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16. Abstract

This report documents research efforts to provide comparative quantitative performance information for various grades of seal coat aggregate available in the Texas Department of Transportation's standard specifications. Length of service before replacement and level of noise generated at the tire-pavement interface were the primary focuses of the relative performance evaluations. The additional service life possible from seal coats with larger aggregate and higher asphalt application rates is compared to the additional cost generally associated with these larger aggregate seal coats. The comparative performance information combined with knowledge gathered from numerous department field engineers resulted in the development of guidelines for optimal seal coat grade selection.

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CHAPTER 1: INTRODUCTION

The Texas Department of Transportation (TxDOT) has the challenging responsibility of maintaining serviceability of almost 80,000 centerline miles of roadway. The agency is pursuing numerous methods of accomplishing this responsibility with diminishing resources. The objective of this study is to develop guidelines for optimal seal coat grade selection based on the physical condition of the pavement, traffic conditions, and the roadway location.

ORGANIZATION OF THE REPORT

This report is composed of seven chapters. The first chapter provides an introduction to the research project and describes the organization of the report.

Chapter 2 outlines information available in the literature review that was pertinent to the use of various seal coat grades and relative performance expectations.

Chapter 3 describes the method that the research team used to gather information from district field engineering personnel as well as the valuable information obtained from a survey of the districts.

Chapter 4 documents construction of field test sections composed of various seal coat grades, aggregate mineral types, and aggregate placement rates.

Chapter 5 describes on-board sound intensity (OBSI) testing performed on test sections constructed during the research project as well as on selected other seal-coated pavements. Pavements were selected for testing to include various aggregate mineral types, various aggregate grades, and various seal coat ages. The test results are reported, and a number of aggregate factors potentially affecting noise level are individually discussed.

Chapter 6 reports several analyses of historical Pavement Management Information System (PMIS) pavement distress data to compare performances generally obtained from Grade 3 and Grade 4 seal coats. Relative performances of Grade 3 and Grade 4 seal coats placed in six districts in 1998 and in three districts in 2003 were separately determined.

Chapter 7 summarizes project conclusions, recommendations, and the guidelines for seal coat grade selection and use that the findings of this project supported.

CHAPTER 2:
LITERATURE SEARCH SUMMARY

The scope of this project included a comprehensive literature review to determine recently developed knowledge pertaining to service life and application recommendations for various types and grades of seal coats. The most relevant references to this study were identified and are discussed below. The amount of available literature addressing the primary objective of this study (that is, when use of various grades of seal coat aggregate are most appropriate) was quite limited.

The search of literature determined that New Zealand has been particularly active in documenting studies pertaining to construction of and applications for seal coats. For that reason, this literature review is divided into two sections: United States Literature and New Zealand Literature.

UNITED STATES LITERATURE

NCHRP Synthesis 342 – Chip Seal Best Practices (*1*). This comprehensive documentation of seal coat practices used throughout the United States and the world includes information on design, material selection, contract administration, construction, and performance characteristics. An international survey of chief maintenance engineers in transportation agencies was prepared and distributed. A total of 92 responses were received, including 42 from U.S. states and 12 from U.S. cities and counties. The survey particularly targeted Australia, New Zealand, South Africa, the United Kingdom, and Canada as well as departments of transportation within the United States.

The number one listed best practice was the use of chip seals as a *preventive* maintenance tool, applied on a regular cycle to preserve pavement structural integrity. The importance of placing the treatment prior to the pavement exhibiting significant distress was underscored with the observation that chip seals are most effective when applied to pavements in good structural condition.

Discussion of the options available when selecting chip size included statements that larger aggregate chip seals are considered more durable because of the inherently thicker binder layer, less sensitivity to variations in the amount of binder being applied, and that they generally provide a higher quality product. On the other hand, the synthesis also pointed out larger aggregate chip seals have higher noise emissions and that loose aggregate are more damaging to vehicles if not properly swept or if they lose bond later in pavement life. The synthesis noted the need for research to quantify expected levels of noise from seal coats of varying types and sizes of aggregate.

Survey questions included inquiring about seal coat cycle usage and cycle lengths, as well as expected service lives from seal coats. Seventeen U.S. states reported using a seal coat cycle, with the average cycle length being 5.4 years. Three of the four responding Australian agencies use a seal coat cycle, with the average cycle length being 10 years. When asked for the typical life span expected from a seal coat, the 42 responding U.S. state responses averaged 5.76 years. In comparison, Canadian responses averaged 5.33 years, Australian responses averaged 10 years, New Zealand responses averaged 7 years, and the response from the United Kingdom was 10 years. The responses were not attributable to a specific grade or size of aggregate or a specific asphalt type.

Life Cycle of Pavement Preservation Seal Coats (*2*). A primary objective of this research project was to determine expected service lives of chip seals and open graded surface courses (OGSC) for conditions in Utah. Variations in materials used, environmental conditions, and traffic volumes were considered.

In Utah, considerations while selecting preventive maintenance treatments include the existing condition of the pavement, traffic volumes, and environmental conditions. Budget restraints, political issues, and experience with different treatments also affect the selection of treatments. However, research has yet to produce detailed rules for choosing one method over another for high-volume, high-speed highways.

Determination of service life potential was based on analyses of pavement database performance information between 1988 and 1999. Two performance indicators were initially selected for the analyses. The International Roughness Index (IRI) and the Skid Number were chosen because they represent pavement quality and pavement safety, respectively, the two most important roadway characteristics. Due to the method of determining roughness changing during the course of this study, Skid Number alone became the primary comparison variable. The study considered a roadway with a Skid Number of less than 40, using a ribbed tire for testing, to require corrective action. For OGSC and chip seals the average service lives before this skid criterion was met were 9 years and 27 years, respectively. The normal difference in average annual daily traffic (AADT) where these two methods are often used is believed to be the primary cause for the sizable difference in service lives. Generally, chip seals are used in Utah where the AADT is less than 5,000. On the other hand, OGSC is used for more heavily trafficked roadways, sometimes with an AADT of greater than 40,000.

As the above service life projections were based solely on loss of skid properties, possibly a more illuminating portion of this report was the result of a survey of state departments of transportation. Twenty-two states responded to the survey. Of those responding, the reported average life to be expected from a seal coat was six and a half years. The range of reported lives was three to 15 years. Expected service life responses were not categorized by size of seal coat aggregate being used.

One conclusion reached in this report was that the use of OGSC should continue in Utah, but that its use should be limited to high-volume, high-speed facilities. In these locations the benefits in improved safety from reduced hydroplaning and spray outweigh the additional costs inherent with OGSC. Similarly, it was concluded that chip seal use should continue for low traffic roadways and for medium volume roadways (5,000 to 25,000 AADT).

Evaluation of Seal Coat Performance Using Macro-Texture Measurements (*3*). The purpose of this study was to determine if pavement macrotexture as determined by the Circular Track Meter (CTM) and by the Outflow Meter (OFM) could be used to create performance curves for seal-coated pavements. The results of the study included that correlation between CTM and OFM test data is good. The R square was found to be 0.75. Further, an outflow test result of 14.5 seconds was determined to approximate a Mean Profile Depth (MPD) value of 0.46 mm, which has been established as a point of safety concern. The conclusion was that macrotexture measurements could be used for measuring seal coat performance. However, the study did not include analyses of macro-texture variations stemming from the use of various grades of seal coat aggregate.

Analysis of Emulsion and Hot Asphalt Cement Chip Seal Performance (*4*). This project compared the performances of several hundred northeast Texas chip seals, about half of which were constructed with an emulsion, CRS-2P, and half of which were constructed with a hot asphalt cement, AC-15-5TR. Lightweight aggregate was used in all chip seals. The report indicated that a single grade, or specification for aggregate gradation, was used on all roadways included in the study, but the grade used was not identified by grade number or by gradation specification. The aggregate was precoated prior to use with AC-15-5TR, but was not precoated when used with CRS-2P. The stated purpose of the study was to determine the effect of design and construction elements on chip seal performance. Chip seal performance was analyzed based on annually collected pavement performance data stored in TxDOT's Pavement Management Information System.

Conclusions from the study included that roadways TxDOT had selected for hot asphalt cement seal coating average almost four times the average daily traffic (ADT) and over nine times the average 18-kip equivalent axle loads as those roadways selected for seal coating with asphalt emulsions. On the other hand, roadways seal coated with emulsions had generally lower distress scores and rutting scores prior to sealing. A comparison of cost versus traffic volume found that hot asphalt seal coats furnished a lower cost per unit of annual daily traffic. However, the use of emulsions is reported as justified on lower traffic roadways due to lower initial cost and satisfactory performance. As the study was limited to use and performance of a single type and gradation of aggregate, little definitive information pertaining to the primary object of this research project was provided.

Implementation of Transverse Variable Asphalt Rates in Texas (*5*). An implementation project was performed to expand use of transversely varied asphalt rate (TVAR) seal coat practices in all Texas districts. The project included nine regional workshops, continued field texture testing of test sites, provided one set of sand patch test equipment to each TxDOT district, and published 500 copies of the *TVAR Field Guide* for broad TxDOT distribution. The texture depth data collected for two years after placement of both Grade 3 and Grade 4 seal coats showed that Grade 3 seal coats performed substantially better than Grade 4 seal coats when placed on pavements that were flushed in retaining a flushing free surface.

The Little Book of Quieter Pavements (*6*). The objective of this publication was to educate practitioners about tire-pavement noise, document current noise testing practices, and when possible to advance knowledge of how traffic noise might be minimized. The publication describes the difference between sound and noise, how we hear, how sound travels, and how sound is measured. This information is then applied to the measurement and control of traffic noise. Pavement surface characteristics affecting a quieter pavement are stated to include low texture, high porosity, and low stiffness. The focus of discussions was divided between flexible and rigid pavements. Among flexible pavement types, porous asphalt mixtures, dense-graded mixtures, and stone-filled mixtures were considered. Seal coated pavements were not specifically addressed.

NEW ZEALAND LITERATURE

Chipsealing Practice in New Zealand (*7*). The typical pavement structure in New Zealand is flexible granular base covered with a thin bituminous surface. Over 60 percent of the country's road network is surfaced with chip seals. Traffic volumes lend themselves to broad chip seal use, as 80 percent of the state highway system carries less than 6,000 AADT. It is not unusual for a chip seal to be used on a New Zealand roadway carrying up to 10,000 AADT. Selection of the surface type is generally based on surface shear stress levels and economics as determined using their Road Asset Maintenance Management System (RAMM). The manual includes typically expected chip seal lives based on daily traffic and the maximum size of the aggregate being applied. See Table 1 for these anticipated service lives. Lower chip seal grade numbers indicate larger aggregate size. Aggregates used in New Zealand for resealing are generally Grades 2, 3, and 4, with maximum sieve sizes of 19 mm, 16 mm, and 14 mm, respectively. Grade 3 is the most commonly used aggregate size.

Table 1. Anticipated Chip Seal Service Lives (after RAMM Rating Manual, National Roads Board, 1988 [*8*]).

Surface Type	Use 1 (<100 vpd)	Use 2 (100–500 vpd)	Use 3 (500–2,000 vpd)	Use 4 (2,000–4,000 vpd)	Use 5 (4,000–10,000 vpd)	Use 6 (10,000–20,000 vpd)	Use 7 (>20,000 vpd)
	Life in Years						
Grade 5	8	7	6	5	4	3	2
Grade 4	12	10	8	7	6	5	4
Grade 3	14	12	10	9	8	7	6
Grade 2	16	14	12	11	10	9	8

New Zealand researchers were contacted concerning this table of anticipated service lives for various grades of seal coats and traffic levels. The response was that this table resulted from consensus opinions of a group of highly experienced pavement engineers. *Chipsealing in New Zealand*, a publication of Transit New Zealand, Roading New Zealand and Road Controlling Authority, 2005, references this table as well, but notes that some practitioners regard the projected lives to be quite generous.

New Zealand chip seals most frequently reach an end of service life due to flushing and loss of macro-texture. Both performance-specified work and method-specified work are used for construction. For performance-specified work, a 12-month warranty period is included. For method-specified work, a 48-hour warranty period is included. A chip seal is considered a failure if it does not provide at least 50 percent of the anticipated service life.

Chipsealing in New Zealand (*9*). Transit New Zealand is the country's primary governmental road authority. New Zealand ranks alongside the United States as international leaders in the use of seal coats and development of improved seal coat methods. This publication serves as the New Zealand seal coat manual, and more, including chapters on the history, industry, and performance of chip sealing in this country. It may be the most comprehensive single publication in the world on seal coats. However, no additional information is provided regarding anticipated service life of seal coats except as already referenced above.

Solutions for Improving Chipseal Life (*10*). This study was designed to identify trends in chip seal failure causes in New Zealand over the prior 10-year period. The most commonly used seal coat over the decade evaluated was Grade 3, which composed 40 to 50 percent of annual seal coat totals. Grade 2 was the next most commonly used seal coat, ranging from 14 to 26 percent of annual seal coats. Throughout the decade being evaluated, New Zealand road authorities increased the percentage of two-coat seals being used substantially. A corresponding increase in expected seal coat lives resulted.

Records are kept of reasons for reseals in New Zealand. This study evaluated these records. A change in requirements to reseal flushed pavements is the probable cause for flushing being the most common reason recorded for resealing. A corresponding major decrease (from approximately 40 percent to approximately 10 percent) was noted in alligator cracking being cause for reseals. Brittleness of the binder was noted as the cause for only 6 percent of reseals.

Perhaps the finding of most interest was that no most-common age for reseal could be identified. While the overall average reseal age for commonly used seal grades and traffic levels was found to be 8.6 years, reseal ages ranged from zero to 16 years with no distinctly identifiable peak found. Indeed, the highest likelihood for reseal at any specific age occurs at age zero and at age one year, when construction-related problems require resealing.

Table 2 shows average service lives identified for reseals based on traffic levels. These differ somewhat from anticipated service lives shown in Table 1. An observation of particular interest is that at each traffic level with adequate data to compare, Grade 3 (coarser seal coats) average service lives are shorter than Grade 4 average service lives. This trend continues although less consistently when Grade 2 and Grade 3 service lives are compared.

Table 2. Average Seal Coat Service Lives (after Ball, Patrick, and Herrington, 2004 [*10*]).

Average Daily Traffic	Service Life prior to Reseal, Years		
	Grade 4	Grade 3	Grade 2
500–2,000	10.2	8.1	7.7
2,000–4,000	8.2	5.6	7.6
4,000–10,000	-	7.2	5.9
10,000–20,000	-	5.4	6.0

Analysis of New Zealand Chip Seal Design and Construction Practices (*11*). This paper documents the history of the evolution of chip seal practices in New Zealand. The entirety of the New Zealand chip sealing process, from the design stages through the construction process and machinery used, are reviewed. It also includes ratings of the quality of roads when sealed over time and the quality of ride on North American chip-sealed roads compared to those in New Zealand. The researchers concluded that New Zealand chip seal design practices and innovations have outpaced those in the United States, citing the continuing research done in New Zealand in recent years. The advancement of watercutter practices to remove excess bitumen from flushed chip seals was another example cited.

The Effects and Significance of New Zealand Road Surfaces on Traffic Noise (*12*). Researchers have expanded on a previous study about the noise effects of road surface types, and the impact the noise has on neighboring communities. However, this study evaluates the traffic noise created on low-textured surfaces made from bituminous mixes. By calculating the combined effects of heavier vehicles along with lighter vehicles, the data show that the larger the aggregate size being used, the louder the noise is from the road. The data also show that the higher the percentage of travel by heavy vehicles, the quieter the resulting noise level. This report also contains guidelines for quantifying public concern with road noise based on the percentage of the total population reporting being acutely affected by noise before the re-surfacing compared to the percentage of those reporting being affected after the re-surfacing. A guideline was also created to aide in the selection of road surfaces when re-surfacing and to identify the impact on the community of the change in noise level.

CHAPTER 3:
SEAL COAT GRADE SELECTION PRACTICES IN THE DISTRICTS

OBJECTIVES OF DISTRICT SURVEY

Districts across Texas are known to approach and resolve challenges in different manners. Usually, the different approaches are being used for specific, logical, and often geologic or climatic reasons. For this reason the research team contacted each district to learn how each decides where and when to use Grade 3, and/or Grade 4, and/or Grade 5 seal coats, and if they currently use modifications (gradation) of these grades. They also discussed the reasons for compelling the use of each seal coat grade.

The objectives of this task were to establish current district selections of seal coat grade and the reasons for these selections to help illuminate roadway conditions best warranting the use of the available seal coat grade options.

DISTRICT INTERVIEWS AND VISITS

Researchers collected information in person, at the district offices, from the majority of the districts. In a number of cases the district visit ended with a trip to the field to look at several seal coats. The research team obtained information from the remaining few districts by telephone and email communications. Initial contacts were generally made with the District Maintenance Engineer, who then determined the best individual or group of individuals to provide the desired information for their district. Using a structured interview process, the research team posed a number of questions pertaining to the district use of seal coats in 2010, but also included inquiries regarding historical experiences in each district. Appendix A includes the question list.

GENERAL INFORMATION OBTAINED FROM DISTRICT INTERVIEWS

Appendix B summarizes the information gathered from the district interviews and is found on the CD-ROM enclosed with this report. As expected, there are differences in seal coat related choices being made around the state. However, there were also a number of common threads of practice and philosophy. Foremost among the latter is a significant move to using finer seal coat grades in Texas. During the last several years, a number of districts have moved to exclusive use of Grade 4 seal coats, and many of those still using both Grade 3 and Grade 4 are using considerably less Grade 3 aggregate. The predominant factor behind the change to use of a finer seal coat grade is initial cost difference. Statewide, district engineering managers responsible for maintenance of pavements cited a lack of adequate funding to handle preventive maintenance needs in their districts. A common reason given for shifting to finer seal coat grades was "to cover more area" with the available funding. These managers also generally believe that shorter performance lives are to be expected from this shift to finer seal coats.

Further, and an even more troubling result of funding shortfalls, the research team noted during the district visits that there are situations where preventive maintenance funding for seal coats is being used to hold heavily deteriorated pavements together for a relatively short period of time until rehabilitation funding becomes available. In this situation, instead of the district obtaining six to 10 years of service from the expenditure required for the seal coat, the district will be obtaining only perhaps one to three years of service. That said, the district decision makers have little choice within their funding availability, as letting a pavement needing major repair go unaddressed altogether is unacceptable to the communities involved.

Of the 25 districts, two reported minimal or no seal coat program construction in 2010, 11 reported using a combination of Grade 3 and Grade 4 seal coat grades, and 11 reported using only Grade 4 seal coat aggregate. One district specified Grade 3 exclusively. In addition, the San Antonio and Lufkin Districts specified Grade 5 seal coats for selected roadways in their 2010 seal coat programs. San Antonio reported using Grade 5 on some of their lowest volume roadways. Lufkin reported use of Grade 5 in urban areas where they experience considerable turning movements and on some hot mix pavements with lower than desired skid numbers.

TxDOT standard specification single-size gradations were specified or allowed as options in five districts in 2010. Thirteen districts reported trying either Grade 3S or Grade 4S at least once since these single-size aggregate grades became available in the standard specifications. The strong consensus of those trying the single-size aggregate was that a premium quality seal coat should result. The most common reason expressed for no longer specifying the single-size grades is increased initial cost of these options.

Only Childress reported specifying a modified aggregate gradation in 2010 other than the single-size options allowed in the standard specifications. The Childress District specified a gradation band allowing Grade 4 aggregate to be a little coarser than the standard specification Grade 4 gradation. This modification allows several Oklahoma aggregate producers to provide competitive bids on Childress projects since the seal coat aggregates they produce for the Oklahoma Department of Transportation will meet this modified gradation requirement. Table 3 shows the modified gradation band specifications compared to the standard specification gradation requirements.

Table 3. Childress District Grade 4 Modified Gradation Requirements.

Sieve	Percent Retained Gradation Bands Required for Grade 4	
	Childress District Modification	2004 Standard Specifications
3/4″	0	-
5/8″	-	0
1/2″	0–10	0–5
3/8″	30–60	20–40
No. 4	85–100	95–100
No. 8	95–100	98–100
No. 10	-	-
No. 200	98.5–100	-

Table 4 summarizes quantities of the various grades of seal coats specified for use in 23 2010 district seal coat programs. For comparison purposes, plans for 20 2002 district seal coat programs were located, with the quantities of the various grades of seal coats gathered and summarized in Table 5. The move toward finer aggregate sizes is evident when comparing quantity information from these two years.

Table 4. Seal Coat Aggregate Specified in 2010 District Seal Coat Programs (23 Districts).

Units	Grade 3	Grade 3S	Grade 4	Grade 4S	Grade 5	Grade 3 Mod.	Grade 4 Mod.	Other	Total
Cubic Yards	252,398	9,791	409,813	37,516	15,207	0	64,058	0	788,783
%	32.0	1.2	52.0	4.8	1.9	0	8.1	0	100.0

Table 5. Seal Coat Aggregate Specified in 2002 District Seal Coat Programs (20 Districts).

Units	Grade 3	Grade 3S	Grade 4	Grade 4S	Grade 5	Grade 3 Mod.	Grade 4 Mod.	Other	Total
Cubic Yards	428,453	0	326,538	0	14,276	9,413	111,586	30,874	921,140
%	46.5	0	35.5	0	1.5	1.0	12.1	3.4	100.0

Personnel from each district were asked their opinions regarding expectations for service lives to be obtained from Grade 3 and Grade 4 seal coats. District personnel expressed a belief that Grade 3 seal coats would perform one to several years longer than Grade 4 seal coats in most application situations. However, no district reported having placed test sections or otherwise having performance data to support this belief.

In addition to higher construction cost, concerns limiting the use of Grade 3 aggregate included the fact that the larger aggregate can be expected to generate more noise under traffic than a finer aggregate. Also, and particularly where siliceous aggregates are being used, Grade 3 aggregate will result in much higher incidence of broken windshields from loose aggregate being kicked up by traffic. For these reasons, Grade 3 aggregate are rarely specified in urban areas, on multi-lane roadways, or on relatively high trafficked two-lane roadways.

CRITERIA FOR SELECTING AGGREGATE GRADE IN DISTRICTS USING BOTH GRADE 3 AND GRADE 4

Eleven districts reported using both Grade 3 and Grade 4 seal coats in their 2010 district seal coat programs. Those interviewed were asked to describe the factors their district considered when determining which grade should be used in each specific location. Traffic level was the most often mentioned factor. Interestingly, however, the districts are divided on whether higher traffic level indicates the need for a larger or smaller aggregate size. Five districts indicated they used Grade 3 on lower traffic levels, while three districts indicated they used Grade 3 primarily on higher traffic levels. The traffic level break points varied widely among the districts mentioning traffic level as a major factor. The districts generally agreed that Grade 3, having larger aggregate, was preferred over Grade 4 when the roadway being sealed had moderate to heavy wheel path flushing. The larger aggregates are less likely to sink completely into the existing pavement, thereby providing longer lasting improved skid properties. Other situations where Grade 3 was mentioned as preferred were in locations with high truck traffic, where higher asphalt is believed needed, such as in locations having higher cracking, and where the pavement is rutted. Grade 4 is generally preferred wherever Grade 3 is not needed due to the lower initial cost of Grade 4. Other locations where Grade 4 is considered the better choice are where the level of road noise is an issue and when windshield breakage is a concern, particularly where the aggregates are generally siliceous in nature.

CHAPTER 4:
CONSTRUCTION AND TESTING OF SEAL COAT TEST SECTIONS

OBJECTIVES OF TEST SECTION CONSTRUCTION

While analysis of PMIS pavement performance information was chosen as the primary means of comparing Grade 3 and Grade 4 seal coat performances in this study, test sections were planned and constructed to further validate expected service life findings. Test sections provide a higher level of confidence in findings because traffic type and level, underlying pavement structure, subgrade conditions, and environmental factors all become constants, or nearly constants, for the seal coat grades being compared. What test sections cannot provide during a two-year research effort is a comparison of long-term performances and length of service lives provided. However, in time, this information will also become available to TxDOT. A secondary objective of the test sections was to determine if tire-pavement interface generated noise levels change during the first year seal coats are under traffic, and if so, to what degree.

