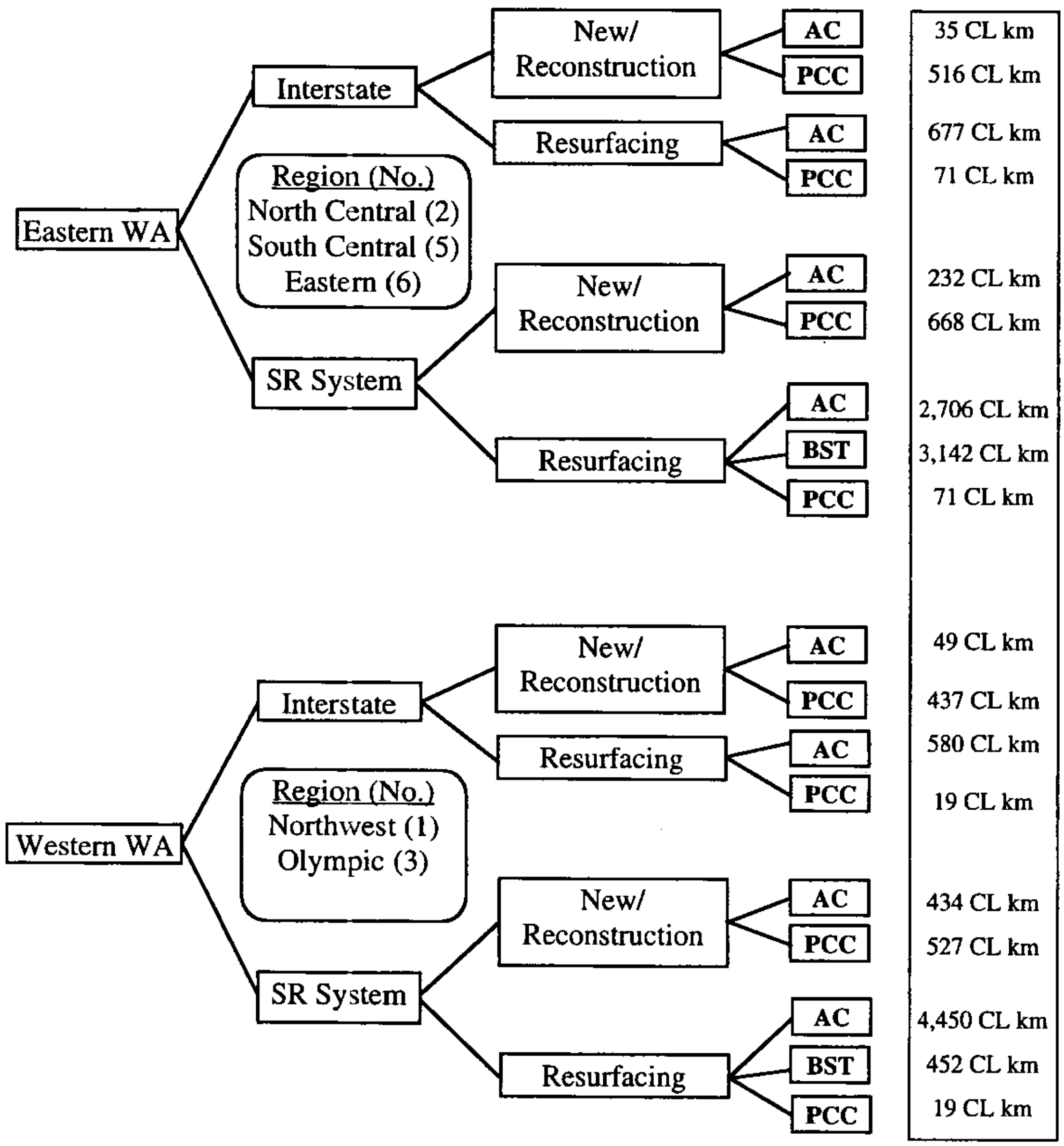
Performance measures provide the basis for analyzing the pavement analysis groups outlined in Figure 3.2. The comparative statistics generated in this report, as well as the candidate pavement selection process, were based on the following five performance measures:

1. Age—In analyzing superior performance, this measure refers to the current (1996) age of the existing surface course. For inferior performance, this refers to the service life of the previous surface course.

2. PSC—The Pavement Structural Condition score (0-worst to 100-best) is objectively determined through annual surveys by WSDOT of the type and extent of pavement distresses. A PSC score of 50 serves as a "trigger" point to program some type of rehabilitation.

3. IRI—The International Roughness Index defines a characteristic of the longitudinal profile of a traveled wheel-track, and it serves as a standardized roughness measurement. In general, a test device develops a ratio of the accumulated vertical displacements of a vehicle (in meters) divided by the distance the vehicle travels during the measurement (in km). Scores range from 0 m/km (perfectly smooth) to 8 m/km (rough, unpaved road) or more.

4. ESALs—The use of ESALs allows the conversion of wheel loads of various magnitudes and repetitions (characterized in "mixed" traffic conditions) to an equivalent number of 80 kN loads. A number of ESAL values can be used: historical, projected, annual, and others. This study exclusively used current annual ESALs applied to the design-lane. Design-lane factors account for the fact that trucks travel in multiple lanes. The design-lane factors used by WSDOT are shown in Table 3.1.



Note: Centerline-kilometer (CL km) values represent the total length of pavements used in the analysis of each pavement group. Values were taken from Appendix A.

Figure 3.2. Analysis Groups

Table 3.1. WSDOT Design-Lane ESAL Factors.

Highway Type	No. of Directional Lanes	Design-lane Factor
Simple Two Way	1	1.00
Extra Lane (one direction only)	1+	1.00
Multiple or Divided lane	1	1.00
Multiple or Divided lane	2	0.90
Multiple or Divided lane	3	0.70
Multiple or Divided lane	4+	0.65

As an example, if the north direction of a six-lane (three lanes in each direction) highway is subjected to an annual total of 1.5 million ESALs, only 1.05 million (0.70 * 1.5 million) "design-lane" ESALs will be used.

5. Rutting- Rutting manifests itself as a depression in the vehicle wheel-path. Values of rutting range from 0 mm (no rutting) to 18 mm (severely rutted). Values greater than 18 mm are possible. A pavement rutting condition (PRC) score is used in WSDOT's WSPMS to more easily represent rutting. The PRC ranges in value from 0 (representing a 18 mm rut depth) to 100 (representing no rutting). Pavements are typically programmed for some type of rehabilitation when they near a PRC of 50 (representing a 10-mm rut depth). The WSDOT equation relating rut depth in millimeters to a PRC score is shown below;

- $PRC = 100 - 3.3(\text{rut depth in mm})^{1.18}$ (Eqn 3.1)

3.3 PHASE 3. GENERATE SUMMARY AND COMPARATIVE STATISTICS

Summary statistics serve two key purposes:

- They describe performance trends among analysis groups.
- They provide the basis for statistically comparing individual pavement performance to known group performance statistics.

All pavement sections within each of the 18 analysis groups were used to generate statistics such as overall group mean and standard deviation. Only then could individual pavements be compared to statistically based threshold values that dictate superior performance. Such values were complemented by the use of frequency and cumulative frequency plots that supported visual interpretation of network pavement performance. Chapter 5 discusses the 1996 summary statistics for the SR system.

Comparative statistics were generated to provide insights to the inter-relationships of the five performance measures. The relationship of PSC and age is well documented within WSDOT and provides the foundation for the WSPMS to predict service life. What is less understood is the relationship of the other key performance measures used in this report, including traffic levels (in terms of design-lane ESALs), IRI, and rutting. Chapter 6 provides a detailed analysis of the relationships of these performance measures.

3.4 PHASE 4. IDENTIFY CANDIDATE PAVEMENT SECTIONS

Use of the summary graphs and comparative statistics described in Phase 3 provided the basis for selecting candidate pavements. Knowing key statistics such as population mean (μ) and standard deviation (σ) for the performance measures within each analysis group allowed for the development of selection threshold values that distinguished pavements as superior and inferior. The population mean and standard deviation are used because the entire SR system "population" is represented in the WSPMS. Although not all of the data for each of the performance measures was necessarily normally distributed, assuming normality and using the standard deviation provided a reasonable starting point for establishing lower and upper limits for selecting candidate pavements. By definition, the normal curve shown in Figure 3.3 is symmetric about its mean (μ), and approximately 68 percent of the area under the curve lies in the interval $\mu \pm \sigma$. The probabilistic implication of this fact is that, assuming a normal distribution, the probability of a randomly selected pavement section falling within the interval $\mu \pm \sigma$ was 0.68. Therefore, the lower limit (μ - σ) and upper limit ($\mu + \sigma$) each represented a 0.16 probability (0.32 total) that randomly selected pavement sections would fall outside these limits and in the lower and upper performance regions.

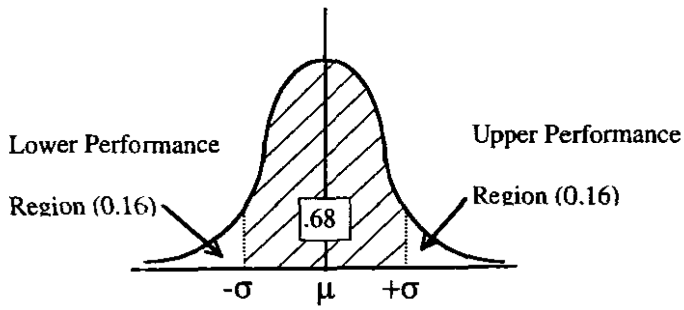


Figure 3.3. The Normal Curve.

These limits may not seem restrictive enough to identify superior and inferior pavement performance, and if applied only to individual performance measures, this would likely be true. However, when applied to all five performance measures simultaneously, the probability of pavements falling in the appropriate lower and upper statistical performance regions had a multiplicative effect that was very restrictive. For example, a pavement with truly superior performance should have high PSC, ESAL, and age values coupled with low rutting and roughness values. Therefore, a candidate pavement section would have to satisfy a 0.16 probability of lying in the upper (or superior) performance region for PSC, ESALs and age and also satisfy a 0.16 probability of lying in the lower performance region for rutting and roughness. The opposite was true for inferior performance, which was represented by low PSC, ESAL and age values coupled with high values of rutting and roughness. The resulting probability of a pavement section meeting all these criteria was approximately 0.0001 (or 0.16^{5}). In other words, there was only a 1 in nearly 10,000 chance of a pavement section meeting the initially established standards for superior performance. This probability was the same for inferior pavement performance. An assumption necessary to support these probability calculations was that the five performance measures were independent variables. This simplifying assumption effectively supported the development of performance measure selection values. However, the relationship between performance measures is more realistically tied to conditional probability (e.g., the amount of rutting a pavement displays depends in part on the level of ESALs). The simplifying assumption of independence was carried forward to present the performance probability results.

It was also assumed likely that PCC pavements (generally on the Interstate system) would dominate the list of pavements with superior performance for three reasons: (1) they were well designed and constructed, (2) PCC is a durable material with good performance, and (3) they generally receive high annual ESALs. Because of this, it seemed likely that two distinct sets of superior and inferior pavement performance would emerge, one set encompassing the Interstate system and the other set the rest of the non-Interstate SR system. Therefore, one of the underlying distinctions in selecting candidate pavements was to develop separate lists for Interstate and non-Interstate pavements.

3.5 PHASE 5. DEVELOP DETAILED PAVEMENT SECTION DATA

Upon selection of candidate pavement sections, section-specific data gathering was needed to support more detailed pavement section analysis. Again, basic structural, performance, and traffic related data are stored within the WSPMS. Climate and construction related factors are not. Fortunately, the Washington State climate has been reasonably characterized (Freezing Index, rainfall), and such information is readily available. Construction data are difficult to obtain. Other useful information could include soils and test results and other site-specific information.

3.6 PHASE 6. CONDUCT ANALYSIS AND SUMMARIZE FINDINGS

The data generated from Phase 5 supported specific pavement section analyses show significant factors that lead to superior and inferior pavement performance. Such analyses included, but were not limited to, the following:

- AASHTO performance equation predictions (i.e., comparison to a full AASHTO pavement design using DARWin software)
- examination of factor trends (e.g., effects of increased AC thicknesses, base course type, construction variables such as nighttime vs. daytime placement of AC, and climatic differences).

CHAPTER 4—DATA SOURCES

4.1 WASHINGTON STATE PAVEMENT MANAGEMENT SYSTEM (WSPMS)

This study was possible for one reason—the availability of the Washington State Pavement Management System (WSPMS). The 1996 version of the WSPMS contained the most up-to-date pavement and traffic related information on the 13,413 unique pavement sections that made up the entire Washington State Route (SR) system at that time.

The WSPMS is updated annually. Data relating to IRI and rutting have been collected annually since 1991 for the entire Interstate system and in alternating years for approximately 50 percent of the remaining non-Interstate system. The pavement condition survey has been performed as follows: every two years from 1969 to 1988 and on an annual basis since 1989.

The annual visual distress surveys provide the backbone of the WSPMS, which allows historical pavement performance to be referenced and future performance to be predicted. See Appendix E of the report by Kay et al. (1993) for the equations used to compute annual IRI, rutting, and PSC scores and for the regression equations used to predict pavement service life based on future values of these performance measures.

The distress types WSDOT uses to support PSC calculations are as follows:

Flexible Pavements

- Alligator cracking
- Longitudinal cracking
- Transverse cracking
- Patching

Rigid Pavements

- Slab cracking
- Spalling
- Faulting and Settlement
- Pumping and Blowing
- Patching
- Raveling and Scaling

The WSPMS provides a user-friendly personal computer interface to access this information quickly. The interface comprises a number of interactive, "pop-up" screens that draw information from a web of interconnected databases. Combining key pieces of information from several databases has resulted in the ability to "mine" the WSPMS. A brief discussion of the key databases used will help illustrate how they made this study possible.

4.1.1 Databases

The WSPMS data are contained within seven relational databases. The analysis database provided the most insights and was used extensively to support this study. The analysis database contains construction, traffic, structural, and performance related information on the unique pavement sections that make up the entire SR system. A unique pavement (or analysis) section is simply a roadway segment that has homogeneous layer properties (depth and type of material) throughout its structure.

The analysis database contains key information for each individual pavement section. Some of the most relevant pieces of information used in this study include the following:

- Exact pavement section location information based on
  - state route number
  - beginning and ending milepost numbers
  - side of the road surveyed

- Detailed traffic information consisting of
  - average daily traffic (ADT) with growth rate
  - single, double and train truck counts used to compute ESALs
  - historical and projected ESALs

- Detailed layer history consisting of
  - year of construction
  - type of construction (e.g., new, reconstruction, rehabilitation, etc.)

- surface type and thickness

- Annual values of IRI, rutting and PSC
- Pavement performance equations used to predict service life based on IRI, rutting and PSC

4.1.2 Refining the Database

An important step in preparing a data set for examination is to determine what records to exclude from the study and the reasons for exclusion. Not all of the available pavement sections in the WSPMS analysis database were used to generate summary statistics and to select candidate pavements for this study. The following discussion outlines which records were excluded and why. The reasons for excluding records could be grouped into one or more of three broad categories: construction parameters, lack of data, and suspect data. In the discussion below, a "record" refers to one of the 13,413 individual pavement sections and its associated supporting information (i.e., traffic data, layer history, etc.).

4.1.2.1 Construction Parameters

The most common types of pavement construction in Washington State are new construction, reconstruction and resurfacing. These three actions account for over 87 percent of all pavement related construction and thus were a main focus of the study. All other construction types were excluded from analysis. Table 4.1 illustrates the breakout of pavement sections by construction type and lists the number of "analysis" center-line kilometers within each type.

This study concentrated on the superior and inferior performance of <u>roadway</u> pavements. Therefore, all bridge sections were excluded from the study.

Some roadway sections were "takeovers," meaning that the state recently assumed responsibility for maintaining them. The WSPMS did not have detailed historical data for the takeover sections specifically related to traffic and structural characteristics such as construction type and layer history. In most cases, the only useful historical data were recent (2-5 years) values of PSC, IRI, and rutting.

Pavements that were under construction or scheduled for construction within the biennium were not considered for selection. Approximately 720 pavement sections were under or awaiting construction.

Table 4.1. Number of Washington SR Pavement Sections by Construction Type.

Construction Type	Number of Sections	% of Total Sections	**Center-line km	Lane-km
New*	1,254	9.3	1,465	3,533
Reconstruction*	641	4.8	449	943
Resurfacing*	9,872	73.6	10,870	22,111
Bridge	1,174	8.8	209	489
Grinding	11	0.0	10	31
Take-over	408	3.0	581	1,178
Other	53	0.5	16	24
TOTAL:	13,413	100	13,600	28,309

* Sections included in the study.
** Represents "analysis" center-line km, not actual center-line km. (See Section 3.2.3)

4.1.2.2 Lack of Data

A small number of pavement sections (128) did not contain any pavement layer information (e.g., layer type, thickness). As with the take-over pavements, values for critical performance measures used to generate summary statistics and to select candidate pavements could not be retrieved for these sections. Therefore, they were excluded from the study.

4.1.2.3 Suspect Data

Some pavement sections (135) contained suspect data. They were generally limited to pavement sections that had recently (0.5 - 2 years) received some type of construction action (typically resurfacing) but for some reason had not yet been updated in the database. The result was sections that displayed excellent pavement performance in terms of IRI, rutting, and PSC with ages that were clearly too high. These sections appeared to be legitimate superior performers as 10+ year old pavements, but their performance was merely standard in comparison with other actual 1- to 2-year-old pavement sections. Four of the five performance measures (IRI, PSC, ESALs, and rutting) were correctly recorded in the database for these sections based on visual surveys. Only the pavement ages were incorrect. Therefore, to produce comprehensive and representative summary statistics, these sections were included in summary statistic generation for all performance measures except age.

4.1.3 Updating the Database

Although most of this study was based on the 1996 WSPMS (the exception is Chapter 10), not all of the data used and reported in the study were generated in 1996. Three performance measures (ESALs, IRI, and rutting) reflected some amount of data from as far back as 1994.

Each version of the WSPMS uses the preceding year's traffic data. Therefore, the most up-to-date ESAL values in this study were based on 1995 traffic data. Because of suspect data, WSDOT personnel were quick to identify approximately 1,200 pavement sections with incorrect 1995 data. These records were immediately replaced in the database with growth-adjusted 1994 traffic data.

As discussed in Section 4.1, only 50 percent of the non-Interstate SR system is surveyed annually to collect IRI and rutting data. Therefore, nearly 6,900 pavement sections used in this study reflect 1995 rather than 1996 data for these two performance measures. Summary statistics were developed in part to help present WSDOT with a snapshot of the "state of the SR system" as of 1996. Therefore, a determination was made at the outset of the study to include only sections with 1996 IRI and rutting data the summary statistics were generated. However, in considering candidate pavements with superior performance, the objective was to consider the entire SR system. To include only 1996 data would have meant excluding 50 percent of the SR system. Although 1996 based summary statistics were used to set candidate selection thresholds, pavements with 1995 data emerged on the list of superior performers.

4.2 SOUTH AFRICA—GAUTRANS PMS

To allow easy reference to the South African PMS information, all pertinent information is contained in this section except pavement performance results. Those logically belong with the WSDOT summary statistics presented in Section 5.4, thus facilitating easy comparison to WSDOT pavement performance. This section also used draws comparisons to WSDOT in other respects such as road network size, pavement types, and more. All South African information presented in this report is drawn from a draft paper by Henning et al. (1998).

4.2.1 Historical Development of the Gautrans PMS

The Gauteng (pronounced "how"-teng) Department of Transportation (Gautrans) of the South African province of Gauteng has maintained a fully operational PMS since 1985. The PMS was implemented in phases. Initially, the pavement condition evaluation was based on only visual "windshield" surveys of a limited number of roads. However, a road inventory was soon developed and a database for storage of pavement structure, surfacing, and traffic data was created. Once users had proved that the PMS was a valuable source of management information, the condition survey was extended to cover the whole road network by means of both visual evaluation and roughness measurements (ride quality).

At present, the visual survey is performed annually and is supplemented by an instrument survey consisting of roughness and rutting measurements.

4.2.2 Comparison of How the Gautrans and WSDOT PMS Results Are Used

Both systems incorporate PMS results at the "project" and "network" levels. Each is discussed.

4.2.2.1 Project Level—Gautrans

Initially, pavement management concentrated on network level elements. Later it was extended to project level analysis, which includes a detailed examination of projects to help select optimal maintenance measures. Besides the annual visual distress survey, a panel inspection has been introduced to evaluate the maintenance category, type of resurfacing, and priority of projects selected by network level analysis.

In its latest developments, Gautrans makes use of the network level optimization process on a project level. This process (discussed in Section 4.2.2.3) is used to determine the time and type of maintenance to apply. Furthermore, a benefit/cost ratio analysis helps prioritize projects and combines individual pavement sections into project size lengths.

4.2.2.2 Project Level—WSDOT

At present, the project level analysis is accomplished through considerable interaction between the six regional program development offices within the state, the regional materials staff, and the Headquarters PMS office in Olympia.

Early in the development of the WSPMS, it became apparent that a step should be provided to analyze the performance of each project before any consideration of rehabilitation action. A major objective in the development of this system was to achieve a predictive capability—something that could only be accomplished with a combined distress rating. Without overlooking the importance of specific types of distress, some type of overall rating (PSC) was necessary to rank projects and to provide a pavement condition rating versus age relationship so that time until failure might be predicted. Roughness (IRI) and rutting are also predicted for each specific project.

Two additional aspects of the project level performance data, which again made this research effort possible, are the potential for statistical analysis of performance trends and the ability to produce performance curves that best represent a specific pavement's anticipated performance over time.

4.2.2.3 Network Level—Gautrans

In the Gauteng Province, network level analysis of the PMS was developed through use of a simple algorithm and a heuristic optimization process (also referred to at the project level). The Deighton software is used for this process. The World Bank's Highway Design and Maintenance (HDM) III models are used to determine pavement deterioration. These models have been calibrated since 1993 for the conditions in Gauteng.

The optimization used at the network level

- motivates funding by showing the network condition that can be achieved with different funding levels
- allocates funding to different maintenance actions, namely rehabilitation, reseals, fog sprays, and routine maintenance
- checks the efficiency of the various maintenance measures.

4.2.2.4 Network Level—WSDOT

Network level analysis has always been performed as a natural extension of the project level analysis programs in the WSPMS. When the WSPMS was first developed, the network level analysis programs consisted simply of iterating runs of the project level analysis data, given different pavement condition cut-offs of funding level constraints. However, it was found that these network programs had been used only a few times for actual program studies. In both cases the exercises confirmed the level of funding already determined by funding policies.

Over the last few years, WSDOT has been working toward network analysis processes that help optimize project selection within each region to deliver the best overall pavement condition over time for fixed funding levels. Currently, a lowest life cycle cost analysis is performed on a network level. This information is then used to select the rehabilitation timing for specific projects in each region

4.2.3 Characteristics of Gautrans and WSDOT Road Networks

Gautrans is a provincial road authority responsible for all provincial rural roads except national roads (similar to US Interstate roads) within the Gauteng Province of South Africa. The WSDOT is responsible for all roads within the state except for municipal and county roads. The WSDOT road network consists of freeways and dual carriageways (one or more lanes in each direction) while the Gautrans network consists mainly of single carriageways (one lane only). Table 4.2 illustrates the total lane-kilometers owned and maintained by each agency. From Table 4.2 it is clear that WSDOT is responsible for over five times more lane-kilometers of roads. It is noteworthy that Washington State is approximately nine times larger in area than the Gauteng Province.

Table 4.2. Size of Gautrans and WSDOT Road Networks

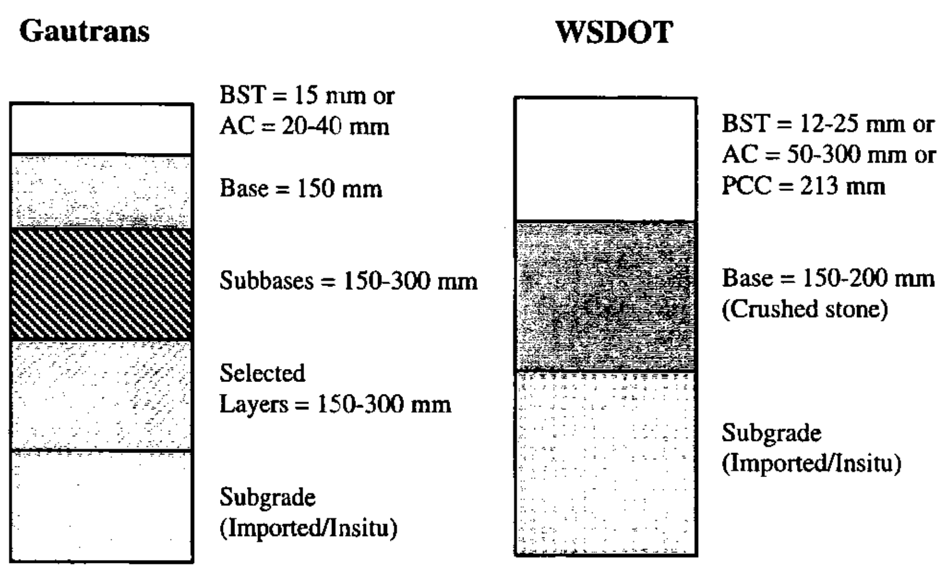
	Agency	
Road Type	Gautrans (ln-km)	WSDOT (ln-km)
Freeway	401	6,109
Dual Carriageway	666	22,871
Single Carriageway	2,871	0
Gravel	1,487	0
Totals	5,426	28,980

Most Gautrans roads have flexible pavement structures consisting of a combination of stone and cemented gravel layers with a thin bituminous surfacing (chip and spray or AC). Most WSDOT roads also have a flexible pavement structure consisting primarily of an AC surface course. Table 4.3 illustrates the percentage of various pavement types within each agency. Gautrans categorizes pavements by base type, namely crushed stone, cemented and natural gravel base. This tends to reflect the agency's selection of base type as a critical design parameter. Most WSDOT pavements have an unstabilized granular base course.

Figure 4.1 depicts common pavement structure cross-sections built by each agency. Gautrans roads have a deep, balanced pavement structure, whereas WSDOT relies more on strength built into their thick AC or PCC layers.

Table 4.3. Gautrans and WSDOT Pavement Types

Agency	Pavement Type	Percentage of ln-km
Gautrans	G1 Base (crushed stone)	53%
	Cemented Base (max 3% cement)	34%
	Natural Gravel Base	13%
WSDOT	AC Surface	60%
	BST Surface	27%
	PCC	13%



Gautrans base and Subbase combinations:
- Crushed stone base on cemented subbase
- Cemented base on natural gravel subbase
- Natural gravel base on natural gravel subbase

Figure 4.1. Pavement Types Used by Gautrans and WSDOT.

4.2.4 Traffic Characteristics of Gautrans

Traffic information on a road network is a critical component of any PMS. As with WSDOT, Gautrans performs traffic counts on a regular basis and represents traffic levels through the use of the 80 -kN equivalent standard single axle load (ESAL), which describes the cumulative axle loads applied to its road network. There is, however, a difference in terminology; whereas uses the term ESALs, Gautrans uses E80s. The level of traffic carried by each pavement type within Gautrans and trends between the two agencies are summarized Section 5.4.

4.2.5 Additional Comparisons

The remaining topics to be developed include a discussion of performance measures used by Gautrans and comparisons of pavement performance between Gautrans and WSDOT. These topics are presented in Section 5.4 to more easily refer to WSDOT summary statistics.

CHAPTER 5—SUMMARY STATISTICS

5.1 STATISTICS GENERATION

It was understood at the outset of the study that summary statistics would be used to distinguish pavement sections with superior and inferior performance. They would also support development of the short list of candidate pavements within each of the analysis groups. To determine whether an individual pavement's performance was truly superior or inferior, it would have to be statistically compared to known group statistics. The following summary statistics were generated for each of the five performance measures:

- mean (weighted)
- minimum
- maximum
- median
- mode
- standard deviation
- number of pavement sections within each analysis group
- number of center-line kilometers within each analysis group.

Mean values for all criteria were weighted by center-line kilometers.

Typically, the preferred method of weighting means is to use lane-kilometers rather than center-line kilometers. However, WSDOT visual performance measure surveys typically only cover the right-hand (or worst) lane in each direction on multilane highways. On two-lane highways, only one direction is surveyed, with the assumption being that both sides of the road generally undergo the same type and extent of traffic and therefore display virtually the same type, extent, and severity of distresses. Therefore, because the surveys do not account for all lanes in either or both directions, the use of center-line kilometers was necessary.

5.1.1 Scope

The summary statistics encompass 13,413 unique pavement sections on the SR system, representing over 13,500 center-line kilometers of roadway. The statistics represent current pavement performance, not survival performance. This study did not consider pavements that were under construction or scheduled for rehabilitation. The WSPMS supports generation of survival statistics based either on a time until a PSC of 50 or time until the actual rehabilitation date. Although these types of survival statistics are valuable, they did not directly support the selection of candidate pavements in this study and were therefore not generated.

Results from the South African Gautrans PMS are presented in Section 5.4. Comparisons to WSDOT performance are drawn and possible explanations for varying performance are suggested.

5.1.2 Output

In addition to summary statistics, frequency and cumulative frequency plots were generated for each of the five performance measures within each of the 18 analysis groups. The frequency plots depict the number of pavement sections within each analysis group that achieved a specified performance measure value. The cumulative frequency plots depict the percentage of center-line kilometers at or below a specified performance measure value. Examples of frequency and cumulative frequency PSC plots for new/reconstructed AC pavements on the Interstate system are shown in figures 5.1 and

5.2. Although Figure 5.2 shows that 360 center-line kilometers were reported on the western side of the state, this value represents "analysis" kilometers rather than actual kilometers. For instance, if a 12.5-center-line-km roadway section were surveyed in both increasing (northbound or eastbound) and decreasing (southbound or westbound) milepost directions, this would represent 25 center-line km for analysis purposes even though only 12.5 actual center-line km of roadway were surveyed. Because there were 18 analysis groups and five performance measures shaping each group, 90 graphs were generated. Plots for eastern and western Washington were combined to more easily show the relative performance of pavements on both sides of the state. These graphs, along with the summary statistics, help provide a comprehensive snapshot of the WSDOT SR system.

The entire set of summary statistics generated for the study is available in Appendix A. Rather than fully reproduce the tables here, only the mean (μ), standard deviation (σ), and population size (n) for each analysis group are reproduced. The cumulative frequency plots for each of the performance measures can be found in the following appendices:

Appendix	Performance Measure Plots
B	Age
C	PSC
D	ESALs
E	IRI
F	Rutting

5.2 WSDOT RESULTS

In addition to supporting the selection of candidate pavements, the summary statistics provide WSDOT with a useful network level snapshot of current pavement performance. Tables 5.1 through 5.5 summarize performance by analysis group. Table 5.6 presents an aggregated network level summary of all pavements without regard to specific analysis groups. Finally, Table 5.7 summarizes the key information presented in Tables 5.1 through 5.5 as a quick reference.

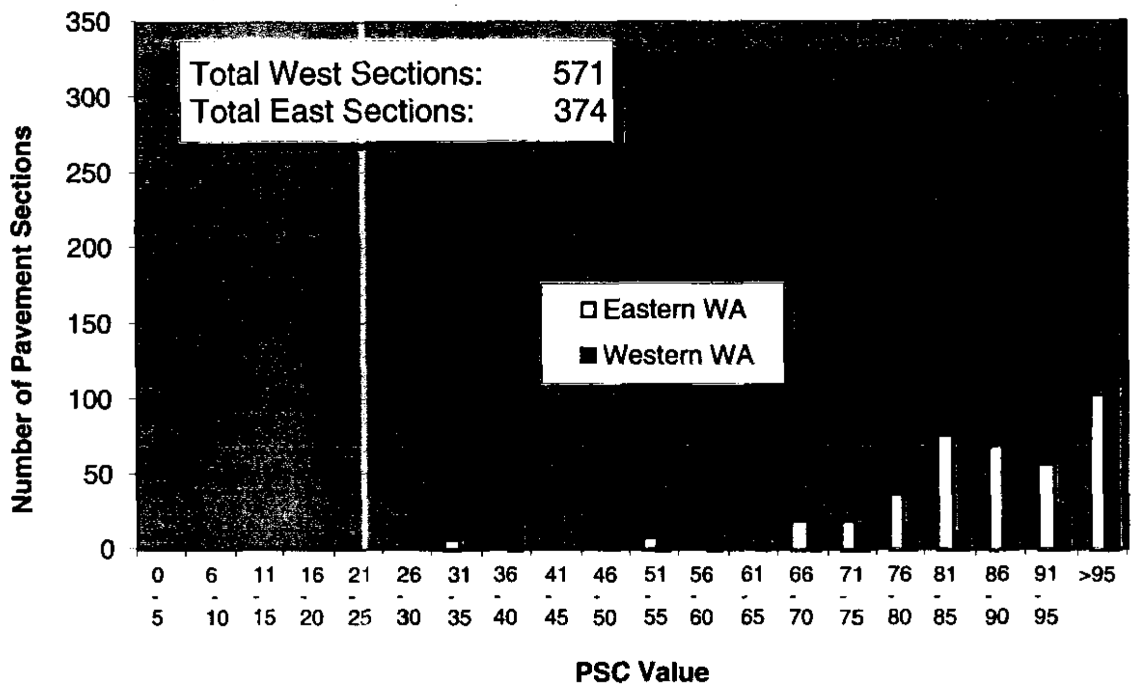


Figure 5.1. PSC Plot for Resurfaced AC Pavements—Interstate

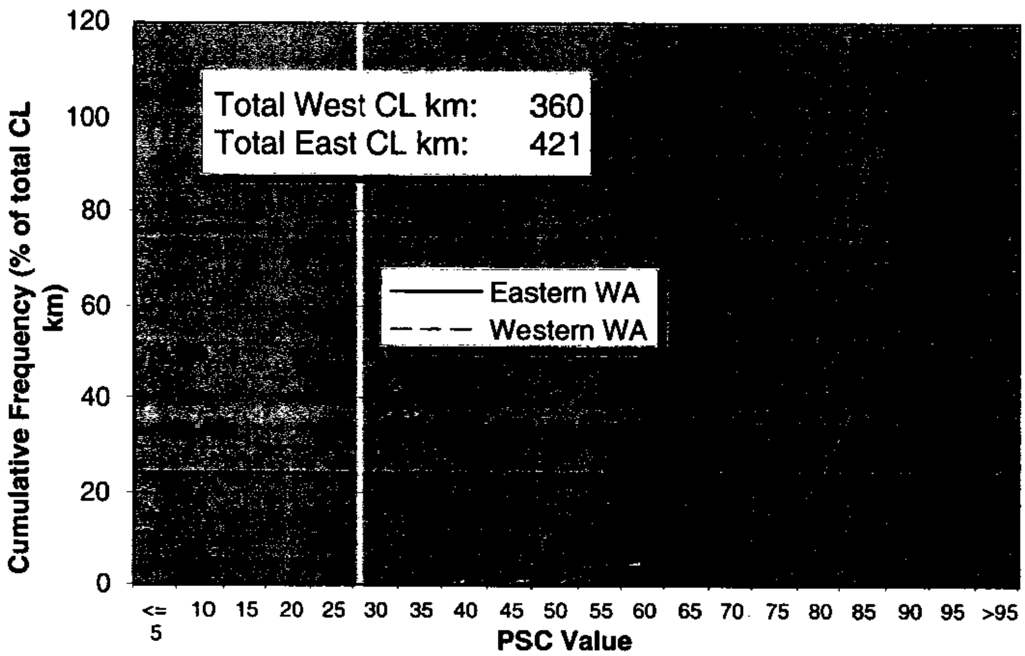


Figure 5.2. PSC Cumulative Frequency Curve for Resurfaced AC-Interstate

Table 5.1. Summary Statistics for New & Reconstructed AC Pavements

Performance Measure	Interstate			Entire SR System		
	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)
Age (years)						
East	10.5	7.8	18	10.2	7.1	238
West	16.4	8.1	79	14.9	10.0	767
All	14.0	8.4	97	13.3	9.6	1005
PSC (0-100)						
East	83.6	14.1	18	79.0	19.3	238
West	78.8	18.7	79	79.7	18.6	767
All	80.8	17.9	97	79.5	18.8	1005
ESALs (design-lane)						
East	362,660	144,488	18	164,636	121,805	238
West	1,266,492	599,168	79	285,143	385,984	766
All	890,455	620,393	97	243,418	345,786	1004
IRI (m/km)						
East	2.05	0.55	18	2.11	0.81	130
West	1.66	0.77	79	1.88	0.77	221
All	1.82	0.74	97	1.98	0.79	351
Rut Depth (mm)						
East	7.4	3.7	18	4.7	2.6	130
West	5.7	3.7	79	3.6	2.9	221
All	6.4	3.7	97	4.1	2.8	351

Note: Annual design-lane ESALs as of 1996 are shown.

Table 5.2. Summary Statistics for Resurfaced AC Pavements

Performance Measure	Interstate			Entire SR System		
	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)
Age (years)						
East	6.0	4.7	374	6.5	4.6	2,226
West	9.2	6.8	571	9.7	7.2	5,538
All	7.4	6.2	945	8.5	6.7	7,764
PSC (0-100)						
East	86.9	13.0	374	81.6	17.1	2,224
West	89.1	15.8	571	81.1	18.1	5,538
All	87.9	14.8	945	81.3	17.0	7,762
ESALs (design-lane)						
East	495,518	208,277	374	207,206	202,139	2,225
West	1,133,627	500,758	567	254,329	364,547	5,533
All	789,221	496,677	941	236,488	327,959	7,758
IRI (m/km)						
East	1.57	0.49	373	1.73	0.85	1,675
West	1.65	0.55	565	1.86	0.74	1,681
All	1.61	0.53	938	1.78	0.80	3,356
Rut Depth (mm)						
East	4.3	3.2	373	4.0	2.7	1,673
West	5.2	3.4	565	4.1	2.9	1,680
All	4.7	3.4	938	4.0	2.8	3,353

Note: Annual design-lane ESALs as of 1996 are shown.

Table 5.3. Summary Statistics for Resurfaced BST Pavements

Performance Measure	Interstate			Entire SR System		
	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)
Age (years)						
East	None	None	None	4.4	3.5	1,583
West	None	None	None	7.1	8.2	437
All				4.7	5.1	2,020
PSC (0-100)						
East	None	None	None	71.8	17.9	1,583
West	None	None	None	74.6	20.8	437
All				72.1	18.6	2,020
ESALs (design-lane)						
East	None	None	None	37,886	42,825	1,581
West	None	None	None	41,621	41,216	437
All				38,355	42,491	2,018
IRI (m/km)						
East	None	None	None	2.66	0.67	1,194
West	None	None	None	3.20	0.82	238
All				2.71	0.75	1,432
Rut Depth (mm)						
East	None	None	None	4.8	2.5	1,194
West	None	None	None	4.4	2.6	238
All				4.8	2.5	1,432

Note: Annual design-lane ESALs as of 1996 are shown.

Table 5.4. Summary Statistics for New & Reconstructed PCC Pavements

Performance Measure	Interstate			Entire SR System		
	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)
Age (years)						
East	17.3	8.3	243	16.9	10.0	288
West	25.8	10.6	477	29.4	15.0	574
All	21.2	10.3	720	22.4	14.0	862
PSC (0-100)						
East	89.8	10.8	243	88.1	14.5	288
West	82.6	11.4	477	80.6	12.9	574
All	86.5	11.4	720	84.7	13.5	862
ESALs (design-lane)						
East	479,776	228,239	243	427,584	247,604	288
West	991,938	455,872	463	854,185	507,933	560
All	713,026	450,678	706	614,427	474,621	848
IRI (m/km)						
East	1.93	0.69	243	1.97	0.80	280
West	2.25	0.66	469	2.28	0.66	481
All	2.08	0.69	712	2.10	0.72	761
Rut Depth (mm)						
East	0.80	1.2	243	1.0	1.4	280
West	2.4	2.4	468	2.5	2.4	481
All	1.5	2.2	711	1.6	2.2	761

Note: Annual design-lane ESALs as of 1996 are shown.

Table 5.5. Summary Statistics for Resurfaced[2] PCC Pavements

Performance Measure	Interstate			Entire SR System		
	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)
Age (years)						
East	2.0	0.0	50	2.0	0.0	50
West	0.0	0.0	12	0.0[3]	0.0	12
All	1.6	0.8	62	1.6	0.8	62
PSC (0-100)						
East	87.3	6.7	50	87.3	6.7	50
West	91.0	0.8	12	91.0	0.8	12
All	88.0	6.4	62	88.0	6.4	62
ESALs[1] (design-lane)						
East	922,574	60,555	50	922,574	60,555	50
West	523,790	80,454	12	523,790	80,454	12
All	839,899	170,930	62	839,899	170,930	62
IRI (m/km)						
East	1.80	0.39	50	1.80	0.39	50
West	1.30	0.24	12	1.30	0.24	12
All	1.70	0.41	62	1.70	0.41	62
Rut Depth (mm)						
East	1.7	1.5	50	1.7	1.5	50
West	0.8	0.8	12	0.8	0.8	12
All	1.5	1.5	62	1.5	1.5	62

Note 1: Annual design-lane ESALs as of 1996 are shown.

Note 2: All resurfaced PCC pavements considered in the study are a product of dowel bar retrofitting.

Note 3: This indicates that all western resurfaced PCC pavements considered in this study were constructed in 1996 resulting in a mean age of 0 years.

Table 5.6. Overall Summary Statistics- All Pavements

Performance Measure	Interstate			Entire SR System		
	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)	Mean (μ)	Std. Dev. (σ)	No. Pvmts (n)
Age (years)						
East	10.4	8.7	685	6.6	6.1	4,385
West	16.1	11.6	1,139	11.6	9.8	7,328
All	13.0	10.9	1,824	8.9	8.9	11,713
PSC (0-100)						
East	88.0	12.0	685	77.6	17.8	4,383
West	86.0	14.7	1,139	80.5	18.1	7,328
All	87.1	13.7	1,824	79.0	18.0	11,711
ESALs (design-lane)						
East	509,061	234,239	685	156,997	209,480	4,382
West	1,072,445	495,525	1,121	294,079	405,689	7,308
All	761,016	488,832	1,762	220,523	349,935	11,690
IRI (m/km)						
East	1.74	0.60	684	2.18	0.83	3,329
West	1.89	0.69	1,125	2.08	0.83	2,633
All	1.81	0.66	1,809	2.15	0.83	5,962
Rut Depth (mm)						
East	2.8	2.9	684	4.0	2.7	3,327
West	4.0	3.2	1,124	3.7	2.8	2,632
All	3.4	3.2	1,808	3.9	2.7	5,959

Note: Annual design-lane ESALs as of 1996 are shown.

Table 5.7. Summary of 1996 Pavement Performance by Construction and Material Type.

Performance Measure		New/Reconstructed AC		Resurfaced AC		Resurfaced BST		New/Reconstructed PCC		Resurfaced PCC	
		Interstate	SR System	Interstate	SR System	Interstate	SR System	Interstate	SR System	Interstate	SR System
Age (years)											
East	μ	10.5	10.2	6.0	6.5	None	4.4	17.3	16.9	2.0	2.0
	σ	7.8	7.1	4.7	4.6		3.5	8.3	10.0	0.0	0.0
West	μ	16.4	14.9	9.2	9.7	None	7.1	25.8	29.4	0.0	0.0
	σ	8.1	10.0	6.8	7.2		8.2	10.6	15.0	0.0	0.0
All	μ	14.0	13.3	7.4	8.5	None	4.7	21.2	22.4	1.6	1.6
	σ	8.4	9.6	6.2	6.7		5.1	10.3	14.0	0.8	0.8
PSC (0-100)											
East	μ	83.6	79.0	86.9	81.6	None	71.8	89.8	88.1	87.3	87.3
	σ	14.1	19.3	13.0	17.1		17.9	10.8	14.5	6.7	6.7
West	μ	78.8	79.7	89.1	81.1	None	74.6	82.6	80.6	91.0	91.0
	σ	18.7	18.6	15.8	18.1		20.8	11.4	12.9	0.8	0.8
All	μ	80.8	79.5	87.9	81.3	None	72.1	86.5	84.7	88.0	88.0
	σ	17.9	18.8	14.8	17.0		18.6	11.4	13.5	6.4	6.4
ESALs											
East	μ	362,660	164,636	495,518	207,206	None	37,886	479,776	427,584	922,574	922,574
	σ	144,488	121,805	208,277	202,139		42,825	228,239	247,604	60,555	60,555
West	μ	1,266,492	285,143	1,133,627	254,329	None	41,621	991,938	854,185	523,790	523,790
	σ	599,168	385,984	500,758	364,547		41,216	455,872	507,933	80,454	80,454
All	μ	890,455	243,418	789,221	236,488	None	38,355	713,026	614,427	839,899	839,899
	σ	620,393	345,786	496,677	327,959		42,491	450,678	474,621	170,930	170,930

Note: Annual design-lane ESALs as of 1996 are shown.

Table 5.7 cont. Summary of 1996 Pavement Performance by Construction and Material Type.

Performance Measure		New/Reconstructed AC		Resurfaced AC		Resurfaced BST		New/Reconstructed PCC		Resurfaced PCC	
		Interstate	SR System	Interstate	SR System	Interstate	SR System	Interstate	SR System	Interstate	SR System
IRI (m/km)											
East	μ	2.05	2.11	1.57	1.73	None	2.66	1.93	1.97	1.80	1.80
	σ	0.55	0.81	0.49	0.85		0.67	0.69	0.80	0.39	0.39
West	μ	1.66	1.88	1.65	1.86	None	3.20	2.25	2.28	1.30	1.30
	σ	0.77	0.81	0.55	0.74		0.82	0.66	0.66	0.24	0.24
All	μ	1.82	1.98	1.61	1.78	None	2.71	2.08	2.10	1.70	1.70
	σ	0.74	0.79	0.53	0.80		0.75	0.69	0.72	0.41	0.41
Rutting (mm)											
East	μ	7.4	4.7	4.3	4.0	None	4.8	0.8	1.0	1.7	1.7
	σ	3.7	2.6	3.2	2.7		2.5	1.2	1.4	1.5	1.5
West	μ	5.7	3.6	5.2	4.1	None	4.4	2.4	2.5	0.8	0.8
	σ	3.7	2.9	3.4	2.9		2.6	2.4	2.4	0.8	0.8
All	μ	6.4	4.1	4.7	4.0	None	4.8	1.5	1.6	1.5	1.5
	σ	3.7	2.8	3.4	2.8		2.5	2.2	2.2	1.5	1.5

5.3 WSDOT FINDINGS

The following sections briefly highlight trends among all five performance measures that are suggested by the statistics presented in Section 5.2. Of particular interest are trends among eastern and western Washington due, in part, to differences in climate and traffic levels. Differences among Interstate pavement sections will be contrasted with the entire SR system. The highlighted trends are most easily referenced in Table 5.7. Additional insights may be gathered by referring to other statistical measures such as median, minimum, and maximum values for each analysis group found in Appendix A.

5.3.1 Age

- The mean age of pavements located in western Washington is higher than that of eastern pavements. This holds true for Interstate pavement sections as well as the entire SR system.
- The difference in mean ages among western and eastern pavement sections ranges from a low of 2.0 years for resurfaced Interstate PCC pavements to a high of 8.5 years for new/reconstructed Interstate PCC pavements.
- The mean age of new/reconstructed PCC pavements exceeds that of new/reconstructed AC pavements by 6.8 years for the eastern Interstate system and by 9.4 years for the western Interstate system. The mean age of new/reconstructed PCC pavements exceeds that of new/reconstructed AC pavements by 6.7 years for the eastern SR system and by 14.5 years for the western SR system. This illustrates a fairly substantial difference in mean

western Washington ages of 5.1 years (14.5 - 9.4) when the entire SR system, rather than just the Interstate system, is considered.

- The mean age of resurfaced BSTs in western Washington is 2.7 years older than that in eastern Washington. Traffic volume is likely not the cause of this disparity because western Washington BSTs are subject to a higher mean level of ESALs than eastern Washington.

5.3.2 PSC

- For the SR system as a whole, western PSC scores tend to exceed eastern PSC scores, with differences in mean values ranging from a low of 0.5 points for resurfaced AC to a high of 7.5 points for new/reconstructed PCC pavements.
- New/reconstructed PCC pavements are older than new/reconstructed AC pavements (3.8 years older for western Washington).
- Resurfaced BSTs have fairly low mean PSC scores of 71.8 for the eastern SR system and 74.6 for the western SR system. However, an examination of WSPMS revealed that many resurfaced BST sections had low PSC scores before resurfacing and did not return to a PSC of 100 after receiving the new BST.
- No definitive PSC trends exist for eastern and western Interstate pavements.

5.3.3 Traffic Levels (Design-Lane ESALs)

- With the exception of resurfaced PCC pavements, all pavements display greater traffic levels in the western part of the state. In most cases the difference is substantial, ranging from a low of approximately 4,000 for resurfaced BST pavements to a high of approximately 900,000 for new/reconstructed Interstate AC pavements.

- Of the nearly 2,209 center-line kilometers of Interstate roadways included in this study, approximately 1,257 (57 percent) are a product of resurfaced AC and 952 (43 percent) are the product of new/reconstructed PCC. The mean ESAL levels accommodated by these two pavement types are similar in most cases (see Table 5.7).

5.3.4 International Roughness Index- IRI

For the SR system as a whole, western IRI values tend to exceed eastern IRI values, with differences in mean values ranging from a low of 0.13 m/km for resurfaced AC to a high of 0.54 m/km for new/reconstructed PCC pavements.

- As a group, resurfaced western Interstate PCC pavements are the smoothest in the state, and resurfaced western BSTs are roughest.
- No definitive IRI trends exist for eastern and western Interstate pavements.

5.3.5 Rutting

- For the SR system as a whole, eastern rutting (or wear) values tend to exceed western rutting values, with differences in mean values ranging from a low of 0.1 mm for resurfaced AC to a high of 1.5 mm for new/reconstructed PCC pavements.
- As a group, new/reconstructed eastern Interstate AC pavements are the most severely rutted, and resurfaced western Interstate PCC pavements are least rutted.
- No definitive rutting trends exist for eastern and western Interstate pavements.

5.4 SOUTH AFRICAN (GAUTRANS) RESULTS AND FINDINGS

Previous discussion in Section 4.2 of the Gautrans PMS and comparisons to the WSPMS indicate similarities in each system. This section presents some important differences, specifically among condition rating systems of the two systems. Two critical points that affect how results are interpreted must be made:

- Gautrans results governing "new" pavements include both new AC and new BST pavements. Because WSDOT results do not deal with new construction BSTs, direct comparison of results is more difficult.
- The WSDOT results are well stratified into analysis groups to uncover trends induced by climate and traffic levels. The Gautrans PMS makes no distinctions about climate and does not include any high traffic volume national roads (similar to our Interstate roads). Therefore, direct comparison of results is difficult. However, the entire WSDOT SR system is heavily weighted by non-Interstate pavements (similar to Gautrans provincial roads). Therefore, perhaps the most meaningful comparison of Gautrans results is to WSDOT results that relate to the entire SR system in western Washington.

5.4.1 Objectives

Three objectives were met and detailed in this Gautrans Investigation:

- Discuss the performance measures utilized by Gautrans.
- Compare pavement performance between Gautrans and WSDOT.
- Summarize performance trends and draw appropriate conclusions.

5.4.2 Comparison of Gautrans and WSDOT Results

To compare the pavement performance of the two systems, certain performance related measures must be discussed. A discussion of WSDOT performance measures was presented in Chapter 3. The primary focus here will be on describing the Gautrans performance measures.

Because of some variations in data collection techniques and computation of certain condition indices, direct comparison of performance measures (e.g., PSC versus VCI) is not always possible. Specific differences in data collection techniques are described by performance measure.

Both Gautrans and WSDOT data are reported separately for new and resurfaced pavements. In this context a new Gautrans pavement means one that has never been re-sealed. The data of Gautrans are reported by base types, namely granular and cemented. This is done to show the difference in performance of these two main types of pavements. Other lesser used base types such as bitumen treated and emulsion treated are not included in this study because of the limited number of pavement sections of each type. Again, no geographical differentiation is made for the Gauteng Province because only minor climatic differences exist throughout the province. The overall climate is mild, with a mean annual rainfall of 700 mm and a mean temperature of 27° C for summer and 18° C for winter. Western Washington has 990 mm of annual rainfall and mean summer and winter temperatures of 18° and 4° C, respectively.

The Gautrans results and performance trend comparisons to WSDOT will be presented by performance measure. All WSDOT performance measure values were summarized (mean and standard deviation only) previously in Section 5.2 (Table 5.7).

5.4.3 Performance Measures Used by Gautrans

The primary pavement performance measures used in the Gautrans PMS to describe pavement performance are

- Visual Condition Index (VCI)
- roughness (measured in terms of International Roughness Index—IRI)
- rutting.

5.4.3.1 Visual Condition Index (VCI)

The VCI is comparable to WSDOT's pavement structural condition (PSC) score in that both indices relate a pavement structure's condition to its ability to physically carry loads (specifically traffic loads). The condition rating methods used by both agencies are based on a 0 (worst) to 100 (best) scale. While the WSDOT PSC score for flexible pavements is based on only four distress types (underlined in the list below), the Gautrans VCI is based on the 19 distress types listed below:

- Block/stabilization cracking
- <u>Longitudinal cracking</u>
- <u>Transverse cracking</u>
- <u>Crocodile (alligator) cracking</u>
- Pumping
- Rutting
- Undulation/settlement
- <u>Patching</u>
- Failures/potholing
- Shoulder condition
- Edge cracking
- Surfacing failure
- Surfacing cracks
- Aggregate loss
- Binder condition
- Bleeding/flushing
- Riding quality
- Skid resistance
- Drainage

The Gautrans VCI condition score is based on the survey procedure described in the *Standard Assessment Manual for Flexible Pavements* (Committee of State Road Authorities 1992), and calculations of VCI are shown in *Procedures to Identify Problems on Gauteng Roads* (Gauteng Provincial Government 1995). Each distress is rated for extent and severity based on a 1 (least) to 5 (maximum) scale. The number of distress types is high, but Gautrans considers it necessary to accurately determine the type and time of maintenance. Gautrans pavements composed of gravel layers with a thin bituminous surfacing are water sensitive, and therefore the integrity of the surface is critical.

Of interest in this comparison between agency practices is an examination of how the two condition scores, VCI and PSC, can be approximately related to each other. To make this examination, Table 5.8 was prepared. The table compares VCI and PSC scores on the basis of fatigue (or crocodile or alligator) cracking. This was done, in part, because fatigue cracking is by far the most important distress type WSDOT measures, and it dominates flexible pavement PSC scores. As shown in Table 5.8, the VCI and PSC values were calculated for various extent and severity levels for fatigue cracking only.

Table 5.8. Calibration of VCI and PSC Scores

SEVERITY		EXTENT		VCI	PSC
VCI	PSC	VCI	PSC*	(Fatigue cracking only)	(Fatigue cracking only)
1	Hairline	1	1%	100	94
		3	5%	97	83
		5	25%	94	50
3	Spalling	1	1%	97	90
		3	5%	89	73
		5	25%	82	33
5	Spalling & Pumping	1	1%	94	84
		3	5%	82	65
		5	25%	70	21

*Refers to percent of wheelpath exhibiting particular severity of fatigue cracking.

On the basis of the results, it can be seen that for pavements exhibiting similar levels of severity and extent of fatigue cracking, WSDOT renders a more severe condition rating, especially at higher extent values.

Table 5.9 presents the current (1996) pavement condition results from the Gautrans PMS.

Table 5.9. Summary of Gautrans Pavement Condition (VCI) Scores

Base Type	Granular		Cemented		Total	
	New	BST Resurf	New	BST Resurf	New	BST Resurf
Mean	67.2	65.1	62.8	64.7	66.0	65.0
Median	69.0	67.0	65.0	68.0	67.9	67.4
Std. Deviation	17.3	16.2	18.1	16.7	17.5	16.4
Minimum	27	21	14	17	14	17
Maximum	99	94	89	96	99	96
No. of Sections	93	723	34	406	127	1,129
Center-line km	242	2,047	79	1,176	321	3,223

Conclusions from investigation of the VCI include the following:

- Similar severity and extent levels of fatigue cracking result in lower PSC scores than VCI scores.
- The condition indices used by both agencies, VCI and PSC, differ to such an extent that direct comparison of results is limited.

5.4.3.2 Pavement Surface Age

Gautrans analysis includes only seal ages of pavements with a VCI score of higher than 50. The main reason for doing this is that pavements with a VCI of lower than 50 should have been rehabilitated or re-sealed earlier but were not because of budget constraints. All pavements regardless of PSC score were included in determining the current age of WSDOT pavement types, making a comparison difficult. Table 5.10 summarizes the current mean service life statistics of Gautrans pavements.

Table 5.10. Summary of Gautrans Current Service Life (years)

Base Type	Granular		Cemented		Total	
	New	BST Resurf	New	BST Resurf	New	BST Resurf
Mean	14.3	6.3	12.9	7.0	13.9	6.6
Median	14.0	6.0	13.0	7.0	13.7	6.4
Std. Deviation	6.5	3.8	6.3	4.0	6.5	3.9
Minimum	2	1	2	1	2	2
Maximum	27	23	20	19	27	27
No. of Sections	73	587	27	331	100	918
Center-line km	180	1,523	160	867	340	2,390

5.4.3.3 Traffic Considerations

Section 4.2 outlined the differences associated with the road networks of both agencies. In general, WSDOT roads carry considerably more ESALs. The one exception is BST pavements, on which Gautrans carries approximately five times more traffic than the WSDOT BST network. These traffic considerations are important because they help put into context the performance displayed by certain pavement types. Table 5.11 illustrates the current annual E80 (or ESAL) traffic levels accommodated by Gautrans pavements. Traffic levels for WSDOT were presented in Table 5.7.

Table 5.11. Summary of Gautrans Annual Design-lane ESALs

Base Type	Granular		Cemented		Total	
	New	BST Resurf	New	BST Resurf	New	BST Resurf
Mean	173,427	207,704	66,215	124,141	144,724	177,654
Median	86,323	158,585	26,645	69,350	70,346	125,214
Std. Deviation	231,000	198,046	88,195	156,797	192,769	183,212
Minimum	2,190	365	1,095	730	1,095	730
Maximum	1,170,190	994,990	339,815	1,070,910	1,170,190	1,070,910
No. of Sections	93	723	34	406	127	1,129
Center-line km	242	2,047	79	1,176	321	3,224

*All values in terms of design-lane E80's (or ESALs).

Conclusions from investigation into traffic considerations include the following:

- WSDOT Interstate roads carry about eight times more traffic than Gautrans roads. There is, however, a functional difference in the sense that the Interstate roads perform the same function as South African national roads, which are not included in the study.
- The entire Washington SR system carries on average two and a half times more traffic than the Gautrans road network.
- The maximum ESAL levels that Gautrans BST pavements currently accommodate is approximately two times greater than the maximum levels accommodated by western Washington BST pavements and four times greater than that accommodated by eastern Washington pavements.

5.4.3.4 Roughness

Gautrans measures roughness with a linear displacement integrator. This device measures the roughness by recording the linear displacement of a fixed rear axle. Therefore, no relative movement between the right and left wheel are recorded. According to the definition of IRI, these measurements must be recorded as a half-car index, which will always be less than the quarter-car index. To adjust their values to represent IRI measurements, a factor of 1.3 was applied to the half-car indices (Sayers et al. 1986). All Gautrans values shown in Table 5.12 were generated by applying the 1.3 factor.

Conclusions from investigation into roughness include the following:

- For "new" pavements, the WSDOT road network has a lower roughness than the Gautrans road network. One should keep in mind, however, that each agency measures roughness differently and therefore, differences likely exist in the accuracy of each agency's results.

- It appears that AC overlays in Washington are smoother (lower IRI) than re-sealed Gautrans pavements.
- Gautrans BST pavements are smoother (lower IRI) than WSDOT BST pavements.

Table 5.12. Summary of Gautrans Roughness Values- IRI (m/km)

Base Type	Granular		Cemented		Total	
	New	BST Resurf	New	BST Resurf	New	BST Resurf
Mean	2.57	2.76	2.69	2.86	2.61	2.79
Median	2.52	2.55	2.70	2.81	2.57	2.64
Std. Deviation	0.59	0.94	0.52	0.75	0.57	0.87
Minimum	1.18	1.18	1.74	1.18	0.91	0.91
Maximum	4.73	8.32	3.74	5.73	3.64	6.41
No. of Sections	93	723	34	406	127	1,129
Center-line km	242	2047	79	1,176	321	3,223

5.4.3.5 Rutting

Both agencies make use of an automated sensor system to measure rut depths in the wheelpaths. The major difference between methods is that Gautrans measurements utilize 14 ultra-sonic sensors, whereas WSDOT utilizes only 5 ultra-sonic sensors on the full width of the lane. This difference may contribute to differences in the reported rutting accuracy of each agency. Table 5.13 illustrates the Gautrans rutting values.

Conclusions from investigation into rutting include the following:

- Rutting values suggest that WSDOT pavements are not as rutted as Gautrans pavements, although differences are small.

- For both systems, rutting is less on resurfaced than on new or reconstructed pavements.

Table 5.13. Summary of Gautrans Rutting Values (mm)

Base Type	Granular		Cemented		Total	
	New	BST Resurf	New	BST Resurf	New	BST Resurf
Mean	7.20	6.78	5.93	6.85	6.86	6.81
Median	6.34	5.85	5.6	6.33	6.14	6.02
Std. Deviation	3.34	3.91	1.83	2.57	2.94	3.43
Minimum	3.22	1.40	3.87	2.27	3.20	1.40
Maximum	25.40	44.25	9.54	16.95	25.40	44.20
No. of Sections	93	723	34	406	127	1,129
Center-line km	242	2047	79	1,176	321	3,223

5.4.4 Overall Conclusions Regarding Gautrans vs. WSDOT Pavement Performance

A comparison was made of two distinctly different pavement management systems representing pavements of the Gauteng Province of South Africa and the state of Washington. The statistical comparison between both systems reflected the following:

- The Gauteng road network is smaller and carries less traffic (ESALs) than the Washington state route system.
- The condition indices used by both agencies, VCI and PSC, differ to such an extent that direct comparison of results is limited.
- WSDOT pavements display less rutting and lower IRI values than Gautrans pavements; however, there are differences in test measurement techniques between the agencies.
- The current mean age of BST pavements in the Gauteng Province is remarkably high.

CHAPTER 6—RELATIONAL PERFORMANCE MEASURE ANALYSIS

6.1 OVERVIEW

The use and proven reliability of relating PSC to pavement service life (Age) is well documented in various WSDOT reports and within the WSPMS. What is perhaps less understood is the relevance of other performance measures such as road roughness, rutting, and traffic levels in determining service life and other relational performance trends.

The main objective of generating comparative statistics was to investigate the interrelationships of the five performance measures used in this study as they relate to the current surface course of Washington State pavements. Another objective was to analyze performance trends and assess the possible use of performance measures other than PSC to predict service life. Finally, this investigation was intended to provide insights into questions about Washington State pavements, including, but not limited to, the following:

- Are rougher pavements necessarily also more rutted?
- Are more rutted pavements necessarily also rougher?
- Because rutting is not directly taken into account when PSC is determined, do more severely rutted pavements have lower PSC scores?
- How do PSC, IRI, and rutting trends vary over time?

6.1.1 Scope

Rather than consider all 18 distinct analysis groups for this relational performance measure analysis, only those groups that contained resurfaced AC and BST pavements were considered because the overwhelming majority of the SR system is a product of resurfaced AC and BST pavements.

These six analysis groups were considered:

- Eastern WA, Interstate, Resurfaced, AC
- Western WA, Interstate, Resurfaced, AC
- Eastern WA, Non-Interstate, Resurfaced, AC
- Western WA, Non-Interstate, Resurfaced, AC
- Eastern WA, Non-Interstate, Resurfaced, BST
- Western WA, Non-Interstate, Resurfaced, BST

6.1.2 Study Development

The following six relationships were analyzed:

- PSC vs. age
- IRI vs. age
- Rutting vs. age
- PSC vs. IRI
- PSC vs. rutting
- IRI vs. rutting

Investigation of each relationship among all six analysis groups involved the following steps:

Step 1: Generate bivariate scatter plots

Step 2: Generate the correlation coefficient

Step 3: Perform a simple linear regression to determine the best "least squares" line representing each set of data

Step 4: Perform a hypothesis test to determine whether the regression slope coefficient is significantly different from zero (0).

Step 5: Analyze the results

6.2 RELEVANT STATISTICS AND REGRESSION DEVELOPMENT

This relational performance measure analysis involved the generation of comparative statistics and regression analysis. Therefore, below is a brief discussion of the different statistics and regression methods used. The discussion centers on the conceptual interpretation of specific statistical measures and much less on equation formats. Discussion of statistical procedures as they relate specifically to WSDOT pavement and material examples is available (Mahoney 1994).

6.2.1 Scatter Plots

To illustrate the correlation among the five performance measures for each of the six relationships of interest, 54 scatter plots were generated (see Appendix G). In each case duplicate data points existed that cannot be seen in the plots because they simply "stacked" when printed. The total population number of data points (n) and correlation coefficient (*r*) are reported on each plot. To visualize the effect of traffic levels, each analysis group was broken into high and low ESAL levels, with the approximate median ESAL value for each analysis group serving as the boundary.

The WSPMS contains some suspect age data primarily because of a lag in updating the database after rehabilitation has been completed. This likely contributed to outliers in the plots (see Appendix G). It is difficult, if not impossible, to accurately detect all outliers within the WSPMS, and no statistical outlier test was performed. Rather, all data were initially plotted. However, the presence of potential outliers with high age values caused severe "clumping" in the scatter plots, making it difficult to visualize performance trends. Experience with the WSPMS suggests that, intuitively, AC and BST pavements in Washington State generally do not last longer than 20 years. So to help alleviate the "clumping" problem, all data points over 20 years were summarily eliminated, and scatter plots were re-generated with 0- to 20-year-old pavement sections only. These revised plots, which helped to spread the data and illustrate performance trends in greater detail, are shown for comparison (on the same page) with plots of all data in Appendix G. This process was only necessary for cases in which performance measures were compared with pavement age. All other performance measure values (PSC, IRI and rutting) are updated in the WSPMS promptly after visual distress surveys have been completed. Therefore, the presence of outliers among these performance measures was assumed to be negligible.

6.2.2 Correlation Coefficient (*r*)

All values of r fall between -1 and +1. Values near -1 represent a relationship in which an increase in x results in a decrease in y, and values near +1 represent a relationship in which an increase in x results in an increase in y. A reasonable question is, "When can it be said that there is a strong correlation between the variables, and when is the correlation weak?" A rule of thumb suggested by Devore (1991) and used in this study is that the correlation is weak if $0 \leq |r| \leq 0.5$, strong if $0.8 \leq |r| \leq 1$, and moderate otherwise.

6.2.3 Regression Statistics

6.2.3.1 Simple Linear Regression Equation

Simple linear regression analysis was performed to determine the importance of the independent variable, x, in predicting values of the dependent variable, y, for each relationship. The method of "least squares" was used to produce the best-fitting least squares line of the form $\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x$, where $\hat{y}$ is the predicted value of the dependent performance measure and $\hat{\beta}_0$ and $\hat{\beta}_1$ are the y-intercept and slope coefficients, respectively. This method minimizes the squared deviations between the actual data points and the fitted line.

6.2.3.2 Regression Statistics

To fully describe the relationship of two variables, a scatter plot should be produced showing all data points. Additionally, at a minimum, certain statistics should be reported that describe the regression equation used to relate the variables. These statistics include the following:

- number of data points (n)
- root mean square error (RMSE)
- coefficient of Determination (R^2)
- residuals
- hypothesis test of regression slope coefficient β_1.

6.3 ANALYSIS AND FINDINGS

The remainder of the chapter is devoted to presenting the analysis of the six performance measure relationships and summarizing findings. Areas of interest include correlation trends, regression statistics, results of hypothesis tests, and others. Within each performance measure relationship, analysis groups could be analyzed on the basis of location, pavement type, Interstate vs. non-Interstate, and traffic level. The possible number of comparisons was large. Because of the large number of scatter plots (54) and regression equations (104), the analysis presentation is kept fairly general and covers the same general points for all performance measure relationships. Extreme trends are highlighted, as are simple trends such as traffic level over all analysis groups, rather than for specific groups.

The six pavement analysis groups are shown below with their abbreviations, which are used throughout the remainder of the chapter. The fourth abbreviation designator signifies whether the data represent pavement sections exposed to low (L) or high (H) traffic levels (measured in design-lane ESALs).

Analysis Group	Abbreviation	Annual ESAL Limits
Eastern WA, Interstate, AC	E-I-AC- (L or H)	L-(0-500,000) H-(>500,000)
Western WA, Interstate, AC	W-I-AC- (L or H)	L-(0-1,000,000) H-(>1,000,000)
Eastern WA, Non-Interstate, AC &	E-NI-AC- (L or H)	L-(0-100,000)/
Western WA, Non-Interstate, AC	W-NI-AC- (L or H)	H-(>100,000)
Eastern WA, Non-Interstate, BST &	E-NI-BST- (L or H)	L-(0-30,000)/
Western WA, Non-Interstate, BST	W-NI-BST- (L or H)	H-(>30,000)

6.3.1 PSC vs. AGE

6.3.1.1 Analysis of the Scatter Plots

Figures G1 through G12 of Appendix G illustrate the scatter plots for the PSC vs. age relationship. The correlation coefficient *r* was negative for all analysis groups, indicating a trend in which increasing age results in decreased PSC values. This is to be expected. Table 6.1 summarizes *r* values that describe trends among analysis groups.

Table 6.1. Correlation Summary for PSC vs. AGE

Statistical Measure	Value	Analysis Group
Overall *r*- Minimum	-0.12	W-NI-BST-L
Maximum	-0.65	E-I-AC-L
Mean *r*- Low ESALs	-0.42	All
High ESALs	-0.48	All
Min. Diff. between Low & High ESALs	0.01	W-NI-AC
Max. Diff. between Low & High ESALs	0.27	W-NI-BST
Mean. Diff. between Low & High ESALs	0.09	All

- Given the rule of thumb from Section 6.2.2 regarding *r* values, most analysis groups displayed weak linear trends ($0 \leq |r| \leq 0.5$). However, five of twelve groups displayed moderate linear trends.

- The PSC values generally ranged from approximately 30 to 100 for any given age group. Data were generally not tightly grouped among age groups, suggesting that pavements of the same age displayed very different conditions.
- The *r* values showed that high ESAL pavement sections produced a higher mean *r* value.

6.3.1.2 Regression Analysis

Results of the linear regression analysis are summarized in Table 6.2. The low R^2 values indicate that linear models did a poor job of reducing the errors in predicting PSC when age was the only independent variable. However, the R^2 values did indicate that a linear model is better at predicting PSC than the mean PSC score. The calculated t-statistic (t_{calc}) for all but one of the slope coefficients (β_1) exceeded the critical t value (t_{crit}), indicating that age did provide useful information in predicting PSC (see Table G1 in Appendix G). The one analysis group that failed the hypothesis test was W-NI-BST-L. In general, the regression analysis provided few additional insights into the analysis of PSC vs. age.

Table 6.2. Regression Summary for PSC vs. AGE

Statistical Measure	**R^2**		**RMSE**	
	Value	Analysis Grp	Value	Analysis Grp
Overall- Minimum	0.01	W-NI-BST-L	9.48	E-I-AC-H
Maximum	0.42	E-I-AC-L	20.32	W-NI-BST-H
Mean- Low ESALs	0.20	All	14.89	All
High ESALs	0.24	All	15.43	All
Min. Diff. between Low & High ESALs	0.01	W-NI-AC	0.44	E-NI-BST
Max. Diff. between Low & High ESALs	0.13	W-NI-BST	2.80	W-I-AC
Mean. Diff. between Low & High ESALs	0.063	All	1.19	All

6.3.2 IRI vs. Age

6.3.2.1 Analysis of the Scatter Plots

Figures G13 through G24 of Appendix G illustrate the scatter plots for the IRI vs. age relationship. The correlation coefficient *r* was positive for all but one case (W-NI-BST-H), indicating a general trend in which increasing age was accompanied by increased IRI values. Table 6.3 summarizes *r* values that describe trends among analysis groups.

Table 6.3. Correlation Summary for IRI vs. AGE

Statistical Measure	Value	Analysis Group
Overall *r*- Minimum	-0.04	W-NI-BST-H
Maximum	0.38	W-NI-AC-L
Mean *r*- Low ESALs	0.22	All
High ESALs	0.12	All
Min. Diff. between Low & High ESALs	0.11	W-NI-AC
Max. Diff. between Low & High ESALs	0.32	E-I-AC
Mean. Diff. between Low & High ESALs	0.16	All

- Given the rule of thumb from Section 6.2.2 regarding *r* values, all analysis groups displayed weak linear trends ($0 \leq |r| \leq 0.5$).
- The *r* values showed that low ESAL volume pavement sections produced a higher mean *r* value. Among the six analysis groups, low volume pavement sections produced a higher *r* value in five of six comparisons (W-NI-BST did not).
- The IRI values illustrated in the scatter plots generally fell within the following ranges:
  - Non-Interstate, AC, all pavements: 1.0 - 9.0 (m/km)
  - Interstate, AC, all pavements: 1.0 - 3.0 (m/km)
  - Non-Interstate, BST, all pavements: 1.5 - 6.0 (m/km)

6.3.2.2 Regression Analysis

Results of the linear regression analysis are summarized in Table 6.4.

Table 6.4. Regression Summary for IRI vs. Age

Statistical Measure	R^2		RMSE	
	Value	Analysis Grp	Value	Analysis Grp
Overall- Minimum	0.00	4 groups	0.12	W-I-AC-L
Maximum	0.15	W-NI-AC-L	0.87	W-I-AC-L
Mean- Low ESALs	0.07	All	0.61	All
High ESALs	0.02	All	15.43	All
Min. Diff. between Low & High ESALs	0.00	W-NI-BST	0.44	E-NI-BST
Max. Diff. between Low & High ESALs	0.11	E-I-AC	2.80	W-I-AC
Mean. Diff. between Low & High ESALs	0.06	All	1.19	All

The low R^2 values indicate that linear models did a poor job of reducing the errors in predicting IRI when age was the only independent variable. In considering all pavement sections, t_{calc} for the slope coefficient (β_1) exceeded the t_{crit} value in only seven of twelve cases (see Table G2). This indicates that age provided useful information in predicting IRI in only about one half of the cases investigated.

6.3.2.3 Additional Insights

Currently WSDOT performs annual visual distress surveys over 100 percent of the State Route system to maintain the integrity of the WSPMS, which projects pavement service life on the basis of PSC scores. Should WSDOT consider changing the WSPMS to program maintenance and rehabilitation on the basis of IRI? The indicators investigated in this study suggest no reason for changing to a basis of IRI to predict pavement service life. In fact, all indicators analyzed suggest that IRI is a less reliable performance measure. The relationship of IRI to age produced a lower overall linear correlation and a lower quality of linear regression than PSC vs. age.

6.3.3 Rutting vs. Age

6.3.3.1 Analysis of the Scatter Plots

Figures G25 through G36 of Appendix G illustrate the scatter plots for the rutting vs. age relationship. The correlation coefficient *r* was positive for all but one case (W-NI-BST-L), indicating a general trend in which increasing age was accompanied by increasing rut depth. Table 6.5 summarizes *r* values that describe trends among analysis groups.

Table 6.5. Correlation Summary for Rutting vs. Age

Statistical Measure	Value	Analysis Group
Overall *r*- Minimum	-0.08	W-NI-BST-L
Maximum	0.70	E-I-AC-L
Mean *r*- Low ESALs	0.28	All
High ESALs	0.26	All
Min. Diff. between Low & High ESALs	0.09	W-NI-BST
Max. Diff. between Low & High ESALs	0.60	E-I-AC
Mean. Diff. between Low & High ESALs	0.25	All

- Given the rule of thumb from Section 6.2.2 regarding *r* values, all analysis groups but one displayed weak linear trends. A moderate linear trend existed for E-I-AC-L, which produced an *r* value of 0.70. This fact alone is somewhat interesting because the other *r* values are so much lower. Perhaps even more interesting is the fact that high volume pavements within the same analysis group produced an *r* value of only 0.10. This resulted in a 0.60 difference between high and low volume pavement sections within this group. The reason for this large difference is unclear.

- The *r* values showed that low ESAL volume pavement sections produced a higher mean *r* value, in large part because of the 0.70 value for the E-I-AC-L group.
- A slight trend in the scatter plots suggests that traffic level plays a role in affecting rutting depth (not a surprise). Higher volume pavement sections were generally more rutted than lower volume pavements—as expected. This does not show up in the correlation values. However, correlation does not consider a fixed (or forced) y intercept, so it is possible for high volume pavements to have a lower *r* value yet also have a linear trend line that is shifted higher along the vertical axis (in this case with increasing rut depth).
- The rut depth values illustrated in the scatter plots were somewhat erratic but generally fell within the following ranges:

- Non-Interstate, AC, all pavements:	0.0 - 17.0 (mm)
- Interstate, AC, all pavements:	0.0 - 16.0 (mm)
- Non-Interstate, BST, all pavements:	0.0 - 13.0 (mm)

- Variation in rut depths among pavements of the same age was large.

6.3.3.2 Regression Analysis

Results of the linear regression analysis are summarized in Table 6.6. The generally low R^2 values indicate that linear models did a poor job of reducing the errors in predicting rutting depth when age was the only independent variable. In considering all pavement sections, t_{calc} for the slope coefficient (β_1) exceeded the t_{crit} value in nine of twelve cases (see Table G3).

Table 6.6. Regression Summary for Rutting vs. Age

Statistical Measure	R^2		RMSE	
	Value	Analysis Grp	Value	Analysis Grp
Overall- Minimum	0.001	E-NI-BST-H	2.11	W-NI-AC-L
Maximum	0.49	W-I-AC-L	3.50	W-I-AC-H
Mean- Low ESALs	0.13	All	2.39	All
High ESALs	0.082	All	2.75	All
Min. Diff. between Low & High ESALs	0.005	E-NI-BST	0.08	E-NI-BST
Max. Diff. between Low & High ESALs	0.49	W-I-AC	0.88	W-I-AC
Mean. Diff. between Low & High ESALs	0.15	All	0.50	All

6.3.3.3 Additional Insights

The indicators investigated in this study suggest no reason for changing to rutting as a basis for predicting pavement service life. In fact, all indicators analyzed suggest that rutting is a less reliable performance measure. The relationship of rutting to age produced lower overall linear correlation and lower quality of linear regression than PSC vs. age.

6.3.4 PSC vs. IRI

6.3.4.1 Analysis of the Scatter Plots

Figures G37 through G42 of Appendix G illustrate the scatter plots for the PSC vs. IRI relationship. The correlation coefficient *r* was negative for all cases, indicating a general trend in which increasing IRI was accompanied by decreasing PSC score. Table 6.7 summarizes *r* values that describe trends among analysis groups.

- Given the rule of thumb from Section 6.2.2 regarding *r* values, all analysis groups displayed weak linear trends ($0 \leq |r| \leq 0.5$).
- The minimum and maximum *r* values were found within the same analysis group (W-NI-BST).

- The *r* values showed that low ESAL volume pavement sections produced a higher mean *r* value.

Table 6.7. Correlation Summary for PSC vs. IRI

Statistical Measure	Value	Analysis Group
Overall *r*- Minimum	-0.05	W-NI-BST-H
Maximum	-0.30	W-NI-BST-L
Mean *r*- Low ESALs	-0.20	All
High ESALs	-0.12	All
Min. Diff. between Low & High ESALs	0.00	E-I-AC
Max. Diff. between Low & High ESALs	0.25	W-NI-BST
Mean. Diff. between Low & High ESALs	0.08	All

- The PSC and IRI boundary values illustrated in the scatter plots generally fell within the following ranges:

		IRI Range (m/km)	
Analysis Group	PSC Range	All Points	Most Points
Non-Interstate, AC, all pavements:	30-100	1.0 - 9.0	1.0 - 3.5
Interstate, AC, all pavements:	30-100	1.0 - 3.0	1.0 - 2.5
Non-Interstate, BST, all pavements:	30-100	1.5 - 6.0	1.5 - 5.0

For IRI values, the first column represents the range of values that encompasses all data points. The second column refers to the smaller (or tighter) range of values that encompasses a majority of the data points. These values were selected by inspection of the scatter plots. The PSC values are fairly evenly distributed between 30 and 100. This range includes all data points.

6.3.4.2 Regression Analysis

Results of the linear regression analysis are summarized in Table 6.8. The extremely low R^2 values indicate that linear models did a poor job of reducing the errors in predicting PSC when IRI was the only independent variable. In considering all pavement sections, t_{calc} for the slope coefficient (β_1) exceeded the t_{crit} value in nine of twelve cases (see Table G4).

Table 6.8. Regression Summary for PSC vs. IRI

Statistical Measure	R^2		RMSE	
	Value	Analysis Grp	Value	Analysis Grp
Overall- Minimum	0.002	W-NI-BST-H	11.94	E-I-AC-H
Maximum	0.088	W-NI-BST-L	22.07	W-NI-BST-H
Mean- Low ESALs	0.043	All	16.15	All
High ESALs	0.017	All	17.53	All
Min. Diff. between Low & High ESALs	0.000	E-I-AC	0.08	E-NI-BST
Max. Diff. between Low & High ESALs	0.086	W-NI-BST	4.01	W-I-AC
Mean. Diff. between Low & High ESALs	0.026	All	2.29	All

6.3.4.3 Additional Insights

A reasonable question to ask is, "Do rougher pavement sections necessarily translate into lower PSC scores?" This investigation indicates that the answer is, "Perhaps." The negative correlation coefficients indicate a trend between increasing IRI and decreasing PSC. However, looking at any value of IRI reveals PSC scores that range from 30 to 100. This indicates that pavement sections with an IRI of 3.0 can be in sound condition or failed.

6.3.5 PSC vs. Rutting

6.3.5.1 Analysis of the Scatter Plots

Figures G43 through G48 of Appendix G illustrate the scatter plots for the PSC vs. rutting relationship. The correlation coefficient *r* was negative for all cases, indicating a general trend in which increasing rut depth (mm) was accompanied by decreasing PSC scores. Table 6.9 summarizes *r* values that describe trends among analysis groups.

Table 6.9. Correlation Summary for PSC vs. Rutting

Statistical Measure	Value	Analysis Group
Overall *r*- Minimum	-0.10	E-I-AC-H
Maximum	-0.53	W-NI-BST-H
Mean *r*- Low ESALs	-0.25	All
High ESALs	-0.28	All
Min. Diff. between Low & High ESALs	0.03	W-I-AC
Max. Diff. between Low & High ESALs	0.36	W-NI-BST
Mean. Diff. between Low & High ESALs	0.15	All

- Given the rule of thumb from Section 6.2.2 regarding *r* values, all analysis groups but one displayed weak linear trends ($0 \leq | r | \leq 0.5$).
- A moderate linear trend existed for W-NI-BST-H, which produced an *r* value of -0.53. Other *r* values were much lower. Perhaps more interesting is the fact that low ESAL volume pavements within the same analysis group produced an *r* value of only -0.17. This resulted in an absolute difference of 0.36 between high and low volume pavement sections within this group. The reason for this relatively large difference is unclear.
- The PSC and rutting boundary values illustrated in the scatter plots generally fell within the following ranges:

		Rutting Range (mm)	
Analysis Group	PSC Range	All Points	Most Points
Non-Interstate, AC, all pavements:	30-100	0.0 - 17.0	0.0 - 14.0
Interstate, AC, all pavements:	30-100	0.0 - 16.0	0.0 - 12.0
Non-Interstate, BST, all pavements:	30-100	0.5 - 13.0	0.5 - 9.0

For rutting values, the first column represents the range of values that encompasses all data points. The second column refers to the smaller (or tighter) range of values that encompasses a majority of the data points. These values were selected by inspection of the scatter plots. The PSC values are fairly evenly distributed between 30 and 100. This range includes all data points.

- The *r* values show that high volume pavement sections produced a higher mean *r* value. A slight trend may exist for W-I-AC. In the plot for this group (Figure G46, Appendix G), high traffic volume pavement sections were definitely more rutted. However, their PSC values were comparable to lower ESAL volume sections that were 4- to 6-mm less rutted.

6.3.5.2 Regression Analysis

Results of the linear regression analysis are summarized in Table 6.10. The extremely low R^2 values indicate that linear models did a poor job of reducing the errors in predicting PSC when rutting was the only independent variable. In considering all pavement sections, the t_{calc} for the slope coefficient (β_1) exceeded the t_{crit} value in eleven of twelve cases (see Table G5).

Table 6.10. Regression Summary for PSC vs. Rutting

Statistical Measure	R^2		RMSE	
	Value	Analysis Grp	Value	Analysis Grp
Overall- Minimum	0.005	E-I-AC-H	11.95	E-I-AC-H
Maximum	0.28	W-NI-BST-H	19.12	W-NI-BST-L
Mean- Low ESALs	0.064	All	16.02	All
High ESALs	0.097	All	16.65	All
Min. Diff. between Low & High ESALs	0.016	W-I-AC	0.23	E-NI-BST
Max. Diff. between Low & High ESALs	0.26	W-NI-BST	3.68	W-I-AC
Mean. Diff. between Low & High ESALs	0.087	All	1.33	All

6.3.5.3 Additional Insights

A reasonable question to ask is, "Do more rutted sections necessarily translate into lower PSC scores?" This investigation indicates that the answer is, "Perhaps." The negative correlation coefficients indicate a trend between increasing rutting and associated decreasing PSC values. However, looking at any value of rut depth reveals PSC scores that range generally from 30 to 100. This indicates, for instance, that pavement sections with a rut depth of 6.0 mm can be in sound condition or failed by WSDOT standards (rut depth ≥ 9 mm).

6.3.6 IRI vs. Rutting

6.3.6.1 Analysis of the Scatter Plots

Figures G49 through G54 of Appendix G illustrate the scatter plots for the IRI vs. rutting relationship. The correlation coefficient *r* was positive for all cases, indicating a general trend in which increasing rut depth was accompanied by increasing IRI values. Table 6.11 summarizes *r* values that describe trends among analysis groups.

Table 6.11. Correlation Summary for IRI vs. Rutting

Statistical Measure	Value	Analysis Group
Overall *r*- Minimum	0.05	W-NI-BST-H
Maximum	0.43	W-NI-BST-L
Mean *r*- Low ESALs	0.29	All
High ESALs	0.15	All
Min. Diff. between Low & High ESALs	0.02	W-I-AC
Max. Diff. between Low & High ESALs	0.38	W-NI-BST
Mean. Diff. between Low & High ESALs	0.14	All

- Given the rule of thumb from Section 6.2.2 regarding *r* values, all analysis groups displayed weak linear trends ($0 \leq | r | \leq 0.5$).

- The minimum and maximum *r* values were produced within the same analysis group. The resulting difference between high and low ESAL volume pavement sections within this group was 0.38. No other *r* value was this large. The reason for this relatively large difference within the W-NI-BST analysis group is unclear.
- The *r* values showed that low volume pavement sections produced a higher mean *r* value. Also, among the six analysis groups, low volume pavement sections produced a higher *r* value in all six comparisons.
- The following traffic-related trends are suggested by inspection of the scatter plots:
  - For the W-I-AC analysis group, high ESAL volume pavement sections appear to be more rutted than low ESAL volume pavements. No low volume pavements exceeded rutting of 11 mm, whereas approximately 10 percent of the high volume pavements fell into the range from 11-16 mm.
  - For the W-NI-BST analysis group, low volume pavement sections appear rougher throughout all rut depths.
- The IRI and rutting boundary values illustrated in the scatter plots generally fell within the following ranges:

Analysis Group	IRI Range (m/km)	Rutting Range (mm) All Points	Most Points
• Non-Interstate, AC, all pavements:	1.0-9.0	0.0 - 17.0	0.0 - 14.0
• Interstate, AC, all pavements:	1.0-3.0	0.0 - 16.0	0.0 - 12.0
• Non-Interstate, BST, all pavements:	1.5-6.0	0.5 - 13.0	0.5 - 9.0

For rutting values, the first column represents the range of values that encompasses all data points. The second column refers to the smaller (or tighter) range of values that encompasses a majority of the data points. These values were selected by inspection of the scatter plots.

6.3.6.2 Regression Analysis

Results of the linear regression analysis are summarized in Table 6.12. The extremely low R^2 values indicate that linear models did a poor job of reducing the errors in predicting IRI when rutting was the only independent variable. In considering all pavement sections, t_{calc} for the slope coefficient (β_1) exceeded the t_{crit} value in nine of twelve cases (see Table G6). Therefore, in these nine cases, rutting provided useful information in predicting IRI.

Table 6.12. Regression Summary for IRI vs. Rutting

Statistical Measure	R^2		RMSE	
	Value	Analysis Grp	Value	Analysis Grp
Overall- Minimum	0.002	W-NI-BST-H	0.48	E-I-AC-H
Maximum	0.18	W-NI-BST-L	0.83	E-NI-AC-L
Mean- Low ESALs	0.09	All	0.67	All
High ESALs	0.03	All	0.64	All
Min. Diff. between Low & High ESALs	0.02	W-I-AC	0.00	E-I-AC
Max. Diff. between Low & High ESALs	0.16	W-NI-BST	0.11	W-NI-BST
Mean. Diff. between Low & High ESALs	0.06	All	0.05	All

- The IRI data appear to be fairly symmetrically distributed around a central IRI value for each of the analysis groups. The symmetry appears to reasonably transcend traffic levels within the groups except for W-NI-BST. The central value for each analysis group, based only on scatter plot inspection, follows:

E-I-AC	1.5 m/km	W-I-AC	1.8 m/km
E-NI-AC	2.4 m/km	W-NI-AC	3.0 m/km
E-NI-BST	2.8 m/km	W-NI-BST-L	4.2 m/km
		W-NI-BST-H	3.0 m/km

6.3.6.3 Additional Insights

Two of the main questions of interest are the following:

- "Are rougher pavements necessarily also more rutted?"
- "Are more rutted pavements necessarily also rougher?"

This investigation indicates that the answer is, "Perhaps." The positive correlation coefficients suggest a trend between increasing rutting and increasing IRI for all analysis groups. This trend is best seen in the W-NI-BST-L analysis group plot (Figure G54, Appendix G).

Analysis of any given rut depth value shows a generally symmetric range of IRI values in a band around a central IRI value. The IRI bands decrease in size as rutting increases. A pavement section that intermittently changes from no rutting to varying degrees of rutting would tend to produce the maximum IRI bands, generally around a rut depth of 4 mm.

6.4 SUMMARY OF RESULTS

This section aggregates some of the major findings in the investigation.

6.4.1 Correlation Results

The following general correlation trends were observed:

Relationship	Correlation Trend	Relationship	Strength of Correlation (r) (# of cases) Weak	Moderate
PSC vs. Age	negative	↓ PSC associated with ↑ Age	7	5
IRI vs. Age	positive	↑ IRI associated with ↑ Age	11	1
Rutting vs. Age	positive	↑ Rut associated with ↑ Age	11	1
PSC vs. IRI	negative	↓ PSC associated with ↑ IRI	12	0
PSC vs. Rutting	negative	↓ PSC associated with ↑ Rutting	11	1
IRI vs. Rutting	positive	↑ IRI associated with ↑ Rutting	12	0

↑ (increasing) ↓ (Decreasing) * Weak: $0 \leq |r| \leq 0.5$ Moderate: $0.5 < |r| < 0.8$

6.4.2 Regression Results

- Generally, the regression analysis resulted in little additional knowledge of the relationships under investigation.
- Results of the hypothesis testing revealed that the independent variable, in most cases, did provide useful information in predicting the value of the dependent variable.
- The R^2 values ranged from extremely low to low, indicating that in general, the linear models were not very good at reducing the prediction error of y. A summary of key regression indicators reveals the overall poor ability of linear models to reduce the errors in predicting y when any of the performance measures was the lone x variable.

	Range of R^2 values		Range of RMSE values		
Relationship	Min	Max	Min	Max	# of cases where tcalc > tcrit for β_1
PSC vs. Age	0.01	0.42	9.48	20.32	11 of 12
IRI vs. Age	0.00	0.15	0.12	0.87	7 of 12
Rutting vs. Age	0.001	0.49	2.11	3.50	9 of 12
PSC vs. IRI	0.002	0.088	11.94	22.07	9 of 12
PSC vs. Rutting	0.005	0.28	11.95	19.12	11 of 12
IRI vs. Rutting	0.002	0.18	0.48	0.83	9 of 12

6.4.3 Additional Insights

- Generally, few traffic related trends were reflected in the scatter plots.
- Investigation results suggest no possible reason to change from PSC to IRI or rutting as a basis for predicting service life.
- There is indication that more rutted pavements are rougher and vice versa.
- There is some indication that increased rutting and roughness are accompanied by decreased PSCs.

CHAPTER 7—CANDIDATE PAVEMENT SELECTION

7.1 METHODOLOGY

This chapter outlines the approach taken to produce a candidate list of pavements with superior and inferior performance selected from the Washington SR system. The research methodologies for selecting pavements with superior and inferior performance were different. Each is outlined separately, beginning with superior performance.

7.2 SELECTION OF PAVEMENTS WITH SUPERIOR PERFORMANCE

The selection methodology was divided into the following five phases:

Phase 1. Establish Statistically Based Selection Threshold Values

Phase 2. Establish a Hierarchy of Performance Measures

Phase 3. Iterate Performance Measure Values

Phase 4. Cross Reference the Results with the WSPMS

Phase 5. Calculate Performance Probabilities

Each phase relates to the systematic selection of candidate pavements with superior performance within the 18 analysis groups identified in Section 3.2. The selection process was the same for all analysis groups. Therefore, only one of the 18 analysis groups is used as an example to illustrate the selection process. Sections 7.2.1 through 7.2.5 discuss the five phases listed above. The resulting candidate pavement list is presented in Section 7.2.6. The example analysis group chosen represents pavements with the following characteristics:

- located in the western half of the state
- located on the Interstate route system

- a product of resurfacing
- AC surface course.

7.2.1 Phase 1. Establish Statistically Based Selection Threshold Values

The summary statistics presented in Chapter 5 set the stage for selecting candidate pavements with superior performance. As outlined in Section 3.2, the population mean (μ) and standard deviation (σ) for each performance measure were used to establish selection threshold values for pavements within each of the 18 analysis groups. Again, superior performance is represented by the following:

- long service life (age)
- high PSC score
- high annual ESALs
- low rutting values
- low IRI scores (representing smooth pavements).

A complete list of the summary statistics generated for all 18 analysis groups can be found in Appendix A. Summary statistics for the example analysis group are reproduced in Table 7.1. On the basis of the discussion in Section 3.2 and the statistics from Table 7.1, initial selection threshold values were established. A summary of the initially selected values for the example analysis group is shown in Table 7.2. The final values, produced through the iteration procedure outlined in Section 7.2.3, were slightly different. A comparison of the mean (μ) and final values is presented later in Table 7.7. A brief discussion of how each value was determined follows.

Table 7.1. Summary Statistics for Example Analysis Group

STATISTIC	PERFORMANCE MEASURES				
	Age (yrs)	PSC	ESALs	IRI (m/km)	Rutting (mm)
Mean (μ)	9.2	89.1	1,133,627	1.65	5.2
Median	6.0	100.0	1,125,541	1.83	4.0
Mode	1.0	100.0	1,788,863	1.92	3.0
S. Deviation (σ)	6.8	15.8	500,758	0.55	3.4
Minimum	1.0	33.0	24,867	0.66	0.0
Maximum	40.0	100.0	2,461,960	4.77	16.0
Pvmt Sections	571	571	567	565	565
Center-line km	580.0	580.0	577.6	577.6	577.6

Table 7.2. Initial Selection Threshold Values for Example Analysis Group.

Performance Measure	(μ)	(σ)	Initial Selection Thresholds	
			Statistic	Value
Age (yrs)	9.2	6.8	(μ)	9*
PSC	89.1	15.8	(μ +0.1σ)	90
ESALs	1,133,627	500,758	(μ + σ)	1,634,385
IRI (m/km)	1.65	0.55	(μ - σ)	1.10
Rutting (mm)	5.2	3.4	(μ - σ)	1.80

* Value rounded down to the nearest whole year from actual μ value of 9.2 years.

Age—This performance measure had the least flexibility. Setting the selection threshold value to select only very old pavements (μ + σ) was too restrictive to allow any pavement sections to emerge from the database. Therefore, the selection threshold value was set to (μ) for all analysis groups.

PSC—A selection threshold value of 90 (which was generally lower than (μ + σ)) was used for all analysis groups for two key reasons: (1) a PSC score of 90 still represents pavements that are in very good to excellent condition, and (2) using a score of 90 "relaxed" the threshold value to a reasonable limit at which a select number of candidate sections emerged from the database.

ESALs—This performance measure has a wide range of values and a great deal of flexibility. It was therefore set to ($\mu + \sigma$) for all analysis groups.

IRI and Rutting—These performance measures also displayed a wide range of values and flexibility. Because low values of roughness and rutting were desirable, the selection threshold was set to ($\mu - \sigma$) for all analysis groups.

7.2.2 Phase 2. Establish a Hierarchy of Performance Measures

A selection hierarchy was developed to perform iterations in the selection process. A method of systematically changing selection threshold values for the performance measures allowed the candidate list to be expanded or reduced. The sequence of applying the changes differed depending on the the desired effect. If no candidate pavements emerged from the WSPMS with the initial threshold values, the standards had to be relaxed to expand the list. Because rutting was established as the least critical performance measure, it was relaxed first to keep all other (increasingly critical) performance measures as stringent as possible. Conversely, if too many pavements emerged from the WSPMS, the first performance measure to be restricted was age because it was deemed the most critical performance measure. Table 7.3 presents the hierarchy.

Table 7.3. Performance Measure Hierarchy.

Performance Measure	Importance Ranking	Sequence to expand list (loosen standards)	Sequence to reduce list (tighten standards)
Age	1	Rutting	Age
PSC	2	IRI	PSC
ESALs	3	ESALs	ESALs
IRI	4	PSC	IRI
Rutting	5	Age	Rutting

7.2.3 Phase 3. Iterate Performance Measure Values

Iterating the selection process was a critical phase in establishing the list of candidate pavements. None of the 18 analysis groups produced candidates with the initial threshold values. The cumulative effect of trying to meet the standards across all five performance measures was too restrictive to allow any pavements to emerge from the database. Therefore, a systematic approach to iterating the selection process was developed to generate an adequate number of candidate pavement sections from the WSPMS. Figure 7.1 illustrates the iteration process. The following trends were generally displayed:

- Candidate pavements generally emerged from the database without having to adjust age (the last resort performance measure, as seen in Table 7.3).
- PSC and IRI generally "drove the train" in producing candidates. In some cases, very minor reductions in threshold values caused multiple pavement sections to emerge or disappear from the list.
- Rutting generally had a minor impact in causing additional pavement sections to emerge from the database.
- The most important factor in looking at east vs. west among analysis groups was ESALs. Pavements in the eastern half of the state generally had fewer annual design-lane ESALS than western pavements.
- Age was also important in transcending east vs. west. Eastern pavement sections were generally younger; however, both halves of the state had a relatively large percentage of older pavements.

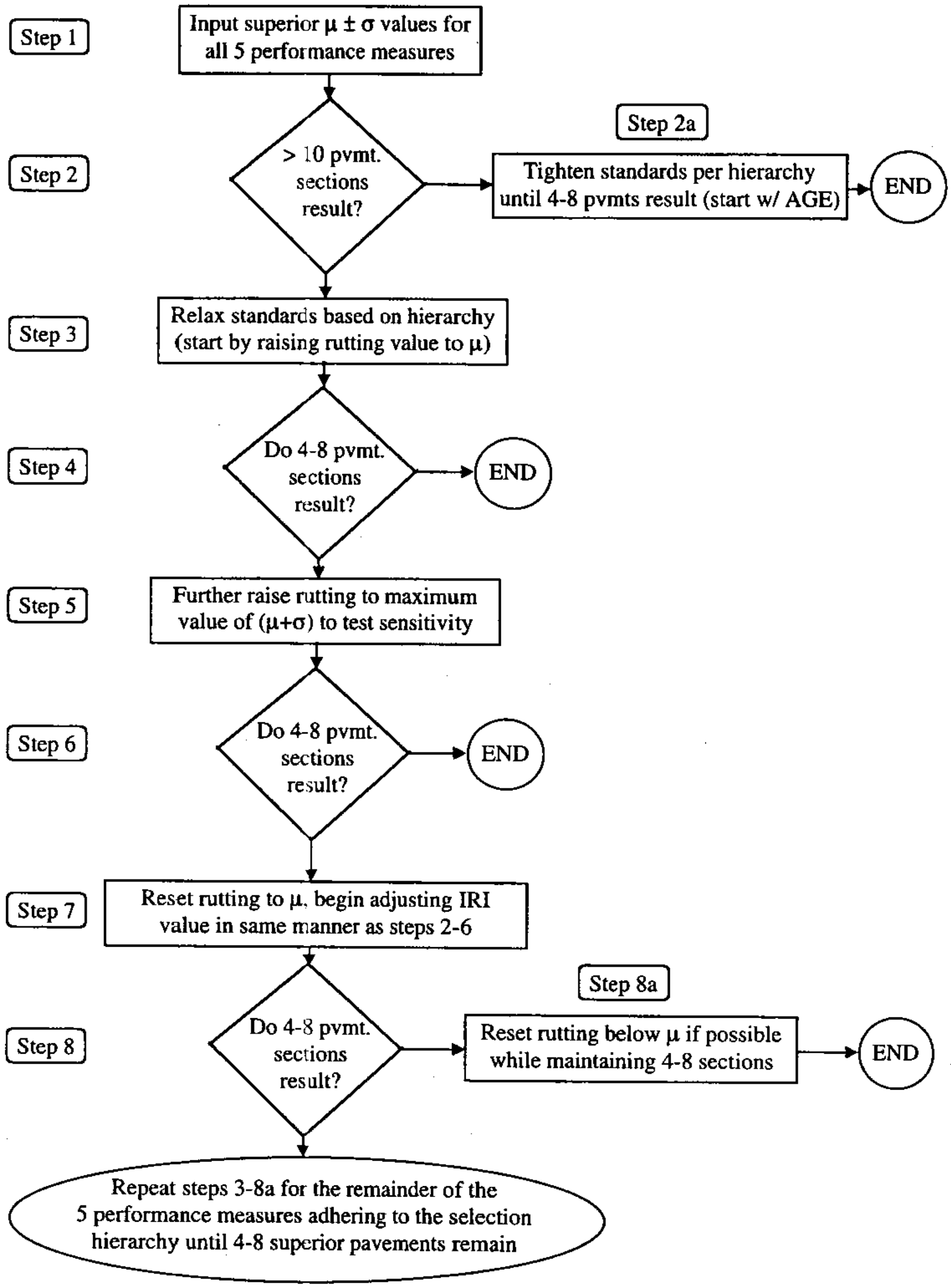


Figure 7.1. Candidate Pavement Selection Algorithm.

Only pavement sections that were at least 0.7 kilometers long were considered candidates. This was done to increase the likelihood of being able to physically locate pavements for field investigation. Additionally, selection threshold values were generally adjusted accordingly until four to eight candidate pavement sections emerged from the database. Because candidate selection was based solely on statistics and other information from within the WSPMS, the researchers felt that some candidates might be dropped later from the list on the basis of new information produced by the regional offices. Having only one or two candidates per group would increase the chance of eliminating an entire group if additional information from the regions warranted removing candidates from the list.

7.2.4 Phase 4. Cross Reference the Results with the WSPMS

The process of cross referencing potential candidate pavement sections with the WSPMS was a valuable candidate validation tool. This process exposed features of some sections that resulted in their exclusion from further study. Over 200 potential candidate pavement sections were excluded from further study for the following reasons:

- Some pavement sections that displayed superior performance had recently undergone major construction, but the database was not updated to reflect it. The performance measure values were verified as correct by WSDOT except for age. A number of these sections displayed ages of 10+ years when in fact they were only 1 to 2 years old.
- Some sections displayed suspect results. For example, some sections that displayed PSC scores in the 50s as late as 1994 had increased into the 90s by 1996 with no accompanying documented construction action. A few possible

reasons include incorrect survey results, input error of survey results, or construction that had not yet been updated in the database. Changes of such magnitude were "red flags," and related pavement sections were excluded from further consideration in the candidate selection process.

There was some concern that the selection process might exclude older pavement sections. This is primarily because the selection threshold value for PSC was set as high as possible to ensure that only the best performing pavements emerged from the database. This fact could result in excluding perhaps a 15-year-old AC pavement with a PSC of 75 if the PSC selection threshold was set above 75. This raises a difficult issue: what defines superior performance? This study clearly defined the criteria used to establish superior and inferior performance. However, a great deal of subjectivity remained in excluding certain pavements. This point led to the development of a second selection process to cross- reference initial candidate selection results.

Initial selection threshold values were fairly strict due, in part, to the presence of newer pavements in the analysis groups. These newer pavement sections were generally defined by high PSC scores and low IRI and rutting values. Because the selection threshold values were based directly on the mean and standard deviation of performance measures in each analysis group, it seemed fair to conclude that older pavements that generally had lower PSC scores and higher IRI and rutting values were unfairly held to performance standards that were skewed by the generally better performance of newer pavements.

Rather than comparing pavements to the overall summary statistics produced from all pavement sections, the second selection method was based on by-year summary statistics produced for each age group. In this way, 15-year-old pavements were compared to summary statistics that were based on only other 15-year-old pavements. The expected trend was that this would generally loosen PSC, IRI, and rutting thresholds, allowing older pavement sections the opportunity to prove their worthiness of being on the superior list. Because the selection thresholds for each age group would be based on the mean and standard deviation values for same-age pavements, this method appeared to be fairer to older pavements.

Because of the amount of work involved in this process, it was performed on only two analysis groups to determine whether further implementation was warranted. The two analysis groups were

- Resurfaced, non-Interstate, AC, eastern Wash.
- Resurfaced, non-Interstate, AC, western Wash.

The results were unexpected. No new pavement sections emerged from the second selection method. In fact, only five pavements emerged from entire the process, all of which had already been selected by the initial selection process. Also unexpected was that numerous same-age selection threshold values were actually more restrictive than the initial process that included all pavements. Given these results, the initial selection process was concluded to be reasonable.

7.2.5 Phase 5. Calculate Performance Probabilities

Selecting candidate pavements on the basis of population statistics also provided a way to compute the probability (or likelihood) for candidate pavements to perform in the superior manner they displayed. This process was outlined in Section 3.2, and results are shown for elements of the example analysis group in Tables 7.5 and 7.6. The performance probabilities are presented for information only because they played no direct role in the selection of candidate pavements.

Summary statistics were generated separately for the Interstate system and for the entire SR system. Given this, the summary statistics generated for the entire SR system were used as the basis of performance probability comparisons for all analysis groups. The Interstate system accounted for approximately 17 percent (2,221) of all pavement sections analyzed, whereas non-Interstate pavements made up over 83 percent (11,192). Resulting performance probabilities would have been slightly different if Interstate and non-Interstate pavements had been compared only to their respective peer groups. Given the method used, Interstate results are likely to be slightly better, and non-Interstate results slightly worse.

Thirteen candidate pavements within the example analysis group (comprising western, Interstate, resurfaced AC pavements) emerged from the selection process. Table 7.4 lists these pavements along with location and resulting performance measure data. The entire superior performing candidate list is presented in the next section (Tables 7.9 - 7.15 in Section 7.2.6).

To generate a performance probability for the example analysis group, the limiting value for each performance measure (see Table 7.4) among all candidate pavements was determined (i.e., lowest Age = 15 yrs, highest rut depth = 7.93 mm, etc.).

These limiting values represent the minimum standards that had to be met or exceeded by a pavement section to be considered a candidate for the example analysis group. Using the simplifying assumptions that the performance measures were independent variables and that the data were normally distributed, the probabilities for these limiting values were multiplied to determine the overall analysis group performance probability. Given the population mean (μ) and standard deviation (σ) from Table 7.1, along with the actual performance measure values from Table 7.4, statistical z-values were computed. These z values were then used in conjunction with a normal distribution to determine the individual performance measure probabilities (i.e., the likelihood that a pavement actually lasted 21 years, etc.). Table 7.5 lists the performance probabilities for each performance measure and the resulting overall probability for the example analysis group.

Table 7.4. Candidate Pavements for Example Analysis Group

SR #	Begin	End	PERFORMANCE MEASURES				
(Direction)	Milepost	Milepost	Age (yrs)	PSC	ESALs*	IRI (m/km)	Rutting (mm)
5 (I)	17.34	18.21	15	92	1,366,670	1.37	5.94
5 (I)	68.93	69.34	15	92	1,816,178	1.62	7.04
5 (I)	64.84	68.12	15	95	1,807,194	1.72	4.99
5 (D)	29.86	31.1	16	81	1,275,124	1.13	5.94
5 (I)	31.92	32.68	16	89	1,403,308	1.25	7.93
5 (D)	76.36	77.13	17	87	1,760,087	1.91	7.04
5 (I)	76.36	77.14	17	87	1,760,793	1.98	7.04
5 (I)	74.01	76.04	17	88	2,461,960	1.92	7.93
5 (D)	73.28	73.82	17	88	2,461,960	1.69	7.93
5 (D)	73.9	76.04	17	88	2,461,960	1.77	7.04
5 (I)	263.49	273.86	21	83	405,500	1.82	4.01
5 (D)	263.49	273.86	21	87	405,500	1.69	4.01
5 (I)	4.55	5.4	21	88	1,118,148	1.25	4.01

Directions: (D) Decreasing- (west or southbound), (I) Increasing- (east or northbound)
* Directional design-lane annual ESALs are used throughout this study.

Table 7.5. Performance Probability for Example Analysis Group

Performance Measure	Desired Value	Initial Threshold Selection Statistic	Initial Threshold Selection Value	Final Threshold Selection Statistic	Final Threshold Selection Value (x)	Performance Probability
Age (yrs)	High	(μ)	9*	$(\mu + 0.9\sigma)$	15	$P(\geq x) = 0.18$
PSC	High	$(\mu + 0.1\sigma)$	90	$(\mu - 0.5\sigma)$	81	$P(\geq x) = 0.69$
ESALs	High	$(\mu + \sigma)$	1,634,385	$(\mu - 1.5\sigma)$	405,500	$P(\geq x) = 0.93$
IRI (m/km)	Low	$(\mu - \sigma)$	1.10	$(\mu + 0.6\,\sigma)$	1.98	$P(\leq x) = 0.73$
Rutting (mm)	Low	$(\mu - \sigma)$	1.80	$(\mu + 0.8\sigma)$	7.93	$P(\leq x) = 0.79$
Overall						**≈ 0.067**

* Value rounded down to the nearest whole year from actual μ value of 9.2 years.

The resulting example analysis group probability of approximately 0.067 indicates that the candidate pavements within the example group had a roughly 1 in 15 chance of simultaneously meeting the minimum selection threshold values across all five performance measures.

The performance probability for the best overall performing pavement (I-405, increasing direction between mileposts 4.55 and 5.4) within the example analysis group is shown in Table 7.6. This individual pavement had a much lower performance probability (or performance likelihood) of approximately 0.0009. Therefore, this pavement displayed a nearly 1 in 1,112 chance of performing as shown.

Table 7.6. Performance Probability for Best Pavement within Example Group

Performance Measure	Desired Value	Initial Threshold Selection Statistic	Initial Threshold Selection Value	Final Threshold Selection Statistic	Final Threshold Selection Value (x)	Performance Probability
Age (yrs)	High	(μ)	9*	$(\mu + 1.7\sigma)$	21	$P(\geq x) = 0.04$
PSC	High	$(\mu + 0.1\sigma)$	90	$(\mu - 0.1\sigma)$	88	$P(\geq x) = 0.54$
ESALs	High	$(\mu + \sigma)$	1,634,385	$(\mu - 0.03\sigma)$	1,118,148	$P(\geq x) = 0.51$
IRI (m/km)	Low	$(\mu - \sigma)$	1.10	$(\mu - 0.7\,\sigma)$	1.25	$P(\leq x) = 0.24$
Rutting (mm)	Low	$(\mu - \sigma)$	1.80	$(\mu - 0.4\sigma)$	4.01	$P(\leq x) = 0.34$
Overall						**≈ 0.0009**

* Value rounded down to the nearest whole year from actual μ value of 9.2 years.

7.2.6 Compare Summary Statistics and Final Selection Threshold Values

A comparison of mean and final selection threshold values for the example analysis group and for the best performing pavement within the example analysis group is presented. Table 7.7 compares the mean and standard deviation of all 571 pavement sections within the example analysis group to the final threshold values used to select the candidate pavement sections. Table 7.8 compares the mean and standard deviation of all 571 pavement sections within the example analysis group to the final threshold values used to select the best performing candidate pavement section.

Table 7.7. Comparison of Mean and Final Selection Values for Example Group.

		All Pavements		Candidate Pavement Sections	
Performance Measure	Desired Value	Mean Value (μ)	Standard Deviation (σ)	Final Selection Thresholds Statistic	Value
Age (yrs)	High	9.2	6.8	($\mu + 0.9\sigma$)	15
PSC	High	89.1	15.8	($\mu - 0.5\sigma$)	81
ESALs	High	1,133,627	500,758	($\mu - 1.5\sigma$)	405,500
IRI (m/km)	Low	1.65	0.55	($\mu + 0.6\ \sigma$)	1.98
Rutting (mm)	Low	5.2	3.4	($\mu + 0.8\sigma$)	7.93

Table 7.8. Comparison of Example Group Mean and Best Pavement Final Values.

		All Pavements		Best Performing Pavement Section	
Performance Measure	Desired Value	Mean Value (μ)	Standard Deviation. (σ)	Final Selection Thresholds Statistic	Value
Age (yrs)	High	9.2	6.8	($\mu + 1.7\sigma$)	21
PSC	High	89.1	15.8	($\mu - 0.1\sigma$)	88
ESALs	High	1,133,627	500,758	($\mu - 0.03\sigma$)	1,118,148
IRI (m/km)	Low	1.65	0.55	($\mu - 0.7\ \sigma$)	1.25
Rutting (mm)	Low	5.2	3.4	($\mu - 0.4\sigma$)	4.01

7.2.7 Results—List Candidate Pavements with Superior Performance

This section presents the candidate pavement sections with superior performance selected across 14 of the 18 analysis groups that make up the entire SR system. Only 14 analysis groups are represented because the selection process did not produce any candidates for the following four analysis groups:

- Resurfaced, PCC, Interstate, Eastern Wash.
- Resurfaced, PCC, Interstate, Western Wash.
- Resurfaced, PCC, non-Interstate, Eastern Wash.
- Resurfaced, PCC, non-Interstate, Western Wash.6

Resurfaced PCC pavements are almost entirely a product of dowel-bar retrofitting (DBR). This process, which involves installing steel dowel bars across transverse joints, is used to restore load transfer capability to faulted joints. The process is fairly new in Washington State. Because most rehabilitated pavement sections are only 2 years old, insufficient time has elapsed to determine whether performance is truly superior. To date, this process has only been employed on the Interstate system.

To fit the necessary pavement location and performance related data into the tables, the use of certain abbreviations within the column headings was necessary.

Column HeadingDescription

Pvmt #: A sequence number used to reference a particular pavement within the tables.

SR: State Route number of the roadway where the pavement section is located.

Side: Side of the roadway the candidate pavement is on; either increasing (I) or decreasing (D). The increasing side is the northbound and eastbound travel directions. The decreasing side is in the southbound and westbound travel directions.

BSRMP: Beginning State Route Milepost

ESRMP: Ending State Route Milepost

Region: Washington is broken into six regions. Regional numbers and names are

Eastern Washington	Western Washington
Region 2- North Central	Region 1- Northwest
Region 5- South Central	Region 3- Olympic
Region 6- Eastern	Region 4- Southwest

E or W: Refers to whether the pavement section is in the eastern or western half of the state.

Age: Current surface course age as of 1996.

PSC: Pavement structural condition score

ESALs: The number of 80 kN equivalent single axle loads carried in the design-lane. For multiple lane highways, only a portion of the total annual ESALs actually travels in the design-lane.

IRI: International Roughness Index

Rutting: The depth of rutting in the current surface course

Traffic Year: The traffic year used to figure ESALs. All 1996 values are based on 1995 traffic data.

IRI/Rut Year: Both IRI and rutting are measured in alternate years for half of the state. Therefore, the actual measurement year is reported.

Table 7.9. Pavements with Superior Performance (New/Reconstructed, AC, Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
1	82	D	84.35	90.03	5	E	8	87	329,420	2.25	7.04	1995	1996
2	82	I	84.35	89.97	5	E	8	91	329,995	2.09	7.04	1995	1996
3	82	I	97.64	100.66	5	E	13	80	429,251	1.72	11.02	1995	1996
4	5	I	38.45	38.99	4	W	15	88	1,322,315	1.67	2.99	1995	1996
5	5	I	39.9	40.53	4	W	15	88	1,547,181	1.28	4.99	1995	1996
6	5	I	39.45	39.88	4	W	15	88	1,555,012	1.79	4.99	1995	1996

Table 7.10. Pavements with Superior Performance (New/Reconstructed, AC, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
7	240	I	33.98	34.8	5	E	12	78	133,765	1.92	4.99	1994	1995
8	240	D	33.98	34.8	5	E	12	80	133,765	1.99	2.99	1994	1995
9	97	I	74.77	75.92	5	E	15	80	211,423	1.52	2.99	1995	1995
10	240	I	32.17	33.98	5	E	16	76	118,933	1.89	2.99	1994	1995
11	240	D	32.17	33.98	5	E	16	78	118,933	1.30	1.89	1994	1995
12	16	D	3.68	4.93	3	W	11	88	440,519	2.18	4.01	1995	1995
13	3	I	37.05	38.29	3	W	13	87	304,963	2.11	4.99	1995	1995
14	3	I	46	48.5	3	W	14	76	205,034	1.93	5.94	1995	1995
15	516	D	7.62	8.2	1	W	14	76	205,263	3.16	4.99	1995	1995
16	16	D	15.81	18.1	3	W	17	92	344,678	2.05	5.94	1995	1995
17	16	D	12.8	13.52	3	W	26	90	472,268	2.29	4.99	1995	1995

Table 7.11. Pavements with Superior Performance (New/Reconstructed, PCC, Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
18	90	I	34.07	34.67	5	E	21	92	603,338	1.65	1.89	1995	1996
19	90	D	34.21	34.65	5	E	21	94	595,979	3.01	0.92	1995	1996
20	82	D	19.88	23.88	5	E	25	85	507,730	2.30	0.92	1995	1996
21	82	D	11.65	15.03	5	E	25	88	506,498	2.16	1.89	1995	1996
22	82	I	11.65	14.96	5	E	25	88	506,498	1.95	1.89	1995	1996
23	82	D	15.11	19.09	5	E	25	88	507,730	2.30	1.89	1995	1996
24	82	I	15.02	19.07	5	E	25	90	507,730	2.36	0.92	1995	1996
25	82	D	19.27	19.88	5	E	25	90	507,730	2.27	1.89	1995	1996
26	82	I	19.88	23.88	5	E	25	91	507,730	2.09	0.92	1995	1996
27	82	I	19.17	19.88	5	E	25	92	507,730	2.45	0.92	1995	1996
28	90	I	52.99	54.69	5	E	26	88	698,716	2.76	0.00	1994	1996
29	90	D	52.99	54.69	5	E	26	89	648,808	3.03	0.00	1994	1996
30	90	D	83.61	86.2	5	E	29	90	856,202	1.46	1.89	1995	1996
31	90	D	82.68	83.54	5	E	29	93	827,328	1.50	0.00	1995	1996
32	5	D	258.01	261.03	1	W	19	97	738,830	1.51	0.92	1995	1996
33	205	D	36.06	37.16	4	W	20	82	652,073	2.41	0.92	1995	1996
34	205	I	31.11	34	4	W	20	88	525,934	2.32	2.99	1995	1996
35	5	D	45.44	47.97	4	W	20	89	1,807,292	1.86	1.89	1995	1996
36	205	D	31.02	34	4	W	20	90	530,099	2.05	1.89	1995	1996
37	205	I	34.33	36.01	4	W	20	90	626,121	2.09	0.92	1995	1996
38	5	I	48	49.84	4	W	20	91	1,677,179	1.85	1.89	1995	1996
39	5	I	209.46	210.61	1	W	20	92	516,966	1.76	1.89	1995	1996
40	5	I	43.92	47.97	4	W	20	93	1,724,804	1.77	2.99	1995	1996
41	5	D	209.71	210.59	1	W	20	94	513,670	2.10	0.92	1995	1996

Table 7.11 cont. Pavements with Superior Performance (New/Reconstructed, PCC, Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
42	5	D	44.25	44.72	4	W	20	98	1,587,792	2.02	1.89	1995	1996
43	405	D	11.76	12.77	1	W	22	87	570,084	2.28	2.99	1994	1996
44	405	D	11.18	11.76	1	W	26	82	1,080,042	2.69	1.89	1995	1996
45	5	I	194.05	194.81	1	W	27	89	1,007,679	2.01	4.01	1995	1996
46	5	I	191.55	192.81	1	W	27	90	1,150,046	2.13	4.01	1995	1996
47	5	D	194.05	194.81	1	W	27	91	1,007,679	2.23	4.01	1995	1996
48	5	D	192.35	192.81	1	W	27	92	1,146,007	1.95	2.99	1995	1996
49	5	D	7.98	9.51	4	W	27	93	720,614	0.73	0.00	1995	1996

Table 7.12. Pavements with Superior Performance (New/Reconstructed, PCC, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
50	195	I	91.58	93.21	6	E	25	67	102,279	2.03	2.99	1995	1996
51	195	I	93.96	94.41	6	E	25	68	94,937	2.23	4.99	1995	1996
52	195	I	55.81	62.2	6	E	30	65	150,252	2.23	1.89	1995	1996
53	195	I	94.41	94.88	6	E	32	68	102,229	2.54	4.01	1995	1996
54	195	I	51.23	53.55	6	E	33	64	128,234	2.55	2.99	1995	1996
55	195	I	89.8	91.16	6	E	35	63	116,371	2.72	4.99	1995	1996
56	195	I	91.18	91.58	6	E	35	66	127,606	2.33	0.92	1995	1996
57	195	I	83.84	86.22	6	E	35	68	111,855	2.58	2.99	1995	1996
58	518	D	3.06	3.51	1	W	27	69	201,283	2.44	0.92	1994	1995
59	518	I	3.06	3.51	1	W	27	83	258,792	2.18	1.89	1994	1995
60	14	I	3.93	7.93	4	W	29	66	324,526	2.64	2.99	1995	1996
61	14	D	2.39	3.66	4	W	32	67	338,339	2.58	4.01	1995	1996
62	14	D	11.54	12.09	4	W	37	77	194,603	2.81	2.99	1995	1996
63	99	D	29.36	29.88	1	W	38	80	315,770	2.62	4.99	1995	1995
64	99	I	29.36	29.88	1	W	38	89	315,770	2.21	4.99	1995	1995
65	14	D	9.47	11.54	4	W	40	79	241,218	2.78	4.01	1994	1996
66	14	D	9.04	9.46	4	W	40	79	256,739	2.24	0.92	1994	1996
67	14	D	3.66	7.93	4	W	42	63	325,100	2.78	4.01	1995	1996
68	7	I	40.1	41.38	3	W	56	76	100,503	2.45	4.01	1995	1995
69	167	I	0.87	3.52	3	W	60	76	104,200	2.78	2.99	1995	1995
70	169	I	11.55	13.95	1	W	76	87	88,294	2.74	1.89	1995	1995

Table 7.13. Pavements with Superior Performance (Resurfaced, AC, Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
71	82	I	12.71	13.48	5	E	11	74	411,939	1.66	7.04	1995	1996
72	82	I	96.61	97.64	5	E	11	78	406,174	1.74	2.99	1995	1996
73	82	D	96.61	97.64	5	E	11	83	405,714	1.86	5.94	1995	1996
74	82	D	95.45	95.96	5	E	11	86	343,644	1.75	7.93	1995	1996
75	82	I	96.1	96.58	5	E	11	86	363,206	2.03	2.99	1995	1996
76	82	D	96.1	96.58	5	E	11	88	363,206	2.09	4.99	1995	1996
77	82	I	95.54	96.01	5	E	11	100	343,644	1.74	7.93	1995	1996
78	90	I	110	120.92	5	E	12	87	505,742	1.49	8.98	1995	1996
79	90	I	175.75	176.74	2	E	13	82	249,381	1.83	4.99	1995	1996
80	90	D	104.79	106.34	5	E	18	78	913,723	1.68	0.92	1995	1996
81	90	D	102.61	103.19	5	E	18	78	966,431	2.06	0.00	1995	1996
82	90	D	103.25	104.71	5	E	18	78	966,431	2.07	0.92	1995	1996
83	90	I	103.25	104.71	5	E	18	85	966,431	1.81	1.89	1995	1996
84	90	I	104.79	106.34	5	E	18	86	913,723	1.88	1.89	1995	1996
85	5	I	17.34	18.21	4	W	15	92	1,366,670	1.37	5.94	1994	1996
86	5	I	68.93	69.34	4	W	15	92	1,816,178	1.62	7.04	1995	1996
87	5	I	64.84	68.12	4	W	15	95	1,807,194	1.72	4.99	1995	1996
88	5	D	29.86	31.1	4	W	16	81	1,275,124	1.13	5.94	1994	1996
89	5	I	31.92	32.68	4	W	16	89	1,403,308	1.25	7.93	1995	1996
90	5	D	76.36	77.13	4	W	17	87	1,760,087	1.91	7.04	1995	1996
91	5	I	76.36	77.14	4	W	17	87	1,760,793	1.98	7.04	1995	1996

Table 7.13 cont. Pavements with Superior Performance (Resurfaced, AC, Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
92	5	I	74.01	76.04	4	W	17	88	2,461,960	1.92	7.93	1995	1996
93	5	D	73.28	73.82	4	W	17	88	2,461,960	1.69	7.93	1995	1996
94	5	D	73.9	76.04	4	W	17	88	2,461,960	1.77	7.04	1995	1996
95	5	I	263.49	273.86	1	W	21	83	405,500	1.82	4.01	1995	1996
96	5	D	263.49	273.86	1	W	21	87	405,500	1.69	4.01	1995	1996
97	405	I	4.55	5.4	1	W	21	88	1,118,148	1.25	4.01	1995	1996

Table 7.14. Pavements with Superior Performance (Resurfaced, AC, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	AGE (yr)	PSC	Annual ESALs (Design)	IRI (m/km)	Rutting (mm)	Traffic Year	IRI/Rut Year
98	195	I	71.67	73.53	6	E	12	83	134,448	1.32	7.04	1995	1996
99	195	I	75.43	76.55	6	E	12	84	126,509	1.61	7.04	1995	1996
100	195	I	76.58	80.01	6	E	12	84	139,384	1.71	7.93	1995	1996
101	12	D	194.39	195.87	5	E	12	85	99,388	1.61	4.01	1995	1995
102	195	I	73.55	75.41	6	E	12	86	129,831	1.36	7.04	1995	1996
103	195	I	69.94	70.78	6	E	12	86	149,322	1.32	4.99	1995	1996
104	150	I	7.5	7.96	2	E	13	76	125,537	1.77	2.99	1994	1996
105	150	D	7.5	7.96	2	E	13	76	125,537	2.24	5.94	1994	1996
106	28	I	0.46	8.7	2	E	17	73	150,307	1.25	4.01	1995	1996
107	12	I	80.52	81.26	4	W	18	88	171,778	1.55	4.99	1995	1996
108	12	I	35.54	37.59	3	W	19	90	159,642	2.24	7.93	1995	1995
109	522	I	20.82	22.5	1	W	19	95	188,778	1.75	4.99	1995	1995
110	12	I	86.32	87.06	4	W	20	81	175,164	2.04	4.99	1995	1996
111	14	I	57.04	57.96	4	W	20	100	60,590	2.35	4.01	1995	1996
112	14	I	57.96	58.45	4	W	20	100	61,566	2.79	4.99	1995	1996
113	99	D	37.45	38.35	1	W	21	71	215,004	2.42	4.99	1995	1995
114	99	D	20.43	21.92	1	W	21	72	70,151	2.40	2.99	1995	1995
115	99	D	21.92	22.57	1	W	21	75	56,486	2.59	4.01	1995	1995
116	16	D	11.3	12.39	3	W	26	85	472,399	2.09	7.04	1995	1995

Table 7.15. Pavements with Superior Performance (Resurfaced, BST, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	Region	E or W	**AGE** (yr)	**PSC**	**Annual ESALs** (Design)	**IRI** (m/km)	**Rutting** (mm)	Traffic Year	IRI/Rut Year
117	17	I	7.73	8.28	5	E	9	83	180,210	2.43	1.89	1995	1996
118	12	I	425.03	432.54	5	E	9	88	67,671	1.81	4.01	1995	1995
119	97	I	137.36	142.33	5	E	9	90	65,499	2.41	4.99	1994	1995
120	14	I	159.42	161.87	5	E	9	93	86,450	2.25	4.01	1995	1995
121	14	I	155.15	159.42	5	E	9	100	80,583	2.08	1.89	1995	1995
122	14	I	152.24	155.12	5	E	9	100	95,484	2.48	1.89	1995	1995
123	9	I	29.94	32.88	1	W	6	89	67,425	2.50	1.89	1,995	1995
124	9	I	78.95	79.41	1	W	6	100	48,864	2.50	1.89	1,994	1995
125	197	I	0.68	2.91	4	W	8	79	42,349	2.57	4.01	1,995	1996
126	14	I	141.29	149.06	4	W	18	73	77,125	2.71	7.93	1,995	1996

7.3 SELECTION OF PAVEMENTS WITH INFERIOR PERFORMANCE

The selection of pavements with inferior performance was different than the selection of superior performers. Three differences were as follows:

1. Unlike the superior performance selection process, which considered the performance of the existing pavement surface, the inferior selection process was concerned only with how long the previous pavement surface had lasted.
2. The inferior selection process was not dependent upon statistically based comparisons of individual pavement performance to the entire analysis group performance.
3. Only two performance measures were used to determine inferior performance, age and PSC. The other performance measures were used merely to prioritize pavements with the same age.

The selection methodology was divided into the following three phases:

- Phase 1. Define Pavement "Failure" Selection Criteria
- Phase 2. Generate a Preliminary Candidate List
- Phase 3. Cross Reference the Results with the WSPMS

Each phase involved the systematic selection of candidate pavements with inferior performance among the 18 analysis groups identified in Section 3.2. Again, the selection process was the same for all analysis groups. Sections 7.3.1 through 7.3.3 discuss the three phases listed above. The resulting final list of pavements with inferior performance is presented in Section 7.3.4.

7.3.1 Phase 1. Define Pavement "Failure" Selection Criteria

The inferior selection process considered the performance of the previous surface course. To illustrate this point, the partial pavement layer history of a WSDOT pavement section located along SR 124 is considered. This section is a non-Interstate pavement section located in the eastern part of the state.

Location: SR 124, MP 0.07 - MP 1.07, Increasing direction

Year	Construction	Thickness (mm)	Surface Type	PSC Prior to/After Action
1995	Resurfacing	12	BST	39/NA
1989	**Resurfacing**	**18**	**AC**	**67/100**
1980	Resurfacing	12	BST	64/99
1973	Resurfacing	6	BST Tack	59/85
1973	Resurfacing	12	BST Prime	59/85

Today's existing pavement surface was constructed in 1995. However, the previous pavement surface (bold) was constructed in 1989 and was rehabilitated in 1995, marking the end of its service life at 6 years. This surfacing was used to determine whether pavement performance was inferior. This pavement, which is included in the final inferior list, had a PSC score of 100 following construction in 1989. It deteriorated to a PSC of 39 in only 6 years (WSDOT considers failure at a PSC of 50).

The only pavement sections considered were ones that had already "failed" and subsequently had undergone a major rehabilitation such as reconstruction or resurfacing. However, defining pavement "failure" remained an issue. Two basic methods to define pavement failure selection criteria exist:

- Time until PSC of 50 for the previous surface course
- Time until actual rehabilitation of the previous surface course

The WSPMS contains some data related to a lag in updating the database after rehabilitation has taken place. This can result in pavements that display premature or delayed pavement failure (i.e., PSC reported as 50 is actually 65 or vice versa). For this reason, a PSC-based definition of failure was not chosen. Using only pavement sections that had received rehabilitation ensured that pavement failure had resulted at some point. The only exception was pavements that were a product of "staged" construction. These pavements purposely receive an additional layer early in their service life (usually 2 to 4 years). However, the PSC of these pavement sections at such young ages is generally high, so their inclusion in the inferior selection process was not an issue because of low PSC selection threshold values.

The use of rehabilitation as a definition of failure could also have skewed failure results if pavement sections had reached a PSC of 50 and then waited additional years, continuing to deteriorate, before rehabilitation. However, this problem was overcome by simply reporting the year the pavement reached a PSC of 50 if it is different than the rehabilitation year. In other words, if a pavement reached a PSC of 50 after only 4 years but was not rehabilitated until year 7, it would likely be deemed inferior because its PSC score deteriorated so fast. However, if the age until failure was used exclusively as the selection criteria, the pavement might not emerge from the selection process as inferior. This situation appeared only a couple of times in the actual selection process. In the majority of cases, WSDOT programmed rehabilitation very near a PSC score of 50. A potential drawback to a rehabilitation-based selection process is that because the inferior surfaces had already been rehabilitated, on-site field inspection for clues to the reasons for inferior performance was not possible.

7.3.2 Phase 2. Generate a Preliminary Candidate List

The WSPMS was initially searched to determine which pavements had received some type of major rehabilitation. The resulting list formed the pool from which potential pavements with inferior performance were selected. Using the query function in the WSPMS database, initial selection threshold values were established to ensure that only pavements with inferior performance emerged from the database. The PSC threshold value generally remained constant during the selection process, but both PSC and age thresholds were altered slightly as needed, depending on the number of candidate pavements that emerged from the database. Generally, the following guidelines ensured that an adequate number of pavements emerged:

- ≤ a specified age representing inferior performance (usually ≤ 5 years)
- ≤ PSC = 55

A PSC score of 55 was used because WSDOT programs rehabilitation as a pavement section <u>approaches</u> a PSC of 50. Therefore, it is possible that some pavements would have been rehabilitated at a PSC of between 51 and 55. If so, setting the threshold to ≤ 50 would keep some otherwise potential pavements from emerging from the database.

7.3.3 Phase 3. Cross Reference the Results with the WSPMS

Cross referencing the preliminary candidate list with the WSPMS resulted in the exclusion of some pavement sections and led to production of the final candidate list. The main reason for excluding pavement sections follows.

Some pavement sections had been rehabilitated after only two years. Ordinarily this would indicate inferior performance because these sections also had to have a PSC of

≤ 55 to emerge from the database. However, most of these pavement sections had received a BST resurfacing, which improved their overall PSC to little more than 55-65. Therefore, following the resurfacing, these sections began their next service life with a relatively low PSC value. Generally, the performance of a BST that begins its service life with a PSC of, say, 60 to 65 and deteriorates to only 55 in two years is not considered inferior. In fact, a section like this is more likely a product of staged construction. Note that many pavement sections do not return to a PSC of 100 following rehabilitation. This can be a function of the type, thickness, or extent of rehabilitation in question.

7.3.4 Results—List of Candidate Pavements with Inferior Performance

This section presents the candidate pavements with inferior performance selected across 10 of the 18 analysis groups that encompass the entire SR system. Only 10 analysis groups are represented because the selection process did not produce any candidates for the following eight analysis groups:

- Resurfaced, PCC, Interstate, Eastern Wash.
- Resurfaced, PCC, Interstate, Western Wash.
- Resurfaced, PCC, non-Interstate, Eastern Wash.
- Resurfaced, PCC, non-Interstate, Western Wash.
- New and Reconstructed, PCC, Interstate, Eastern Wash.
- New and Reconstructed, PCC, Interstate, Western Wash.
- New and Reconstructed, PCC, non-Interstate, Eastern Wash.
- New and Reconstructed, PCC, non-Interstate, Western Wash.

Again, resurfaced PCC pavements are almost entirely a product of dowel-bar retrofitting (DBR). Because most rehabilitated pavement sections are only 2 to 5 years old, insufficient time has elapsed to determine their performance. To date, this process has only been employed along the Interstate system. As discussed in Section 7.3.1, the only pavement sections considered were ones that had already "failed" and subsequently undergone a major rehabilitation such as reconstruction or resurfacing.

To fit the necessary pavement location and performance related data into the tables, the use of certain abbreviations within the column headings was necessary. A list of the column headings and a brief discussion of each is presented below, followed by the candidate list of pavements with inferior performance in tables 7.17 through 7.20.

Column Heading	Description
Pvmt #:	This is an assigned sequence number used to easily reference a particular pavement within the tables.
SR:	This refers to the State Route number of the roadway where the pavement section is located.
Side:	This refers to which side of the roadway the candidate pavement is on; either increasing (I) or decreasing (D). The increasing side is the northbound and eastbound travel directions. The decreasing side is in the southbound and westbound travel directions.
BSRMP:	Beginning State Route Milepost
ESRMP:	Ending State Route Milepost
Region:	Washington is broken into six regions. Regional numbers and names are

Eastern Wshington	Western Washington
Region 2- North Central	Region 1- Northwest
Region 5- South Central	Region 3- Olympic
Region 6- Eastern	Region 4- Southwest

E or W:	Refers to whether the pavement section is in the eastern or western half of the state.
Age:	Age at time of rehabilitation of the most recent (previous) surface course.
Rehab Year:	Year the last pavement surface was rehabilitated (or failed).

PSC: Pavement structural condition score

PSC Year: Year that PSC score was recorded.

ESALs: The number of 80 kN Equivalent Single Axle Loads carried in the design-lane. For multiple lane highways, only a portion of the total annual ESALs actually travels in the design-lane.

Rutting: Depth of rutting in the current surface course

IRI: International Roughness Index

IRI/Rut Year: Year nearest to failure year that IRI and rutting were recorded.

Pvmt Depth: New/Reconstructed pavements: Refers to the total depth of new AC.

Resurfaced AC pavements

- **Surface** refers to the depth of the previous AC surface course (at the time it was placed).
- **Existing** refers to the existing depth of AC pavement structure before the previous surface course was added.

Resurfaced BST pavements

- **Pvmt. depth** refers to the total depth of the overlaid surface and existing layers.
- **Overlaid surface type** refers to the type of material that was present at the time of the BST overlay.

Table 7.16 Performance Snapshot of (New/Reconstructed, AC, Interstate) **Pavements**

Pvmt #	SR	Side	BSRMP	ESRMP	E or W/ Region	**AGE** (yr)	YR of Rehab.	**PSC**	PSC YR	**ESALs** (Design)	**Rutting** (mm)	**IRI** (m/km)	IRI/Rut Year	AC Pvmt Depth* (mm)
1	90	I	104.79	106.34	E / 5	11	1978	0	1977	452,529	5.94	0.87	1973	253
2	90	I	103.25	104.71	E / 5	11	1978	0	1977	478,633	5.94	1.87	1973	253
3	90	D	102.61	103.19	E / 5	11	1978	0	1977	478,633	5.94	1.81	1973	253
4	90	D	103.25	104.71	E / 5	11	1978	0	1977	478,633	5.94	1.87	1973	253
5	90	D	104.79	106.34	E / 5	11	1978	9	1977	452,529	5.94	0.7	1973	253
6	90	I	102.61	103.19	E / 5	11	1978	27	1977	478,633	5.94	1.86	1973	253
7	82	I	96.61	97.64	E / 5	11	1985	44	1984	314,223	5.75	1.64	1981	107
8	82	D	96.61	97.64	E / 5	11	1985	49	1984	313,867	12.99	2.52	1973	107
9	405	I	5.44	7.17	W / 1	11	1975	13	1975	426,301	10.52	2.19	1975	128
10	405	D	5.44	7.17	W / 1	13	1971	52	1971	342,297	5.94	2.05	1971	76
11	405	D	4.79	5.4	W / 1	13	1971	56	1971	303,443	5.94	2.7	1971	76
12	5	D	220.16	221.66	W / 1	14	1985	22	1984	286,565	5.75	1.87	1983	244

* For new/reconstructed pavements, pvmt. depth refers to the total depth of new AC that was placed as part of the previous surface course.

Note: The overall performance displayed by these pavement sections is not considered inferior. However, these sections are the poorest overall performing pavements within this particular group and are shown merely for comparison to other groups. Pavement performance displayed in Tables 7.17-7.20 represent true inferior performance.

Table 7.17. Pavements with Inferior Performance (New/Reconstructed, AC, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	E or W/ Region	**AGE** (yr)	YR of Rehab.	**PSC**	PSC YR	**ESALs** (Design)	**Rutting** (mm)	**IRI** (m/km)	IRI/Rut Year	AC Pvmt Depth* (mm)
13	12	I	348.3	351.15	E / 5	5	1990	47	1990	64,393	4.21	2.63	1989	46
14	17	I	48.28	49.03	E / 2	7	1995	49	1995	156,576	2.77	1.44	1994	76
15	17	I	11.1	12.73	E / 5	8	1993	19	1993	162,356	7.40	1.80	1993	76
16	2	D	294.06	298.42	E / 6	8	1996	50	1995	341,613	4.60	1.99	1994	91
17	12	I	342.62	344.33	E / 5	8	1989	58	1989	56,273	5.94	1.43	1989	76
18	221	I	13.71	17.14	E / 5	9	1995	2	1995	84,534	4.60	2.12	1995	76
19	395	D	13.22	13.82	E / 5	9	1995	16	1994	490,927	8.46	1.95	1993	244
20	12	I	291.67	294.16	E / 5	9	1993	19	1993	226,755	9.50	2.20	1993	107
21	395	I	13.4	13.82	E / 5	9	1995	47	1994	447,351	3.81	1.92	1993	244
22	20	I	355.84	356.27	E / 6	9	1993	50	1993	28,388	8.63	2.15	1992	61
23	20	I	356.64	357.19	E / 6	9	1993	58	1993	27,851	4.99	2.08	1992	61
24	101	I	224.43	224.88	W / 3	3	1988	30	1988	78,321	12.99	1.89	1988	107
25	101	I	227.66	228.27	W / 3	3	1988	45	1988	76,783	12.66	1.94	1988	101
26	101	I	229.57	231.44	W / 3	3	1988	49	1988	90,338	7.58	3.33	1981	52
27	101	I	228.36	229.51	W / 3	3	1988	56	1988	81,921	3.40	1.96	1988	52
28	500	I	1.28	2.61	W / 4	7	1991	39	1990	128,894	5.94	2.10	1990	107
29	500	D	1.28	2.61	W / 4	7	1991	57	1990	128,894	5.94	2.26	1990	107
20	12	I	86.32	87.06	W / 4	8	1976	0	1975	95,221	16.16	2.16	1975	76
31	20	I	25.18	25.88	W / 1	8	1991	42	1991	50,716	10.01	3.12	1981	107
32	112	I	0	0.47	W / 3	9	1982	0	1981	6,591	5.94	4.59	1981	46
33	112	I	1.03	1.55	W / 3	9	1982	0	1981	6,999	5.94	4.72	1981	46

* For new/reconstructed pavements, pvmt. depth refers to the total depth of new AC that was placed as part of the previous surface course.

Table 7.18. Pavements with Inferior Performance (Resurfaced, AC, Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	E or W/ Region	**AGE** (yr)	YR of Rehab.	**PSC**	PSC YR	**ESALs** (Design)	**Rutting** (mm)	**IRI** (m/km)	IRI/Rut Year	AC Pvmt Depth (mm)	
														Surface	Existing
34	90	D	208.16	210.03	E / 6	4	1989	52	1988	300,393	5.94	1.74	1988	52	259
35	90	D	215.25	218.63	E / 6	4	1989	59	1988	292,589	10.68	1.51	1988	52	259
36	90	D	79.41	80.79	E / 5	8	1973	31	1971	372,655	5.94	1.65	1971	24	76*
37	90	D	81.72	82.61	E / 5	8	1973	37	1971	358,841	5.94	1.58	1971	24	76*
38	90	I	200.36	202.13	E / 6	9	1994	35	1993	403,758	9.33	1.61	1993	52	259
39	90	D	202.14	206.85	E / 6	9	1994	53	1993	390,341	11.85	1.59	1993	52	259
40	90	I	202.15	206.84	E / 6	9	1994	56	1993	390,341	8.11	1.25	1993	52	259
41	90	D	206.88	208.16	E / 6	9	1994	57	1993	356,956	8.98	1.74	1993	52	259
42	5	D	42.67	43.39	W / 4	5	1976	42	1975	859,867	5.94	2.19	1975	46	**
43	5	D	50.4	50.88	W / 4	5	1976	44	1975	721,409	5.94	1.88	1975	46	**
44	5	D	43.81	44.25	W / 4	5	1976	47	1975	831,987	5.94	2.53	1975	46	**
45	5	D	36.3	36.85	W / 4	6	1977	29	1977	682,572	5.94	1.58	1975	46	**
46	5	D	2.38	2.87	W / 4	10	1980	27	1979	559,794	12.99	3.06	1979	46	**

* These sections also have a 177 mm PCC layer at the bottom of the pavement structure.

** These sections consist of an AC overlay directly over a 229 mm PCC layer.

Table 7.19. Pavements with Inferior Performance (Resurfaced, AC, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	E or W/ Region	**AGE** (yr)	YR of Rehab.	**PSC**	PSC YR	**ESALs** (Design)	**Rutting** (mm)	**IRI** (m/km)	IRI/Rut Year	AC Pvmt Depth (mm) Surface	Existing
47	221	I	23.57	26.05	E / 5	5	1987	18	1986	66,140	6.31	2.43	1981	46	37
48	2	I	290.63	291.06	E / 6	5	1983	26	1983	89,396	16.78	3.80	1983	55	76*
49	2	I	290.18	290.63	E / 6	5	1983	32	1983	125,707	5.94	2.32	1979	35	140*
50	2	D	290.63	291.06	E / 6	5	1983	48	1983	89,396	16.78	3.53	1983	35	140*
51	2	D	290.18	290.63	E / 6	5	1983	50	1983	125,707	5.94	2.68	1979	35	140*
52	125	I	6.09	6.56	E / 5	6	1986	32	1986	23,863	5.94	4.77	1986	46	55
53	124	I	0.07	1.07	E / 5	6	1995	39	1995	135,780	7.75	2.13	1995	18	37
54	24	I	0.93	1.97	E / 5	6	1985	52	1984	97,046	5.94	1.82	1984	37	94
55	24	I	2.11	3.95	E / 5	6	1985	54	1984	44,351	5.94	1.75	1984	61	94
56	112	I	26.49	28.6	W / 3	2	1981	0	1981	11,243	12.34	4.87	1981	46	61
57	112	I	28.6	30.85	W / 3	2	1981	0	1981	11,243	11.35	4.45	1981	46	61
58	542	I	19.41	19.96	W / 1	2	1976	44	1975	10,307	12.99	2.04	1973	18	35
59	20	I	67.54	69.93	W / 1	3	1982	36	1981	50,557	5.56	2.27	1981	18	37
60	20	I	69.94	70.54	W / 1	3	1982	43	1981	51,014	5.94	2.81	1981	18	37
61	6	I	49.12	49.57	W / 4	4	1984	44	1984	90,330	5.94	2.48	1984	46	76
62	99	D	16.02	16.88	W / 1	4	1980	53	1979	25,545	5.94	2.26	1979	18	116*
63	522	D	6.61	7.52	W / 1	5	1975	12	1975	168,022	12.99	3.04	1975	61	76*

* These sections also have a 177 mm PCC layer at the bottom of the pavement structure.

Table 7.20. Pavements with Inferior Performance (Resurfaced, BST, non-Interstate)

Pvmt #	SR	Side	BSRMP	ESRMP	E or W/ Region	**AGE** (yr)	YR of Rehab.	**PSC**	PSC YR	**ESALs** (Design)	**Rutting** (mm)	**IRI** (m/km)	IRI/Rut Year	Tot. Pvmt Depth* (mm)	Overlaid Surface Type
64	28	I	0.46	8.7	E / 2	3	1979	27	1979	99,063	5.75	2.33	1979	128	BST
65	12	I	295.6	299.72	E / 5	4	1982	1	1981	153,550	5.94	1.14	1981	55	BST
66	20	I	285.52	288.47	E / 2	4	1994	29	1994	24,098	5.56	2.34	1994	30	BST
67	31	I	21.07	26.79	E / 6	4	1993	33	1992	11,611	8.63	3.03	1992	49	BST
68	31	I	16.48	19.48	E / 6	4	1993	34	1992	14,678	11.85	2.95	1992	55	BST
69	31	I	19.48	21.04	E / 6	4	1993	37	1992	13,953	7.93	3.26	1992	49	BST
70	203	I	15.69	16.1	W / 1	4	1993	36	1993	59,895	6.31	2.49	1993	55	BST
71	14	I	49.65	50.84	W / 4	5	1976	55	1975	39,412	12.99	2.67	1975	82	BST
72	14	I	95.72	96.61	W / 4	6	1977	29	1977	32,899	12.34	3.74	1977	88	BST
73	14	I	106.04	106.57	W / 4	6	1994	35	1994	82,719	4.99	2.22	1994	43	BST
74	12	I	165.31	165.95	W / 4	6	1989	39	1989	42,627	5.94	3.48	1989	113	BST
75	14	I	96.61	97.11	W / 4	6	1977	50	1977	33,169	12.99	4.09	1977	67	BST
76	12	I	164.53	165.2	W / 4	6	1989	51	1989	42,627	5.94	3.45	1989	113	BST
77	14	I	107.72	114.06	W / 4	6	1994	54	1994	84,433	7.75	2.99	1994	43	BST
78	14	I	102.32	105.02	W / 4	6	1994	55	1994	83,287	5.37	2.56	1994	43	BST

* For resurfaced BSTs, refers to the total depth of the pavement structure including the previous BST layer.

CHAPTER 8—DETAILED PAVEMENT SECTION ANALYSIS

Chapter 7 focused on selecting candidate pavements with superior and inferior performance. This chapter focuses on possible reasons why the candidate sections performed in a superior or inferior manner. Section 3.2 discuss in some detail the types of data gathering and analysis that could be conducted to best gain insights into the pavement performance displayed by the pavement sections. Because of timeline constraints, the initial scope of data gathering and analysis was necessarily re-evaluated for this study. Data gathering was limited to available information contained within the WSPMS specifically related to pavement layer materials and thicknesses (or depths). The relevant performance factors considered included Interstate vs. non-Interstate traffic levels (in terms of design-lane ESALs), eastern vs. western Washington climate effects, and construction types.

It is likely that data that will offer the greatest insights into superior and inferior pavement performance trends is construction or site specific related. Information regarding material placement conditions, techniques, compaction, subgrade support, and more is not contained within the WSPMS. The best sources of this type of information are the six WSDOT regional offices. The regional offices will more than likely be able to offer reasons why certain pavements have performed as well or as poorly as shown.

8.1 TERMS

Common pavement characteristics were collected for all candidate pavements. To understand the data and results within the chapter, some terms need explanation. These terms are seen in the tables as column headings.

8.1.1 Structural Depth

The type and depth (mm) of relevant pavement layers are reported. The following layer classifications are distinguished within the results tables:

8.1.1.1 Base

Refers to the base depth (mm) present in the pavement structure.

8.1.1.2 Previous Surface

For resurfaced pavement sections only, this represents the total depth of previous surfacing (excluding the base) that the existing pavement section is placed upon. Previous surfacing tends to serve as an extended base.

8.1.1.3 Surface

This refers to the existing (as of 1996) surface depth for pavement sections with superior performance and to the previous layer for pavement sections with inferior performance.

8.1.1.4 Total Structural Depth

This measure takes into account all of the relevant layer depths to present a total stuctural pavement section depth.

8.1.2 Material Type

The type and depth of base courses and previous pavement surfaces (for resurfaced sections only) in each pavement segment is reported. Previous surfacing consists of PCC, AC, and BSTs. The following base types are represented:

- untreated base
- asphalt treated base (ATB)
- cement treated base (CTB).

8.1.3 Dominant Failure Mechanism

The pavement layer considered for superior performance was the existing surface course in service as of 1996. For inferior performance, the most recently rehabilitated surface course was considered because it had "failed." For resurfaced pavement sections, analysis was conducted to determine whether past failure mechanisms tend to propagate through to new surfacings. The dominant failure mechanism of new and reconstructed pavements was limited to the existing surface course because it was the only surface layer. Although most pavement sections suffered from multiple failure types, the one failure mechanism that resulted in the greatest PSC loss was considered "dominant." A brief description of the failure mechanisms was warranted. Only the failure mechanisms that directly resulted in PSC deductions were considered. Detailed descriptions of failure types, extent and severity ratings, and visual photographs of all types of failure can be found in the report by Kay (1992).

8.2 UNDERSTANDING THE DATA

Extracting the correct pavement layer information from the WSPMS was not difficult but required attention to detail. Different pavement layers were used to define superior and inferior pavement sections.

8.2.1 Data Gathering for Superior Pavements

A brief example is presented to illustrate the data gathering and analysis process. The example uses a hypothetical pavement section.

Example

Pavement Layer History

Year	Construction Action	Depth (mm)	Material Type
1978	**Resurfacing**	**52**	**AC**
1971	Resurfacing	52	AC
1952	Resurfacing	27	AC
1939	Reconstruction	177	PCC
1939	Base	152	Untreated

Again, superior performance was based on the existing surface course. For the hypothetical pavement section, the existing surface course (bold) was 52 mm thick, made of AC, the product of resurfacing (or overlay), and was placed in 1978. Its age (18 years as of 1996) would be a primary determinant in its selection as a superior performer (layer depths played no part in the selection process). The old surfacing (excluding base) consisted of a PCC layer placed in 1939 and AC layers in 1952 and 1971 totaling 256 mm. Because it included a PCC layer, that layer is reported separately to draw attention to its presence. A PCC layer is extremely stiff and may add considerable stiffness to the overall pavement structure even after it has been resurfaced numerous times. This could have contributed to the section's superior performance.

A final consideration is the dominant failure mechanism. Because is was a resurfaced pavement section, the failure mechanism of the existing surface (built in 1978) and previous layer (built in 1971) were determined. For each surface, the visual distress survey data within the WSPMS were studied. For the existing surface, the dominant failure mechanism as of 1996 was used. For the previous layer, the dominant failure mechanism just before its rehabilitation in 1978 would be needed. Comparison of the failure mechanisms was made to determine whether past failure mechanisms tend to propagate through to new surface courses.

8.2.2 Data Gathering for Inferior Pavements

The following hypothetical pavement section is used to describe the inferior data gathering process.

Example

Pavement Layer History

Year	Construction Action	Depth (mm)	Material Type
1995	Resurfacing	46	AC
1991	**Resurfacing**	**52**	**AC**
1971	Reconstruction	177	PCC
1971	Base	152	Untreated

Again, inferior performance was based on the previous surface course. For the example pavement section, this surface course (bold) was 52 mm thick, made of AC, the product of resurfacing (or overlay), and placed in 1991. The old surfacing consisted of a PCC layer placed in 1971 totaling 177 mm. The failure mechanism of the inferior layer (built in 1991) and previous layer (built in 1971) were determined. For each surface, the visual distress survey data within the WSPMS were studied. The dominant failure mechanism of the inferior layer just before rehabilitation in 1995 was used because the 1995 rehabilitation marked the end of the inferior surface's service life. For the most recent but previous layer, the dominant failure mechanism just before its rehabilitation in 1991 would be used.

8.3 FINDINGS—PAVEMENT SECTIONS WITH SUPERIOR PERFORMANCE

The results of data gathering for the candidate sections with superior performance are presented in tables 8.1 through 8.7. In viewing these tables, the pavement sections are listed in order from worst to best overall performance within each analysis group.

The mean and standard deviation of pavement layer depths were generated for each layer within each analysis group. The results are summarized in Table 8.13. The findings are highlighted next by layer type, followed by additional insights into other factors such as traffic level and failure mechanisms. Note that analysis group sample sizes were small, ranging from only 2 to 18 pavement sections. Although mean and standard deviation values are provided, small sample sizes can produce wide variations in the statistics.

Table 8.1. Candidate Pavements with Superior Performance (New/Reconstructed, AC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of existing surface
1	82 D	84.35	90.03	E / 5	329,420	183	198	381	U	Longitudinal Cracking
2	82 I	84.35	89.97	E / 5	329,995	183	198	381	U	Longitudinal Cracking
3	82 I	97.64	100.66	E / 5	429,251	165	216	381	U	Alligator Cracking
4	5 I	38.45	38.99	W / 4	1,322,315	NA	244	244*	NA	Longitudinal Cracking
5	5 I	39.9	40.53	W / 4	1,547,181	107	244	351	ATB	Longitudinal Cracking
6	5 I	39.45	39.88	W / 4	1,555,012	107	244	351	ATB	Longitudinal Cracking

*** Total excluding base depth.**

Table 8.2. Candidate Pavements with Superior Performance (New/Reconstructed, AC, Non-Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of existing surface
7	240 I	33.98	34.8	E / 5	133,765	168	213	381	U	Alligator Cracking
8	240 D	33.98	34.8	E / 5	133,765	168	213	381	U	Longitudinal Cracking
9	97 I	74.77	75.92	E / 5	211,423	137	244	381	U	Alligator Cracking
10	240 I	32.17	33.98	E / 5	118,933	274	76	350	U	Longitudinal Cracking
11	240 D	32.17	33.98	E / 5	118,933	274	76	350	U	Longitudinal Cracking
12	16 D	3.68	4.93	W / 3	440,519	107	198	305	U	Longitudinal Cracking
13	3 I	37.05	38.29	W / 3	304,963	61/137	46	244	U/ATB	Longitudinal Cracking
14	3 I	46	48.5	W / 3	205,034	152	152	304	U	Alligator Cracking
15	516 D	7.62	8.2	W / 1	205,263	335	107	442	U	Longitudinal Cracking
16	16 D	15.81	18.1	W / 3	344,678	122	183	305	U	Patching
17	16 D	12.8	13.52	W / 3	472,268	91	213	304	ATB	Patching

Table 8.3. Candidate Pavements with Superior Performance (New, Reconstructed, PCC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of existing surface
18	90 I	34.07	34.67	E / 5	603,338	122/107	229	458	U/ATB	Slab Cracking
19	90 D	34.21	34.65	E / 5	595,979	122/107	229	458	U/ATB	Scaling
20	82 D	19.88	23.88	E / 5	507,730	229	229	458	U	Scaling
21	82 D	11.65	15.03	E / 5	506,498	229	229	458	U	Joint/Crack Spalling
22	82 I	11.65	14.96	E / 5	506,498	229	229	458	U	Joint/Crack Spalling
23	82 D	15.11	19.09	E / 5	507,730	61	229	290	U	Joint/Crack Spalling
24	82 I	15.02	19.07	E / 5	507,730	61	229	290	U	Joint/Crack Spalling
25	82 D	19.27	19.88	E / 5	507,730	229	229	458	U	Slab Cracking
26	82 I	19.88	23.88	E / 5	507,730	229	229	458	U	Scaling
27	82 I	19.17	19.88	E / 5	507,730	229	229	458	U	Scaling
28	90 I	52.99	54.69	E / 5	698,716	213	229	442	U	Faulting
29	90 D	52.99	54.69	E / 5	648,808	213	229	442	U	Slab Cracking
30	90 D	83.61	86.2	E / 5	856,202	253	229	482	U	Slab Cracking
31	90 D	82.68	83.54	E / 5	827,328	253	229	482	U	Scaling
32	5 D	258.01	261.03	W / 1	738,830	1,036	229	1,265	U	Scaling
33	205 D	36.06	37.16	W / 4	652,073	NA	235	335*	NA	Slab Cracking
34	205 I	31.11	34	W / 4	525,934	107	229	336	ATB	Scaling
35	5 D	45.44	47.97	W / 4	1,807,292	122	229	351	ATB	Slab Cracking
36	205 D	31.02	34	W / 4	530,099	107	229	336	ATB	Scaling
37	205 I	34.33	36.01	W / 4	626,121	NA	235	235*	NA	Slab Cracking
38	5 I	48	49.84	W / 4	1,677,179	122	229	351	ATB	Slab Cracking
39	5 I	209.46	210.61	W / 1	516,966	137	229	366	ATB	Scaling
40	5 I	43.92	47.97	W / 4	1,724,804	122	229	351	ATB	Scaling
41	5 D	209.71	210.59	W / 1	513,670	137	229	366	ATB	Scaling

*** Total excluding base depth.**

Table 8.3 cont. Candidate Pavements with Superior Performance (New/Reconstructed, PCC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of existing surface
42	5 D	44.25	44.72	W / 4	1,587,792	122	229	351	ATB	Scaling
43	405 D	11.76	12.77	W / 1	570,084	107	229	336	ATB	Slab Cracking
44	405 D	11.18	11.76	W / 1	1,080,042	204	229	433	U	Slab Cracking
45	5 I	194.05	194.81	W / 1	1,007,679	152/91	229	472	U/ATB	Slab Cracking
46	5 I	191.55	192.81	W / 1	1,150,046	152/91	229	472	U/ATB	Slab Cracking
47	5 D	194.05	194.81	W / 1	1,007,679	152/91	229	472	U/ATB	Slab Cracking
48	5 D	192.35	192.81	W / 1	1,146,007	152/91	229	472	U/ATB	Scaling
49	5 D	7.98	9.51	W / 4	720,614	76/152	229	457	U/ATB	Faulting

Table 8.4. Candidate Pavements with Superior Performance (New/Reconstructed, PCC, Non-Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of existing surface
50	195 I	91.58	93.21	E / 6	102,279	229	204	433	U	Joint/Crack Spalling
51	195 I	93.96	94.41	E / 6	94,937	229	204	433	U	Joint/Crack Spalling
52	195 I	55.81	62.2	E / 6	150,252	229	204	433	U	Joint/Crack Spalling
53	195 I	94.41	94.88	E / 6	102,229	152	204	356	U	Joint/Crack Spalling
54	195 I	51.23	53.55	E / 6	128,234	229	204	433	U	Faulting
55	195 I	89.8	91.16	E / 6	116,371	229	204	433	U	Faulting
56	195 I	91.18	91.58	E / 6	127,606	229	204	433	U	Faulting
57	195 I	83.84	86.22	E / 6	111,855	229	204	433	U	Faulting
58	518 D	3.06	3.51	W / 1	201,283	107/91	198	396	U/ATB	Faulting
59	518 I	3.06	3.51	W / 1	258,792	107/91	198	396	U/ATB	Slab Cracking
60	14 I	3.93	7.93	W / 4	324,526	256	204	460	U	Slab Cracking
61	14 D	2.39	3.66	W / 4	338,339	152	204	356	U	Slab Cracking
62	14 D	11.54	12.09	W / 4	194,603	152	204	356	U	Slab Cracking
63	99 D	29.36	29.88	W / 1	315,770	229	229	458	U	Faulting
64	99 I	29.36	29.88	W / 1	315,770	229	229	458	U	Slab Cracking
65	14 D	9.47	11.54	W / 4	241,218	152	204	356	U	Patching
66	14 D	9.04	9.46	W / 4	256,739	152	204	356	U	NA
67	14 D	3.66	7.93	W / 4	325,100	128	204	332	U	Slab Cracking
68	7 I	40.1	41.38	W / 3	100,503	253	165	418	U	Slab Cracking
69	167 I	0.87	3.52	W / 3	104,200	152	177	329	U	Slab Cracking
70	169 I	11.55	13.95	W / 1	88,294	152	152	304	U	NA

Table 8.5 Candidate Pavements with Superior Performance (Resurfaced, AC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRM P	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Old Surf.	Surface	Total	Material Old Surf.	Base	Dominant Failure Mechanism Existing layer	Previous layer
71	182 I	12.71	13.48	E / 5	411,939	305	305	107	717	AC	U	NA	Long. Crack
72	82 I	96.61	97.64	E / 5	406,174	91/76	213	61	441	AC	U/ATB	Long. Crack	Patching
73	82 D	96.61	97.64	E / 5	405,714	91/76	213	61	441	AC	U/ATB	Long. Crack	Long. Crack
74	82 D	95.45	95.96	E / 5	343,644	91/76	213	61	441	AC	U/ATB	Long. Crack	Long. Crack
75	82 I	96.1	96.58	E / 5	363,206	91/76	213	61	441	AC	U/ATB	Long. Crack	Long. Crack
76	82 D	96.1	96.58	E / 5	363,206	91/76	213	61	441	AC	U/ATB	Long. Crack	Long. Crack
77	82 I	95.54	96.01	E / 5	343,644	91/76	213	61	441	AC	U/ATB	Long. Crack	None
78	90 I	110	120.92	E / 5	505,742	128	204	64	396	AC	U	Long. Crack	Long. Crack
79	90 I	175.75	176.74	E / 2	249,381	253/152	210	67	682	AC	U/CTB	Trans. Crack	Long. Crack
80	90 D	104.79	106.34	E / 5	913,723	101	253	18	372	AC	U	Allig. Crack	Allig. Crack
81	90 D	102.61	103.19	E / 5	966,431	101	253	18	372	AC	U	Allig. Crack	Allig. Crack
82	90 D	103.25	104.71	E / 5	966,431	101	253	18	372	AC	U	Allig. Crack	Allig. Crack
83	90 I	103.25	104.71	E / 5	966,431	101	253	18	372	AC	U	Allig. Crack	Long. Crack
84	90 I	104.79	106.34	E / 5	913,723	101	253	18	372	AC	U	Allig. Crack	Long. Crack
85	5 I	17.34	18.21	W / 4	1,366,670	229	229/46	46	550	PCC/AC	U	Long. Crack	Trans. Crack
86	5 I	68.93	69.34	W / 4	1,816,178	152	229	91	472	PCC	U	Faulting	Trans. Crack
87	5 I	64.84	68.12	W / 4	1,807,194	152	229	91	472	PCC	U	Faulting	Long. Crack
88	5 D	29.86	31.1	W / 4	1,275,124	152	244	49	445	AC	U	Long. Crack	Allig. Crack
89	5 I	31.92	32.68	W / 4	1,403,308	107	244	49	400	AC	ATB	Long. Crack	Long. Crack
90	5 D	76.36	77.13	W / 4	1,760,087	152	229	91	472	PCC	U	Faulting	Long. Crack
91	5 I	76.36	77.14	W / 4	1,760,793	152	229	91	472	PCC	U	Faulting	Long. Crack

Table 8.5 cont. Candidate Pavements with Superior Performance (Resurfaced, AC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm)				Material		Dominant Failure Mechanism	
						Base	Old Surf.	Surface	Total	Old Surf.	Base	previous layer	Existing layer
92	5 I	74.01	76.04	W / 4	2,461,960	152	229	91	472	PCC	U	Faulting	Long. Crack
93	5 D	73.28	73.82	W / 4	2,461,960	152	229	91	472	PCC	U	Faulting	Long. Crack
94	5 D	73.9	76.04	W / 4	2,461,960	152	229	91	472	PCC	U	Faulting	Long. Crack
95	5 I	263.49	273.86	W / 1	405,500	116	204	40	360	AC	U	None	Long. Crack
96	5 D	263.49	273.86	W / 1	405,500	116	204	40	360	AC	U	None	Long. Crack
97	405 I	4.55	5.4	W / 1	1,118,148	357	128	91	576	AC	U	Patching	Long. Crack

Table 8.6. Candidate Pavements with Superior Performance (Resurfaced, AC, Non-Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design)	Structural Depth (mm)				Material		Dominant Failure Mechanism	
						Base	Old Surf.	Surface	Total	Old Surf.	Base	Existing layer	previous layer
98	195 I	71.67	73.53	E / 6	134,448	305	213	46	564	AC	U	Long. Crack	Long. Crack
99	195 I	75.43	76.55	E / 6	126,509	305	213	46	564	AC	U	Long. Crack	Long. Crack
100	195 I	76.58	80.01	E / 6	139,384	305	213	46	564	AC	U	Long. Crack	Long. Crack
101	12 D	194.39	195.87	E / 5	99,388	204	82/46	37	369	BST/AC	U	Long. Crack	Long. Crack
102	195 I	73.55	75.41	E / 6	129,831	305	213	46	564	AC	U	Long. Crack	Long. Crack
103	195 I	69.94	70.78	E / 6	149,322	305	213	46	564	AC	U	Long. Crack	Long. Crack
104	150 I	7.5	7.96	E / 2	125,537	241	76	18	335	AC	U	Allig. Crack	Long. Crack
105	150 D	7.5	7.96	E / 2	125,537	241	76	18	335	AC	U	Allig. Crack	Long. Crack
106	28 I	0.46	8.7	E / 2	150,307	204	55/131	46	436	BST/AC	U	Allig. Crack	Long. Crack
107	12 I	80.52	81.26	W / 4	171,778	280	177	76	533	AC	U	Long. Crack	Long. Crack
108	12 I	35.54	37.59	W / 3	159,642	204	165/46	46	461	PCC/AC	U	Patching	Long. Crack
109	522 I	20.82	22.5	W / 1	188,778	204	101	46	351	AC	U	Patching	Patching
110	12 I	86.32	87.06	W / 4	175,164	280	76	46	402	AC	U	Allig. Crack	Allig. Crack
111	14 I	57.04	57.96	W / 4	60,590	256	106	46	408	AC	U	Allig. Crack	NA
112	14 I	57.96	58.45	W / 4	61,566	256	76	46	378	PM	U	Allig. Crack	NA
113	99 D	37.45	38.35	W / 1	215,004	152	177/131	46	506	PCC/AC	U	Long. Crack	Long. Crack
114	99 D	20.43	21.92	W / 1	70,151	204	177/116	46	543	PCC/AC	U	Long. Crack	Long. Crack
115	99 D	21.92	22.57	W / 1	56,486	253	204	76	533	PCC	U	Faulting	Long. Crack
116	16 D	11.3	12.39	W / 3	472,399	305/152	64	107	628	MB	U/CTB	Long. Crack	Patching

Table 8.7. Candidate Pavements with Superior Performance (Resurfaced, BST, Non-Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design)	Structural Depth (mm) Base	Old Surf.	Surface	Total	Material Old Surf.	Base	Dominant Failure Mechanism previous layer	Existing layer
117	17 I	7.73	8.28	E / 5	180,210	381	12	12	405	MB	U	Patching	Allig. Crack
118	12 I	425.03	432.54	E / 5	67,671	396	183	12	591	AC	U	Long. Crack	Long. Crack
119	97 I	137.36	142.33	E / 5	65,499	594	49	12	655	BST	U	Long. Crack	Long. Crack
120	14 I	159.42	161.87	E / 5	86,450	305	55	12	372	BST	U	Allig. Crack	Patching
121	14 I	155.15	159.42	E / 5	80,583	482	55	12	549	BST	U	None	None
122	14 I	152.24	155.12	E / 5	95,484	482	55	12	549	BST	U	None	None
123	9 I	29.94	32.88	W / 1	67,425	204	107	24	335	AC	U	Allig. Crack	Long. Crack
124	9 I	78.95	79.41	W / 1	48,864	180	122	24	326	AC	U	Allig. Crack	None
125	197 I	0.68	2.91	W / 4	42,349	NA	18	12	30*	BST	NA	Patching	Patching
126	14 I	141.29	149.06	W / 4	77,125	482	37	18	537	BST	U	Patching	Patching

* Total excluding base depth.

8.3.1 Base Depth

- In all but one case (western new/reconstructed PCC), the mean base depth of non-Interstate pavements exceeded that of Interstate pavements.
- Among non-Interstate pavements by construction type, the mean base depths of all eastern Washington pavements were thicker than those of their western counterparts. For Interstate pavements, the mean base depth of eastern pavements was thicker in three of four cases (new/reconstructed PCC was the exception).
- Both eastern and western non-Interstate resurfaced BSTs had the thickest mean base depths of all analysis groups. The mean eastern base depth exceeded the western mean base depth by nearly 150 mm.
- Approximately 72 percent of base courses were untreated, 10 percent were asphalt-treated, and 13 percent were a combination of untreated and asphalt-treated. All three types of base were associated with the worst performing pavement section among at least one analysis group. There is nothing to suggest that base type played a major role in determining superior performance.

8.3.2 Previous Surface Depth

Previous surface depth (considering all layer types) was only a consideration in resurfaced pavements because new/reconstructed sections have no previous layers.

- A comparison of mean Interstate/non-Interstate previous surface depths was possible for only one analysis group—resurfaced AC. In this case, the mean depth of previous surfacing was greater in eastern Washington for both Interstate and non-Interstate pavements.

- Among all pavements by construction type, the mean previous surface depths of eastern Washington pavements were thicker than those of their western counterparts in two of three cases (resurfaced BST was the exception).
- For resurfaced AC pavements, the primary material type of previous surfaces was AC. Where PCC was the old surface material type, overall pavement performance was better.

8.3.3 Total Structure Depth

- Among non-Interstate pavements by construction type, the mean total structure depths of eastern Washington pavements were thicker than those of their western counterparts in all cases. For Interstate pavements, the mean total structure depths of eastern pavements were thicker in two of three cases.
- Western resurfaced AC pavements had the thickest total structure depths among Interstate pavements (461 mm). Among non-Interstate pavements, resurfaced BSTs in eastern Washington had the thickest mean total structure depths (520 mm).

8.3.4 Additional Insights

- Traffic levels (ESALs) seemed randomly distributed among superior performers. In other words, some of the pavements with the least superior performances had the lowest and highest ESAL levels, depending on which analysis group was considered. The same was true for the best performing pavements.
- The dominant failure mechanism for most new/reconstructed flexible pavements was longitudinal cracking, followed by alligator and transverse cracking.

- For resurfaced pavements, the existing AC layer was placed over AC in 44 cases. In 23 of these 44 cases (52 percent), the dominant failure mechanism of the previous surface layer was also dominant in the existing surface course. This suggests a tendency for failure mechanisms to propagate. Propagation of failure mechanisms occurred fairly equally among both Interstate and non-Interstate pavements. In seven of the eight cases (88 percent) in which the existing AC layer had been placed directly over a PCC layer, the dominant failure mechanism of the previous surface course (longitudinal cracking) was again dominant in the existing surface. In four of eight cases (50 percent) in which existing BSTs were placed over old BSTs, the former failure mechanism was again dominant in the existing surface course.

8.4 FINDINGS —PAVEMENT SECTIONS WITH INFERIOR PERFORMANCE

The results for the candidate sections with inferior performance are presented in tables 8.8 through 8.12. These tables also list pavement sections in order from worst to best overall performance within each analysis group. However, since the focus here is on inferior performers, the first pavements of each analysis group are most interesting (rather than the last pavements for each group as in the superior performance groups).

The mean and standard deviation of pavement layer depths were generated for each layer within each analysis group. Table 8.14 summarizes the results. The findings are highlighted next by layer type, followed by additional insights into other factors such as traffic level and failure mechanisms. Again, analysis group sample sizes were small, ranging from only 2 to 18 pavement sections.