TEST SECTION TYPES AND LOCATIONS

Test sections were built in three different environmental areas of the state. Four different aggregate mineral types were included. These test sections are shown in Table 6. OBSI noise testing was performed on these test sections within a week after construction, between three and six months after construction, and approximately one year after construction. Chapter 5 discusses the OBSI test results from these test sections along with other OBSI noise testing results.

Table 6. Seal Coat Test Sections Constructed by Districts.

District	County	Highway	Mineral Aggregate	Typical Length, miles	Grade 3	Grade 4	Grade 4S	Grade 5
Amarillo	Potter	Loop 335	Cr. Siliceous and Scoria	0.5		X	X	
Brownwood	Brown	US 183	Limestone	2	X	X		X
Lufkin	Nacogdoches	SH 7	Lightweight	1	X	X		X

Lufkin District Test Sections

The Lufkin District constructed end-to-end test sections of Grades 3, 4, and 5 seal coats during their 2010 district seal coat program. The aggregate for each grade was rotary kiln expanded shale and clay lightweight material produced by Texas Industries, Incorporated. The aggregate grades were precoated with asphalt prior to delivery to the construction site. The seal coat asphalt cement was AC-15P, with application rates averaging 0.42, 0.31, and 0.22 gallons/SY for the three grades of aggregate, respectively. These test sections are located southwest of Nacogdoches on SH 7. Figures 1, 2, and 3 show photographs of the three seal coat grades soon after construction.

Figure 1. Grade 3 Lightweight Aggregate Seal Coat.

Figure 2. Grade 4 Lightweight Aggregate Seal Coat.

Figure 3. Grade 5 Lightweight Aggregate Seal Coat.

Brownwood District Test Sections

The Brownwood District provided end-to-end test sections of limestone aggregate Grades 3, 4, and 5 seal coats during their 2010 district seal coat program. The seal coat asphalt was an emulsion, CRS-2H. The asphalt application rates averaged 0.48, 0.35, and 0.19 gallons/ SY for the three grades of aggregate, respectively. In addition, the Brownwood District placed two test sections where the Grade 3 and 4 aggregate application rates were reduced slightly, allowing determination of whether small changes in aggregate application rate have a measurable effect on tire-pavement interface generated noise level. The Grade 3 aggregate coverage rates were 1CY/85SY and 1CY/90SY. For the Grade 4 the two aggregate coverage rates were 1CY/120SY and 1CY/125SY. The reduced aggregate coverage rates were placed in climbing lanes immediately adjacent to the standard aggregate coverage rates, so when comparing aggregate application rates over time, traffic levels cannot be assumed to be equal. The Brownwood District test sections are located between May and Rising Star on US 183 north of Brownwood. Figures 4, 5, and 6 show photographs of the seal coats soon after construction.

Figure 4. Grade 3 Limestone Aggregate Seal Coat (1CY/85SY).

Figure 5. Grade 4 Limestone Aggregate Seal Coat (1CY/120SY).

Figure 6. Grade 5 Limestone Aggregate Seal Coat.

Amarillo District Test Sections

The Amarillo District constructed end-to-end test sections of Grades 4 and 4S seal coats during their 2011 district seal coat program. These test sections sought to determine the difference in performance and noise generation between the standard gradation for Grade 4 and the near single-sized Grade 4S aggregate. This comparison was thwarted when the contractor was unable to obtain both aggregate grades from the same quarry. The Grade 4 aggregate is crushed siliceous gravel, and the Grade 4S aggregate is a lightweight scoria material. These test sections are located in the northeast quadrant of Loop 335 around Amarillo. As these test section were placed in the second summer of this research project, OBSI testing was performed only once, soon after construction. Figures 7 and 8 are photographs of the seal coats soon after construction.

Figure 7. Grade 4 Crushed Siliceous Aggregate Seal Coat.

Figure 8. Grade 4S Scoria Aggregate Seal Coat.

CHAPTER 5:
OBSI NOISE TESTING

NOISE TESTING TEST PROCEDURE

The level of noise heard on the side of the road as a vehicle passes is a compilation of noise levels generated from several sources. The primary sources are from the engine compartment, from the exhaust system, and the noise generated at the tire-pavement interface as the vehicle passes. For a given vehicle passing over two differing pavement surfaces at the same speed, the first two noise sources can be considered constants. It is the third component of total roadside noise, the component generated at the tire-pavement interface, which varies based on the type of pavement surface. For this reason, OBSI noise testing was selected to compare sound levels associated with the various types and grades of seal coats. Figure 9 shows OBSI test equipment mounted on the passenger side rear tire of a test vehicle. The OBSI method of test was AASHTO TP 76-09, "Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method." TxDOT's OBSI equipment was used for all testing, and TxDOT's noise test specialist, John Wirth, participated in all noise testing on the project.

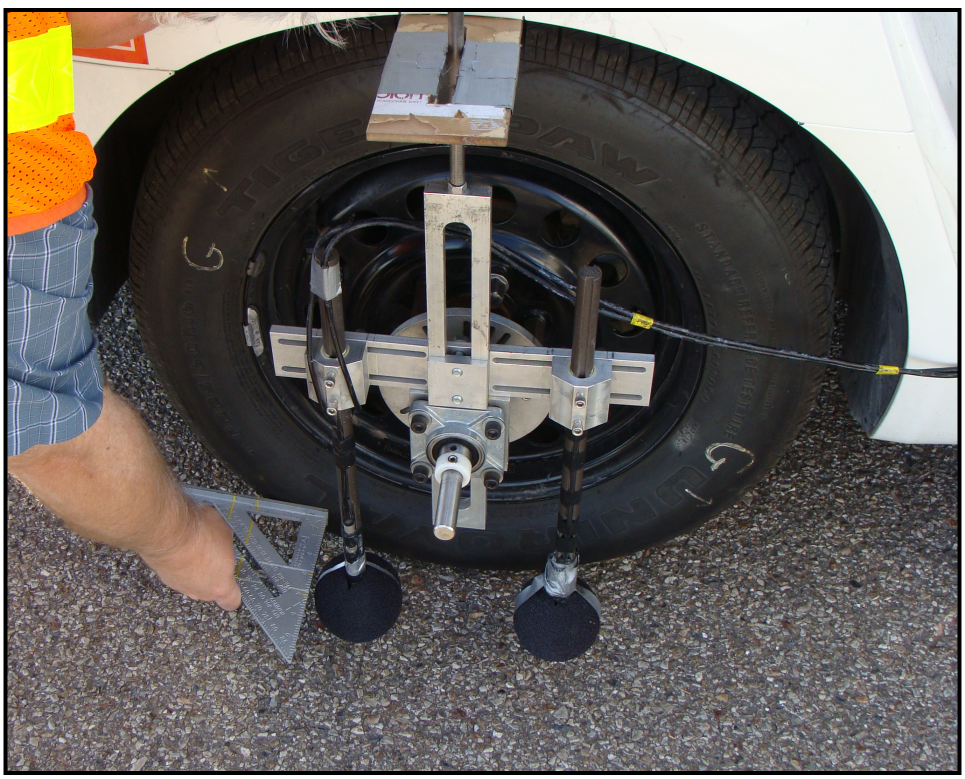

Figure 9. Mounted TxDOT OBSI Noise Testing Equipment.

SELECTION OF PAVEMENTS FOR NOISE TESTING

The research team developed a noise test plan to provide as broad a range of information as possible about seal coat pavement sound levels and the factors affecting them. Table 7 summarizes the noise testing plan. Appendix C has the detailed noise test plan that the study sponsor approved. As seal coat noise data were virtually nonexistent in the literature, the noise test plan included limited replications to allow the project to obtain a cursory look at the effect of a larger number of seal coat pavement variables.

The majority of noise tests were performed on existing seal coated pavements, of varying ages, under varying traffic levels, of varying mineral aggregate types, and of varying aggregate grade. The noise test sections constructed during the project, as described in Chapter 4, were also part of the comprehensive noise test plan. Figure 10 shows locations of noise-tested pavements.

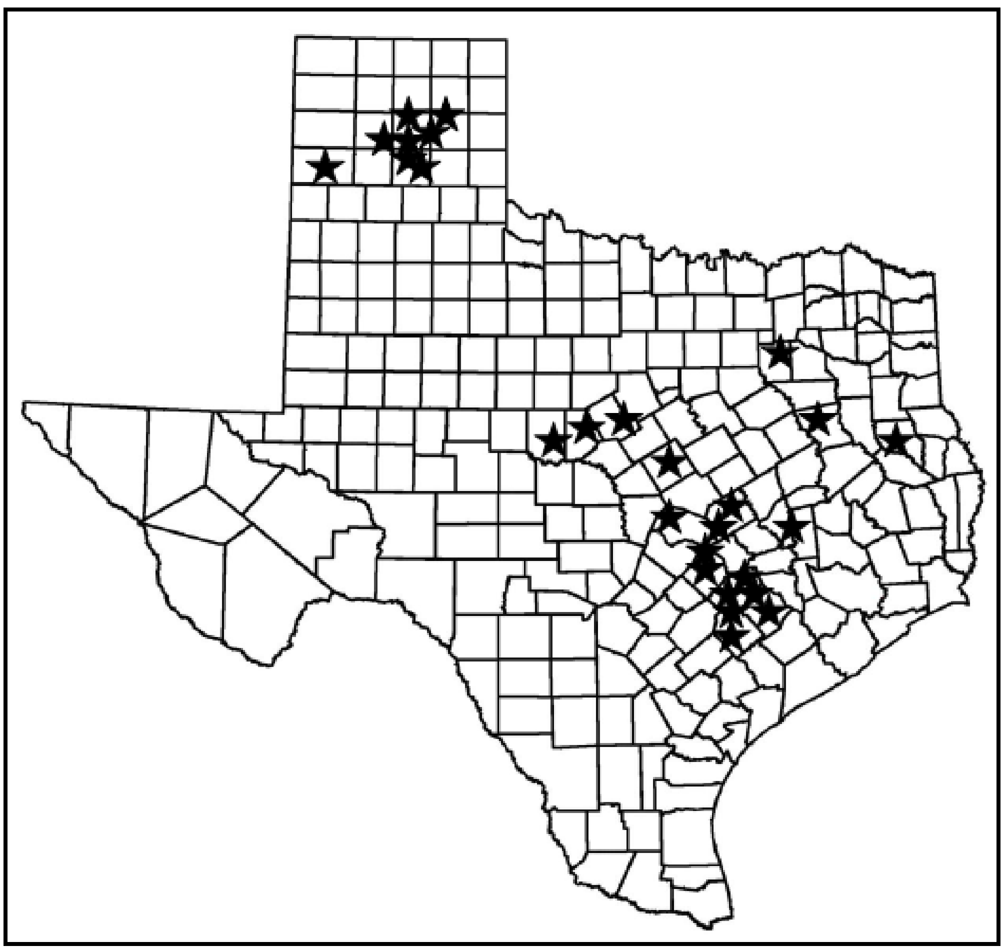

Figure 10. Noise-Tested Pavement Location Map.

Table 7. Summary of Noise Test Plan.

Noise Testing Objectives	Aggregate	Probable Aggregate Sources	Probable District Roadway Locations	Existing Pavement or End-to-End Test Section	Desired Individual Test Sections			Age for OBSI Noise Testing				
								Within 2 weeks	3 to 6 Months	1 year	3-4 years	6-8 years
1. Determine degree of inherent difference in noise levels of Grade 3 and Grade 4 seal coats in Texas. 2. Determine affect of aggregate mineralogy on seal coat noise level. 3. Determine extent that noise levels change over normal seal coat service lives.	Limestone - Grade 3	CSA, Colorado Materials, Vulcan (Bwd)	San Angelo, San Antonio, Yoakum, Brownwood	Existing						**3 sites** (summer of 2009 seals)	**1 site** (summer of 2006 and 2007 seals)	**1 site** (summer of 2002 thru 2004 seals)
	Limestone - Grade 4	Vulcan (Bwd), Hanson (Servtex), Jones Bros., Colorado Materials, Vulcan (Weatherford)	Brownwood, Austin, Odessa, Yoakum, Bryan, Fort Worth	Existing						As above.	As above.	As above.
	Gravel - Grade 3	Capitol Aggr. (Hoban)	Odessa	Existing						As above.	As above.	As above.
	Gravel - Grade 4	Capitol Aggr. (Hoban), J. L. Milligan	Lubbock, Odessa	Existing						As above.	As above.	As above.
	Lightweight - Grade 3	TXI	Dallas, Waco, Lufkin, Tyler, Bryan	Existing						As above.	As above.	As above.
	Lightweight - Grade 4	TXI	Waco, Bryan, Lufkin	Existing						As above.	As above.	As above.
4. Determine early age noise levels characteristic of Grade 3, Grade 4, and Grade 5 seal coats.	Limestone	Central Texas limestone	San Antonio	Test Sections	Grade 3	Grade 4	Grade 5	X	X	X	**Optional**	**Optional**
	Lightweight or Contractor's other choice	TXI	Lufkin	Test Sections	Grade 3	Grade 4	Grade 5	X	X	X	**Optional**	**Optional**
5. Determine affect of rock spread rate on noise.	Grade 3	Central Texas limestone	Yoakum	Test Sections	Grade 3 normal rock rate	Grade 3 heavier rock rate (adjust AC rate as needed)		X	X	X	**Optional**	**Optional**
	Grade 4	Central Texas limestone	Brownwood, Yoakum	Test Sections	Grade 4 normal rock rate	Grade 4 heavier rock rate (adjust AC rate as needed)		X	X	X	**Optional**	**Optional**
6. Determine affect of single sizing aggregate on noise.	Grade 3 and 3S and/or Grade 4 and 4S	Oklahoma sandstone, North Texas limestone	Laredo	Test Sections	Grade 3 or Grade 4	Grade 3S or Grade 4S		X	X	**Optional**	**Optional**	**Optional**
7. Document noise level of seal coats reported as particularly loud or quiet by districts during survey. Test up to six locations.	Any	Any	Statewide	Existing				**Current Pavement Age**				

With the approval of the project monitoring committee to proceed, the research team contacted district offices in pursuit of the test sections shown on the plan. Existing seal coat locations appropriate to fill the desired test matrix were identified through study of historical construction plans and records. These locations were then visited and in most cases discussed with local TxDOT personnel prior to the final determination of including them in the study. All seal coat variables identified in the desired test matrix were successfully included in testing, except for the one-year old crushed siliceous Grade 3. No Grade 3 siliceous aggregate seals of this age could be found in the state.

ANALYSES OF NOISE TESTING RESULTS

Electronically collected noise test data were analyzed to determine overall sound intensity levels, measured in decibels with A-weighting, or dB(A), emitted from the tire-pavement interface. The noise data were also evaluated to determine the pattern of sound frequencies being emitted. The primary study interest was in comparing overall sound intensity levels to determine the effect of a number of aggregate characteristics on noise level. Discussions about the apparent effect of these various characteristics on sound intensity level follow. Appendix D includes a graphical display of sound frequency data from each tested roadway.

Effect of Aggregate Grade

The end-to-end test sections of Grades 3, 4, and 5 constructed in the Brownwood and Lufkin Districts were noise tested within a week of construction. These offer the best comparisons of seal coat grade noise levels since age, traffic level, asphalt, construction equipment and method, and underlying pavement were constants. Figure 11 displays the results of testing soon after construction.

The test results in Figure 11 confirm that noise intensity tends to increase with increasing aggregate size, an expected outcome. The amounts of difference in noise intensity levels measured from the three aggregate grades were surprisingly little and are less than is usually perceivable to the human ear. A difference of 3 dB or less will not be noticeable to most people, while a change of 5 dB is readily perceived *(6)*. Based on the pronounced differences in noise heard *inside* the vehicle during testing, larger differences in the tire-pavement interface noise levels were expected.

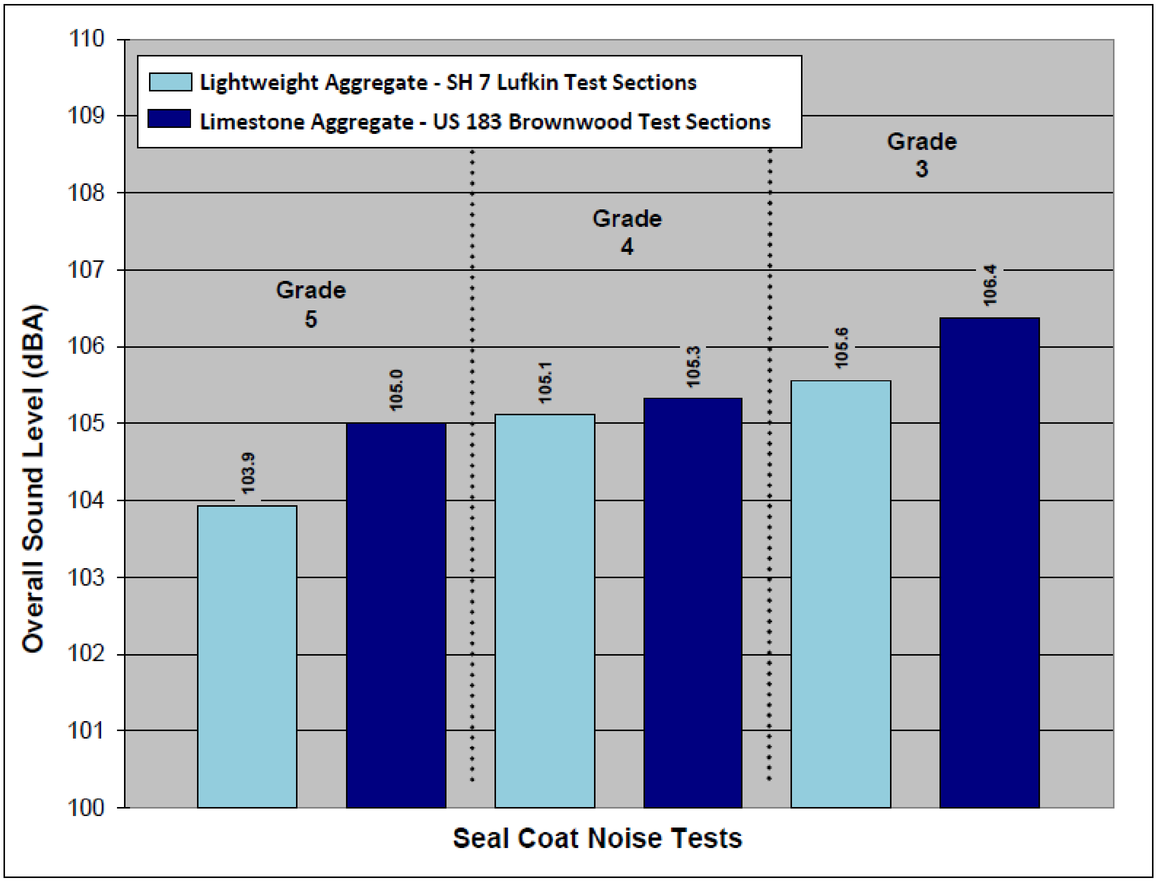

Figure 11. Noise Level Comparison of Grades 3, 4, and 5 Lightweight and Limestone Seal Coat Test Sections Less Than 1 Week under Traffic.

Figure 12 displays noise levels as determined from all testing performed on the project. These data include lightweight, limestone, siliceous, limestone rock asphalt, and scoria aggregate mineral types, and seal coat ages from several days old to 11 years old.

An interesting aspect seen in Figure 12 is the degree of overlap between noise intensity levels among the aggregate grades. Some Grade 5 seal coats are louder than Grade 4 seal coats, and some Grade 4 seal coats are louder than Grade 3 seal coats. This is not a particularly surprising finding as the seal coats tested and displayed in Figure 12 are of different mineral types and vary in age from a few days to 11 years. While the research team did not include significantly flushed pavements in the test group, differences in texture depth resulting from differing amounts of aggregate embedment certainly existed among the pavements tested.

Average noise intensity levels were determined for all Grades 3, 4, and 5 seal coats tested. The average noise intensity level averages were 106.2 dBA, 105.5 dBA, and 104.5 dBA, respectively, for Grades 3, 4, and 5 seal coats.

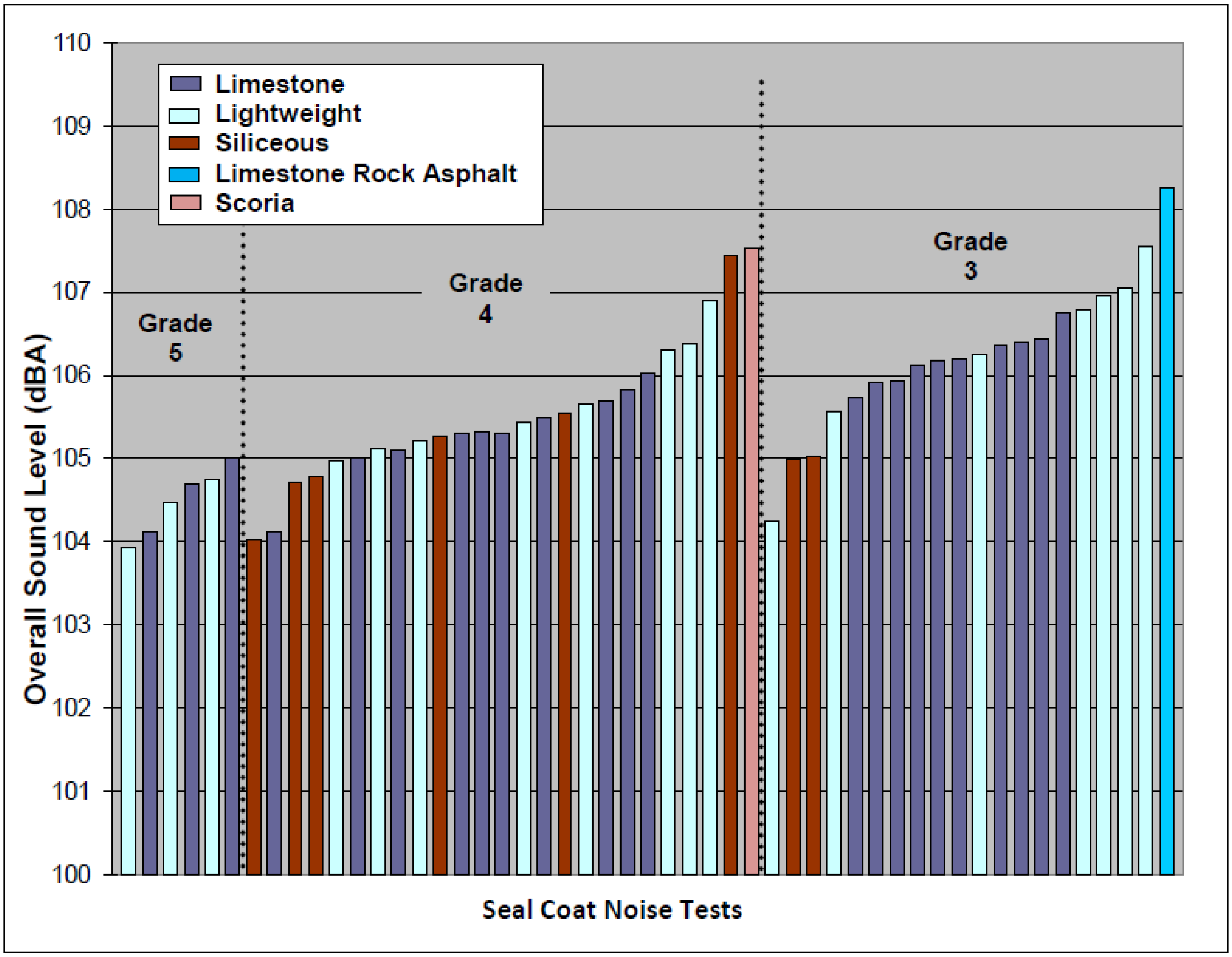

Figure 12. Comprehensive Noise Level Comparison of Seal Coat Grades 3, 4, and 5 – All Ages.