Table 8.8. Candidate Pavement Performance (New/Reconstructed, AC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of inferior surface
1	90 I	104.79	106.34	E / 5	452,529	101	253	354	U	Alligator Cracking
2	90 I	103.25	104.71	E / 5	478,633	101	253	354	U	Alligator Cracking
3	90 D	102.61	103.19	E / 5	478,633	101	253	354	U	Alligator Cracking
4	90 D	103.25	104.71	E / 5	478,633	101	253	354	U	Alligator Cracking
5	90 D	104.79	106.34	E / 5	452,529	101	253	354	U	Alligator Cracking
6	90 I	102.61	103.19	E / 5	478,633	101	253	354	U	Alligator Cracking
7	82 I	96.61	97.64	E / 5	314,223	91/76	213	380	U/ATB	Longitudinal Cracking
8	82 D	96.61	97.64	E / 5	313,867	91/76	213	380	U/ATB	Longitudinal Cracking
9	405 I	5.44	7.17	W / 1	426,301	152/152	128	432	U/CTB	Alligator Cracking
10	405 D	5.44	7.17	W / 1	342,297	52/152	76	280	U/CTB	Alligator Cracking
11	405 D	4.79	5.4	W / 1	303,443	204/152	76	432	U/CTB	Alligator Cracking
12	5 D	220.16	221.66	W / 1	286,565	137	244	381	ATB	Alligator Cracking

Note: The overall performance displayed by these pavement sections is not considered inferior. However, these sections are the poorest overall performing pavements within this particular group and are shown merely for comparison to other groups. Pavement performance displayed in Tables 8.9-8.12 represent true inferior performance.

Table 8.9. Candidate Pavements with Inferior Performance (New/Reconstructed, AC, Non-Interstate)

Pvmt #	SR/ Side	BSRM P	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Surface	Total	Base Type	Dominant Failure Mechanism of inferior surface
13	12 I	348.3	351.15	E / 5	64,393	457	46	503	U	Patching
14	17 I	48.28	49.03	E / 2	156,576	107	76	183	U	Alligator Cracking
15	17 I	11.1	12.73	E / 5	162,356	350	76	381	U	Alligator Cracking
16	2 D	294.06	298.42	E / 6	341,613	366	91	457	U	Longitudinal Cracking
17	12 I	342.62	344.33	E / 5	56,273	290	76	366	U	Patching
18	221 I	13.71	17.14	E / 5	84,534	305	76	381	U	Alligator Cracking
19	395 D	13.22	13.82	E / 5	490,927	137	244	381	U	Patching
20	12 I	291.67	294.16	E / 5	226,755	274	107	381	U	Alligator Cracking
21	395 I	13.4	13.82	E / 5	447,351	137	244	381	U	Alligator Cracking
22	20 I	355.84	356.27	E / 6	28,388	335	61	396	U	Alligator Cracking
23	20 I	356.64	357.19	E / 6	27,851	396	61	457	U	Longitudinal Cracking
24	101 I	224.43	224.88	W / 3	78,321	293	107	400	U	Patching
25	101 I	227.66	228.27	W / 3	76,783	305	101	406	U	Patching
26	101 I	229.57	231.44	W / 3	90,338	305	52	357	U	Longitudinal Cracking
27	101 I	228.36	229.51	W / 3	81,921	305	52	357	U	Alligator Cracking
28	500 I	1.28	2.61	W / 4	128,894	259	107	366	U	Alligator Cracking
29	500 D	1.28	2.61	W / 4	128,894	259	107	366	U	Alligator Cracking
20	12 I	86.32	87.06	W / 4	95,221	280	76	356	U	Alligator Cracking
31	20 I	25.18	25.88	W / 1	50,716	198	107	305	U	Patching
32	112 I	0	0.47	W / 3	6,591	223	46	269	U	Patching
33	112 I	1.03	1.55	W / 3	6,999	223	46	269	U	Patching

Table 8.10. Candidate Pavements with Inferior Performance (Resurfaced, AC, Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Old Surf.	Surface	Total	Material Old Surf.	Base	Dominant Failure Mechanism Previous layer	Inferior layer
34	90 D	208.16	210.03	E / 6	300,393	198	259	52	509	AC	U	Long. Cracking	Allig. Cracking
35	90 D	215.25	218.63	E / 6	292,589	198	259	52	509	AC	U	Long. Cracking	Allig. Cracking
36	90 D	79.41	80.79	E / 5	372,655	152	177/76	24	429	PCC/AC	U	NA	NA
37	90 D	81.72	82.61	E / 5	358,841	152	177/76	24	429	PCC/AC	U	NA	NA
38	90 I	200.36	202.13	E / 6	403,758	198	259	52	509	AC	U	Long. Cracking	Patching
39	90 D	202.14	206.85	E / 6	390,341	198	259	52	509	AC	U	Long. Cracking	Patching
40	90 I	202.15	206.84	E / 6	390,341	198	259	52	509	AC	U	Trans. Cracking	Patching
41	90 D	206.88	208.16	E / 6	356,956	198	259	52	509	AC	U	Long. Cracking	Allig. Cracking
42	5 D	42.67	43.39	W / 4	859,867	152/107	229	46	534	PCC	U/ATB	Faulting	Patching
43	5 D	50.4	50.88	W / 4	721,409	229/122	229	46	626	PCC	U/ATB	Faulting	Trans. Cracking
44	5 D	43.81	44.25	W / 4	831,987	152/107	229	46	534	PCC	U/ATB	Faulting	Trans. Cracking
45	5 D	36.3	36.85	W / 4	682,572	104	229	46	379	PCC	U	Faulting	Long. Cracking
46	5 D	2.38	2.87	W / 4	559,794	52	229	46	327	PCC	U	Faulting	Patching

Table 8.11. Candidate Pavements with Inferior Performance (Resurfaced, AC, Non-Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm)				Material		Dominant Failure Mechanism	
						Base	Old Surf.	Surface	Total	Old Surf.	Base	Previous layer	Inferior layer
47	221 I	23.57	26.05	E / 5	66,140	305	55	46	406	BST	U	Patching	Allig. Cracking
48	2 I	290.63	291.06	E / 6	89,396	152	177/76	55	460	PCC/AC	U	Patching	Patching
49	2 I	290.18	290.63	E / 6	125,707	152	177/64	76	469	PCC/AC	U	Patching	Patching
50	2 D	290.63	291.06	E / 6	89,396	152	177/76	55	460	PCC/AC	U	Patching	Patching
51	2 D	290.18	290.63	E / 6	125,707	152	177/64	76	469	PCC/AC	U	Patching	Patching
52	125 I	6.09	6.56	E / 5	23,863	152	55	46	253	BST	U	Long. Cracking	Allig. Cracking
53	124 I	0.07	1.07	E / 5	135,780	229	85	18	332	BST	U	Allig. Cracking	Allig. Cracking
54	24 I	0.93	1.97	E / 5	97,046	76	94	37	207	AC	U	Trans. Cracking	Trans. Cracking
55	24 I	2.11	3.95	E / 5	44,351	76	94	61	231	AC	U	Long. Cracking	Trans. Cracking
56	112 I	26.49	28.6	W / 3	11,243	204	74	46	324	BST	U	Allig. Cracking	Allig. Cracking
57	112 I	28.6	30.85	W / 3	11,243	204	92	46	342	BST	U	Allig. Cracking	Allig. Cracking
58	542 I	19.41	19.96	W / 1	10,307	305	43	18	366	BST	U	Allig. Cracking	Patching
59	20 I	67.54	69.93	W / 1	50,557	332	49/18	18	417	BST/AC	U	Allig. Cracking	Allig. Cracking
60	20 I	69.94	70.54	W / 1	51,014	332	49/18	18	417	BST/AC	U	Allig. Cracking	Allig. Cracking
61	6 I	49.12	49.57	W / 4	90,330	204/152	76	46	478	AC	U/CTB	Patching	Patching
62	99 D	16.02	16.88	W / 1	25,545	204	177/116	18	515	PCC/AC	U	Patching	Long. Cracking
63	522 D	6.61	7.52	W / 1	168,022	253	177	76	506	PCC	U	Trans. Cracking	Long. Cracking

Table 8.12. Candidate Pavements with Inferior Performance (Resurfaced, BST, Non-Interstate)

Pvmt #	SR/ Side	BSRMP	ESRMP	E or W/ Region	Annual ESALs (Design-lane)	Structural Depth (mm) Base	Old Surf.	Surface	Total	Material Old Surf.	Base	Dominant Failure Mechanism Previous layer	Inferior layer
64	28 I	0.46	8.7	E / 2	99,063	204	37/131	18	390	BST/AC	U	Allig. Cracking	Allig. Cracking
65	12 I	295.6	299.72	E / 5	153,550	332	52/18	18	420	BST/AC	U	Allig. Cracking	Allig. Cracking
66	20 I	285.52	288.47	E / 2	24,098	549	18	12	579	BST	U	Patching	Patching
67	31 I	21.07	26.79	E / 6	11,611	305	67	12	384	BST	U	Allig. Cracking	Patching
68	31 I	16.48	19.48	E / 6	14,678	305	61	12	378	BST	U	Allig. Cracking	Allig. Cracking
69	31 I	19.48	21.04	E / 6	13,953	305	67	12	384	BST	U	Allig. Cracking	Allig. Cracking
70	203 I	15.69	16.1	W / 1	59,895	152	73	18	243	BST	U	Allig. Cracking	Patching
71	14 I	49.65	50.84	W / 4	39,412	152	64	18	234	AC	U	Allig. Cracking	Allig. Cracking
72	14 I	95.72	96.61	W / 4	32,899	253	70	18	341	BST	U	Allig. Cracking	Allig. Cracking
73	14 I	106.04	106.57	W / 4	82,719	256	73	24	353	BST	U	Patching	Patching
74	12 I	165.31	165.95	W / 4	42,627	229	55/76	12	372	BST/AC	U	Patching	Patching
75	14 I	96.61	97.11	W / 4	33,169	253	70/30	18	371	BST/AC	U	Allig. Cracking	Patching
76	12 I	164.53	165.2	W / 4	42,627	229	55/76	12	372	BST/AC	U	Patching	Patching
77	14 I	107.72	114.06	W / 4	84,433	256	73	24	353	BST	U	Long. Cracking	Patching
78	14 I	102.32	105.02	W / 4	83,287	256	73	24	353	BST	U	Patching	Patching

8.4.1 Base Depth

- In all but one case (eastern resurfaced AC), the mean base depth of non-Interstate pavements exceeded that of Interstate pavements. For new/reconstructed AC, the difference in means between non-Interstate and Interstate sections was 169 mm.
- Among non-Interstate pavements by construction type, the mean base depths of eastern Washington pavements were thicker than those of their western counterparts except for resurfaced AC. For Interstate pavements, the mean base depths of western pavements were thicker in all cases.
- Eastern resurfaced BSTs had the thickest mean base depth among non-Interstate pavements, whereas western new/reconstructed AC was thickest among Interstate pavements.
- Approximately 88 percent of the base courses was untreated, 6 percent was a combination of untreated and asphalt-treated, and 5 percent was a combination of untreated and cement-treated.

8.4.2 Previous Surface Depth

Previous surface depth was only a consideration in resurfaced pavements because new/reconstructed pavement sections had no previous layers.

- For resurfaced Interstate AC pavements, the primary material type of previous pavement surfaces was evenly distributed between AC and PCC. Where PCC was the previous surface material type, overall pavement performance was better.

8.4.3 Total Structure Depth

- In three of four cases, the mean total structure depths of Interstate pavements exceeded those of non-Interstate pavements.
- Among non-Interstate pavements by construction type, the mean total structure depths of eastern Washington pavements were thicker than those of their western counterparts in two of three cases. For Interstate pavements, the mean total structure depths of eastern pavements were thicker for resurfaced AC, whereas new/reconstructed AC was thicker in the west.
- Eastern resurfaced AC pavements had the thickest total structure depths among Interstate pavements (489 mm). Among non-Interstate pavements, resurfaced BSTs in eastern Washington had the thickest mean surface courses (423 mm).

8.4.4 Additional Insights

- Traffic levels (ESALs) seemed randomly distributed among inferior performers. In other words, some of the pavements with the least inferior performance had the lowest and highest ESAL levels, depending on which analysis group was considered. The same was true for the pavements with the best performance.
- The dominant failure mechanism for most new/reconstructed flexible pavements was alligator cracking (61 percent), followed by patching and longitudinal cracking (24 and 15 percent, respectively).
- For resurfaced pavements, the inferior AC layer was placed over AC in 22 cases. In 13 of these 22 cases (59 percent), the dominant failure mechanism

of the previous surface layer was also dominant in the inferior surface. This suggests a tendency for failure mechanisms to propagate through to the new surface course, but only among non-Interstate pavements because none of the 13 matching cases were located along the Interstate system. Where the inferior AC was placed over a BST, the former failure mechanism propagated through to the inferior layer in nine of the fifteen cases (60 percent).

8.5 COMPARISON OF SUPERIOR AND INFERIOR LAYERS

This section focuses on a comparison of superior and inferior pavement performance through analysis of pavement layer data. The mean and standard deviation values for the pavement layers of each analysis group are summarized in Table 8.13 on the basis of route system and in Table 8.14 on the basis of construction/material type for both superior and inferior sections. The findings are highlighted next by layer type.

Table 8.15 illustrates the fact that in six of a possible ten analysis group comparisons, the total pavement structure depth of inferior performing pavements was actually greater than that of superior performing pavements within the same analysis groups. The differences in mean total structure depths ranged from 4 to 66 mm. In other words, for new/reconstructed Interstate AC pavements in western Washington, the mean total pavement structure depth of pavements with inferior performance was 66 mm greater than that of pavements with superior performance in the same analysis group. The search for differences in pavement performance based on traffic levels produced no insightful results.

Table 8.13. Summary of Structural Layer Depths for Superior Pavements

Pavement Layers		New/Reconstructed AC		Resurfaced AC		Resurfaced BST		New/Reconstructed PCC		Resurfaced PCC	
(Depths in mm)		Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.
Total Base Depth											
East	Mean	177	204	168	268	NA	440	206	219	NA	NA
	Std dev.	10	65	87	45		101	63	27		
	n	3	5	14	9		6	14	8		
West	Mean	107	168	165	255	NA	289	220	185	NA	NA
	Std dev.	0	90	65	82		168	225	44		
	n	2	6	13	10		3	16	13		
Old Surface Depth											
East	Mean	NA	NA	233	170	NA	68	NA	NA	NA	NA
	Std dev.			29	60		59				
	n			14	9		6				
West	Mean	NA	NA	223	162	NA	71	NA	NA	NA	NA
	Std dev.			34	91		51				
	n			13	10		4				
Existing Surface Depth											
East	Mean	204	164	50	39	NA	12	229	204	NA	NA
	Std dev.	10	82	27	12		0	0	0		
	n	3	5	14	9		6	14	8		
West	Mean	244	150	73	58	NA	20	230	198	NA	NA
	Std dev.	0	63	24	21		6	2	22		
	n	3	6	13	10		4	18	13		
Total Structure Depth											
East	Mean	381	369	450	477	NA	520	435	423	NA	NA
	Std dev.	0	17	111	107		110	63	27		
	n	3	5	14	9		6	14	8		
West	Mean	315	317	461	474	NA	307	425	383	NA	NA
	Std dev.	62	66	62	89		209	222	53		
	n	3	6	13	10		4	18	13		

Table 8.14. Summary of Structural Layer Depths for Inferior Pavements

Pavement Layers		New/Reconstructed AC		Resurfaced AC		Resurfaced BST		New/Reconstructed PCC		Resurfaced PCC	
(Depths in mm)		Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.
Total Base Depth											
East	Mean	118	287	187	161		333				
	Std dev.	31	115	21	71	NA	115	NA	NA	NA	NA
	n	8	11	8	9		6				
West	Mean	250	265	190	274		226				
	Std dev.	98	39	104	65	NA	43	NA	NA	NA	NA
	n	4	10	7	8		9				
Old Surface Depth											
East	Mean			258	152		75				
	Std dev.	NA	NA	3	91	NA	49	NA	NA	NA	NA
	n			8	9		6				
West	Mean			229	111		88				
	Std dev.	NA	NA	0	84	NA	27	NA	NA	NA	NA
	n			7	8		9				
Inferior Surface Depth											
East	Mean	243	105	45	52		14				
	Std dev.	19	70	13	18	NA	3	NA	NA	NA	NA
	n	8	11	8	9		6				
West	Mean	131	80	59	36		19				
	Std dev.	79	28	22	21	NA	5	NA	NA	NA	NA
	n	4	10	7	8		9				
Total Structure Depth											
East	Mean	361	392	489	365		423				
	Std dev.	12	82	37	111	NA	78	NA	NA	NA	NA
	n	8	11	8	9		6				
West	Mean	381	345	478	421		332				
	Std dev.	72	49	101	74	NA	54	NA	NA	NA	NA
	n	4	10	7	8		9				

Table 8.15. Differences Between Superior and Inferior Mean Layer Depths

Pavement Layers		New/Reconstructed AC		Resurfaced AC		Resurfaced BST		New/Reconstructed PCC		Resurfaced PCC	
(Depths in mm)		Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.	Interstate	non-Int.
Total Base Depth											
East	Diff.	60	(83)	(19)	108	NA	107	NA	NA	NA	NA
	% Diff.	34	(40)	(11)	40		24				
West	Diff.	(143)	(98)	(25)	(19)	NA	62	NA	NA	NA	NA
	% Diff.	(134)	(58)	(15)	(8)		22				
Old Surface Depth											
East	Diff.	NA	NA	(25)	18	NA	(7)	NA	NA	NA	NA
	% Diff.			(11)	10		(10)				
West	Diff.	NA	NA	(6)	50	NA	(17)	NA	NA	NA	NA
	% Diff.			(3)	31		(23)				
Inferior Surface Depth											
East	Diff.	(39)	59	5	(13)	NA	(2)	NA	NA	NA	NA
	% Diff.	(19)	36	9	(35)		(17)				
West	Diff.	113	70	14	22	NA	1	NA	NA	NA	NA
	% Diff.	46	47	20	38		4				
Total Structure Depth											
East	Diff.	21	(23)	(39)	112	NA	98	NA	NA	NA	NA
	% Diff.	5	(6)	(9)	23		19				
West	Diff.	(66)	(28)	(17)	54	NA	(25)	NA	NA	NA	NA
	% Diff.	(21)	(9)	(4)	11		(8)				

Difference = Superior depth values - Inferior depth values in (mm) with negative depth values shown in parenthesis ()
% Difference = (Difference/Superior depth values) with negative differences shown in parenthesis ()

8.6 COMPARISON OF PREDICTED AND ACTUAL DESIGN THICKNESSES

As a final step in the layer analysis investigation, the pavement designs of a small sample of pavements with superior and inferior performance were analyzed. Two eastern and western pavement sections were selected from each superior and inferior analysis group of new/reconstructed AC and PCC pavements. This represents a total of 16 (of 204 total) sections. Each section was analyzed with the American Association of State Highway and Transportation Official's (AASHTO) DARWin pavement design software package. The purpose of the analysis was to determine whether design factors (specifically over/underdesign) may have contributed to the superior and inferior performance displayed. Resurfaced pavements were not considered, primarily because of the difficulty of assuming reasonable input values for DARWin.

The design process depends on several input values. Many of the inputs, including soil condition, climate, material type, and more, are unique to individual pavement sections. For example, parameters such as subgrade modulus generally require field testing to determine the exact values of elastic modulus (E). Although the WSDOT Pavement Guide (Volume 2) (1995) provides ranges of design values based on certain soil, material, and other conditions, specific input values for the individual pavement sections that were used in the actual design procedure were not known. However, assumed input values were used for each analysis group. This made it somewhat difficult to accurately determine whether the actual pavement design was appropriate. Because of the uncertainty in knowing specific inputs used to design the pavements, this analysis serves more as a "back of the envelope" type of check. Although small changes in the design inputs can change designed layer thicknesses, the changes are usually no more than about plus or minus 25 mm. Therefore, this analysis focused more on discovering sizable discrepancies between DARWin predicted designs and actual constructed pavement layers.

The flexible and rigid design processes that form the basis of the DARWin software package are based on design procedures in the 1993 AASHTO design guide. Using generally accepted WSDOT design input values, the resulting pavement layer depths determined from DARWin were compared with the actual "in-place" WSDOT pavement structures. The following inputs were used for flexible and rigid design analysis:

<u>Flexible Pavements:</u>

- Modulus of Elasticity
  - Asphalt Concrete: 500,000 psi
  - Asphalt treated base: 475,000 psi
  - Crushed Stone base: 30,000 psi
  - Subgrade: 10,000 psi
- Layer Coefficients
  - AC: 0.44 - ATB: 0.42
  - CTB: 0.20 - CS base: 0.13
- Reliability
  - Urban Interstate: 95%
  - Rural Interstate: 90%
  - Urban Principal Arterial: 85%
  - Rural Principal Arterial: 80%
- Standard Deviation- 0.50
- Serviceability

	AC	BST
- Initial (p_o):	4.5	4.2
- Terminal (p_t):	3.0	3.0
- Δ PSI = $p_0 - p_t$	1.5	1.2

- Drainage Coefficient: 1.0
- Design period = 20 years

<u>Rigid Pavements:</u>

- Modulus of Elasticity
  - PCC: 4,000,000 psi
  - Other: see flexible
- Modulus of Rupture (S'c)
  - S'c = 700 psi
- Reliability
  - Same as flexible
- Standard Deviation- 0.40
- Load transfer coefficient (J)
  - J = 3.4
- Effective Modulus of Subgrade reaction (k) = 200 pci
- Drainage Coefficient (c_d)
  - $C_d = 1.0$
- Design period = 20 years

Perhaps the most difficult input to quantify was design ESALs. The projected design ESALs at the time of construction were needed to determine layer depths. Because the

ESAL levels of pavements constructed from 5 to 20 years ago were not directly known, they were estimated on the basis of current ESAL levels. The 1996 annual design-lane ESALs were known, along with a truck growth rate (G). The truck growth rate used for all pavements was 3.6 percent. With these values, past traffic levels could be back-calculated. Once the construction year ESAL level was known, it was projected forward over 20 years (the design period) to obtain the design level of traffic.

This process was needed to develop the necessary design period ESALs for input into the DARWin program. A possible (and perhaps likely) problem with the process was the use of a uniform truck growth rate. This was a simplifying assumption that was likely not valid but should result in usable results. This process was less of a problem for the rigid design process, in which changes in ESAL levels have a small impact on overall PCC layer thicknesses.

8.6.1 Superior Pavement Findings

Comparisons of predicted and actual pavement layer depths of new/reconstructed AC pavements showed that WSDOT designed pavements matched fairly closely with DARWin results. Of the eight pavement sections analyzed, three designs met a 95 percent reliability. One each of the other five pavements matched DARWin results at 90 percent, 85 percent, 70 percent, 65 percent, and 50 percent reliability levels. It must be pointed out that minor changes in assumed input parameters (subgrade modulus, etc.) could have meant that all pavements would have matched DARWin results at 95 percent—or none might have matched. Given the uncertainty in this analysis procedure, in general, WSDOT new/reconstructed AC designs appeared to be quite acceptable.

Comparisons of predicted and actual pavement layer depths of new/reconstructed PCC pavements showed that WSDOT designed pavements matched fairly closely with DARWin results. Of the eight pavement sections analyzed, three were designed properly at 95 percent reliability (all non-Interstate). Three other pavements matched DARWin results at 90 percent, 80 percent, and 70 percent reliability levels. The remaining two pavements required an additional 38 mm and 69 mm of PCC (at 95 percent reliability) according to DARWin. Again, relatively minor changes made to assumed input parameters could have brought these two pavements in line with DARWin results. Given the uncertainty in this analysis procedure, in general, WSDOT new/reconstructed PCC designs appeared to be quite acceptable.

Therefore, it is likely that superior performance was made possible, in part, because WSDOT adequately designed the pavement sections to accommodate the design period ESALs.

8.6.2 Inferior Pavement Findings

Inferior results were slightly more erratic. Comparisons of predicted and actual pavement layer depths of new/reconstructed AC pavements showed that WSDOT designed inferior pavements did not match DARWin results as well as did the superior pavements. Of the eight pavement sections analyzed, only one design met a 95 percent reliability. In fact, this particular section (pavement #12 from the inferior list) was overdesigned by over 102 mm according to DARWin. One each of four other pavements matched DARWin results at 94 percent, 93 percent, 75 percent, and 74 percent reliability levels. Of the remaining three sections (all non-Interstate), DARWin results indicated additional AC thicknesses of 38, 74, and 127 mm were needed at 90 percent reliability.

Given the uncertainty in this analysis procedure, in general, WSDOT new/reconstructed AC designs appeared to be acceptable. This suggests that inferior performance occurred in pavements that appeared to have properly designed layer thicknesses.

8.6.3 DARWin Conclusions

Results of the comparison between DARWin design predictions and actual WSDOT designs support the suggestion that inferior performance is more likely a function of construction and/or site specific factors. The specific result that supports this suggestion is the fact that four of the eight inferior pavements were designed at over 90 percent reliability.

CHAPTER 9—ASSESSMENT OF PAVEMENTS WITH SUPERIOR AND INFERIOR PERFORMANCE

This chapter provides an assessment of the study results.

9.1 SUMMARY STATISTICS ANALYSIS

The summary statistics provide a current snapshot of pavement performance throughout the SR system; however, the values do not constitute survival statistics. The summary graphs presented in appendices B through F provide a visual representation of network performance. Assessments are provided by performance measure.

9.1.1 Age

- The mean pavement age was higher for pavements located in the western part of the state. This holds true for both the Interstate system and the entire SR system. The western Washington pavement network was simply older as of 1996.
- The mean age of new/reconstructed Interstate PCC pavements exceeded new/reconstructed Interstate AC pavements by 6.8 years in eastern Washington and by 9.4 years in western Washington.
- The mean age of new/reconstructed non-Interstate PCC pavements exceeded new/reconstructed non-Interstate AC pavements by 6.7 years in eastern Washington and by 14.5 years in western Washington.

9.1.2 PSC

- Trends among PSC scores were less pronounced than for age. In considering the Interstate system only, the best currently performing pavement groups in eastern and western Washington were ranked as shown in Table 9.1.

Table 9.1. Summary of Interstate PSC Values

Eastern Washington		Western Washington	
Analysis Group	Mean PSC	Analysis Group	Mean PSC
New/Reconstructed PCC	89.8	Resurfaced PCC	91.0
Resurfaced PCC	87.3	Resurfaced AC	89.1
Resurfaced AC	86.9	New/Reconstructed PCC	82.6
New/Reconstructed AC	83.6	New/Reconstructed AC	78.8
Resurfaced BST	NA	Resurfaced BST	NA

- For the entire SR system, the best currently performing pavement groups in eastern and western Washington were ranked as shown in Table 9.2.

Table 9.2. Summary of Entire SR System PSC Values

Eastern Washington		Western Washington	
Analysis Group	Mean PSC	Analysis Group	Mean PSC
New/Reconstructed PCC	88.1	Resurfaced PCC	91.0
Resurfaced PCC	87.3	Resurfaced AC	81.1
Resurfaced AC	81.6	New/Reconstructed PCC	80.6
New/Reconstructed AC	79.0	New/Reconstructed AC	79.7
Resurfaced BST	71.8	Resurfaced BST	74.6

9.1.3 Traffic (Annual Design-Lane ESALs)

- With the exception of resurfaced PCC pavements, all analysis groups were subjected to higher ESAL levels in the western part of the state.

- The difference in annual ESAL levels between western and eastern Washington ranged from a low of approximately 4,000 ESALs to a high of approximately 900,000.
- New/reconstructed PCC and resurfaced AC pavements carried nearly the same ESAL levels in most cases.

9.1.4 Roughness (IRI)

- No definitive trends emerged among eastern and western Washington pavements when either the Interstate or entire SR systems was considered.
- As a group, resurfaced western Washington Interstate PCC pavements were the smoothest in the state (mean IRI = 1.30 m/km), and resurfaced BSTs were the roughest (mean IRI = 3.20 m/km).

9.1.5 Rutting

- No definitive trends emerged among eastern and western pavements when either the Interstate or entire SR systems was considered.
- As a group, new/reconstructed eastern Washington Interstate AC pavements were the most rutted in the state (mean rut depth = 7.4 mm), and resurfaced western Interstate PCC pavements were the least rutted (mean rut depth = 0.8 mm).

9.2 RELATIONAL PERFORMANCE MEASURE ANALYSIS

This analysis involved the network level investigation of the following six performance measure relationships among flexible pavements only:

1. PSC vs. age
2. IRI vs. age
3. Rutting vs. age
4. PSC vs. IRI
5. PSC vs. rutting
6. IRI vs. rutting

9.2.1 General Correlation Findings

- Few traffic related trends were reflected in the scatter plots, which suggests that design parameters that account for traffic have resulted in adequate pavement designs.
- Most correlation values were low, indicating that minimal linear trends existed among the performance measures studied.
- The following general correlation trends were observed:

Relationship	Correlation Trend	Relationship	Strength of r* (# of cases) Weak	Moderate
• PSC vs. Age	negative	↓ PSC associated with ↑ Age	7	5
• IRI vs. Age	positive	↑ IRI associated with ↑ Age	11	1
• Rutting vs. Age	positive	↑ Rut associated with ↑ Age	11	1
• PSC vs. IRI	negative	↓ PSC associated with ↑ IRI	12	0
• PSC vs. Rutting	negative	↓ PSC associated with ↑ Rutting	11	1
• IRI vs. Rutting	positive	↑ IRI associated with ↑ Rutting	12	0

↑ (increasing) ↓ (Decreasing) * Weak: $0 \leq |r| \leq 0.5$ Moderate: $0.5 < |r| < 0.8$

9.2.2 General Regression Results

- The regression analysis resulted in little additional knowledge about the relationships under investigation.
- Results of the hypothesis testing revealed that the independent variable, in most cases, did provide useful information in predicting the value of the dependent variable.
- The R^2 values ranged from extremely low to low. This indicates that, in general, the linear models did not result in a substantial reduction in the prediction error of y because of the use of the performance measures as independent variables.

9.2.3 PSC vs. Age

PSC values for pavements of all ages and within each analysis group generally ranged from 30 to 100, indicating a large range of differences in pavement condition for pavements of the same age.

9.2.4 IRI vs. Age

- Analysis indicated a weak linear trend of increasing roughness over time for all groups.
- One question at the outset was whether WSDOT should change to a process of programming rehabilitation and maintenance on the basis of IRI. This analysis suggested no reason to believe that changing to IRI as a basis for predicting pavement service life would improve pavement maintenance and rehabilitation programming. In comparison to PSC vs. age, the IRI vs. age relationship produced a lower overall linear correlation and lower quality linear regression results.

9.2.5 Rutting vs. Age

- Analysis indicated a weak linear trend of increasing rutting over time for all analysis groups.
- In comparison to PSC vs. age, the rutting vs. age relationship produced lower overall linear correlation and lower quality linear regression results.

9.2.6 PSC vs. IRI

- One of the questions posed at the beginning of this analysis was, "Do rougher pavements necessarily translate into lower PSC scores?" This study suggested that the answer is, "Perhaps." The negative correlation indicated a trend of decreased PSC with increasing roughness (IRI). However, inspection of the scatter plots (Figures G37 through G42 of Appendix G) indicated PSC values of 30 to 100 for nearly any IRI value. This indicates that pavement sections with an IRI of 3.0, for example, could either be in sound condition or failed.

- Results did not support the use of IRI to predict PSC scores.

9.2.7 PSC vs. Rutting

Another of the questions posed at the beginning of this analysis was, "Do more rutted pavements necessarily translate into lower PSC scores?" This study suggested that the answer is, "Perhaps." The negative correlation indicated a trend of decreased PSC with increasing rutting. However, inspection of the scatter plots (Figures G43 through G48 of Appendix G) again indicated PSC values of 30 to 100 for nearly any rutting value. This indicates that pavement sections with a rut depth of 6.0 mm, for example, could either be in sound condition or failed.

9.2.8 IRI vs. Rutting

- A question posed in Chapter 6 was, "Are rougher pavements necessarily also more rutted?" The answer is, "Perhaps." The positive correlation indicated a trend of increased rutting with increasing roughness. This trend can best be seen in Figure G54 of Appendix G for low traffic volume, western, non-Interstate, resurfaced BST pavements.
- Analysis of the scatter plots (Figures G49 through G54 in Appendix G) indicated that for any given rut depth value, a generally symmetric range of IRI values exist in a band around a central IRI value. The IRI bands decreased in size as rutting increased. A pavement section that intermittently changed from no rutting to varying degrees of rutting would tend to produce

the maximum IRI bands seen generally around a rut depth of 4 mm in the IRI vs. rutting scatter plots.

9.3 COMPARISON OF SOUTH AFRICAN AND WSDOT PAVEMENT PRACTICES AND PERFORMANCE

General similarities and differences in management systems are first presented. These are followed by a discussion of performance measure results and possible reasons for differences.

9.3.1 Similarities

- Both agencies implement their PMSs at the project and network levels.
- Both agencies utilize condition ratings and consider roughness (IRI) and rutting effects on pavement performance.
- Both agencies perform annual distress surveys as the backbone of their pavement management systems.
- Both agencies perform regular traffic counts and utilize an equivalent standard 80-kN axle load to describe the cumulative axle loads applied to each road network.
- The majority of lane-kilometers in each system are flexible pavements.

9.3.2 Differences

- The Gautrans PMS does not consider any national roads (equivalent to our Interstate system).
- The WSDOT route system has over 23,000 more lane-kilometers of roadway.
- Gautrans utilizes the Highway Design and Maintenance (HDM III) model of the World Bank to determine pavement deterioration, whereas WSDOT developed its own system (the WSPMS) in-house.

- Gautrans categorizes pavements by base type, namely crushed stone, cemented, and natural gravel base. This tends to reflect the agency's selection of base type as a critical design parameter. Most WSDOT pavements have an unstabilized granular base course.
- Gautrans roads have a deep, "balanced" pavement structure, whereas WSDOT relies more on strength built into its thick AC or PCC layers, resulting in shallower overall pavement structures.
- Gautrans produced results for "new" pavements that included AC and BST pavements. The WSDOT results do not include "new" BSTs, only BST resurfacing. This hinders direct comparison of results.

9.3.3 Condition Indices

- Gautrans utilizes 19 flexible pavement distress types in computing its condition rating known as a Visual Condition Index (VCI), whereas WSDOT uses only four flexible pavement distress types for its index—the Pavement Structural Condition (PSC).
- Both indices are based on a 0 (worst) to 100 (best) scale.
- Fatigue cracking is the dominant distress for both indices; however, similar levels of severity and extent of fatigue cracking render more severe ratings under WSDOT's PSC rating system.
- Direct comparison of PSC and VCI results is difficult, in large part because of the difference in number of distress types used to compute each index.

9.3.4 Current Pavement Age

- There is little difference in surface course ages for new pavements between agencies. The current mean surface course age is approximately 14 years.
- Gautrans resurfaced BSTs are older than eastern Washington BSTs but similar to western Washington BSTs, which is more similar in overall climatic conditions.

9.3.5 Traffic Considerations

- The entire Washington SR system (Interstate plus non-Interstate) carries on average two and a half times more traffic than the Gautrans road network.
- In contrast, the Gautrans BST road network carries approximately five times more ESALs than the WSDOT BST road network.

9.3.6 Roughness

- Both agencies consider roughness in terms of the International Roughness Index (IRI).
- Both agencies measure roughness by a different means. Gautrans uses a linear displacement integrator, whereas WSDOT uses the South Dakota Profilometer (recently replaced by newer equipment).
- The entire WSDOT route system has a lower overall level of roughness than the Gautrans road network.
- Data comparisons suggest that AC overlays in Washington are smoother (lower mean IRI) than re-sealed Gautrans pavements.
- Results suggest that Gautrans BSTs are smoother (lower mean IRI) than WSDOT BST pavements.

9.3.7 Rutting

- Both agencies use automated sensor technology to measure rutting. However, Gautrans uses fourteen ultra-sonic sensors to WSDOT's five. This likely hinders comparison of results because of possible differences in the measurements.
- Comparison of agency data suggests that WSDOT pavements are not as rutted as Gautrans.
- For both agencies, resurfaced pavement rutting is less than new/reconstructed pavement rutting.
- WSDOT data do not suggest that climate substantially affects rutting between eastern and western Washington. This may be expected since climatic effects can, and should be, taken into account during the design process.

9.3.8 Overall

- Differences in measuring techniques, condition index calculations, and pavement types make direct comparisons of the two agency's pavement performance measures difficult.
- It appears that WSDOT stands to gain the greatest insights from South Africa in the areas of BST pavement design and construction.

9.4 SELECTION OF CANDIDATE PAVEMENTS WITH SUPERIOR AND INFERIOR PERFORMANCE

- It is difficult define superior performance. Although the criteria used in this study were clearly defined, room remains for improvement.
- In almost all cases, a sufficient number of candidates emerged from the database without having to lower the three most critical performance

measures: age, PSC, and ESALs. This supported selection of generally older pavements that remained in good to very good condition while accommodating relatively heavy traffic levels.

9.4.1 Superior Pavement Selection

- The superior pavement selection process was based on the use of analysis group mean values as selection threshold values for each of the five performance measures. Because these group statistics included many newer pavement sections, it was possible that the selection process may have resulted in selection standards that were too stringent to fairly consider older pavement sections. A separate analysis was conducted to evaluate older pavement sections on the basis of selection thresholds that were generated through statistics that considered same-age pavements only. This process resulted in the selection of only five pavements; all of these had already been selected by the original process. The resulting conclusion was that older pavement sections were considered fairly and had an equal opportunity of being selected under the original selection process.
- Table 9.3 presents the number of superior performing candidate pavements selected by region. The total number of pavements in each region and the number of center-line kilometers they account for are shown to provide a sense of the level of selectivity attained in the selection process.
- Pavement sections had to be at least 0.7 km long to be considered. Shorter sections would have been too difficult to locate in the field.

Table 9.3. Number of Superior Candidate Pavements by Region

Side of State	Region Name/ Region #		Superior Pavements		Region Totals		% of Totals	
			#	CL-km	#	CL-km	#	CL-km
Eastern WA	North Central	2	4	33	1,389	3,973	0.3	0.8
	South Central	5	42	283	1,722	4,729	2.4	6.0
	Eastern	6	13	79	1,792	5,718	0.7	1.4
	SUBTOTAL		59	395	4,903	14,420	1.2	2.7
Western WA	Northwest	1	24	158	3,823	5,613	0.6	2.8
	Olympic	3	9	49	2,624	4,557	0.3	1.1
	Southwest	4	34	221	2,063	3,732	1.6	5.9
	SUBTOTAL		67	428	8,510	13,902	0.8	3.1
OVERALL			**126**	**821**	**13,413**	**28,322**	**0.9**	**2.9**

CL- center-line

- In evaluating the results in Table 9.3, readers are cautioned against concluding whether certain regions design and/or build better pavements.

9.4.2 Inferior Pavement Selection

- Table 9.4 presents the number of candidate pavements with inferior performance selected by region. The total number of pavements in each region and the number of center-line kilometers they account for are shown to provide a sense of the level of selectivity attained in the selection process.

Table 9.4. Number of Inferior Candidate Pavements by Region

Side of State	Region Name/ Region #		Inferior Pavements		Region Totals		% of Totals	
			#	CL-km	#	CL-km	#	CL-km
Eastern WA	North Central	2	3	38	1,389	3,973	0.2	1.0
	South Central	5	23	115	1,722	4,729	1.3	2.4
	Eastern	6	16	113	1,792	5,718	0.9	2.0
	SUBTOTAL		42	266	4,903	14,420	0.9	1.8
Western WA	Northwest	1	11	41	3,823	5,613	0.3	0.7
	Olympic	3	8	30	2,624	4,557	0.3	0.7
	Southwest	4	17	69	2,063	3,732	0.8	1.8
	SUBTOTAL		36	140	8,510	13,902	0.4	1.0
OVERALL			**78**	**406**	**13,413**	**28,322**	**0.6**	**1.4**

CL- center-line

- Again, in evaluating the results in Table 9.4, readers are cautioned against making conclusions about whether certain regions design and/or build more inferior pavements.

9.4.3 Comparison of Superior Pavements and Summary Statistic Values

Summary statistics for each analysis group provided the basis for determining superior pavement selection threshold values. A comparison of superior pavement statistics and overall analysis group statistics provided the following:

- The youngest resurfaced AC pavements with superior performance were nearly twice as old as the analysis group mean age for both eastern and western Washington.
- Age comparisons for other analysis groups did not reflect that superior pavements were substantially older than the analysis group as a whole, although they were older.
- Annual design-lane ESAL levels for superior new/reconstructed non-Interstate AC pavements were generally 1.5 to 4 times higher than the analysis group mean.
- Pavement with superior performance had PSC, IRI, and rutting values that were, in some cases, greater and less than analysis group mean values; however, in most cases, superior pavements displayed better values than the analysis group mean. No definitive trends of substantially better performance by the superior performers emerged for these performance measures.

9.4.4 Comparison of Inferior Pavements and Summary Statistic Values

A comparison of statistics from inferior pavements and overall analysis group statistics provided the following insights:

- The youngest pavements with inferior performance were generally 1.5 to 2 times younger than the analysis group mean age for both eastern and western Washington.
- In most cases, pavements with inferior performance displayed lower annual ESAL levels than their analysis group mean values. An exception was new/reconstructed non-Interstate AC pavements.

9.5 PAVEMENT LAYER ANALYSIS

9.5.1 Superior Pavements

- Among non-Interstate pavements by construction type, the mean total structure depths of eastern Washington pavements exceeded western Washington pavements in all cases.
- No definitive trends emerged relating traffic level to superior performance. Some superior pavements had the most or least traffic within certain analysis groups.
- Longitudinal, alligator, and transverse cracking were the dominant failure mechanisms, in order, of new/reconstructed flexible pavements with superior performance.
- Investigation into superior flexible pavements suggested some tendency for the dominant failure mechanism of the previously "failed" layer to propagate through to the new surface.
- Investigation into design layer thicknesses produced by DARWin software and compared to actual WSDOT design layer thicknesses suggested that WSDOT is properly designing its new/reconstructed AC and PCC pavements

at appropriate reliability levels. Analysis was done with assumed input parameters on a small sample set. Resurfaced pavement comparisons were not considered.

9.5.2 Inferior Pavements

- Among non-Interstate pavements by construction type, the mean total structure depths of eastern Washington pavements exceeded western Washington pavements in two of three cases.
- No definitive trends emerged relating traffic level to inferior performance. Some inferior pavements had the most or least traffic within certain analysis groups.
- Alligator cracking, patching, and longitudinal cracking were the dominant failure mechanisms, in order (61, 24, and 15 percent) of new/reconstructed flexible pavements with inferior performance.
- Investigation into inferior flexible pavements suggested some tendency for the dominant failure mechanism of the previously failed layer to propagate through to the inferior surface studied.
- Investigation into design thicknesses produced by DARWin software and compared to actual WSDOT design thicknesses suggested that WSDOT properly designed its new/reconstructed AC and PCC pavements at appropriate reliability levels. Because pavement sections with inferior performance appeared to have adequately designed layer thicknesses, this finding supports the suggestion that inferior performance is not design related but rather construction, materials, and/or site related. Analysis was done with

assumed input parameters and not parameters specific to individual pavement sections.

9.5.3 Comparison of Superior and Inferior Pavement Sections

- Again, no definitive traffic related trends emerged from the analysis. Pavements superior and inferior performance accommodated similar traffic levels.
- Chapter 8 noted that in six of a possible ten analysis group comparisons of total mean pavement structure depth, <u>inferior pavements were thicker than superior pavements</u>.
- The fact that pavements with inferior performance were generally thicker than superior pavements among the same analysis groups, and the fact that WSDOT properly designs its pavement layer thicknesses, suggests that inferior performance is <u>not</u> design related. This points to factors such as construction and material properties.

CHAPTER 10—REVIEW OF INTERSTATE 90 PERFORMANCE

The field performance data for Interstate 90 were reviewed within the 1999 version of the WSPMS. The purpose was to examine all pavement segments on the 480 km of Interstate 90 within Washington State. Specifically, the pavement segments all fit into three categories (based on original construction): flexible, cement treated base with AC wearing course, and PCC pavements. Various statistics were generated and are shown in tables 10.1 through 10.6.

Note that some WSPMS performance data have changed betweem 1996 (WSPMS data used in the preceding chapters) and 1999 (WSPMS data used in this chapter). The most notable change is that, starting in 1999, IRI has been determined with lasers (Pathway van) as opposed to ultrasonic sensors. This has resulted in an approximately 10 percent reduction in IRI between 0 to 1.5 m/km and a 20 percent reduction for IRIs greater than 1.5 m/km.

An examination of the complete length of Interstate 90 within Washington spans two very different climate zones and, to some extent, traffic levels. This kind of information can provide insight into some of the thicker pavement structures designed and maintained by WSDOT, as well as subsequent rehabilitation. Though the purpose was not to identify superior or inferior pavement performance, information is provided that is directly relevant to life cycle cost analyses and pavement design assumptions.

The data are split into western and eastern Washington categories, with the dividing point being the summit of Snoqualmie Pass. Data from the 1999 WSPMS were grouped into uniform segments defined as pavement structures with the same structural design, constructed at the same time, and in the same vicinity. Individual pavement sections within a uniform segment could have different performance as measured by rutting, cracking, IRI, and other factors. The individual sections ranged in length from 0.02 to 17.0 km, and the uniform segments ranged from 0.15 to 24.4 km. A limited number of sections was eliminated because of questionable data in the WSPMS. The final tally for the three pavement types is as follows:

Pavement Type	Length (km)	Percent of Total
Flexible	208	47
Cement Treated Base	88	33
Portland Cement Concrete	142	20

Only data in the eastbound direction were used. The assumption was that the westbound data would be essentially the same.

10.1 FLEXIBLE PAVEMENTS

Tables 10.1 and 10.2 provide an overview of flexible pavement performance on Interstate 90. Table 10.1 shows that, on average (average weighted by segment length), the time since original construction for flexible uniform segments ranged from about 26 years for western Washington (WW) to 29 years for eastern Washington (EW). The original thickness of asphalt concrete (various types ranging from Class B wearing courses to ATB) was 370 mm in WW and 240 mm for EW. The time from original construction to the first resurfacing ranged from 18.5 years in WW to 12.4 years in EW. For EW the times to the first resurfacing ranged from 6 to 21 years. A range of such width is significant and suggests that something other than traditional pavement performance factors, such as thickness and traffic, may be influencing performance—at least for the "under performing" segment. An inspection of the WSPMS data suggests that the most likely cause is stage construction.

Table 10.1 Summary of Performance of Interstate 90 Flexible Pavements

Location	Time Since Original Construction (years)	Thickness of Original AC (mm)	Time from Original Construction to First Resurfacing (years)	Age of Current Wearing Course (years)	Current IRI (m/km)	Current Rut Depth (mm)
Western Wash.						
Weighted Average	25.8	370	18.5	7.4	1.0	5
n	9	9	9	9	9	9
Range	23 to 29	13.8-18.6 in.	17 to 22	4 to 12	0.7 to 1.3	2 to 7
Eastern Wash.						
Weighted Average	29.3	240	12.4	4.7	0.8	5
n	27	27	25	25	25	25
Range	6 to 35	6.0-13.9 in.	6 to 21	2 to 10	0.6 to 1.2	1 to 9

- Weighted Average: values weighted by length of individual uniform segments
- n = number of uniform segments
- Range = smallest and largest values

For the current in-service wearing courses with ages of about 7 years (WW) to 5 years (EW), the IRI mean value fit into the "good" category as defined by LTPP (refer to Table 2.7, Chapter 2). The ranges of segment IRIs for WW (0.7 to 1.3 m/km) and EW

(0.6 to 1.2 m/km) all fit within the LTPP "good" category (defined as IRI<1.4 to 1.5 m/km, depending on age). For rutting, the mean value was at the boundary of the "good-average" LTPP category. The rut depth ranges all fit within the LTPP "good" or "average" categories. Thus, in general, the performance of this pavement type was good as defined by criteria developed by LTPP. Furthermore, none of the originally constructed flexible pavement structures on Interstate 90 have been reconstructed to date.

Table 10.2 summarizes the percentage of flexible pavement segments on Interstate 90 that have been resurfaced (implying AC overlays). In WW all of the segments have been resurfaced once since original construction; however, none have been resurfaced twice. Eastern Washington is different. Most of the segments have been resurfaced twice since original construction. Additionally, the data reveal that the first resurfacing (first AC overlay) has served about as long as the original wearing course (12.4 versus 12.2 years). This implies that the basic pavement structure has survived well, since virtually all of the overlays have rarely exceeded 45 mm. Furthermore, many of the AC overlays have been "mill and fill," and thus there was no net gain in pavement thickness.

Table 10.2 Summary of Resurfacings for Interstate 90 Flexible Pavements

Location	Percentage of Segments Resurfaced				Wearing Course Life (years)	
	First Resurf	Second Resurf	Third Resurf	Fourth Resurf	Original AC	First Resurf
West. Wash. (total number of segments = 9)	100	0	0	0	Mean = 18.5 n = 9 Range 17 to 22	-
East. Wash. (total number of segments = 27)	93	85	11	0	Mean = 12.4 n = 25 Range 6 to 21	Mean = 12.2 n = 21 Range 8 to 17

Mean = weighted average (weighted by length of individual uniform segments)

10.2 CEMENT TREATED BASE PAVEMENTS

Tables 10.3 and 10.4 overview the pavement performance of cement treated base (CTB) with AC wearing course on Interstate 90. Table 10.3 shows that, on average, the time since original construction for uniform segments was about 38 years for EW. No CTB pavements were built on Interstate 90 in WW. The original thickness of AC and CTB (combined) was 230 mm—interestingly about the same as that of flexible pavements for that part of the state (240 mm). The mean time from original construction to the first resurfacing was 13 percent less than that for flexible pavements at 10.8 years. The range of times to the first resurfacing ranged from 3 to 16 years.

Table 10.3 Summary of Performance of Interstate 90 Cement Treated Base Pavements

Location	Time Since Original Construction (years)	Thickness of Original AC and CTB (mm)	Time from Original Construction to First Resurfacing (years)	Age of Current Wearing Course (years)	Current IRI (m/km)	Current Rut Depth (mm)
West. Wash.	NA	NA	NA	NA	NA	NA
East. Wash.						
Weighted Average	38.2	230	10.8	7.1	0.9	7
n	21	21	21	21	21	21
Range	33 to 42	8 to 10 in.	3 to 16	1 to 10	0.6 to 1.2	1 to 11

- NA: There are no segments of CTB construction on I-90 in Western Washington
- Weighted Average: values weighted by length of individual uniform segments
- n = number of uniform segments
- Range = smallest and largest values

The current in-service wearing courses had a mean age of about 7 years. The associated IRI mean value of these segments fit into the "good" category as defined by LTPP. The range of segment IRIs (0.6 to 1.2 m/km) all fit within the LTPP "good" category (defined as IRI<1.5 m/km). For rutting, the mean value was in the LTPP "average" category. The rut depth range fit within the LTPP "average" category. Thus, in general, the performance of this pavement type was good to average as defined by criteria developed by LTPP. It is important to note that most of the pavement reconstruction done on Interstate 90 to date has involved this pavement type.

Table 10.4 summarizes the percentage of the originally constructed CTB pavement segments on Interstate 90 that have been resurfaced. Most of the segments have been resurfaced three times since original construction; however, these segments are, on average, the oldest on Interstate 90. Additionally, the data reveal that the first and second resurfacings have served longer than the original wearing course (10.8 versus 11.9 and 11.5 years). For this pavement type, there were wider ranges of resurfacing treatments and thicknesses. A number of the resurfacings involved granular overlays (crushed stone base material plus AC wearing course) placed directly on the original pavement structure. Furthermore, many of the AC overlays were thicker (75 to 107 mm) than the traditional 45-mm thickness. This is not unexpected because most of the CTB was constructed before the completion of Interstate 90.

Table 10.4 Summary of Resurfacings for Interstate 90 Cement Treated Base Pavements

Location	Percentage of Segments Resurfaced				Wearing Course Life (years)		
	First Resurf	Second Resurf	Third Resurf	Fourth Resurf	Original AC	First Resurf	Second Resurf
West. Wash.	-	-	-	-	-	-	-
East. Wash. (total number of segments = 21)	100	100	71	10	Mean = 10.8 n = 21 Range 3 to 16	Mean = 11.9 n = 21 Range 7 to 21	Mean = 11.5 n = 15 Range 8 to 14

- Mean = weighted average (weighted by length of individual uniform segments)
- No CTB segments on I-90 in Western Washington

10.3 PORTLAND CEMENT CONCRETE PAVEMENTS

Tables 10.5 and 10.6 provide an overview of portland cement concrete (PCC) pavement performance on Interstate 90. Table 10.5 shows that, on average, the time since original construction for uniform segments was about 20 years for WW and 31 years for EW. The original mean thickness of the PCC slabs was 230 mm—the same as the original construction for CTB pavements. The mean time from original construction to the first resurfacing was 19 for WW and 18 years for EW. The range of times to the first resurfacing was large. All of the PCC slabs in WW were placed on ATB. In EW, the base type was typically crushed stone.

Table 10.5 Summary of Performance of Interstate 90 Rigid Pavements

Location	Time Since Original Construction (years)	Thickness of Original PCC (mm)	Time from Original Construction to First Rehabilitation (years)	Age of Current Wearing Course (years)	IRI (m/km)	Rut Depth (mm)
Western Wash.						
Weighted Average	20.0	235	19.0	18.3	1.5	2
n	19	19	3	19	19	19
Range	5 to 49	8 to 12 in.	13 to 28	4 to 24	0.9 to 1.9	1 to 6
Eastern Wash.						
Weighted Average	30.6	230	18.0	11.6	1.6	3
n	21	21	12	21	21	21
Range	4 to 42	8 to 11 in.	18 to 42	0 to 42	1.1 to 2.4	1 to 4

- Weighted Average: values weighted by length of individual uniform segments
- n = number of uniform segments
- Range = smallest and largest values

The current pavement surfaces had mean ages of about 18 years for WW and 12 years for EW. The associated IRI mean values of these segments fit into the "good" category as defined by LTPP (Table 2.8, Chapter 2). The range of segment IRIs all fit within the LTPP "average" category. The current mean wheelpath wear depths for WW and EW were 2 and 3 mm, respectively.

Table 10.6 summarizes the percentage of the originally constructed PCC pavement segments on Interstate 90 that have been "resurfaced." Only 16 percent of the WW slabs have been resurfaced, whereas 57 percent have been resurfaced in EW. Resurfacing is generally defined as retrofitted dowel bars followed by grinding or an AC overlay (typically 90 mm thick). The original PCC slabs that had been resurfaced survived about 19 in WW and 30 years in EW.

Table 10.6 Summary of Resurfacings for Interstate 90 Rigid Pavements

Location	Percentage of Segments Resurfaced				Wearing Course Life (years)		
	First Resurf	Second Resurf	Third Resurf	Fourth Resurf	Original PCC (only segments that have been rehabilitated)	First Resurf	Second Resurf
West. Wash. (total number of segments = 19)	16	5	0	0	Mean = 19.0 n = 3 Range 13 to 28	-	-
East. Wash. (total number of segments = 21)	57	0	0	0	Mean = 29.5 n = 12 Range 18 to 42	-	-

❑ Mean = weighted average (weighted by length of individual uniform segments)

10.4 IMPLICATIONS OF INTERSTATE 90 PERFORMANCE

The implications of the performance assessment of Interstate 90 for WSDOT can be summarized as follows:

- Design Period: The structural sections for flexible and rigid pavements are all intact (no significant reconstruction to date) with most of the segments approaching 30 years of service. The design life assumption in the 2000 version of the WSDOT Pavement Guide (Volume 1, Section 2.1 Design Period) is that both pavement types can be structurally designed for 40 years. These data from Interstate 90 support that design assumption.
- Life Cycle Cost Analyses: The following statements/assumptions in the WSDOT Pavement Guide, Volume 1, Section 2.3 are supported:
  - use of an analysis period of 40 years
  - the expectation that AC resurfacing will occur following 10 to 15 years of service
  - grinding of PCC slabs following 20 years of service to restore smoothness.
- CTB Pavements: CTB pavements have not been constructed on the WSDOT route system since the 1960s. The data support that decision made long ago.
- Overall Performance: The WSDOT pavements, as represented by those on Interstate 90, generally fall into the LTPP "good" performance category (the other possibilities being "average" and "poor"). The IRI of the current wearing courses (AC and PCC) all fall into the "good" category. The PCC slabs are rougher than the AC surfaced pavements but have been in service more than twice as long.

CHAPTER 11—CONCLUSIONS AND RECOMMENDATIONS

11.1 CONCLUSIONS

The following conclusions are appropriate given the preceding information:

¤ A comparison of Interstate highway resurfacing time (time from original construction to resurfacing or times between resurfacings) showed that WSDOT pavement performance is generally equal to that reported by states such as Minnesota and Illinois. Refer to Tables 11.1 through 11.3.

Table 11.1 Time to Resurfacing for Flexible Pavements (Original Construction)—Interstate Highways Only

Agency	Pavement Type	Mean Time to Resurfacing (years)
Minnesota DOT	AC over Aggregate Base	14.1
	AC Full-Depth	16.9
WSDOT	I-90-Western WA	18.5
	I-90-Eastern WA	12.4

Note: Source data contained in Chapters 2 and 10.

Table 11.2 Time to Resurfacing for PCC Pavements (Original Construction)-Interstate Highways Only

Agency	Pavement Type	Mean Time to Resurfacing (years)
Illinois DOT	CRCP (203 mm)	20.0
	JRCP (254 mm)	22.0
Minnesota DOT	PCC	22.2
WSDOT	JPCP-I90-Western WA	19.0
	JPCP-I90-Eastern WA	18.0

Note: Source data contained in Chapters 2 and 10.

Table 11.3 Time to Resurfacing for AC Overlays-Interstate Highways Only

Agency	Pavement Type	Mean Time to Resurfacing (years)
Illinois DOT	AC over JRCP (76-83 mm)	
	Non "D" Cracked PCC	11.9
	"D" Cracked PCC	7.3
	AC over JRCP (102-152 mm)	
	Non "D" Cracked PCC	16.4
	"D" Cracked PCC	14.5
Minnesota DOT	AC Overlay over PCC (1st Overlay)	6.2
	AC Overlay over PCC (2nd Overlay)	9.0
	AC Overlay over AC (1st Overlay)	13.0
	AC Overlay over AC (2nd Overlay)	9.3
WSDOT	AC Overlay over AC (1st Overlay I-90—Western WA)	18.5
	AC Overlay over AC (1st Overlay I-90—Eastern WA)	12.2
	AC Overlay over AC/CTB (1st Overlay I-90—Eastern WA)	11.9
	AC Overlay over AC/CTB (2nd Overlay I-90—Eastern WA)	11.5

Note: Source data contained in Chapters 2 and 10.

¤ Results from LTPP GPS experiments revealed the following (based on two reports evaluated for the literature review and other studies):

Jointed Plain Concrete Pavement

- PCC slabs placed on asphalt treated bases perform best with respect to IRI.

- It is important to use dowel bars in JPCP transverse joints. This enhances long-term smoothness and decreases faulting. Use the largest dowel diameters possible. Thicker slabs are no substitute for dowels.
- Shorter joint spacings are preferred. Generally, this means a spacing between 3.8 to 4.6 m.
- Cold and/or wet climates in the U.S. result in rougher JPCP.

Asphalt Concrete Pavements

- Increased AC thickness decreases rutting, fatigue cracking, and roughness. This is not a "new" finding.
- Air voids in AC must be controlled. This too is not a new concept.

¤ The information contained in Chapter 6 (Relational Performance Measure Analysis) showed the following:

- PSC is the best predictor of pavement service life for WSDOT pavements (in comparison to IRI and rutting).
- There was a high correlation between rutting and age for eastern Washington Interstate AC pavements. This suggests a systemic issue that merits further examination.
- A low correlation was found between PSC and IRI. This suggests that the WSPMS should continue to emphasize the use of PSC for identifying pavements for rehabilitation.

¤ Superior WSDOT Pavements

- In Chapter 7 (Candidate Pavement Selection) 126 pavement sections were identified as superior performers. These fall into the following categories:

- New/Reconstructed AC, Interstate: 6
- New/Reconstructed AC, Non-Interstate: 11
- New/Reconstructed PCC, Interstate: 32
- New/Reconstructed PCC, Non-Interstate: 21
- Resurfaced AC, Interstate: 27
- Resurfaced AC, Non-Interstate: 19
- Resurfaced BST, Non-Interstate: 10

The associated ranges and means for current pavement age, PSC, annual ESALs, IRI, and rut depth for each category are shown in Table 11.4. As expected, Interstate pavements with superior performance carried the highest ESALs—up to 2.5 million per year in the design lane (Resurfaced AC, Interstate category). In general, the minimum age of these pavements was at least 10 years (with two exceptions). As expected, the PCC pavements had the highest ages. When comparing AC to PCC pavements in the same highway category (Interstate or Non-Interstate), AC pavements were smoother (lower IRIs) but had more rut depth (or wear depth). Data collected on Interstate 90 and summarized in Chapter 10 (Review of Interstate 90 Performance) showed that thick AC pavements have been in place, on average, longer than PCC pavements. However, the wearing courses for these AC pavements have been resurfaced more frequently. Finally, these data show that BST surfaced pavements can perform well (as measured by PSC, IRI, and rut depth) and under ESALs of up to 180,000 per year in the design lane.

Table 11.4 Ranges (and Means) of Performance Measures for WSDOT Pavements with Superior Performance

Pavement Category	Ranges (Means)				
	Age (years)	PSC	Annual ESALs (x1000)	IRI (m/km)	Rut Depth (mm)
New/Reconstructed AC, Interstate	8-15 (12)	80-91 (87)	330-1,555 (919)	1.3-2.2 (1.8)	3-11 (6)
New/Reconstructed AC, Non-Interstate	11-26 (15)	76-92 (82)	119-472 (245)	1.3-3.2 (2.0)	2-6 (4)
New/Reconstructed PCC, Interstate	19-29 (24)	82-98 (90)	506-1,807 (809)	0.7-3.0 (2.1)	0-4 (2)
New/Reconstructed PCC, Non-Interstate	25-76 (38)	63-89 (72)	88-338 (190)	2.0-2.8 (2.5)	1-5 (3)
Resurfaced AC, Interstate	11-21 (15)	74-100 (86)	344-2,462 (1,060)	1.1-2.1 (1.7)	0-9 (5)
Resurfaced AC, Non-Interstate	12-26 (17)	71-100 (84)	56-472 (148)	1.2-2.8 (1.9)	3-8 (5)
Resurfaced BST, Non-Interstate	6-18 (9)	73-100 (90)	42-180 (81)	1.8-2.7 (2.4)	2-8 (3)

Data from Tables 7.9 through 7.15. Values are rounded.

- AC pavements with superior performance were nearly twice as old as the analysis group mean age for both western and eastern Washington.
- Annual design-lane ESAL levels for superior new/reconstructed non-Interstate AC pavements were generally 1.5 to 4 times higher than the analysis group mean.
- Longitudinal, alligator, and transverse cracking were the dominant failure mechanisms, in order, for new/reconstructed flexible pavements with superior performance. There is a tendency for the dominant failure mode in resurfaced pavements to be similar to that in the underlying pavement structure.
- Analyses suggest that WSDOT thickness design practices are working well for the design of new AC and PCC pavements.

¤ Inferior WSDOT Pavements

- In Chapter 7 (Candidate Pavement Selection) 78 pavement sections were identified as inferior performing. These fall into the following categories:
  - New/Reconstructed AC, Interstate: 12
  - New/Reconstructed AC, Non-Interstate: 21
  - Resurfaced AC, Interstate: 13
  - Resurfaced AC, Non-Interstate: 17
  - Resurfaced BST, Non-Interstate: 15

  The associated ranges of resurfacing age, PSC, annual ESALs, IRI, and rut depth for each category are shown in Table 11.5.

Table 11.5 Ranges (and Means) of Performance Measures for WSDOT Pavements with Inferior Performance

Pavement Category	Ranges (Means)				
	Age (years)	PSC	Annual ESALs (x1000)	IRI (m/km)	Rut Depth (mm)
New/Reconstructed AC, Interstate	11-14 (12)	0-56 (23)	287-479 (400)	0.7-2.7 (1.8)	6-13 (7)
New/Reconstructed AC, Non-Interstate	3-9 (7)	0-58 (35)	7-491 (135)	1.4-4.7 (2.4)	3-16 (7)
Resurfaced AC, Interstate	4-10 (7)	27-59 (44)	293-860 (520)	1.2-3.1 (1.8)	6-13 (8)
Resurfaced AC, Non-Interstate	2-6 (4)	0-54 (34)	10-168 (72)	1.8-4.9 (2.9)	6-17 (9)
Resurfaced BST, Non-Interstate	3-6 (5)	1-55 (38)	12-154 (55)	1.1-4.1 (2.8)	5-13 (8)

Data from Tables 7.16 through 7.20. Values are rounded.

- In comparison to pavements with superior performance, pavements with inferior performance
    - were about two times younger
    - had PSCs of about three times lower
    - carried about two times fewer ESALs
    - had IRIs of about 14 percent larger
    - had about 40 percent greater rut depth.

  Note: The above ratios and percentages would be more extreme if the "ages" were calculated the same: superior performing age is current wearing course age; inferior performing age is the time from construction to resurfacing.
- Alligator cracking, patching, and longitudinal cracking were the dominant failure mechanisms, in order, for new /reconstructed flexible pavements with inferior performance.
- An examination into inferior flexible pavements showed a tendency for the dominant failure mechanism of the underlying layer to propagate through to the pavement surface.

¤ Comparison of pavements with superior and inferior performance

- In six of ten analysis group comparisons of total mean pavement depth (Chapter 8, Detailed Pavement Section Analysis) showed that pavements with inferior performance were thicker than those with superior performance.

- Given that pavements with inferior performance are generally thicker than pavements with superior performance, and assuming that WSDOT properly designs layer thicknesses, the conclusion is that inferior performance is not design related.

11.2 RECOMMENDATIONS

During the time this study was conducted and, in part, as a result of the early study findings, it is recommended that WSDOT continue to emphasize the reduction of construction variability. Studies such as temperature differentials, the construction case studies, and others will all contribute to improvement in this area. Specific emphasis needs to be placed on improved training—for both WSDOT and contractor personnel. Early efforts to aid this process are already under way at this time (July 2000).

REFERENCES

Committee of State Road Authorities (CSRA), Pavement Management Decisions: "Standard Assessment Manual for Flexible Pavements", Technical Methods for Highways (TMH9), Pretoria, South Africa, 1992.

Devore, Jay L., Probability and Statistics for Engineering and the Sciences, Third Ed., Brooks/Cole Publishing Co., Pacific Grove, CA, 1991.

Dwiggins, Mark E., et al., "Pavement Performance Analysis of the Illinois Interstate Highway System", Interim Report for Federal Highway Administration, Report No FHWA-IL-UI-220, July 1989.

Eltahan, A.A., Simpson, A.L., and Rauhut, J.B., "Common Characteristics of Good and Poorly Performing AC Pavements", Draft Report for Federal Highway Administration, Washington, D.C., April 1997.

Gauteng Provincial Government (GPG), "Procedures to Identify Problems on Gauteng Roads", Report No. PPS/T/2, VKE Consulting Engineers, Pretoria, South Africa, February 1995

Hall, Kathleen T., et al., "Performance of Asphalt Concrete Resurfacing of Jointed Reinforced Concrete Pavement on the Illinois Interstate Highway system", Transportation Research Record No. 1307, Transportation Research Board, Washington D.C., 1991.

Henning, T., Mahoney, J., Sadzik, E., and Jackson, N., "Comparison of Two Implemented Pavement Management Systems in the Republic of South Africa and the United States", Draft Paper for Proceedings, Fourth International Conference on Managing Pavements, May 1998 (Pending).

Kay, R. Keith and Northwest Pavement Management Systems Users Group, Pavement Surface Condition Rating Manual, Washington State Transportation Center (TRAC)-University of Washington, March 1992.

Kay, K., Mahoney, J., and Jackson, N., "The WSDOT Pavement Management System - A 1993 Update", Research Report WA-RD 274.1, Washington State Department of Transportation, Olympia, Washington, September 1993.

Khazanovich, L., Darter, M., Bartlett, R., and McPeak, T., "Common Characteristics of Good and Poorly Performing Pavements," Report FHWA-RD-97-131, Federal Highway Administration, McLean, Virginia, January 1998.

Lukanen, Erland O., et al., "Performance History and Prediction Modeling for Minnesota Pavements", in Proceedings-Third International Conference on Managing Pavements, Volume 1, 1994, National Academy Press, Washington, D.C. 1994.

Mahoney, Joe P., "Statistical Methods for WSDOT Pavement and Material Applications", Interim Report, WA-RD 315.1, February 1994.

Mahoney, J., Lary, J., Pierce, L., Jackson, N., and Barenberg, E. (1991), "Urban Interstate Portland Cement Concrete Pavement Rehabilitation Alternatives for Washington State," Research Report WA-RD 202.1, Washington State Department of Transportation, Olympia, Washington, April 1991.

Sayers, M. W., Gillespie, T. D., and Patterson, W. D. O., "Guidelines for the Conduct and Calibration of Road Roughness Measurements", World Bank Technical Paper No. 46, The World Bank, Washington D.C., 1986.

Washington State Department of Transportation, "WSDOT Pavement Guide," Volumes 1, 2, 3, Olympia, Washington. WSDOT Compact Disc. 2000

ADDITIONAL SOURCES

Hudson, Stuart W., et al., "Minimum Requirements for Standard Pavement Management Systems," In: Pavement Management Implementation, ed. Holt, F.B. and Gramling W.L. Philadelphia: ASTM, 1991: 19.

LTPP Data Analysis Technical Support Team (ERES Consultants, Inc. And Brent Rauhut Engineering Inc.), "Common Characteristics of Good and Poorly Performing PCC Pavements", Draft Report for Federal Highway Administration, Washington, D.C., April 1997 (Pending).

Sincich, Terry, Statistics by Example, Fifth Ed., MacMillan Publishing Co., New York, 1993.

APPENDIX A

Comprehensive Summary Statistics

Table A1. Summary Statistics for Current Pavement Surface Age (years)

New & Reconstructed AC Pavements

Interstate Only	East	West	Total	Entire SR System	East	West	Total
Mean	10.5	16.4	14.0	Mean	10.2	14.9	13.3
Median	9.5	19.0	15.0	Median	9.0	13.0	12.0
Mode	8.0	15.0	15.0	Mode	8.0	1.0	1.0
S.Deviation	7.8	8.1	8.4	S.Deviation	7.1	10.0	9.6
Minimum	2.0	1.0	1.0	Minimum	1.0	0.0	0.0
Maximum	37.0	32.0	37.0	Maximum	43.0	59.0	59.0
Pvmt Sections3	18	79	97	Pvmt Sections3	238	767	1,005
Center-line km4	35.1	49.3	84.4	Center-line km4	231.8	434.2	665.9

Resurfaced AC Pavements

Interstate Only	East	West	Total	Entire SR System	East	West	Total
Mean	6.0	9.2	7.4	Mean	6.5	9.7	8.5
Median	4.0	6.0	6.0	Median	5.0	8.0	7.0
Mode	2.0	1.0	1.0	Mode	1.0	2.0	2.0
S.Deviation	4.7	6.8	6.2	S.Deviation	4.6	7.2	6.7
Minimum	1.0	1.0	1.0	Minimum	0.0	0.0	0.0
Maximum	21.0	40.0	40.0	Maximum	38.0	52.0	52.0
Pvmt Sections3	374	571	945	Pvmt Sections3	2,226	5,538	7,764
Center-line km4	677.4	580.0	1,257.4	Center-line km4	2,705.6	4,450.2	7,155.8

BST Resurfaced Pavements

Interstate Only	East	West	Total	Entire SR System	East	West	Total
Mean				Mean	4.4	7.1	4.7
Median				Median	4.0	7.0	4.0
Mode				Mode	1.0	1.0	1.0
S.Deviation		NONE		S.Deviation	3.5	8.2	5.1
Minimum				Minimum	1.0	1.0	1.0
Maximum				Maximum	50.0	56.0	56.0
Pvmt Sections3				Pvmt Sections3	1,583	437	2,020
Center-line km4				Center-line km4	3,142.0	451.5	3,593.5

Table A1 cont. Summary Statistics for Current Pavement Surface Age

New & Reconstructed PCC Pavements

Interstate Only

	East	West	Total
Mean	17.3	25.8	21.2
Median	15.0	27.0	21.5
Mode	15.0	27.0	17.0
S.Deviation	8.3	10.6	10.3
Minimum	1.0	1.0	1.0
Maximum	45.0	59.0	59.0
Pvmt Sections3	243	477	720
Center-line km4	515.5	436.8	952.3

Entire SR System

	East	West	Total
Mean	16.9	29.4	22.4
Median	17.0	28.0	25.0
Mode	15.0	27.0	27.0
S.Deviation	10.0	15.0	14.0
Minimum	1.0	1.0	1.0
Maximum	45.0	84.0	84.0
Pvmt Sections3	288	574	862
Center-line km4	668.4	526.6	1,195.0

Resurfaced (Dowel Bar Retrofit) PCC Pavements

Interstate Only

	East	West	Total
Mean	2.0	0.0	1.6
Median	2.0	0.0	2.0
Mode	2.0	0.0	2.0
S.Deviation	0.0	0.0	0.8
Minimum	2.0	0.0	0.0
Maximum	2.0	0.0	2.0
Pvmt Sections3	50	12	62
Center-line km4	71.1	18.6	89.7

Entire SR System

	East	West	Total
Mean	2.0	0.0	1.6
Median	2.0	0.0	2.0
Mode	2.0	0.0	2.0
S.Deviation	0.0	0.0	0.8
Minimum	2.0	0.0	0.0
Maximum	2.0	0.0	2.0
Pvmt Sections3	50	12	62
Center-line km4	71.1	18.6	89.7

Overall Age Statistics- All Pavements

Interstate Only

	East	West	Total
Mean	10.4	16.1	13.0
Median	9.0	15.0	12.0
Mode	2.0	1.0	2.0
S.Deviation	8.7	11.6	10.9
Minimum	1.0	0.0	0.0
Maximum	45.0	59.0	59.0
Pvmt Sections3	685	1,139	1,824
Center-line km4	1,299.2	1,084.7	2,383.9

Entire SR System

	East	West	Total
Mean	6.6	11.6	8.9
Median	5.0	9.0	7.0
Mode	2.0	2.0	2.0
S.Deviation	6.1	9.8	8.9
Minimum	0.0	0.0	0.0
Maximum	50.0	84.0	84.0
Pvmt Sections3	4,385	7,328	11,713
Center-line km4	6,818.8	5,881.1	12,699.9

Table A2. Summary Statistics for PSC

New & Reconstructed AC Pavements

Interstate Only

	East	West	Total
Mean	83.6	78.8	80.8
Median	84.0	88.0	87.0
Mode	88.0	100.0	100.0
S.Deviation	14.1	18.7	17.9
Minimum	32.0	36.0	32.0
Maximum	98.0	100.0	100.0
Pvmt Sections3	18	79	97
Center-line km4	35.1	49.3	84.4

Entire SR System

	East	West	Total
Mean	79.0	79.7	79.5
Median	82.0	88.0	86.0
Mode	100.0	100.0	100.0
S.Deviation	19.3	18.6	18.8
Minimum	19.0	11.0	11.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	238	767	1,005
Center-line km4	76.7	263.5	340.2

Resurfaced AC Pavements

Interstate Only

	East	West	Total
Mean	86.9	89.1	87.9
Median	86.0	100.0	92.0
Mode	100.0	100.0	100.0
S.Deviation	13.0	15.8	14.8
Minimum	32.0	33.0	32.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	374	571	945
Center-line km4	677.4	580.0	1,257.4

Entire SR System

	East	West	Total
Mean	81.6	81.1	81.3
Median	82.0	88.0	86.0
Mode	100.0	100.0	100.0
S.Deviation	17.1	18.1	17.0
Minimum	1.0	10.0	1.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	2,224	5,538	7,762
Center-line km4	2,703.0	4,450.2	7,153.2

BST Resurfaced Pavements

Interstate Only

	East	West	Total
Mean			
Median			
Mode			
S.Deviation		**NONE**	
Minimum			
Maximum			
Pvmt Sections3			
Center-line km4			

Entire SR System

	East	West	Total
Mean	71.8	74.6	72.1
Median	76.0	78.0	76.0
Mode	100.0	100.0	100.0
S.Deviation	17.9	20.8	18.6
Minimum	10.0	29.0	10.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	1,583	437	2,020
Center-line km4	3,141.8	451.5	3,593.3

Table A2 cont. Summary Statistics for PSC

New & Reconstructed PCC Pavements

Interstate Only

	East	West	Total
Mean	89.8	82.6	86.5
Median	91.0	87.0	90.0
Mode	91.0	91.0	91.0
S.Deviation	10.8	11.4	11.4
Minimum	37.0	37.0	37.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	243	477	720
Center-line km4	515.5	436.8	952.3

Entire SR System

	East	West	Total
Mean	88.1	80.6	84.7
Median	91.0	84.0	89.0
Mode	91.0	91.0	91.0
S.Deviation	14.5	12.9	13.5
Minimum	25.0	24.0	24.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	288	574	862
Center-line km4	668.4	526.6	1,195.0

Resurfaced (Dowel Bar Retrofit) PCC Pavements

Interstate Only

	East	West	Total
Mean	87.3	91.0	88.0
Median	88.5	92.0	90.0
Mode	91.0	92.0	90.0
S.Deviation	6.7	0.8	6.4
Minimum	61.0	90.0	61.0
Maximum	95.0	93.0	95.0
Pvmt Sections3	50	12	62
Center-line km4	71.1	18.6	89.7

Entire SR System

	East	West	Total
Mean	87.3	91.0	88.0
Median	88.5	92.0	90.0
Mode	91.0	92.0	90.0
S.Deviation	6.7	0.8	6.4
Minimum	61.0	90.0	61.0
Maximum	95.0	93.0	95.0
Pvmt Sections3	50	12	62
Center-line km4	71.1	18.6	89.7

Overall PSC Statistics- All Pavements

Interstate Only

	East	West	Total
Mean	88.0	86.0	87.1
Median	90.0	91.0	90.0
Mode	100.0	100.0	100.0
S.Deviation	12.0	14.7	13.7
Minimum	32.0	33.0	32.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	685	1,139	1,824
Center-line km4	1299.2	1084.7	2383.9

Entire SR System

	East	West	Total
Mean	77.6	80.5	79.0
Median	82.0	88.0	85.0
Mode	100.0	100.0	100.0
S.Deviation	17.8	18.1	18.0
Minimum	1.0	10.0	1.0
Maximum	100.0	100.0	100.0
Pvmt Sections3	4,383	7,328	11,711
Center-line km4	6818.6	5881.1	12,699.7

Table A3. Summary Statistics for Design-lane Annual ESALs

New & Reconstructed AC Pavements

	Interstate Only			Entire SR System		
	East	West	Total	East	West	Total
Mean	362,660	1,266,492	890,455	164,636	285,143	243,418
Median	332,976	1,283,205	1,200,556	98,828	101,671	100,119
Mode	327,646	1,739,137	1,739,137	205,358	1,739,137	205,358
S.Deviation	144,488	599,168	620,393	121,805	385,984	345,786
Minimum	36,245	12,795	12,795	1,278	438	438
Maximum	861,064	2,033,448	2,033,448	861,064	2,033,448	2,033,448
Pvmt Sections3	18	79	97	238	766	1,004
Center-line km4	35.1	49.3	84.4	231.8	437.6	669.4

Resurfaced AC Pavements

	Interstate Only			Entire SR System		
	East	West	Total	East	West	Total
Mean	495,518	1,133,627	789,221	207,206	254,329	236,488
Median	479,372	1,125,541	662,929	118,278	98,021	104,171
Mode	504,297	1,788,863	1,788,863	6,059	8,112	8,112
S.Deviation	208,277	500,758	496,677	202,139	364,547	327,959
Minimum	249,381	24,867	24,867	3,714	986	3,714
Maximum	1,882,075	2,461,960	2,461,960	1,882,075	2,461,960	2,461,960
Pvmt Sections3	374	567	941	2,225	5,533	7,758
Center-line km4	677.4	577.7	1,255.1	2,730.2	4,481.1	7,211.3

BST Resurfaced Pavements

	Interstate Only			Entire SR System		
	East	West	Total	East	West	Total
Mean				37,886	41,621	38,355
Median				22,858	30,231	23,866
Mode				6,059	28,452	6,059
S.Deviation		NONE		42,825	41,216	42,491
Minimum				548	475	475
Maximum				274,133	581,921	581,921
Pvmt Sections3				1,581	437	2,018
Center-line km4				3,141.3	451.5	3,592.8

Table A3 cont. Summary Statistics for Design-lane Annual ESALs

New & Reconstructed PCC Pavements

	Interstate Only			Entire SR System		
	East	West	Total	East	West	Total
Mean	479,776	991,938	713,026	427,584	854,185	614,427
Median	475,717	953,126	731,561	413,516	779,174	550,140
Mode	861,064	1,599,967	861,064	861,064	1,599,967	861,064
S.Deviation	228,239	455,872	450,678	247,604	507,933	474,621
Minimum	147,515	18,018	18,018	50,361	6,096	6,096
Maximum	1,002,122	2,144,891	2,144,891	1,002,122	2,144,891	2,144,891
Pvmt Sections3	243	463	706	288	560	848
Center-line km4	515.5	431.1	946.6	668.4	520.9	1,189.2

Resurfaced (Dowel Bar Retrofit) PCC Pavements

	Interstate Only			Entire SR System		
	East	West	Total	East	West	Total
Mean	922,574	523,790	839,899	922,574	523,790	839,899
Median	921,705	552,348	902,685	921,705	552,348	902,685
Mode	925,187	416,834	925,187	925,187	416,834	925,187
S.Deviation	60,555	80,454	170,930	60,555	80,454	170,930
Minimum	788,186	416,834	416,834	788,186	416,834	416,834
Maximum	1,077,365	598,741	1,077,365	1,077,365	598,741	1,077,365
Pvmt Sections3	50	12	62	50	12	62
Center-line km4	71.1	18.6	89.7	71.1	18.6	89.7

Overall ESAL Statistics- All Pavements

	Interstate Only			Entire SR System		
	East	West	Total	East	West	Total
Mean	509,061	1,072,445	761,016	156,997	294,079	220,523
Median	487,757	1,063,787	685,005	78,516	100,160	91,820
Mode	507,730	1,285,561	1,285,561	6,059	8,112	6,059
S.Deviation	234,239	495,525	488,832	209,480	405,689	349,935
Minimum	36,245	12,795	12,795	548	438	438
Maximum	1,882,075	2,461,960	2,461,960	1,882,075	2,461,960	2,461,960
Pvmt Sections3	685	1,121	1,762	4,382	7,308	11,690
Center-line km4	1,299.2	1,084.7	2,383.9	6,842.7	5,909.6	12,752.3

Table A4. Summary Statistics for IRI (m/km)

New & Reconstructed AC Pavements

Interstate Only

	East	West	Total
Mean	2.05	1.66	1.82
Median	2.03	1.82	1.86
Mode	NA	1.15	1.46
S.Deviation	0.55	0.77	0.74
Minimum	1.35	0.81	0.81
Maximum	3.38	4.48	4.48
Pvmt Sections3	18	79	97
Center-line km4	35.1	49.3	84.4

Entire SR System

	East	West	Total
Mean	2.11	1.88	1.98
Median	2.15	2.18	2.16
Mode	2.21	1.62	2.57
S.Deviation	0.81	0.77	0.79
Minimum	1.18	0.81	0.81
Maximum	6.33	5.18	6.33
Pvmt Sections3	130	221	351
Center-line km4	100.0	120.9	220.9

Resurfaced AC Pavements

Interstate Only

	East	West	Total
Mean	1.57	1.65	1.61
Median	1.72	1.83	1.80
Mode	1.10	1.92	1.83
S.Deviation	0.49	0.55	0.53
Minimum	0.65	0.66	0.65
Maximum	3.48	4.77	4.77
Pvmt Sections3	373	565	938
Center-line km4	677.4	577.6	1,255.0

Entire SR System

	East	West	Total
Mean	1.73	1.86	1.78
Median	1.84	2.00	1.92
Mode	1.81	1.92	1.81
S.Deviation	0.85	0.74	0.80
Minimum	0.65	0.66	0.65
Maximum	6.90	7.16	7.16
Pvmt Sections3	1,675	1,681	3,356
Center-line km4	2,219.8	1,528.8	3,748.6

BST Resurfaced Pavements

Interstate Only

	East	West	Total
Mean			
Median			
Mode			
S.Deviation		**NONE**	
Minimum			
Maximum			
Pvmt Sections3			
Center-line km4			

Entire SR System

	East	West	Total
Mean	2.66	3.20	2.71
Median	2.61	3.25	2.71
Mode	2.39	3.49	2.39
S.Deviation	0.67	0.82	0.75
Minimum	1.15	1.28	1.15
Maximum	5.91	7.40	7.40
Pvmt Sections3	1,194	238	1,432
Center-line km4	2,418.9	259.6	2,679.0

Table A4 cont. Summary Statistics for IRI (m/km)

New & Reconstructed PCC Pavements

Interstate Only	East	West	Total	Entire SR System	East	West	Total
Mean	1.93	2.25	2.08	Mean	1.97	2.28	2.10
Median	2.01	2.41	2.30	Median	2.13	2.42	2.33
Mode	1.65	1.68	2.13	Mode	1.44	1.68	2.13
S.Deviation	0.69	0.66	0.69	S.Deviation	0.80	0.66	0.72
Minimum	1.07	0.73	0.73	Minimum	1.07	0.73	0.73
Maximum	4.72	4.97	4.97	Maximum	5.79	4.97	5.79
Pvmt Sections3	243	469	712	Pvmt Sections3	280	481	761
Center-line km4	515.5	435.2	950.7	Center-line km4	617.4	462.5	1,079.9

Resurfaced (Dowel Bar Retrofit) PCC Pavements

Interstate Only	East	West	Total	Entire SR System	East	West	Total
Mean	1.80	1.30	1.70	Mean	1.80	1.30	1.70
Median	1.91	1.45	1.78	Median	1.91	1.45	1.78
Mode	1.53	1.83	1.53	Mode	1.53	1.83	1.53
S.Deviation	0.39	0.24	0.41	S.Deviation	0.39	0.24	0.41
Minimum	1.29	1.19	1.19	Minimum	1.29	1.19	1.19
Maximum	2.98	1.87	2.98	Maximum	2.98	1.87	2.98
Pvmt Sections3	50	12	62	Pvmt Sections3	50	12	62
Center-line km4	71.1	18.6	89.7	Center-line km4	71.1	18.6	89.7

Overall IRI (m/km)- All Pavements

Interstate Only	East	West	Total	Entire SR System	East	West	Total
Mean	1.74	1.89	1.81	Mean	2.18	2.08	2.15
Median	1.81	2.01	1.94	Median	2.18	2.18	2.18
Mode	1.86	1.92	1.92	Mode	1.81	1.92	1.80
S.Deviation	0.60	0.69	0.66	S.Deviation	0.83	0.83	0.83
Minimum	0.65	0.66	0.65	Minimum	0.65	0.66	0.65
Maximum	4.72	4.97	4.97	Maximum	6.90	7.40	7.40
Pvmt Sections3	684	1,125	1,809	Pvmt Sections3	3,329	2,633	5,962
Center-line km4	1,299.2	1,080.7	2,379.9	Center-line km4	5,427.2	2,390.4	7,817.6

Table A5. Summary Statistics for Rutting (mm)

New & Reconstructed AC Pavements

Interstate Only

	East	West	Total
Mean	7.4	5.7	6.4
Median	3.0	5.0	5.0
Mode	0.9	5.0	0.9
S.Deviation	3.7	3.7	3.7
Minimum	0.0	0.0	0.0
Maximum	12.0	15.1	15.1
Pvmt Sections3	18	79	97
Center-line km4	35.1	49.3	84.4

Entire SR System

	East	West	Total
Mean	4.7	3.6	4.1
Median	3.0	3.0	3.0
Mode	3.0	1.9	1.9
S.Deviation	2.6	2.9	2.8
Minimum	0.0	0.0	0.0
Maximum	12.0	15.1	15.1
Pvmt Sections3	130	221	351
Center-line km4	100.0	120.9	220.9

Resurfaced AC Pavements

Interstate Only

	East	West	Total
Mean	4.3	5.2	4.7
Median	3.0	4.0	4.0
Mode	0.9	3.0	3.0
S.Deviation	3.2	3.4	3.4
Minimum	0.0	0.0	0.0
Maximum	16.0	16.0	16.0
Pvmt Sections3	373	565	938
Center-line km4	677.4	577.6	1255.0

Entire SR System

	East	West	Total
Mean	4.0	4.1	4.0
Median	3.0	3.0	3.0
Mode	3.0	3.0	3.0
S.Deviation	2.7	2.9	2.8
Minimum	0.0	0.0	0.0
Maximum	16.9	16.0	16.9
Pvmt Sections3	1,673	1,680	3,353
Center-line km4	2,218.4	1,528.2	3,746.6

BST Resurfaced Pavements

Interstate Only

	East	West	Total
Mean			
Median			
Mode			
S.Deviation		**NONE**	
Minimum			
Maximum			
Pvmt Sections3			
Center-line km4			

Entire SR System

	East	West	Total
Mean	4.8	4.4	4.8
Median	4.0	4.0	4.0
Mode	4.0	4.0	4.0
S.Deviation	2.5	2.6	2.5
Minimum	0.0	0.0	0.0
Maximum	13.0	13.0	13.0
Pvmt Sections3	1,194	238	1,432
Center-line km4	2418.9	259.6	2678.5

Table A5 cont. Summary Statistics for Rutting (mm)

New & Reconstructed PCC Pavements

	Interstate Only				Entire SR System		
	East	West	Total		East	West	Total
Mean	0.8	2.4	1.5	Mean	1.0	2.5	1.6
Median	0.9	1.9	0.9	Median	0.9	1.9	1.9
Mode	0.0	0.0	0.0	Mode	0.0	0.0	0.0
S.Deviation	1.2	2.4	2.2	S.Deviation	1.4	2.4	2.2
Minimum	0.0	0.0	0.0	Minimum	0.0	0.0	0.0
Maximum	5.9	14.0	14.0	Maximum	5.9	14.0	14.0
Pvmt Sections3	243	468	711	Pvmt Sections3	280	481	761
Center-line km4	515.5	435.2	950.7	Center-line km4	617.4	462.5	1079.9

Resurfaced (Dowel Bar Retrofit) PCC Pavements

	Interstate Only				Entire SR System		
	East	West	Total		East	West	Total
Mean	1.7	0.8	1.5	Mean	1.7	0.8	1.5
Median	0.9	0.9	0.9	Median	0.9	0.9	0.9
Mode	0.9	0.9	0.9	Mode	0.9	0.9	0.9
S.Deviation	1.5	0.8	1.5	S.Deviation	1.5	0.8	1.5
Minimum	0.0	0.0	0.0	Minimum	0.0	0.0	0.0
Maximum	5.9	3.0	5.9	Maximum	5.9	3.0	5.9
Pvmt Sections3	50	12	62	Pvmt Sections3	50	12	62
Center-line km4	71.1	18.6	89.7	Center-line km4	71.1	18.6	89.7

Overall Rutting (mm)- All Pavements

	Interstate Only				Entire SR System		
	East	West	Total		East	West	Total
Mean	2.8	4.0	3.4	Mean	4.0	3.7	3.9
Median	1.9	3.0	3.0	Median	3.0	3.0	3.0
Mode	0.0	3.0	0.0	Mode	3.0	3.0	3.0
S.Deviation	2.9	3.2	3.2	S.Deviation	2.7	2.8	2.7
Minimum	0.0	0.0	0.0	Minimum	0.0	0.0	0.0
Maximum	16.0	16.0	16.0	Maximum	16.9	16.0	16.9
Pvmt Sections3	684	1,124	1,808	Pvmt Sections3	3,327	2,632	5,959
Center-line km4	1299.2	1080.7	2,379.9	Center-line km4	5,425.8	2,389.8	7,815.6

NOTES

1. Statistics include only new, reconstructed, and resurfaced pavement sections.
2. All roadway types except bridges were included in the statistical analysis.
3. Number of pavement sections represents only those sections that were both surveyed in 1996 and included in the statistical analysis, and therefore may not represent the actual number of pavement sections within a particular analysis group (e.g. approximately only 50% of pavement sections were surveyed for IRI and rutting in 1996).
4. Center-line kilometers (km) represent the total roadway length included in the statistical analysis, which in most cases does not equal actual center-line km since many roadway sections were surveyed in both directions.
5. In most cases, 1995 traffic data was used to produce the annual design lane ESAL values. In cases where 1995 traffic data was unavailable, growth adjusted 1994 traffic data was used.

APPENDIX B

Age Frequency and Cumulative Frequency Plots

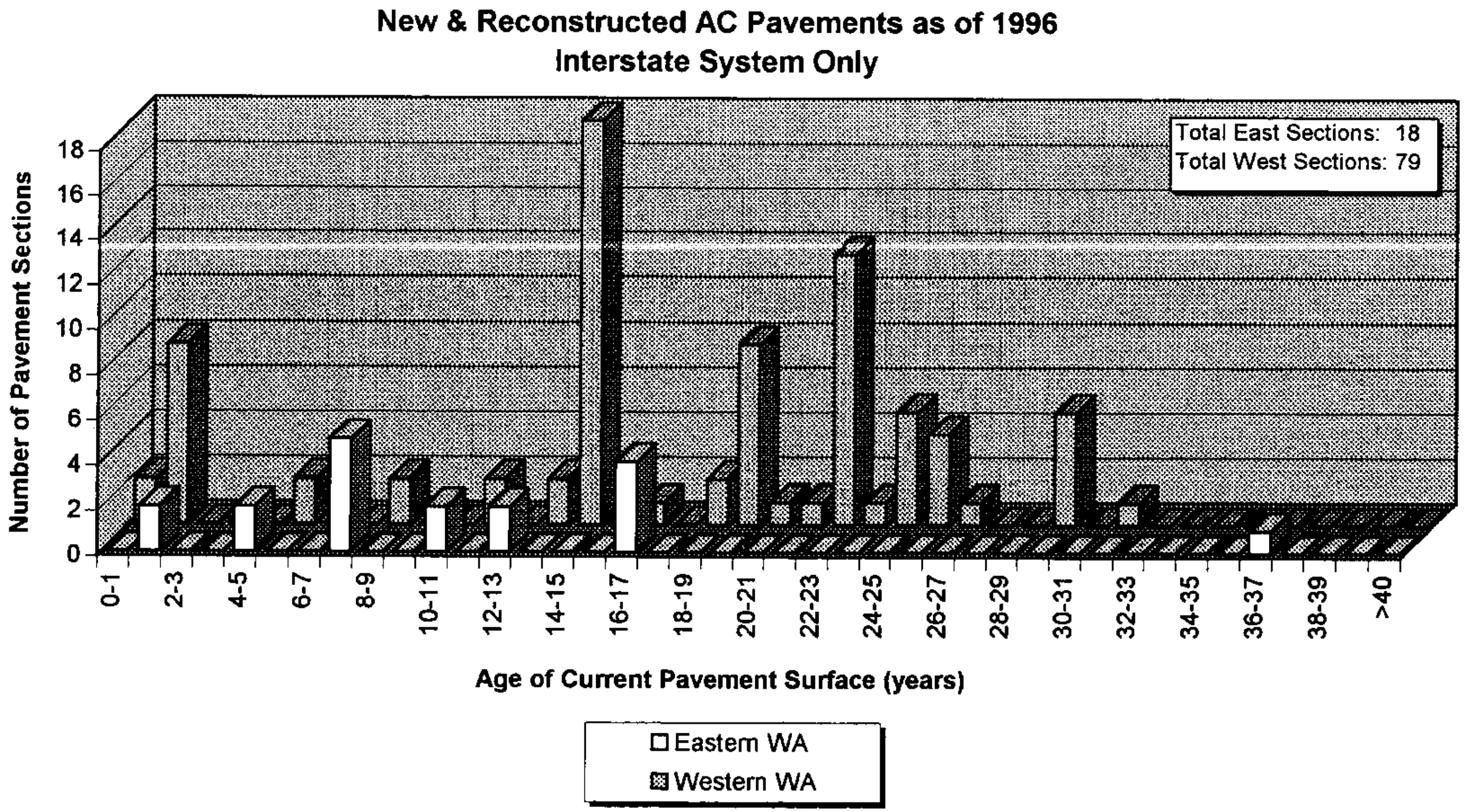


Figure B1. Age Plot for New & Reconstructed AC- Interstate

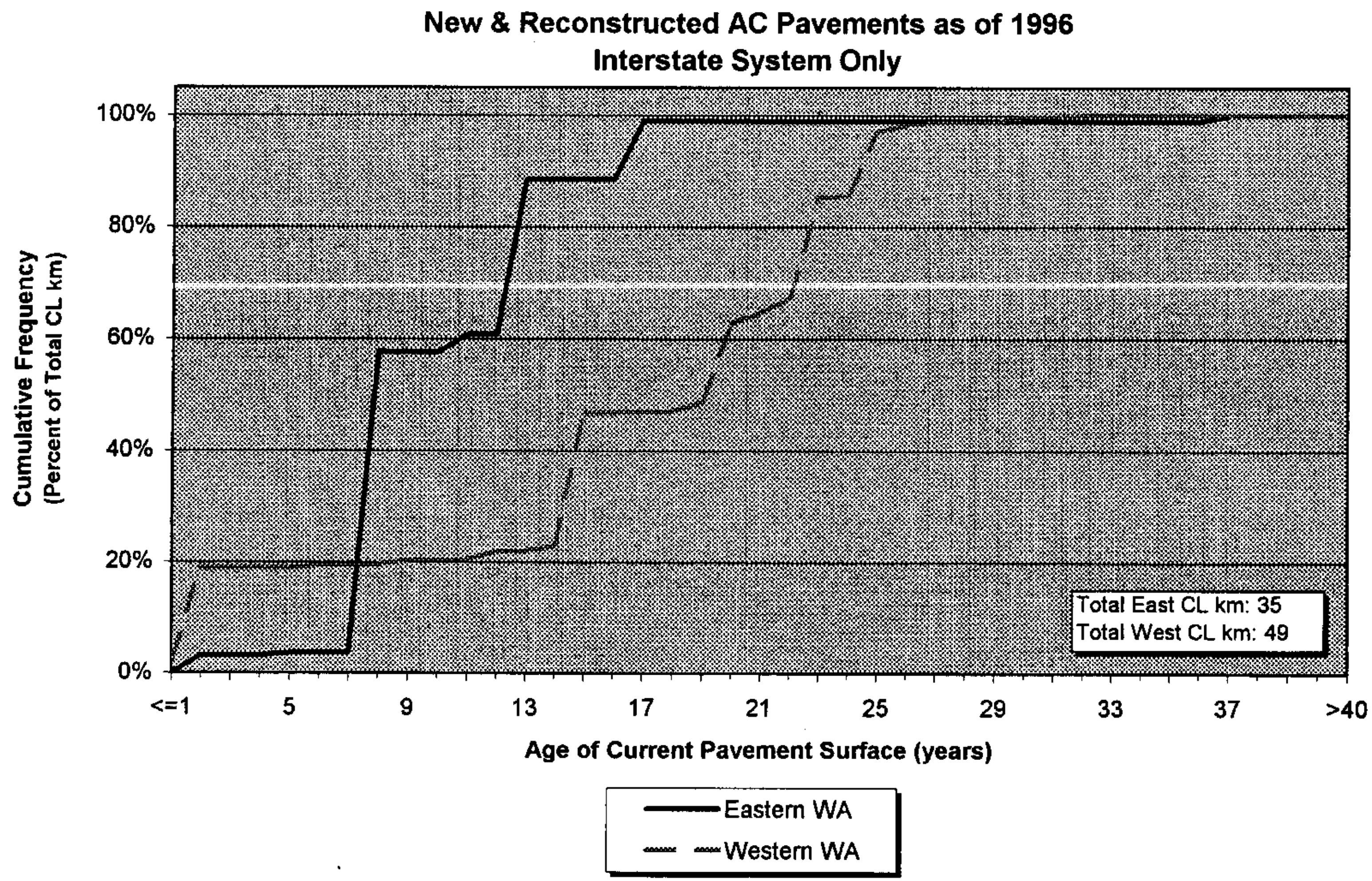


Figure B2. Age Cumulative Frequency Curve for New & Reconstructed AC- Interstate

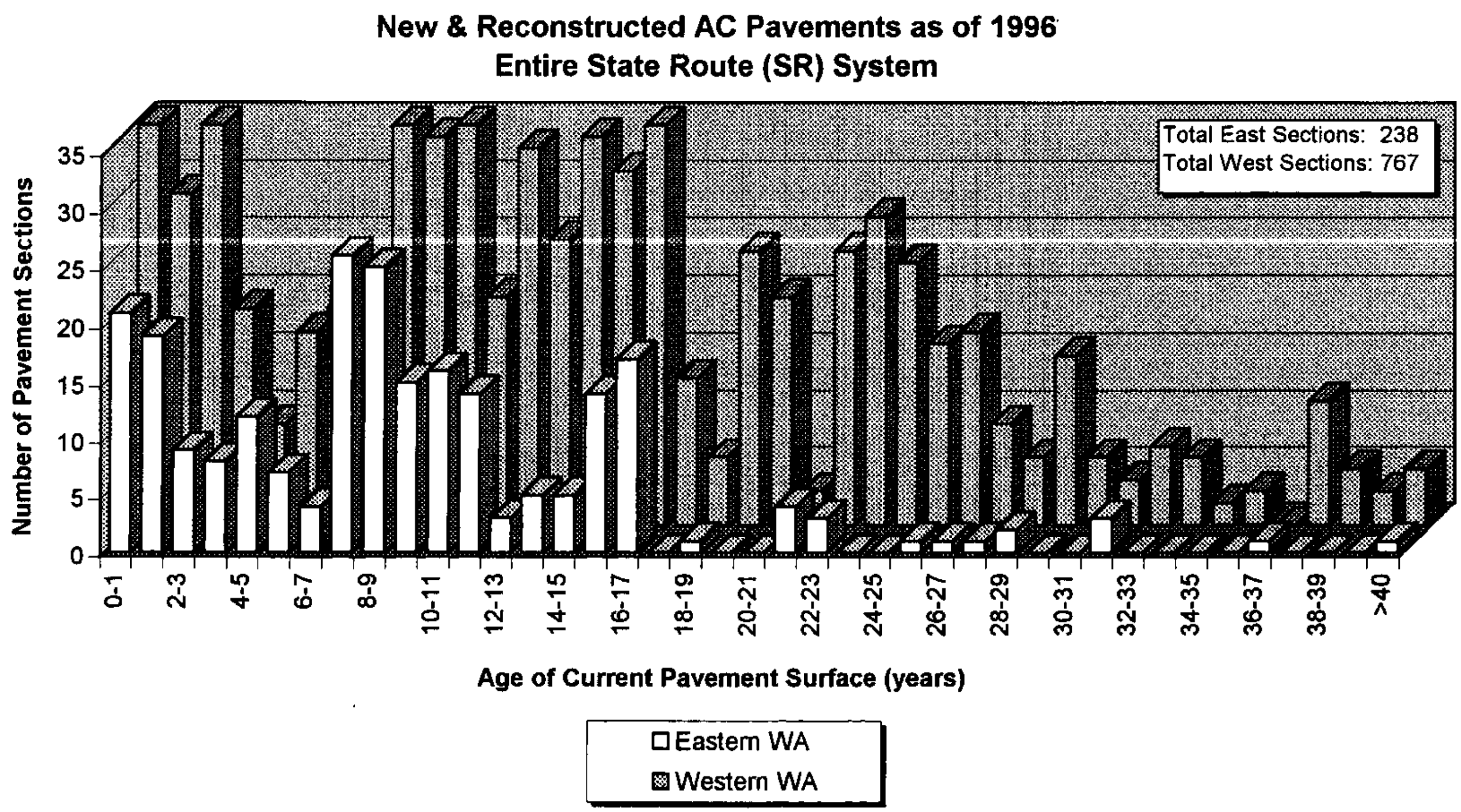


Figure B3. Age Plot for New & Reconstructed AC- SR System

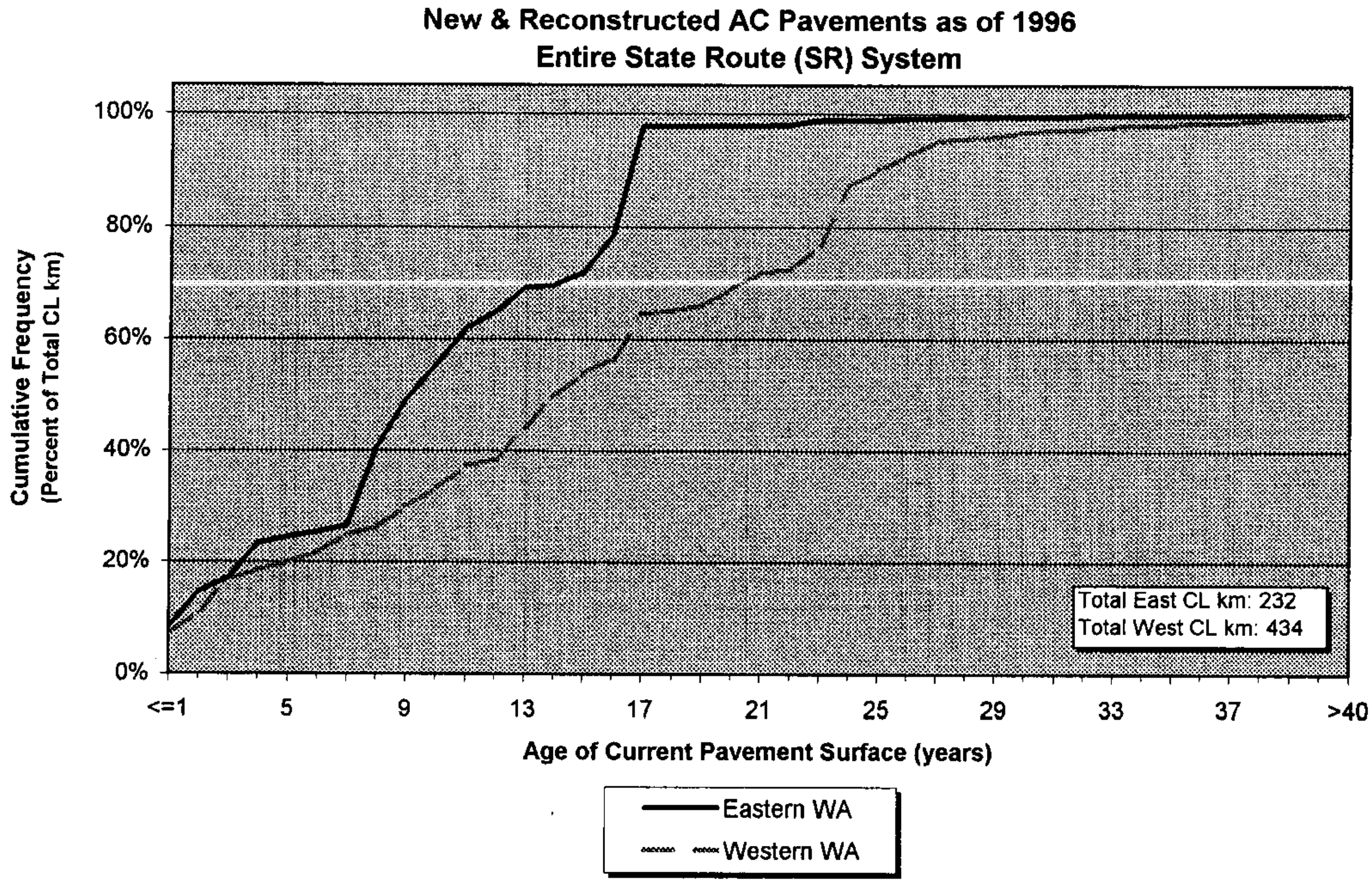


Figure B4. Age Cumulative Frequency Curve for New & Reconstructed AC- SR System

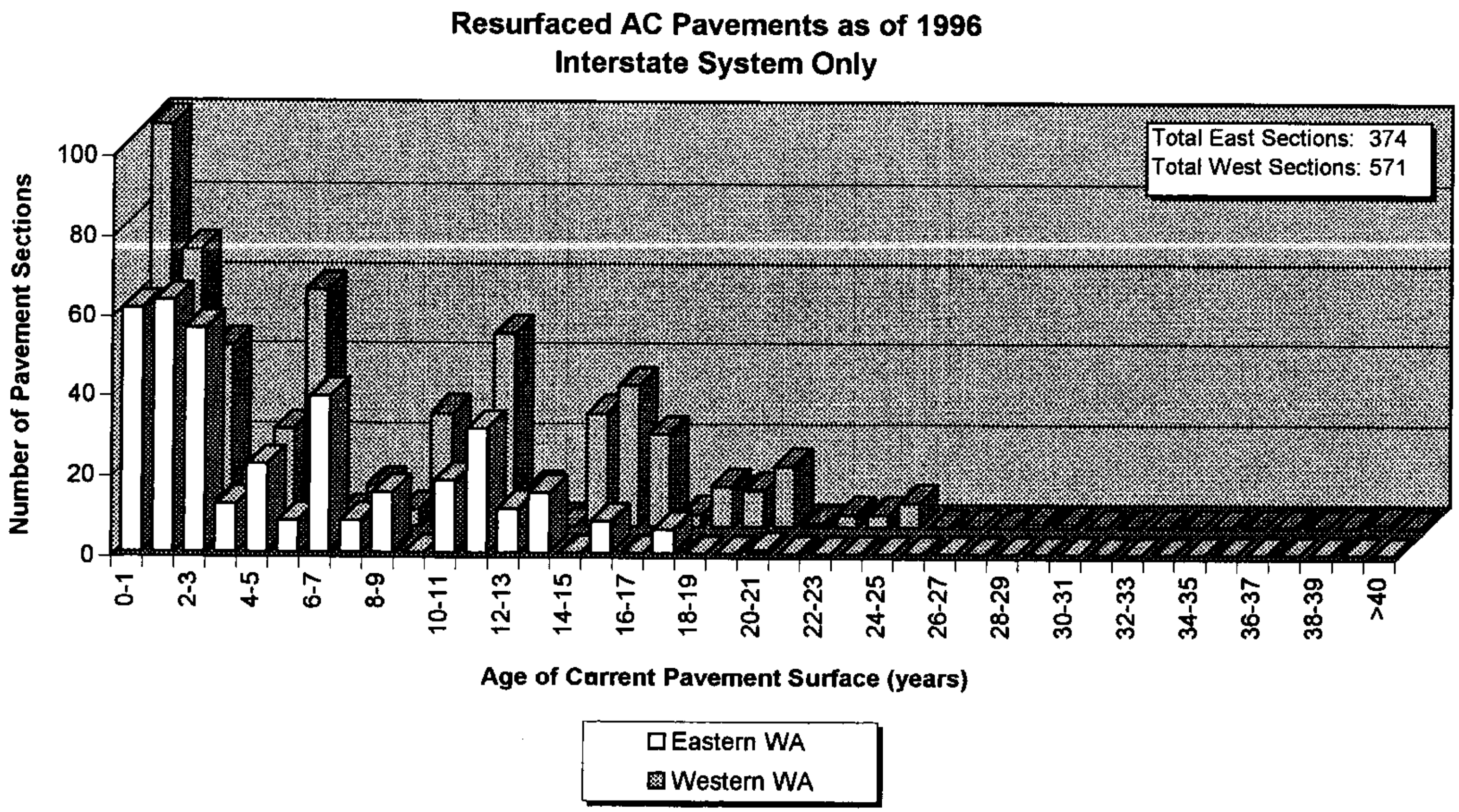


Figure B5. Age Plot for Resurfaced AC- Interstate

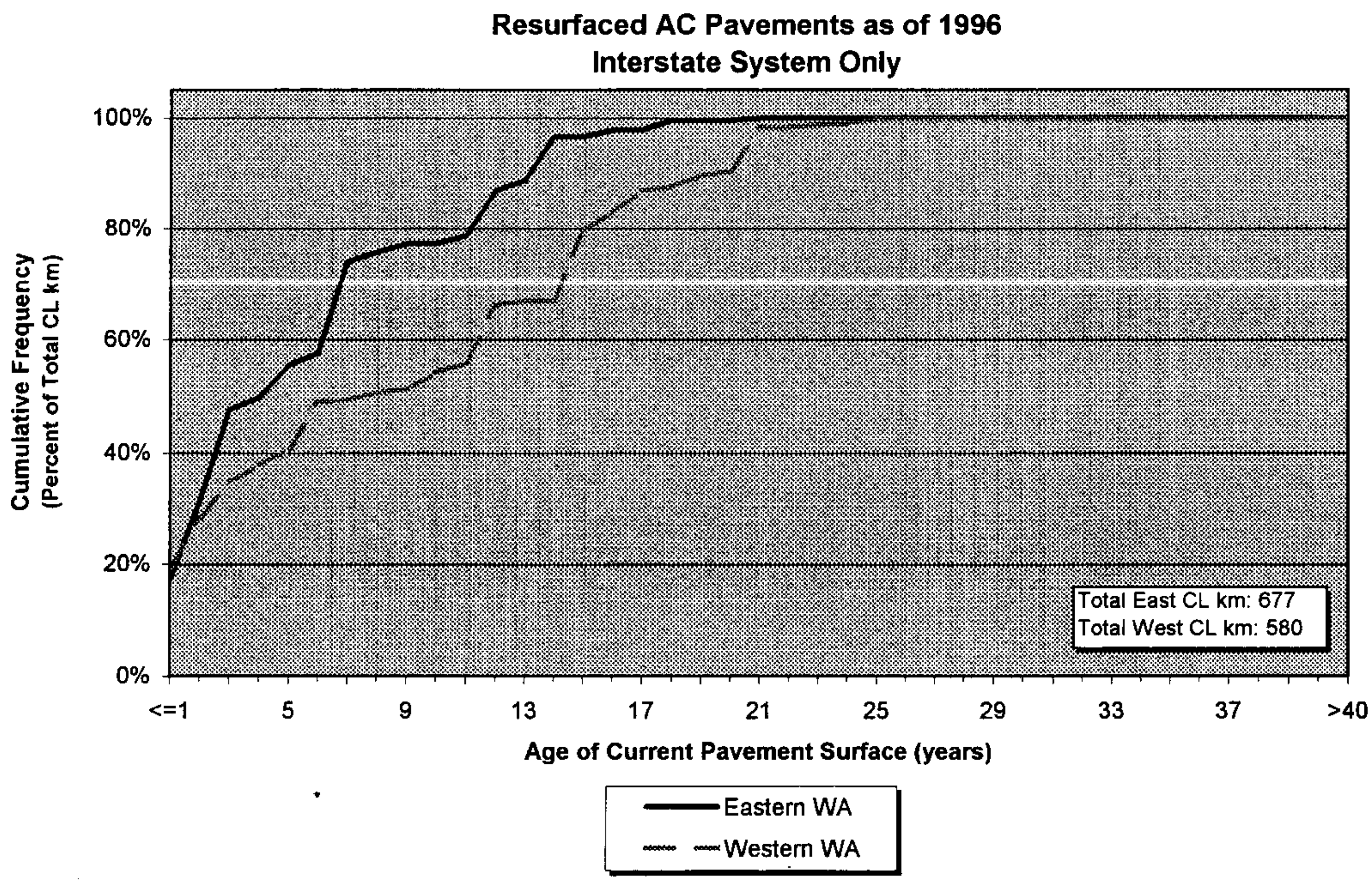


Figure B6. Age Cumulative Frequency Curve for Resurfaced AC- Interstate

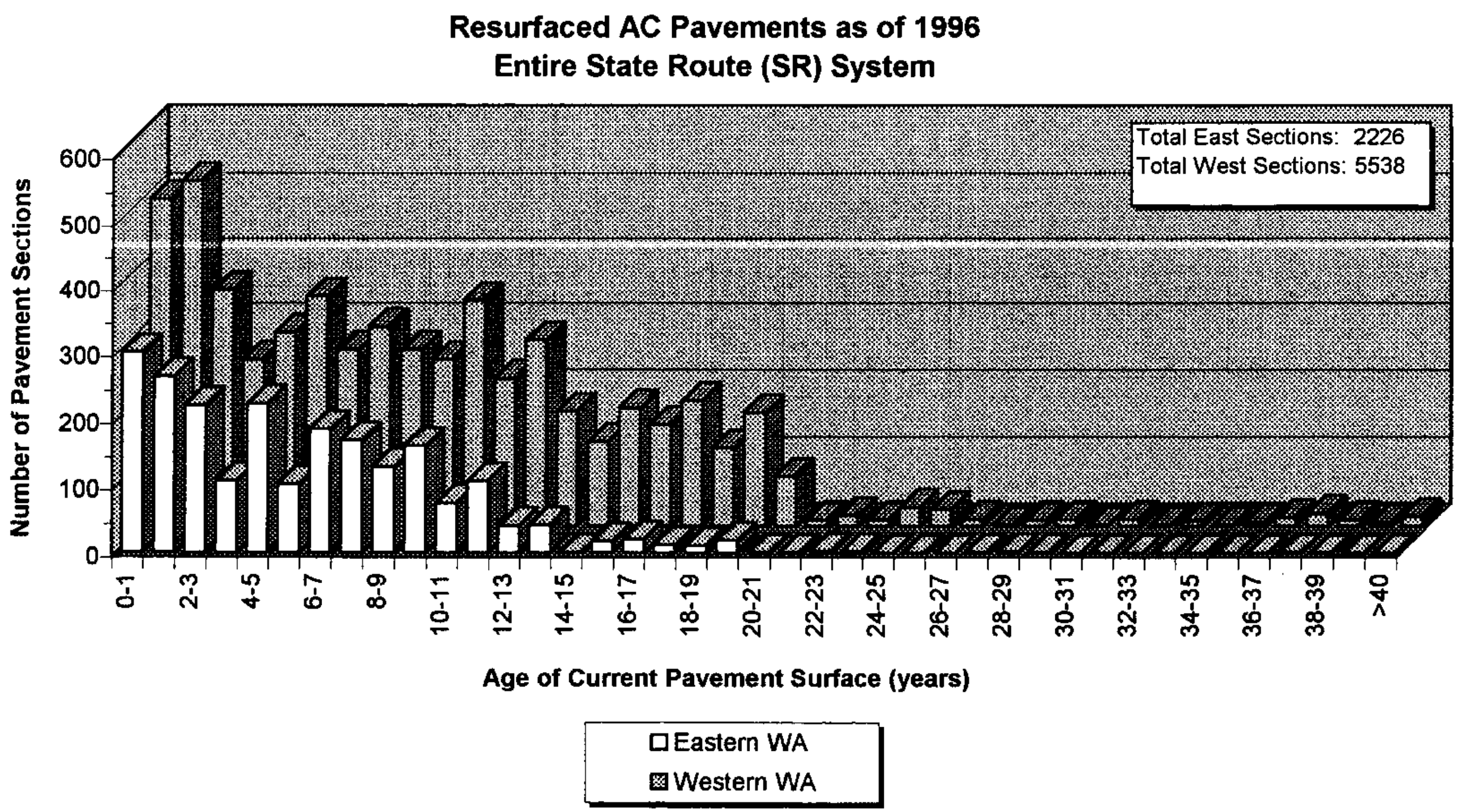


Figure B7. Age Plot for Resurfaced AC- SR System

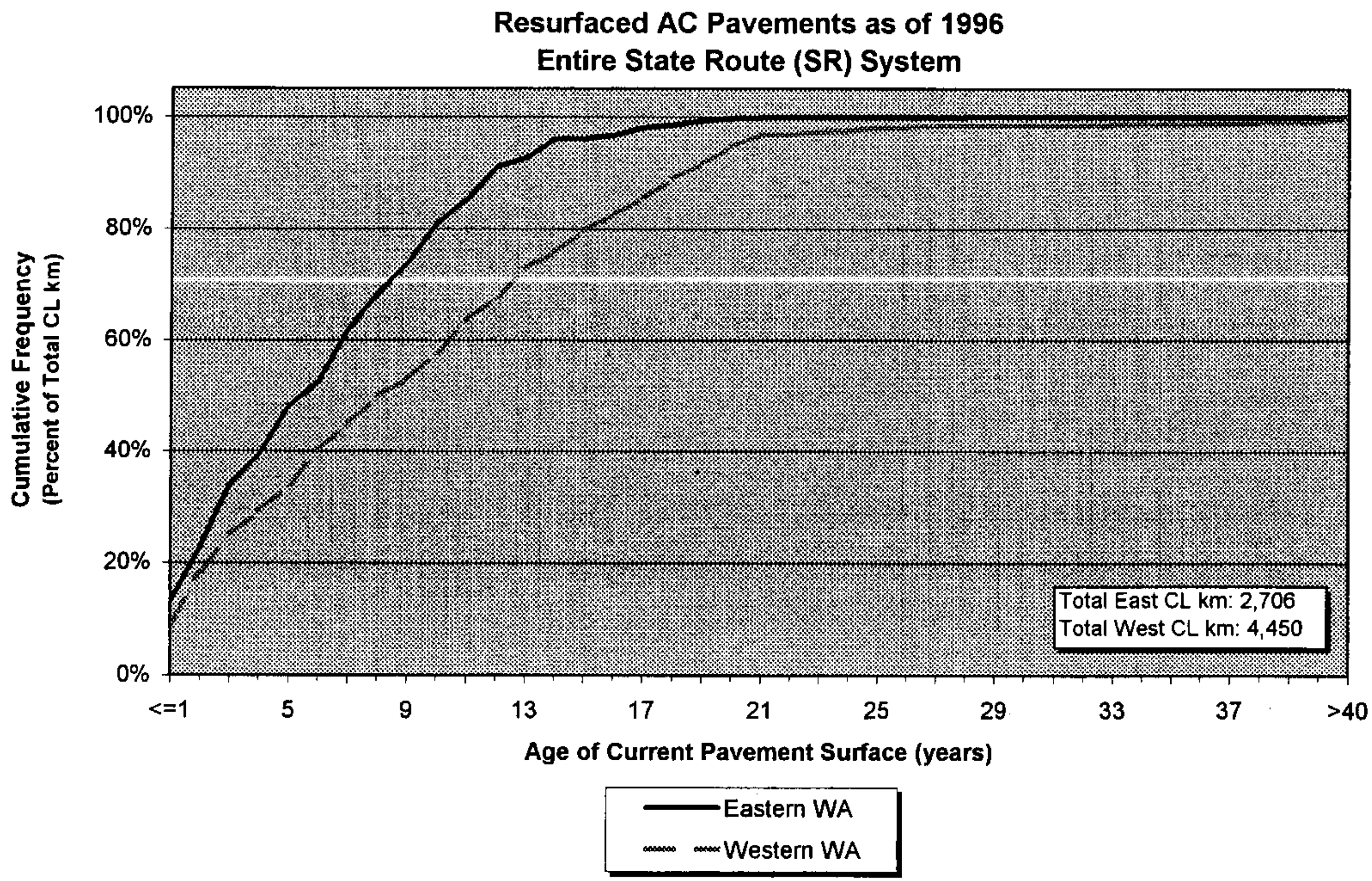


Figure B8. Age Cumulative Frequency Curve for Resurfaced AC- SR System

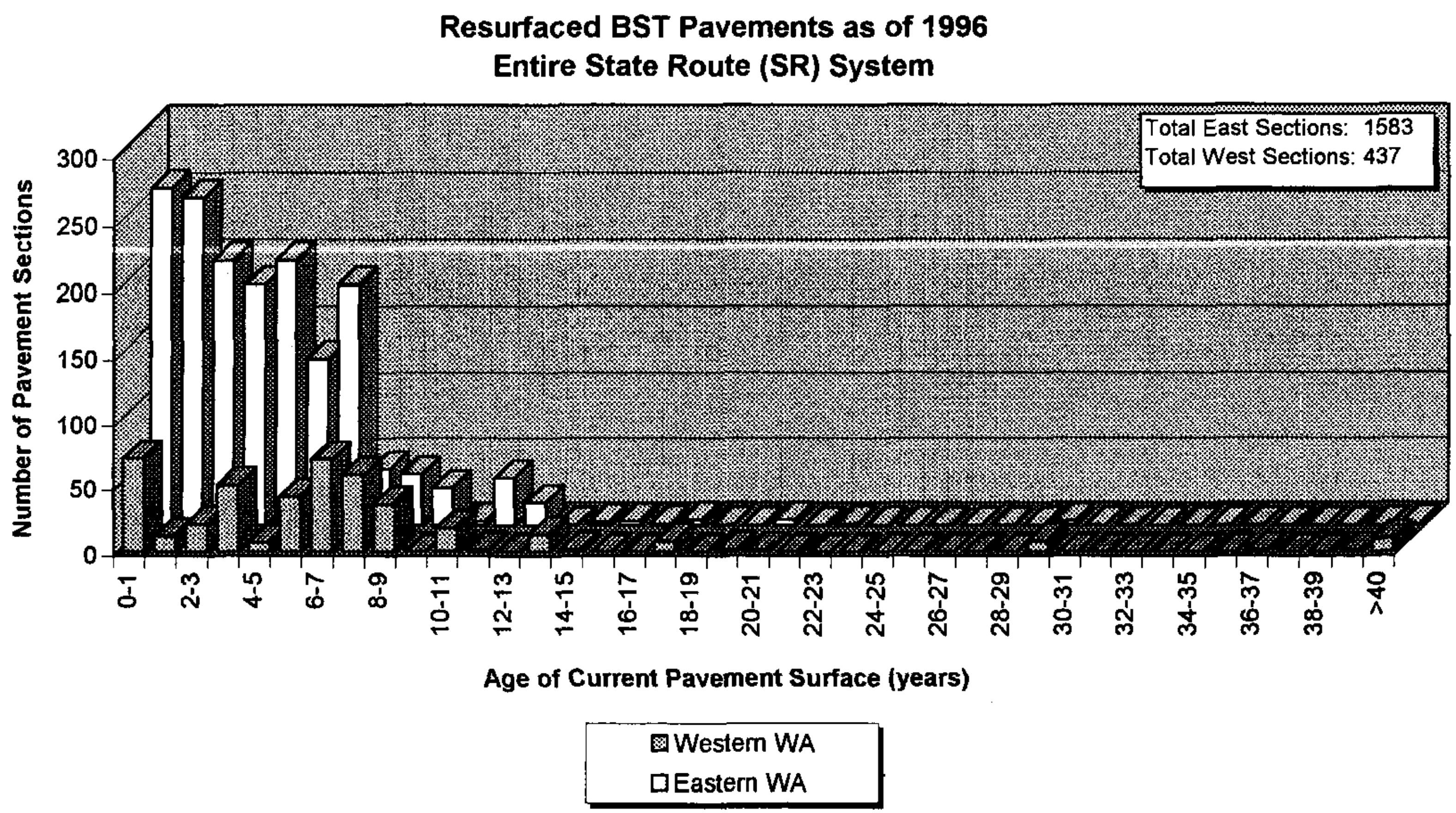


Figure B9. Age Plot for Resurfaced BST- SR System

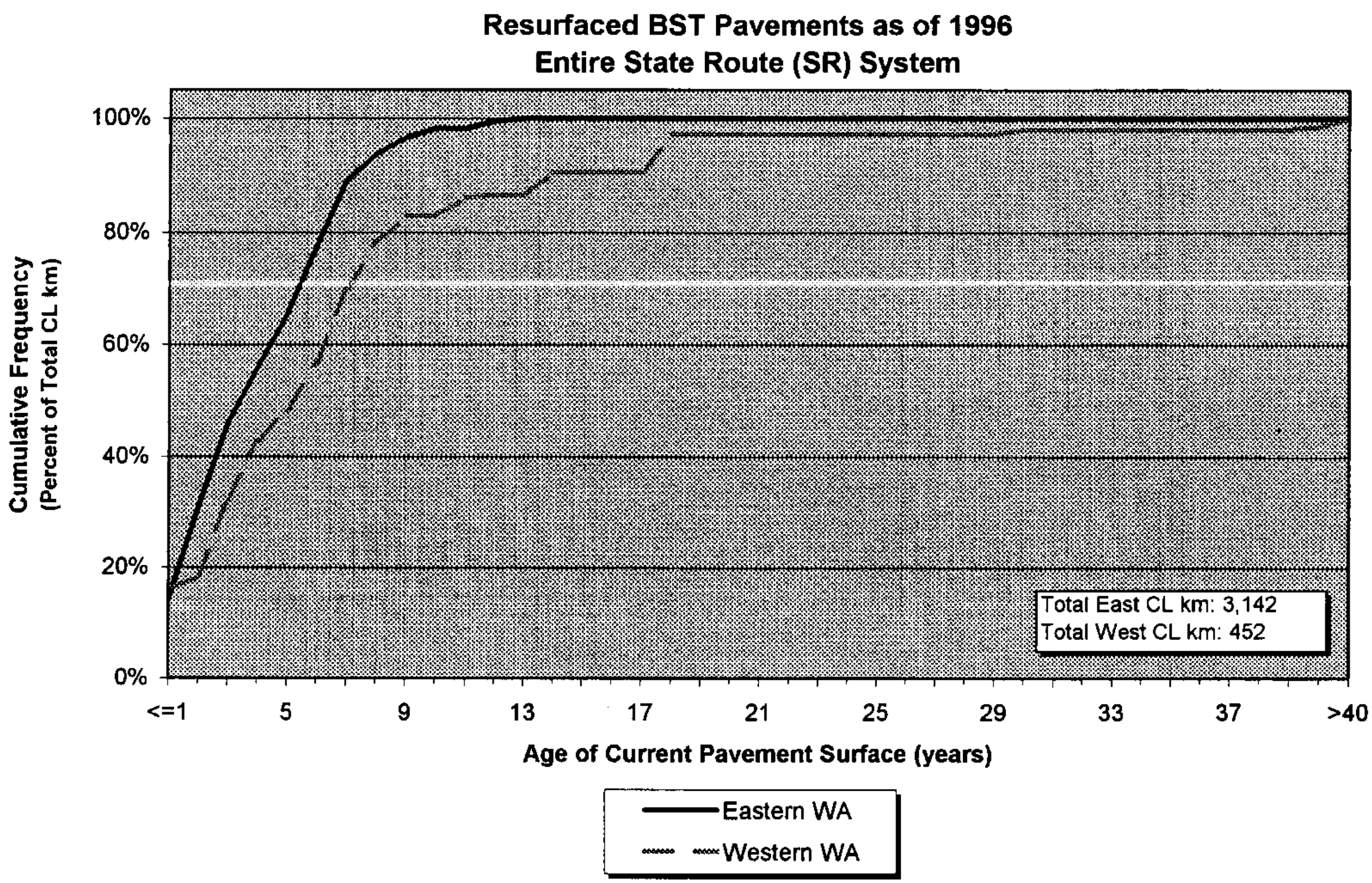


Figure B10. Age Cumulative Frequency Curve for Resurfaced BST- SR System

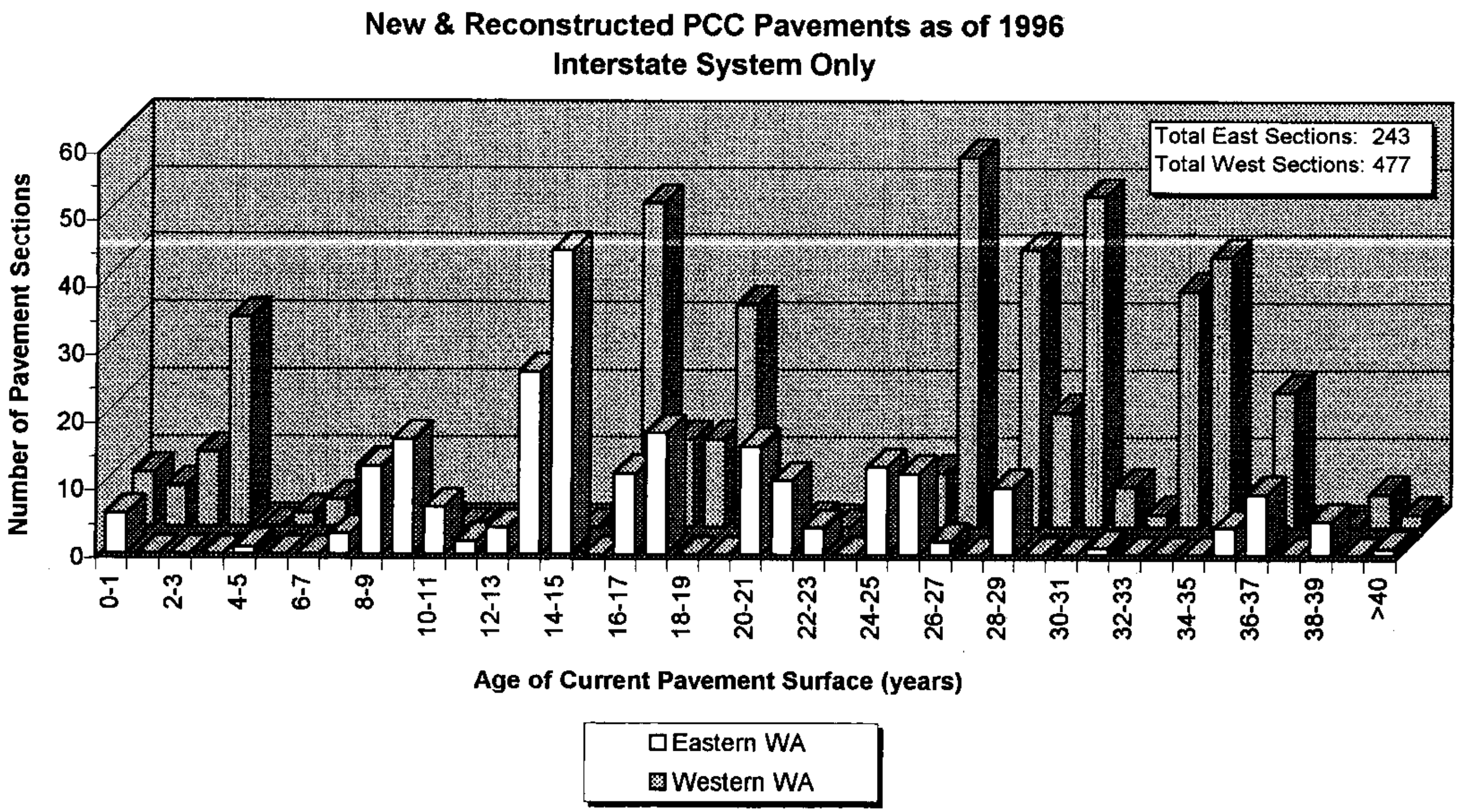


Figure B11. Age Plot for New & Reconstructed PCC- Interstate

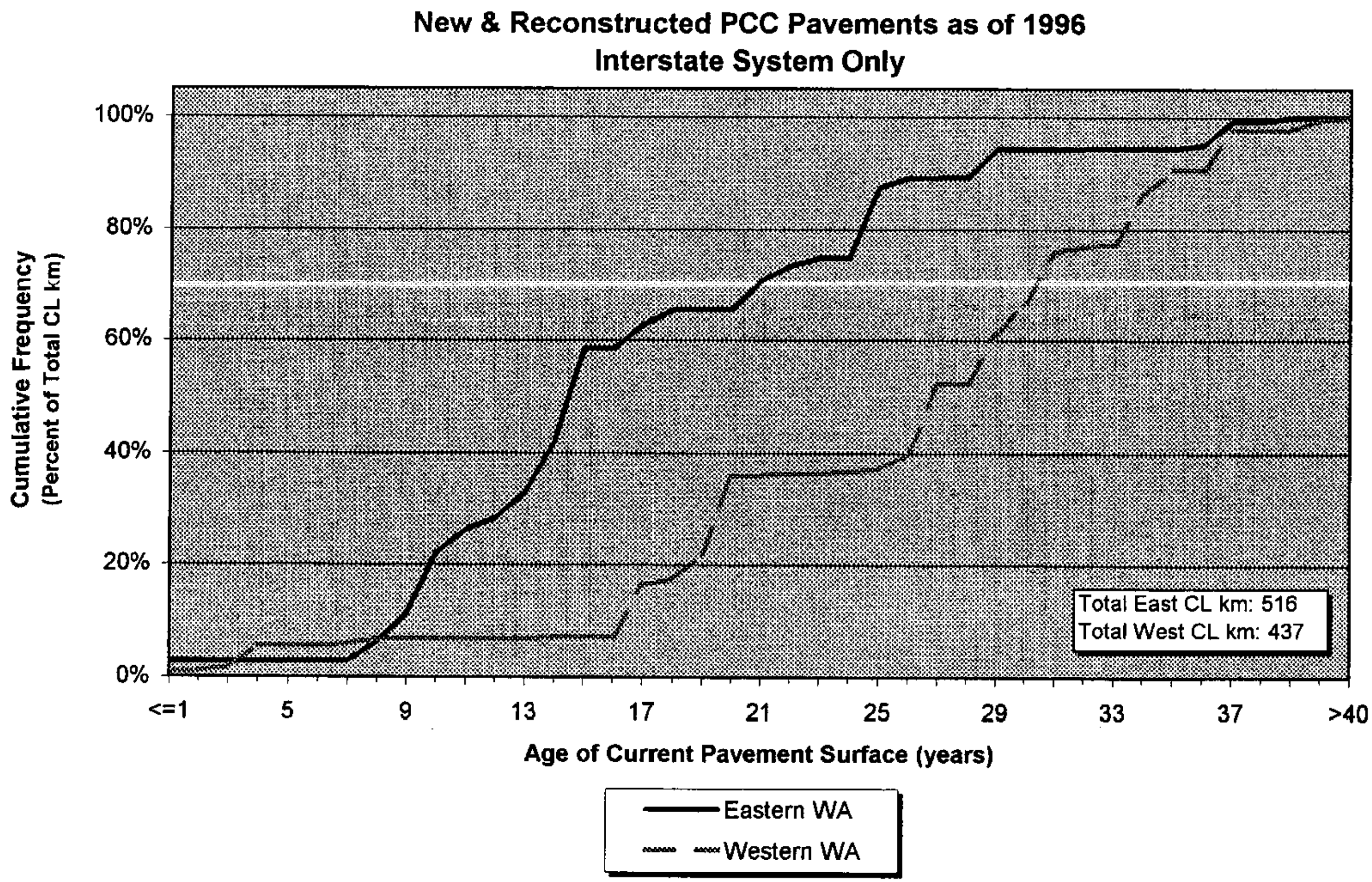


Figure B12. Age Cumulative Frequency Curve for New & Reconstructed PCC- Interstate

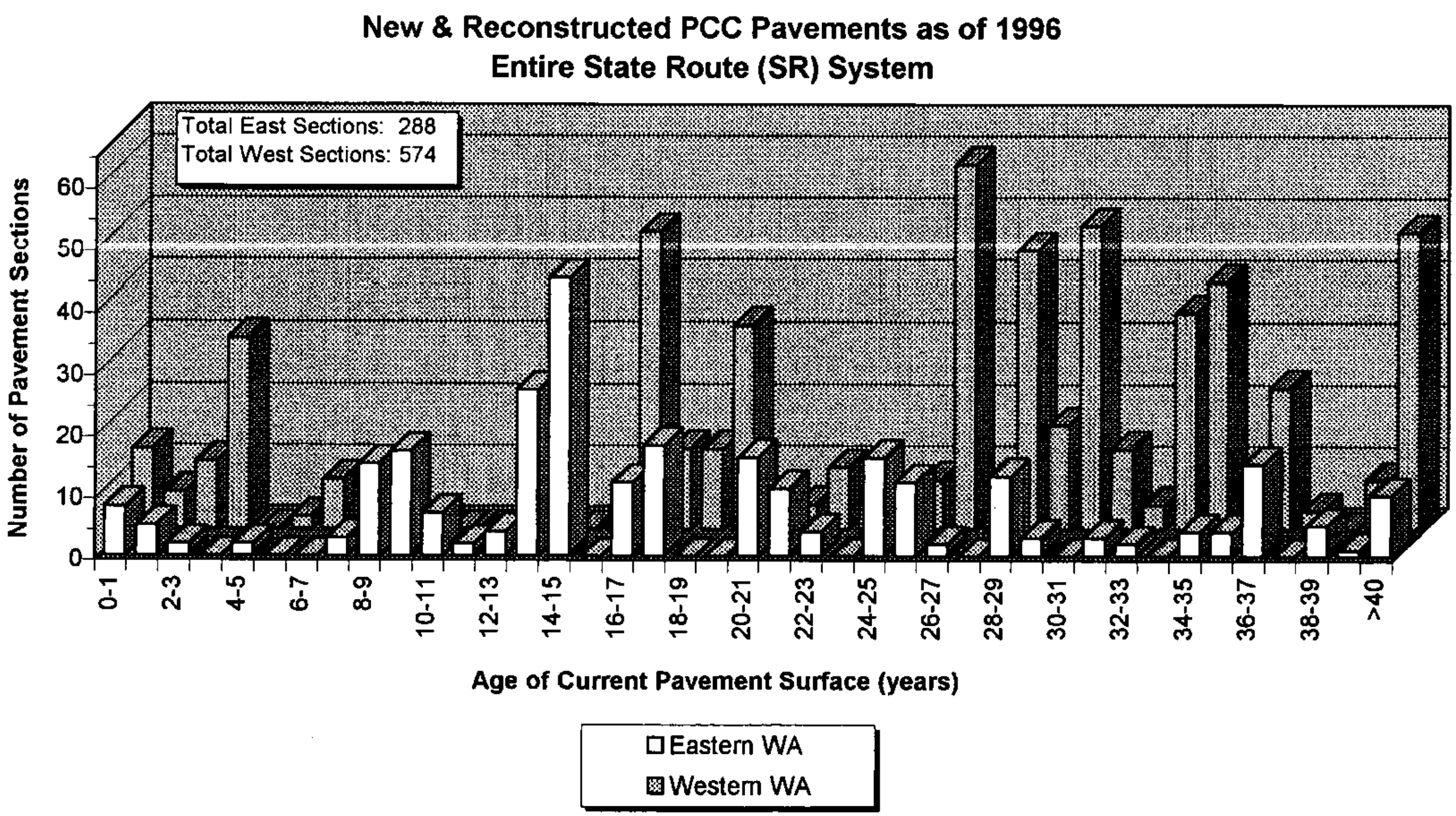


Figure B13. Age Plot for New & Reconstructed PCC- SR System

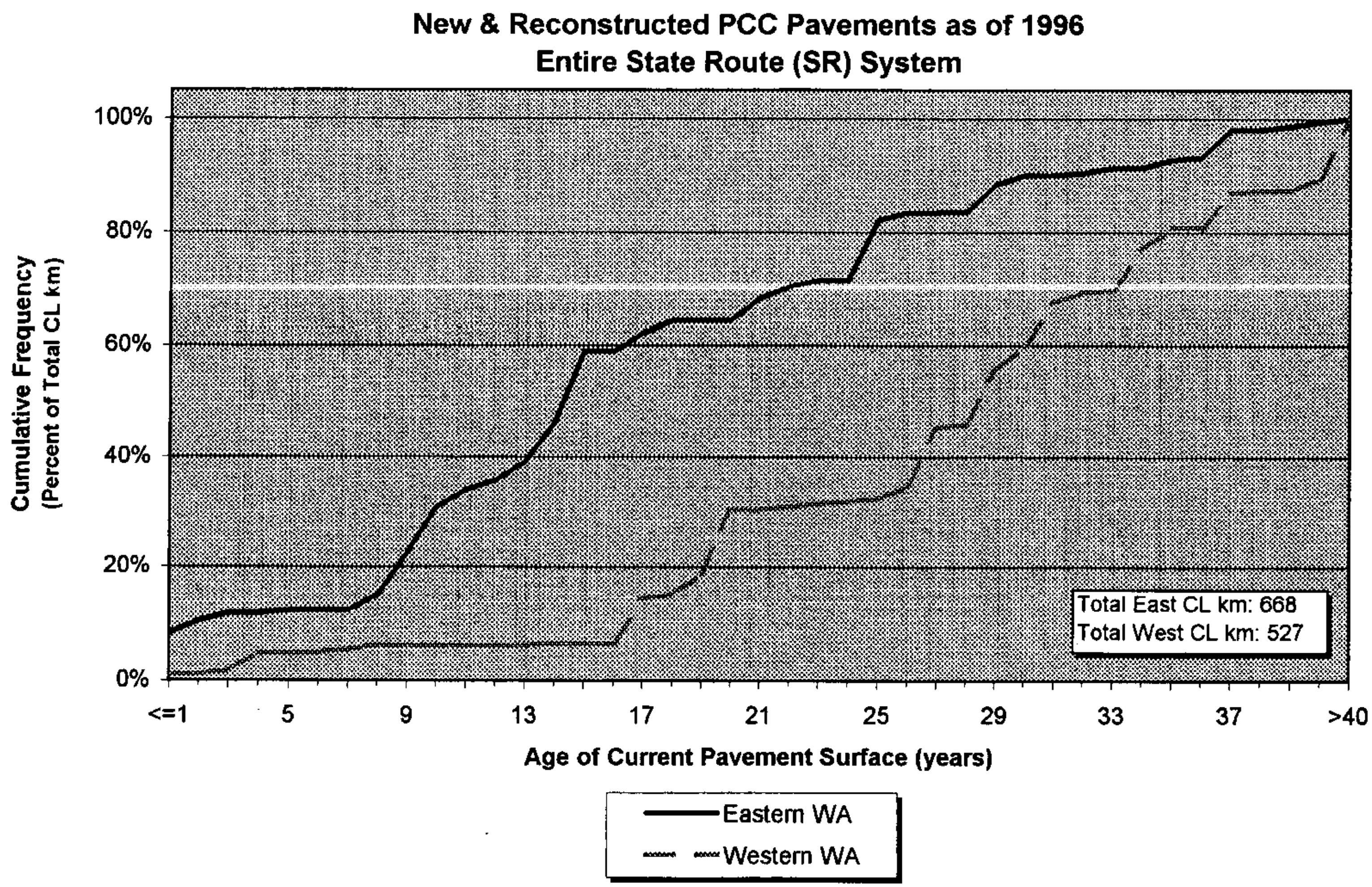


Figure B14. Age Cumulative Frequency Curve for New & Reconstructed PCC- SR System