The single limestone rock asphalt seal coat included in the noise test study was selected for testing because the local district considered it particularly loud. This seal coat was approximately 10 years old when noise tested, and it was still in very good condition. The district had not yet scheduled it for resealing. This pavement was found to be the loudest seal coat included in project testing, at 108.3 dBA. Figures 13 and 14 show the appearance and texture of this pavement. On the other extreme among Grade 3 seal coats, an eight-year-old lightweight Grade 3 was found to have a noise level of 104.3 dBA, which is well within the noise level range found for Grade 5 seal coats. Figures 15 and 16 show the appearance and texture of this particularly quiet Grade 3 seal coat. The texture photo shows a distinct lack of macro-texture, which may be a factor in the lower noise level being emitted.

Figure 13. US 80 Limestone Rock Asphalt Grade 3 Seal Coat Appearance.

Figure 14. US 80 Limestone Rock Asphalt Grade 3 Seal Coat Texture.

Figure 15. FM 503 Lightweight Grade 3 Seal Coat Appearance.

Figure 16. FM 503 Lightweight Grade 3 Seal Coat Texture.

Effect of Mineral Type

Testing included seal coats composed of limestone, siliceous, lightweight, limestone rock asphalt, and scoria mineral types. Figure 17 displays the range of noise levels found in siliceous, limestone, and lightweight aggregate Grade 3 seal coats after at least one year under traffic. The single limestone rock asphalt Grade 3 seal coat noise level of 108.3 dBA is not included in the figure for comparison since this pavement was selected for testing due to its particular loudness. Figure 18 shows the range of noise levels found in Grade 4 seal coats of varying mineral types after at least one year under traffic. The single noise test of scoria seal coat aggregate is also not displayed as this test was performed after one week of traffic. A noise intensity of 107.5 dBA was determined.

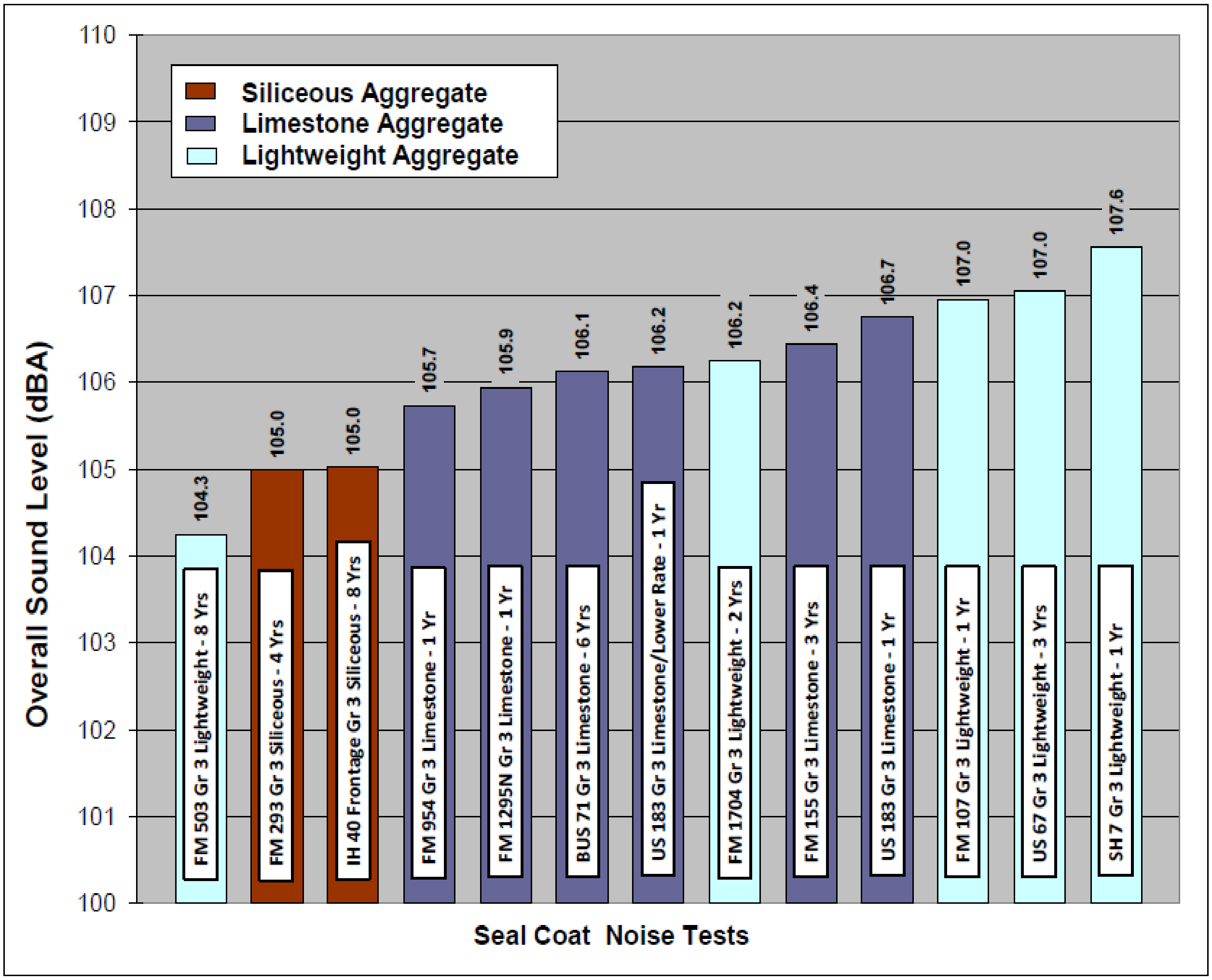

Figure 17. Noise Level Comparison of Various Grade 3 Mineral Aggregate Types after 1 or More Years under Traffic.

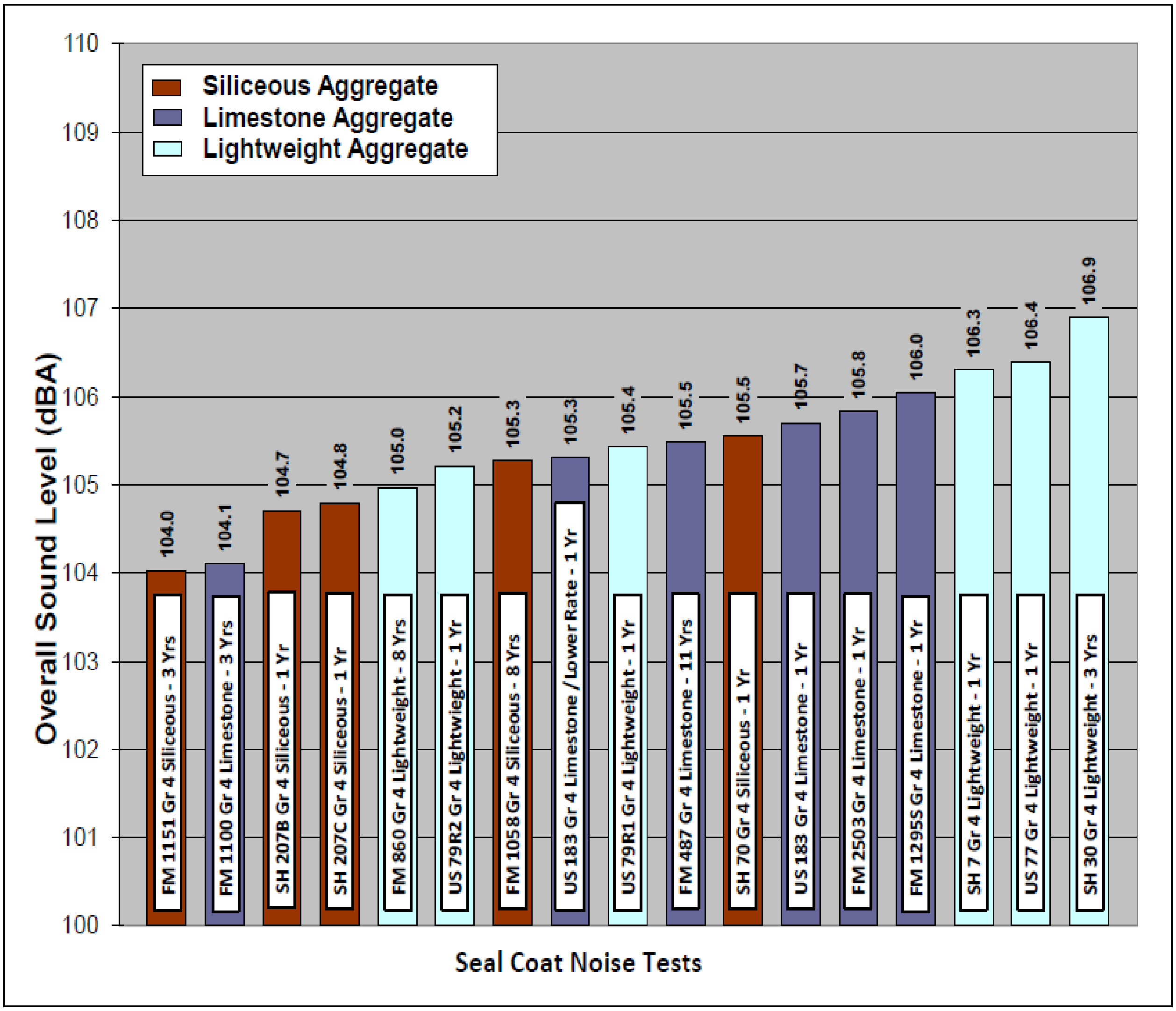

Figure 18. Noise Level Comparison of Various Grade 4 Mineral Aggregate Types after 1 or More Years under Traffic.

While no conclusion is possible from the limited testing, there is an indication that siliceous aggregate tend to generally provide slightly lower noise intensity levels after seal coats have been in service for at least a year. However, the degree of difference in noise level emanating from the tire-pavement interfaces was slightly less than 3 dBA for the entire range of test results evaluated, making the effect of mineral type minor if it is in fact a determinant of noise level.

Effect of Seal Coat Age

Seal coats of varying ages were tested during the project. The test sections constructed for this study were OBSI tested within a week after construction, after approximately three months under traffic, and after one year under traffic. Existing seal-coated pavements noise tested ranged from one year to 11 years old. Figures 19 and 20 display noise test results obtained from the limestone and lightweight aggregate seal coat test sections constructed for this project. During the first year under traffic, a mild increase in tire-pavement interface noise is noted in two of the three limestone aggregate test sections and in all three of the lightweight aggregate test sections. However, the degree of increase in noise level is so small as to be indiscernible to the human ear.

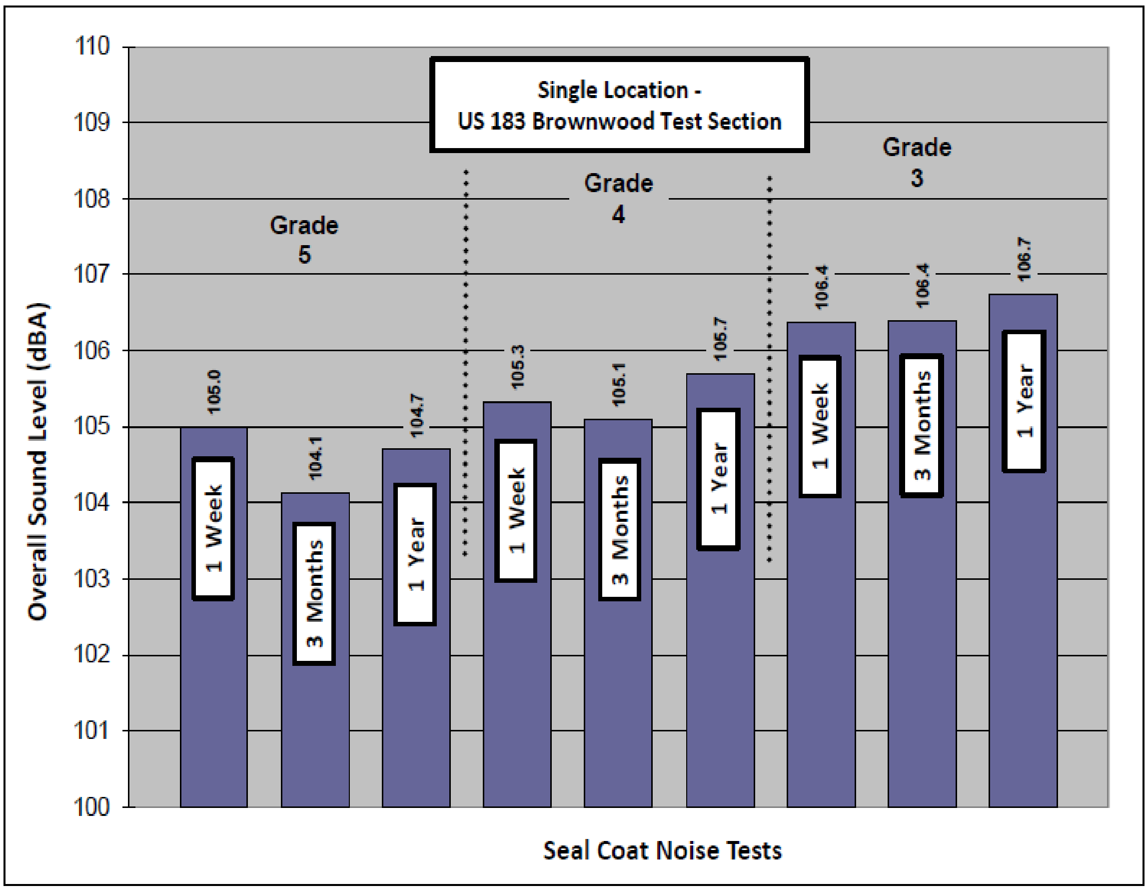

Figure 19. Noise Level Comparison of Limestone Seal Coats at Early Ages.

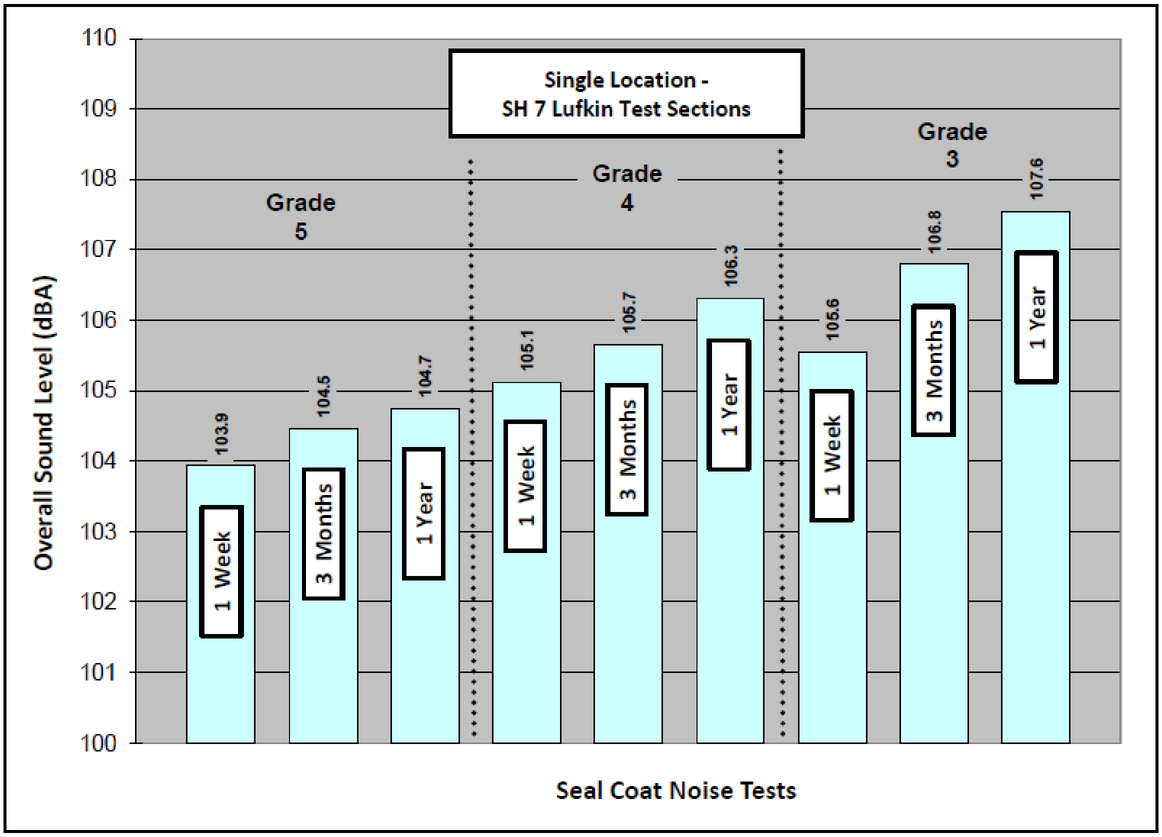

Figure 20. Noise Level Comparison of Lightweight Seal Coats at Early Ages.

Figures 21 through 25 display noise test results from multiple locations, including both the constructed test sections and the existing pavements tested at various later ages. As such, they show the range of noise levels found for the full range of seal coat ages included in the study. The test results are grouped by age at the time of noise testing.

As shown in these five figures, no obvious trend between age and noise level being generated at the tire-pavement interface was observed. A possible trend is noted for the lightweight aggregate to become slightly louder with age. When interpreting these results, one should keep in mind the process of selecting existing pavements for testing. If a pavement was found to have notable flushing in the wheel path, it was not included in the set of pavements to be tested. A number of pavements did exhibit a degree of flushing deemed normal for aged seal coats. Although mild, differences in degree of flushing between pavements may have had an effect on noise test results. Appendix E contains photographs of the roadway and the pavement wheel path texture representative of each noise test location.

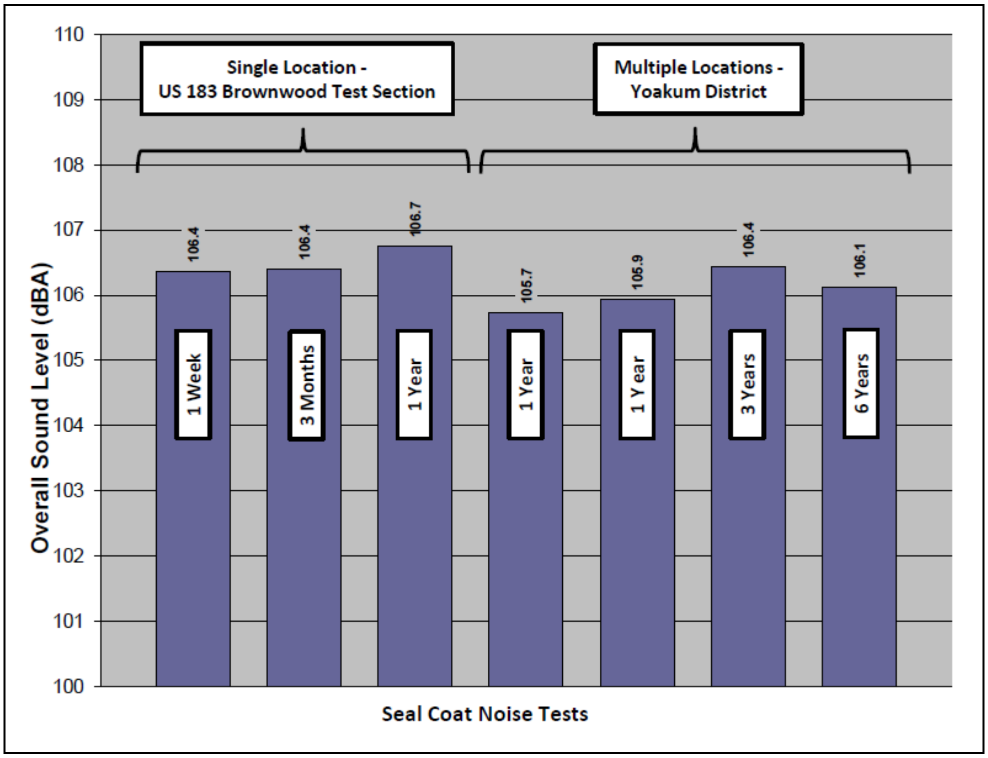

Figure 21. Noise Level Comparison of Limestone Grade 3 Seal Coats at All Ages.

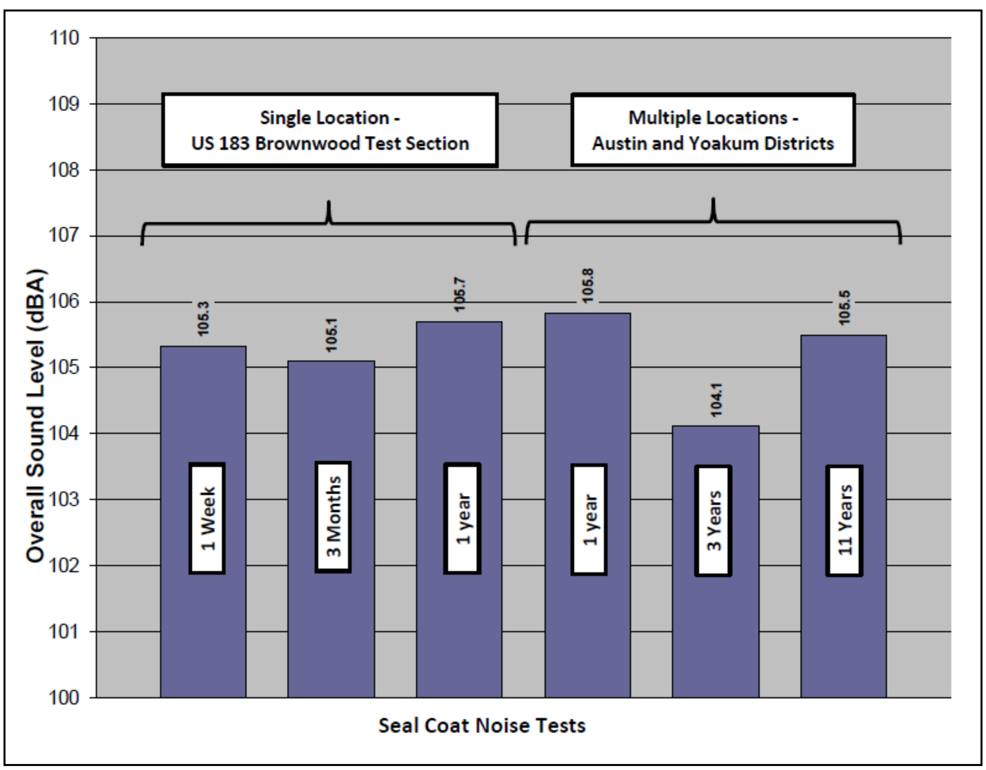

Figure 22. Noise Level Comparison of Limestone Grade 4 Seal Coats at All Ages.