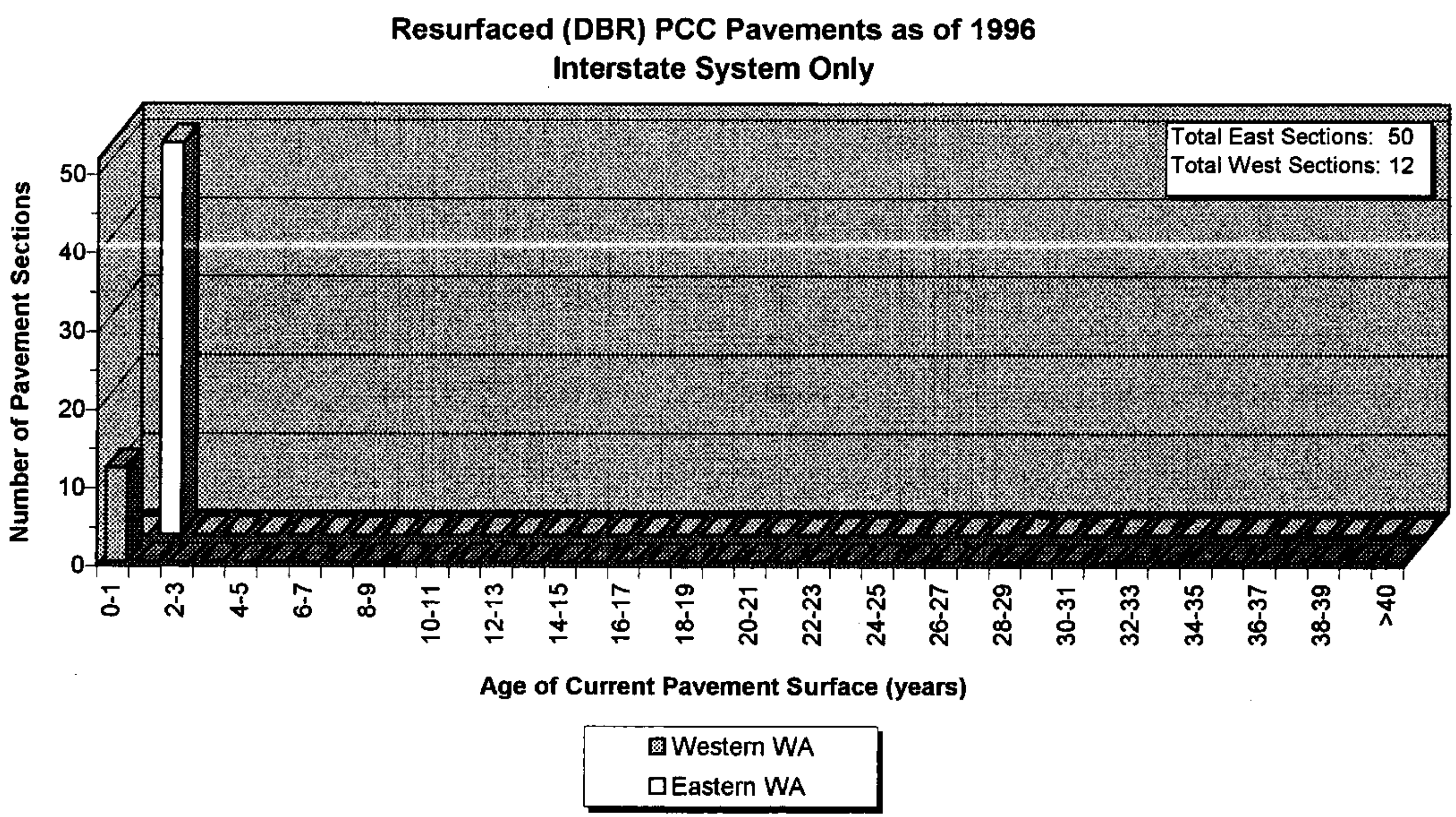


Figure B15. Age Plot for Resurfaced PCC- Interstate

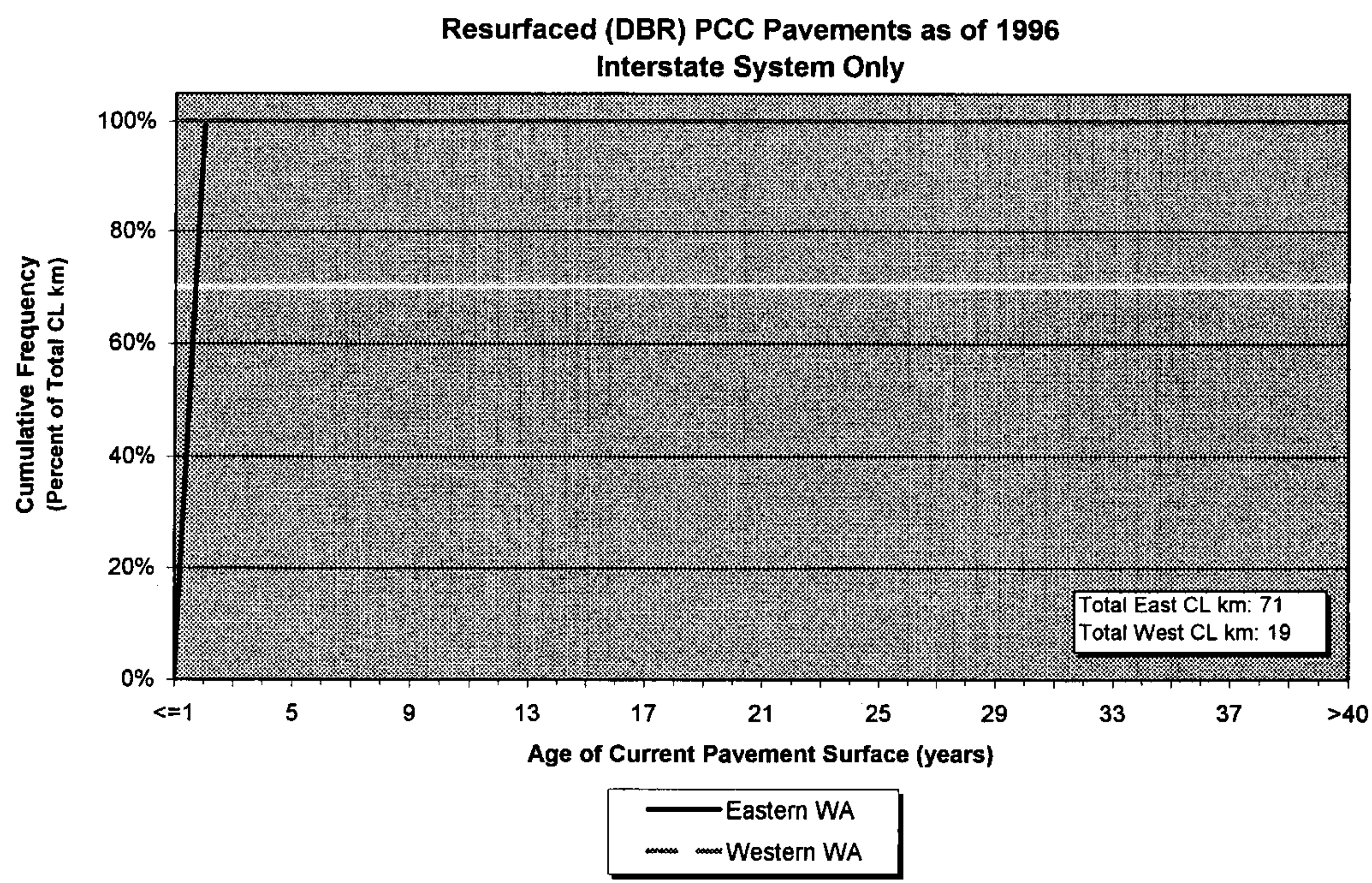


Figure B16. Age Cumulative Frequency Curve for Resurfaced PCC- Interstate

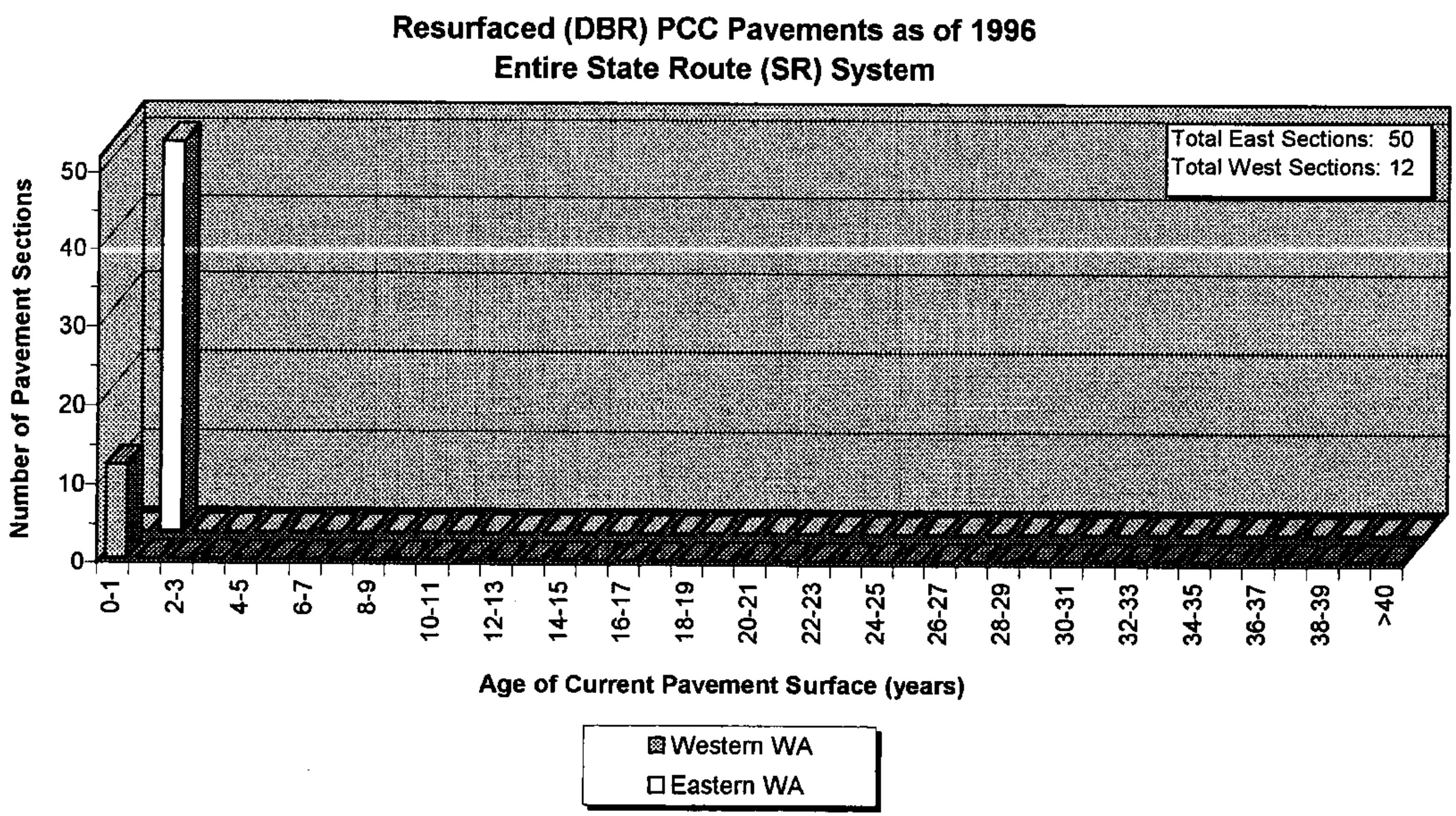


Figure B17. Age Plot for Resurfaced PCC- SR System

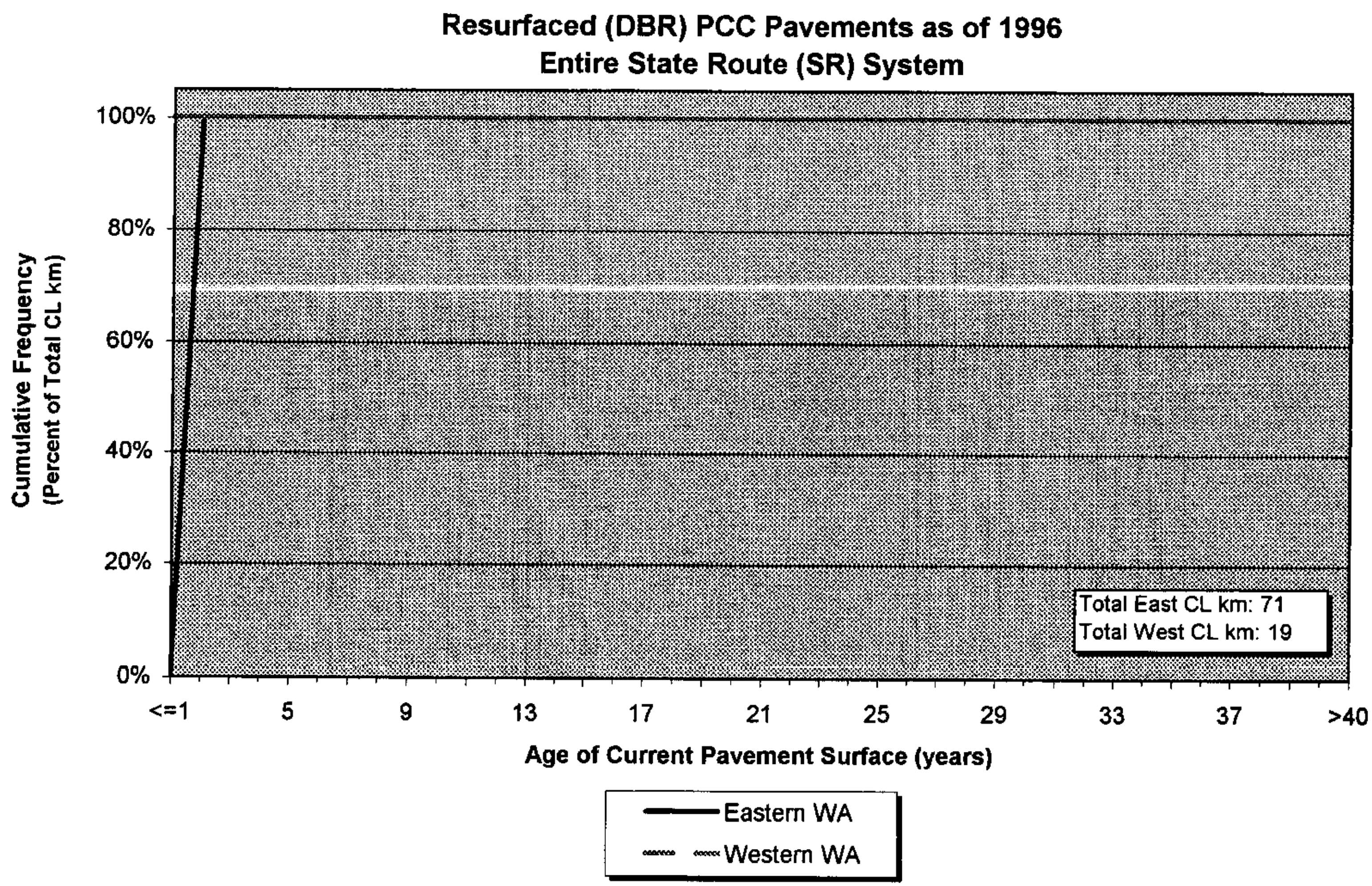


Figure B18. Age Cumulative Frequency Curve for Resurfaced PCC- SR System

APPENDIX C

PSC Frequency and Cumulative Frequency Plots

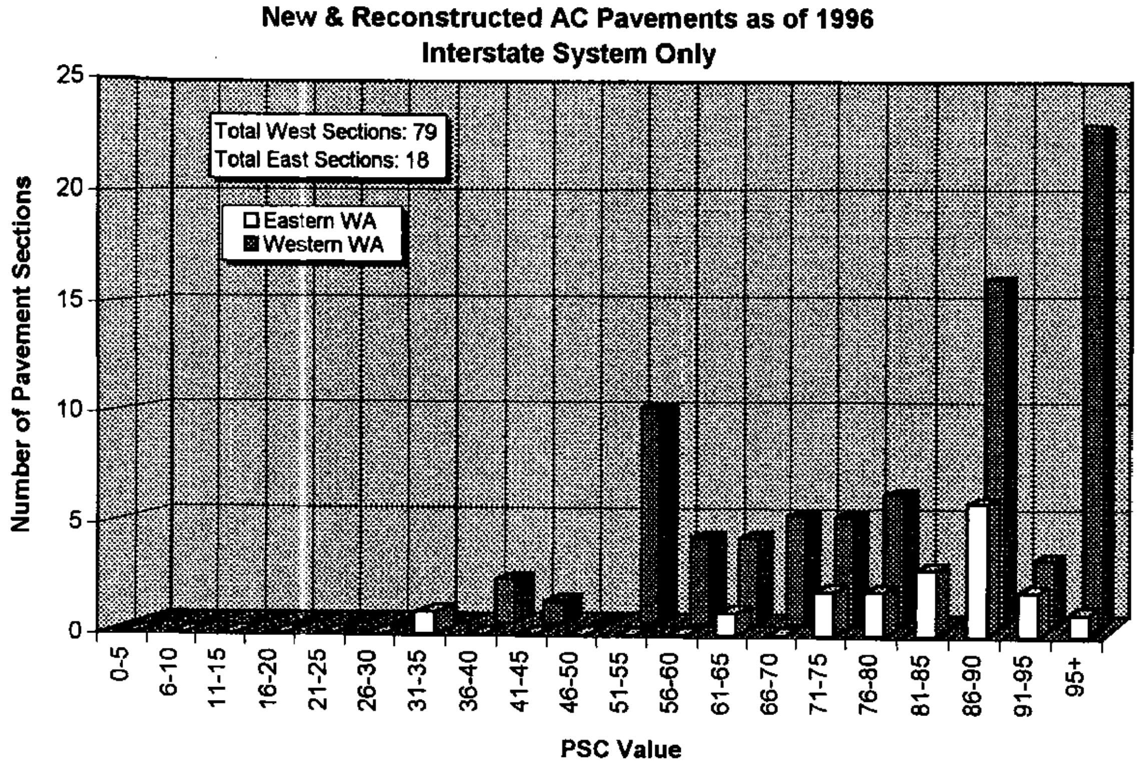


Figure C1. PSC Plot for New & Reconstructed AC- Interstate

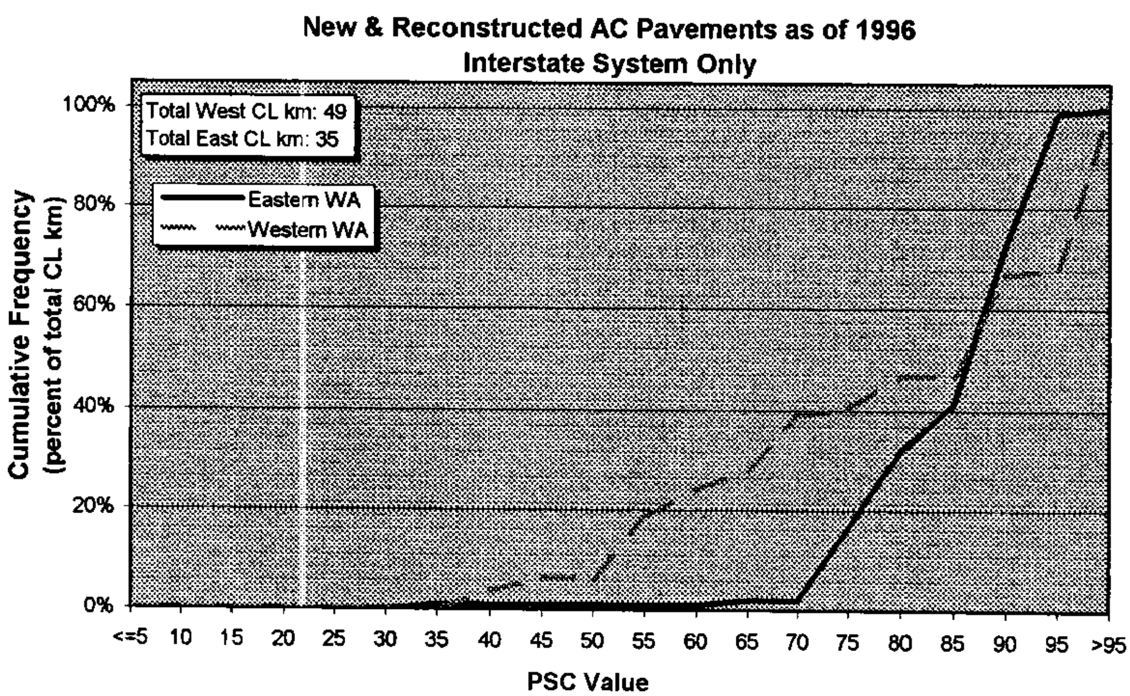


Figure C2. PSC Cumulative Frequency Curve, New/Reconstructed AC- Interstate

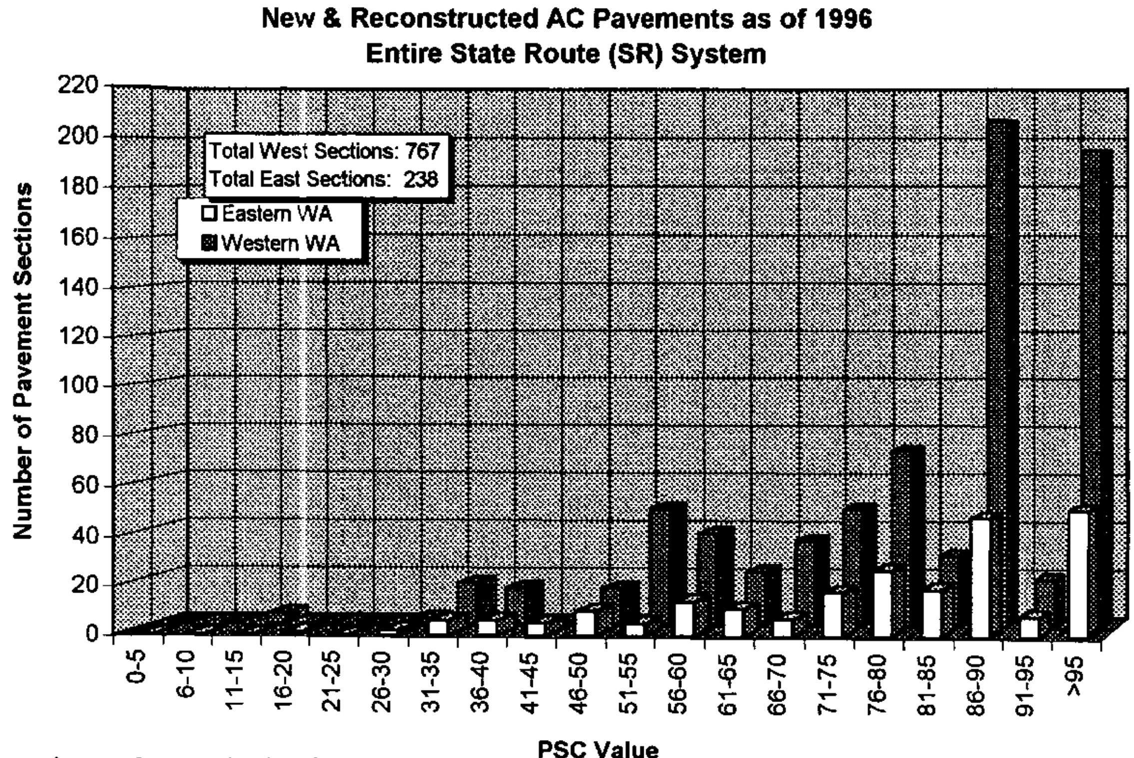


Figure C3. PSC Plot for New & Reconstructed AC- SR System

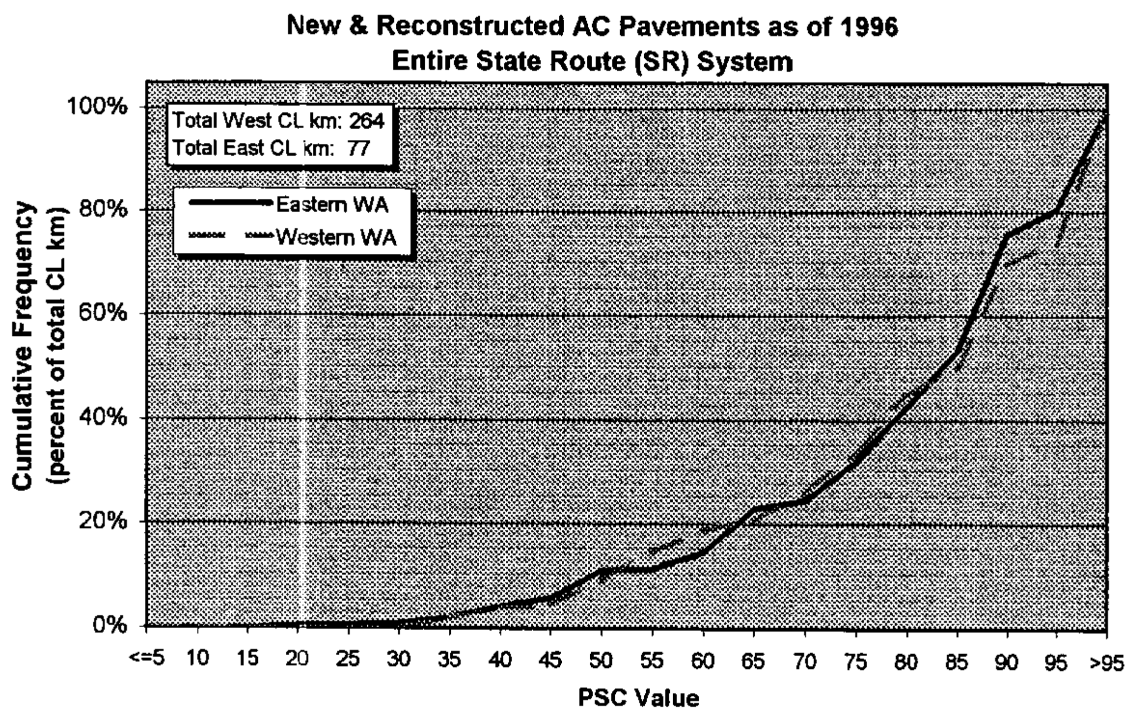


Figure C4. PSC Cumulative Frequency for New/Reconstructed AC- SR System

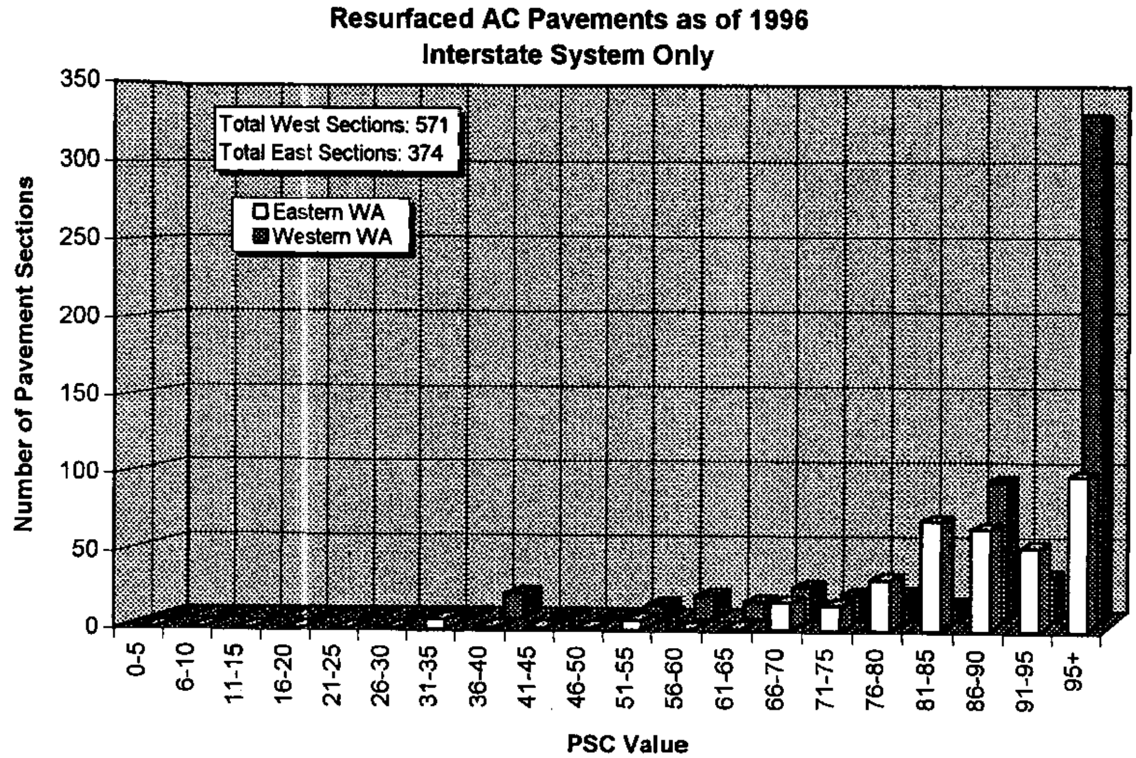


Figure C5. PSC Plot for Resurfaced AC Pavements- Interstate System

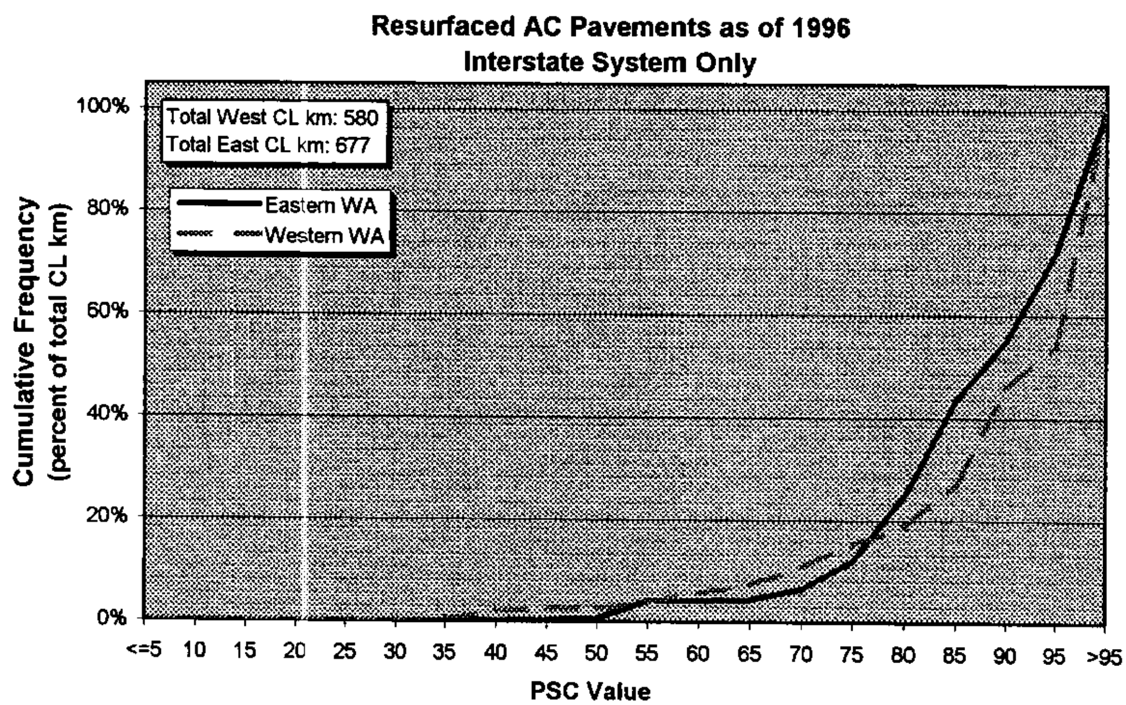


Figure C6. PSC Cumulative Frequency Curve for Resurfaced AC - Interstate

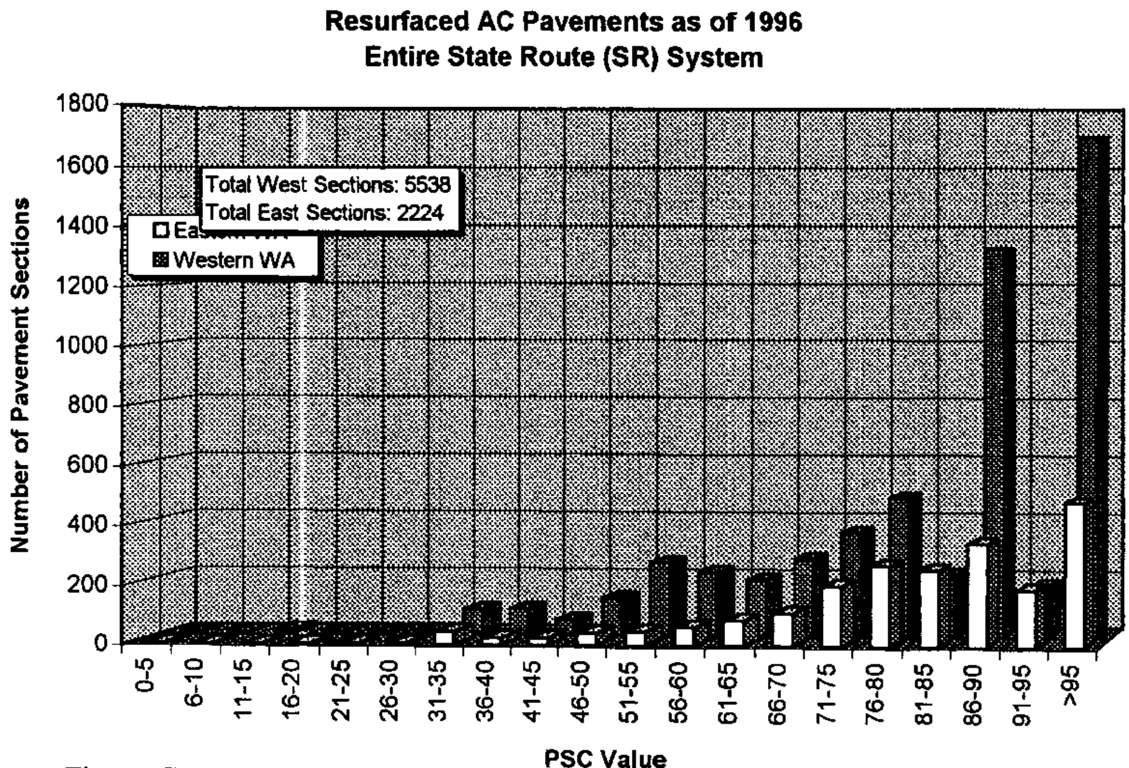


Figure C7. PSC Plot for Resurfaced AC Pavements- SR System

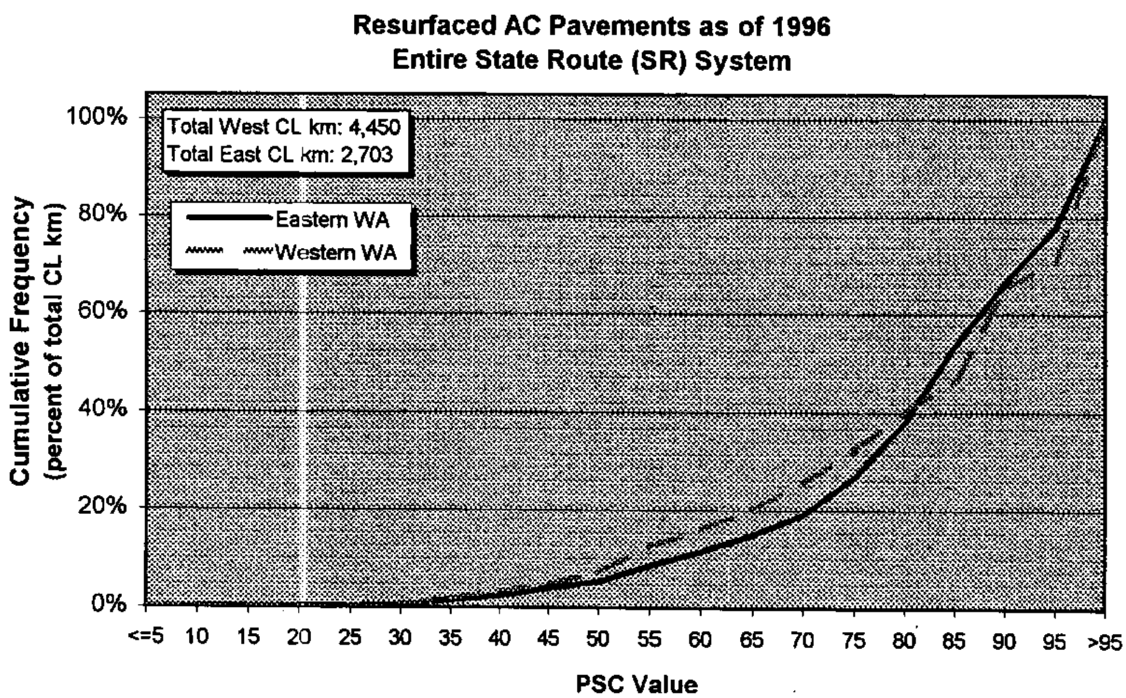


Figure C8. PSC Cumulative Frequency Curve for Resurfaced AC- SR System

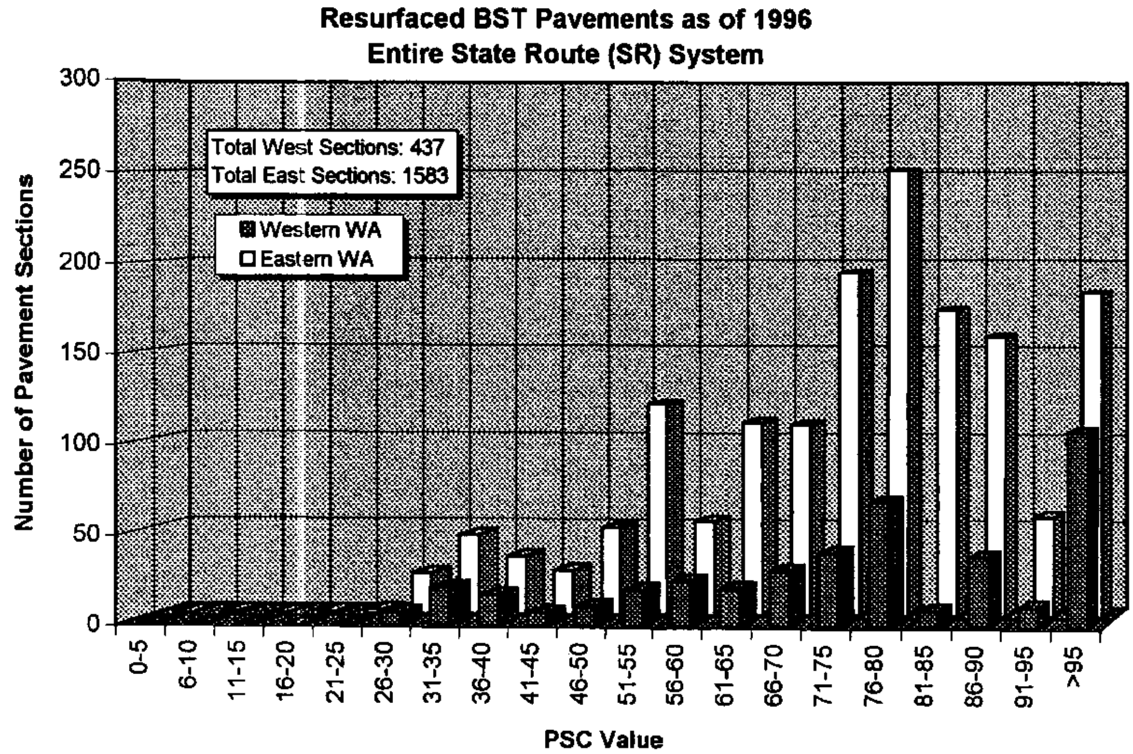


Figure C9. PSC Plot for Resurfaced BSTs- SR System

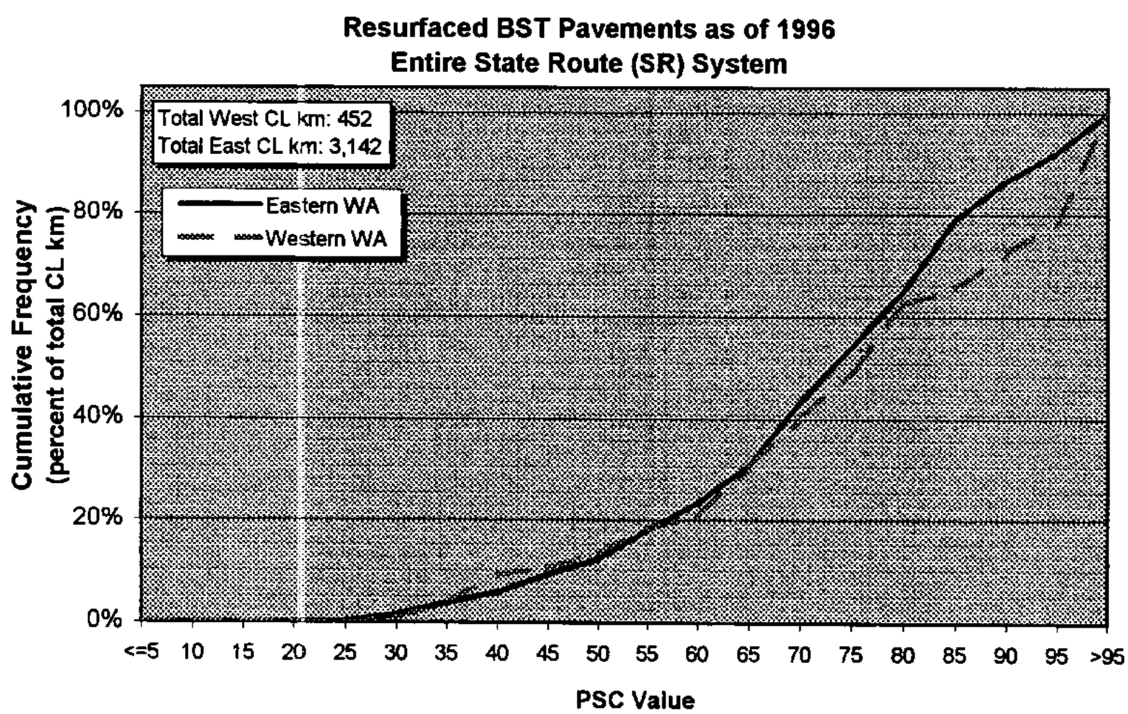


Figure C10. PSC Cumulative Freauncv Curve for Resurfaced BSTs- SR Svstem

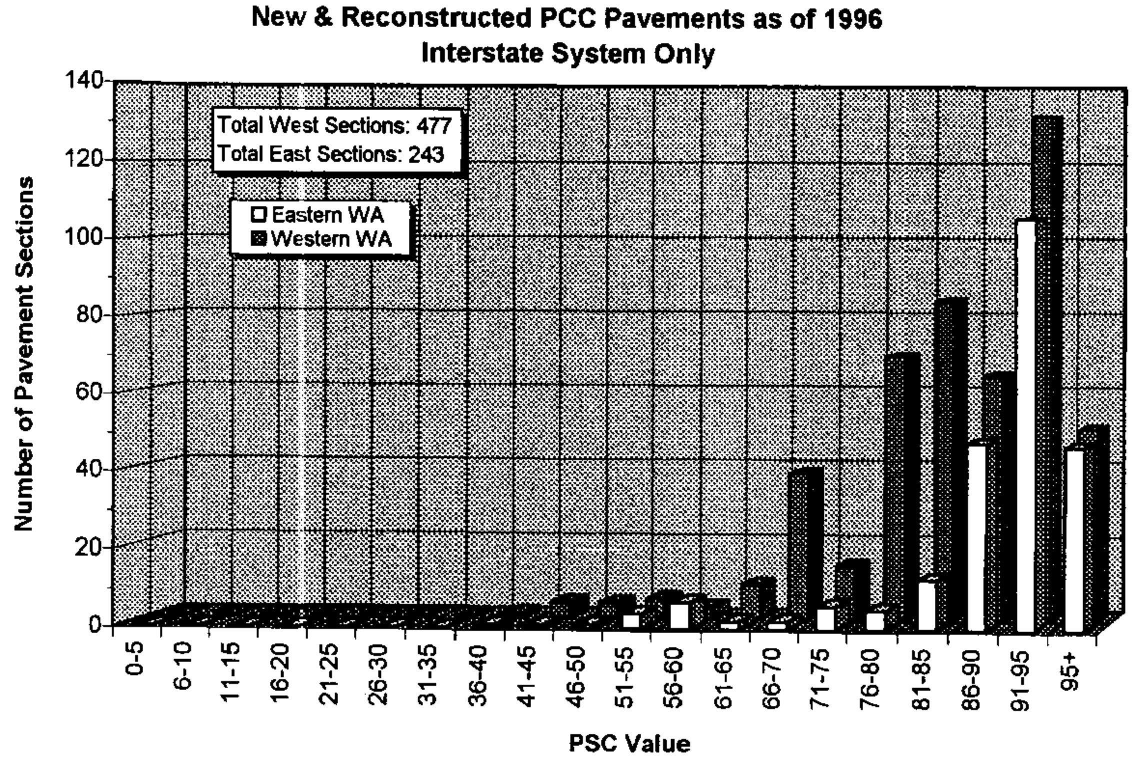


Figure C11. PSC Plot for New & Reconstructed PCC- Interstate

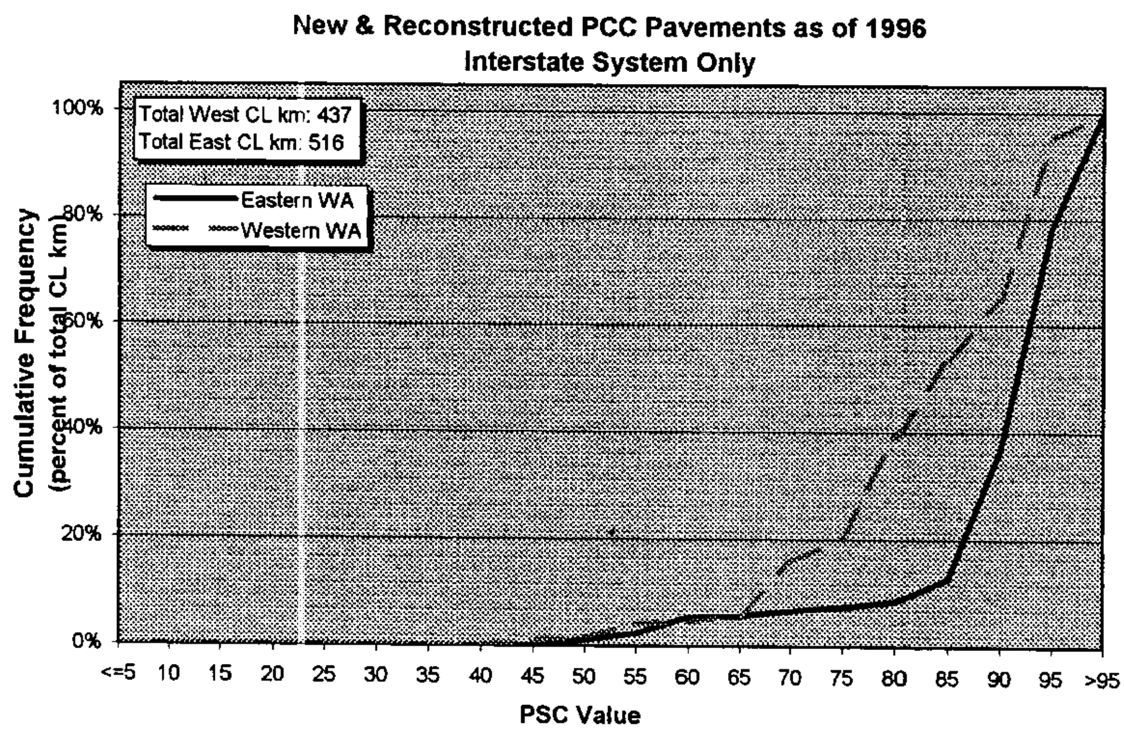


Figure C12. PSC Cumulative Frequency Curve, New/Reconstructed PCC- Interstate

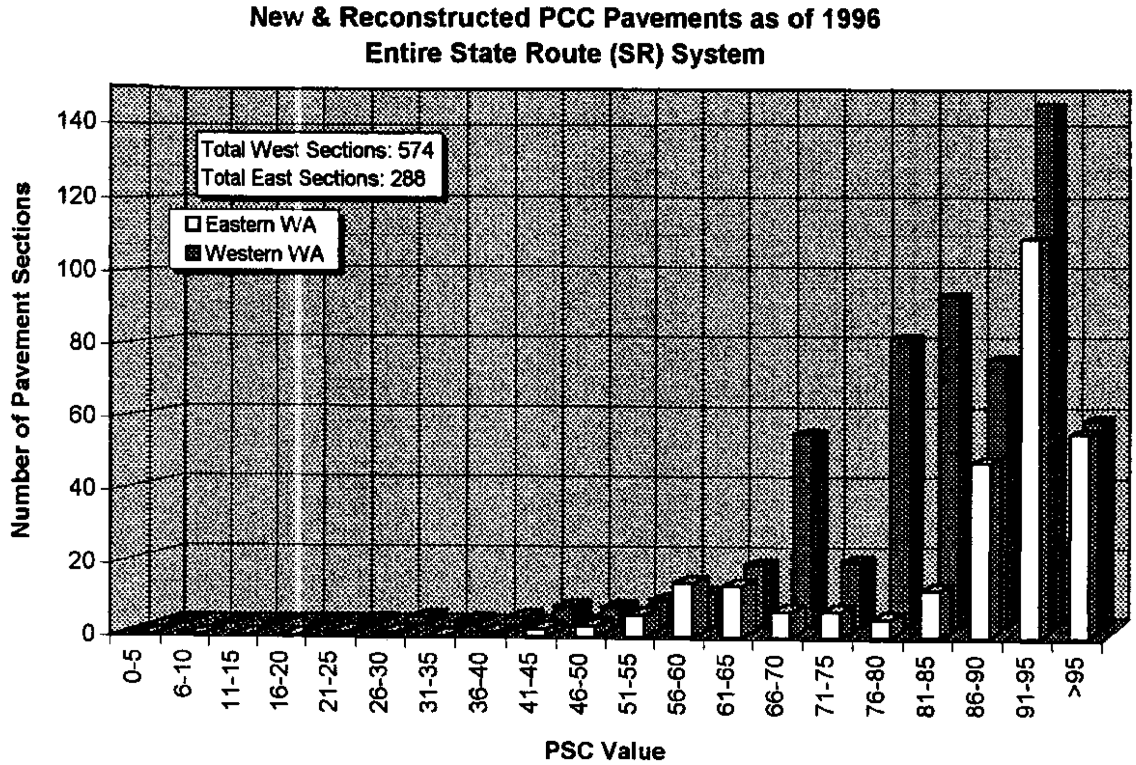


Figure C13. PSC Plot for New & Reconstructed PCC - SR System

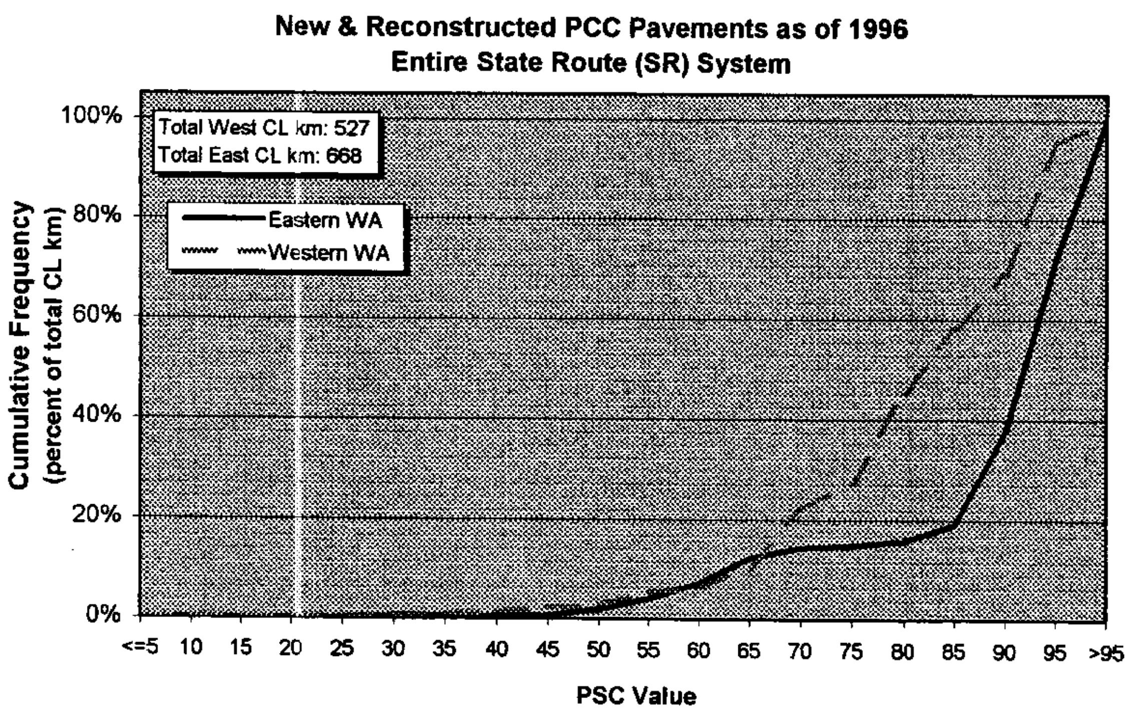


Figure C14. PSC Cumulative Freq. Curve for New/Reconstructed PCC- SR System

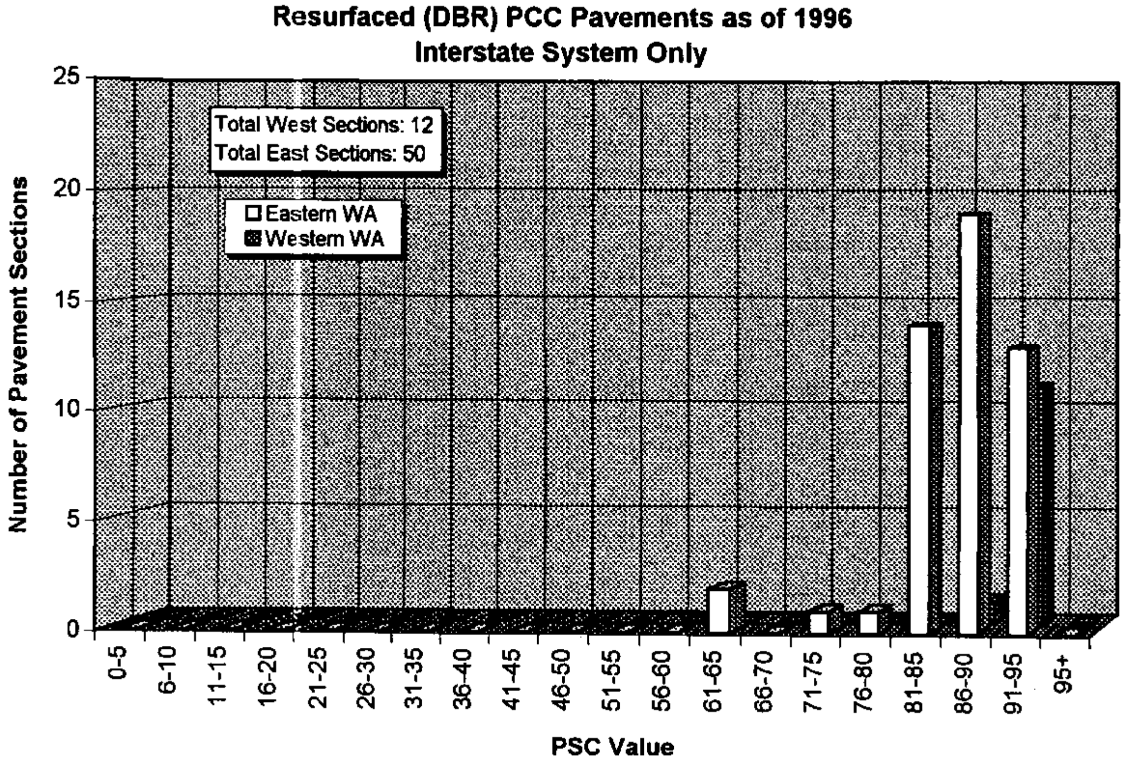


Figure C15. PSC Plot for Resurfaced PCC Pavements- Interstate

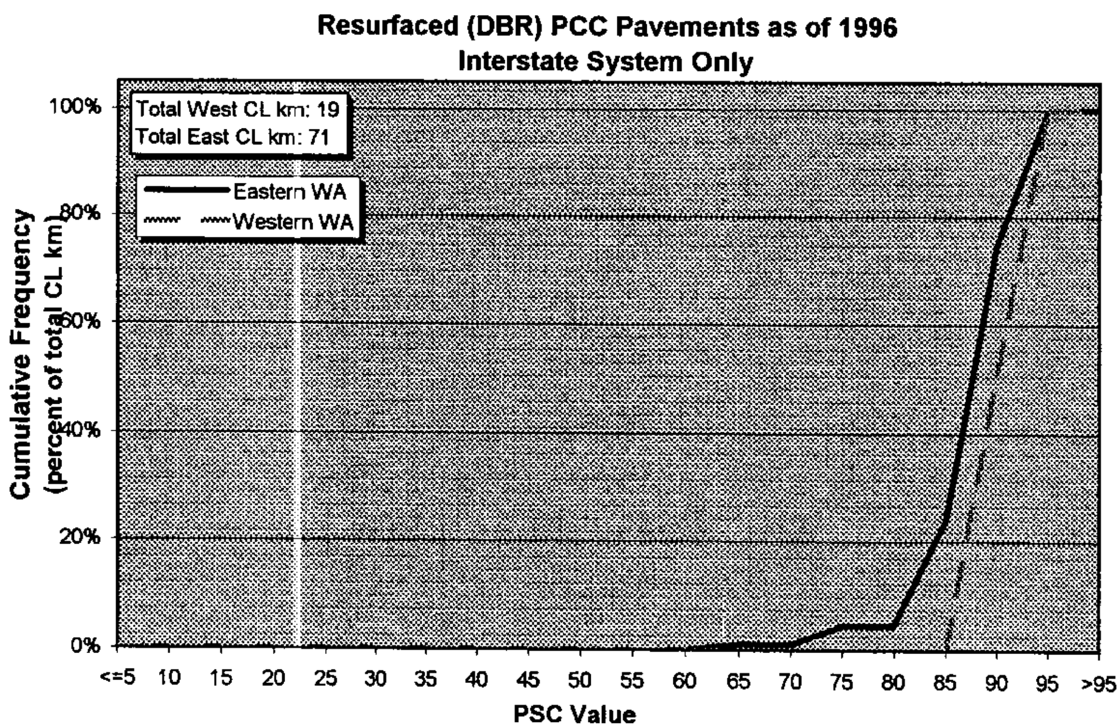


Figure C16. PSC Cumulative Frequency Curve for Resurfaced PCC- Interstate

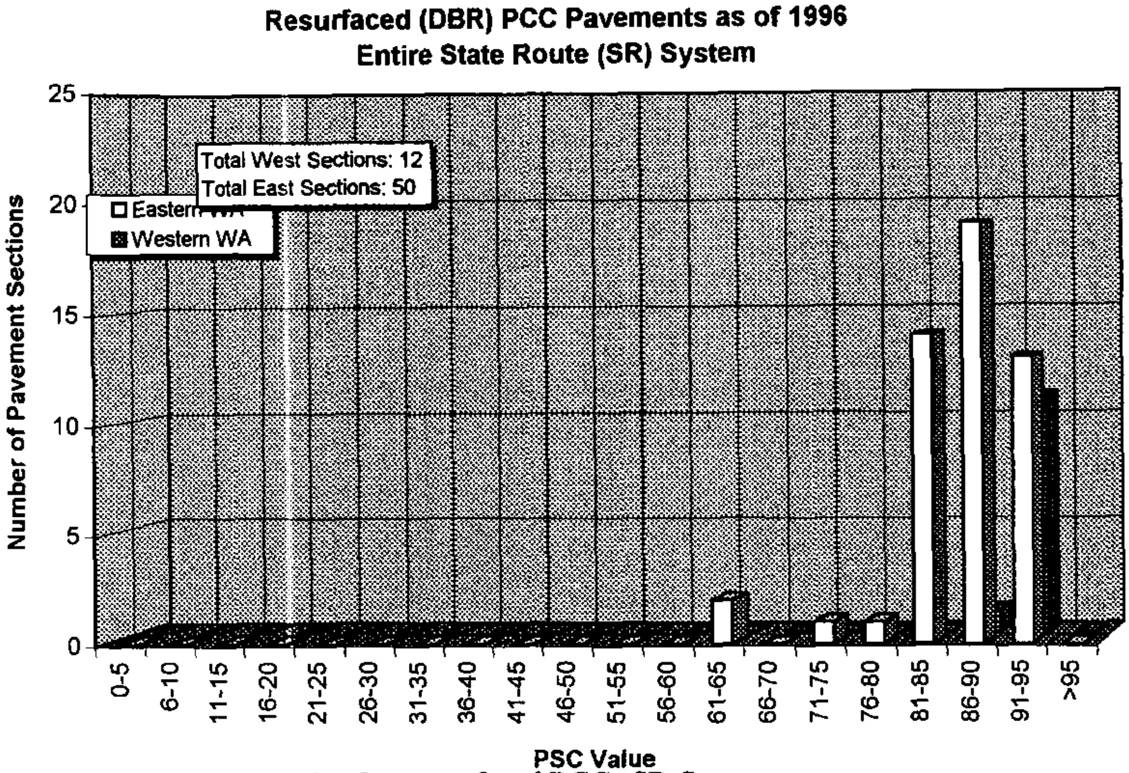


Figure C17. PSC Plot for Resurfaced PCC- SR System

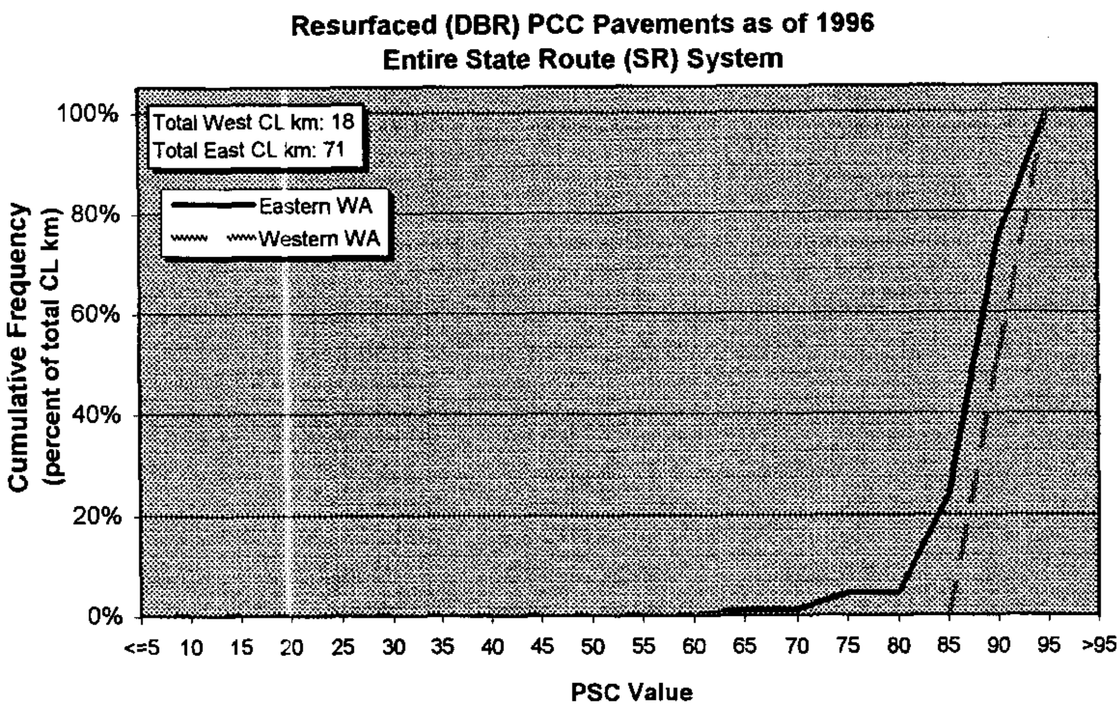


Figure C18. PSC Cumulative Frequency Curve for Resurfaced PCC- SR System

APPENDIX D

ESAL Frequency and Cumulative Frequency Plots

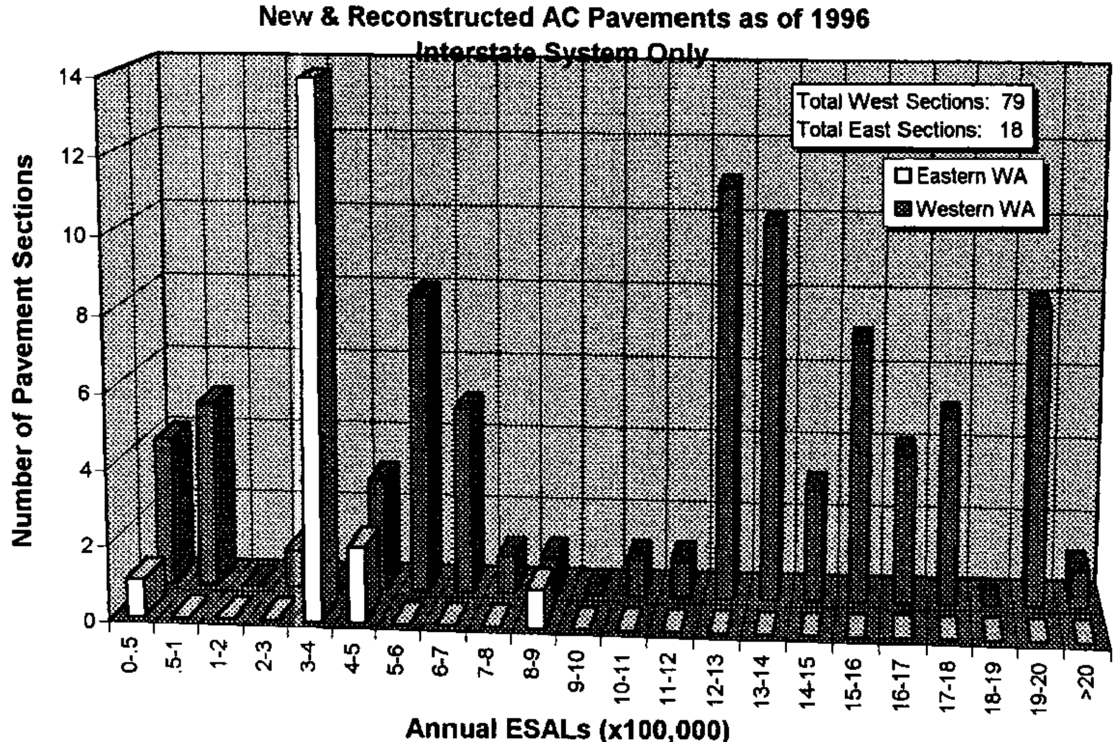


Figure D1. ESAL Plot for New & Reconstructed AC - Interstate

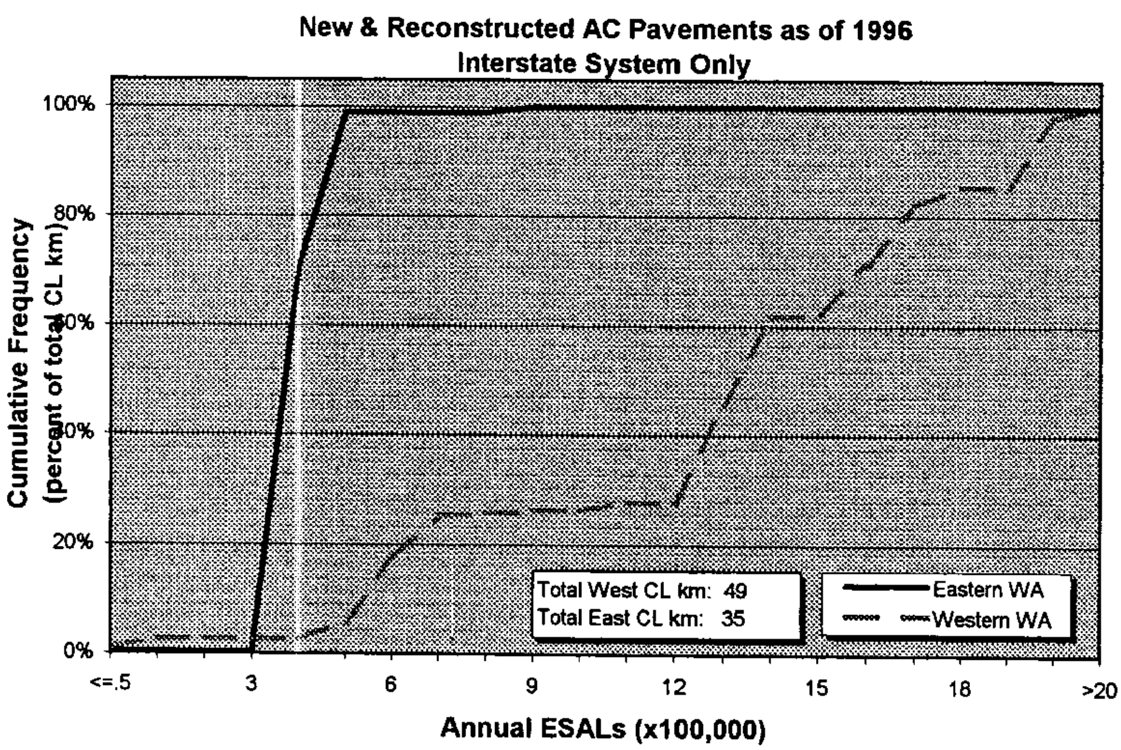


Figure D2. ESAL Cumulative Freq. Curve for New & Reconstructed AC - Interstate

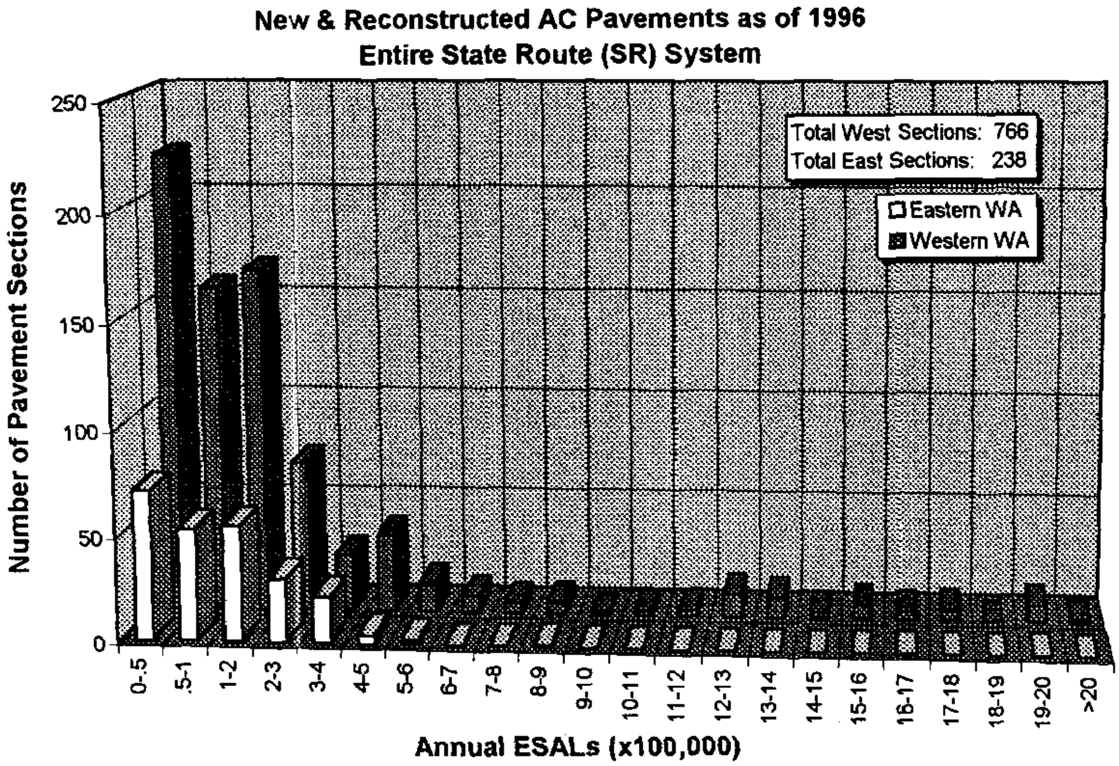


Figure D3. ESAL Plot for New & Reconstructed AC- SR System

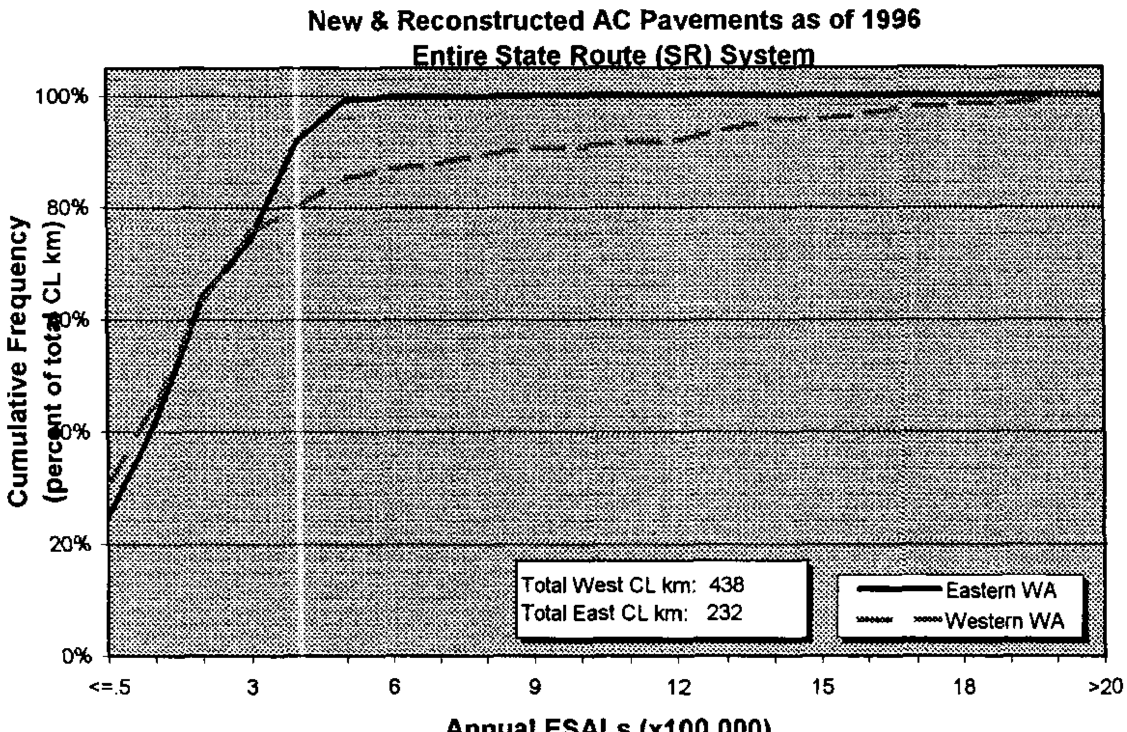


Figure D4. ESAL Cumulative Freq. Curve for New/Reconstructed AC- SR System

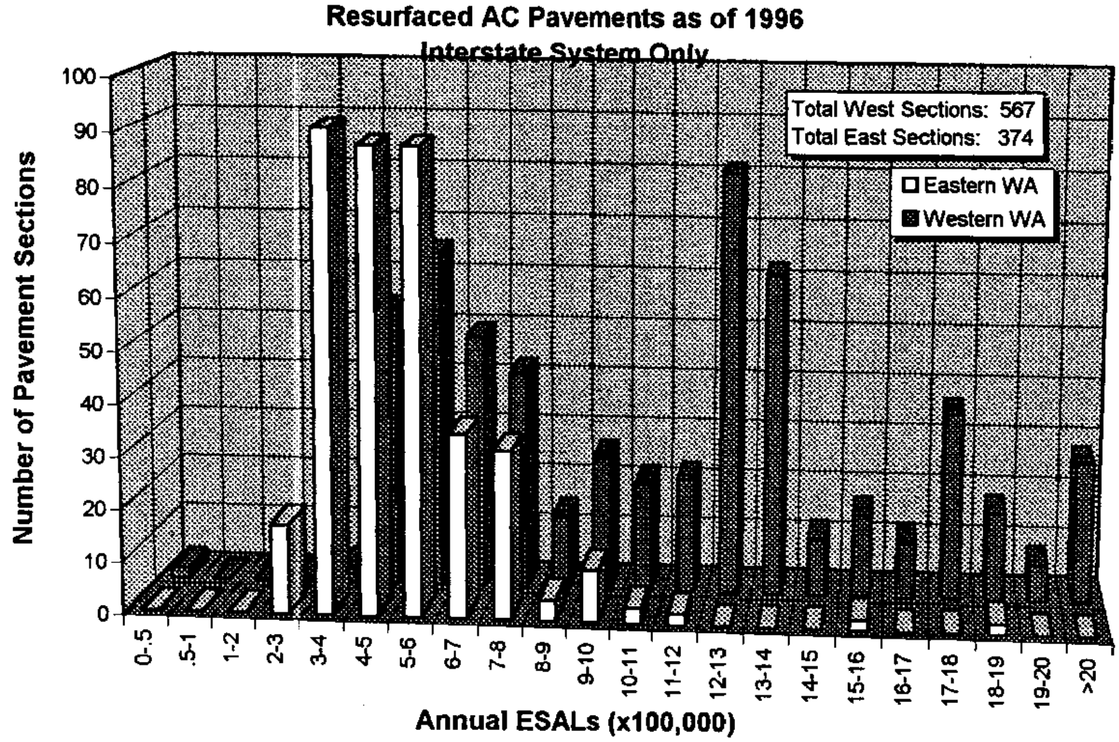


Figure D5. ESAL Plot for Resurfaced AC Pavements- Interstate

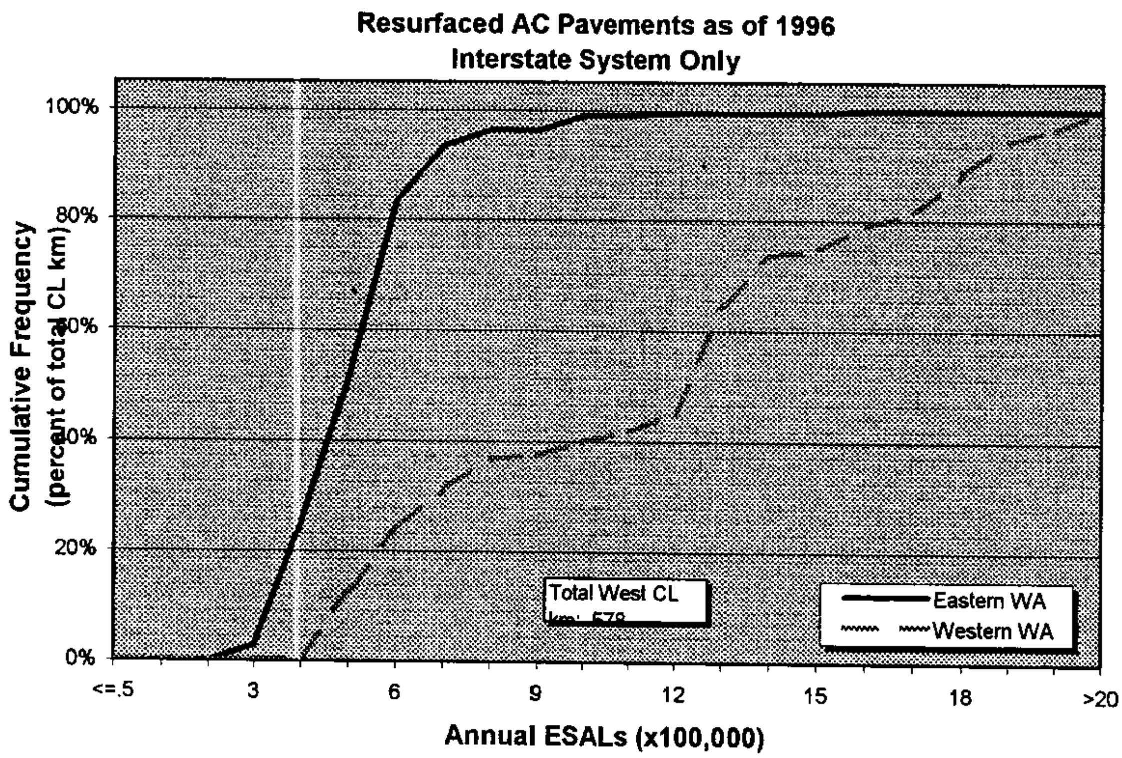


Figure D6. ESAL Cumulative Frequency Curve for Resurfaced AC - Interstate

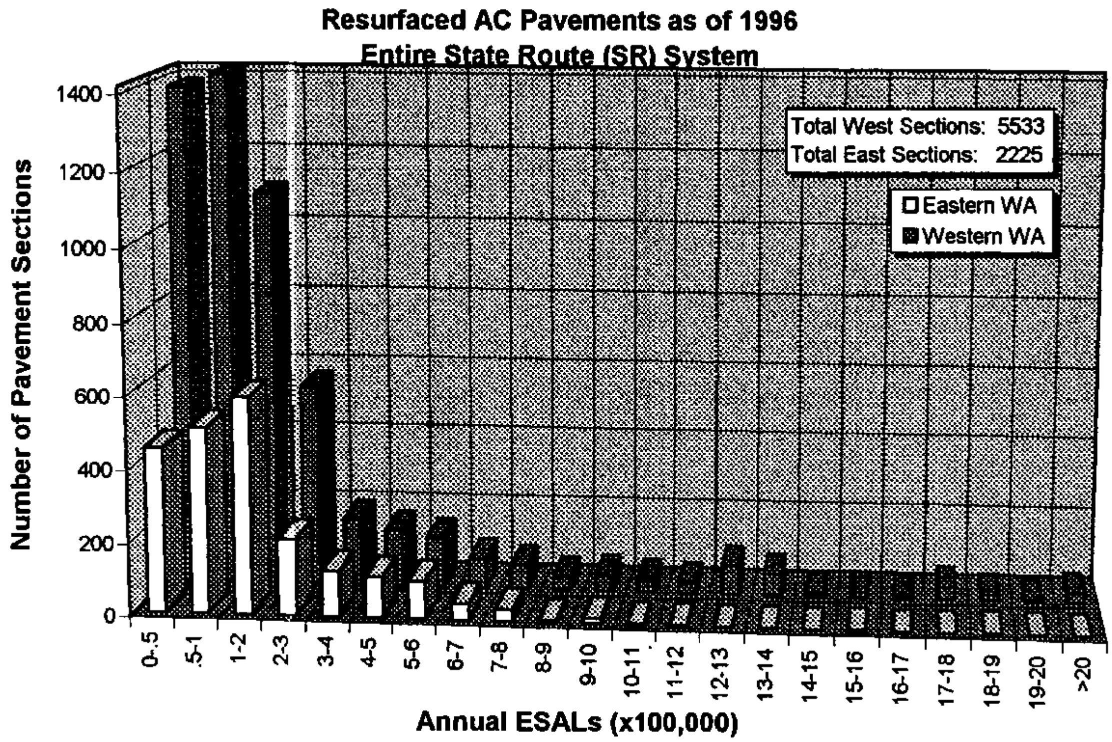


Figure D7. ESAL Plot for Resurfaced AC- SR System

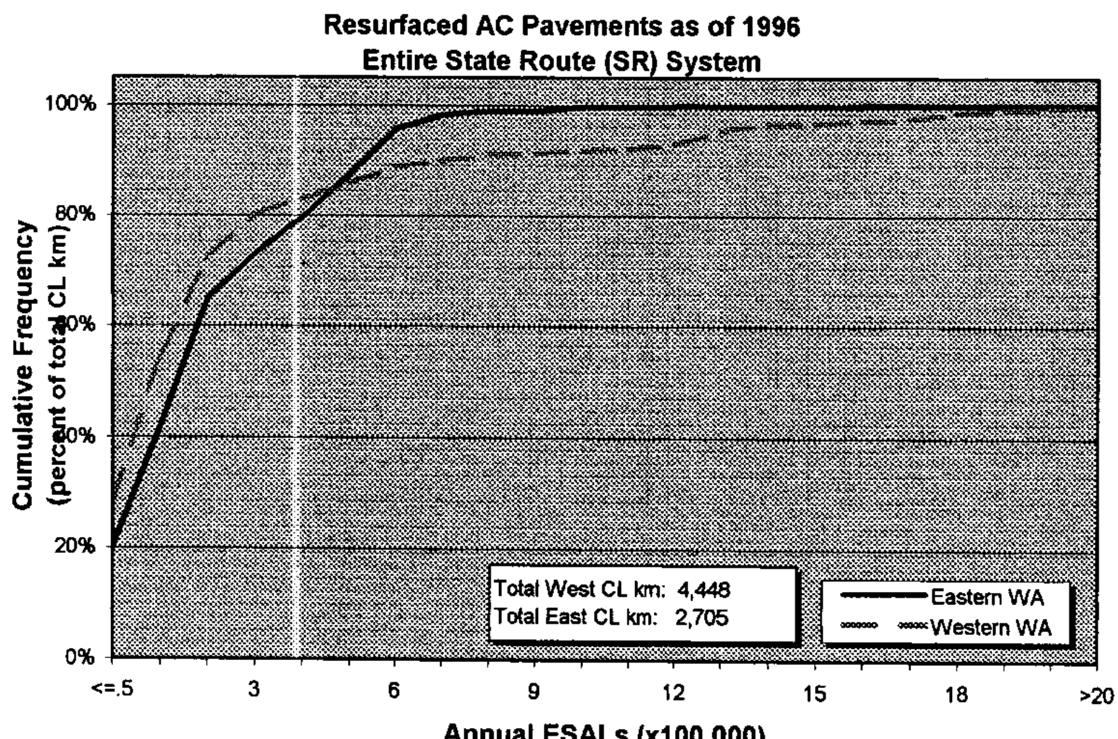


Figure D8. ESAL Cumulative Freq. Curve for Resurfaced AC- SR System

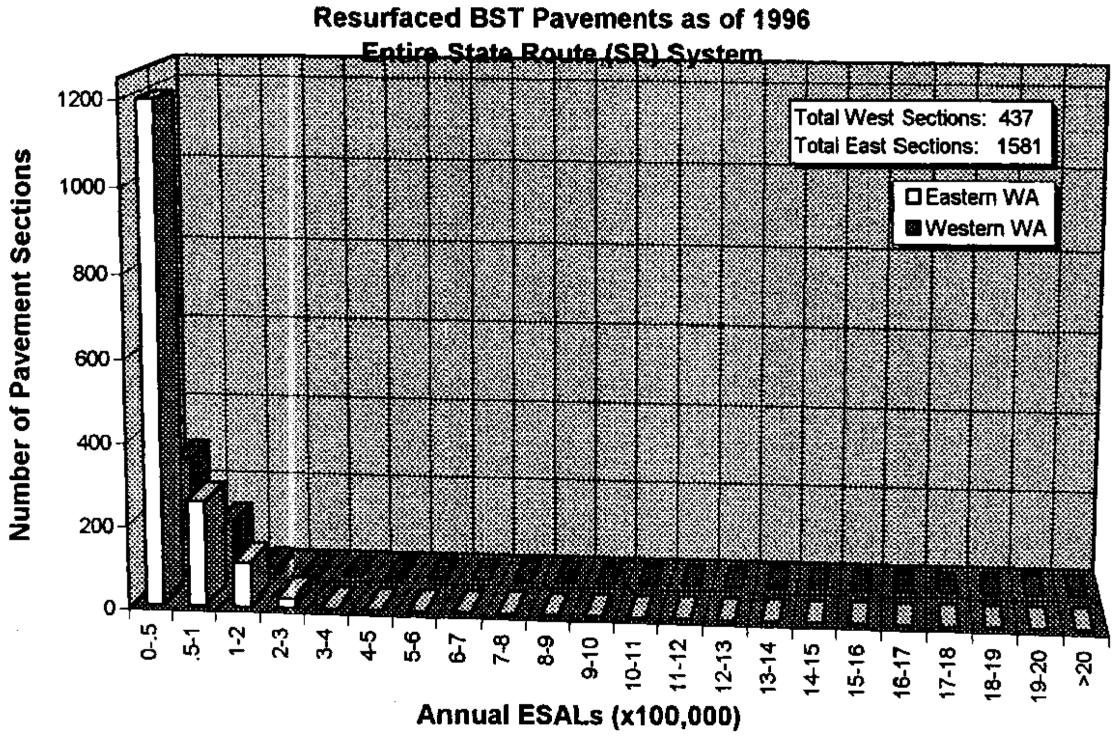


Figure D9. ESAL Plot for Resurfaced BST- SR System

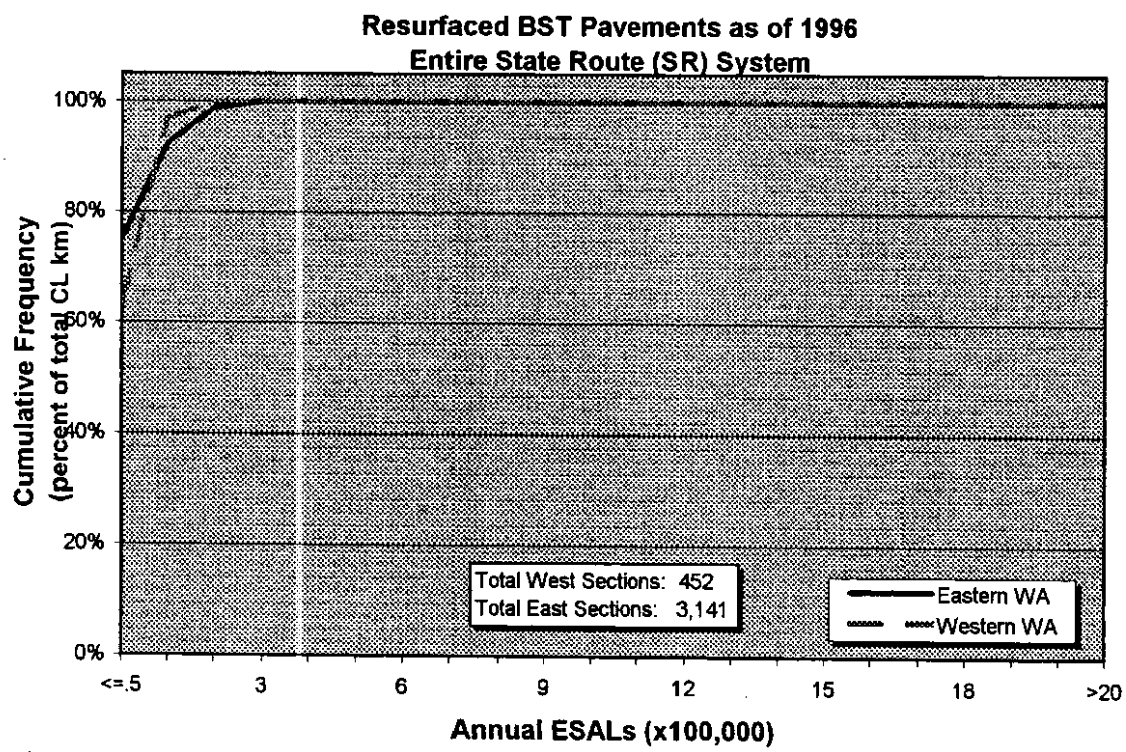


Figure D10. ESAL Cumulative Freq. Curve for Resurfaced BST- SR System

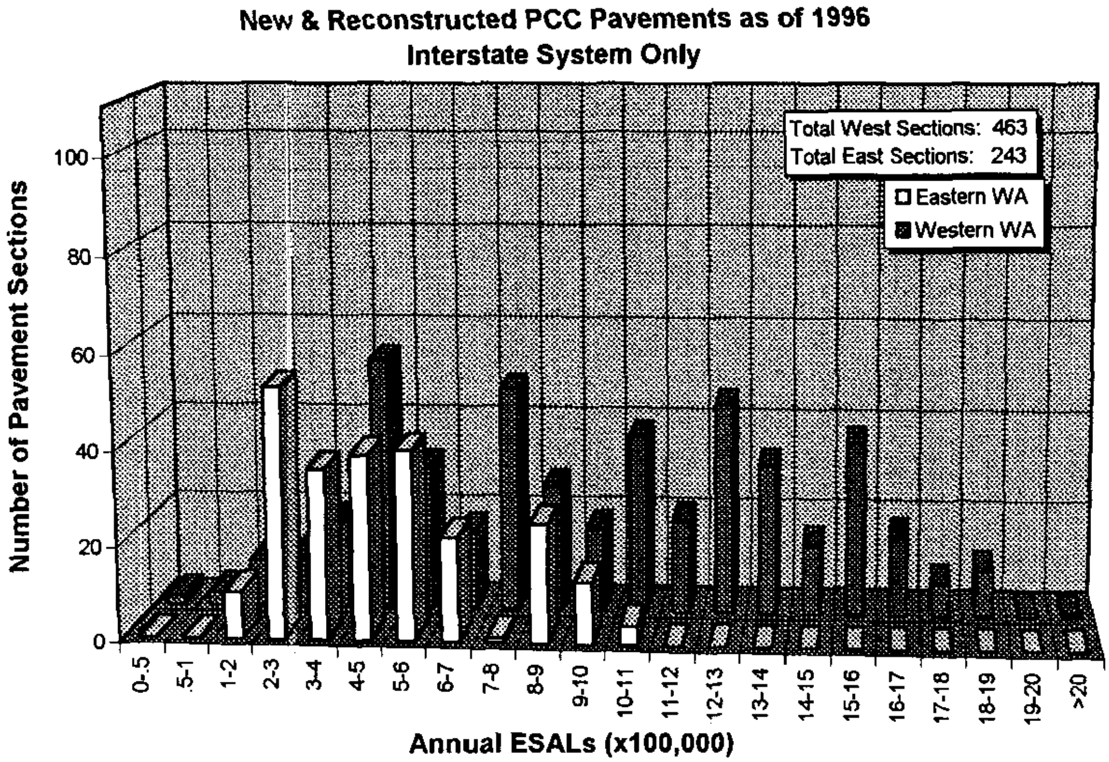


Figure D11. ESAL Plot for New & Reconstructed PCC Pavements- Interstate

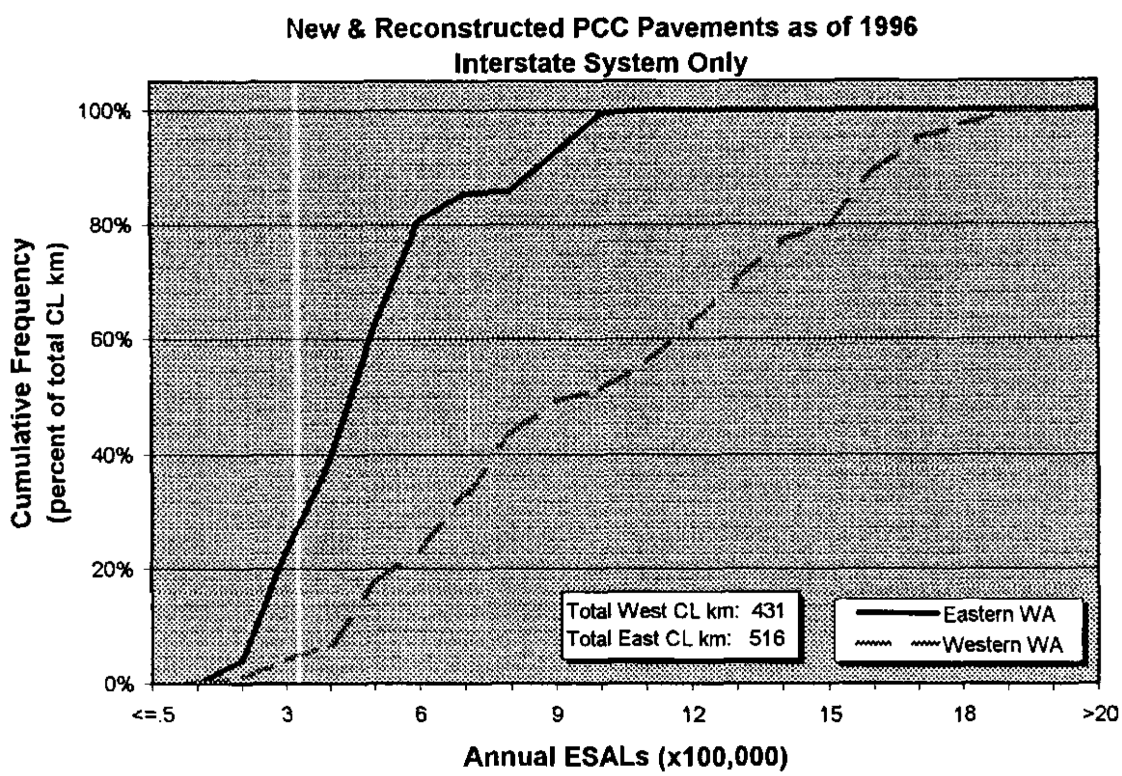


Figure D12. ESAL Cumulative Freq. Curve, New/Reconstructed PCC- Interstate

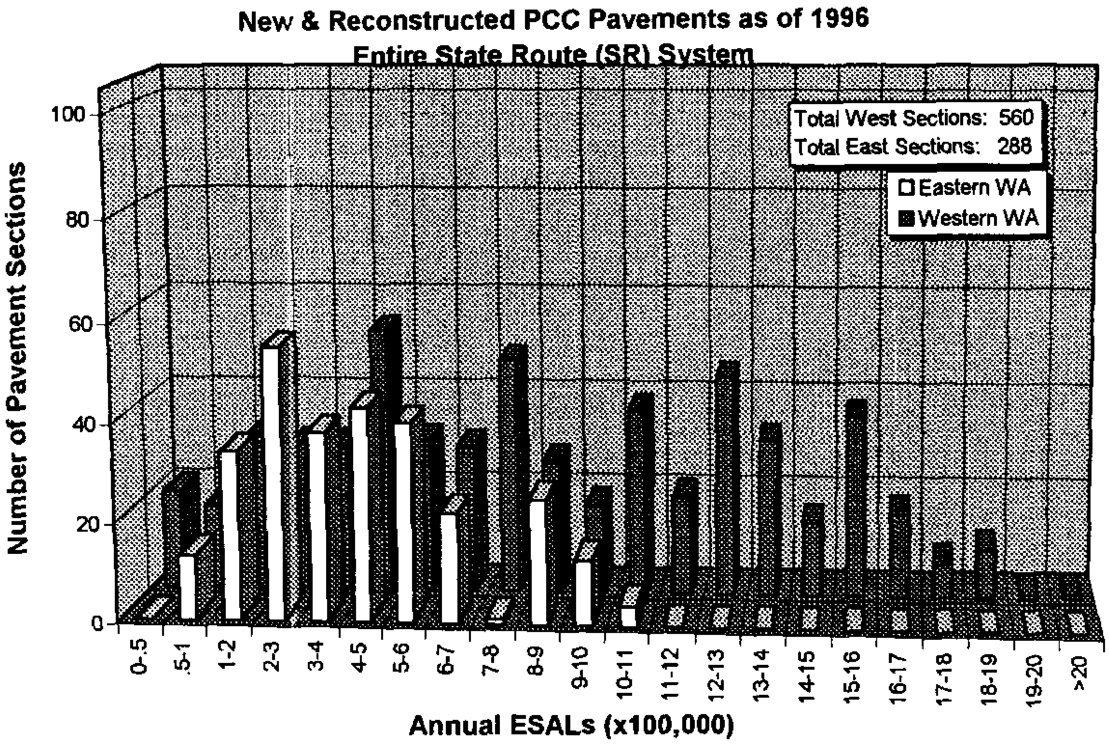


Figure D13. ESAL Plot for New & Reconstructed PCC- SR System

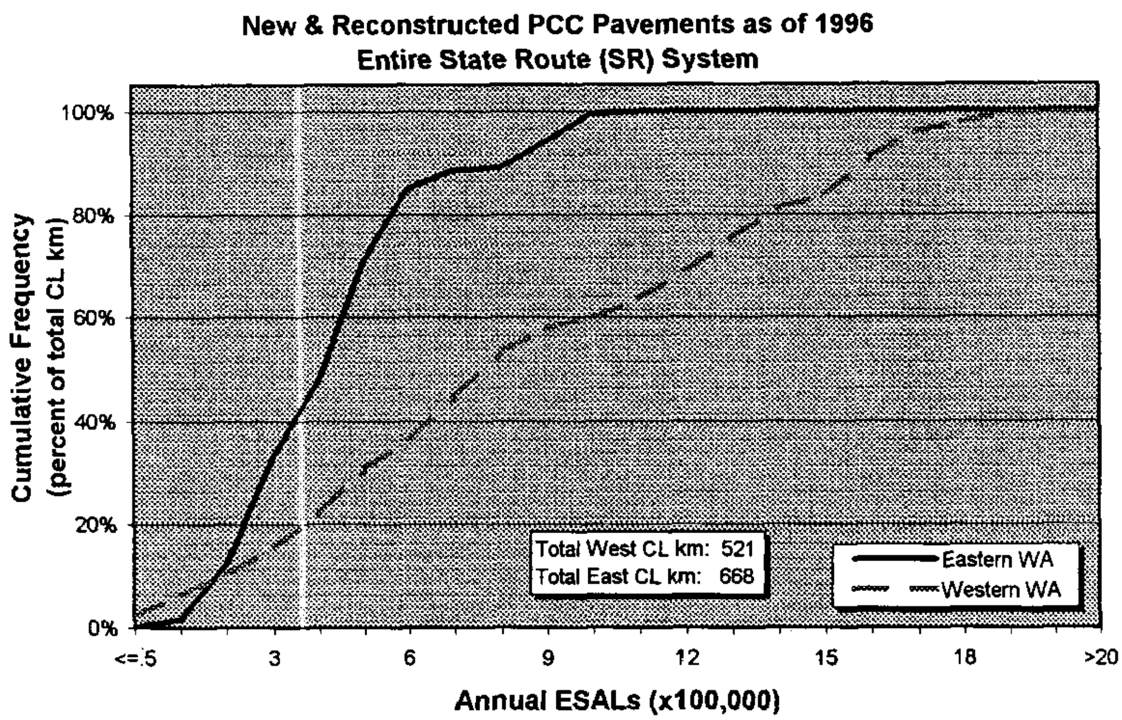


Figure D14. ESAL Cumulative Freq. Curve for New/Reconstructed PCC- SR System

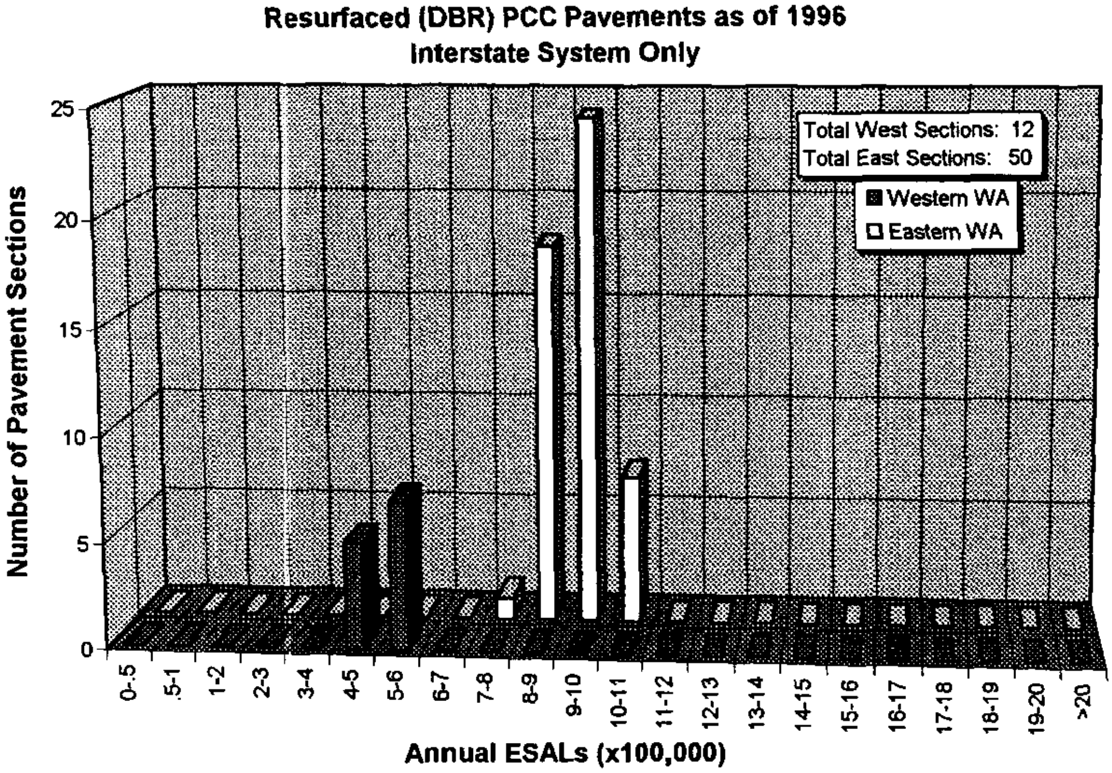


Figure D15. ESAL Plot for Resurfaced PCC- Interstate

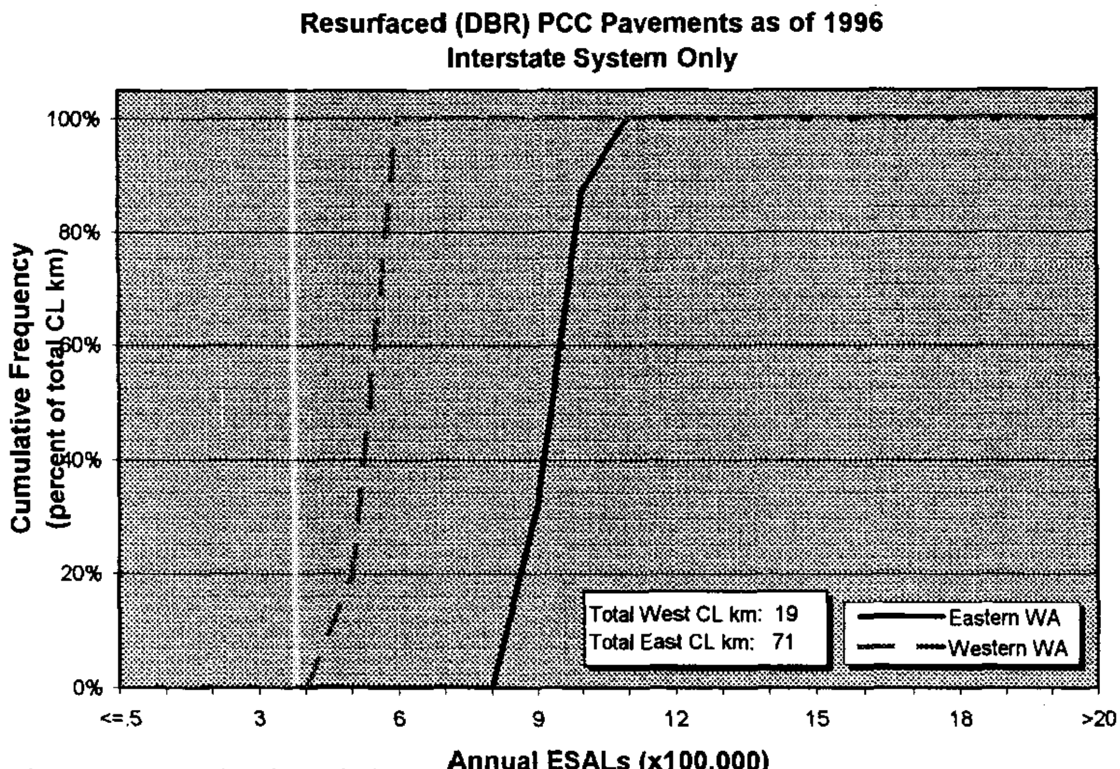


Figure D16. ESAL Cumulative Freq. Curve for Resurfaced PCC - Interstate

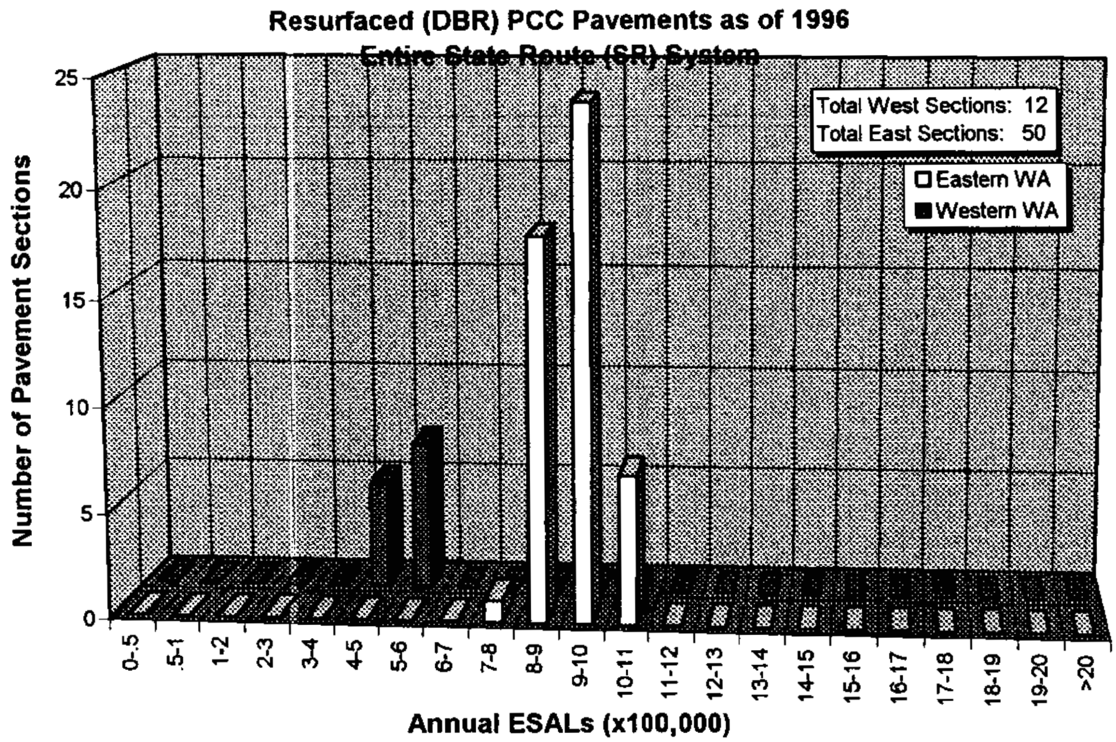


Figure D17. ESAL Plot for Resurfaced PCC- SR System

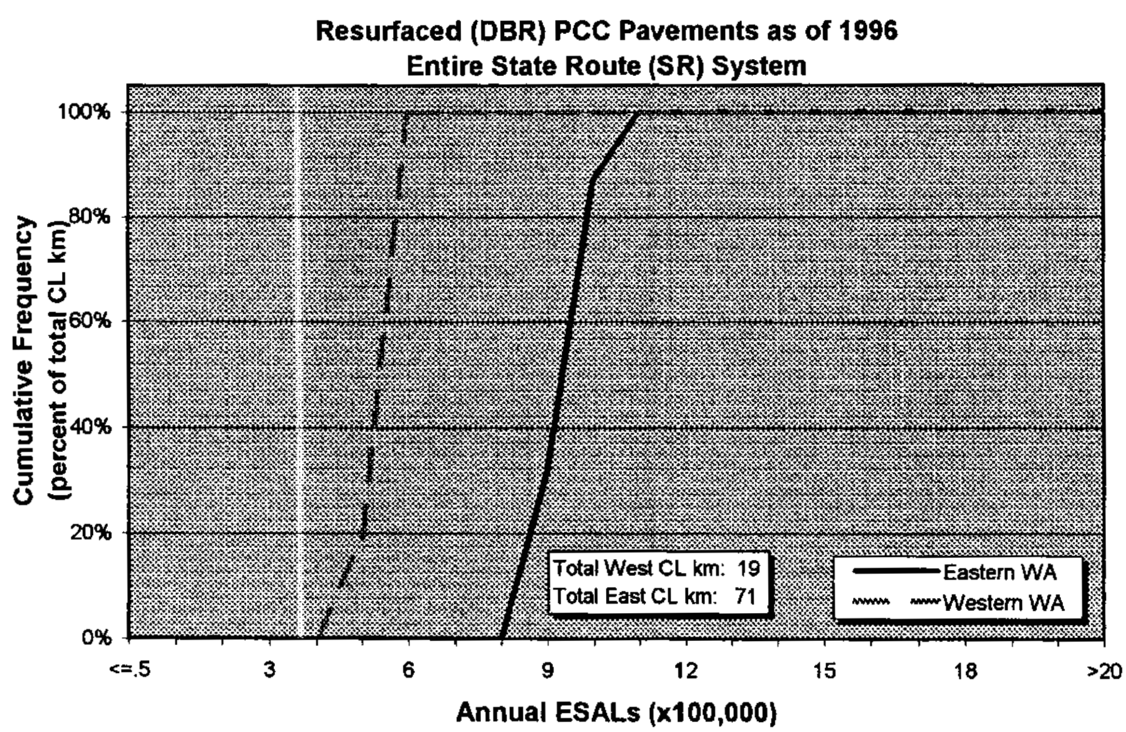


Figure D18. ESAL Cumulative Freq. Curve for Resurfaced PCC- SR System

APPENDIX E

IRI Frequency and Cumulative Frequency Plots

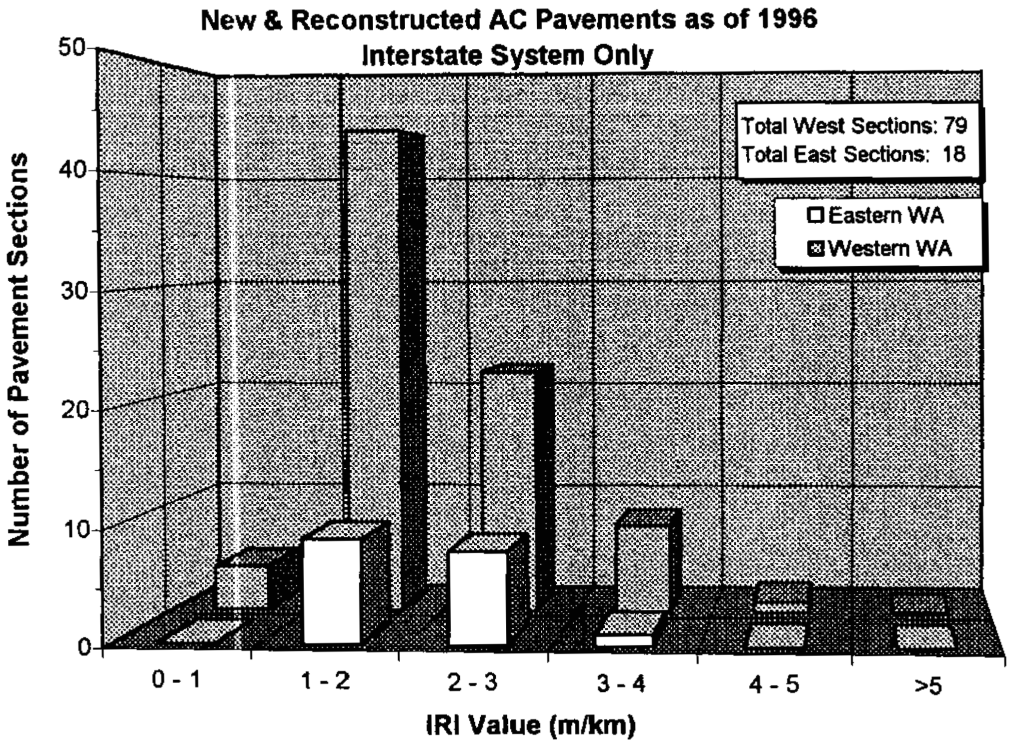


Figure E1. IRI Plot for New & Reconstructed AC- Interstate

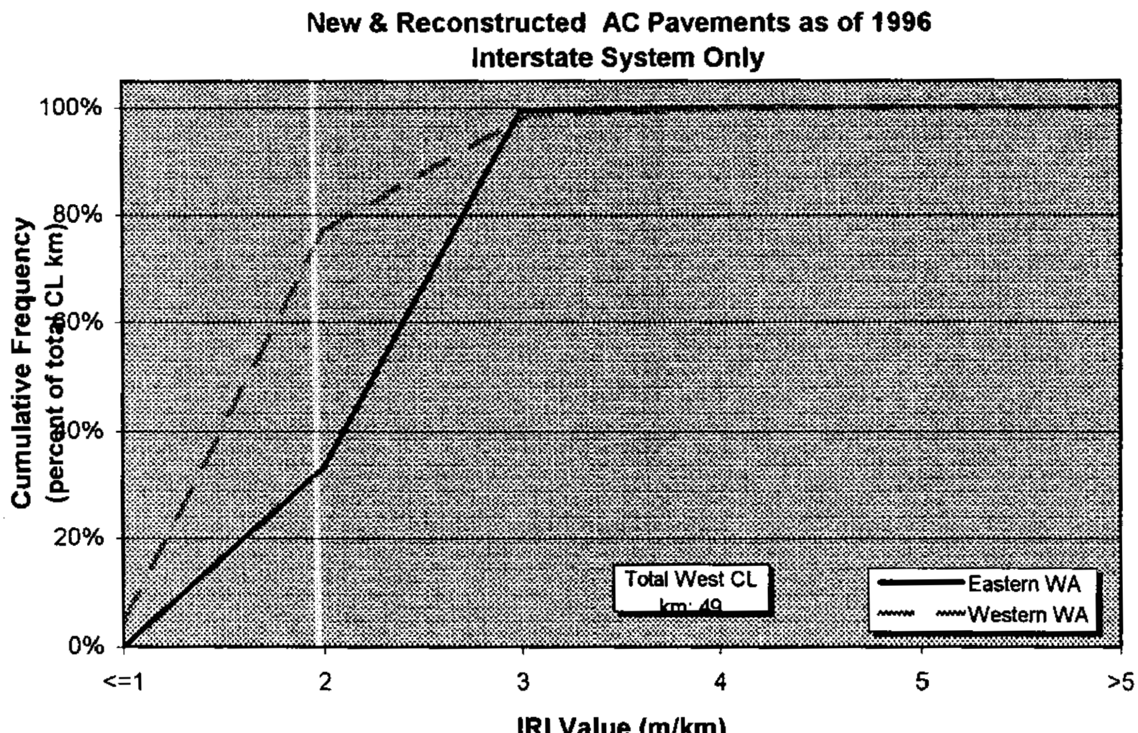


Figure E2. IRI Cumulative Frequency Curve for New/Reconstructed AC- Interstate

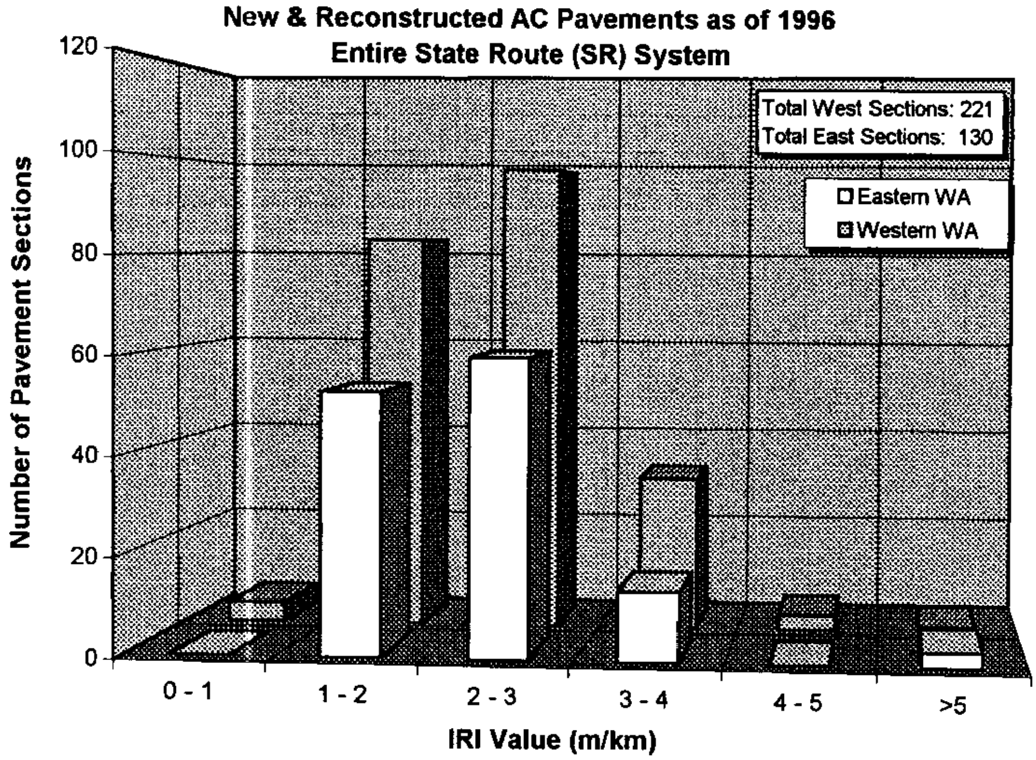