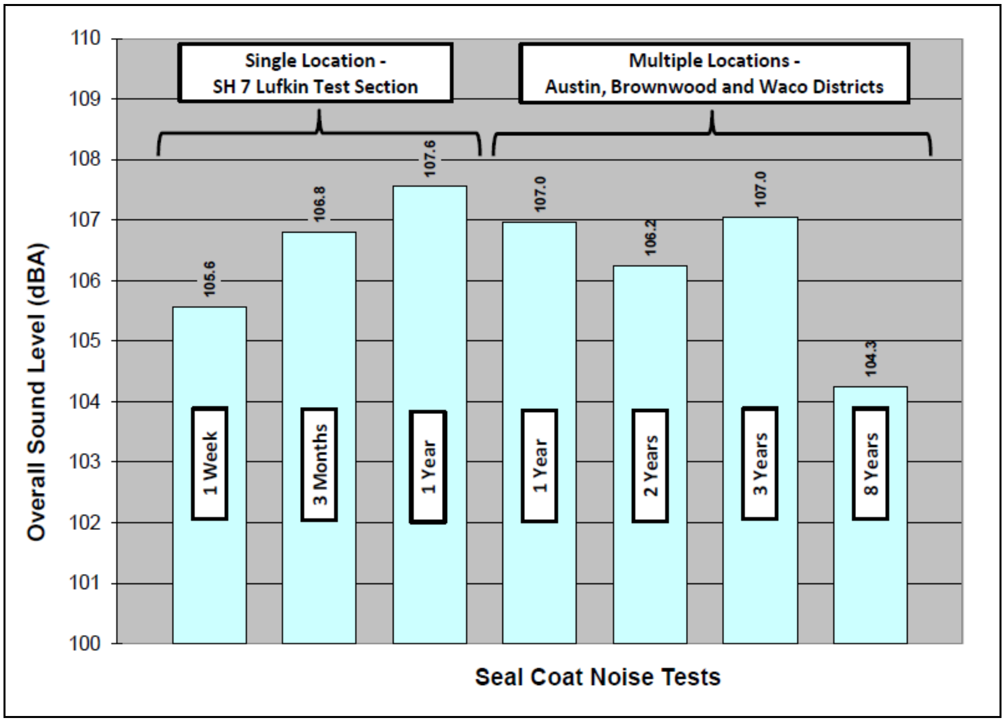

Figure 23. Noise Level Comparison of Grade 3 Lightweight Seal Coats at All Ages.

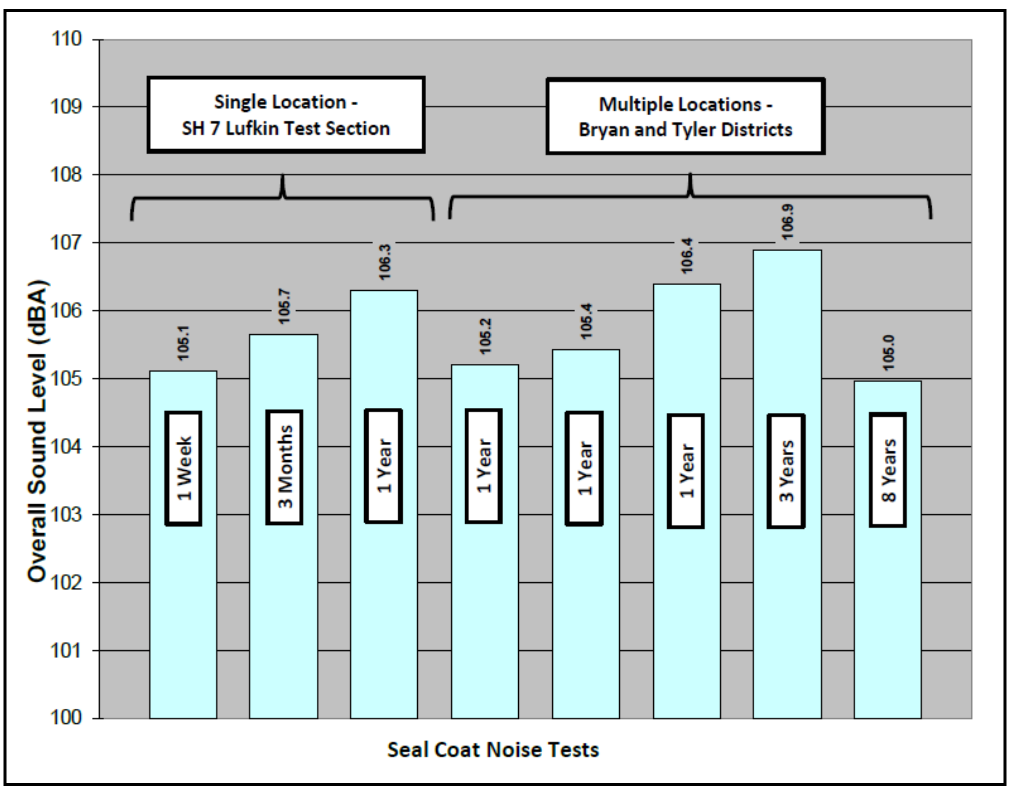

Figure 24. Noise Level Comparison of Grade 4 Lightweight Seal Coats at All Ages.

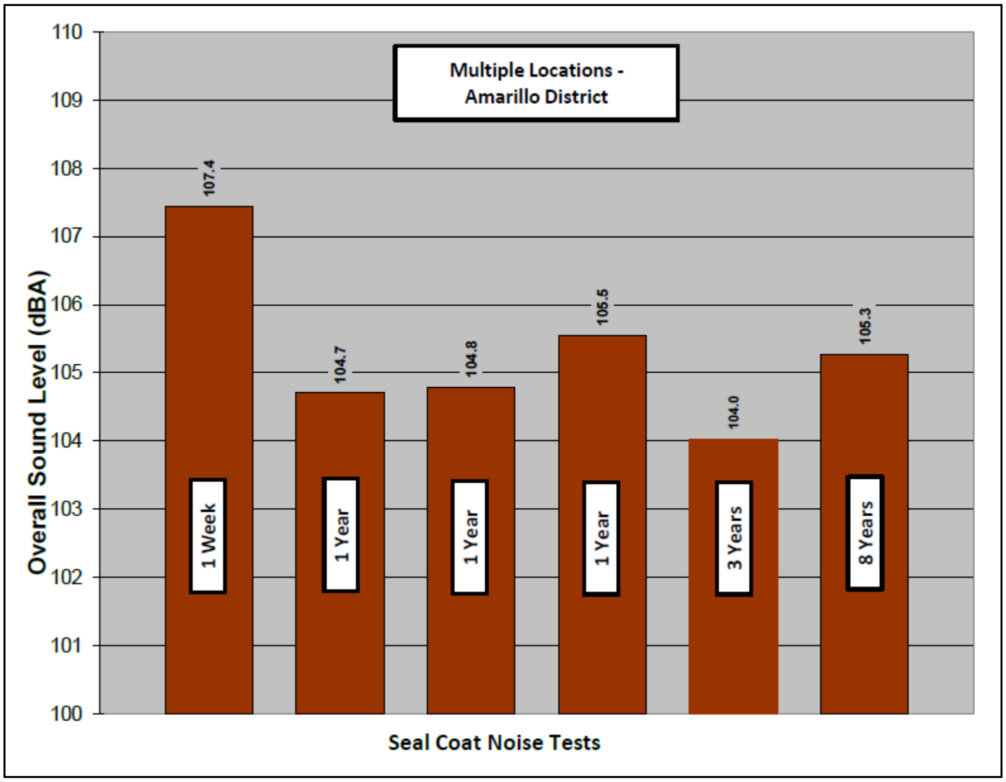

Figure 25. Noise Level Comparison of Grade 4 Siliceous Aggregate Seal Coats at All Ages.

Effect of Aggregate Application Rate

Two rates of aggregate application were placed during construction of the Grade 3 and Grade 4 Brownwood District test sections. A lower application rate was used on climbing lanes adjacent to the test sections using the district's chosen application rates. For the Grade 3 aggregate test sections, the application rates were 1CY/85SY and 1CY/90SY. For the Grade 4 aggregate test sections, the application rates were 1CY/120SY and 1CY/125SY. Figure 26 displays results of the noise testing.

A reduction in tire-pavement interface noise intensity resulted from lowering the aggregate application rate for both Grade 3 and Grade 4 limestone aggregates. However, the degree of reduction is so small that the human ear would not be able to detect this difference.

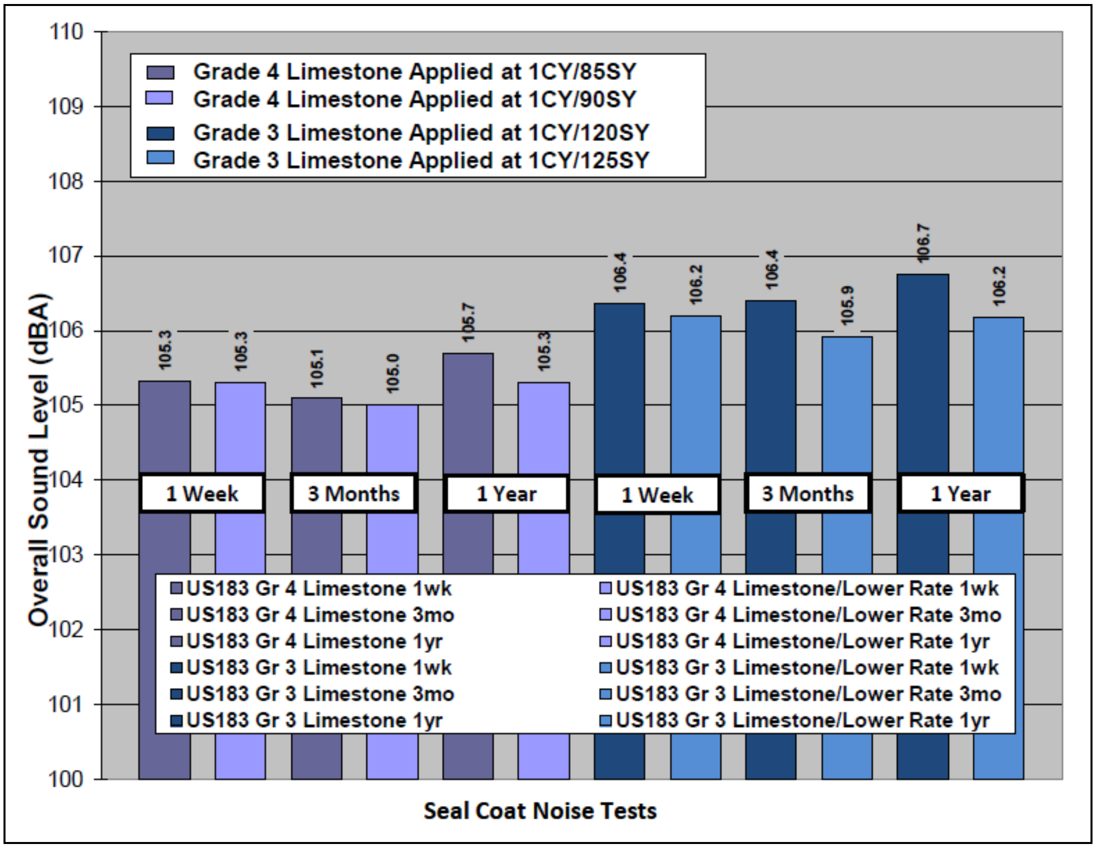

Figure 26. Noise Level Comparison of Varied Aggregate Application Rates.

Effect of Aggregate Shape

The extent of exploring the effect of aggregate shape was limited to the aggregates placed in the Lufkin District and Brownwood District test sections. Samples of each aggregate were obtained from the stockpiles and were tested for gradation and Flakiness Index in accordance with Texas Test Methods Tex-200-F (Part I) and Tex-224-F, respectively. Each was also tested using an aggregate image measurement system (AIMS). Table 8 shows the results of gradation and Flakiness Index testing, and Table 9 shows results of the AIMS testing.

The Flakiness Index values in Table 8 clearly indicate that the limestone aggregates used to construct the US 183 test sections in the Brownwood District are considerably flakier in shape than the lightweight aggregates used to construct the SH 7 test sections in the Lufkin District. The data also indicate an increasing tendency toward flakiness in the finer Grade 5 aggregates compared to the larger Grade 3 and Grade 4 aggregates for both aggregate types.

Table 8. Gradation and Flakiness Index Values.

Test	Sieve Size	Limestone Aggregate			Lightweight Aggregate		
		Grade 3	Grade 4	Grade 5	Grade 3	Grade 4	Grade 5
Sieve Analysis, % Retained	3/4"	0			0		
	5/8"	1.1	0		0.6	0	
	1/2"	36.5	0.5	0	24.2	1.3	0
	3/8"	86.9	38.5	3.8	88.2	31.5	1
	1/4"	98.3		44.3	99.1		33.4
	#4		98.9	66.2		97.3	65.2
	#8	99.1	99.5	97.9	99.9	99.9	96.8
Flakiness Index		11	8	18	4	4	7

Table 9. Aggregate Image Measurement System Test Results.

Sample ID		Size, mm	Angularity		Texture		Sphericity		Form 2D	
			Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Limestone	Grade 3	12.5	3126.9	478.3	222.5	68.5	0.65	0.07		
		9.5	2827.0	672.7	245.3	77.6	0.67	0.10		
		4.75	2935.2	735.6	180.2	82.5	0.60	0.08		
		2.36	2859.3	857.2					7.78	2.35
		All	**2937.1**		**216.0**		**0.64**		**7.78**	
	Grade 4	12.5	2343.0	683.2	227.2	76.0	0.75	0.06		
		9.5	2739.2	714.5	264.1	98.7	0.67	0.08		
		4.75	2944.3	742.5	179.9	94.8	0.65	0.10		
		2.36	2776.7	670.1					8.10	2.66
		All	**2700.8**		**223.7**		**0.69**		**8.10**	
	Grade 5	9.5	2827.2	713.3	234.7	88.7	0.68	0.08		
		4.75	2705.9	583.7	139.6	65.9	0.64	0.10		
		2.36	2935.2	535.3					7.37	1.76
		2.36	2763.6	493.1					7.26	1.70
		1.18	2982.2	607.2					8.59	2.41
		0.6	3067.8	951.3					7.80	2.16
		All	**2880.3**		**187.1**		**0.66**		**7.75**	
Lightweight	Grade 3	12.5	2316.6	813.4	305.7	35.6	0.74	0.10		
		9.5	2378.5	890.4	287.2	46.7	0.69	0.07		
		4.75	2554.7	700.1	343.4	86.2	0.67	0.08		
		2.36	2624.9	699.2					6.55	1.84
		All	**2468.7**		**312.1**		**0.70**		**6.55**	
	Grade 4	12.5	2608.1	1030.8	415.5	62.3	0.71	0.08		
		9.5	2426.7	680.9	321.6	93.0	0.70	0.07		
		4.75	2683.4	790.8	286.5	93.1	0.69	0.09		
		2.36	2574.7	568.6					6.62	1.72
		All	**2573.2**		**341.2**		**0.70**		**6.62**	
	Grade 5	9.5	2229.2	1003.2	407.0	79.8	0.76	0.06		
		4.75	2095.7	592.4	173.5	67.5	0.68	0.08		
		2.36	2142.0	668.6					6.17	1.60
		1.18	2942.6	1264.6					6.82	1.69
		1.18	2549.8	747.7					6.40	1.39
		0.6	3210.0	964.4					7.00	1.79
		All	**2528.2**		**290.2**		**0.72**		**6.60**	

Consistent with the Flakiness Index test results, the AIMs test results for Angularity, Sphericity, and Form 2D indices in Table 9 indicate the limestone aggregate is more angular and slightly less cubical and circular in overall shape. AIMs-derived Angularity has a range of 0 to 10,000 with a perfect circle having a value of 0. AIMs-derived Sphericity has a range of 0 to 1 with a value of 1 indicating a particle with equal dimensions, thereby being cubical. AIMs-derived Form 2D has a range of 0 to 20 with a value of 0 indicating a perfect circle. The AIMs-derived Texture data show the lightweight aggregates to have more micro-texture than the limestone aggregates, an expected finding from observing the photographs of these aggregates in Figures 1 through 6. AIMs-derived Texture values range from 0 to 1000 with a smooth polished surface approaching a value of 0.

No conclusions can be drawn concerning the effect of aggregate shape on seal coat pavement noise levels because of the number of variables existing in the test sections and the limited amount of shape data available for analysis versus resulting noise levels.

Effect of Aggregate Precoating

It is common practice in certain situations for construction plans to require the contractor to precoat the seal coat aggregate with asphalt prior to placement of the aggregate during seal coat paving. Noise test results from all limestone seal coats having been under traffic for one year or less are displayed in Figure 27. The results show no clear indication of effect on tire-pavement interface noise intensity level resulting from whether or not the aggregate had been precoated with asphalt prior to construction.

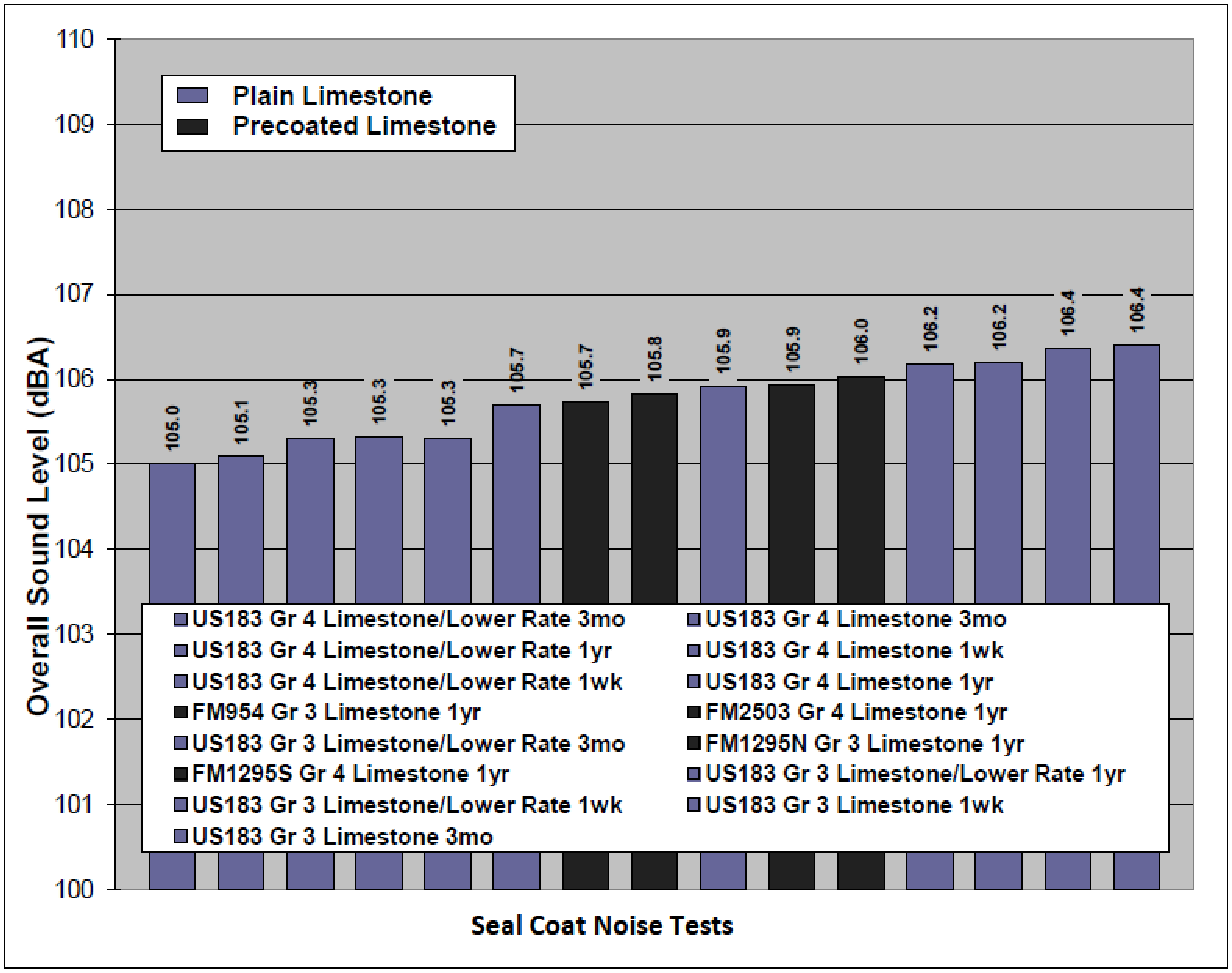

Figure 27. Noise Level Comparison of Plain and Precoated Limestone Aggregate.

COMPARISON OF SEAL COAT NOISE LEVELS TO THOSE OF OTHER PAVEMENT TYPES

In recent years, TxDOT and other TxDOT-sponsored research teams have OBSI noise tested a number of other pavement types. Project 0-5185, "Noise Level Adjustments for Highway Pavements in TxDOT," conducted by the Center for Transportation Research at the University of Texas at Austin, provided considerable test data. Figure 28 compares average OBSI tire-pavement interface noise levels from a variety of pavement types and includes data from earlier research *(13)*. It should be noted that OBSI noise testing performed for Project 0-5185 used the Uniroyal Tiger Paw AWP tire while the seal coat pavement noise testing performed for this project used the Uniroyal SRTT tire. The difference between the AWP and SRTT is not considered great, but the comparison testing performed to date indicates the AWP tire may provide noise levels a decibel or two lower than the SRTT tire.

While the pavement type noise data are displayed from left to right in descending order of average overall noise intensity level, not all of the displayed pavement types have an adequate number of representative pavements to properly assess relative noise levels between them and the other pavement types shown.

It is clear that numerous factors affect the level of noise being generated at the tire-pavement interface on most, if not all, of the pavement surface types, based on the range of noise levels found when numerous roadways of a given surface type have been tested. Because of the considerable range in noise levels from given pavement surface types, and the overlap of these ranges, selecting a pavement surface type based on the order they are displayed in Figure 28 does not provide great assurance that another pavement type might provide just as quiet or even a roadway that is more quiet.

It is apparent from Figure 28 that seal coat pavement surfaces are generally the loudest pavement surface options, followed closely by continuously reinforced concrete pavement (CRCP). Permeable friction course (PFC) surfaces tend to be noticeably quieter, on average, but it is possible to have a PFC just as loud as any of the seal coat grades or CRCP.

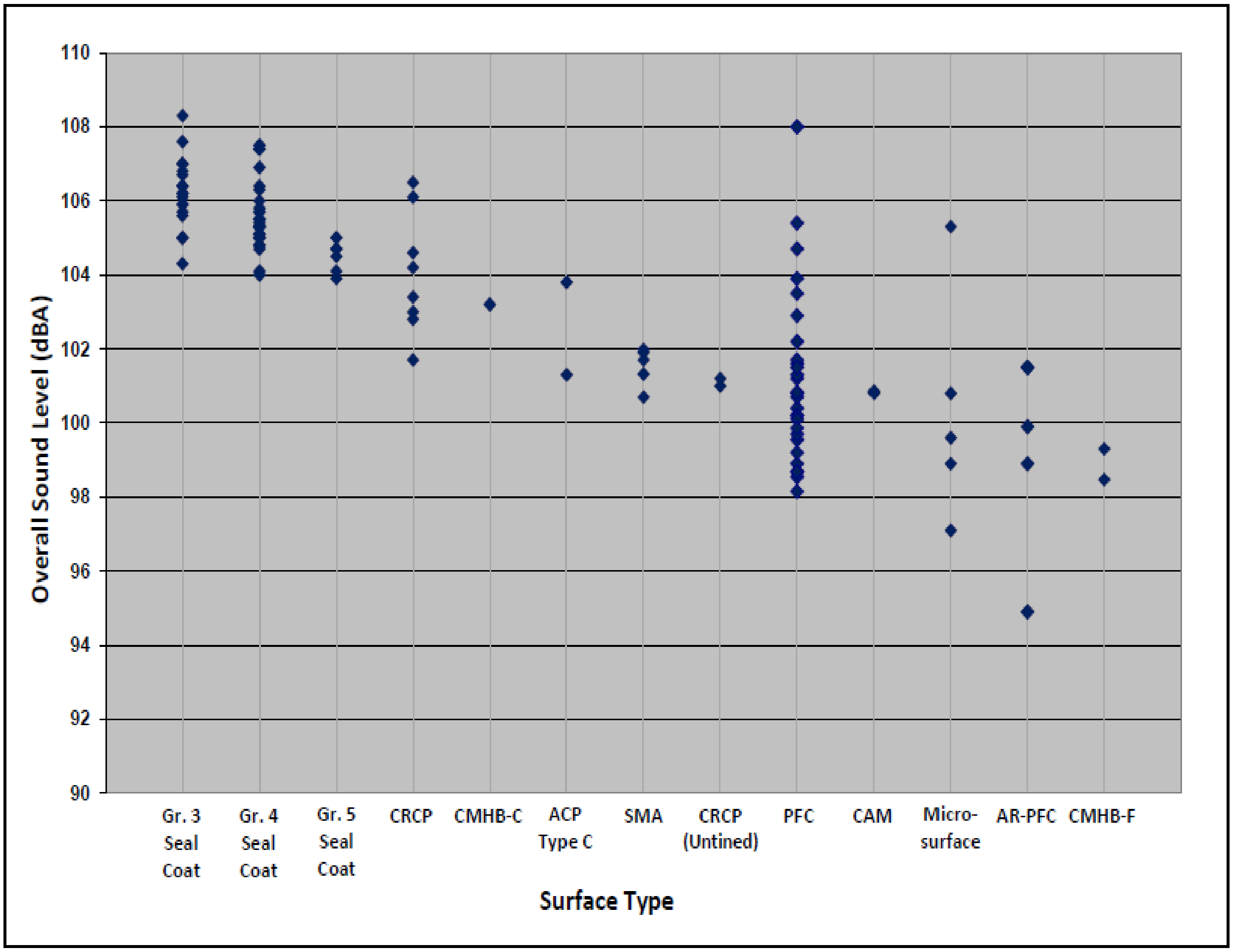

Figure 28. Noise Level Comparison of Various Pavement Types.