Figure E3. IRI Plot for New & Reconstructed AC- SR System

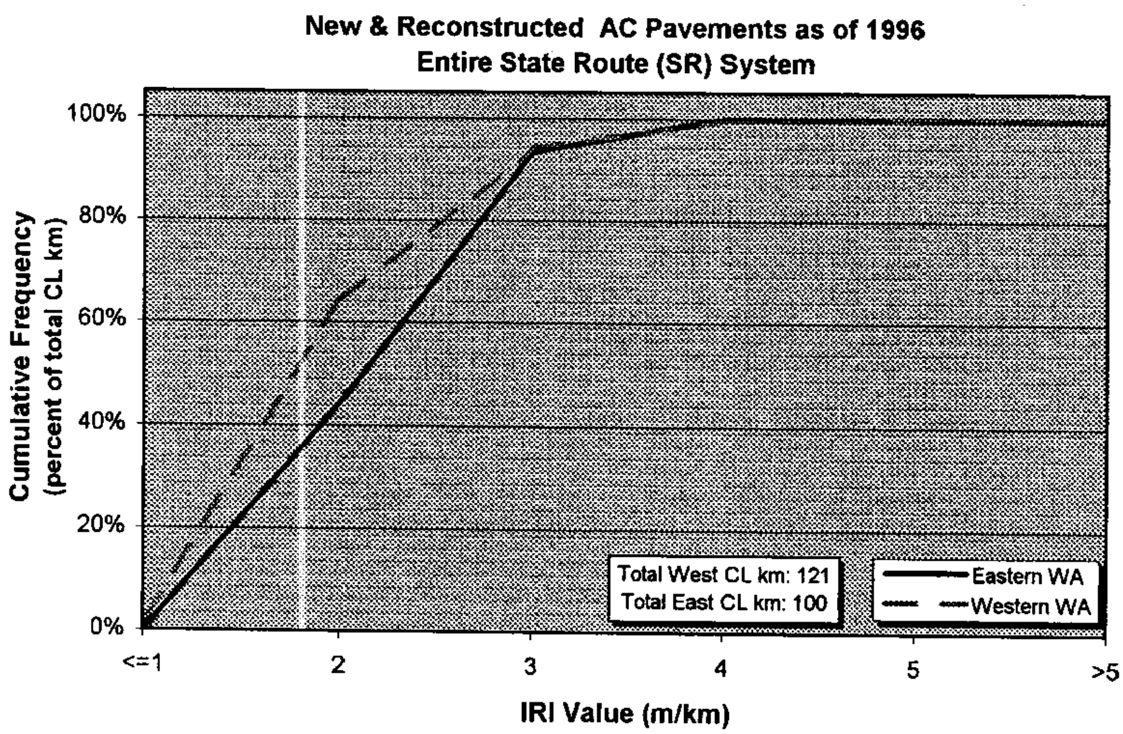


Figure E4. IRI Cumulative Frequency Curve for New/Reconstructed AC- SR System

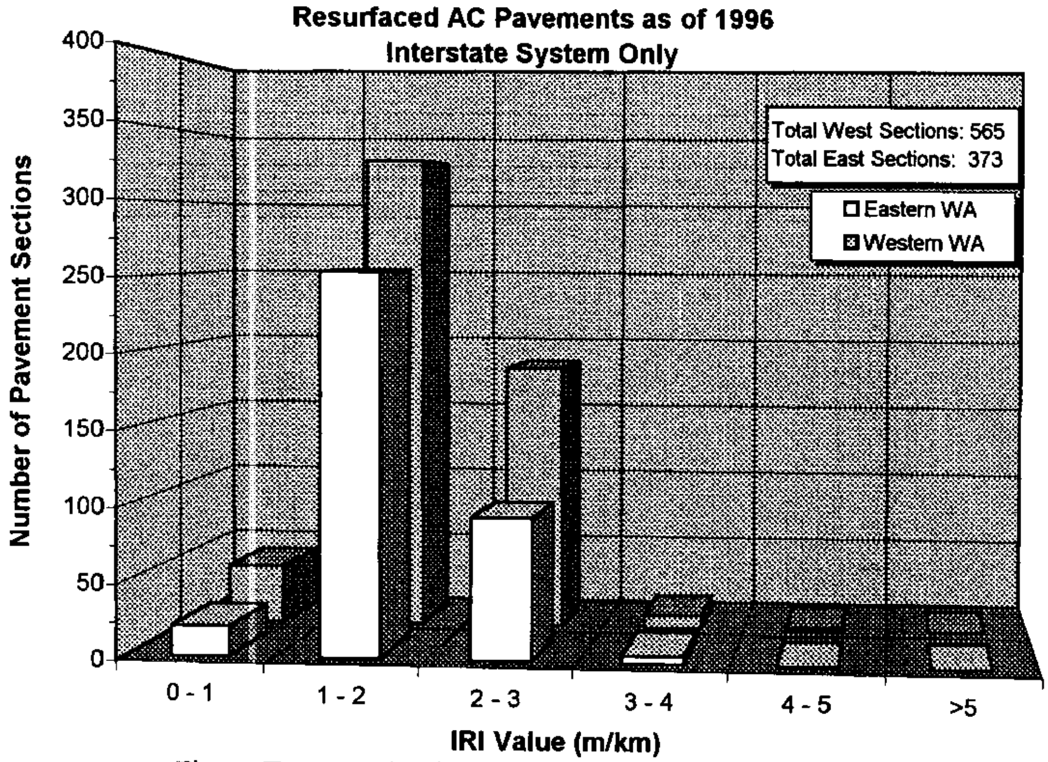


Figure E5. IRI Plot for Resurfaced AC- Interstate

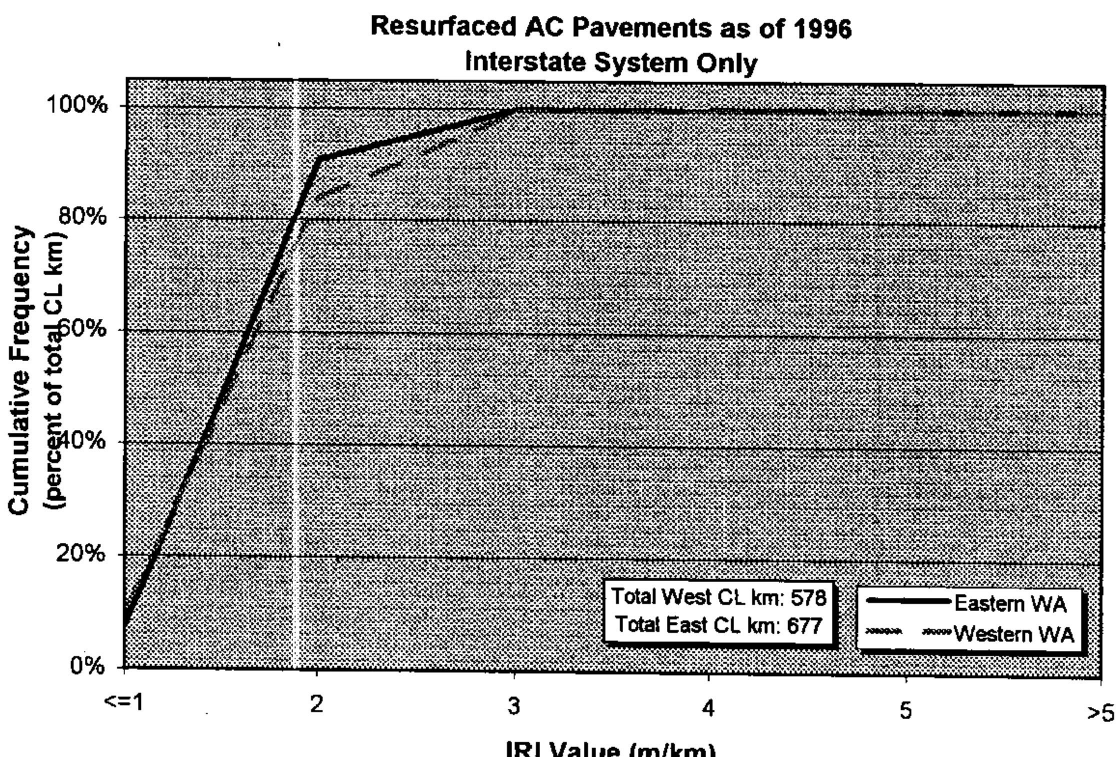


Figure E6. IRI Cumulative Frequency Curve for Resurfaced AC- Interstate

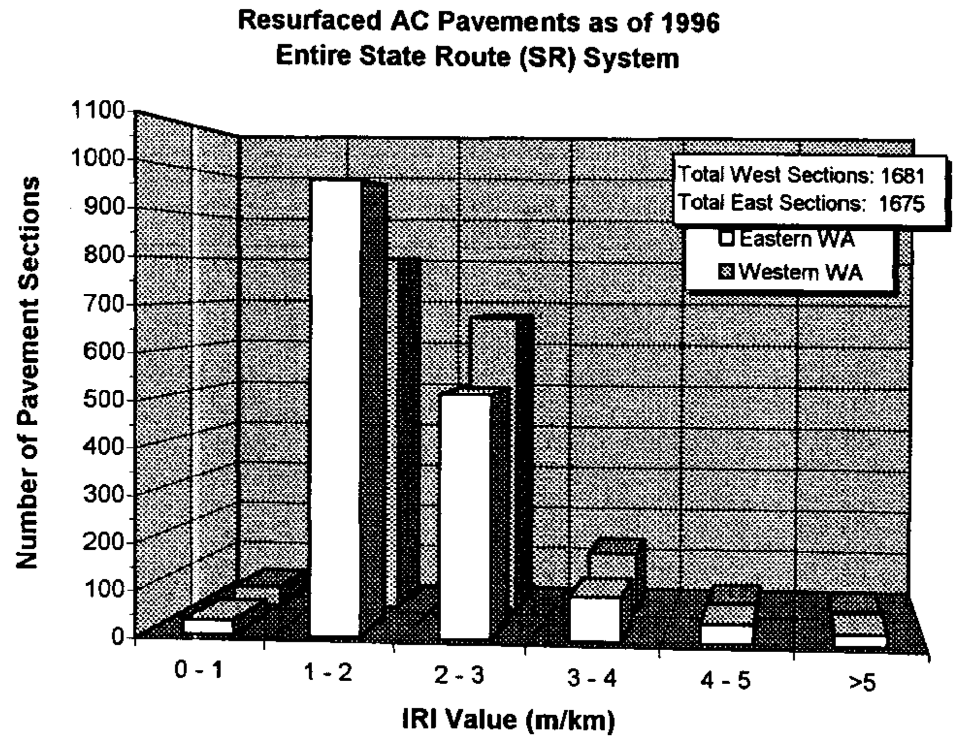


Figure E7. IRI Plot for Resurfaced AC Pavements- SR System

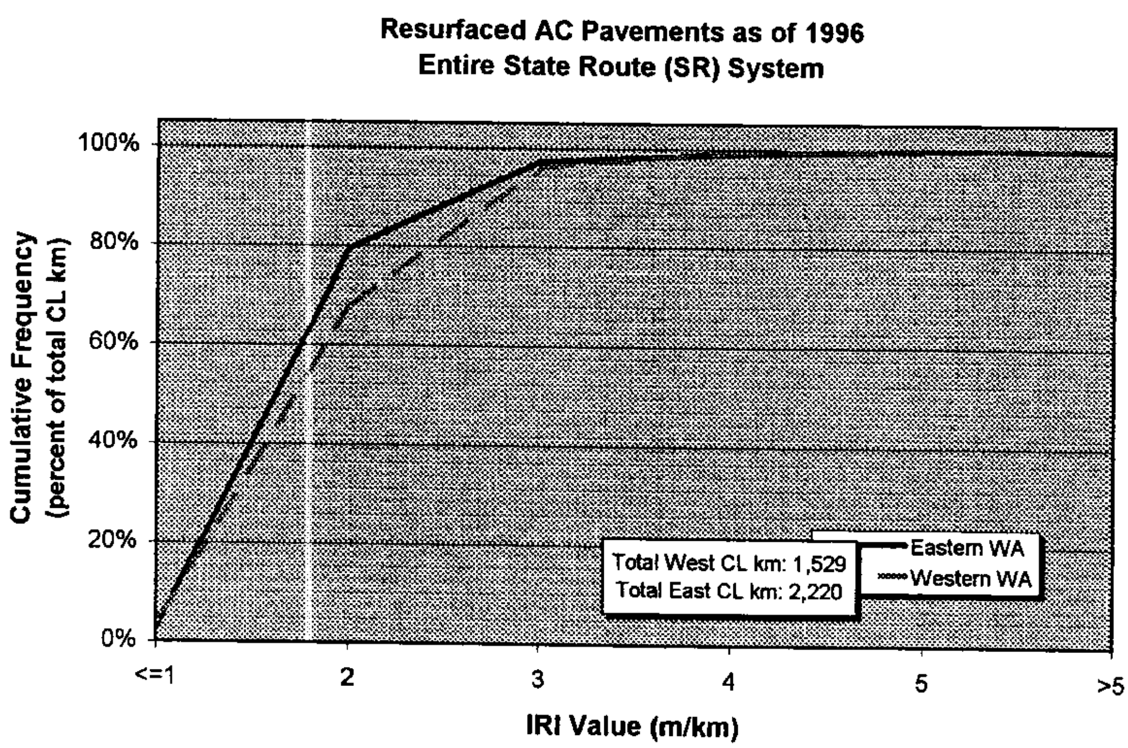


Figure E8. IRI Cumulative Frequency Curve for Resurfaced AC- SR System

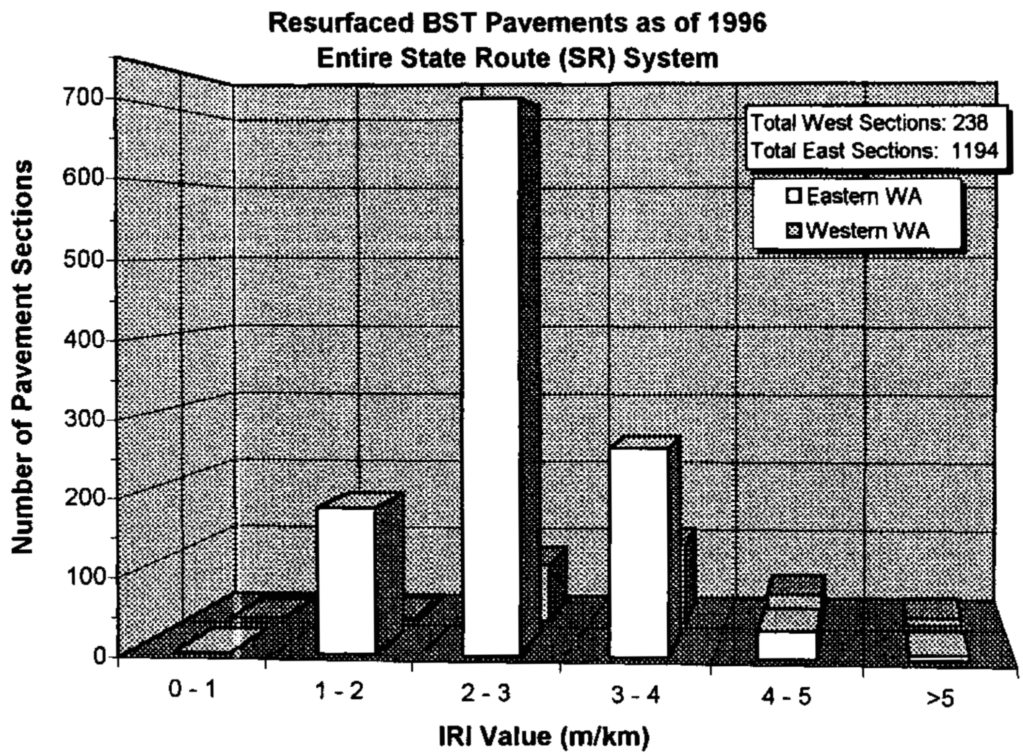


Figure E9. IRI Plot for Resurfaced BST Pavements- SR System

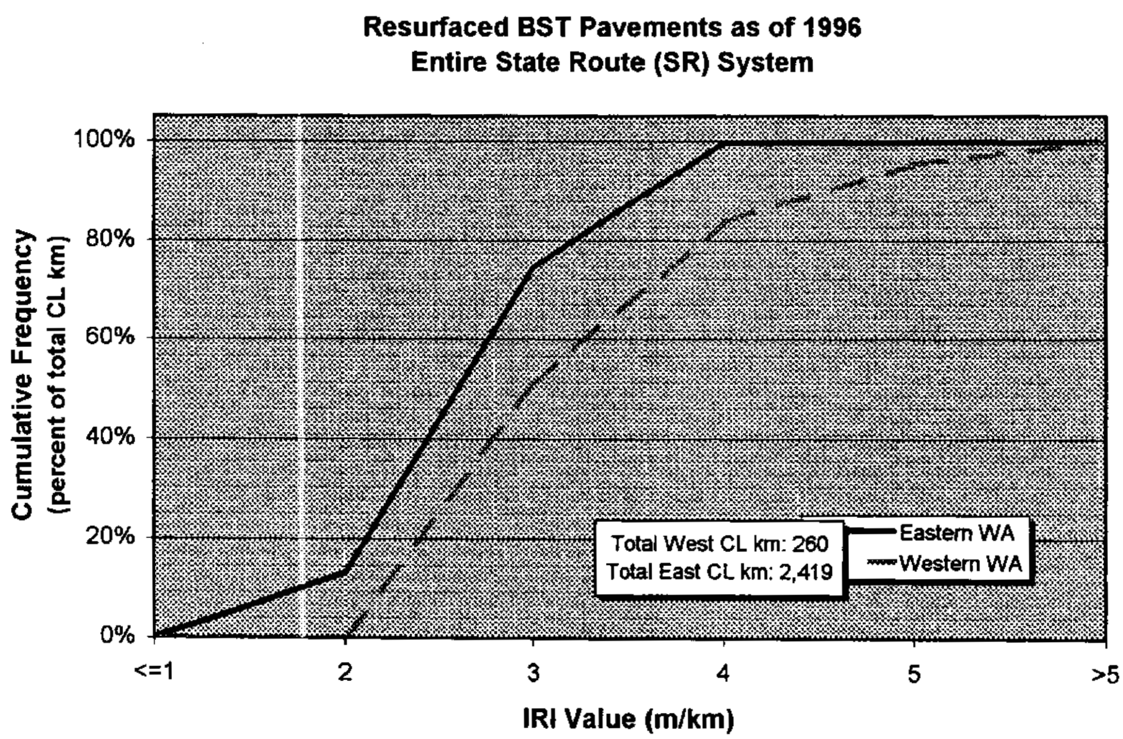


Figure E10. IRI Cumulative Frequency Curve for Resurfaced BSTs- SR System

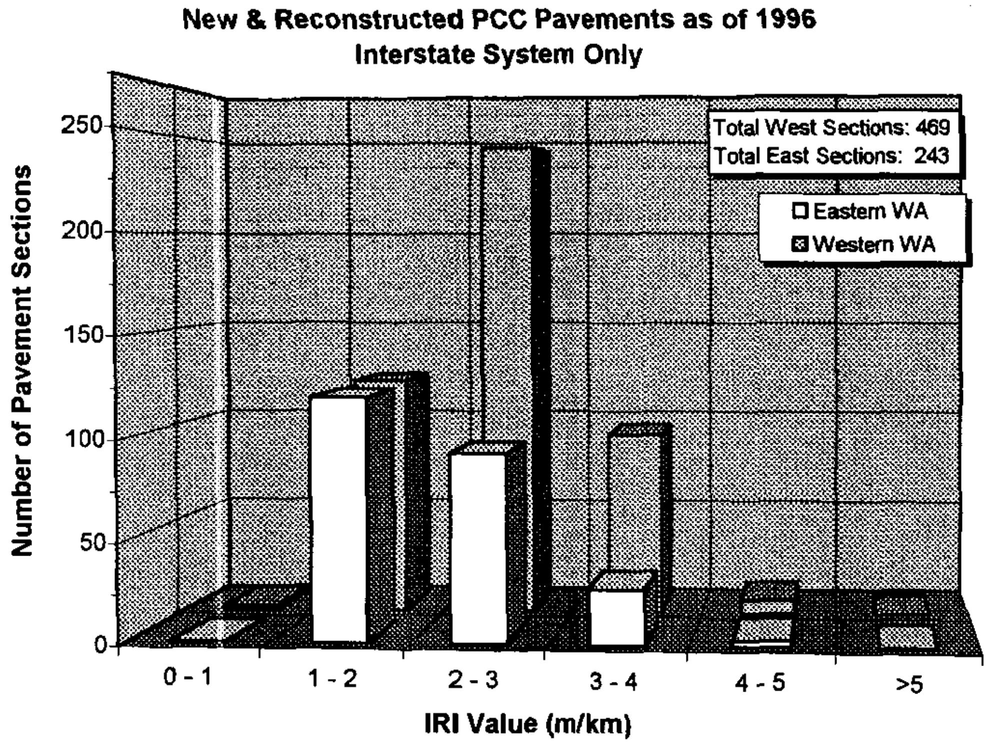


Figure E11. IRI Plot for New & Reconstructed PCC- Interstate

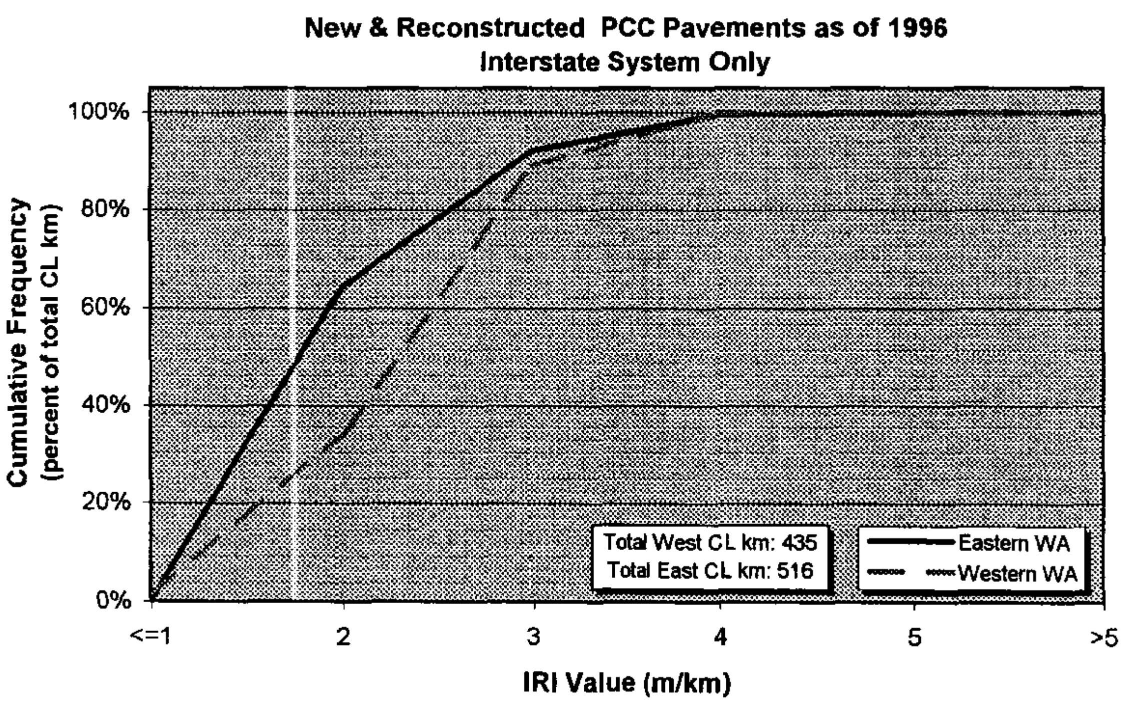


Figure E12. IRI Cumulative Frequency Curve for New/Reconstructed PCC- Interstate

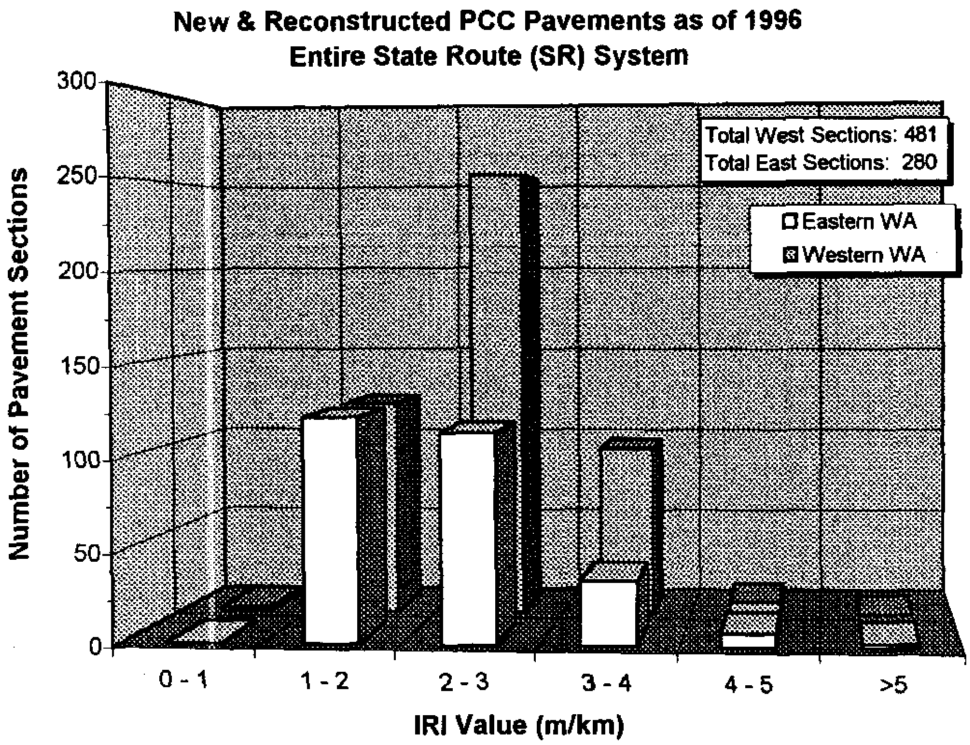


Figure E13. IRI Plot for New & Reconstructed PCC- SR System

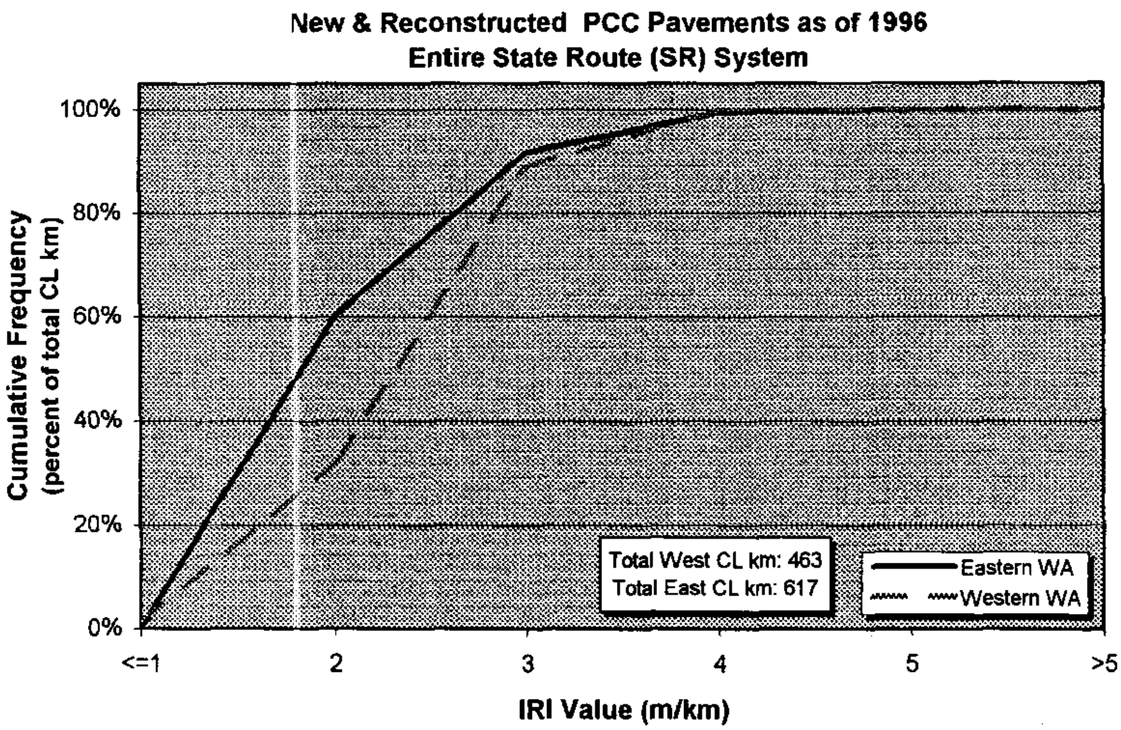


Figure E14. IRI Cumulative Freq. Curve for New/Reconstructed PCC- SR System

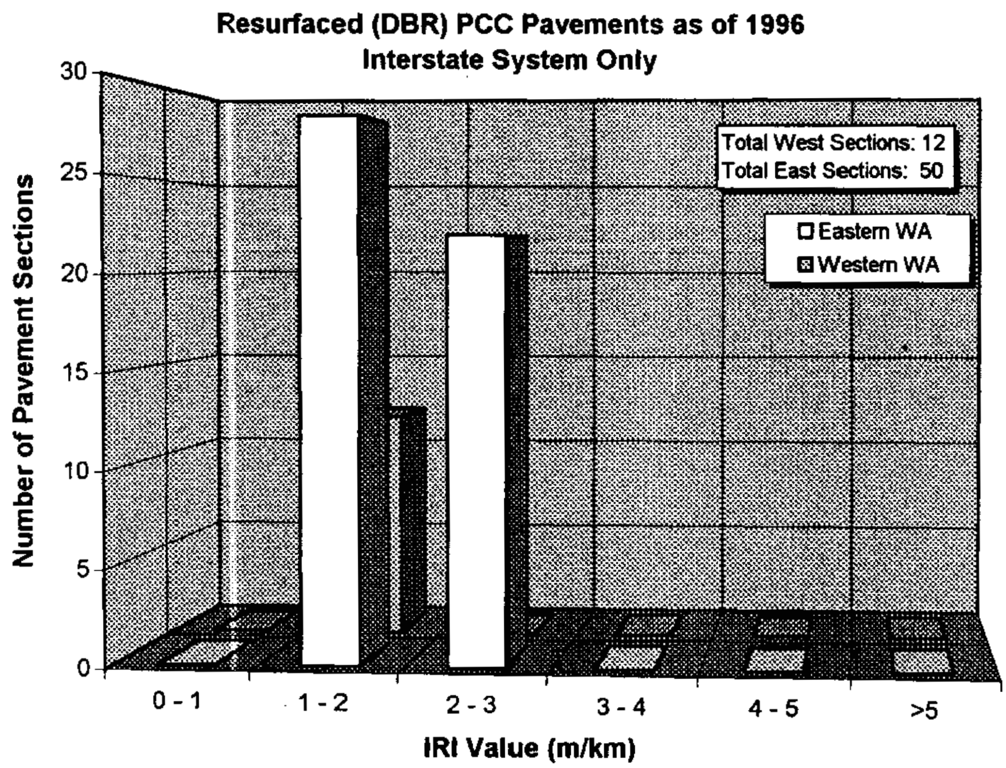


Figure E15. IRI Plot for Resurfaced PCC- Interstate

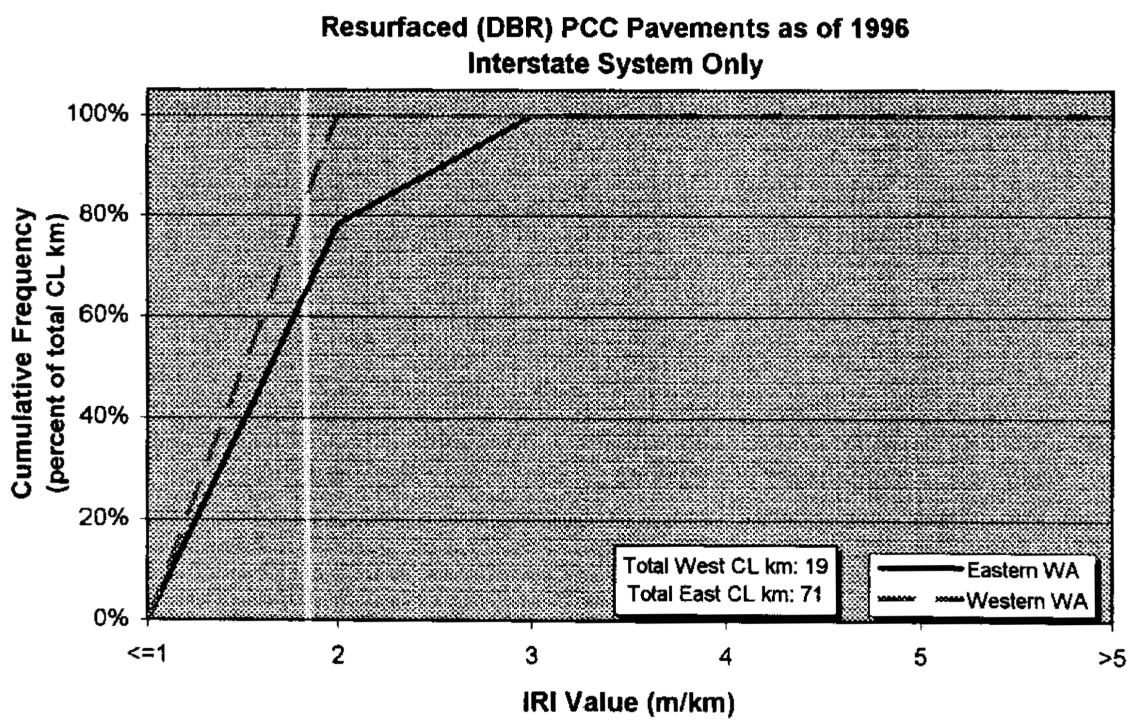


Figure E16. IRI Cumulative Frequency Curve for Resurfaced PCC- Interstate

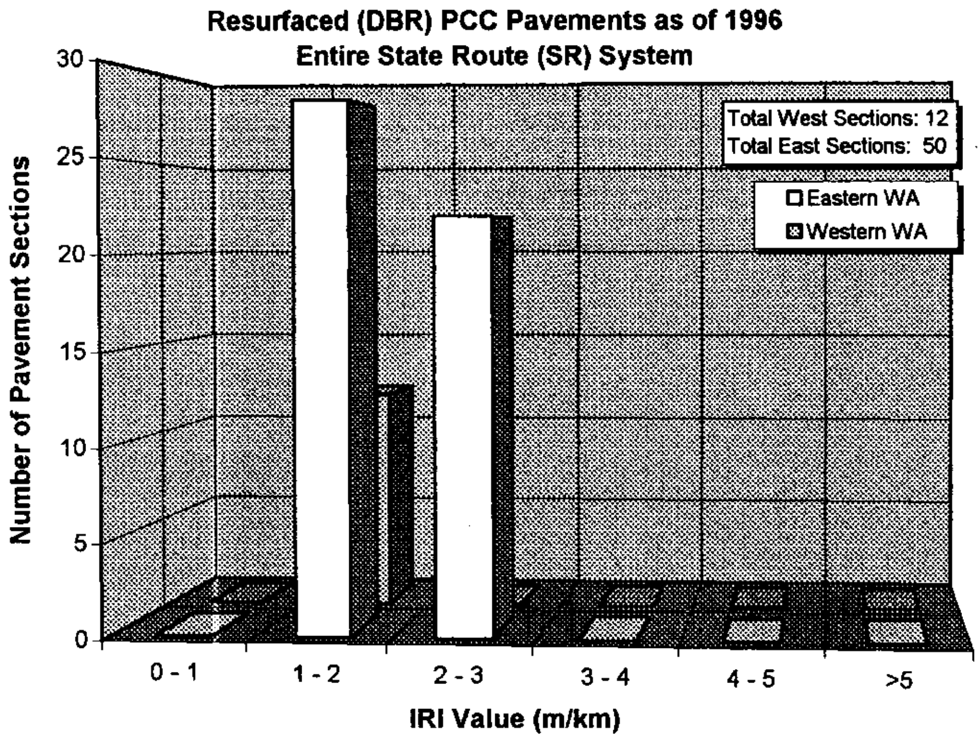


Figure E17. IRI Plot for Resurfaced PCC- SR System

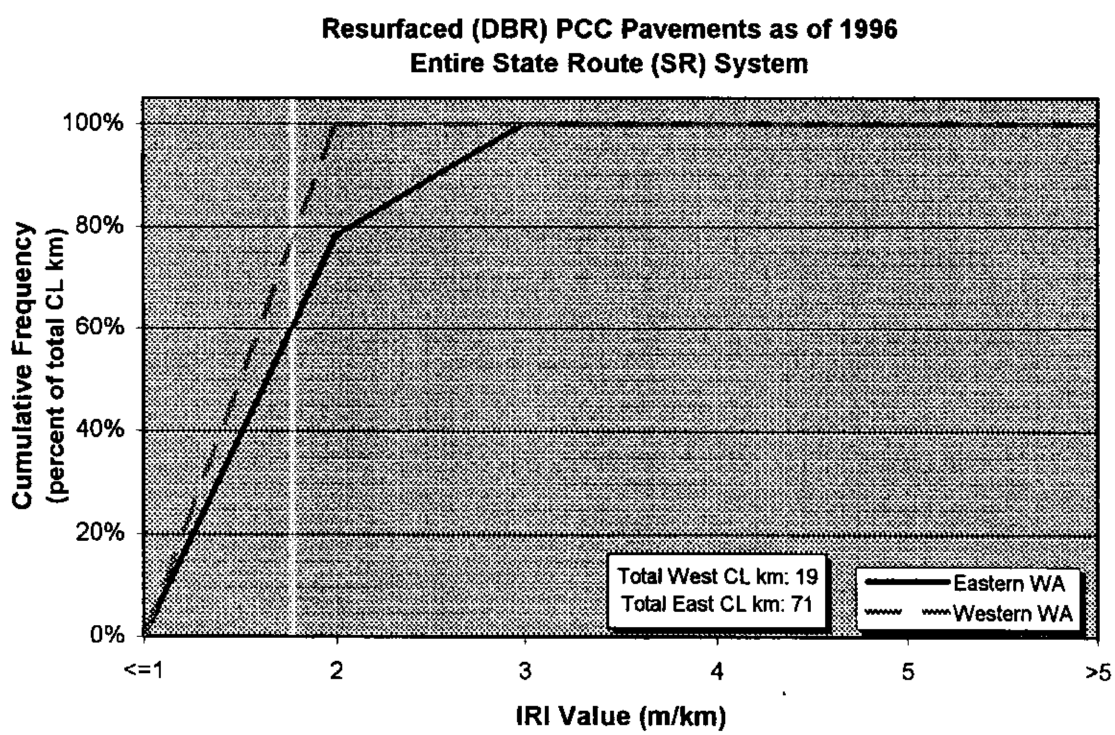


Figure E18. IRI Cumulative Frequency Curve for Resurfaced PCC- SR System

APPENDIX F

Rutting Frequency and Cumulative Frequency Plots

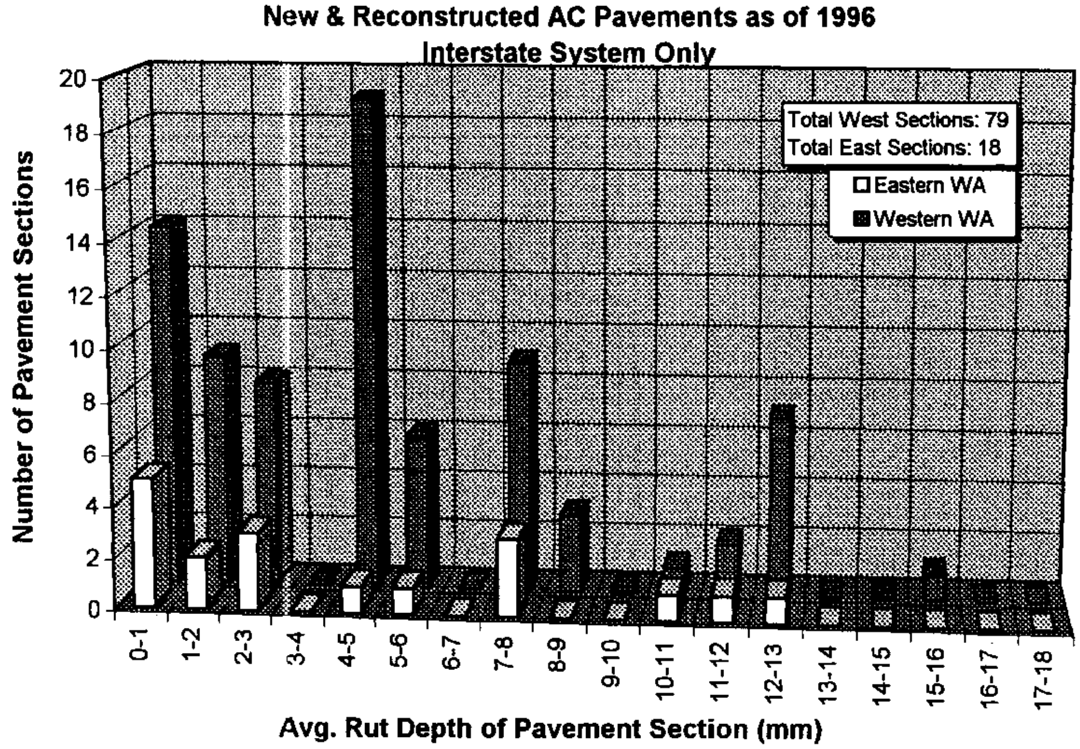


Figure F1. Rutting plot for New & Reconstructed AC- Interstate

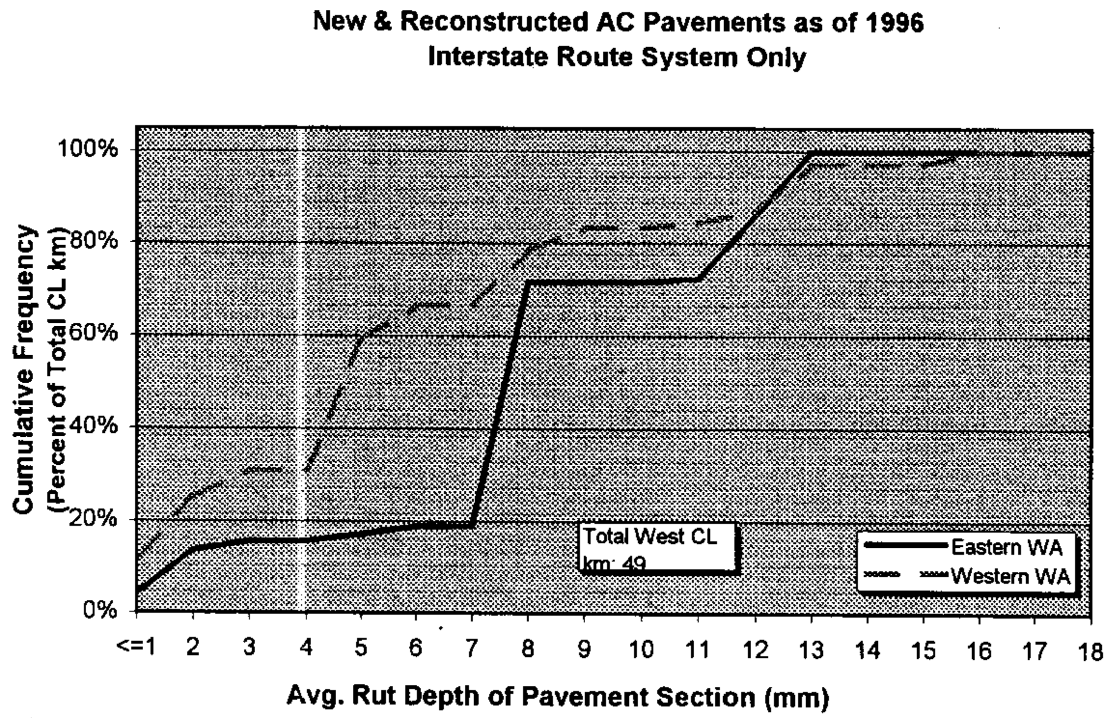


Figure F2. Rutting Cumulative Freq. Curve, New/Reconstructed AC- Interstate

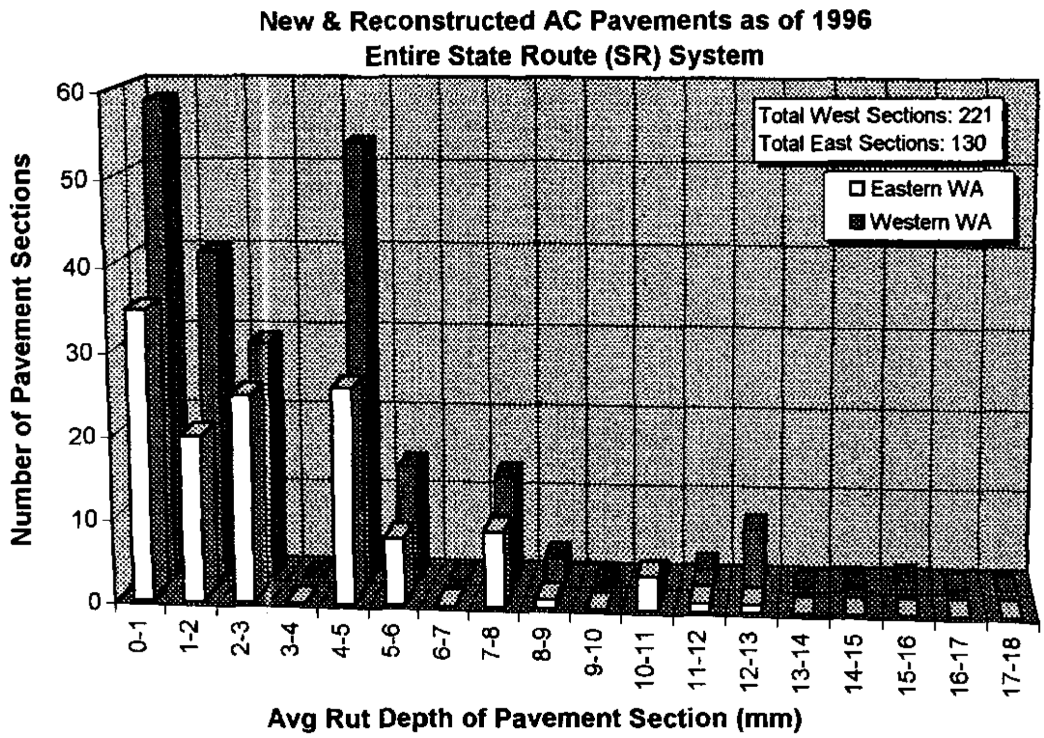


Figure F3. Rutting plot for New & Reconstructed AC- SR System

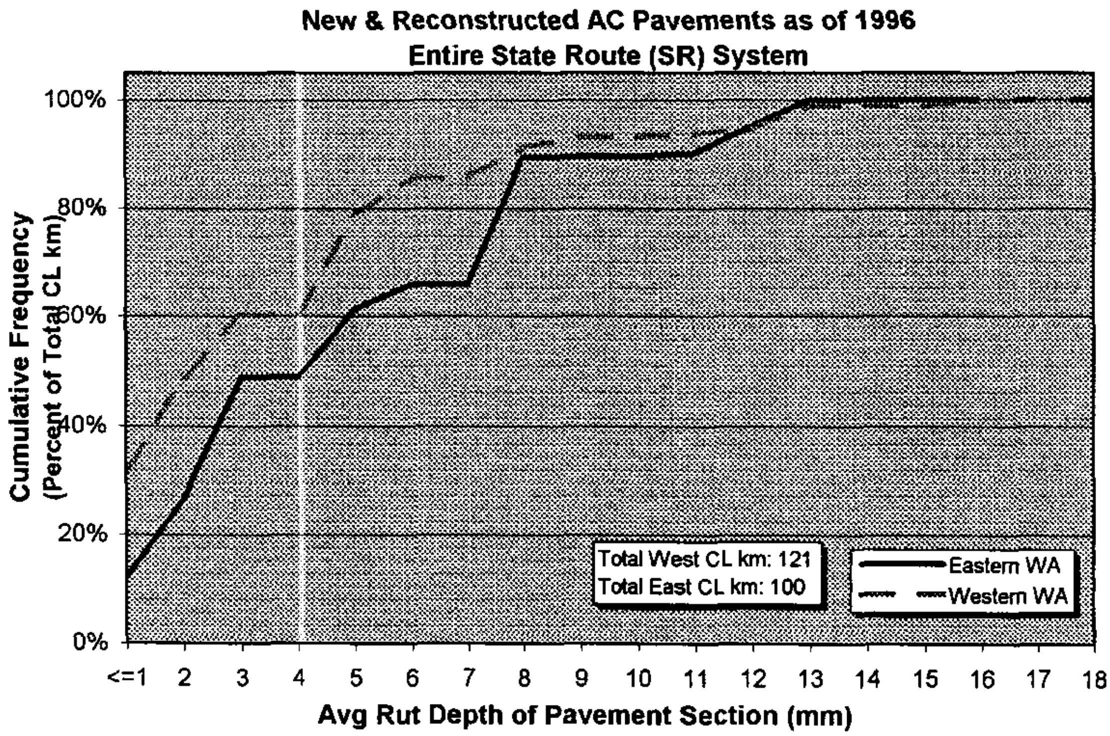


Figure F4. Rutting Cumulative Freq. Curve. New/Reconstructed AC- SR System

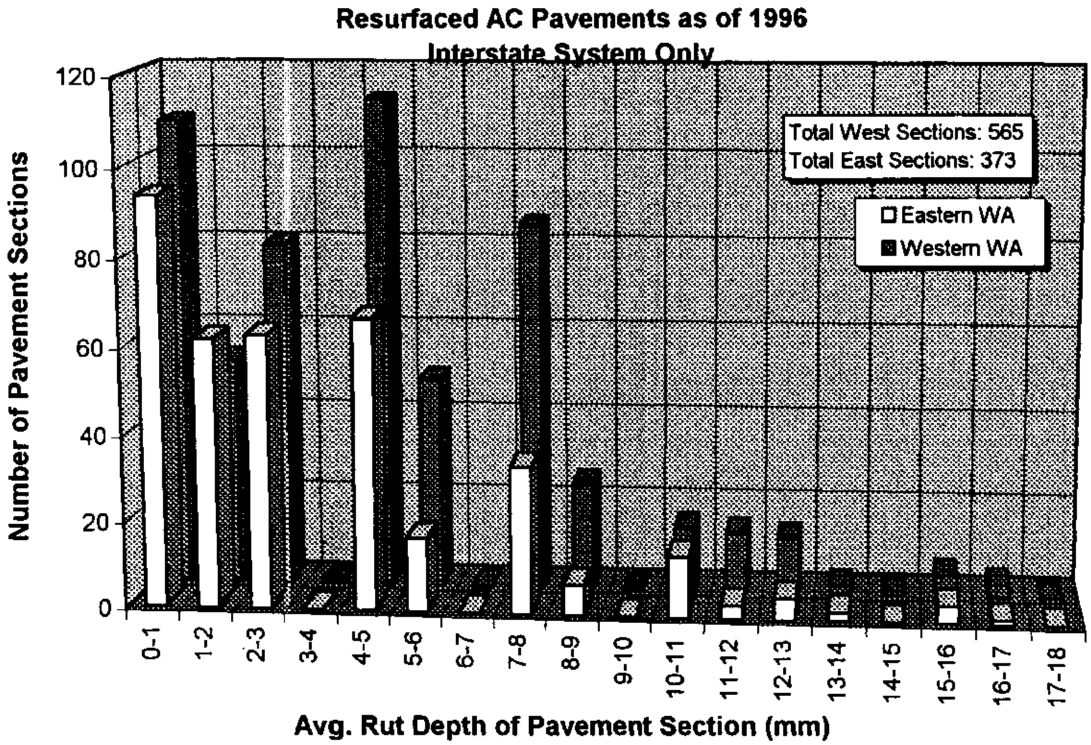


Figure F5. Rutting plot for Resurfaced AC Pavements- Interstate

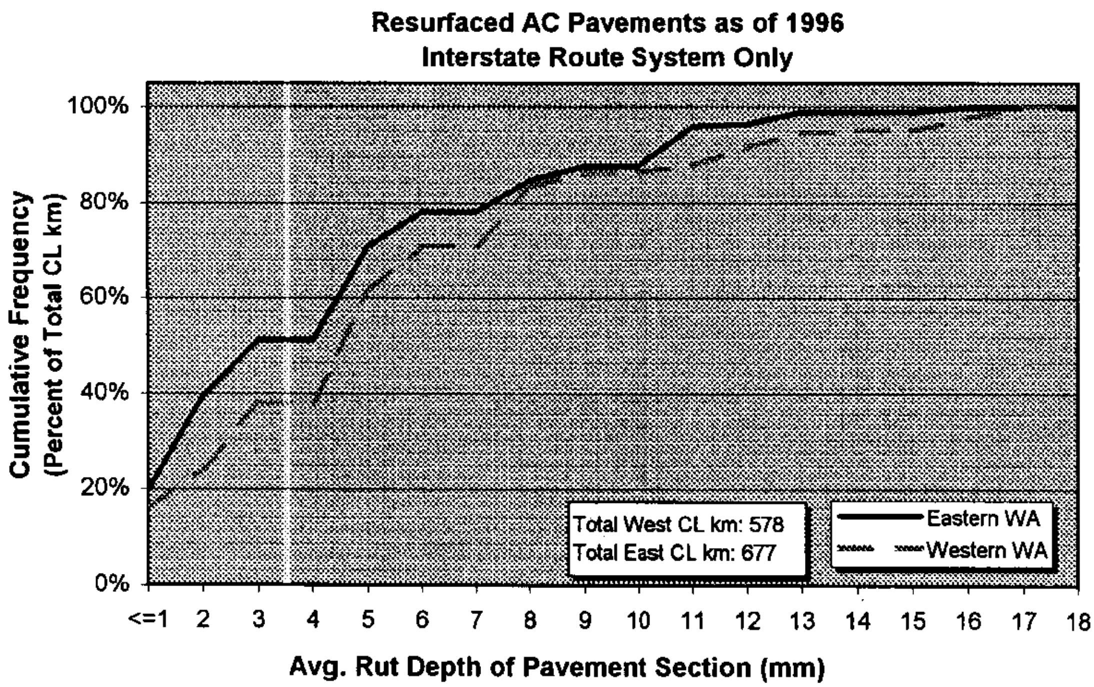


Figure F6. Rutting Cumulative Frequency Curve for resurfaced AC- Interstate

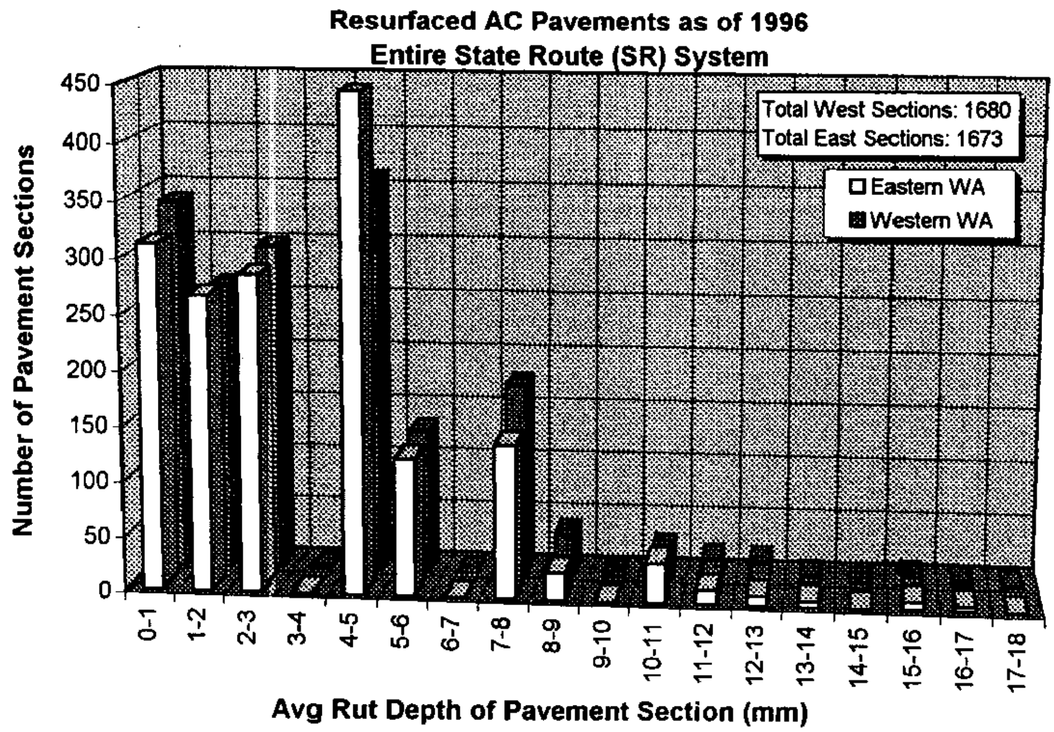


Figure F7. Rutting plot for Resurfaced AC Pavements- SR System

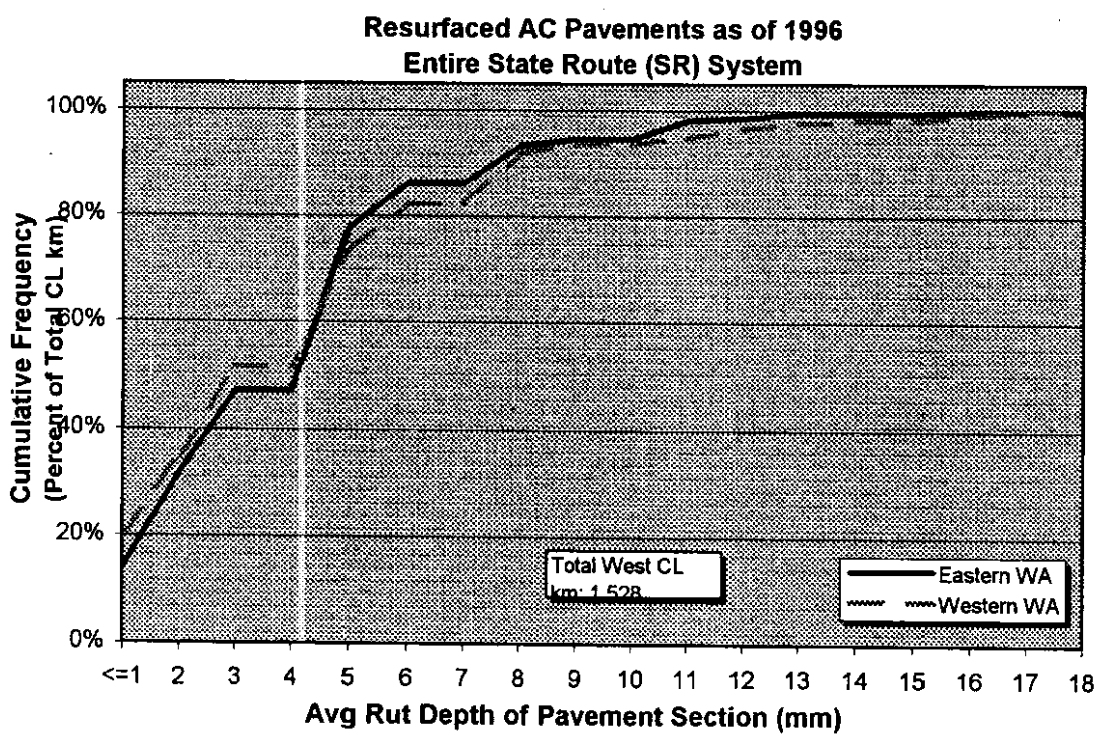


Figure F8. Rutting Cumulative Frequency Curve for Resurfaced AC- SR System

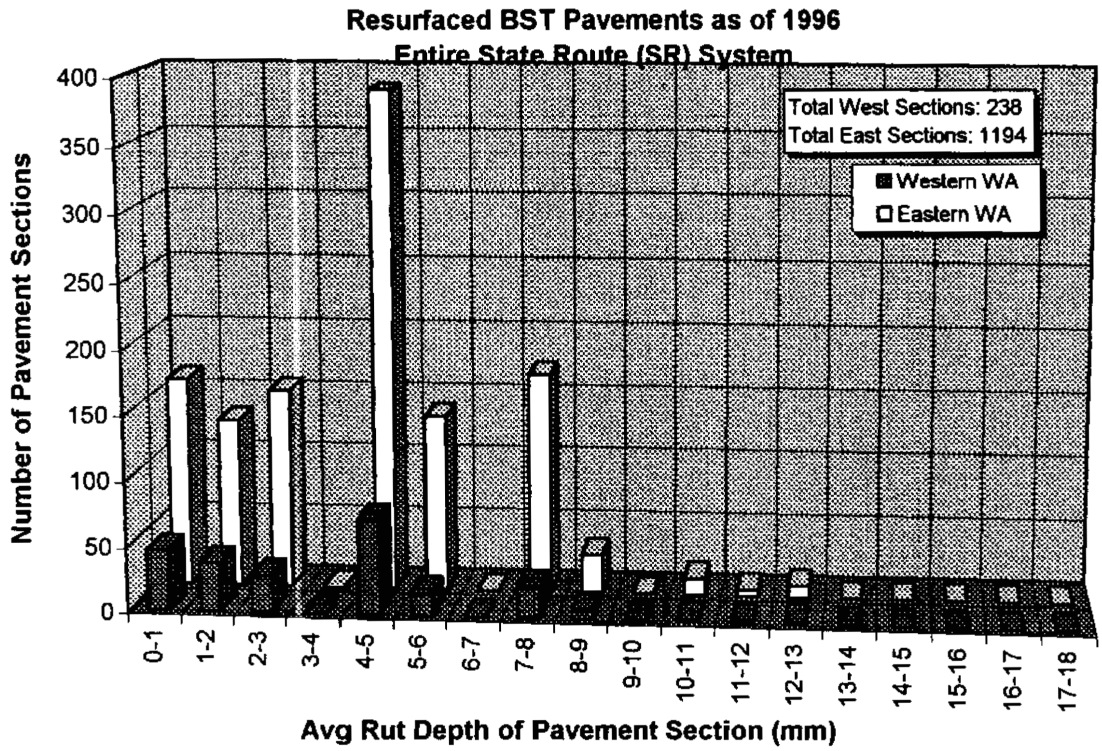


Figure F9. Rutting plot for Resurfaced BST Pavements- SR System

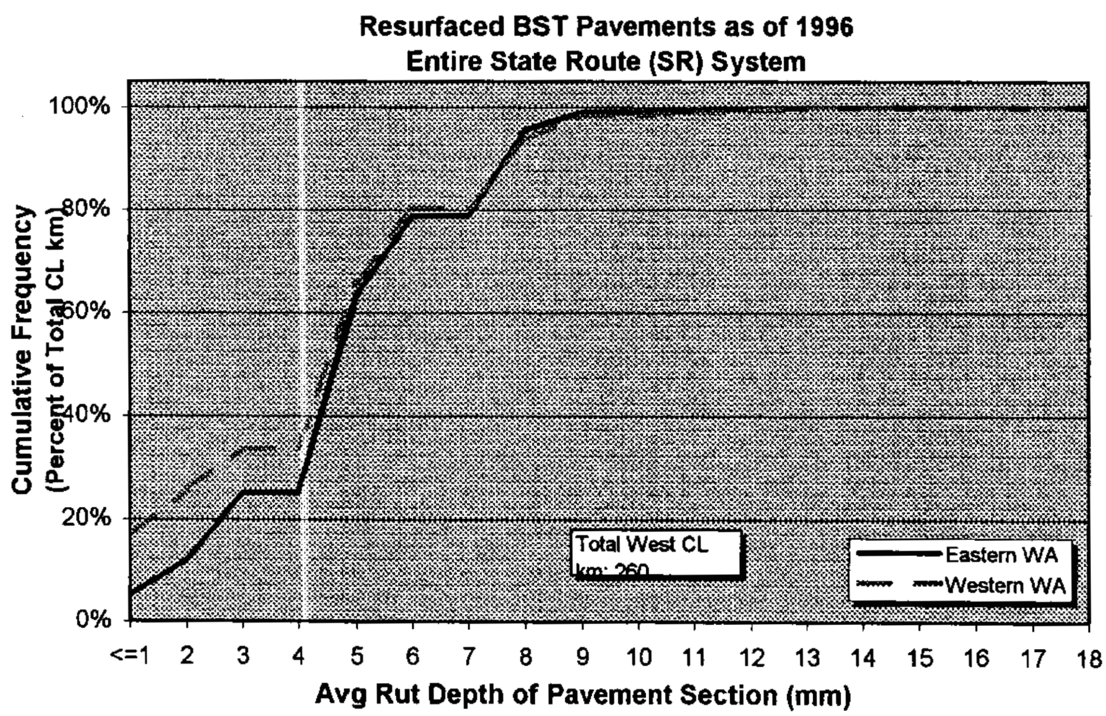


Figure F10. Rutting Cumulative Freq. Curve for Resurfaced BST- SR System

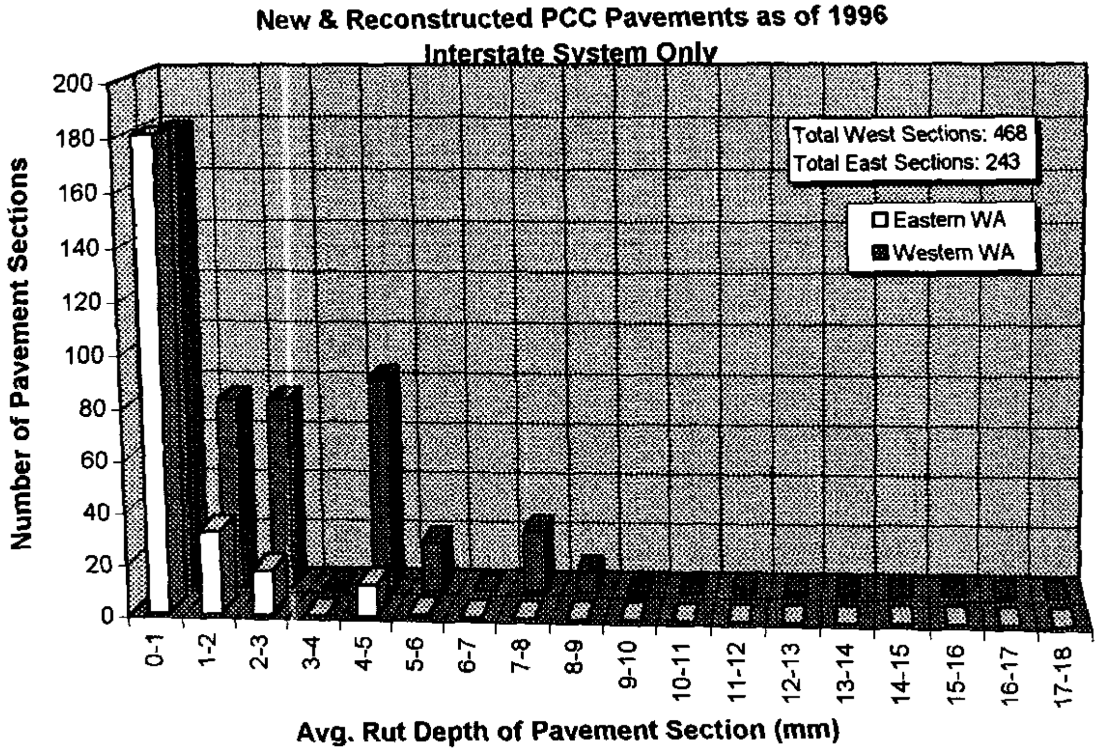


Figure F11. Rutting plot for New & Reconstructed PCC- Interstate

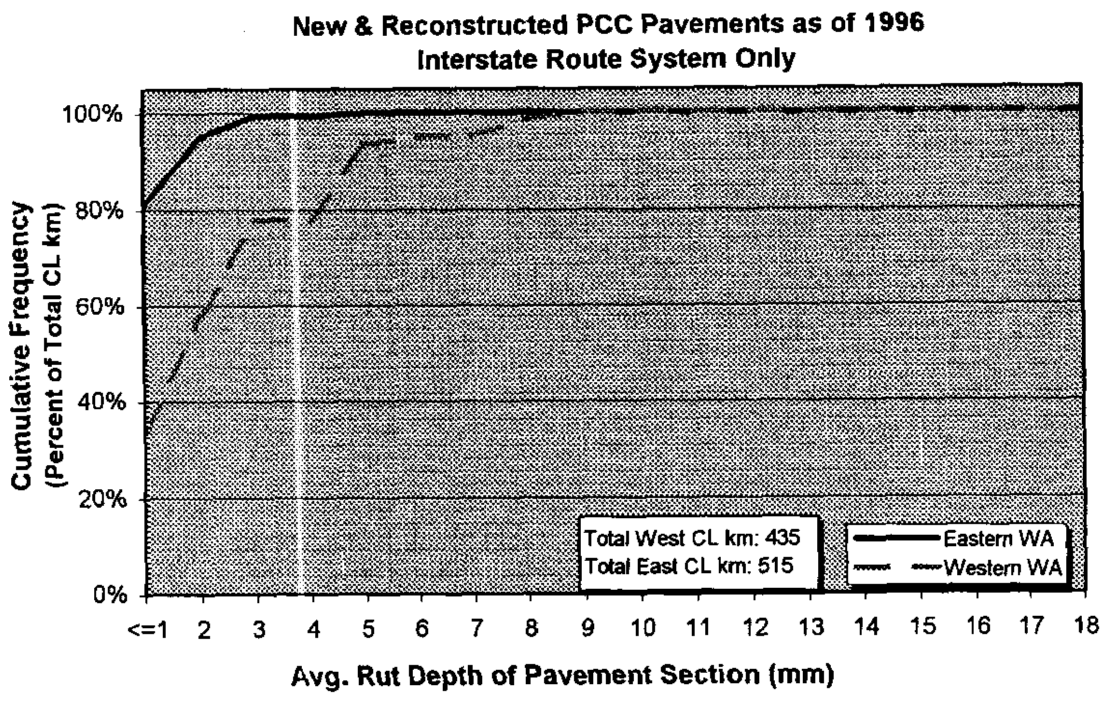


Figure F12. Rutting Cumulative Freq. Curve, New/Reconstructed PCC- Interstate

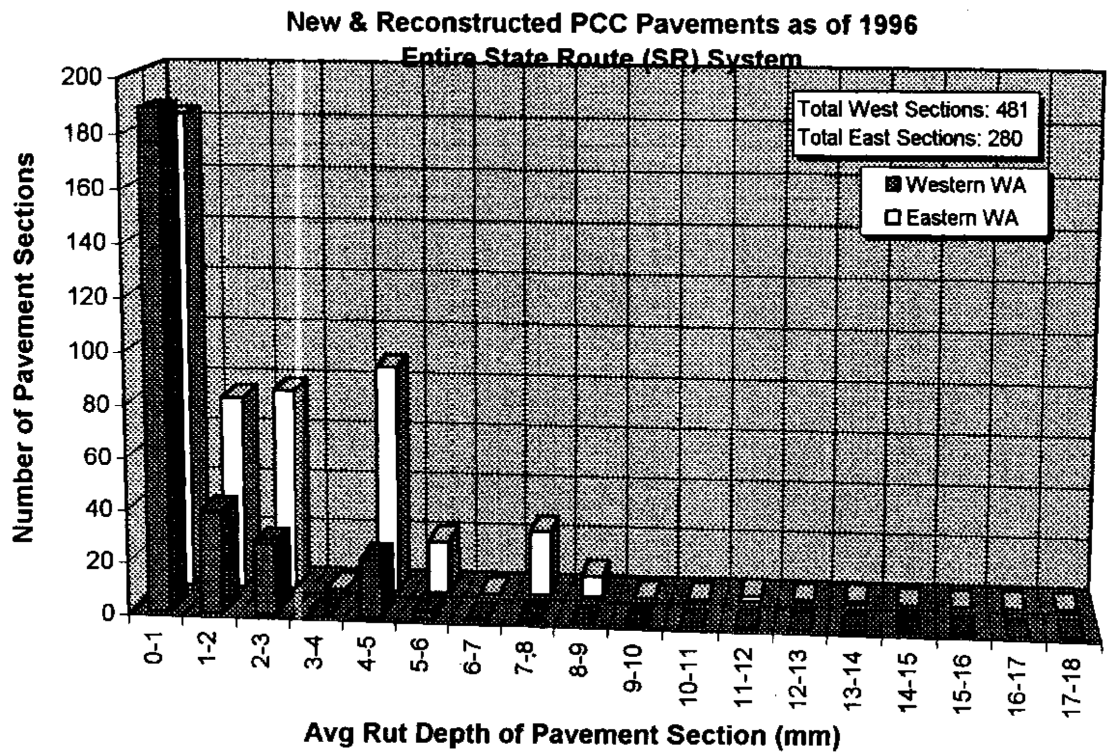


Figure F13. Rutting plot for New & Reconstructed PCC- SR System

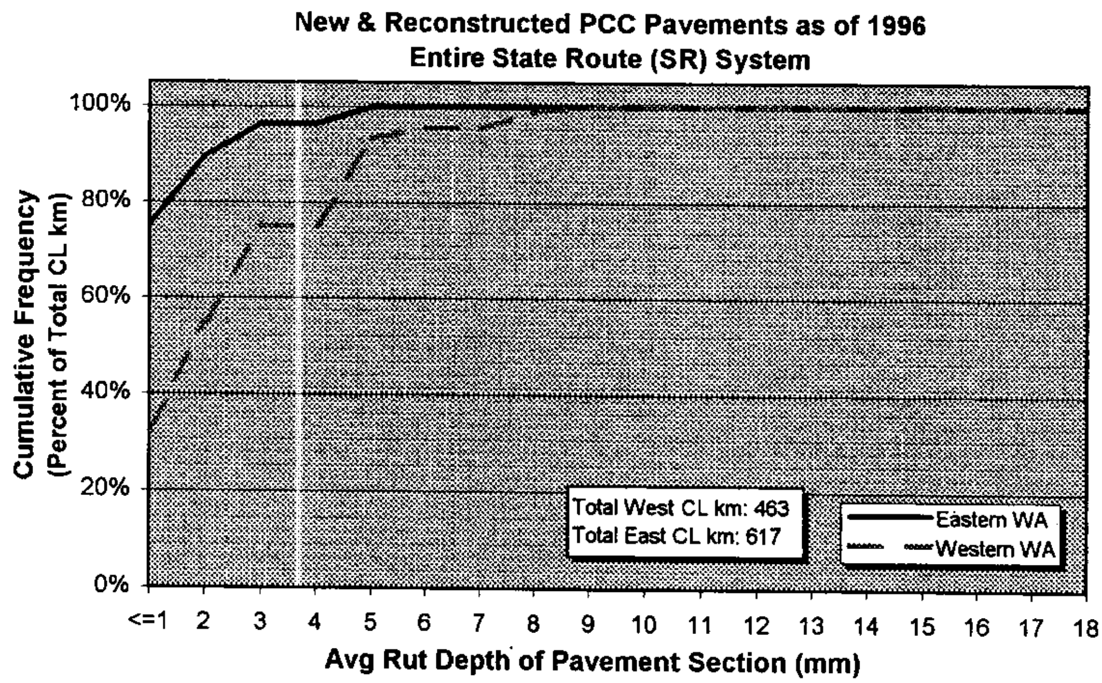


Figure F14. Rutting Cumulative Freq. Curve, New/Reconstructed PCC- SR System

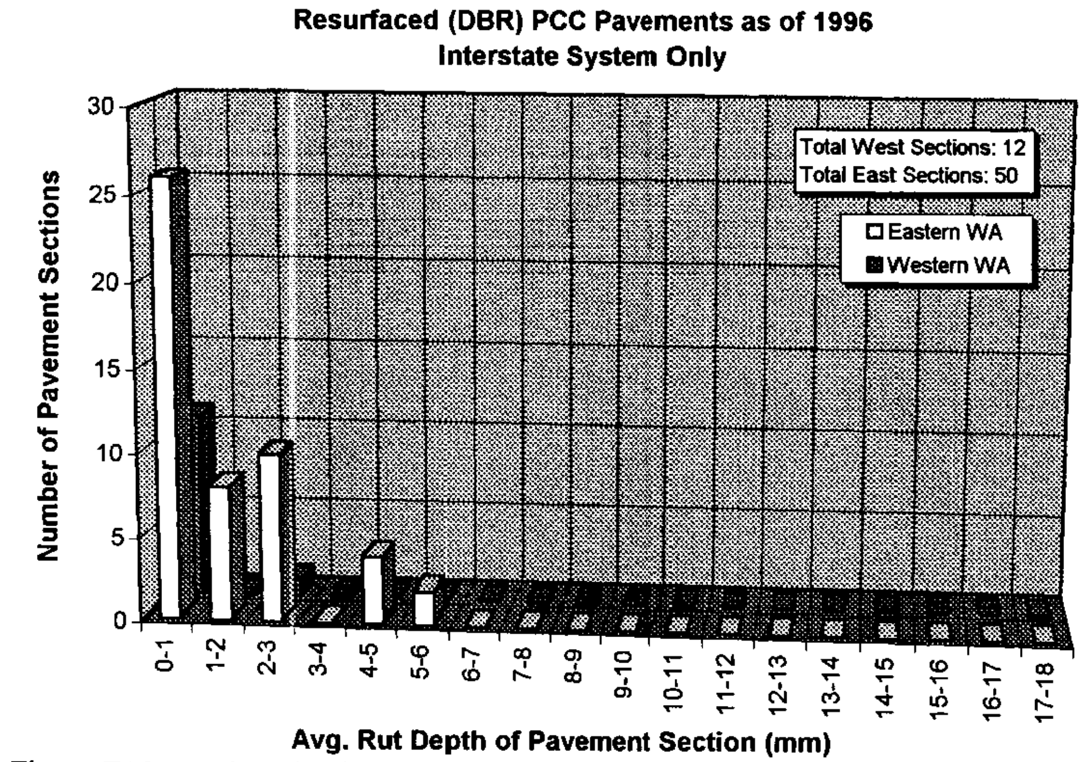


Figure F15. Rutting plot for Resurfaced PCC- Interstate

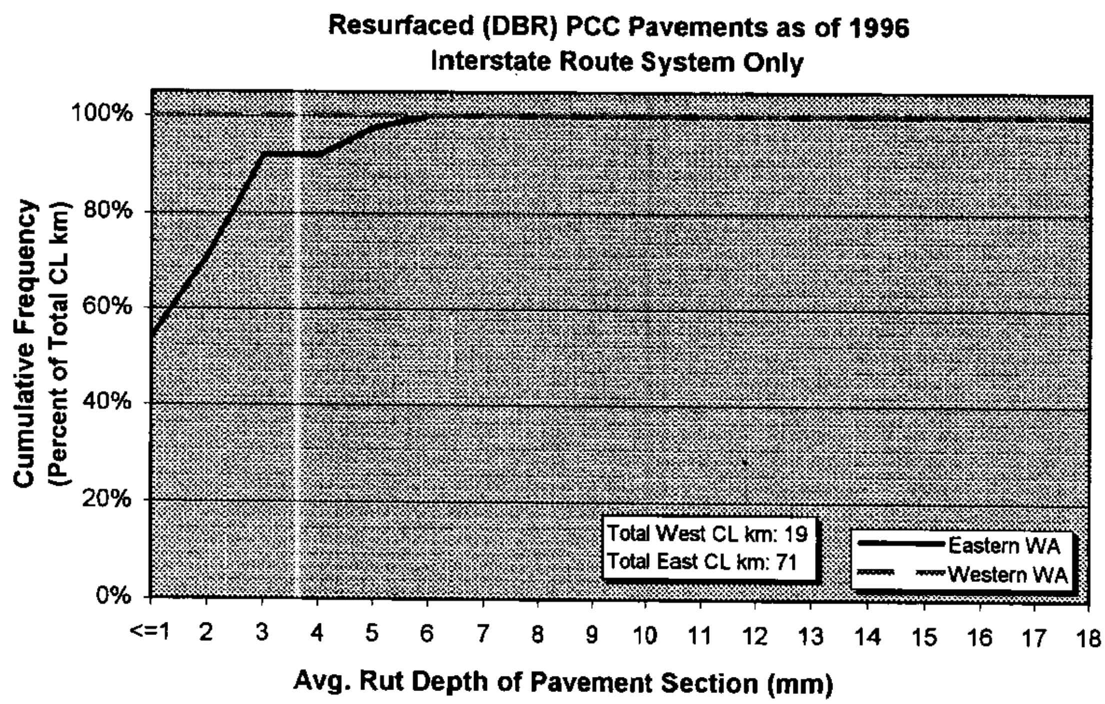


Figure F16. Rutting Cumulative Frequency Curve for Resurfaced PCC- Interstate

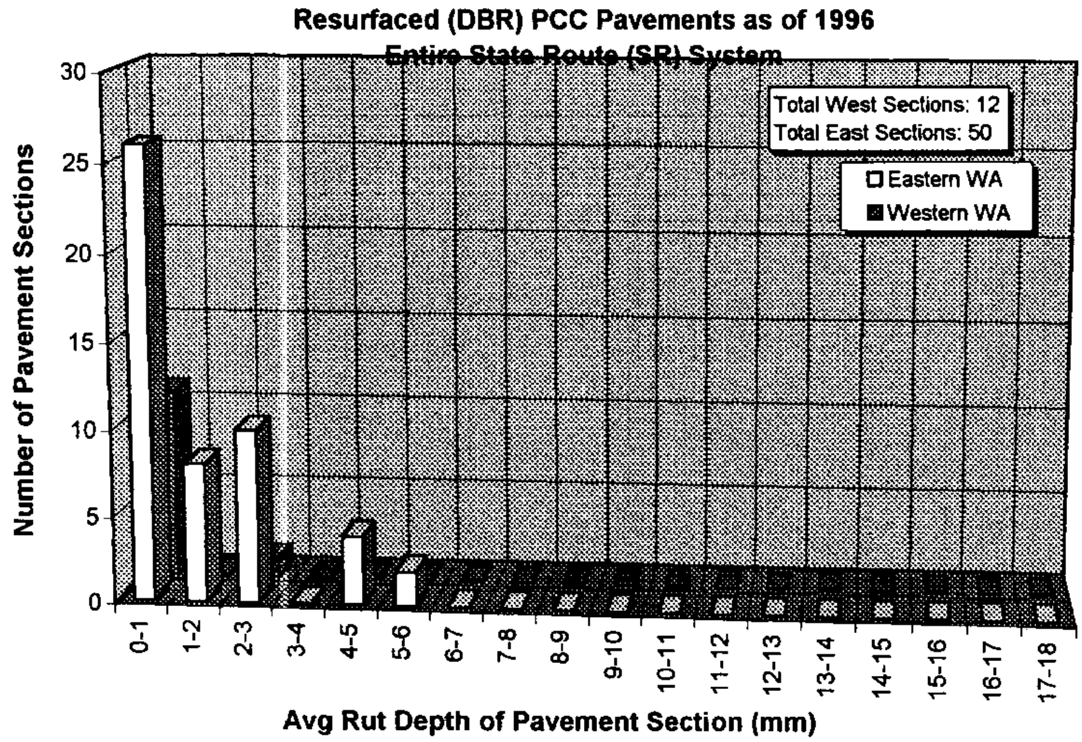


Figure F17. Rutting plot for Resurfaced PCC Pavements- SR System

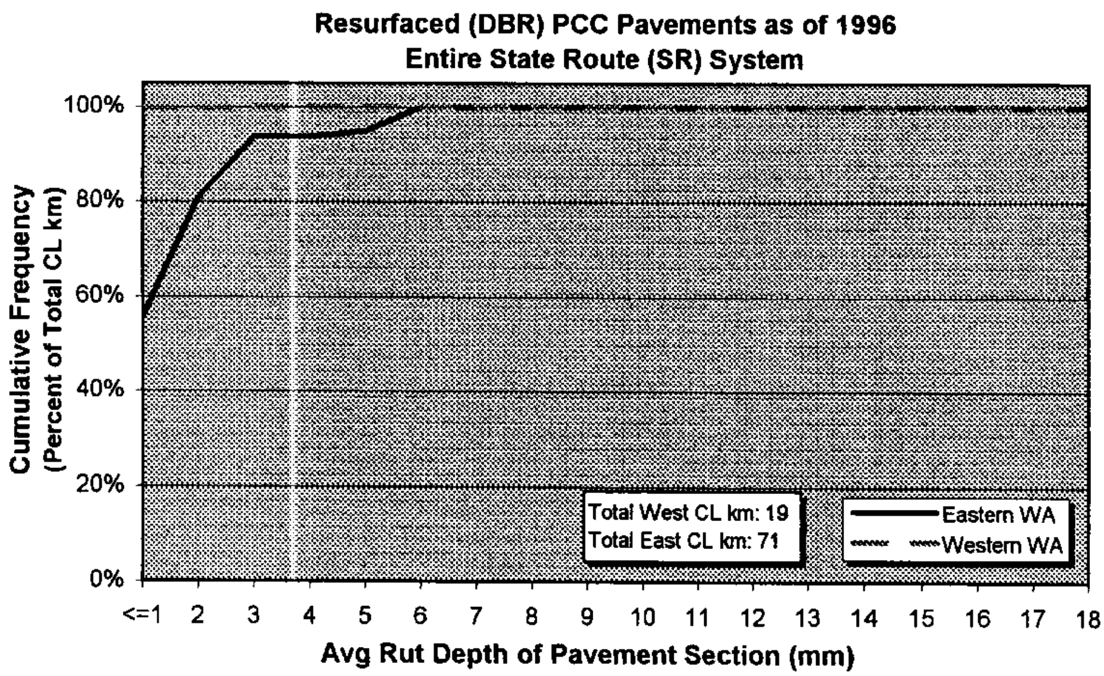


Figure F18. Rutting Cumulative Freq. Curve for Resurfaced PCC- SR System

APPENDIX G: Relational Performance Measure Graphs and Equations

SCATTER PLOTS

The scatter plots contained in this appendix support the relational performance measure analysis summarized in Chapter 6. A total of 54 scatter plots (figures G1-G54) were generated to illustrate the correlation among the five different performance measures for each of the six relationships of interest:

- PSC vs Age
- IRI vs Age
- Rutting vs Age
- PSC vs IRI
- PSC vs Rutting
- IRI vs Rutting

A total of 104 relationships were plotted, since relationships were stratified by high and low ESAL levels. In each case, duplicate data points exist that cannot be seen in the plots because they simply "stack" when printed. This has little if any effect on visualizing performance trends. The total population number of data points (n) and correlation coefficient (*r*) are reported on each plot. To help viewers visualize the effect of traffic levels, each analysis group was broken into high and low ESAL levels with the approximate median ESAL value serving as the boundary.