CHAPTER 6:
PMIS DATA ANALYSES TO DETERMINE RELATIVE SEAL COAT GRADE SERVICE LIFE PERFORMANCES

OBJECTIVES OF THE PMIS DATA ANALYSIS TASK

The objective of this task was to compare PMIS performance data for Texas seal coats to determine if a statistically significant difference existed between performances of Grade 3 and Grade 4 seal coats. If the answer was affirmative, then a secondary objective was to estimate the degree of performance difference to be expected. The research team considered traffic level, the level of deterioration of the roadways at the time of seal coat construction, and the region of the state as variables to be reconciled during the analyses. No consideration was given to whether the aggregate had been precoated or plain at the time of construction. Seal coats placed during the summer of 1998 were the initial focus of performance comparisons. Data on seal coats placed in six districts were ultimately included in this analysis. A second PMIS data analysis was also performed on seal coats placed in three districts during the summer of 2003.

PMIS DATA GATHERING AND PROCESSING

TxDOT's Construction Division was able to provide electronic copies of construction plans for seal coats placed over a number of years in a majority of geographical districts in the state. Seven districts were initially chosen, based primarily on geographic location, for the 1998 PMIS performance data analysis. These were the Abilene, Amarillo, Beaumont, Bryan, Odessa, Paris, and San Angelo Districts. Only two of these districts—Abilene and Amarillo—placed both Grade 3 and Grade 4 seal coats that year. The three districts selected for analyses of 2003 seal coat performances were the Amarillo, Paris, and Yoakum Districts, all having placed both grades of seal coats. The research team identified locations of Grade 3 and Grade 4 seal coats in the construction plans and harvested historical performance data from PMIS database records.

1998 SEAL COAT PERFORMANCE ANALYSES

1998 Data Analyses Methodology

Data analyses included a study of distress score changes over time, with the primary goal of establishing if a statistically significant performance difference occurs between the two seal coat grades. The secondary goal was to quantify any determined performance difference. Each

PMIS pavement section was considered individually for the data analysis. For example, a seal-coated roadway 8 miles in length would generally have 16 PMIS sections of 0.5-mile length.

The distress score was the performance indicator selected to best characterize the current performance level of each PMIS section, each year. The research team chose to characterize rates of deterioration of individual PMIS sections by calculating the difference in distress scores between year 1 and year 5 of performance life (D1-D5). Year 5 was selected because of the relatively large number of roadway sections that were resurfaced beginning after year 5.

Table 10 displays the numbers of 1998 seal-coated PMIS sections available to the research team for analysis as broken down by district, seal coat grade, pavement condition, and traffic level. Pavement condition categories are based on the lowest distress score of the three years preceding seal coat construction in 1998, because districts often conduct substantial repair of roadways in the year prior to sealing. PMIS sections above 98, based on the lowest preceding distress scores, were categorized as excellent; those with distress scores between 70 and 98 were categorized as good; and those with distress scores under 70 were categorized as fair.

Table 10. PMIS Sections Available from 1998 Seal Coats.

District	Pavement Condition Prior to Seal Coat	Number of PMIS Pavement Sections with Distress Scores					
		AADT below 1,000		AADT 1,000 to 5,000		AADT above 5,000	
		Grade 3	Grade 4	Grade 3	Grade 4	Grade 3	Grade 4
Bryan	Excellent		41		56		8
	Good		67		49		16
	Fair		106		95		11
Beaumont	Excellent	58		167		46	
	Good	13		2		22	
	Fair	14		31		18	
Abilene	Excellent	128	31	81		2	
	Good	104	20	23	5	1	2
	Fair	34	3	8			
Odessa	Excellent		416		116		
	Good		70		29		
	Fair		24		12		
San Angelo	Excellent	94			51		3
	Good	103			76		1
	Fair	55			56		9
Amarillo	Excellent	141	563		67		24
	Good	158	456		68		5
	Fair	76	125	1	73		3
Paris	Excellent	139		41		1	
	Good	159		48			
	Fair	136		43			
All Districts	Excellent	560	1051	289	290	49	35
	Good	537	613	73	227	23	24
	Fair	315	258	83	236	18	23
				Total Number of PMIS Pavement Sections with Distress Scores			4,704

The research team performed quality control reviews of the available PMIS section data and eliminated sections having contradictory or obviously erroneous information such as not being sealed in 1998 or sections that were resealed after only a few years. The Paris District data were found generally anomalous and was eliminated entirely. The "High Traffic" category of data was also excluded from further analyses due to inadequate population size. The remaining district data were then aggregated into two geographic regions to minimize confounding of factors: the Eastern region includes the Bryan and Beaumont Districts, while the Abilene, Odessa, San Angelo, and Amarillo Districts comprised the Western region. Table 11 displays the numbers of 1998 seal coat PMIS sections remaining after quality control, the information for which became the focus of all ensuing 1998 data analyses. The total length of roadway included in the 1998 seal coat performance analyses is approximately 1,560 miles.

Table 11. Number of PMIS Section Distress Differences – 1998 Seal Coats.

Region	Pavement Condition Prior to Seal Coat	Number of PMIS Distress Differences			
		AADT below 1,000		AADT 1,000 to 5,000	
		Grade 3	Grade 4	Grade 3	Grade 4
East	Excellent	43	38	84	55
	Good	11	64	25	41
	Fair	10	75	14	65
West	Excellent	224	949	79	193
	Good	176	501	22	128
	Fair	82	149	6	93
All	Excellent	267	987	163	248
	Good	187	565	47	169
	Fair	92	224	20	158
Total Number of PMIS Distress Differences					3,127

Overall Comparison of 1998 Grade 3 and Grade 4 Seal Coat Performances

The decline in distress scores between the first and fifth years after seal coat application (D1–D5) is observed to be considerably less for Grade 3 seal coats in Table 12. The Wilcoxon

Signed Rank test has determined this difference in distress score decline as highly significant (p-value < 0.0001). It can be said that, on average, Grade 4 seal coats show approximately 60 percent more distress after five years of age than do Grade 3 seal coats.

Table 12. Distress Score Declines by Grade – 1998 Seal Coats.

Grade	Average Difference in Distress Scores (D1-D5)	N
3	3.56	776
4	5.71	2,351

Regional Comparisons of 1998 Seal Coat Performance

Distress score difference over five years declines differently depending on geographic region (see in Table 13), although the difference is not as large as that observed between seal coat grades on a statewide basis. The Wilcoxon Signed Rank test has determined that the difference in distress score decline between regions is marginally significant (p-value = 0.0495) at the 5 percent significance level. It can be said that, on average, 1998-constructed seal coats in the two districts representing the eastern region of the state show approximately 20 percent more distress after five years of age than do seal coats in the four districts representing the western region of the state.

Table 13. Distress Score Declines by Region – 1998 Seal Coats.

Region	Average Difference in Distress Scores (D1-D5)	N
East	6.09	525
West	5.00	2,602

Statistical Modeling of 1998 Seal Coat Distress Scores

This phase of the analysis considers the effects of region, seal coat grade, pre-construction pavement condition, and traffic levels on distress score declines. A full factorial, four-way analysis of variance model was constructed to determine the nature of any interactions among these four factors. All four factors were found to be significant, and several interactions were found between them. The final model chosen is specified as:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + (\alpha\gamma)_{ik} + (\beta\delta)_{jl} + (\gamma\delta)_{kl} + (\alpha\gamma\delta)_{ikl} + \varepsilon_{ijklm}$$

Where:

y_{ijkl} is the difference in distress score between year 1 and year 5,

μ is the overall mean difference in distress score,

$\alpha_i,\ i = 1,2$ are the effects of region (East, West),

$\beta_j,\ j = 1,2$ are the effects of seal coat grade (Grade 3, Grade 4),

$\gamma_k,\ k = 1,2,3$ are the effects of pavement condition (Excellent, Fair, Good),

$\delta_l,\ l = 1,2$ are the effects of traffic (Low, Medium),

$(\alpha\gamma)_{ik},\ i,j = 1,2$ denote the two-way interaction effects between region and pavement condition,

$(\beta\delta)_{jl},\ j,l = 1,2$ denote the two-way interaction effects between seal coat grade and traffic,

$(\gamma\delta)_{kl},\ k = 1,2,3\ and\ \ l = 1,2$ denote the two-way interaction effects between pavement condition and traffic,

$(\alpha\gamma\delta)_{ikl},\ i,l = 1,2\ and\ k = 1,2,3$ denote the three-way interaction effects between region, pavement condition, and traffic, and

ε_{ijklm} are the error terms.

Table 14 summarizes the average difference in distress scores for combinations of the four factors. A review of the table suggests that in most instances, Grade 3 seal coats experience less decline in distress scores than Grade 4 seal coats. But there are a couple of exceptions to this trend. These exceptions may be the result of interactions, or synergistic effects, of particular combinations of factors. This possibility is explored more fully in the next section. Another quirk of the data in Table 14 is the negative distress difference shown for East region pavements in fair condition and having low traffic. The relatively low number of pavement sections in this category is likely a contributing factor to this anomaly.

Table 14. Distress Score Declines – All Factors – 1998 Seal Coats.

Region	Condition	Traffic	PMIS Distress Differences (D1-D5)			
			Grade 3		Grade 4	
			Average	N	Average	N
East	Excellent	Low	2.09	43	5.05	38
		Medium	5.77	84	7.53	55
	Good	Low	0.45	11	5.73	64
		Medium	7.28	25	10.66	41
	Fair	Low	-3.60	10	7.55	75
		Medium	5.93	14	6.35	65
West	Excellent	Low	1.86	224	2.40	949
		Medium	6.06	79	3.83	193
	Good	Low	1.79	176	8.03	501
		Medium	3.82	22	5.67	128
	Fair	Low	5.77	82	6.90	149
		Medium	30.83	6	24.17	93

Discussion of Interactions between Factors

The presence of interaction terms in the model indicates that certain factors cannot be considered apart from one another. In other words, the combined effect of two interacting factors cannot be expressed as the addition of the separate or marginal effects from each factor. There are four significant interactions between factors indicated in the analysis of variance model.

1) Two-way interaction between Region and Pre-Construction Pavement Condition.

Distress scores decline much more rapidly for fair to poor pre-construction pavement condition sections in the western region than for those in the eastern region (see Table 14 and Figure 29). A different situation applies for excellent and good pavement conditions, where distress scores decline less in the western region.

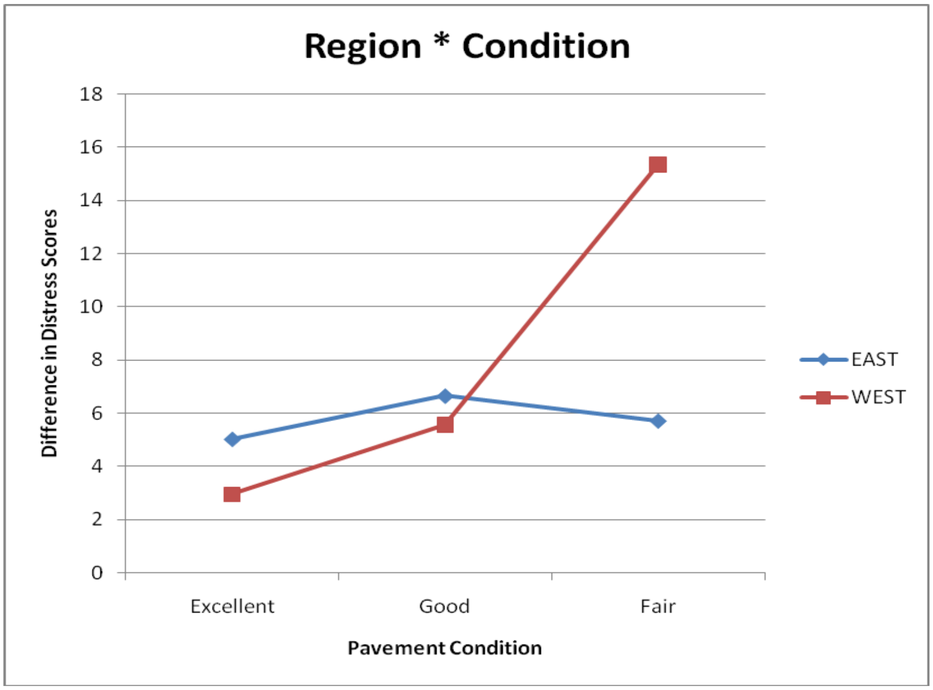

Figure 29. Interaction Plot for 1998 Region and Pre-Construction Pavement Condition.

2) Two-way Interaction between Seal Coat Grade and Traffic Level.

As seen in Figure 30, Grade 3 seal coats experience less than half the decline in distress scores for low traffic sections, while declines are comparable for medium traffic sections.

3) Two-way Interaction between Pre-Construction Pavement Condition and Traffic Level.

Traffic levels appear to have a much larger effect on distress scores for sections in only fair condition (see Figure 31), with medium traffic sections exhibiting more than a two-fold decline in distress scores over that found in low traffic sections. Although less pronounced, average declines in distress scores are greater for medium traffic compared to low traffic also for the good and excellent pre-construction pavement conditions.

4) Three-way Interaction between Region, Pre-Construction Pavement Condition, and Traffic Level.

For the eastern region, PMIS sections having good or excellent pre-construction pavement condition prior to seal coat application show consistently greater declines in distress score for Grade 4 seal coats than Grade 3 seal coats (see Figure 32). The declines in distress scores for both grades of seal coats are proportional to traffic levels, with medium traffic sections experiencing greater declines.

Figure 30. Interaction Plot for 1998 Seal Coat Grade and Traffic Level.

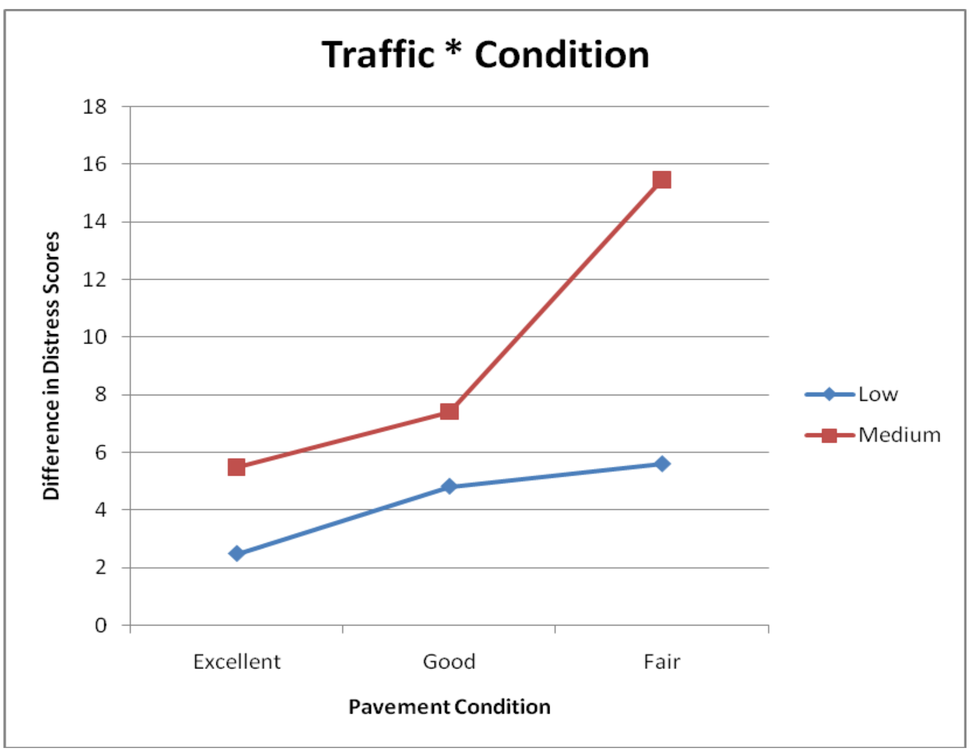

Figure 31. Interaction Plot for 1998 Traffic Level and Pre-Construction Pavement Condition.

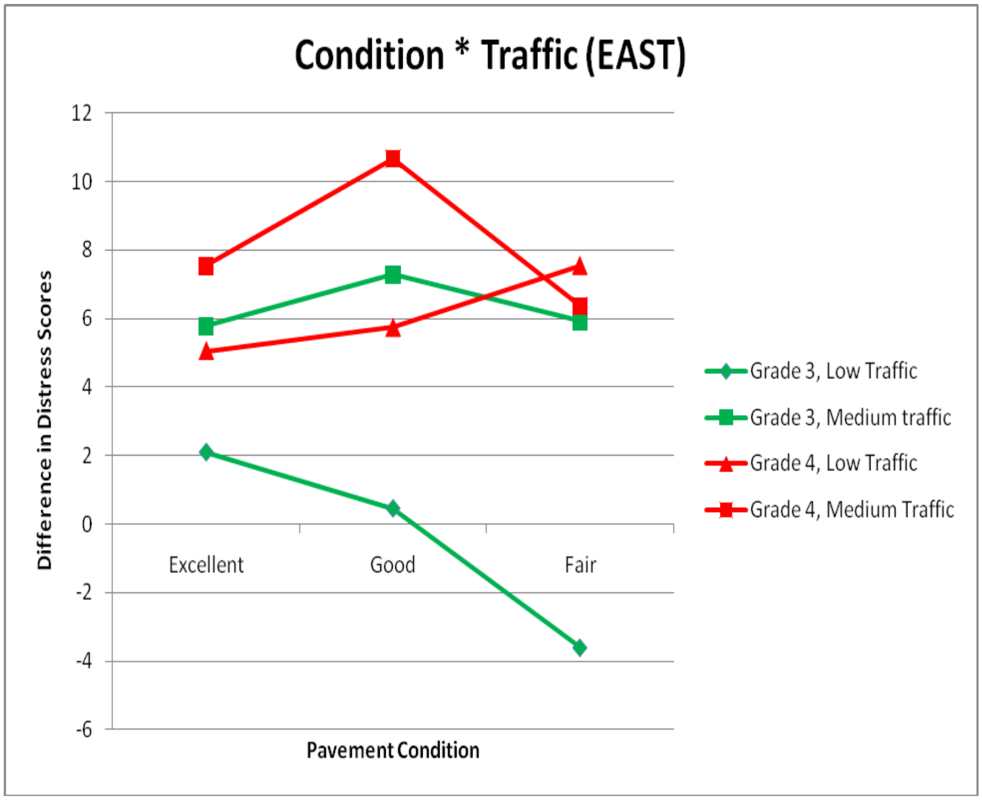

Figure 32. Interaction Plot for 1998 Pre-Construction Pavement Condition and Traffic Level by Grade, Eastern Region.

Declines in distress scores are much more unpredictable when seal coats are applied to roadways in only fair condition. In the Eastern region, Grade 4 seal coats on fair condition segments experience roughly the same decline in distress scores for low and medium traffic levels (see Figure 32). The same cannot be said for the western region, where traffic level appears to have a disproportionately large effect on distress scores for sections in fair condition, (see Figure 33), with medium traffic sections exhibiting a fourfold to sixfold decline in distress scores compared to the declines seen in low traffic sections.

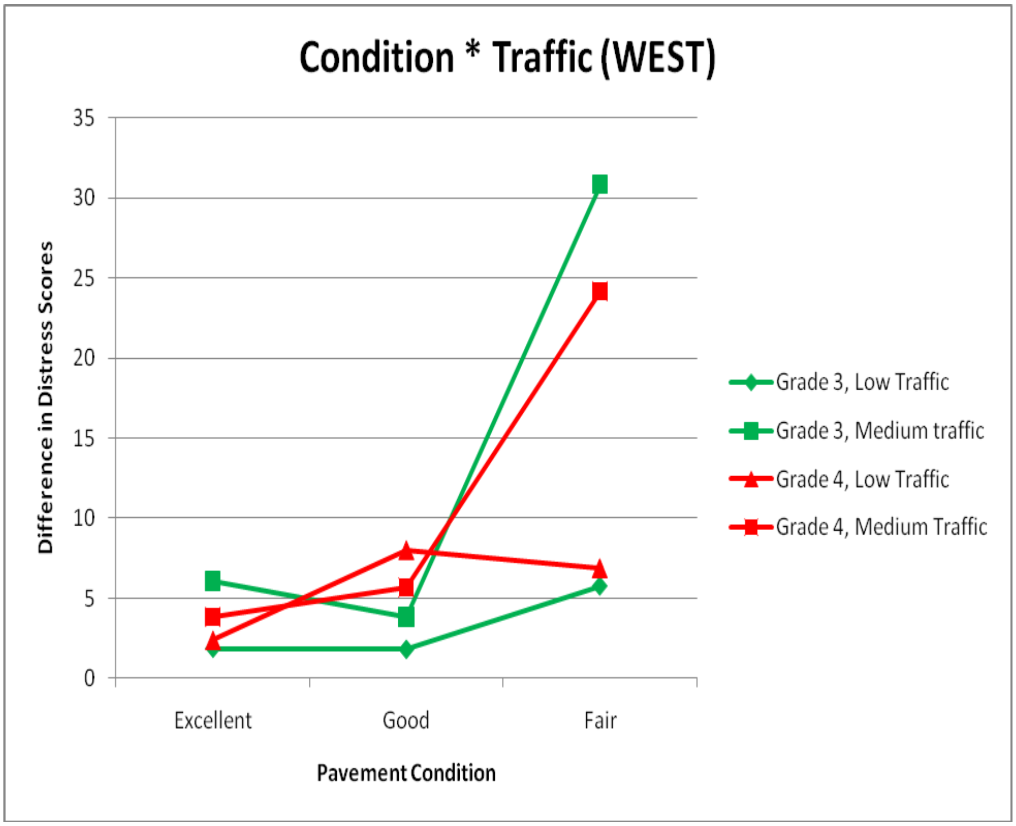

Figure 33. Interaction Plot for 1998 Pre-Construction Pavement Condition and Traffic Level by Grade, Western Region.

Survival Analysis of 1998 Seal Coats

The 1998 seal coat information was also analyzed based on length of time, in years, before each roadway was again surfaced. Year of resurfacing for each roadway was determined by looking for dramatic improvements in multiple distress categories in the PMIS database. While in theory this approach would seem to quickly provide accurate determinations, in practice, district maintenance activities in advance of resurfacing made end-of-service life determination, quite often, a challenge. In some cases, district seal coat plans in later years were consulted to confirm year of resealing. Roadway sections were eliminated from the survival analysis when a reasonably confident selection of resurfacing year was not possible. This process was conducted without knowledge of traffic or seal coat grade.