The WSPMS contains some suspect Age data, primarily because of a lag in updating the database after rehabilitation has taken place. This likely contributed to what is seen as potential outliers in many of the plots. It is difficult, if not impossible, to accurately detect all outliers within the WSPMS, and no statistical outlier test was performed. Rather, all data were initially taken at face value and plotted. However, the presence of potential outliers with high age values caused severe "clumping" in the scatter plots, making it difficult to clearly visualize performance trends. Experience with the WSPMS suggests that, intuitively, AC and BST pavements in Washington State generally do not last longer than 20 years. So to help alleviate the "clumping" problem, all data points over 20 years were summarily eliminated, and scatter plots were regenerated to consider 0- to 20-year-old pavement sections only.

These revised plots, which helped to spread the data and illustrate performance trends in greater detail, are shown for comparison (on the same page) with plots of all data in Appendix G. This process was only necessary for cases in which performance measures were compared with pavement Age. All other performance measure values (PSC, IRI, and rutting) are updated in the WSPMS promptly after visual distress surveys have been completed. Therefore, the presence of outliers among these performance measures was assumed to be reasonably reduced or eliminated.

REGRESSION EQUATIONS

The linear regression equations defining each of the 104 scatter plot relationships illustrated are listed in table G1 through G6 for each of the six analysis groups studied. Section 6.2.4 of Chapter 6 briefly describes the variables and statistics represented in the tables.

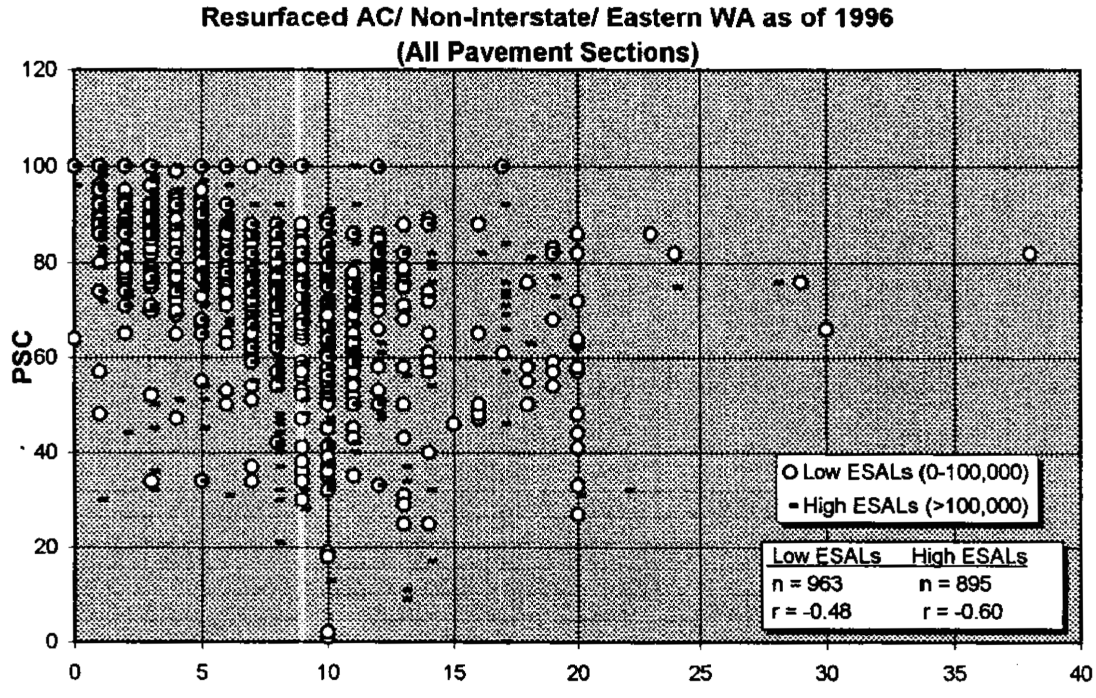


Figure G1. PSC vs. Age for Resurfaced, Non-Interstate AC in Eastern WA- All Sections

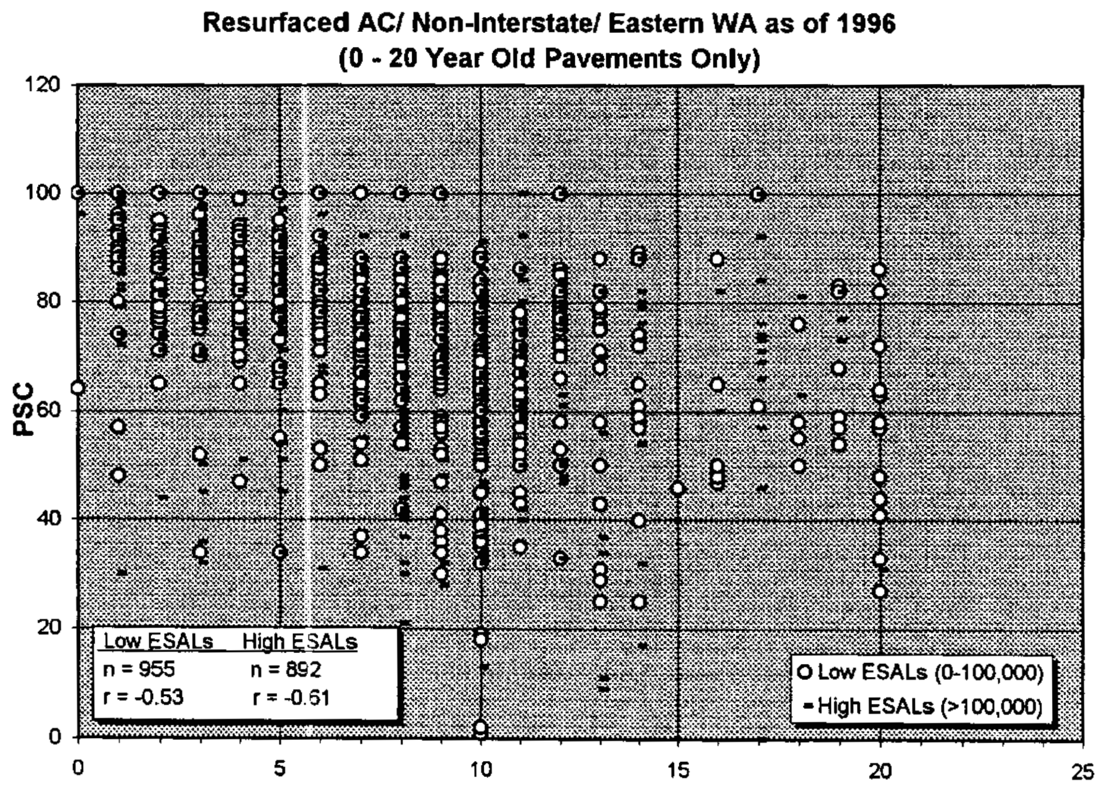


Figure G2. PSC vs. Age for Resurfaced, Non-Interstate AC in Eastern WA- (0-20 years)

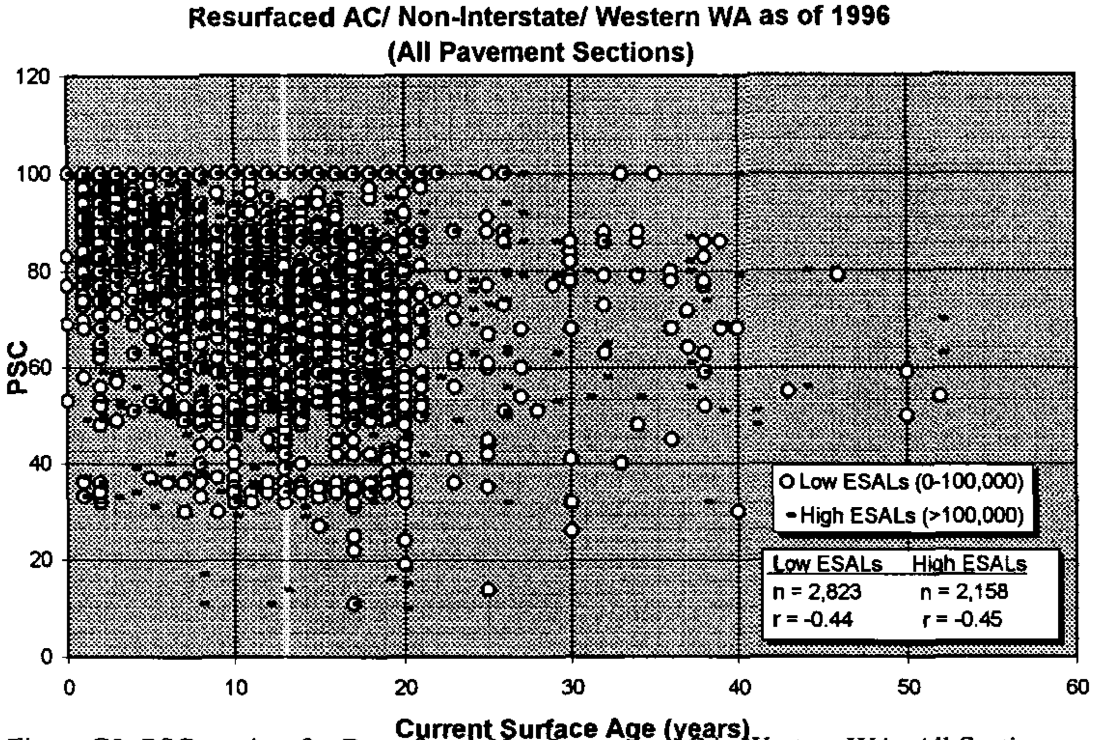


Figure G3. PSC vs. Age for Resurfaced, Non-Interstate AC in Western WA- All Sections

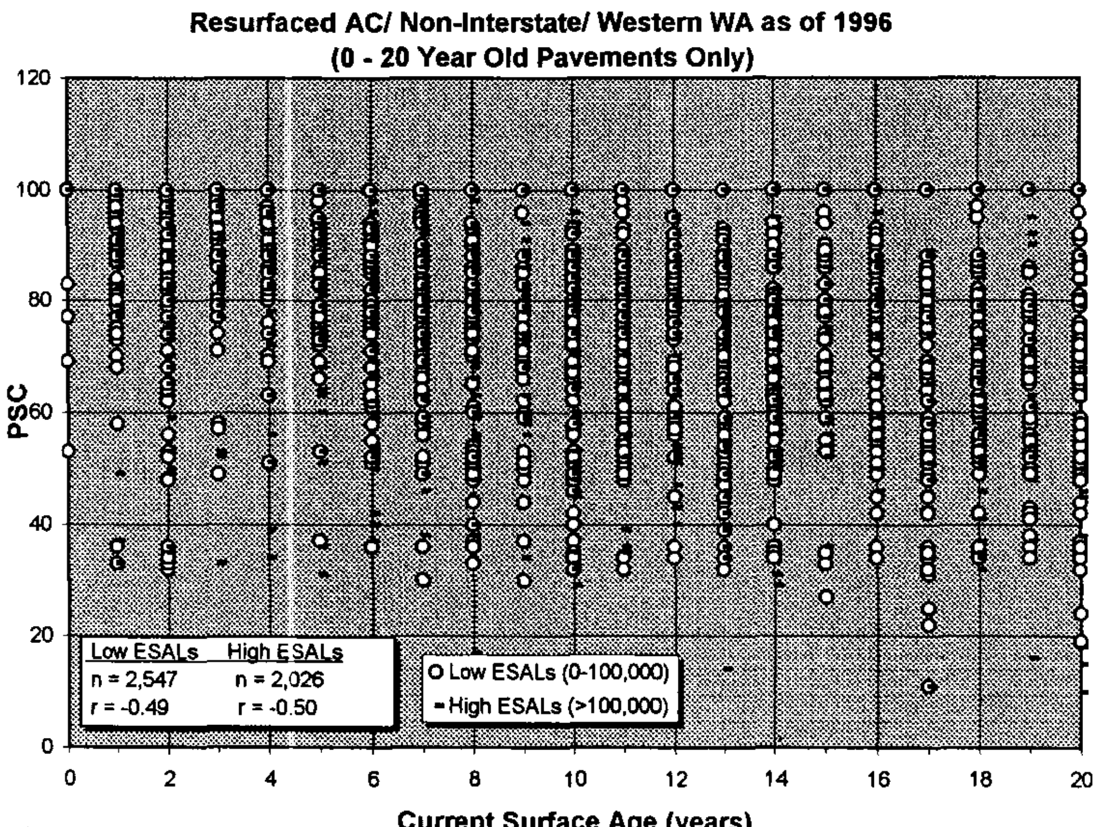


Figure G4. PSC vs. Age for Resurfaced, Non-Interstate AC in Western WA- (0-20 years)

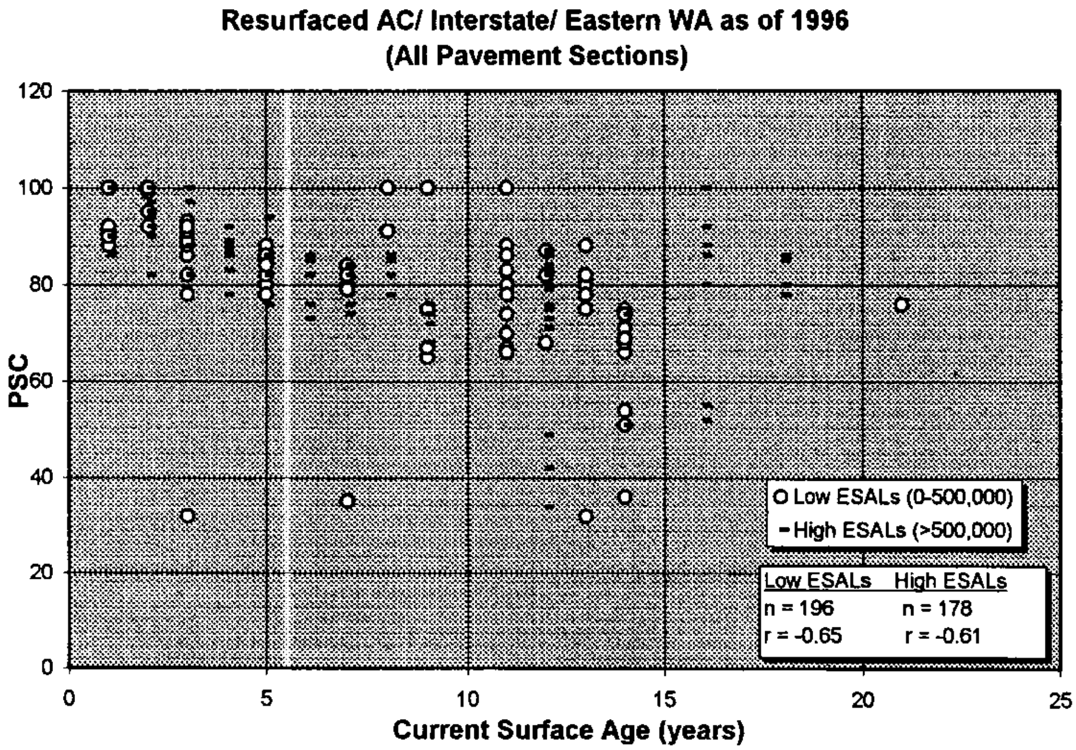


Figure G5. PSC vs. Age for Resurfaced, Interstate AC in Eastern WA- All Sections

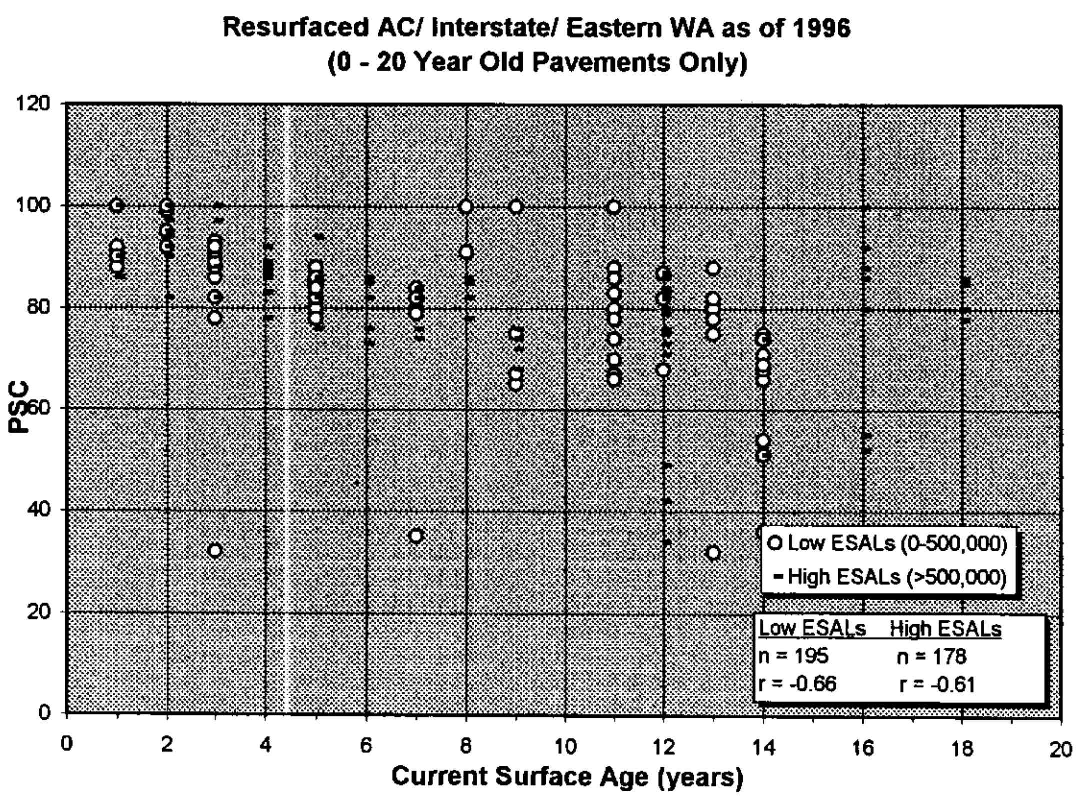


Figure G6. PSC vs. Age for Resurfaced, Interstate AC in Eastern WA- (0-20 years)

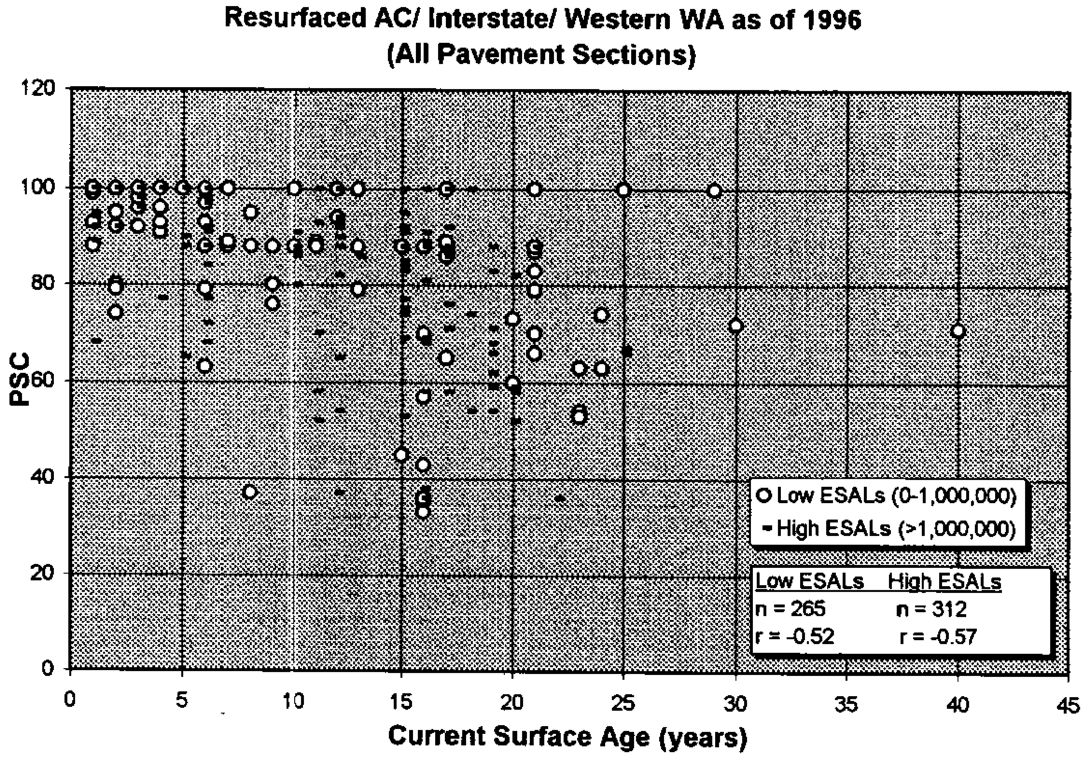


Figure G7. PSC vs. Age for Resurfaced, Interstate AC in Western WA- All Sections

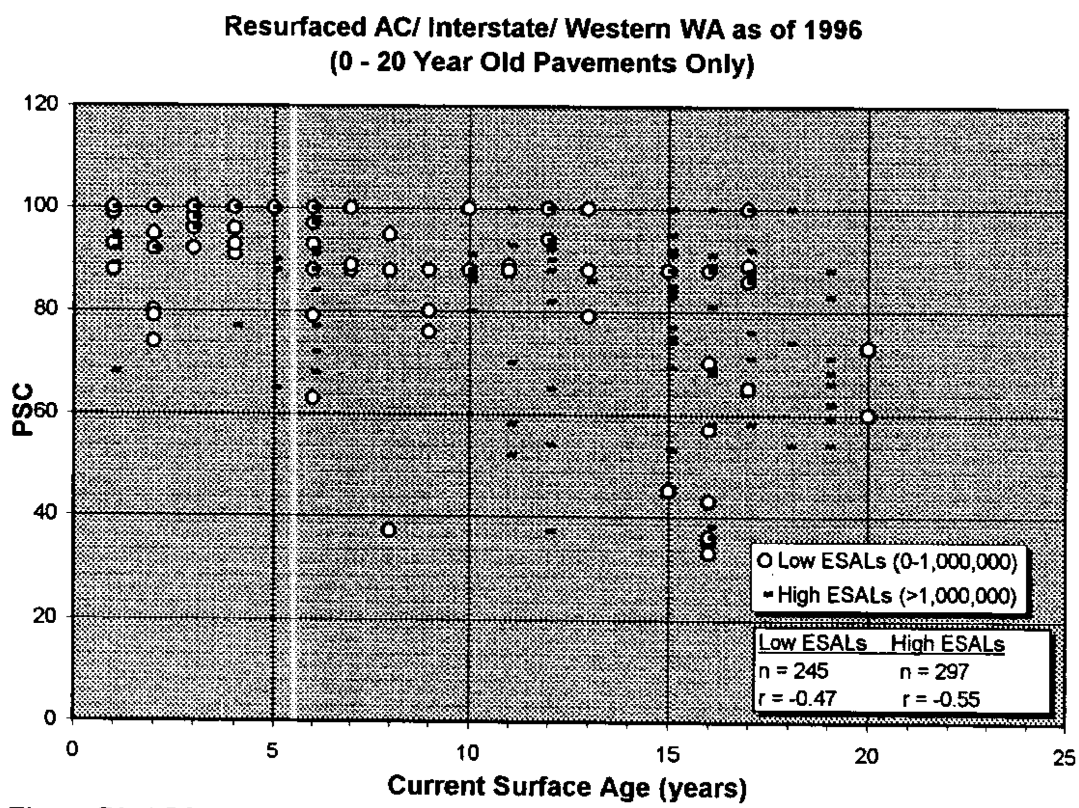


Figure G8. PSC vs. Age for Resurfaced. Interstate AC in Western WA- (0-20 years)

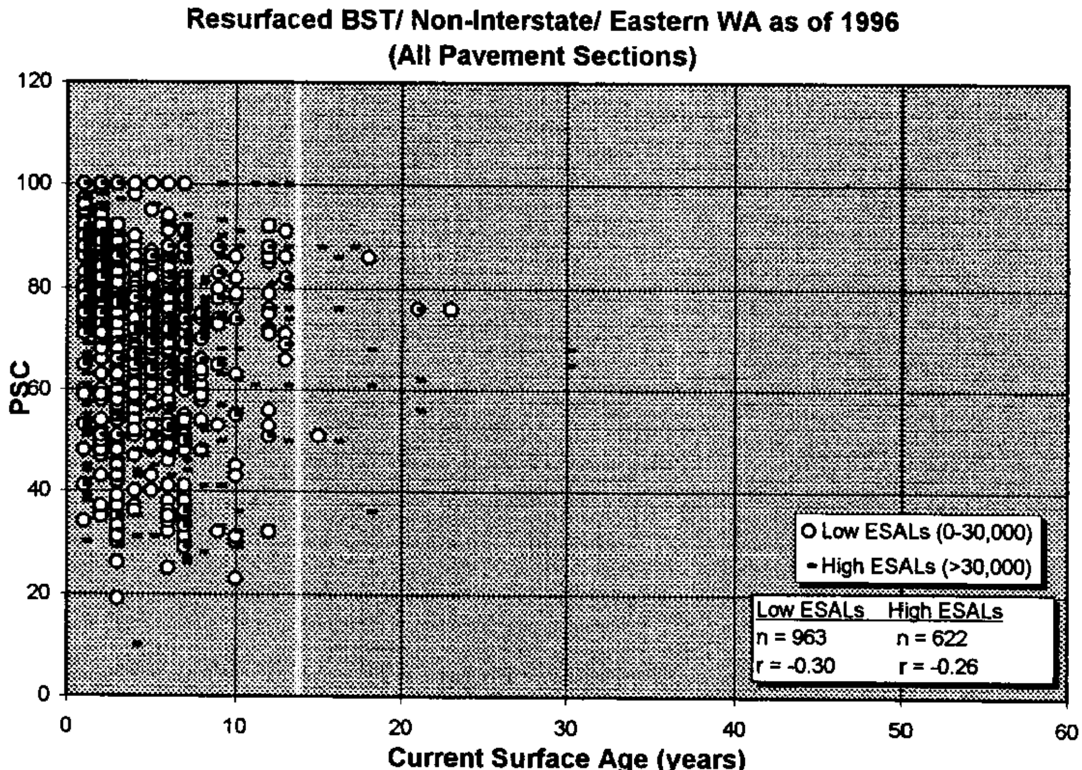


Figure G9. PSC vs. Age for Resurfaced, Non-Interstate BST in Eastern WA- All

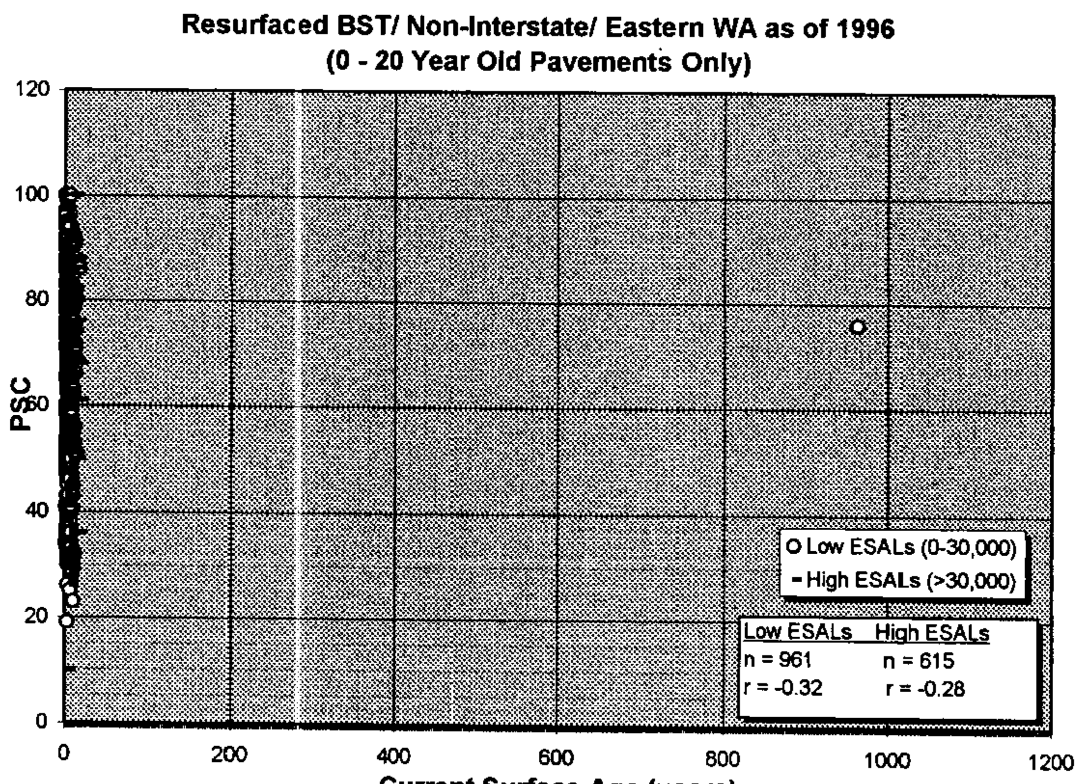


Figure G10. PSC vs. Age for Resurfaced, Non-Interstate BST in Eastern WA- (0-20

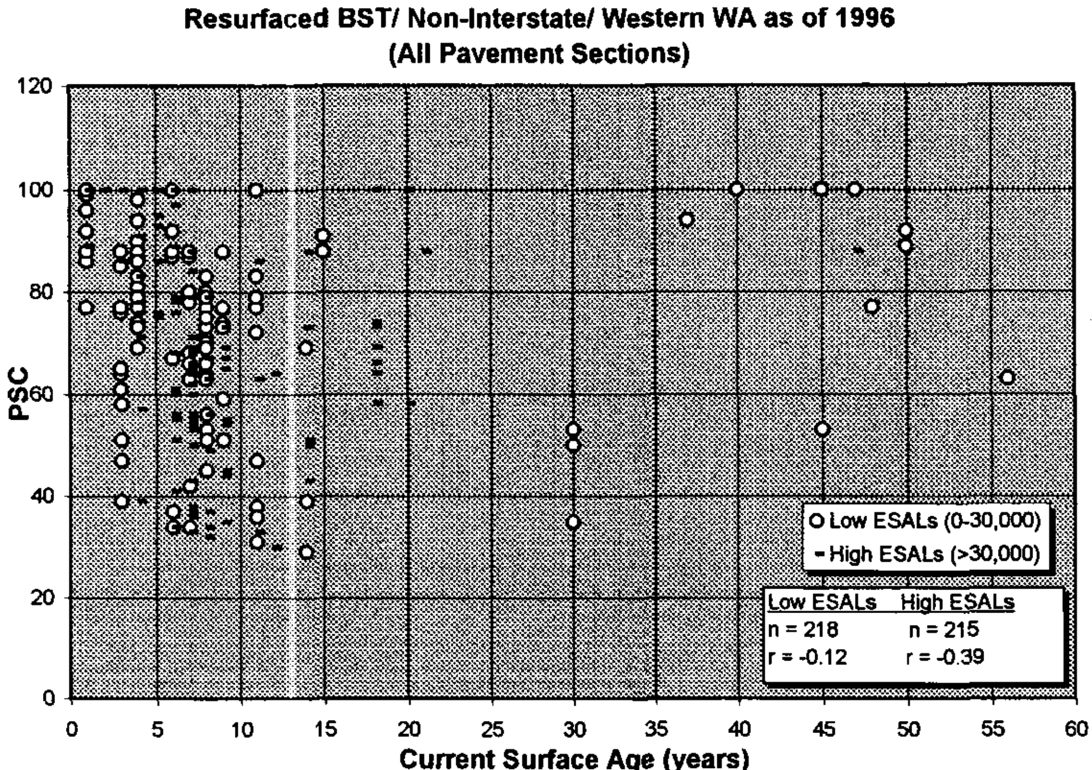


Figure G11. PSC vs. Age for Resurfaced, Non-Interstate BST, Western WA- All Sections

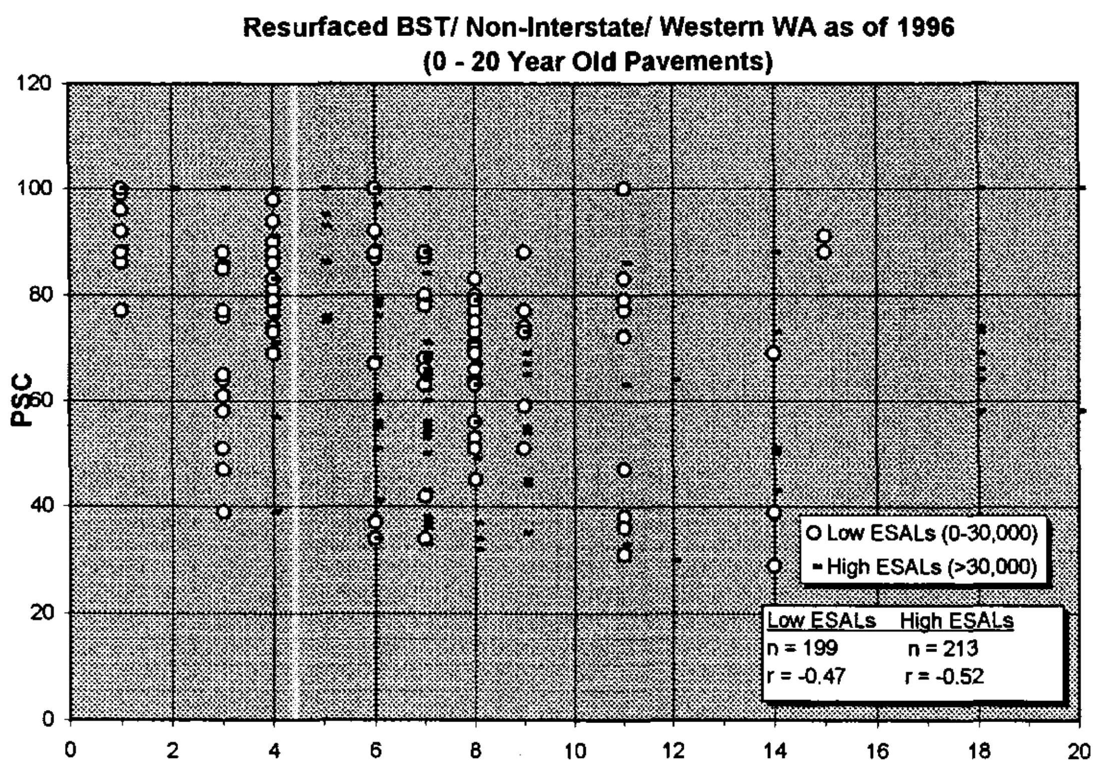


Figure G12. PSC vs. Age for Resurfaced, Non-Interstate BST, Western WA- (0-20 years)

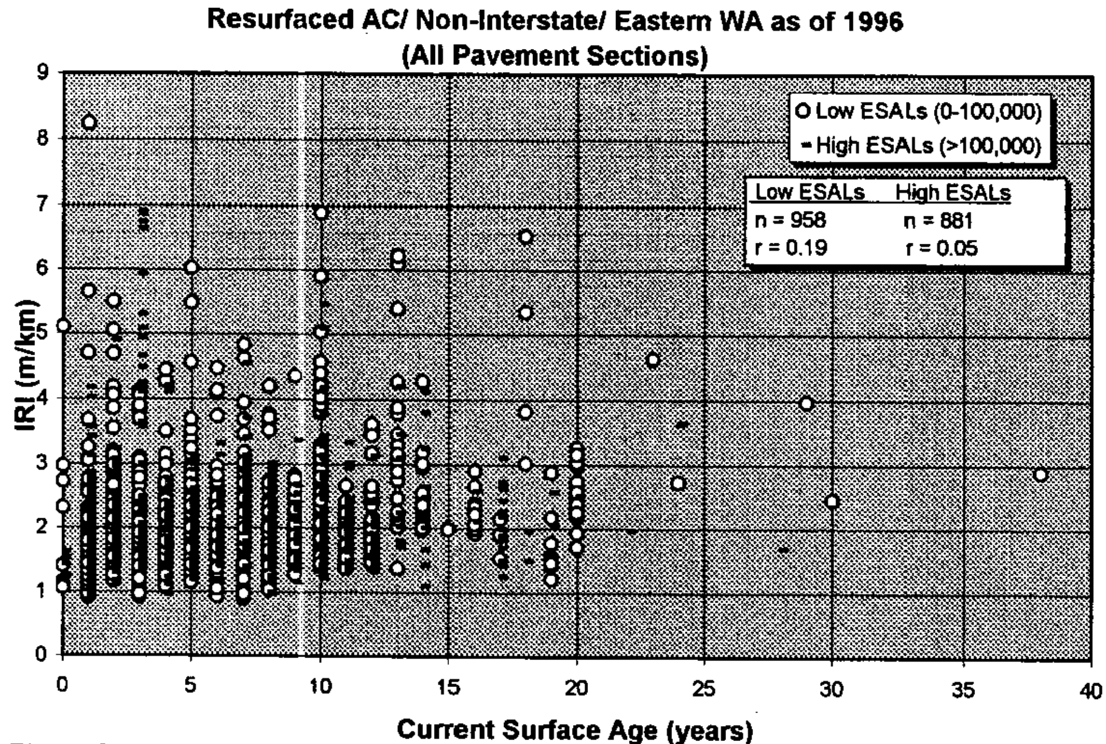


Figure G13. IRI vs. Age for Resurfaced, Non-Interstate AC in Eastern WA- All Sections

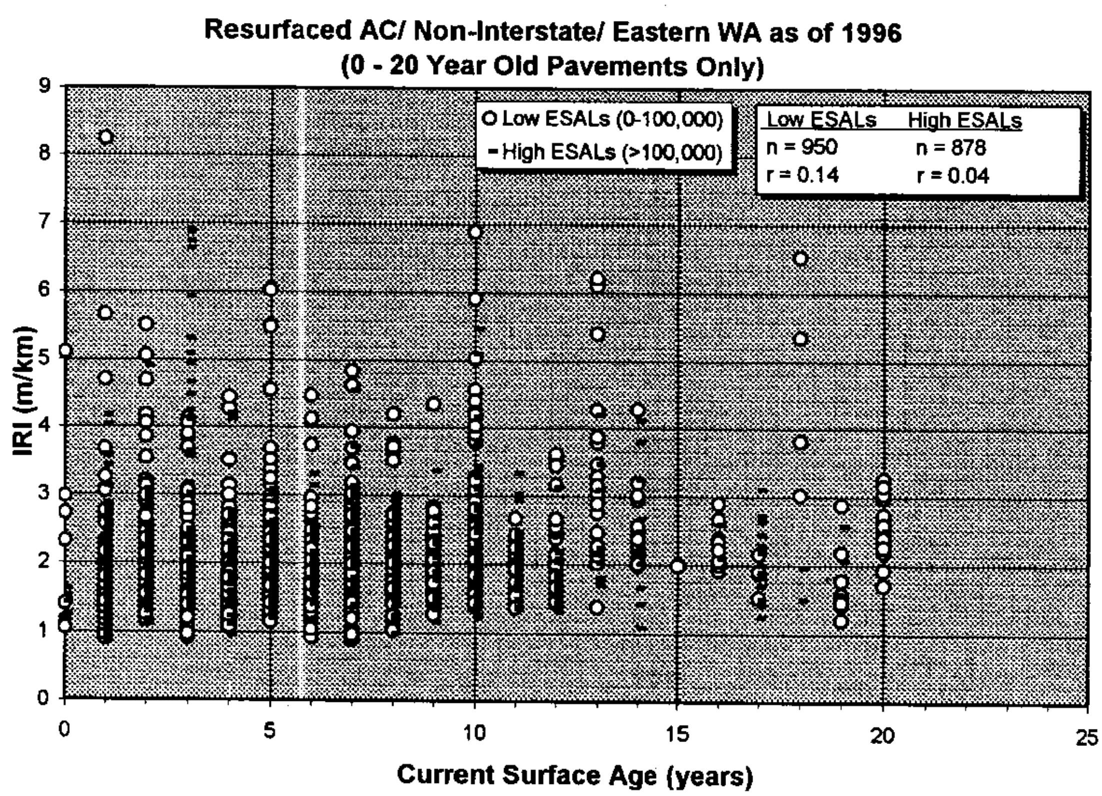


Figure G14. IRI vs. Age for Resurfaced, Non-Interstate AC in Eastern WA- (0-20 years)

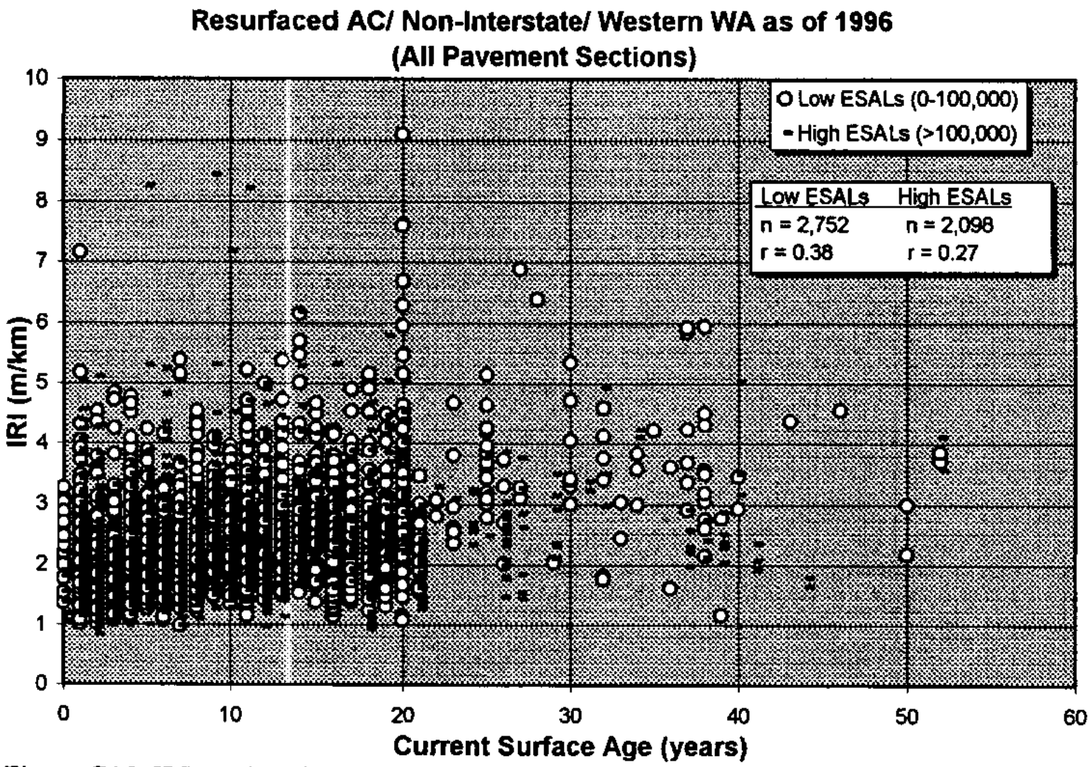


Figure G15. IRI vs. Age for Resurfaced, Non-Interstate AC in Western WA- All Sections

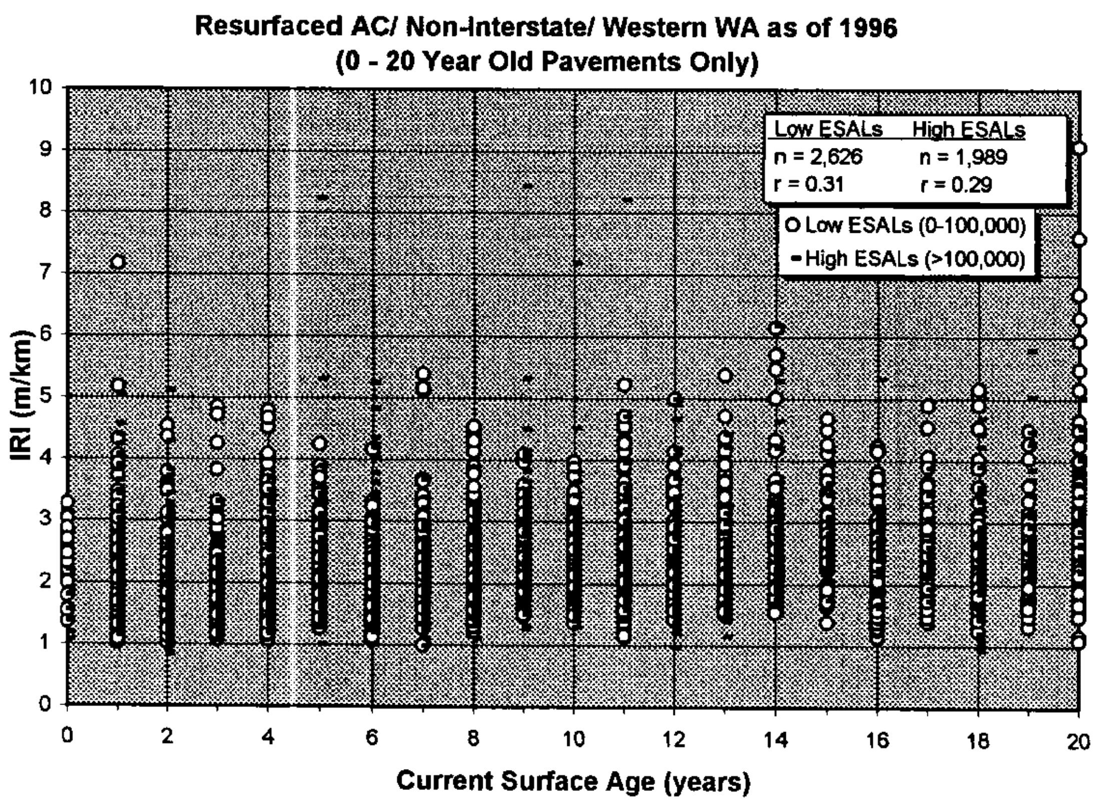


Figure G16. IRI vs. Age for Resurfaced, Non-Interstate AC in Western WA- (0-20 years)

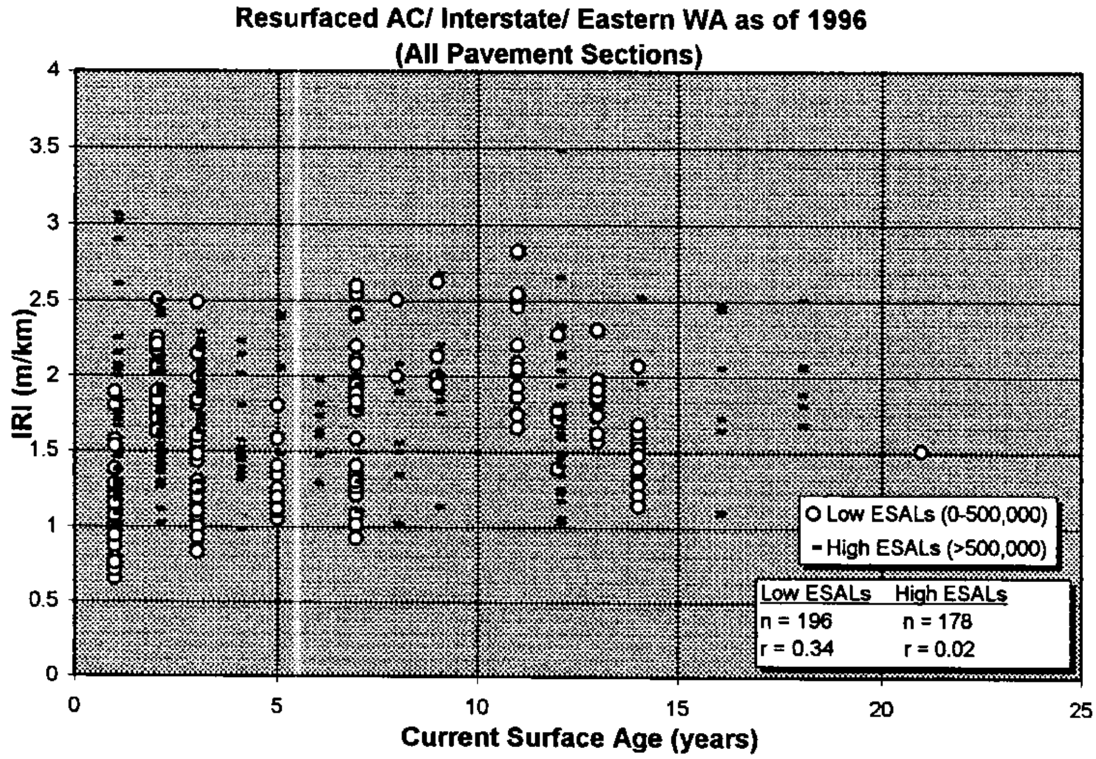


Figure G17. IRI vs. Age for Resurfaced, Interstate AC in Eastern WA- All Sections

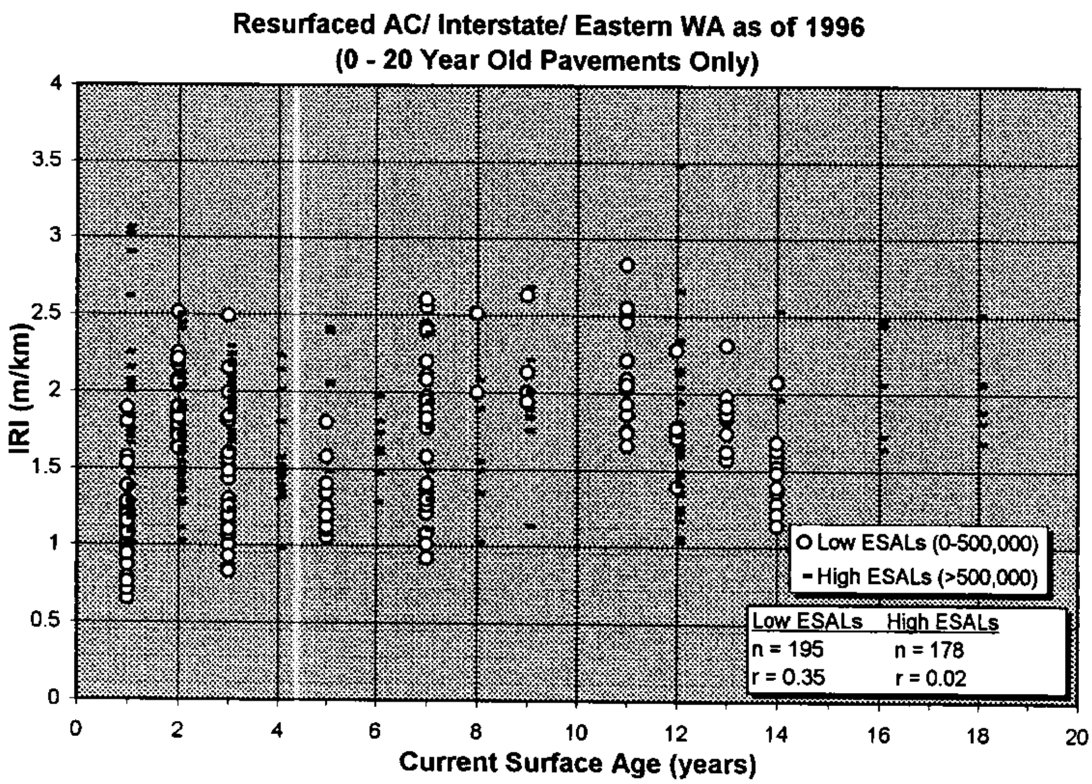


Figure G18. IRI vs. Age for Resurfaced, Interstate AC in Eastern WA- (0-20 years)

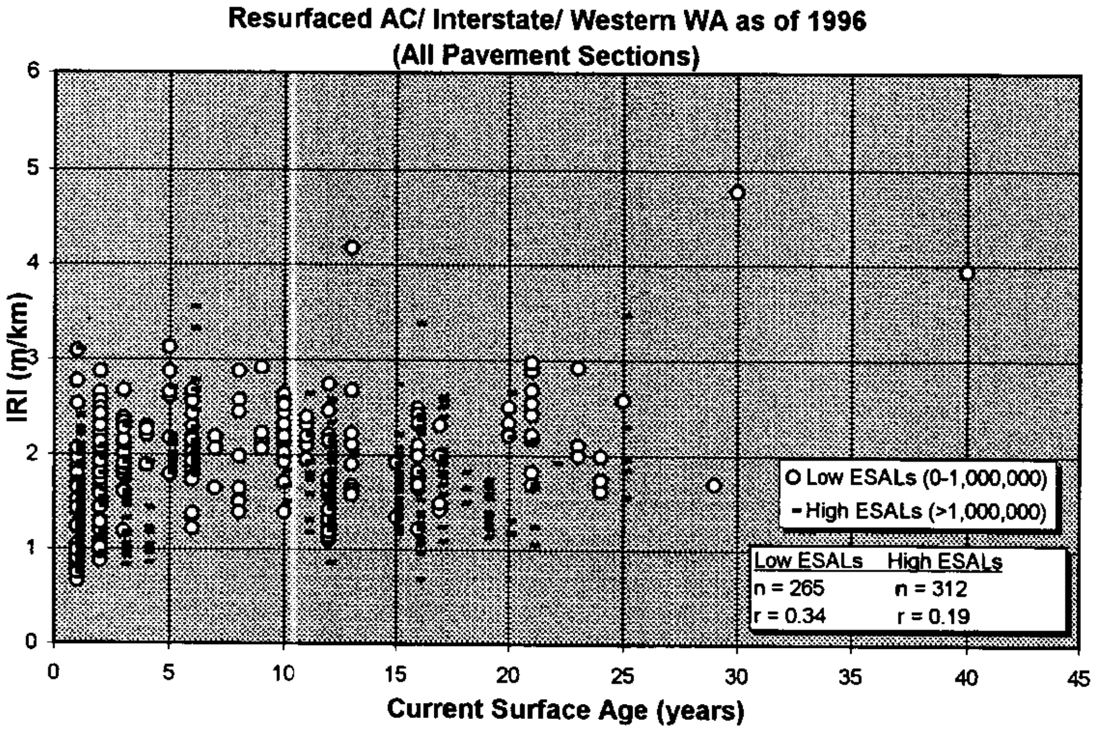


Figure G19. IRI vs. Age for Resurfaced, Interstate AC in Western WA- All Sections

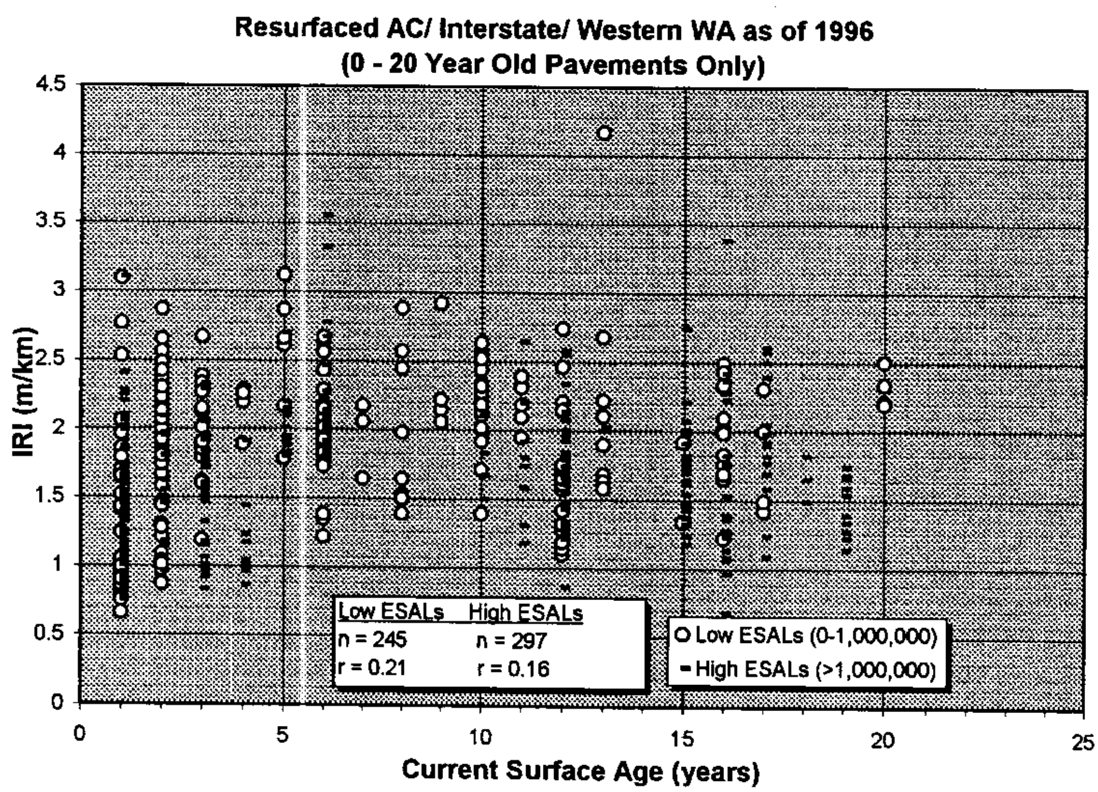


Figure G20. IRI vs. Age for Resurfaced, Interstate AC in Western WA- (0-20 years)

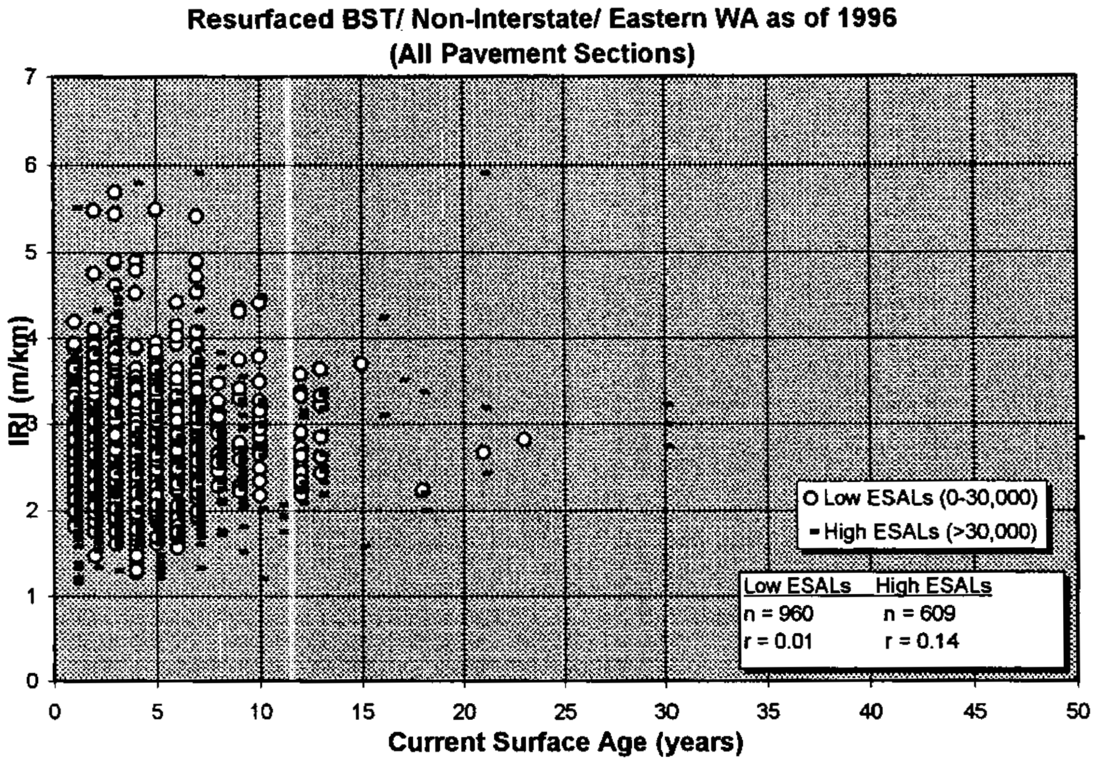


Figure G21. IRI vs. Age for Resurfaced. Non-Interstate BST in Eastern WA- All Sections

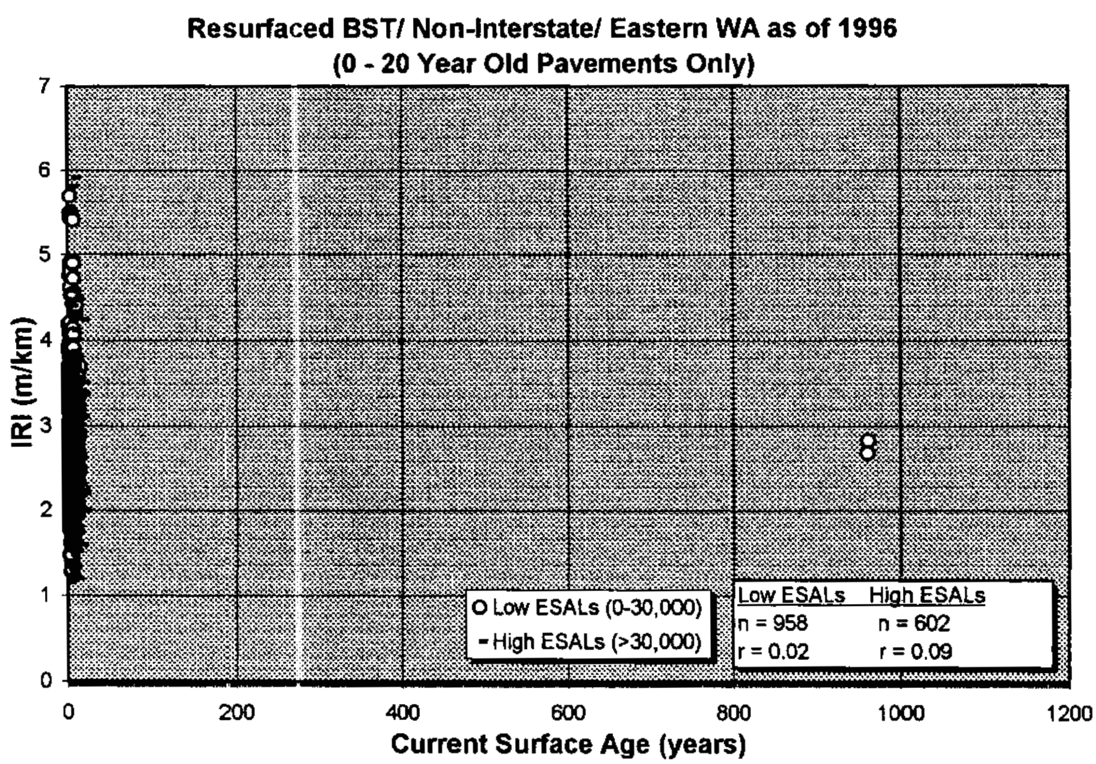


Figure G22. IRI vs. Age for Resurfaced, Non-Interstate BST in Eastern WA- (0-20 years)

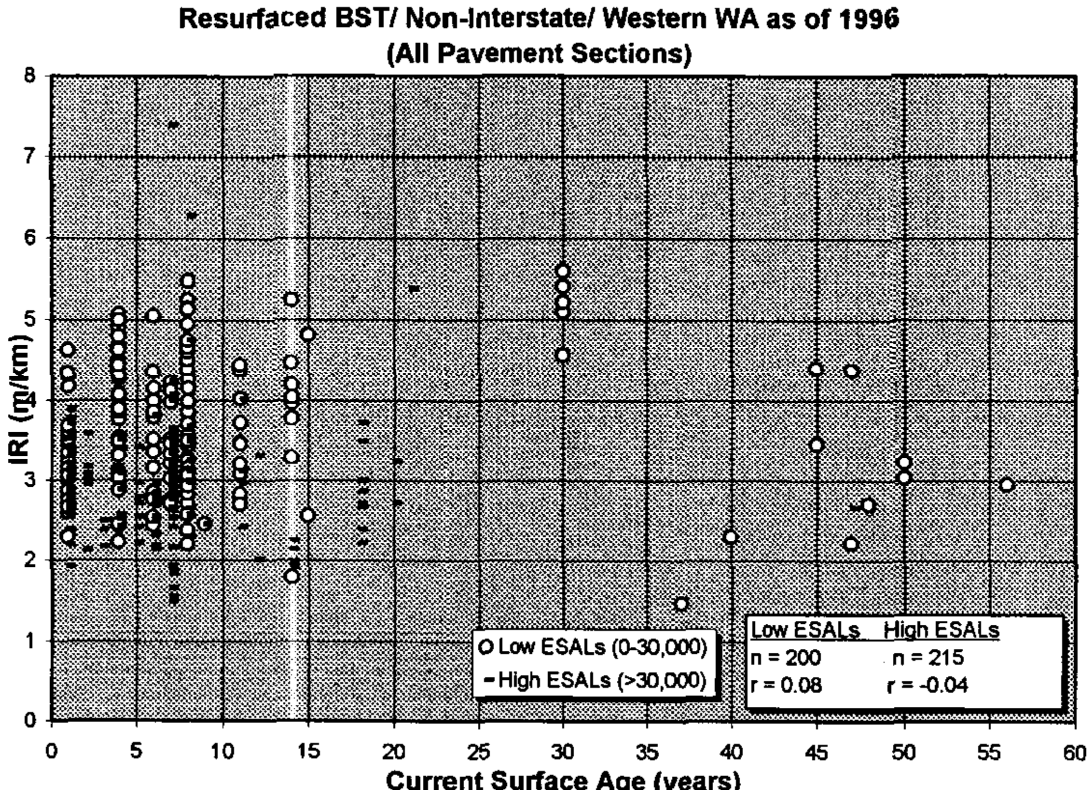


Figure G23. IRI vs. Age for Resurfaced, Non-Interstate BST, Western WA- All Sections

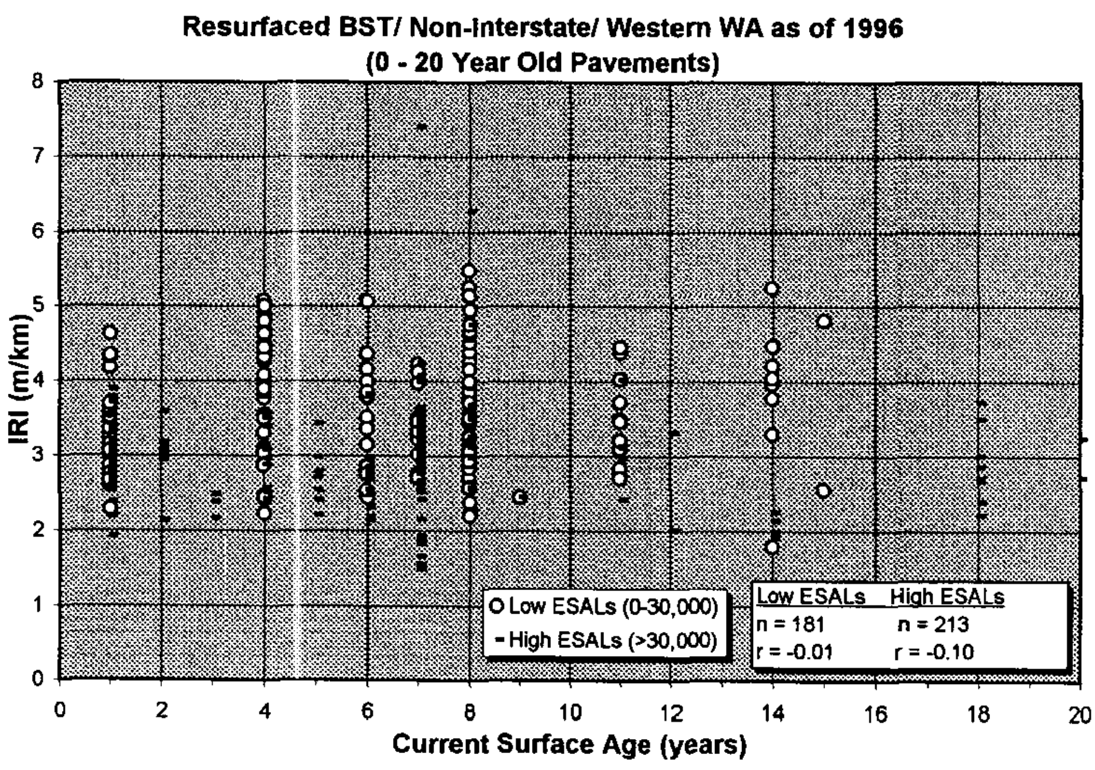


Figure G24. IRI vs. Age for Resurfaced, Non-Interstate BST, Western WA- (0-20 years)

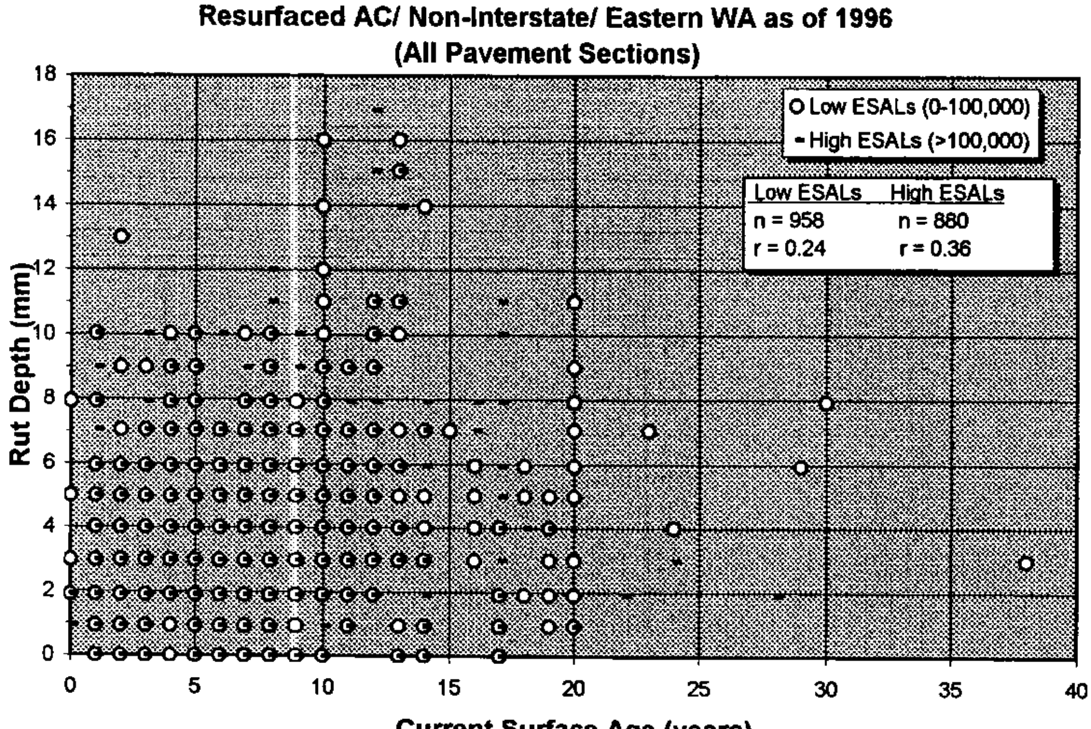


Figure G25. Rutting vs. Age for Resurfaced, Non-Interstate AC, Eastern WA- All Sections

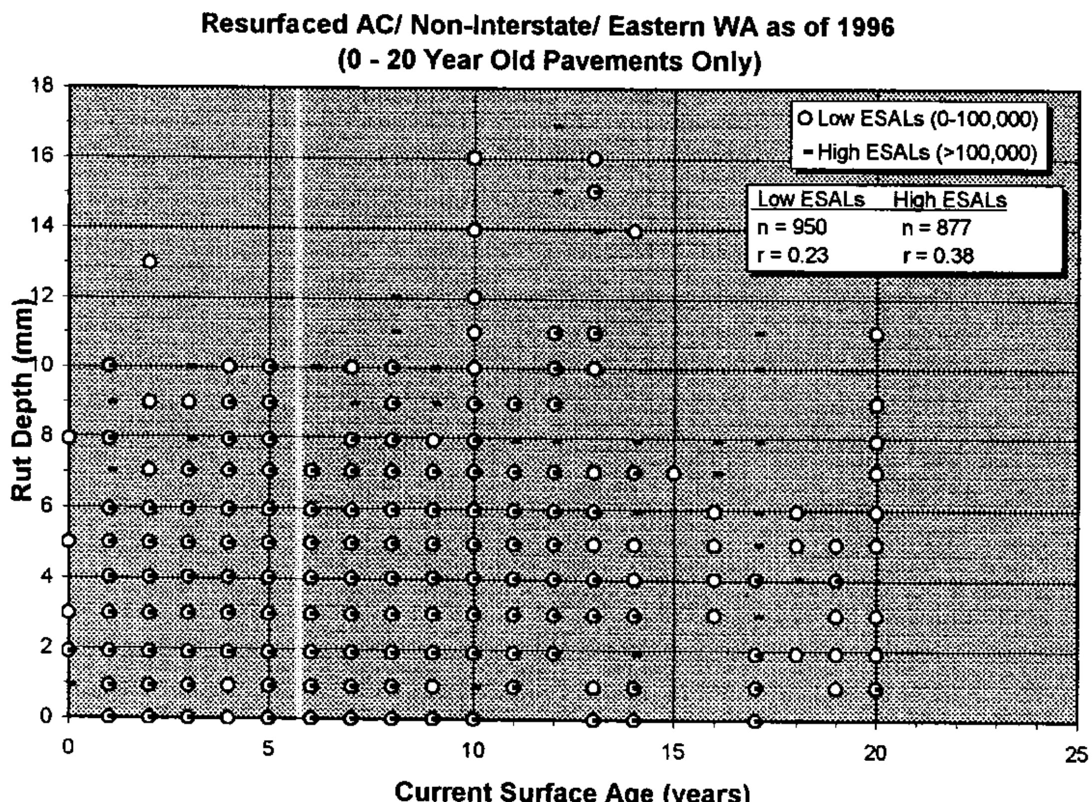


Figure G26. Rutting vs. Age for Resurfaced. Non-Interstate AC. Eastern WA- (0-20 years)

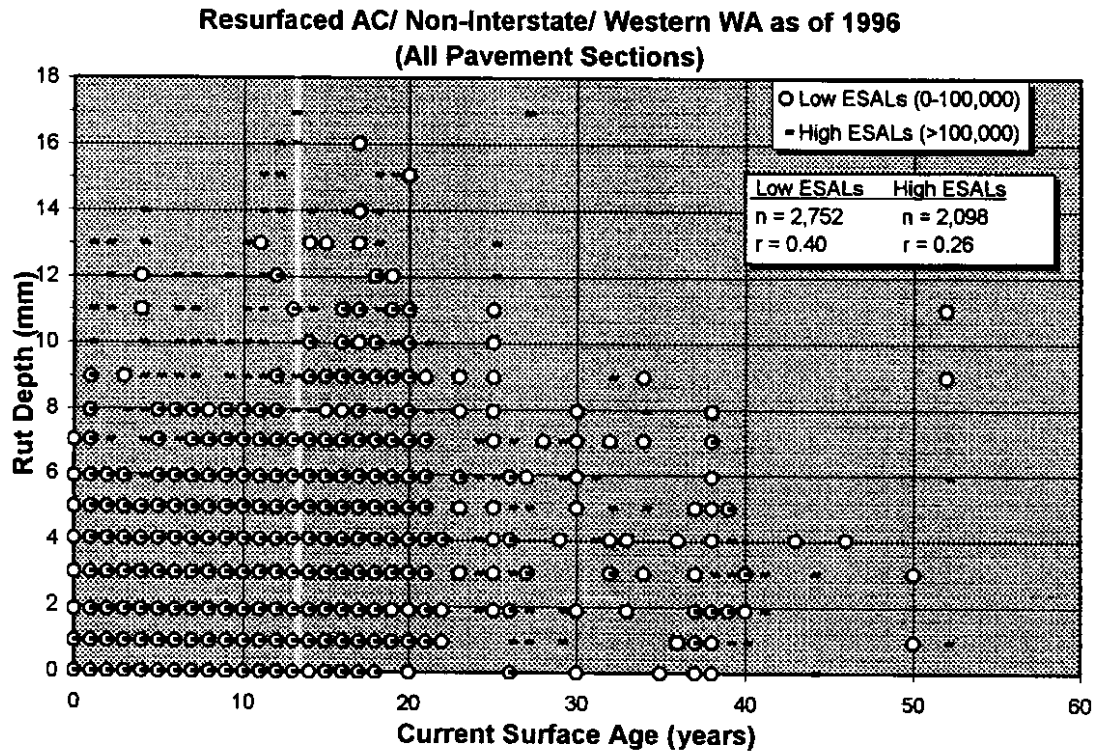


Figure G27. Rutting vs. Age for Resurfaced, Non-Interstate AC, Western WA- All Sections

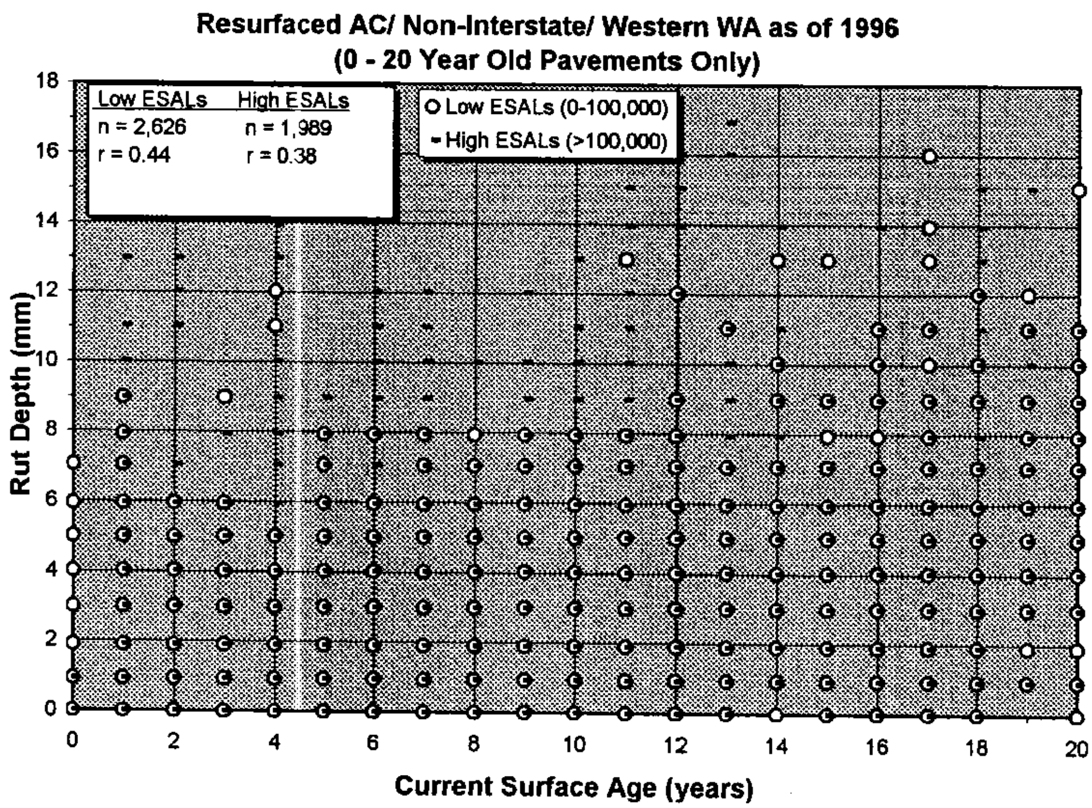


Figure G28. Rutting vs. Age for Resurfaced, Non-Interstate AC, Western WA- (0-20 years)

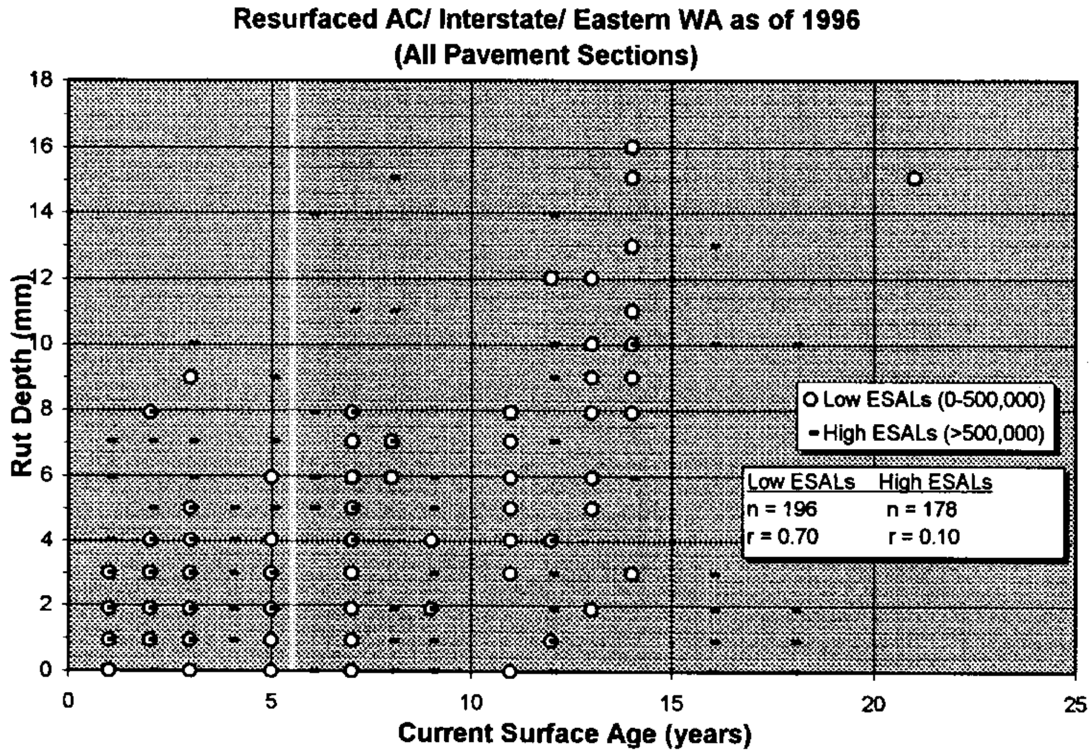


Figure G29. Rutting vs. Age for Resurfaced, Interstate AC, Eastern WA- All Sections

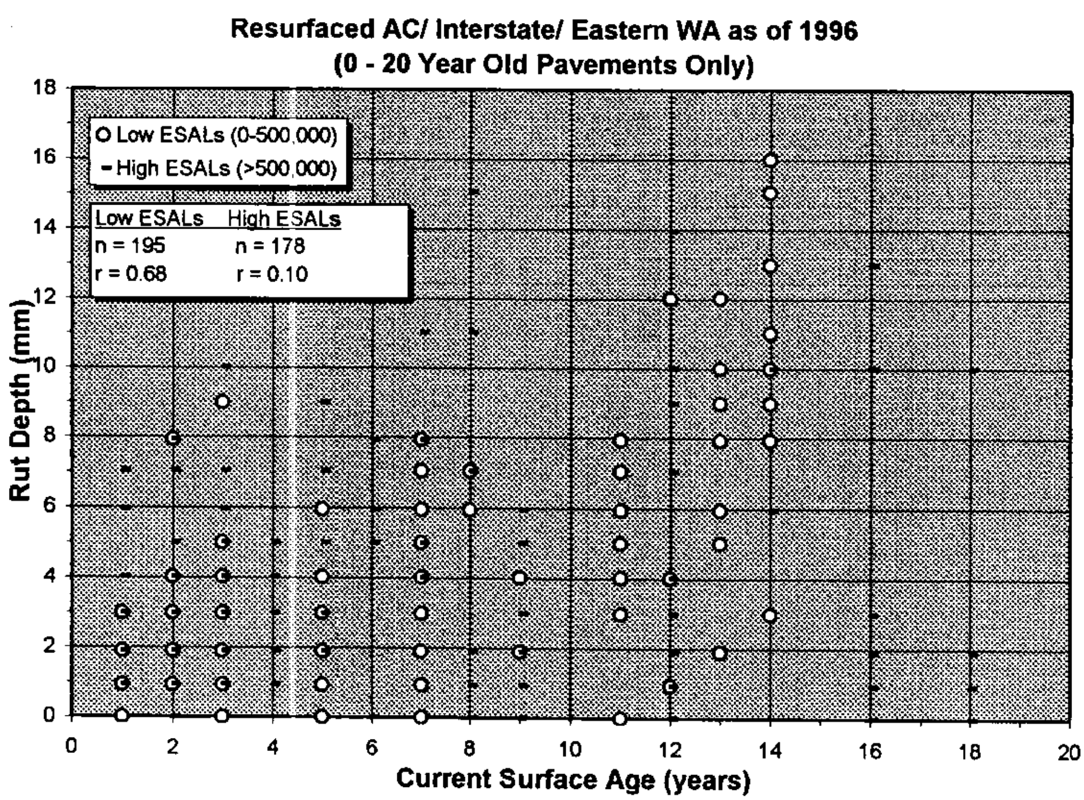


Figure G30. Rutting vs. Age for Resurfaced, Interstate AC, Eastern WA- (0-20 years)

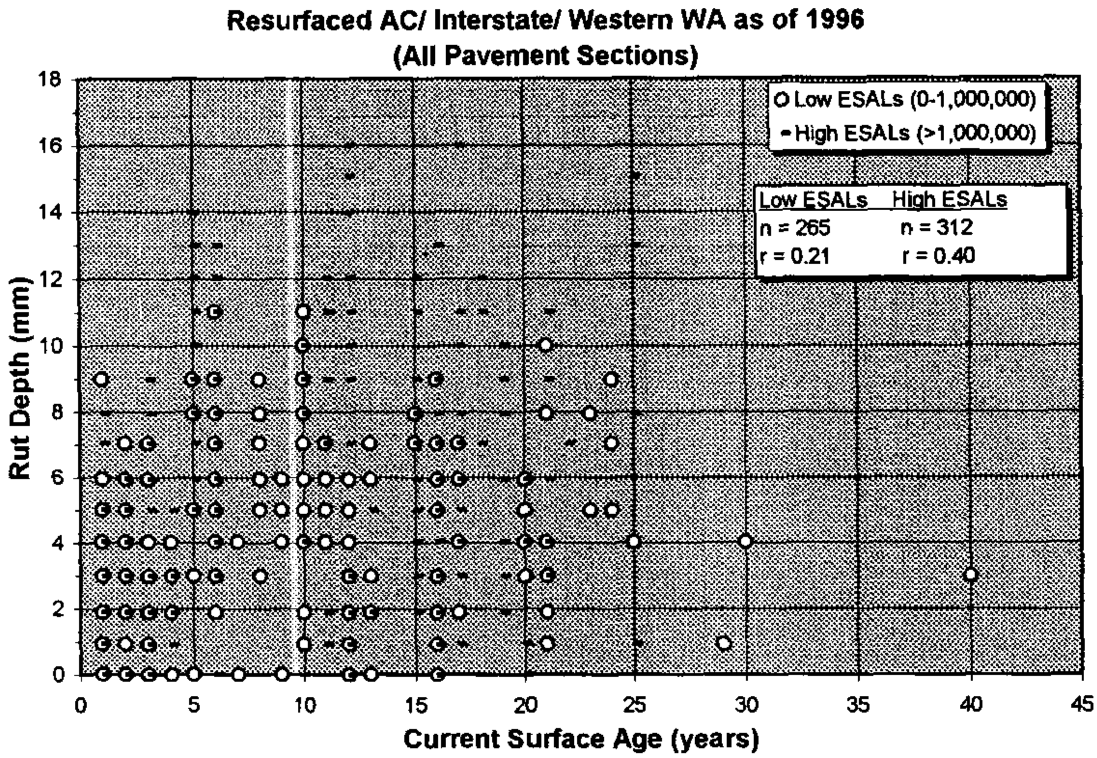


Figure G31. Rutting vs. Age for Resurfaced, Interstate AC, Western WA- All Sections

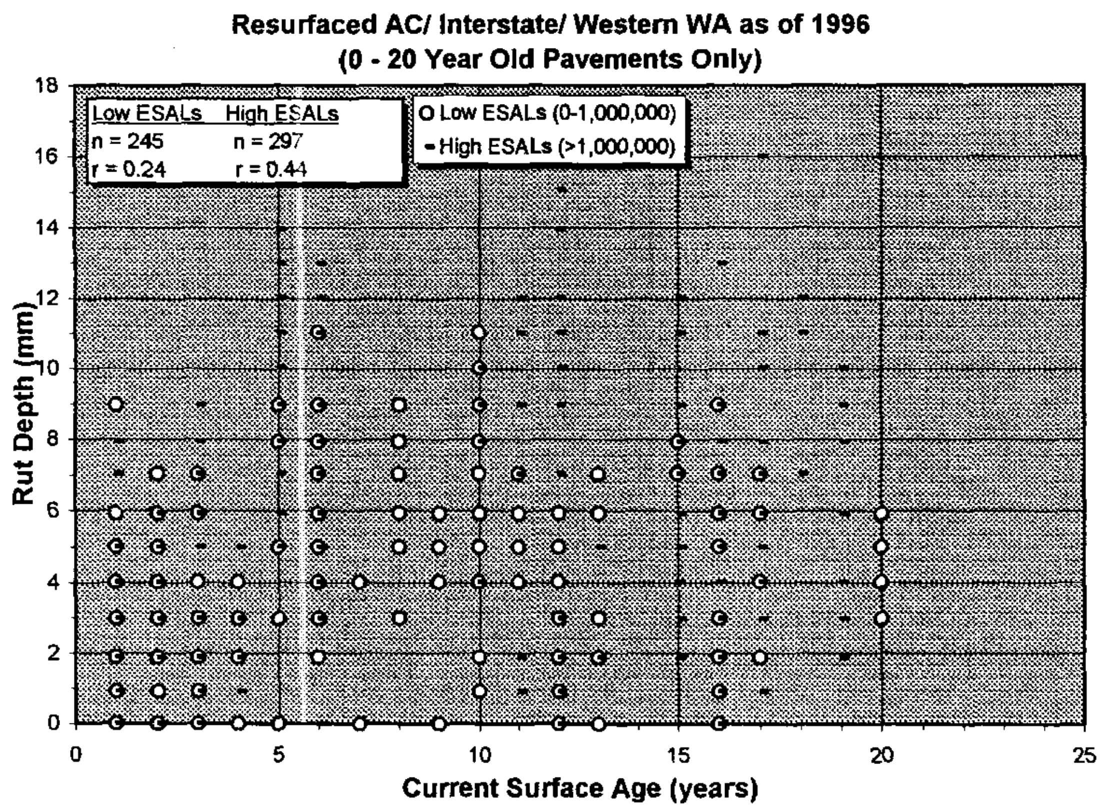


Figure G32. Rutting vs. Age for Resurfaced, Interstate AC, Western WA- (0-20 years)

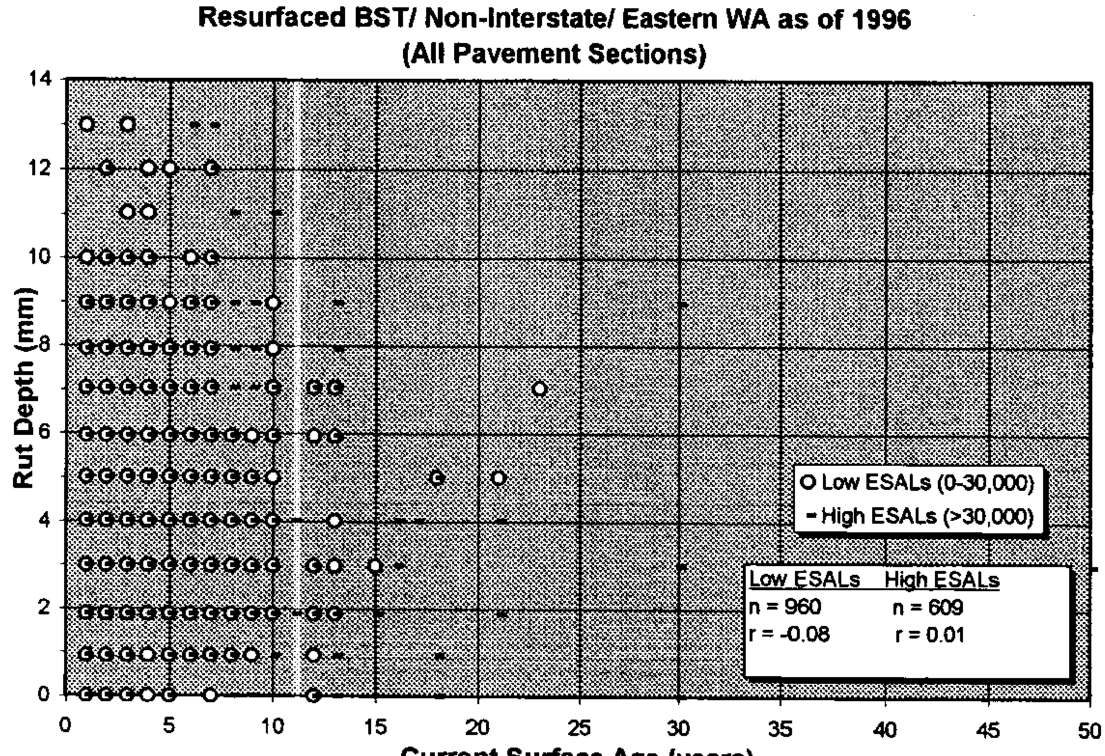


Figure G33. Rutting vs. Age, Resurfaced, Non-Interstate BST, Eastern WA- All Sections

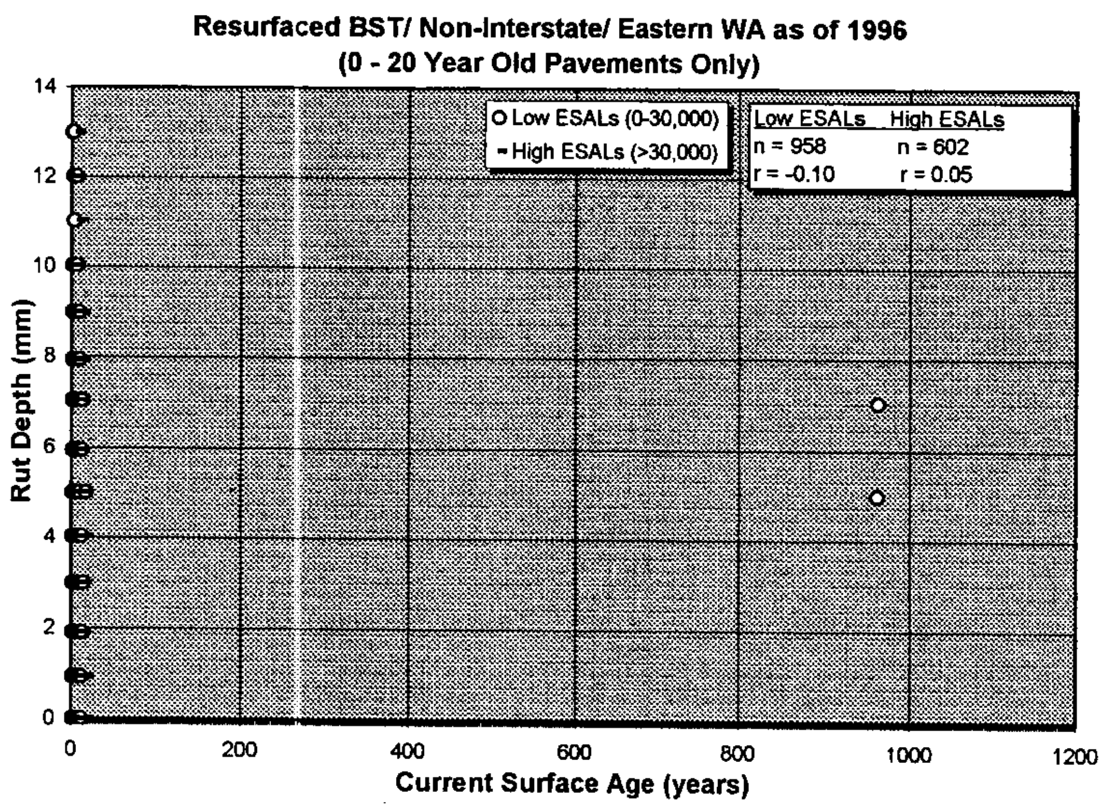


Figure G34. Rutting vs. Age, Resurfaced, Non-Interstate BST, Eastern WA- (0-20 years)

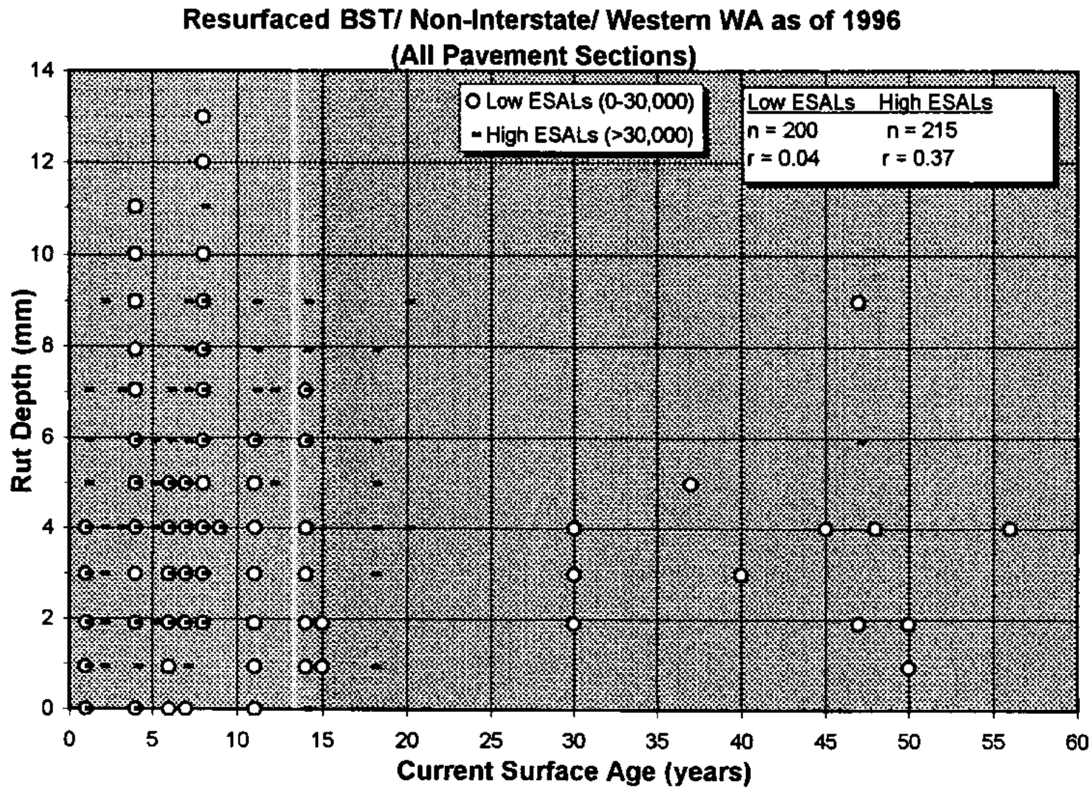


Figure G35. Rutting vs. Age, Resurfaced, Non-Interstate BST, Western WA- All Sections

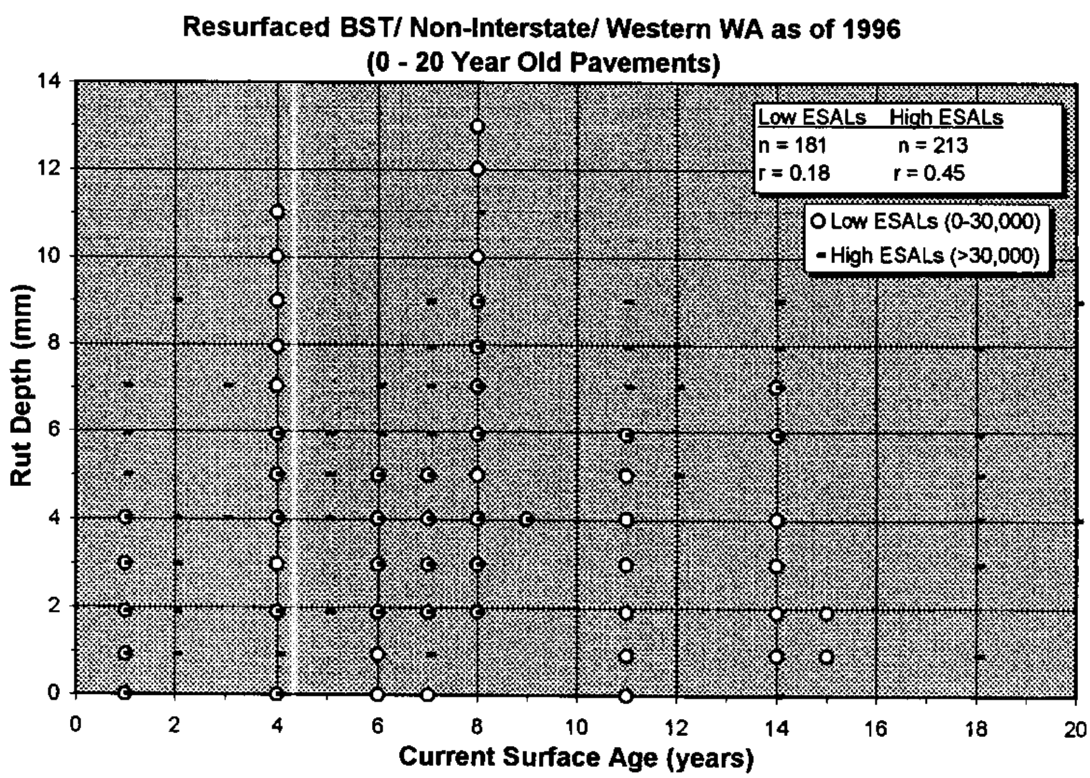


Figure G36. Rutting vs. Age, Resurfaced, Non-Interstate BST, Western WA- (0-20 years)

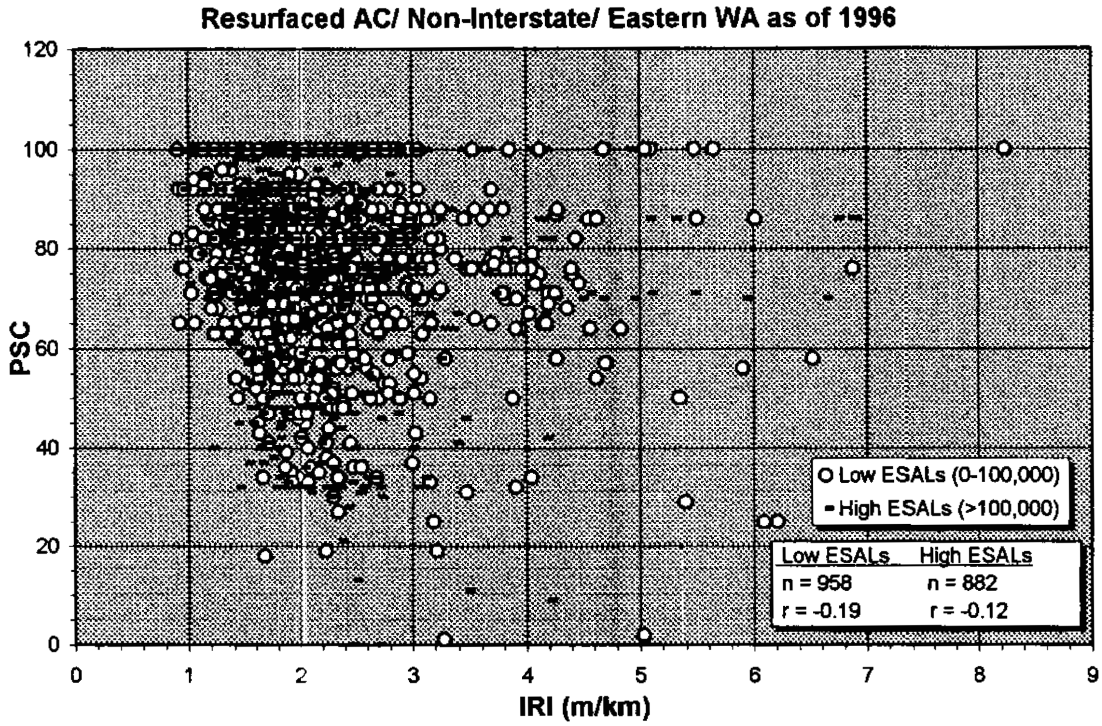


Figure G37. PSC vs. IRI for Resurfaced, Non-Interstate AC in Eastern WA

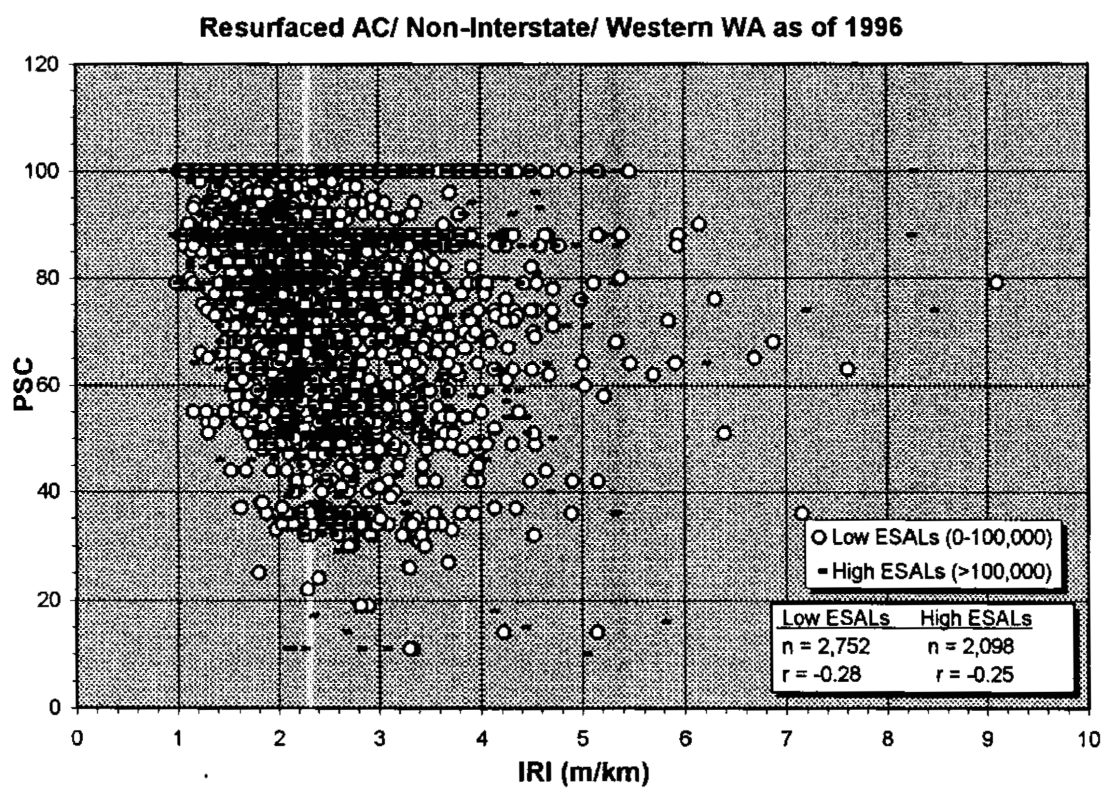


Figure G38. PSC vs. IRI for Resurfaced, Non-Interstate AC in Western WA

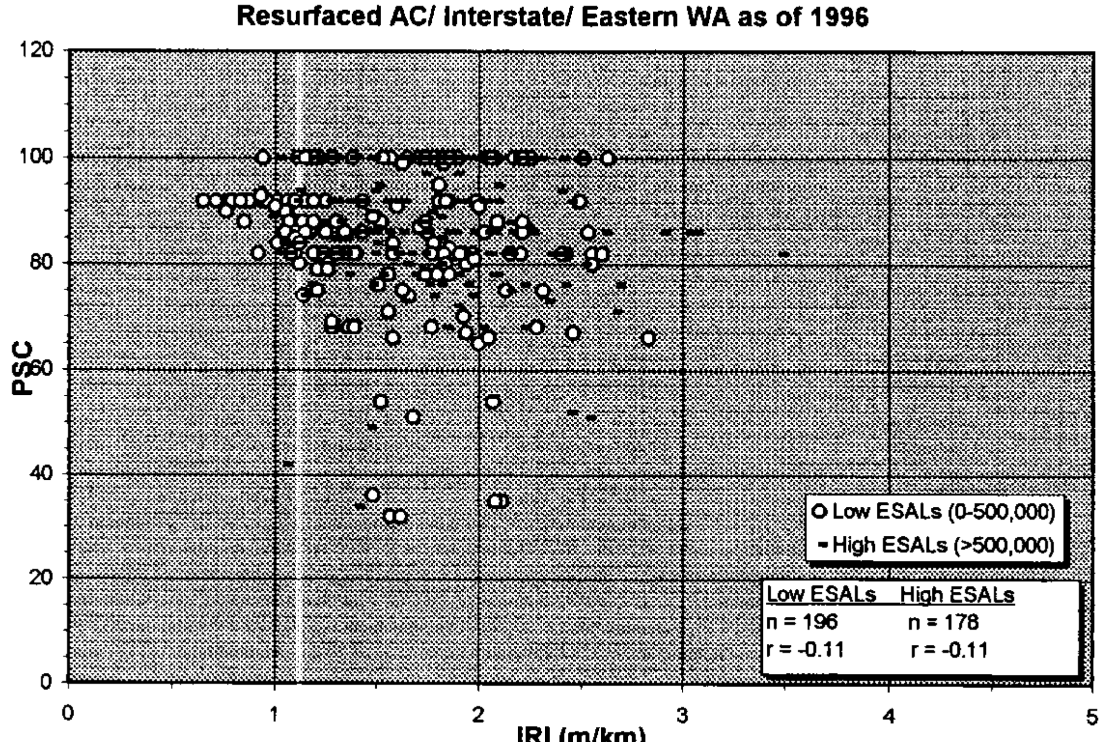


Figure G39. PSC vs. IRI for Resurfaced, Interstate AC in Eastern WA

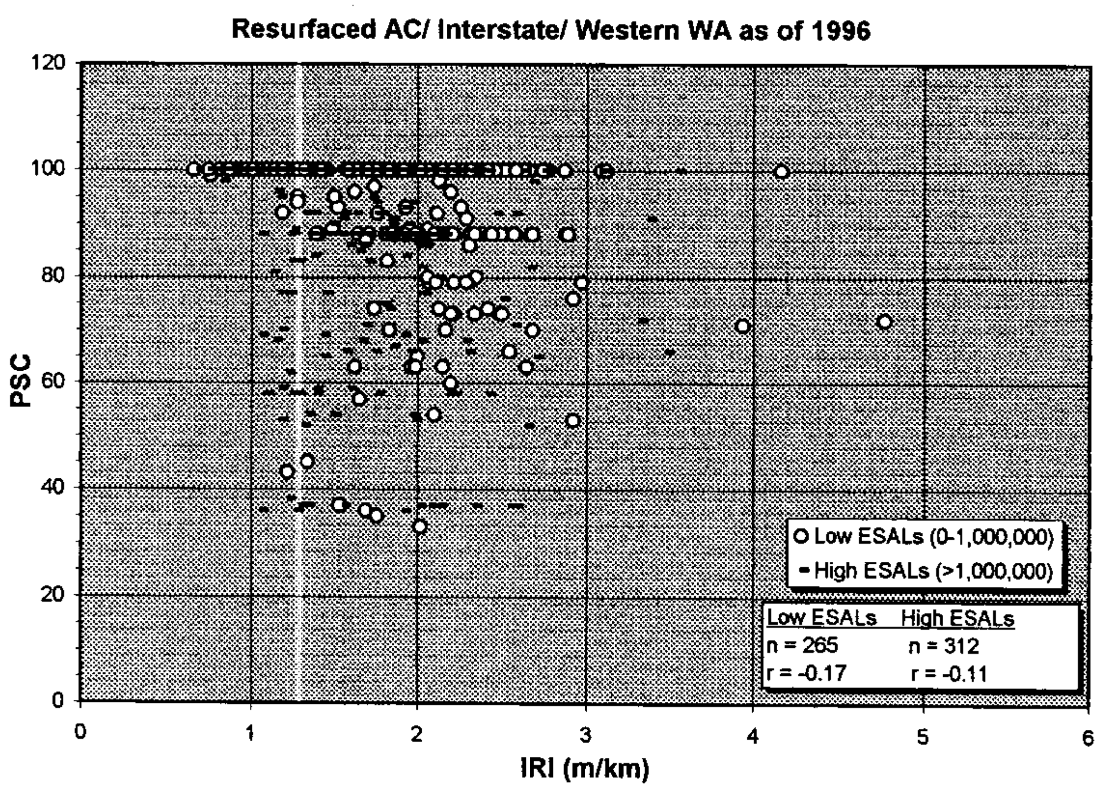


Figure G40. PSC vs. IRI for Resurfaced, Interstate AC in Western WA

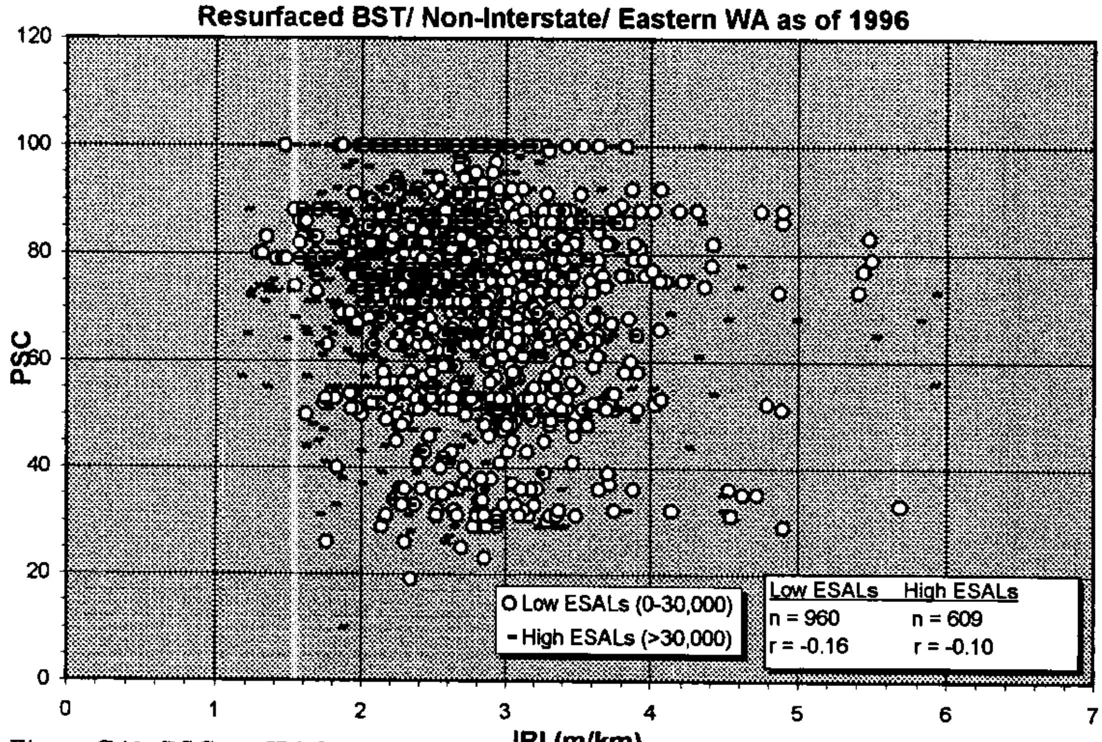


Figure G41. PSC vs. IRI for Resurfaced, Non-Interstate BST in Eastern WA

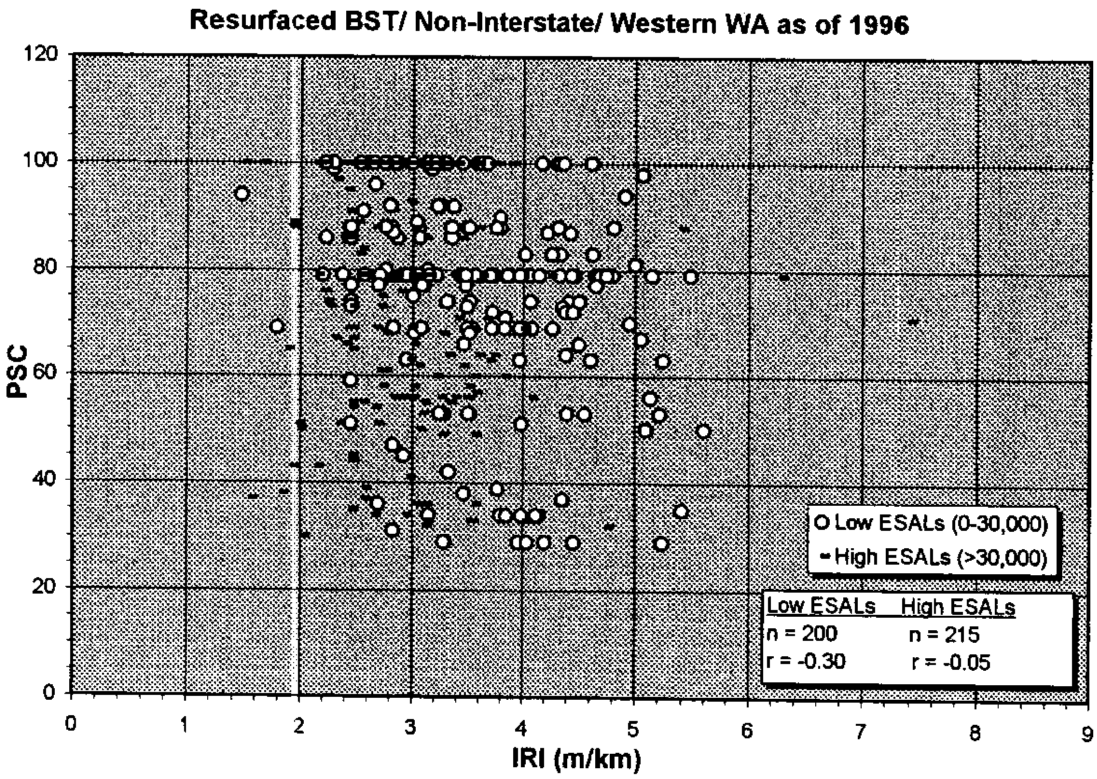


Figure G42. PSC vs. IRI for Resurfaced. Non-Interstate BST in Western WA

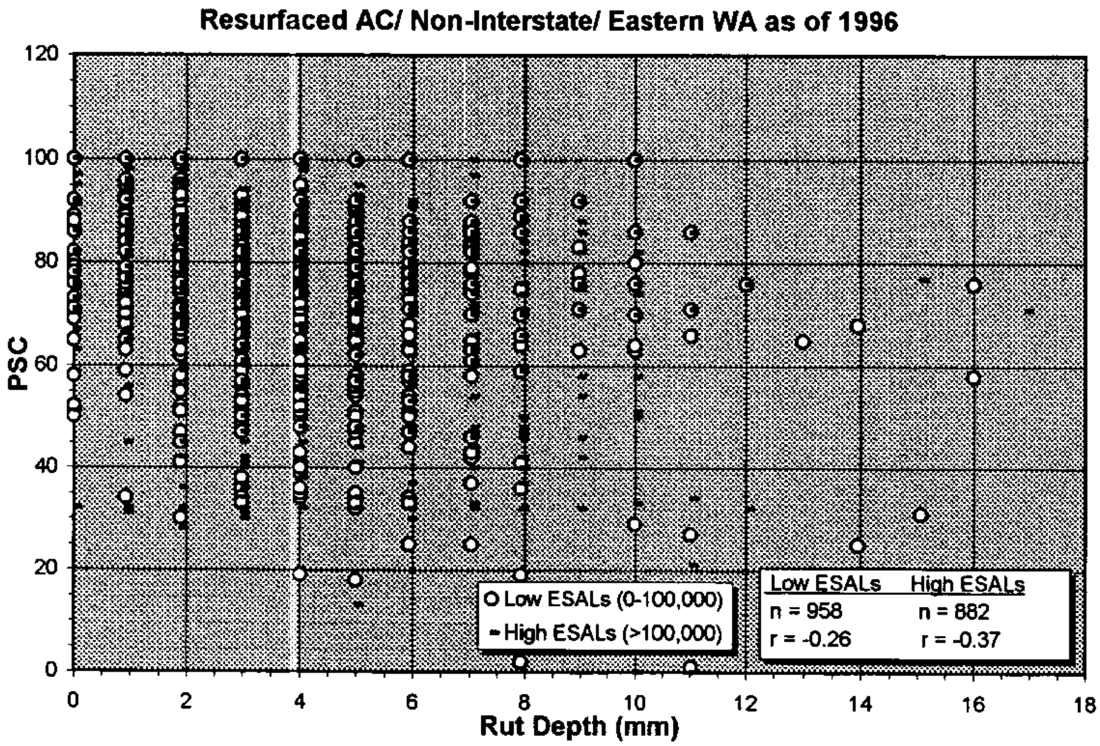


Figure G43. PSC vs. Rutting for Resurfaced, Non-Interstate AC in Eastern WA

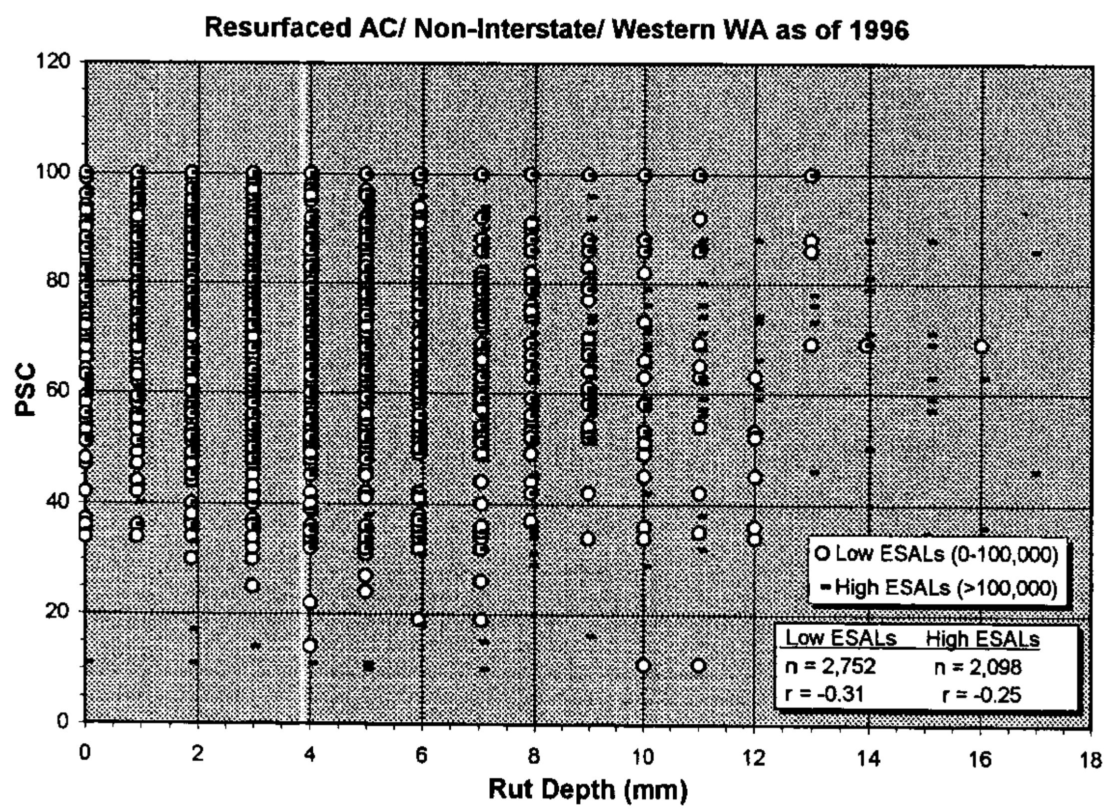


Figure G44. PSC vs. Rutting for Resurfaced, Non-Interstate AC in Western WA

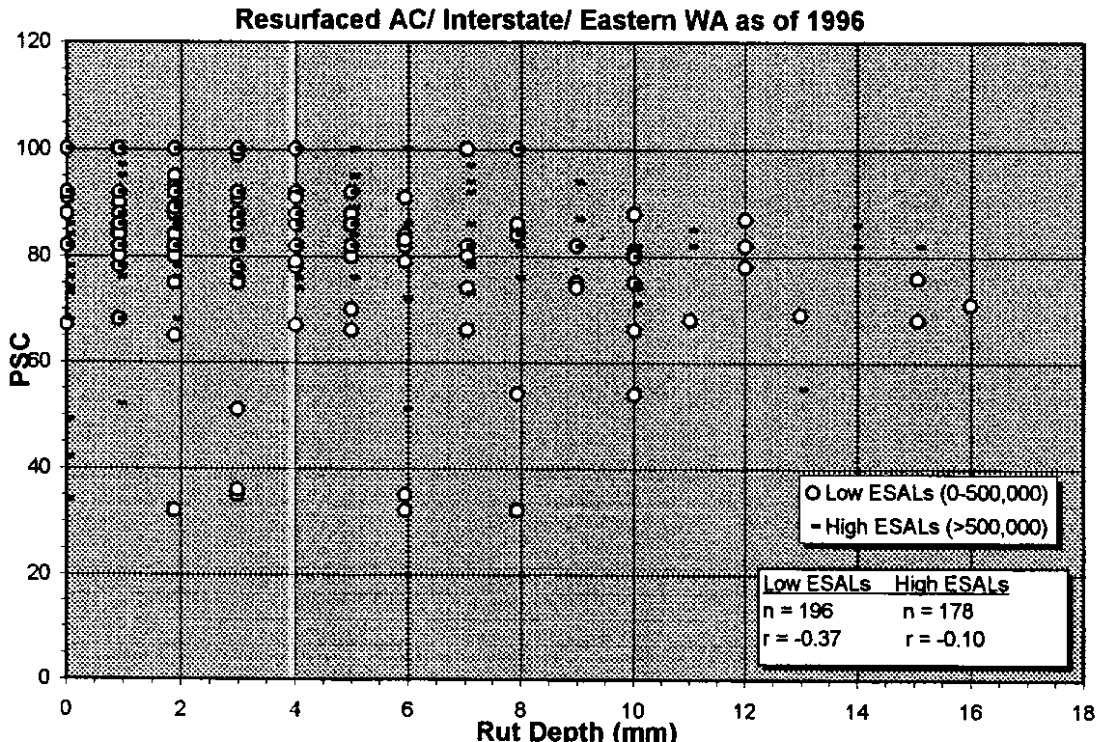


Figure G45. PSC vs. Rutting for Resurfaced, Interstate AC in Eastern WA

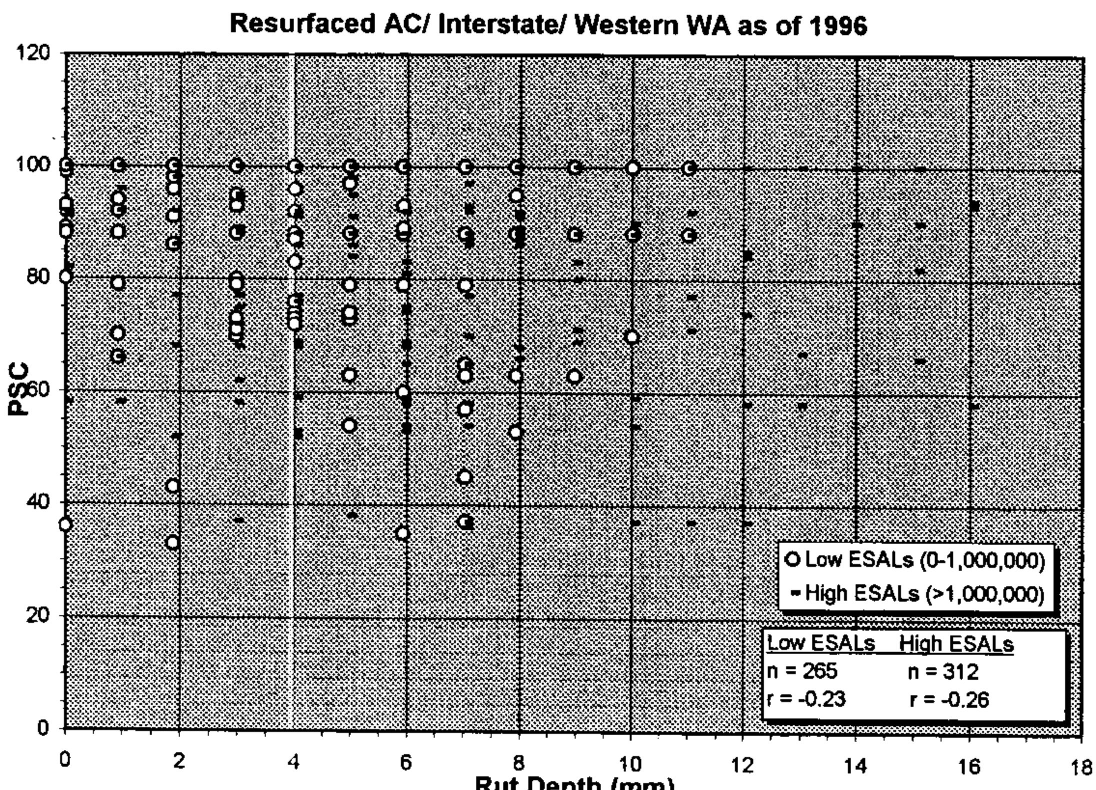


Figure G46. PSC vs. Rutting for Resurfaced, Interstate AC in Western WA

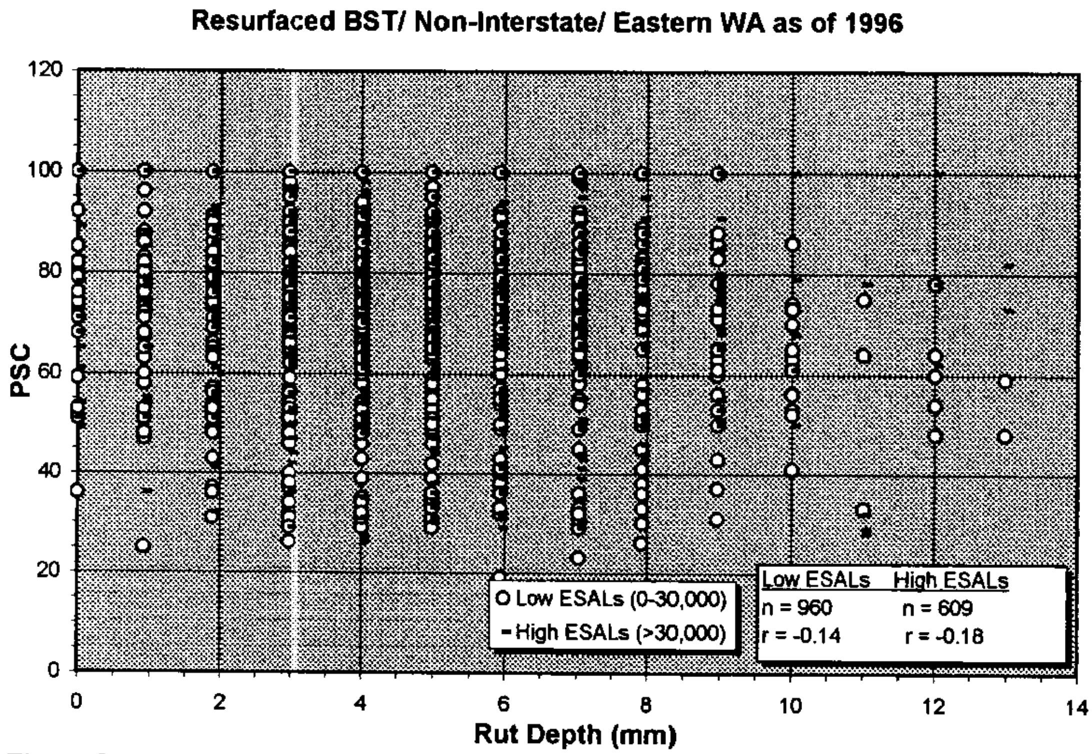


Figure G47. PSC vs. Rutting for Resurfaced, Non-Interstate BST, Eastern WA

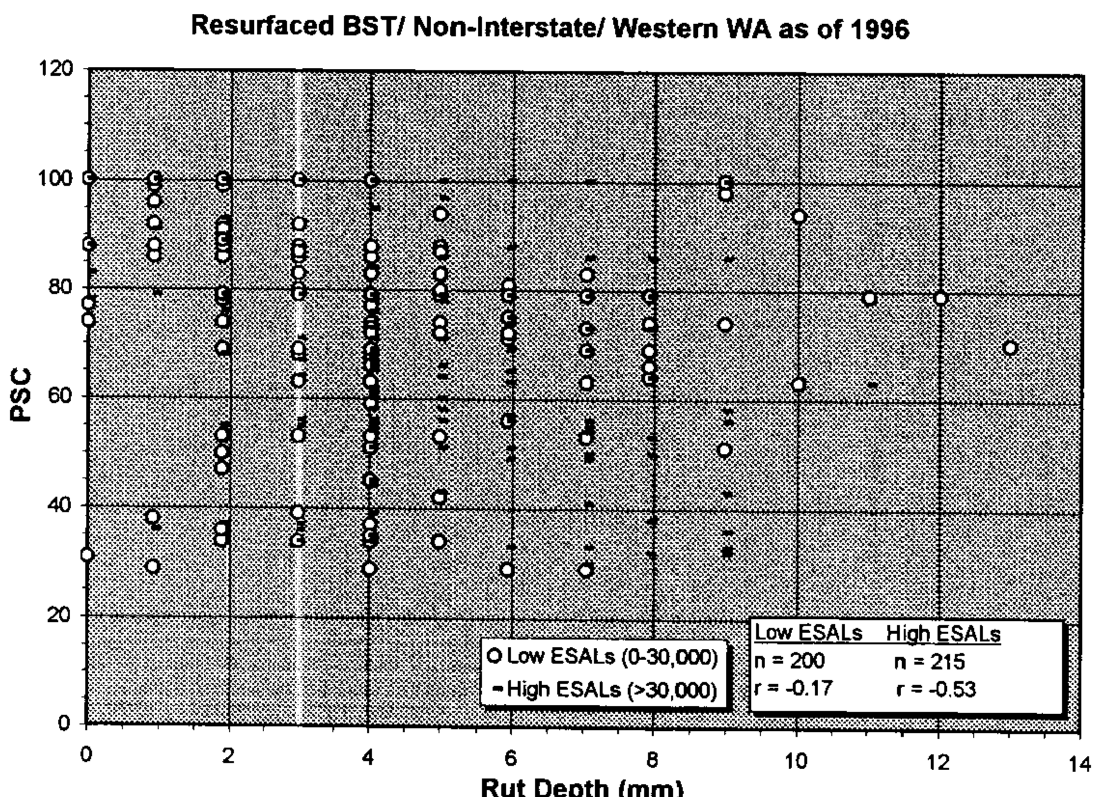


Figure G48. PSC vs. Rutting for Resurfaced, Non-Interstate BST, Western WA

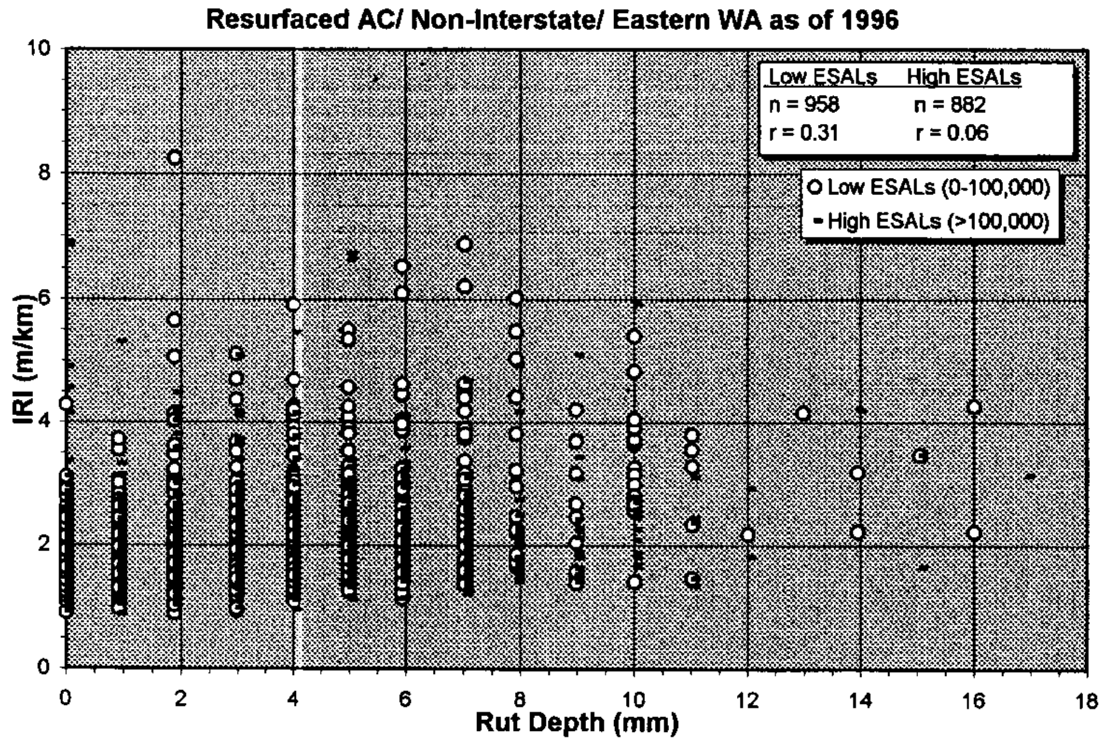


Figure G49. IRI vs. Rutting for Resurfaced. Non-Interstate AC in Eastern WA

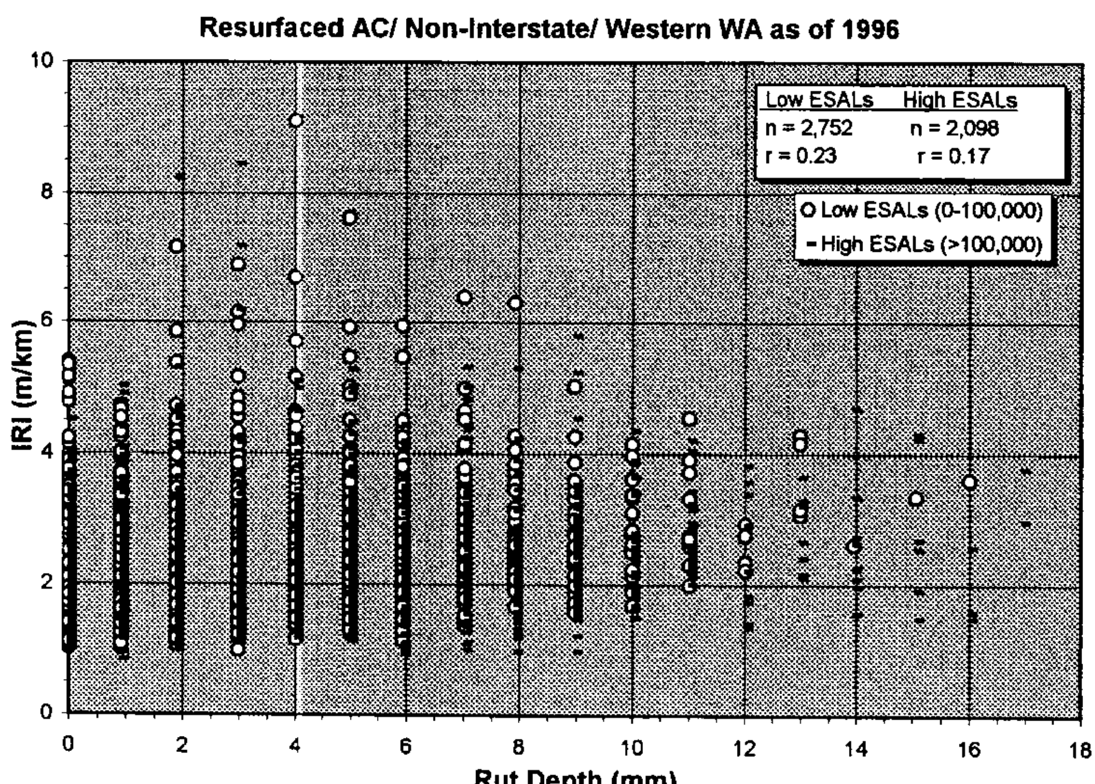


Figure G50. IRI vs. Rutting for Resurfaced, Non-Interstate AC in Western WA

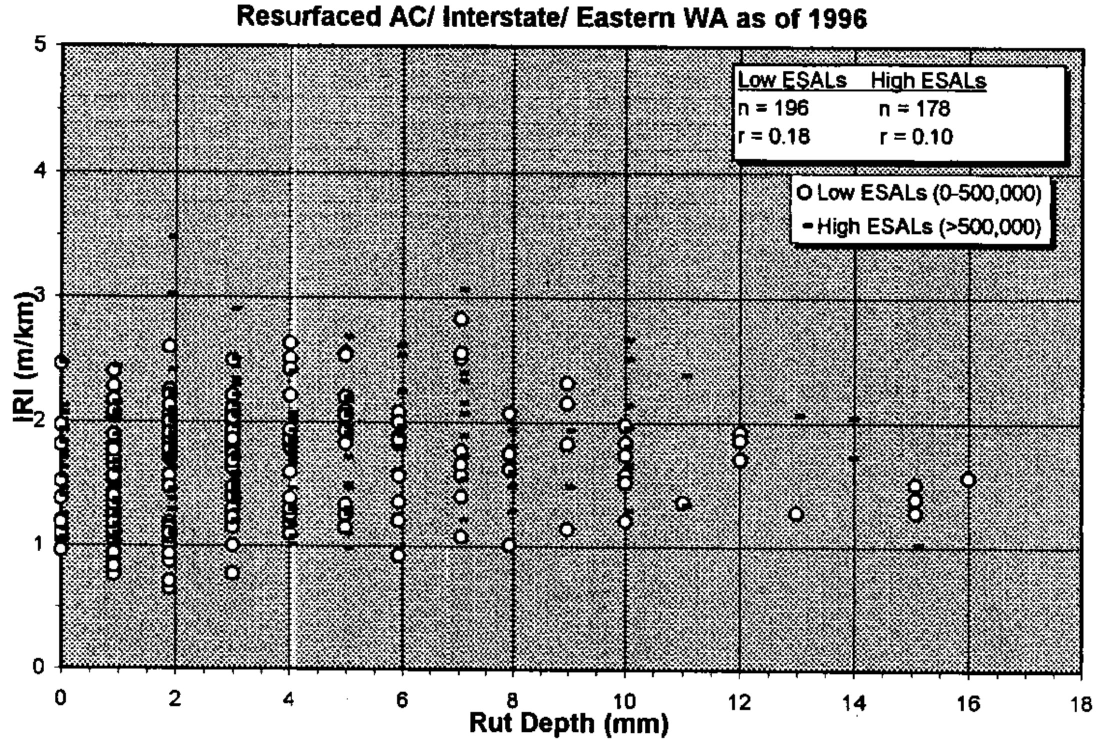


Figure G51. IRI vs. Rutting for Resurfaced, Interstate AC in Eastern WA

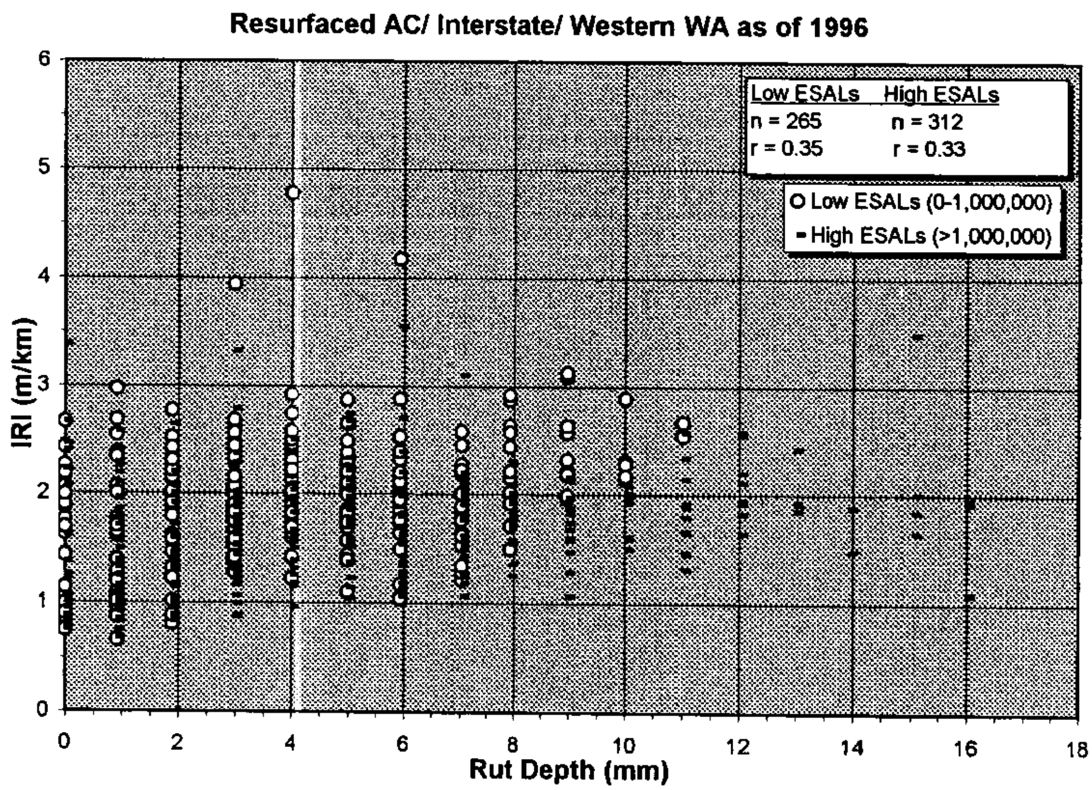


Figure G52. IRI vs. Rutting for Resurfaced, Interstate AC in Western WA

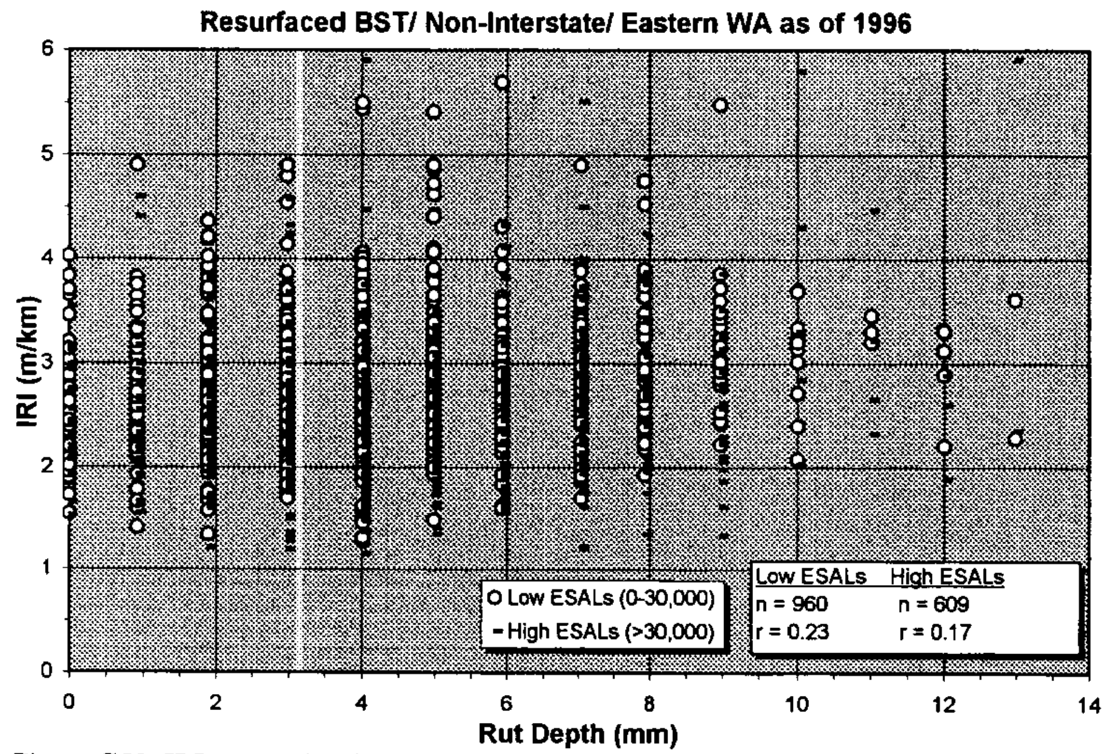


Figure G53. IRI vs. Rutting for Resurfaced, Non-Interstate BST in Eastern WA

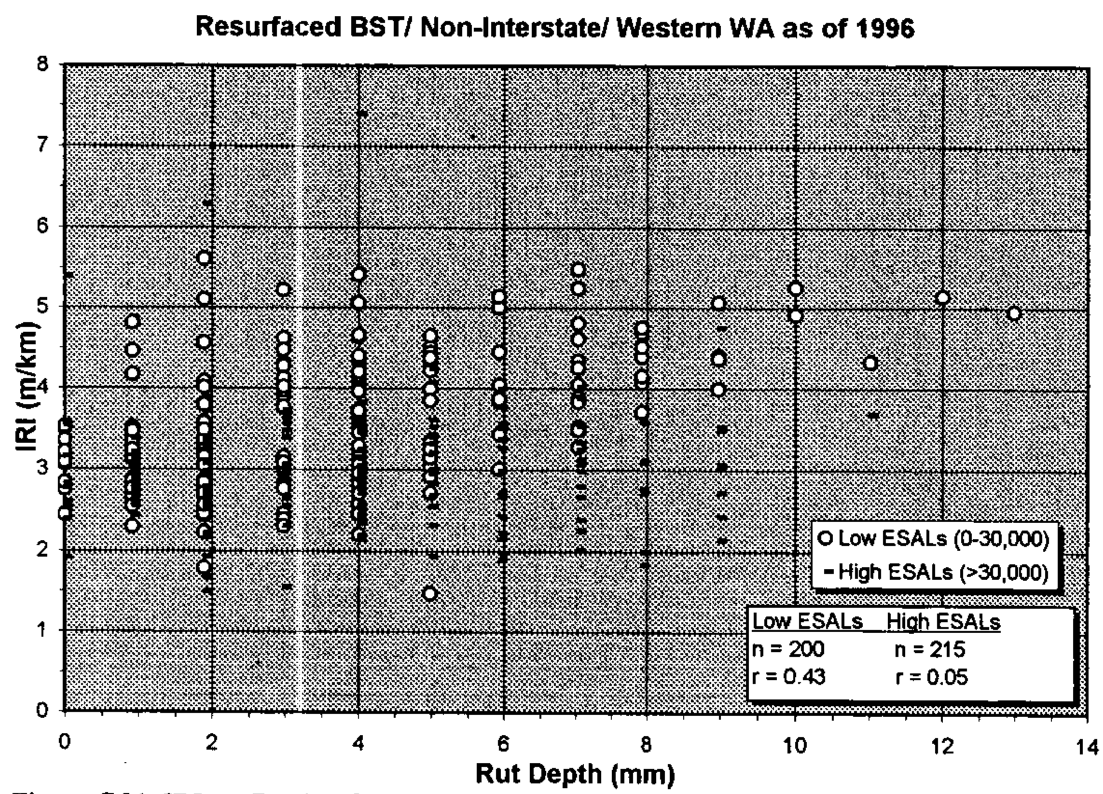


Figure G54. IRI vs. Rutting for Resurfaced, Non-Interstate BST, Western WA

Table G1. Regression Equations for **PSC vs. Age**.

Analysis Group	See App. G Figure #	ESALs (10^3) H-High L-Low	Regression Equation $y= B_0 + B_1 (x)$	Regression Statistics			Calculated t-statistics		stat. diff. from 0? (i.e., |t-calc| > 1.96*) Y or N	
				n	RMSE	Adj. R^2	B_0	B_1	B_0	B_1
E,NI,AC- All	G1	L-(0-100)	PSC= 89.5-1.65(Age)	963	14.32	0.23	109.48	-16.93	Y	Y
E,NI,AC- All		H-(>100)	PSC= 96.2-2.73(Age)	895	15.49	0.35	108.84	-22.16	Y	Y
E,NI,AC- (0-20)	G2	L-(0-100)	PSC= 91.5-1.98(Age)	955	13.91	0.28	110.00	-19.18	Y	Y
E,NI,AC- (0-20)		H-(>100)	PSC= 96.9-2.87(Age)	892	15.32	0.37	108.97	-22.69	Y	Y
W,NI,AC- All	G3	L-(0-100)	PSC= 91.1-1.12(Age)	2823	16.59	0.19	168.47	-25.98	Y	Y
W,NI,AC- All		H-(>100)	PSC= 92.6-1.10(Age)	2158	15.68	0.20	171.20	-23.11	Y	Y
W,NI,AC- (0-20)	G4	L-(0-100)	PSC= 95.0-1.63(Age)	2547	15.62	0.24	161.37	-28.44	Y	Y
W,NI,AC- (0-20)		H-(>100)	PSC= 96.4-1.68(age)	2026	14.84	0.25	161.06	-25.66	Y	Y
E,I,AC- All	G5	L-(0-500)	PSC= 97.1-2.03(Age)	196	10.51	0.42	77.99	-11.96	Y	Y
E,I,AC- All		H-(>500)	PSC= 96.1-1.47(Age)	178	9.48	0.37	86.48	-10.32	Y	Y
E,I,AC- (0-20)	G6	L-(0-500)	PSC= 97.5-2.12(Age)	195	10.42	0.43	78.08	-12.22	Y	Y
E,I,AC- (0-20)		H-(>500)	PSC= 96.1-1.47(Age)	178	9.48	0.37	86.48	-10.32	Y	Y
W,I,AC- All	G7	L-(0-1,000)	PSC= 100.1-1.03(Age)	265	11.44	0.27	93.73	-9.98	Y	Y
W,I,AC- All		H-(>1,000)	PSC= 100.8-1.44(Age)	312	14.24	0.32	78.20	-12.22	Y	Y
W,I,AC- (0-20)	G8	L-(0-1,000)	PSC= 100.7-1.14(Age)	245	11.10	0.21	87.65	-8.19	Y	Y
W,I,AC- (0-20)		H-(>1,000)	PSC= 100.9-1.47(Age)	297	14.20	0.30	76.46	-11.19	Y	Y
E,NI,BST- All	G9	L-(0-30)	PSC= 80.8-1.93(Age)	963	16.95	0.089	78.80	-2.32	Y	Y
E,NI,BST- All		H-(>30)	PSC= 79.7-1.13(Age)	622	17.39	0.074	77.59	-7.09	Y	Y
E,NI,BST- (0-20)	G10	L-(0-30)	PSC= 81.6-2.13(Age)	961	16.88	0.10	77.04	-10.34	Y	Y
E,NI,BST- (0-20)		H-(>30)	PSC= 81.2-1.52(Age)	615	17.34	0.079	70.29	-7.31	Y	Y
W,NI,BST- All	G11	L-(0-30)	PSC= 76.2-0.22(Age)	218	19.52	0.01	43.68	-1.73	Y	N
W,NI,BST- All		H-(>30)	PSC= 86.3-1.71(Age)	215	20.32	0.14	37.84	-6.22	Y	Y
W,NI,BST- (0-20)	G12	L-(0-30)	PSC= 90.1-2.59(Age)	199	17.07	0.21	37.04	-7.37	Y	Y
W,NI,BST- (0-20)		H-(>30)	PSC= 92.5-2.78(Age)	213	18.93	0.27	38.92	-8.84	Y	Y

* t-critical assuming 2-tails, $\alpha= 0.05$ and ∞ d.f. since n is > 120 in every case

Table G2. Regression Equations for **IRI vs. Age.**

Analysis Group	See App. G Figure #	ESALs (10^3) H-High L-Low	Regression Equation $y = B_0 + B_1 (x)$	Regression Statistics			Calculated t-statistics		stat. diff. from 0? (i.e., |t-calc| > 1.96*) Y or N	
				n	RMSE	Adj. R^2	B_0	B_1	B_0	B_1
E,NI,AC- All	G13	L-(0-100)	IRI= 1.96+0.034(Age)	958	0.86	0.034	40.03	5.86	Y	Y
E,NI,AC- All		H-(>100)	IRI= 2.03+0.009(Age)	881	0.78	0.00	45.31	1.44	Y	N
E,NI,AC- (0-20)	G14	L-(0-100)	IRI= 2.00+0.028(Age)	950	0.85	0.019	39.11	4.41	Y	Y
E,NI,AC- (0-20)		H-(>100)	IRI= 2.04+0.009(Age)	878	0.78	0.009	44.59	1.31	Y	N
W,NI,AC- All	G15	L-(0-100)	IRI= 1.95+0.043(Age)	2752	0.74	0.15	79.81	21.84	Y	Y
W,NI,AC- All		H-(>100)	IRI= 2.00+0.028(Age)	2098	0.71	0.071	80.15	12.72	Y	Y
W,NI,AC- (0-20)	G16	L-(0-100)	IRI= 1.96+0.040(Age)	2626	0.72	0.10	74.03	16.79	Y	Y
W,NI,AC- (0-20)		H-(>100)	IRI= 1.92+0.041(Age)	1989	0.71	0.09	66.85	13.38	Y	Y
E,I,AC- All	G17	L-(0-500)	IRI= 1.38+0.037(Age)	196	0.46	0.11	25.49	4.99	Y	Y
E,I,AC- All		H-(>500)	IRI= 1.80+0.002(Age)	178	0.48	0.00	32.24	0.32	Y	N
E,I,AC- (0-20)	G18	L-(0-500)	IRI= 1.37+0.040(Age)	195	0.46	0.12	25.02	5.21	Y	Y
E,I,AC- (0-20)		H-(>500)	IRI= 1.80+0.002(Age)	178	0.48	0.00	32.24	0.32	Y	N
W,I,AC- All	G19	L-(0-1,000)	IRI= 1.74+0.028(Age)	265	0.12	0.12	35.24	5.95	Y	Y
W,I,AC- All		H-(>1,000)	IRI= 1.57+0.014(Age)	312	0.5	0.03	34.95	3.33	Y	Y
W,I,AC- (0-20)	G20	L-(0-1,000)	IRI= 1.77+0.022(Age)	245	0.51	0.04	33.73	3.39	Y	Y
W,I,AC- (0-20)		H-(>1,000)	IRI= 1.57+0.013(Age)	297	0.49	0.03	34.5	2.85	Y	Y
E,NI,BST- All	G21	L-(0-30)	IRI= 2.79+0.003(Age)	960	0.61	0.00	74.39	0.44	Y	Y
E,NI,BST- All		H-(>30)	IRI= 2.39+0.021(Age)	609	0.67	0.02	59.68	3.41	Y	N
E,NI,BST- (0-20)	G22	L-(0-30)	IRI= 2.78+0.004(Age)	958	0.61	0.00	72.30	0.50	Y	N
E,NI,BST- (0-20)		H-(>30)	IRI= 2.40+0.019(Age)	602	0.66	0.01	53.59	2.31	Y	Y
W,NI,BST- All	G23	L-(0-30)	IRI= 3.51+0.001(Age)	200	0.87	0.001	42.50	1.16	Y	N
W,NI,BST- All		H-(>30)	IRI= 2.97-0.006(Age)	215	0.67	0.00	39.58	-0.62	Y	N
W,NI,BST- (0-20)	G24	L-(0-30)	IRI= 3.53-0.002(Age)	181	0.80	0.006	28.65	-0.01	Y	N
W,NI,BST- (0-20)		H-(>30)	IRI= 3.02-0.015(Age)	213	0.65	0.005	37.14	-1.42	Y	N

* t-critical assuming 2-tails, $\alpha = 0.05$ and ∞ d.f. since n is > 120 in every case

Table G3. Regression Equations for **Rutting vs. Age.**

Analysis Group	See App. G Figure #	ESALs (10^3) H-High L-Low	Regression Equation $y= B_0 + B_1 (x)$	Regression Statistics			Calculated t-statistics		stat. diff. from 0? (i.e., |t-calc| > 1.96*) Y or N	
				n	RMSE	Adj. R^2	B_0	B_1	B_0	B_1
E,NI,AC- All	G25	L-(0-100)	Rut= 2.89+0.12(Age)	958	2.30	0.058	21.92	7.74	Y	Y
E,NI,AC- All		H-(>100)	Rut= 2.28+0.23(Age)	881	2.51	0.13	15.86	11.35	Y	Y
E,NI,AC- (0-20)	G26	L-(0-100)	Rut= 2.85+0.13(Age)	950	2.30	0.053	20.66	7.37	Y	Y
E,NI,AC- (0-20)		H-(>100)	Rut= 2.18+0.25(Age)	878	2.49	0.14	14.93	12.13	Y	N
W,NI,AC- All	G27	L-(0-100)	Rut= 1.80+0.13(Age)	2752	2.11	0.16	25.71	23.08	Y	Y
W,NI,AC- All		H-(>100)	Rut= 3.07+0.11(Age)	2098	2.82	0.065	30.94	12.14	Y	Y
W,NI,AC- (0-20)	G28	L-(0-100)	Rut= 1.47+0.17(Age)	2626	2.04	0.19	19.47	24.82	Y	Y
W,NI,AC- (0-20)		H-(>100)	Rut= 2.31+0.22(Age)	1989	2.70	0.15	20.99	18.54	Y	Y
E,I,AC- All	G29	L-(0-500)	Rut= 0.59+0.52(Age)	196	2.37	0.49	2.10	13.68	Y	Y
E,I,AC- All		H-(>500)	Rut= 3.58+0.06(Age)	178	3.15	0.003	9.71	1.27	Y	N
E,I,AC- (0-20)	G30	L-(0-500)	Rut= 0.66+0.51(Age)	195	2.37	0.46	2.32	12.94	Y	Y
E,I,AC- (0-20)		H-(>500)	Rut= 3.58+0.06(Age)	178	3.15	0.003	9.71	1.27	Y	N
W,I,AC- All	G31	L-(0-1,000)	Rut= 3.33+0.08(Age)	265	2.62	0.040	13.63	3.45	Y	Y
W,I,AC- All		H-(>1,000)	Rut= 3.37+0.22(Age)	312	3.5	0.16	10.63	7.70	Y	Y
W,I,AC- (0-20)	G32	L-(0-1,000)	Rut= 3.10+0.12(Age)	245	2.57	0.053	11.68	3.84	Y	Y
W,I,AC- (0-20)		H-(>1,000)	Rut= 3.16+0.26(Age)	297	3.40	0.19	10.00	8.39	Y	Y
E,NI,BST- All	G33	L-(0-30)	Rut= 4.58-0.075(Age)	960	2.47	0.006	30.24	-2.54	Y	Y
E,NI,BST- All		H-(>30)	Rut= 4.61-0.003(Age)	609	2.39	0.001	32.09	0.16	Y	N
E,NI,BST- (0-20)	G34	L-(0-30)	Rut= 4.65-0.091(Age)	958	2.47	0.008	29.90	-3.02	Y	Y
E,NI,BST- (0-20)		H-(>30)	Rut= 4.49+0.033(Age)	602	2.39	0.000	27.66	1.16	Y	N
W,NI,BST- All	G35	L-(0-30)	Rut= 3.66+0.23(Age)	200	2.47	0.003	15.67	0.56	Y	N
W,NI,BST- All		H-(>30)	Rut= 2.79+0.17(Age)	215	2.15	0.13	11.55	5.86	Y	Y
W,NI,BST- (0-20)	G36	L-(0-30)	Rut= 2.96+0.13(Age)	181	2.46	0.028	7.83	2.47	Y	Y
W,NI,BST- (0-20)		H-(>30)	Rut= 2.33+0.25(Age)	213	2.06	0.20	9.00	7.31	Y	Y

* t-critical assuming 2-tails, $\alpha = 0.05$ and ∞ d.f. since n is > 120 in every case

Table G4. Regression Equations for **PSC vs. IRI**.

Analysis Group	See App. G Figure #	ESALs (10^3) H-High L-Low	Regression Equation $y= B_0 + B_1 (x)$	Regression Statistics			Calculated t-statistics		stat. diff. from 0? (i.e., |t-calc| > 1.96*) Y or N	
				n	RMSE	Adj. R^2	B_0	B_1	B_0	B_1
E,NI,AC- All	G37	L-(0-100)	PSC= 85.8-2.95(IRI)	958	16.05	0.034	60.89	-5.92	Y	Y
E,NI,AC- All		H-(>100)	PSC= 86.6-2.95(IRI)	881	18.94	0.013	47.53	-3.60	Y	Y
W,NI,AC- All	G38	L-(0-100)	PSC= 95.4-6.65(IRI)	2752	17.80	0.081	89.04	-15.59	Y	Y
W,NI,AC- All		H-(>100)	PSC= 96.1-5.89(IRI)	2098	16.90	0.062	81.12	-11.78	Y	Y
E,I,AC- All	G39	L-(0-500)	PSC= 90.3-3.21(IRI)	196	13.77	0.007	26.62	-1.58	Y	N
E,I,AC- All		H-(>500)	PSC= 92.3-2.77(IRI)	178	11.94	0.007	26.07	-1.47	Y	N
W,I,AC- All	G40	L-(0-1,000)	PSC= 100.2-4.17(IRI)	265	13.23	0.027	33.93	-2.87	Y	Y
W,I,AC- All		H-(>1,000)	PSC= 95.1-3.93(IRI)	312	17.24	0.01	27.91	-2.03	Y	Y
E,NI,BST- All	G41	L-(0-30)	PSC= 85.0-4.57(IRI)	960	17.57	0.023	31.96	-4.92	Y	Y
E,NI,BST- All		H-(>30)	PSC= 81.1-2.82(IRI)	609	18.06	0.009	28.94	-2.59	Y	Y
W,NI,BST- All	G42	L-(0-30)	PSC= 99.6-6.71(IRI)	200	18.48	0.088	18.07	-4.48	Y	Y
W,NI,BST- All		H-(>30)	PSC= 79.6-1.56(IRI)	215	22.07	0.002	11.72	-0.69	Y	N

* t-critical assuming 2-tails, α= 0.05 and ∞ d.f. since n is > 120 in every case

Table G5. Regression Equations for **PSC vs. Rutting.**

Analysis Group	See App. G Figure #	ESALs (10^3) H-High L-Low	Regression Equation $y= B_0 + B_1 (x)$	Regression Statistics			Calculated t-statistics		stat. diff. from 0? (i.e., |t-calc| > 1.96*) Y or N	
				n	RMSE	Adj. R^2	B_0	B_1	B_0	B_1
E,NI,AC- All	G43	L-(0-100)	PSC= 84.8-1.82(Rut)	958	15.76	0.069	89.36	-8.48	Y	Y
E,NI,AC- All		H-(>100)	PSC= 90.0-2.63(Rut)	881	17.72	0.14	89.77	-11.82	Y	Y
W,NI,AC- All	G44	L-(0-100)	PSC= 87.3-2.48(Rut)	2752	17.67	0.094	153.79	-16.93	Y	Y
W,NI,AC- All		H-(>100)	PSC= 88.8-1.47(Rut)	2098	16.92	0.060	141.36	-11.60	Y	Y
E,I,AC- All	G45	L-(0-500)	PSC= 90.9-1.55(Rut)	196	12.87	0.13	66.35	-5.57	Y	Y
E,I,AC- All		H-(>500)	PSC= 88.8-0.39(Rut)	178	11.95	0.005	61.83	-1.35	Y	N
W,I,AC- All	G46	L-(0-1,000)	PSC= 96.5-1.17(Rut)	265	13.09	0.048	67.02	-3.76	Y	Y
W,I,AC- All		H-(>1,000)	PSC= 94.7-1.17(Rut)	312	16.77	0.064	58.45	-4.70	Y	Y
E,NI,BST- All	G47	L-(0-30)	PSC= 76.4-0.97(Rut)	960	17.63	0.017	67.66	-4.24	Y	Y
E,NI,BST- All		H-(>30)	PSC= 80.4-1.35(Rut)	609	17.86	0.030	51.01	-4.48	Y	Y
W,NI,BST- All	G48	L-(0-30)	PSC= 80.5-1.32(Rut)	200	19.12	0.024	32.70	-2.41	Y	Y
W,NI,BST- All		H-(>30)	PSC= 94.9-5.07(Rut)	215	18.70	0.28	37.79	-9.18	Y	Y

* t-critical assuming 2-tails, $\alpha= 0.05$ and ∞ d.f. since n is > 120 in every case

Table G6. Regression Equations for **IRI vs. Rutting.**

Analysis Group	See App. G Figure #	ESALs (10^3) H-High L-Low	Regression Equation $y= B_0 + B_1 (x)$	Regression Statistics			Calculated t-statistics		stat. diff. from 0? (i.e., |t-calc| > 1.96*) Y or N	
				n	RMSE	Adj. R^2	B_0	B_1	B_0	B_1
E,NI,AC- All	G49	L-(0-100)	IRI= 1.77+0.12(Rut)	958	0.83	0.098	35.49	10.24	Y	Y
E,NI,AC- All		H-(>100)	IRI= 2.02+0.018(Rut)	881	0.78	0.003	45.82	1.88	Y	N
W,NI,AC- All	G50	L-(0-100)	IRI= 2.12+0.085(Rut)	2752	0.77	0.061	85.44	13.35	Y	Y
W,NI,AC- All		H-(>100)	IRI= 2.09+0.042(Rut)	2098	0.73	0.027	77.17	7.64	Y	Y
E,I,AC- All	G51	L-(0-500)	IRI= 1.50+0.027(Rut)	196	0.48	0.028	29.47	2.59	Y	Y
E,I,AC- All		H-(>500)	IRI= 1.76+0.016(Rut)	178	0.48	0.005	30.75	1.39	Y	N
W,I,AC- All	G52	L-(0-1,000)	IRI= 1.66+0.074(Rut)	265	0.53	0.12	28.72	6.10	Y	Y
W,I,AC- All		H-(>1,000)	IRI= 1.46+0.043(Rut)	312	0.48	0.10	31.61	6.06	Y	Y
E,NI,BST- All	G53	L-(0-30)	IRI= 2.56+0.056(Rut)	960	0.60	0.051	67.19	7.22	Y	Y
E,NI,BST- All		H-(>30)	IRI= 2.27+0.047(Rut)	609	0.67	0.026	38.76	4.17	Y	Y
W,NI,BST- All	G54	L-(0-30)	IRI= 3.00+0.15(Rut)	200	0.79	0.18	29.45	6.76	Y	Y
W,NI,BST- All		H-(>30)	IRI= 2.88+0.013(Rut)	215	0.67	0.002	32.10	0.67	Y	N

* t-critical assuming 2-tails, $\alpha= 0.05$ and ∞ d.f. since n is > 120 in every case