The research team also noted the distress score in the year prior to resurfacing, and averaged these for each year, which led to rather interesting findings. Figure 34 shows the percentages of all Grade 3 and Grade 4 1998-constructed seal coated roadway sections that were resurfaced, each year, between 1999 and 2010. The average distress scores for the roadways being resurfaced in peak activity years are also shown in this figure.

The curves clearly reveal two things. First, the six districts tended to replace Grade 3 seal coats more quickly than Grade 4 seal coats. The most frequently occurring resurfacing ages for Grade 3 and Grade 4 seal coats were after six years and seven years, respectively. Second, the Grade 3 seal coats selected for replacement each year consistently had higher distress scores (less distress observed) than the Grade 4 seal coats selected for resealing in the same year. No explanations for these tendencies were determined, and these findings were a surprise to those contacted in the districts as well. Certainly, something in addition to visually observable distresses noted during annual PMIS inspections triggered selection for resurfacing of seal coats constructed in these six districts in 1998.

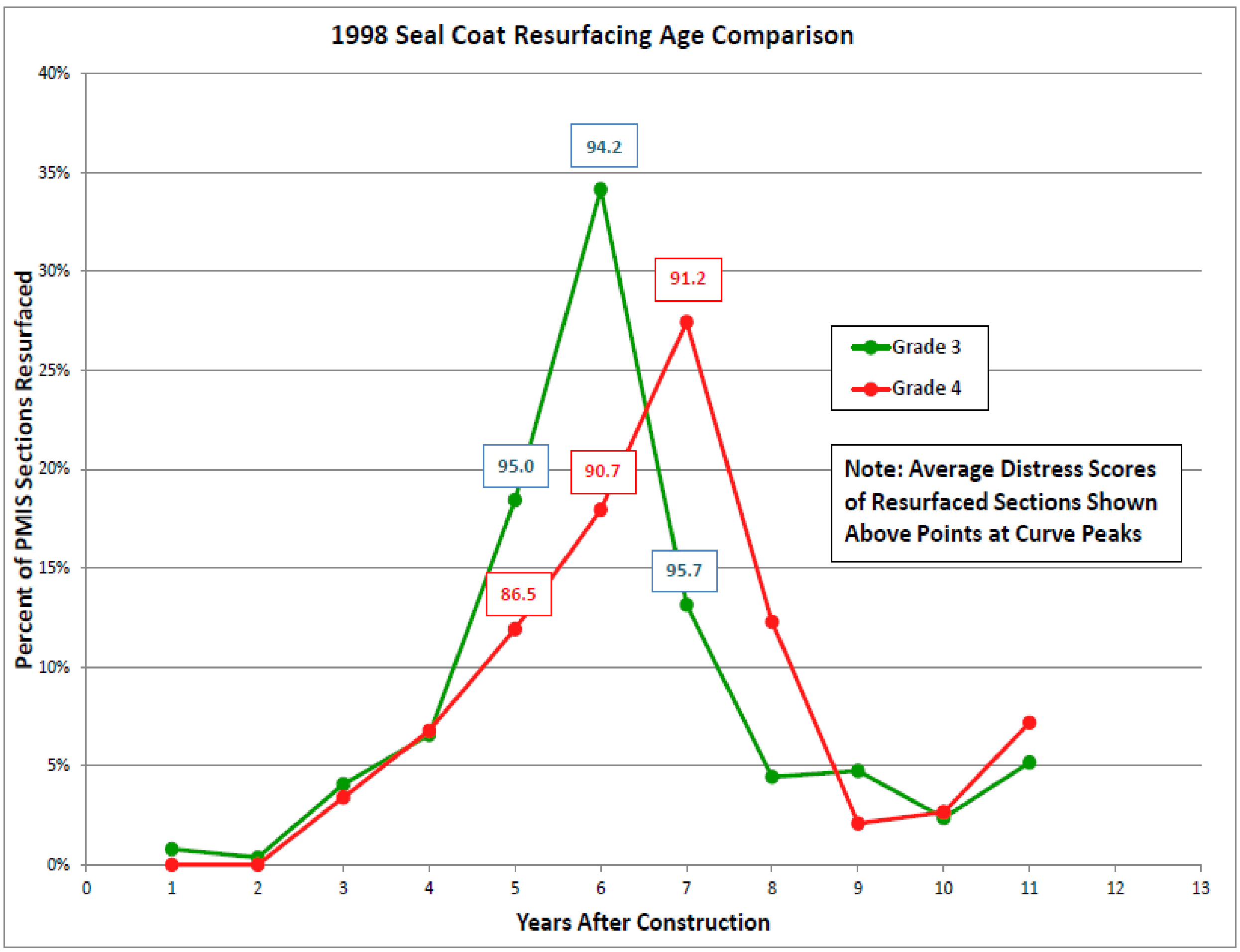

Figure 34. Annual Percentages of 1998 Seal Coats Resurfaced.

Figure 35 shows another method of comparing seal coat grade survival, where the declines in sections remaining in service can be seen. As in earlier comparisons of Grade 3 and Grade 4 performance, both groups of seal coats being compared include both precoated and plain aggregate.

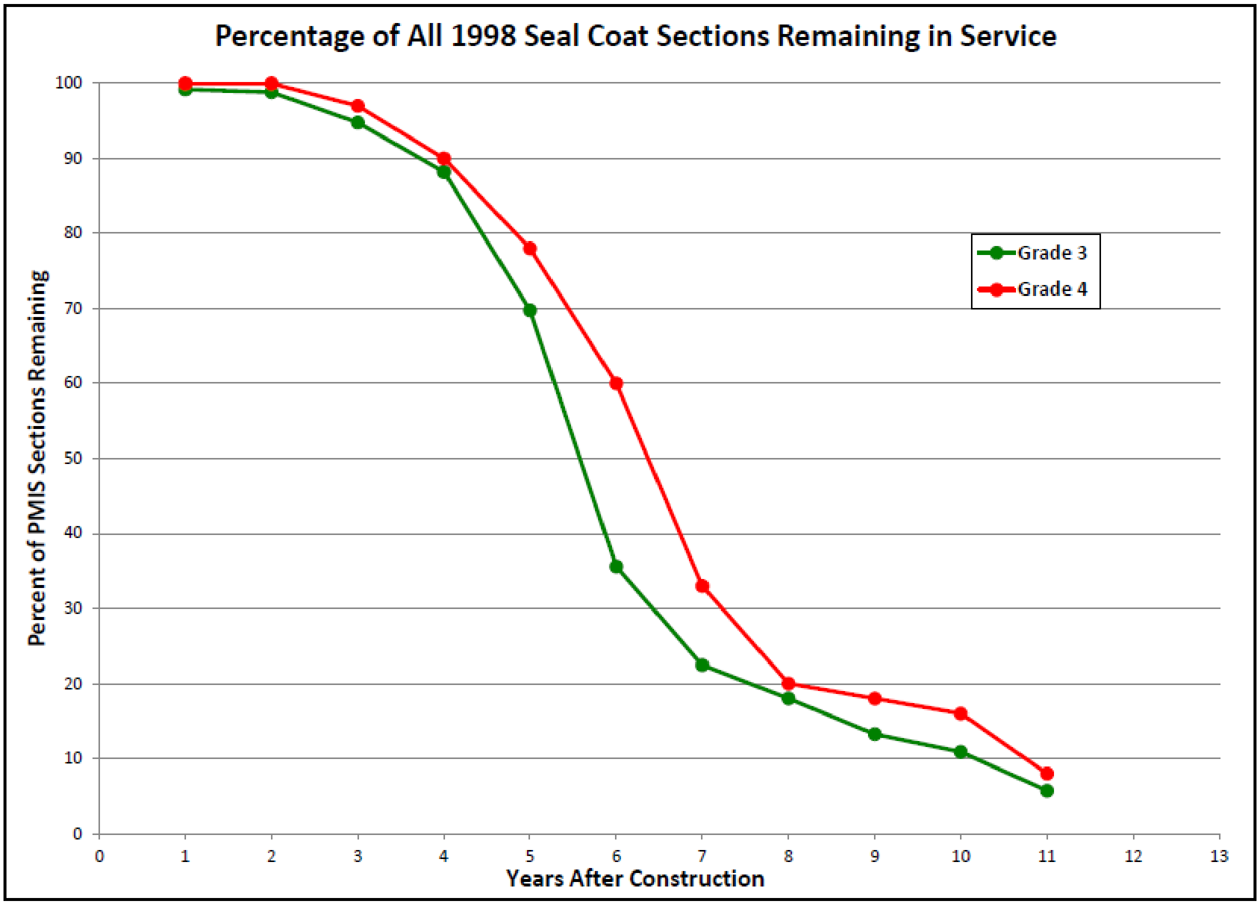

Figure 35. Survival Grade Comparison for All 1998 Seal Coats.

Experimental Limitations of the 1998 Seal Coat Performance Data Analyses

The observational nature of the historical PMIS data imposes limitations on the inferences that can be obtained from a statistical analysis. Unlike a designed experiment, where treatments (combinations of factors thought to affect the measured response) are independently applied to the experimental units (pavement sections), the experimental units here are essentially "come as you are." In other words, important additional factors/variables affecting the response may be ignored or left uncontrolled simply because they are unknown. These are sometimes referred to as "unknown unknowns." Failure to control factors that can potentially affect the response often results in inflated experimental error; i.e., the variation between nominally identical road segments may be disproportionately large due to the effects of unsuspected variables/factors. Increased variability among pavement sections necessarily impairs the level of sensitivity that can be achieved in findings.

The model developed for 1998 seal coat performance is a severely unbalanced design in that particular combinations of factors occur in as few as six pavement sections or in as many as 949 sections. This degree of imbalance impairs the sensitivity of pair-wise comparisons among different factor combinations. Because of the number of factors involved, any set of multiple comparisons between combinations of all four factors will impose excessively stringent significance criteria and therefore will not be informative. Conversely, comparisons between combinations of fewer factors, such as shown in Tables 12 and 13 when only grade and only region are considered, are more likely to yield statistically significant results. However, these two-factor analyses fail to reveal characteristics of the interaction between the other factors. Considering all four factors, with the more stringent significance criteria imposed, only one statistically significant ($p\text{-}value < 0.0001$) difference in distress scores across seal coat grades is found to occur. That is for the western region for good pre-construction pavement condition and low traffic level.

Also noteworthy to interpreting these analyses is the fact that many of the segments used are contiguous to one another and cannot be considered independent experimental units in a complete sense. Given the number of factor combinations and pavement segments involved in the data, a more complex model structure would not necessarily improve the model performance while substantially reducing the model comprehensibility. Under these circumstances, the analysis of variance model should be viewed more as a descriptive tool as opposed to a definitive quantitative assessment.

Asphalt Consideration in the 1998 Seal Coat Performance Analysis

The survey of seal coat program plans revealed that the most common asphalt binders specified in 1998 were AC-5, AC-10, and AC-15-5TR. This group of binders is considerably different from the binders most often specified in 2010, i.e., AC-20-5TR, AC-10-2TR, AC-15P, and AC-20XP. The increased use of polymer-modified asphalt binders in later years may considerably change seal coat performance characteristics from those generally obtained from 1998-constructed seal coats.

1998 PMIS Data Analyses Conclusions

The 1998 performance data strongly suggest that, for the majority of factor combinations, a performance advantage in terms of reduced visually observable distresses is obtained when using Grade 3 instead of Grade 4 aggregate in Texas seal coats. Table 12 most clearly indicates the degree of difference found. However, considering the large number of factor combinations being considered compared to the population size of the 1998 data set available for analyses, and because of potential anomalies encountered for certain combinations of factors, a definitive and quantitative estimation of difference in performance life expectancy between these two seal coat grades was not possible based on this analyses. Therefore, with the permission of the TxDOT project monitoring committee, the team conducted a second set of analyses based on performances of seal coats constructed during summer 2003.

2003 SEAL COAT PERFORMANCE ANALYSES

2003 Data Analyses Methodology

As with the 1998 seal coat performance data analyses, the primary goals of the second set of analyses were twofold:

- Establish if a statistically significant performance difference in PMIS distress scores occurs between the two seal coat grades.
- Determine whether a statistically significant difference in seal coat lifetimes can be observed between the two seal coat grades.

The secondary goal was to quantify any determined performance differences in distress scores and seal coat service lifetimes. As during the analyses of 1998 seal coat performance data, the performance of each 0.5-mile PMIS pavement section was considered individually.

The 2003 group of seal coats was selected for this second analysis because by this date the asphalt binders were more similar to those currently in use. This, plus the fact that analyzing seal coats constructed in even later years would have further shortened the length of performance which could be observed, made 2003 the year of choice. In addition, by 2003 districts were inspecting nearly 100 percent of the sections each year, while previous to 2001, FM roads were often inspected only every three years.

Construction plans for 2003 seal coats were available for a majority of the districts. However, among the districts for which the research team obtained plans, only three used both Grade 3 and Grade 4 in their seal coat programs. The decision was made to base the 2003 PMIS performance data analysis on only these three districts, thereby eliminating differences in environmental factors, materials, design, and construction techniques, which become additional variables when a number of districts utilizing only one grade of the two grades are included in the analyses. Table 15 displays the numbers of 2003 seal coat PMIS sections available to the research team for analysis as broken down by district, seal coat grade, pavement condition, and traffic level.

Table 15. Total Number of PMIS Sections Available for 2003 Seal Coats.

District	Pavement Condition prior to Seal Coat	Number of PMIS Sections					
		AADT below 1,000		AADT 1,000 to 5,000		AADT above 5,000	
		Grade 3	Grade 4	Grade 3	Grade 4	Grade 3	Grade 4
Amarillo	Excellent	50	42		16		
	Good	235	195		9		
	Fair	73	100		6		
Paris	Excellent	68	30	50	1	1	
	Good	67	80	37	47	8	4
	Fair	68	75	10	29	4	2
Yoakum	Excellent	52	3	34	27	14	5
	Good	70	11	32	33	8	20
	Fair	39	23	37	35		5
All	Excellent	170	75	84	44	15	5
	Good	372	286	69	89	16	24
	Fair	180	198	47	70	4	7
Total Available Number of PMIS Sections							**1,755**

An inadequate number of high traffic sections was available for proper analysis, so the data representing this traffic category were excluded. This reduced the total number of PMIS sections to 1,684, or about 840 miles of roadway. While this is less than the total roadway length included in the 1998 analyses, the reduction in extent of variables and the generally improved data quality by 2003 were expected to easily outweigh the effect of population size reduction.

The range of annual average daily traffic (AADT) on these pavement sections ranged from extremely low to approximately 4,500. As might be expected for pavements selected for seal coat surfacing, the bulk of the pavements are carrying between 100 and 500 vehicles per day. The histogram displayed in Figure 36 shows additional detail about the AADT distribution in the data set used in this Grade 3 and Grade 4 seal coat performance comparison.

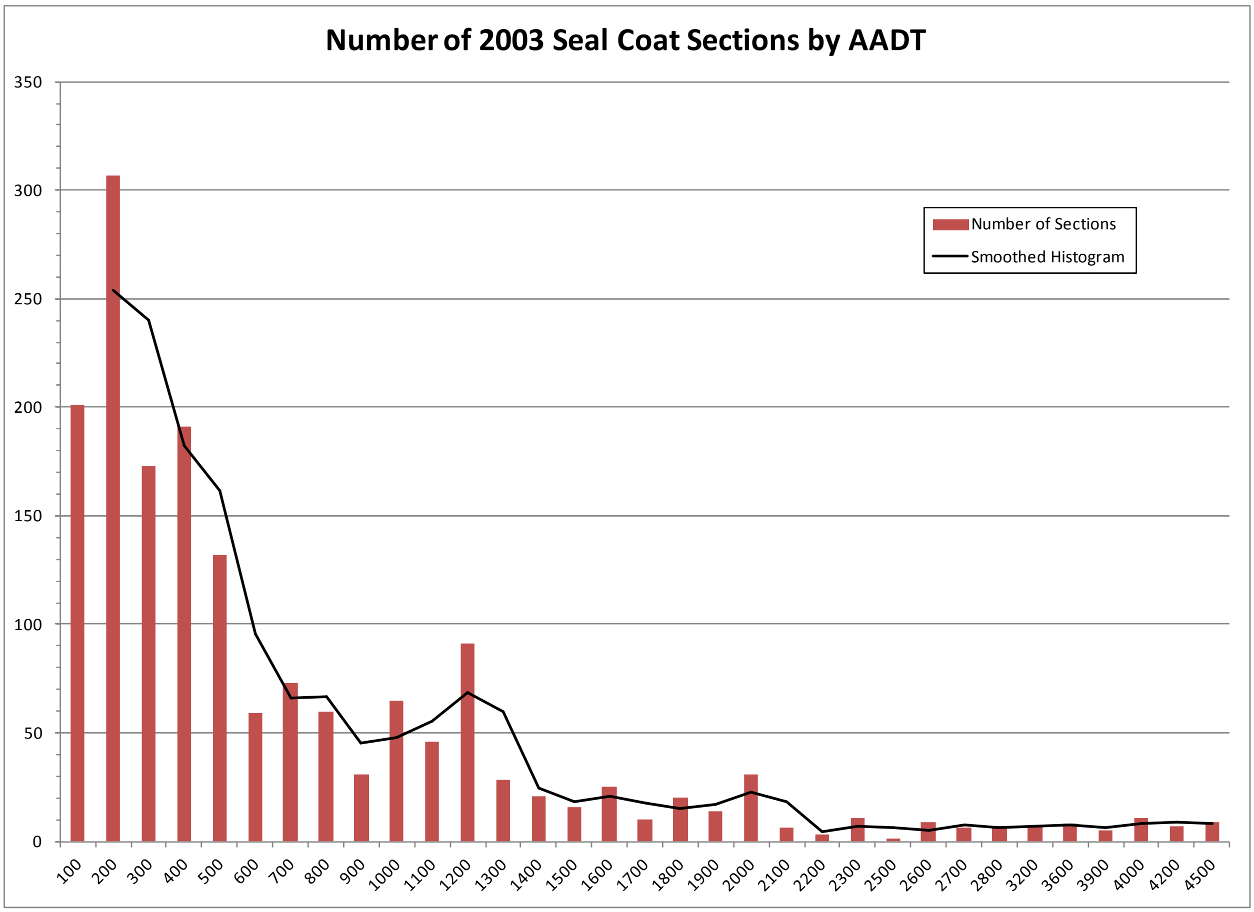

Figure 36. Histogram of Seal Coat Sections by AADT.

The AADT distribution is further broken down, this time into prior pavement condition categories (described earlier), in Figure 37. The prior pavement condition categories of pavements appear to be reasonably well distributed among the traffic categories selected for this study. The pre-existing pavement condition categories are Excellent if the lowest distress score for the past three years for the pavement section is above 98, Good if the distress score is between 70 and 98, and Fair if the distress score is below 70. The traffic level is considered in the Low traffic category if AADT is below 1,000, the Moderate traffic category if the AADT is between 1,000 and 5,000, and any roadway with traffic above 5,000 is considered in the High traffic category.

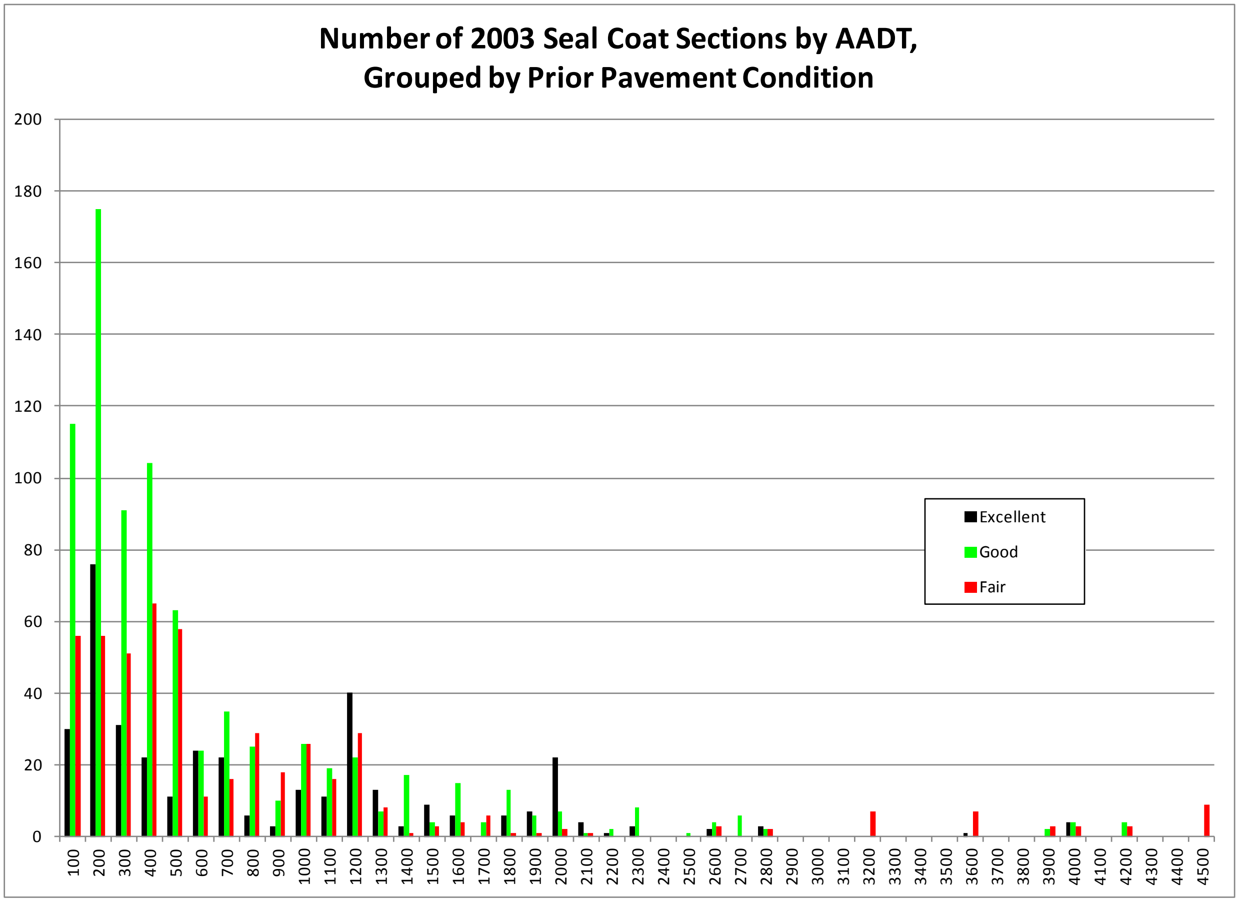

Figure 37. Histogram of Seal Coat Sections by AADT, Grouped by Condition.

The performance indicator selected to best characterize relative performance of each PMIS section, each year, was the PMIS distress score. Several modifications of the distress score, such as removing the rutting distress effect, and cracking only, were analyzed to determine if better performance insight was attainable. The PMIS-reported distress score was shown to provide as clear an indication of relative seal coat performance as any of the labor-intensive modified distress score approaches.

The initial step in the analyses of 2003-constructed seal coats was to develop an individual survival analysis for seal coats that each of the three districts constructed. Thereafter, distress score change over time was analyzed, as well as additional nonparametric and parametric statistical analyses of seal coat lifetimes, in each district.

Individual District Grade 3 and Grade 4 Seal Coat Survival Analyses

Preliminary data exploration indicated possible differences in distress score behavior over time, among the three districts. This led the research team to prepare separate analyses for each district. Figures 38, 39, and 40 show percentages of Grade 3 and Grade 4 seal coats remaining in service in the Amarillo, Paris, and Yoakum Districts, over time, following construction in 2003. Each of the three districts, on average, have left their Grade 3 seal coats in service longer than their Grade 4 seal coats. This is a reversal from the findings from the earlier analysis of seal coats that the six districts placed in 1998. No reason for this shift was evident, though only Amarillo District data were included in both the 1998 and 2003 seal coat analyses. This lack of geographic and management overlap could be a factor involved in this difference.

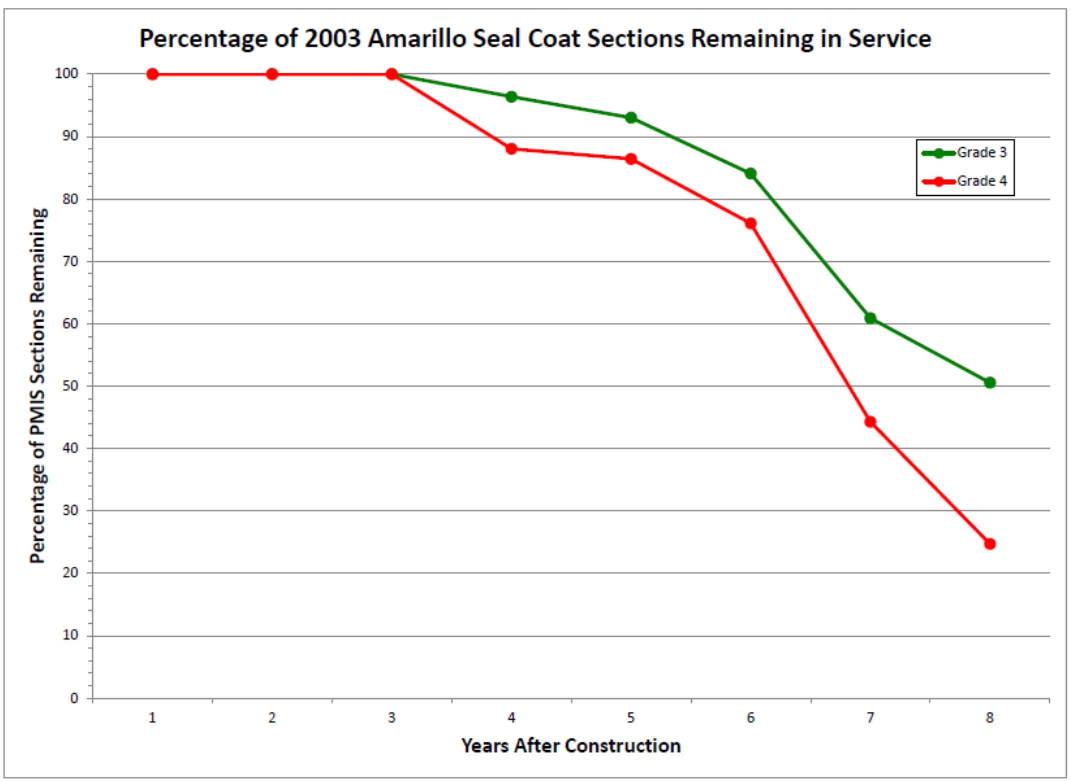

Figure 38. Percent PMIS Sections Remaining in Service – Amarillo District.

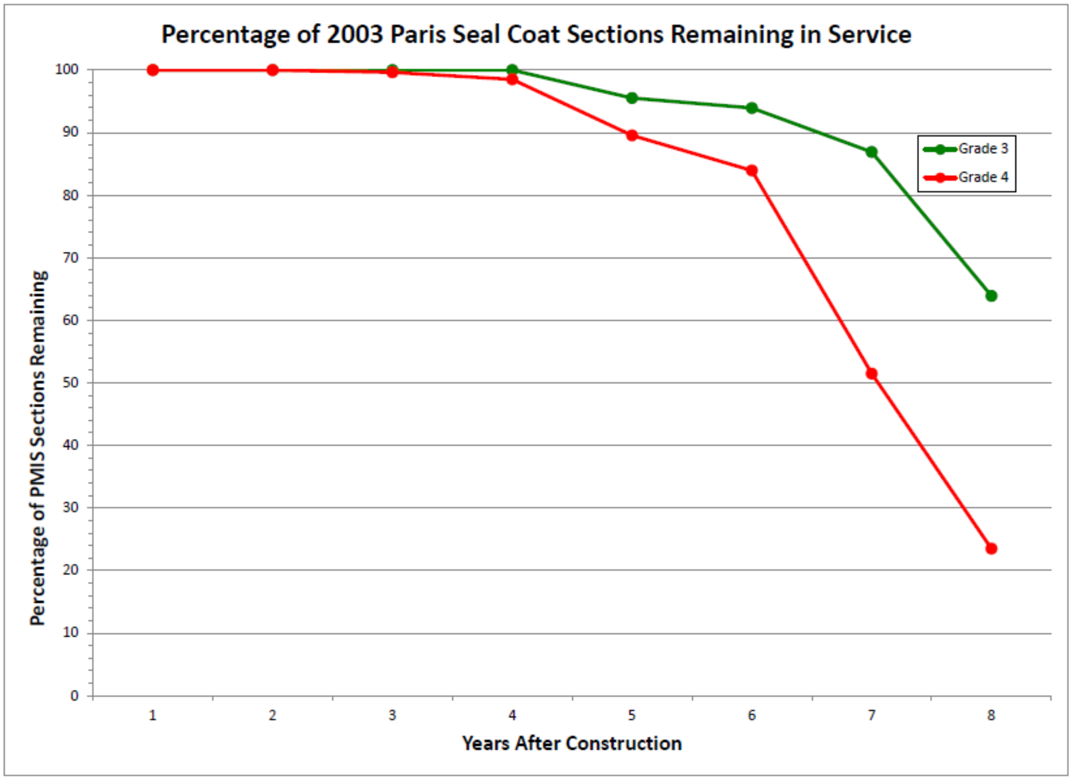

Figure 39. Percent PMIS Sections Remaining in Service – Paris District.

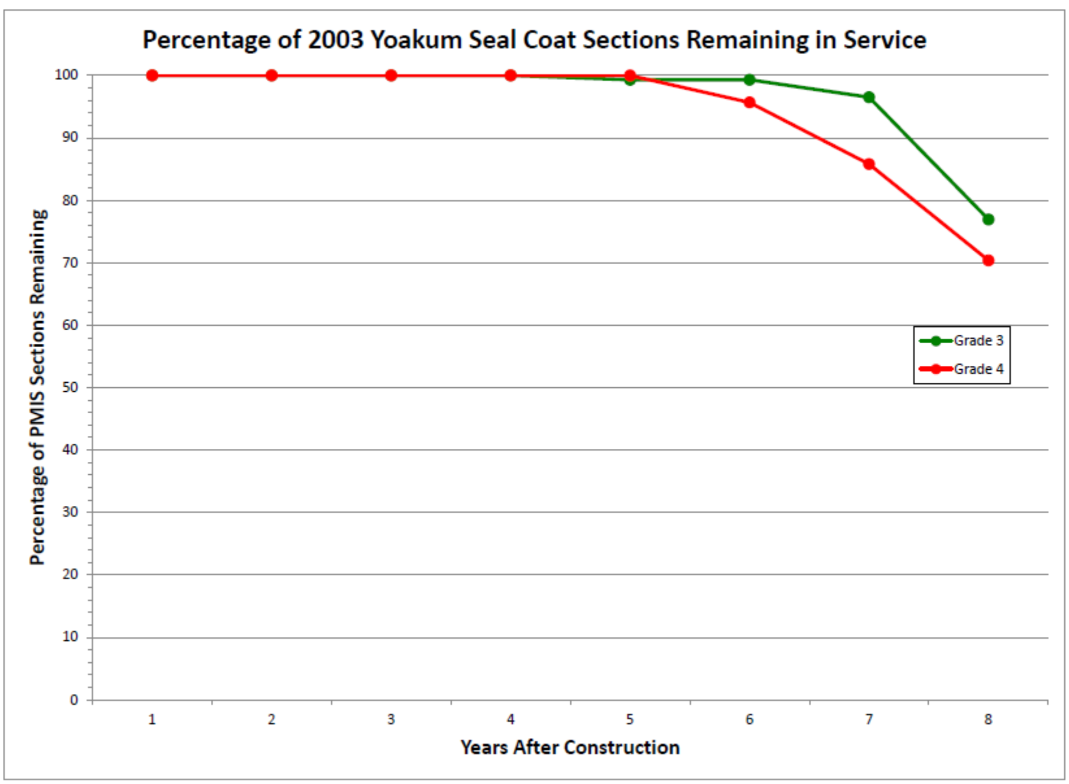

Figure 40. Percent PMIS Sections Remaining in Service – Yoakum District.

Data obtained show the greatest difference between Grade 3 and Grade 4 service life was obtained in the Paris District with the least difference found in the Yoakum District. See Table 16 for the accumulated percentages of seal coats that the three districts replaced each year. The Yoakum District resurfaced virtually none of their 2003-constructed seal coats until the seventh year after construction and had smaller percentages being resurfaced in later years as well. This may be a testament to the particular excellence of the district's seal coat design and of the contractor's construction that particular year. It could also be a reflection of difference in preventive maintenance policy or funding levels over ensuing years in this district, or that the Paris and Amarillo Districts have distinctly cooler environments.

Table 16. Accumulated Percentages of Resurfaced Seal Coats, by District.

Years After Construction	Percentages of 2003-Constructed Seal Coats Resurfaced					
	Amarillo		Paris		Yoakum	
	Grade 3	Grade 4	Grade 3	Grade 4	Grade 3	Grade 4
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	4	12	0	1	0	0
5	7	14	4	10	1	0
6	16	24	6	16	1	4
7	39	56	13	49	3	14
8	49	75	36	76	23	30

Based on the differences observed between individual districts in timing of resurfacing, pooling of data for aggregated analysis was deemed inappropriate.

Individual District Distress Score Change Analyses

Initial analysis focused on comparisons of average yearly distress score by seal coat grade and district. As was the case for the 1998 survivor analyses, preliminary data exploration indicated strong differences in distress score behavior over time among the three districts. For the 2003 data, researchers chose to conduct separate distress score analyses for each district.

A series of analyses and graphical and tabular representations were prepared for each district's data. These included determination of average distress scores for all remaining seal coats, each year, as well as the average distress scores for all resurfaced sections, each year. See Figures 41 through 46 and Tables 17, 19, and 21 for this information. The data boxes in Figures 41, 43, and 45 show the percentages of the seal coats that remained in service each year. An inverse regression was also performed for each combination of seal coat grade and prior pavement condition to obtain an estimate of time, in years, until the sections should be expected to reach various levels of distress score. Tables 18, 20, and 22 show the results of these analyses.

Care must be taken in interpreting Figures 41, 43, and 45. These figures display the average distress scores found in pavement sections that were seal coated in 2003 and whose seal coats *remained in service* through each given year. The points on these curves are affected by both natural pavement deterioration (lowering distress scores) occurring over time and the effect of reducing the amount of data being averaged as sections are resurfaced. As shown in Figures 42, 44, and 46, the average prior distress scores of pavement sections being resurfaced each year tend to be lower than the average distress scores for the sections remaining in service. Therefore, the effect of dropping these data out of the data pool being averaged tends to increase the average distress scores being plotted in Figure 41. A district-by-district presentation of the results of these analyses follows.

Amarillo District Distress Score Analyses

Despite the counteracting factors involved, a significant finding is provided in Figure 41. The average distress scores plotted in Figure 41 for years 1, 2, and 3 are true deterioration curves as none of the pavements had been resurfaced until year 4 after construction. The 95-percent confidence limits at year 3 in Figure 41 do not overlap, thereby indicating a highly significant difference in performance being obtained from Grade 3 and Grade 4 seal coats at this time in their service lives. The average distress score for all Grade 3 seal coats after three years was 96.19 while the average distress score for all Grade 4 seal coats was 93.28. This group of Grade 4 seal coats in the Amarillo District averaged approximately 75 percent more distress than the Grade 3 seal coat group after three years of service.

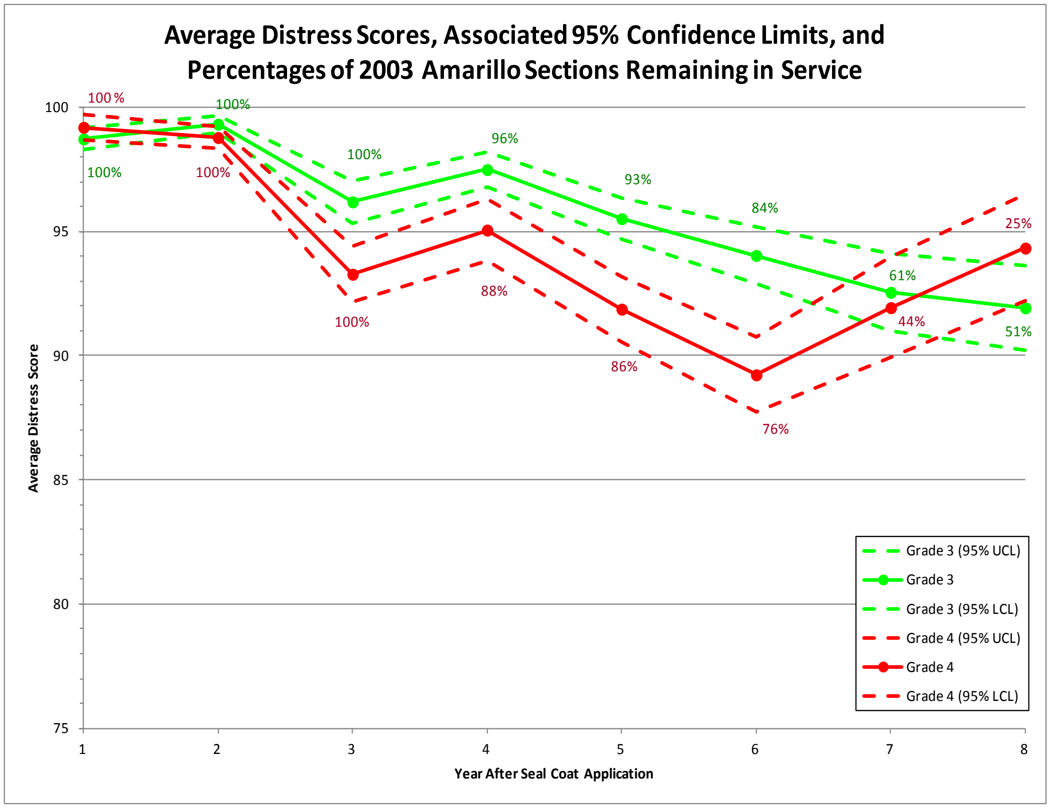

Figure 41. Average Distress Scores of Remaining Sections by Year – Amarillo District.

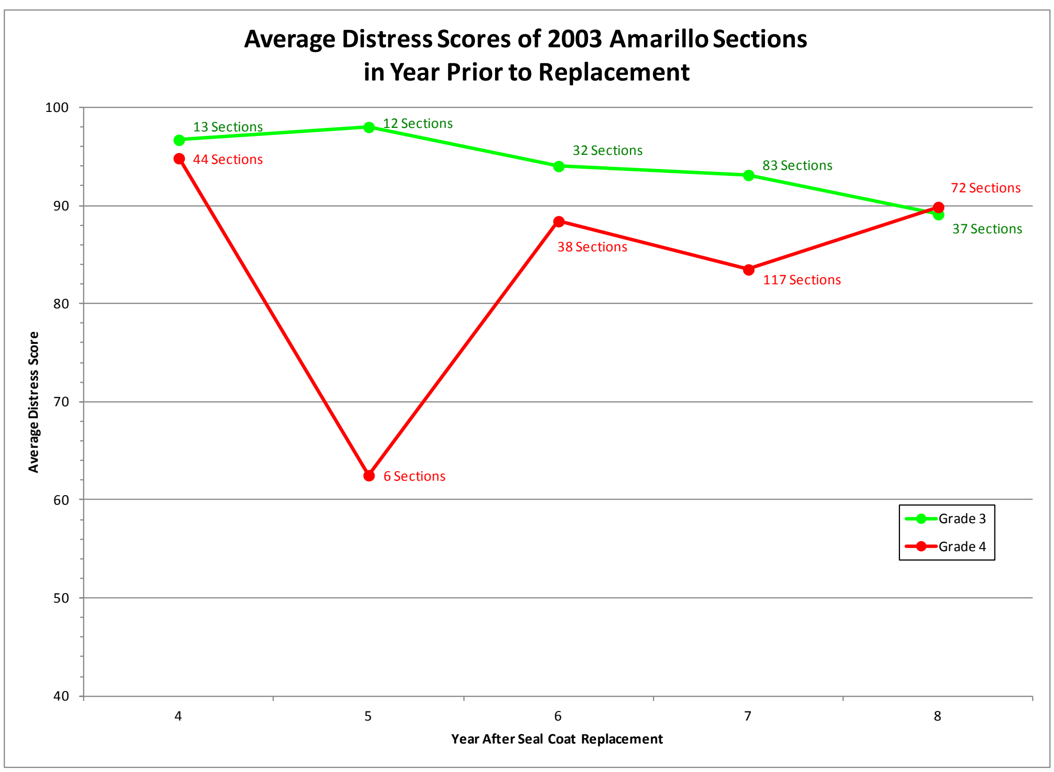

Figure 42. Average Distress Scores of Resurfaced Sections by Year – Amarillo District.

Table 17. Average Distress Scores of Remaining Sections and Interval Estimates by Year – Amarillo District.

Years after Construction	Seal Coat Grade	Average Distress Score	Lower 95% C.I.	Upper 95% C.I.
1	3	98.72	98.29	99.16
	4	99.19	98.68	99.70
2	3	99.32	98.97	99.66
	4	98.78	98.32	99.24
3	3	96.19	95.33	97.05
	4	93.28	92.14	94.41
4	3	97.49	96.77	98.21
	4	95.06	93.81	96.30
5	3	95.51	94.70	96.33
	4	91.87	90.56	93.18
6	3	94.03	92.91	95.16
	4	89.23	87.71	90.75
7	3	92.55	91.01	94.09
	4	91.93	89.91	93.96
8	3	91.92	90.21	93.64
	4	94.33	92.19	96.47

For the Amarillo District, Table 18 displays estimated seal coat ages at which various average distress scores may be reached based on an inverse regression. As these projections are based on data only up to 7 years of performance service life, and since the projections are linear extrapolations, projected ages beyond 12 years are not displayed, and those between 7 and 12 years have growing uncertainty levels as age progresses.

The finding of note shown in Table 18 is that when comparing ages of service projected for Grade 3 and Grade 4 seal coats under a single pavement condition (for example, the Excellent pavement condition), the Grade 4 seal coats are projected to reach the given distress score levels in approximately half the number of years as the Grade 3 seal coats placed on the same pavement condition. As the pre-existing pavement condition worsens to the level of Good and then to Fair, anticipated ages become closer for the two seal coat grades, but remain significantly longer for the Grade 3 seal coats.

Table 18. Amarillo Estimated Distress Scores.

Prior 3-year Average Pavement Condition	Seal Coat Grade	Estimated Years until Average Distress Score					
		95	90	85	80	75	70
Excellent	3	12.5	-	-	-	-	-
	4	6.2	12.1	-	-	-	-
Good	3	5.8	11.7	-	-	-	-
	4	3.3	5.5	7.7	10.0	12.2	-
Fair	3	3.7	7.3	11.0	-	-	-
	4	2.3	5.1	7.9	10.7	-	-

Notes:
Estimates are based on average distress scores for the first 6 or 7 years after seal coat application.
Inverse regression was separately performed for each combination of seal coat grade and prior pavement condition to obtain the estimates.
Estimates greater than 6 or 7 years are linear extrapolations and may not provide reliable information about the estimated ages of degraded seal coat sections.

Paris District Distress Score Analyses

The Paris District's data showed similar but more pronounced trends. Figure 41 provides true comparative deterioration curves through year 3, and the data pool in year 4 is also virtually complete. A clear and significant difference in performance exists between the two grades of seal coat. At year 4 in service life, the average distress score for all Grade 3 seal coats constructed in 2003 was 91.24 while the average distress score for all Grade 4 seal coats constructed the same year was 83.08. This group of Grade 4 seal coats exhibited approximately 94 percent more distress after four years in service than did the group of Grade 3 seal coats.

The results of the inverse regression of Paris District data in Table 20 show more comparable performance expectations between Grade 3 and Grade 4 seal coats when the pre-existing pavement condition is Good or Fair than with the Amarillo District data. If the pavement condition prior to placing the seal coat is Excellent, however, the Grade 4 seal coats are projected to reach given distress levels approximately twice as quickly as Grade 3 seal coats will. This latter finding is similar to the findings of the analysis of the Amarillo District data.

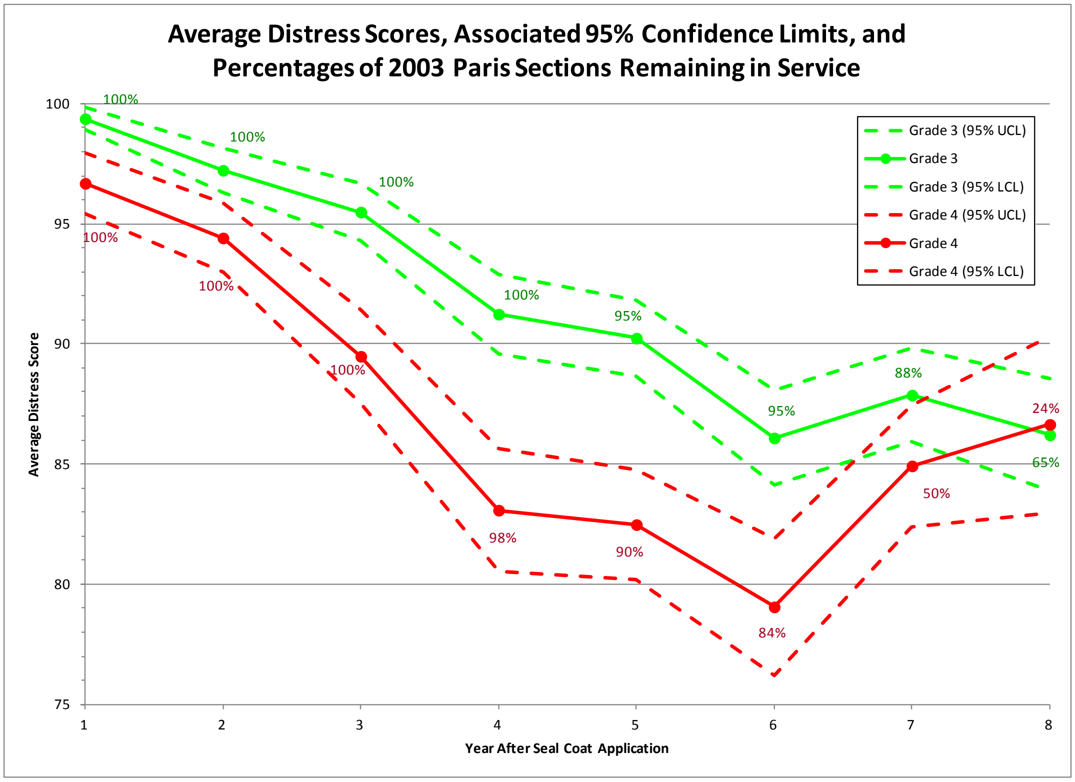

Figure 43. Average Distress Scores of Remaining Sections by Year – Paris District.

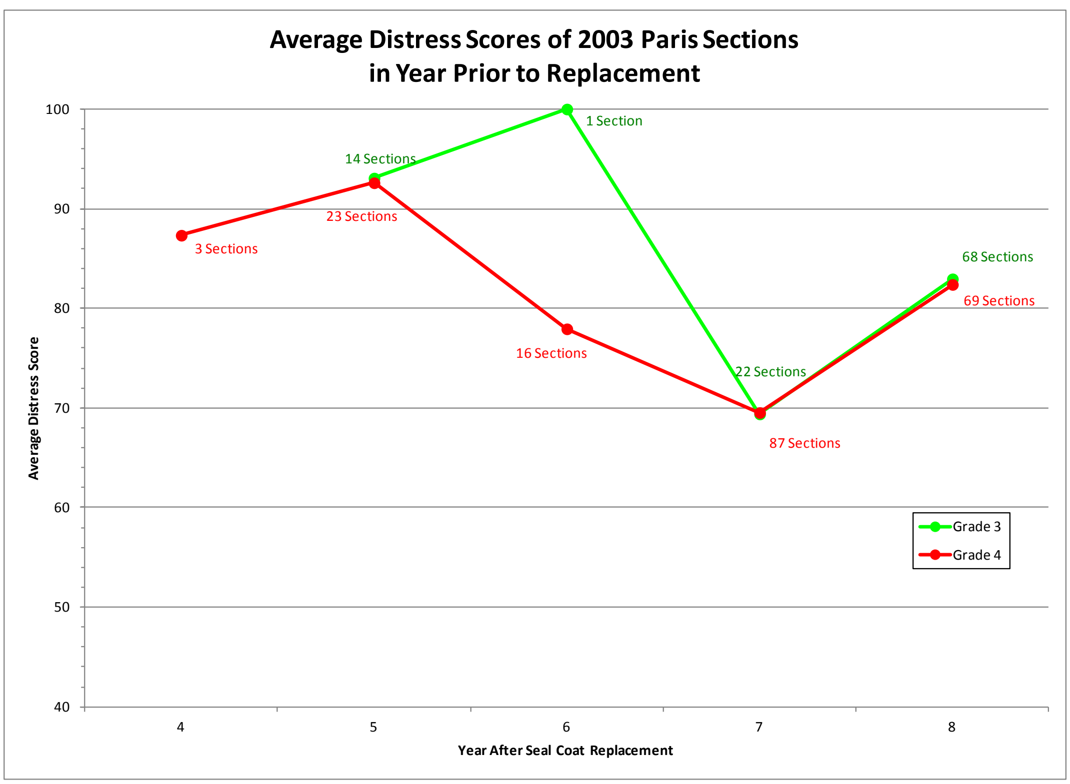

Figure 44. Average Distress Scores of Resurfaced Sections by Year – Paris District.

Table 19. Average Distress Scores of Remaining Sections and Interval Estimates by Year – Paris District.

Years after Construction	Seal Coat Grade	Average Distress Score	Lower 95% C.I.	Upper 95% C.I.
1	3	99.38	98.92	99.83
	4	96.69	95.43	97.94
2	3	97.23	96.30	98.16
	4	94.41	92.99	95.84
3	3	95.49	94.29	96.69
	4	89.49	87.56	91.42
4	3	91.24	89.58	92.90
	4	83.08	80.53	85.63
5	3	90.24	88.67	91.81
	4	82.48	80.19	84.77
6	3	86.09	84.12	88.06
	4	79.05	76.21	81.90
7	3	87.87	85.94	89.81
	4	84.92	82.39	87.46
8	3	86.22	83.87	88.57
	4	86.65	82.98	90.32

Table 20. Paris Estimated Distress Scores.

Prior 3-year Average Pavement Condition	Seal Coat Grade	Estimated Age of Seal Coat for Specified Average Distress Score					
		95	90	85	80	75	70
Excellent	3	4.4	7.6	10.8			
	4	2.1	3.6	5.1	6.6	8.1	9.6
Good	3	2.8	4.8	6.8	8.8	10.8	12.8
	4	2.3	4.1	5.9	7.7	9.5	11.3
Fair	3	1.3	2.5	3.7	5.0	6.2	7.4
	4	0.9	2.0	3.0	4.1	5.1	6.1

Note:

Estimates are based on average distress scores for the first 6 or 7 years after seal coat application.

Inverse regression was separately performed for each combination of seal coat grade and prior pavement condition to obtain the estimates.

Estimates greater than 6 or 7 years are linear extrapolations and may not provide reliable information about the estimated ages of degraded seal coat sections.

Yoakum District Distress Score Analyses

The Yoakum District's data and resulting analyses outcomes were largely different from those resulting from analyses of data from the Amarillo and Paris Districts. As noted earlier, the Yoakum District resurfaced almost none of their 2003-constructed seal coats until seven years of pavement service had been obtained. The average distress scores over this initial seven-year service period were considerably higher (better) than those in the other two districts, obviously warranting the delay in resurfacing. After eight years of service, only 25 percent of their Grade 3 seal coats had been resurfaced and only 31 percent of their Grade 4 seal coats had been resurfaced. These percentages compare to 49 percent and 75 percent in the Amarillo District, and 35 percent and 76 percent in the Paris District.

Another distinct difference between the seal coat performances in Yoakum and the other two districts is that the true deterioration curves for Grade 3 and Grade 4, observable with Yoakum data through year 6, were very similar. If the trend for Grade 3 to outperform Grade 4 is to continue in Yoakum, it will occur at later ages. The data show an indication of this beginning to occur in that somewhat higher percentages of Grade 4 seal coats were resurfaced in years 7 and 8 than were the district's Grade 3 seal coats.

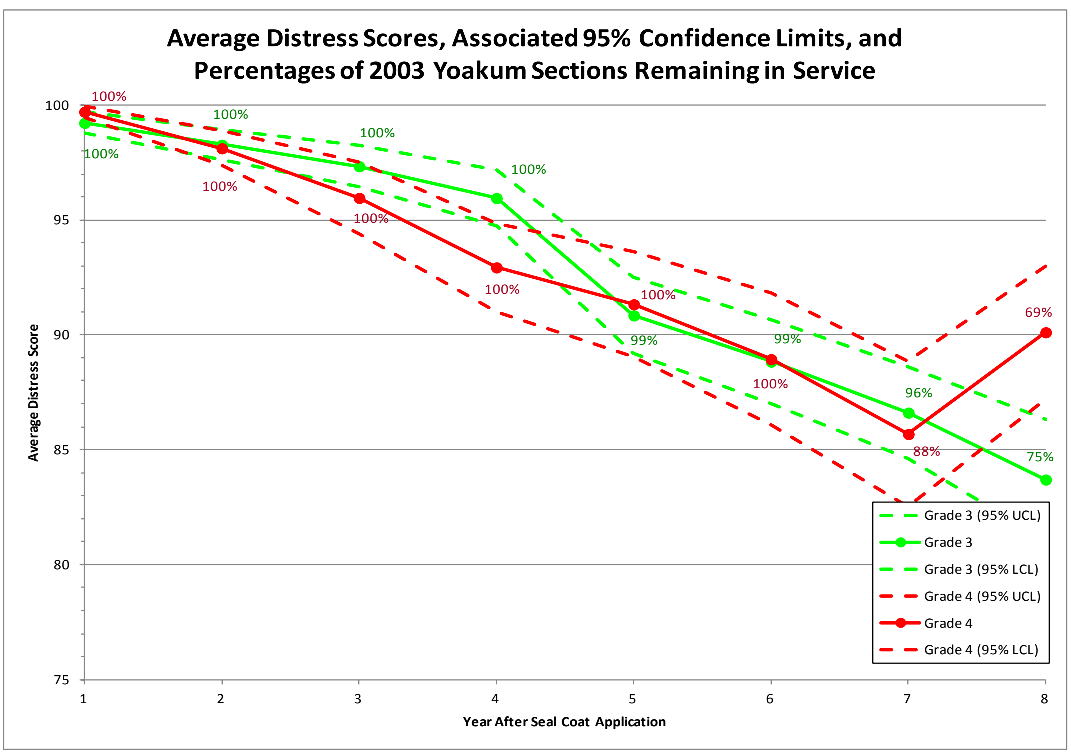

Figure 45. Average Distress Scores of Remaining Sections by Year – Yoakum District.

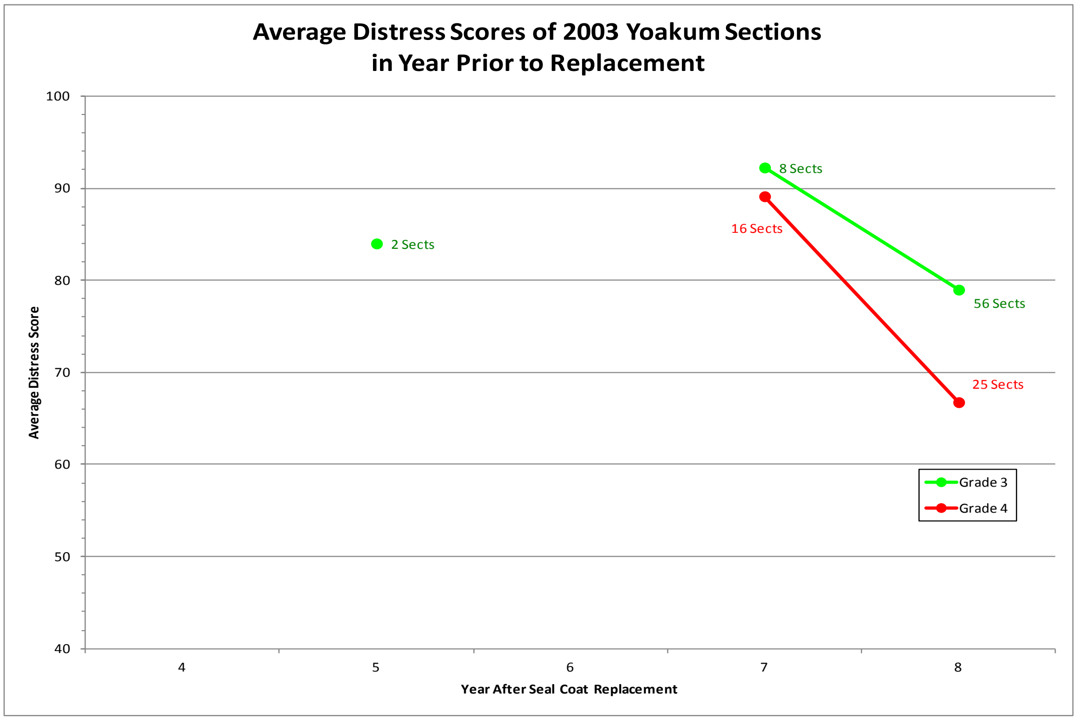

Figure 46. Average Distress Scores of Resurfaced Sections by Year – Yoakum District.

Table 21. Average Distress Scores of Remaining Sections and Interval Estimates by Year – Yoakum District.

Years after Construction	Seal Coat Grade	Average Distress Score	Lower 95% C.I.	Upper 95% C.I.
1	3	99.22	98.76	99.69
	4	99.70	99.45	99.96
2	3	98.27	97.63	98.91
	4	98.11	97.34	98.88
3	3	97.33	96.44	98.23
	4	95.95	94.39	97.52
4	3	95.95	94.73	97.16
	4	92.93	91.01	94.85
5	3	90.84	89.18	92.51
	4	91.33	89.03	93.62
6	3	88.83	87.00	90.66
	4	88.94	86.05	91.83
7	3	86.61	84.64	88.59
	4	85.68	82.52	88.84
8	3	83.70	81.08	86.32
	4	90.11	87.21	93.01

Table 22 further indicates the differences between the experiences in the Yoakum District and those of the Amarillo and Paris Districts. The inverse regression of the data indicates that in the Yoakum District the Grade 4 will outperform the Grade 3, although only slightly, when pre-existing pavement conditions are in the Excellent or Good categories.

Table 22. Yoakum Estimated Distress Scores.

Prior 3-year Average Pavement Condition	Seal Coat Grade	Estimated Years Until Average Distress Score					
		95	90	85	80	75	70
Excellent	3	5.6	7.6	9.6	11.6		
	4	6.9					
Good	3	3.5	5.5	7.6	9.7	11.7	
	4	3.1	5.6	8.0	10.5		
Fair	3	2.7	4.4	6.2	7.9	9.6	11.4
	4	2.4	3.7	5.0	6.3	7.6	8.9

Note:
Estimates are based on average distress scores for the first 6 or 7 years after seal coat application.
Inverse regression was separately performed for each combination of seal coat grade and prior pavement condition to obtain the estimates.
Estimates greater than 6 or 7 years are linear extrapolations and may not provide reliable information about the estimated ages of degraded seal coat sections.

Statistical Modeling of 2003 Seal Coat Service Lifetimes

Survival analysis is an area of statistical analysis concerned with what is variously referred to as lifetime, survival time, or failure time data. For the 2003 data, the researchers sought to quantify the expected difference in service life of Grade 3 over Grade 4 seal coats. Since data from the Paris and Yoakum Districts displayed a very high rate of censoring for Grade 3 seal coats, this presented problems with estimating mean or median service lives.

Identifying the Correct Parametric Model

Parametric survival analysis models offer the advantage over nonparametric models in that they are more amenable to extrapolation. When fitting a fully parametric model, the survival times are assumed to follow a statistical distribution, and the identification of the most suitable distribution for the observed data is a crucial step in the survival analysis. The most obvious distinguishing feature between parametric models is in the shape of the hazard they assume the data follow.

The hazard function specifies the instantaneous rate of failure at time *t*, given survival up until *t*. The shape or distribution of the hazard function determines the class of the data set. The set of hazard function results developed for the 2003 PMIS data are displayed graphically in Figure 47. One can see that the hazard functions for all three districts increase at an accelerating rate until between 6 years (Amarillo) and 8 years (Yoakum), followed by swift declines after 8 years. This latter feature is most probably caused by the high degree of censoring in the data (i.e., many PMIS sections with Grade 3 seal coats were still in service at the end of the observation period). Such hazard functions suggest something other than a pure deterioration process is at work. Under a pure deterioration process, the hazard rate is typically non-decreasing with respect to time.

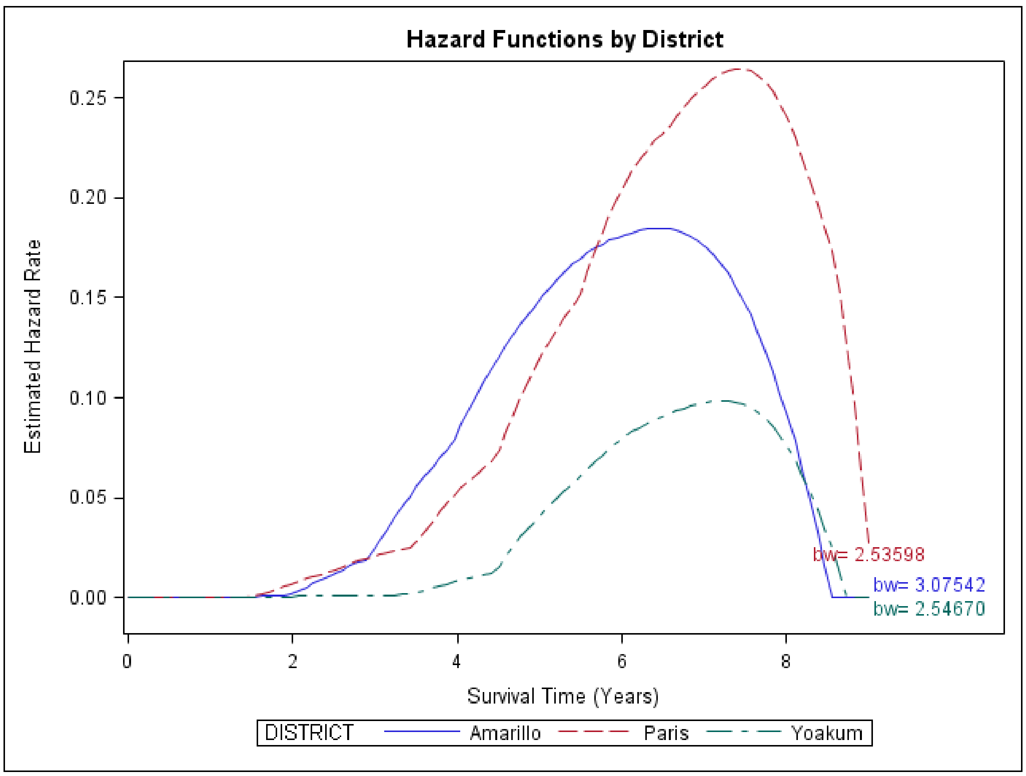

Figure 47. Hazard Functions for Seal Coat Sections – All Districts.

Figure 48 shows a plot of the natural logarithm of the cumulative hazard function, known as the log (−log(survival)) plot, for each seal coat grade in the Amarillo District. This plot is used to determine the nature of the interaction between model covariates – in this case, seal coat grade – and survival time, with straight and parallel lines suggesting the class of proportionate hazard models. Figure 48 reveals this is not the case; both lines are neither linear nor parallel (the other districts display similar behavior). In the statistical area of survival analysis, an accelerated failure time model (AFT model) is a parametric model that provides an alternative to the commonly used proportional hazards models. Whereas a proportional hazards model assumes that the effect of a covariate is to multiply the hazard by some constant, an AFT model assumes that the effect of a covariate is to multiply the predicted event time by some constant. AFT models can therefore be framed as linear models for the logarithm of the survival time.

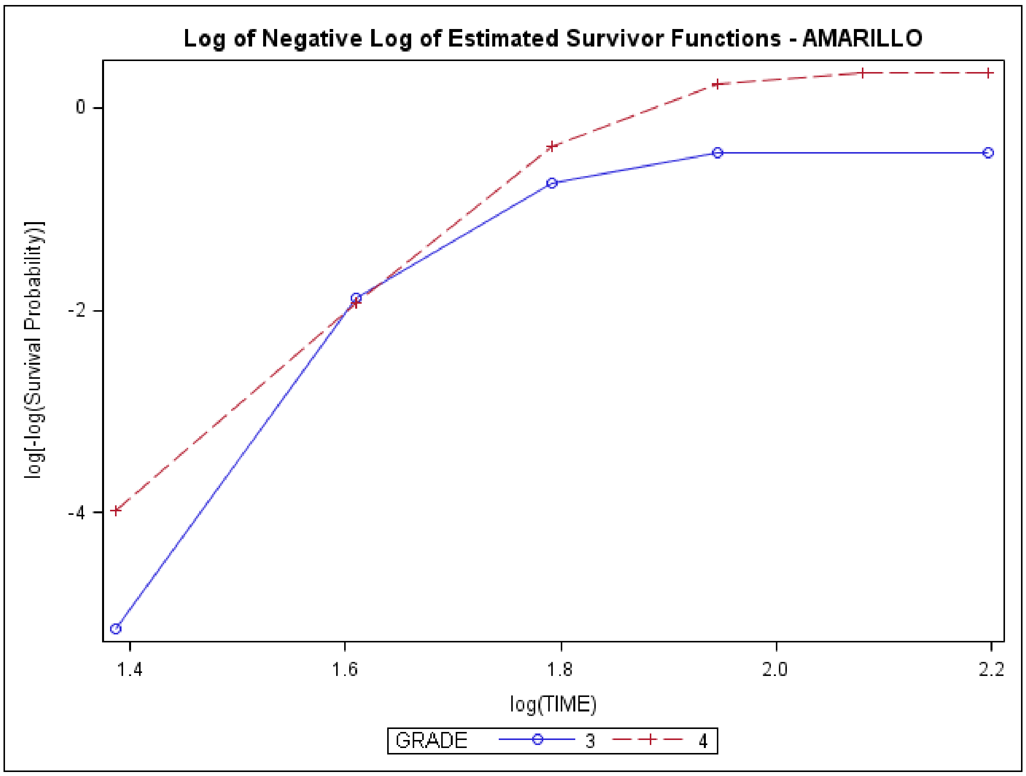

Figure 48. Log of Negative Log Functions – Amarillo District.

Based on consideration of the hazard function and cumulative hazard functions, the parametric models selected in the analyses assume the log logistic distribution of:

$$S(w) = \left(1 + \exp\left(\frac{w - \mathbf{x\beta}}{\sigma}\right)\right)^{-1}$$

where w is the natural log of survival time, σ is the scale factor or variance, and $\mathbf{x\beta}$ is the linear combination of explanatory variables.

The explanatory variables for both the Amarillo and the Yoakum survival models include seal coat grade and prior pavement condition. The survival model for the Paris district includes traffic level in addition to both of these variables.

The following analysis was developed for Amarillo District seal coat performance.

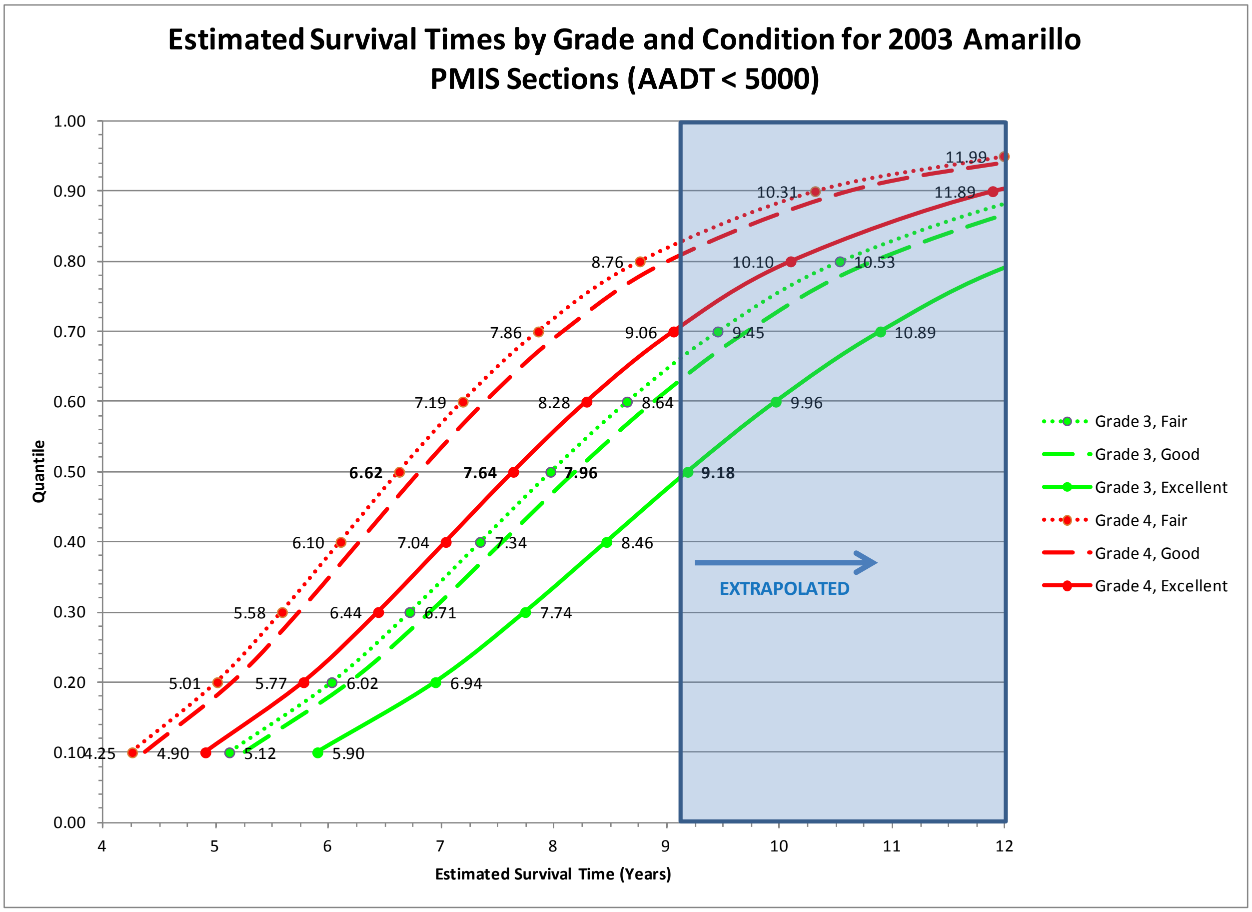

Figure 49. Amarillo Estimated Survival Curves.

The survival analysis results for Amarillo indicate the estimated median service lifetimes for Grade 3 seal coats exceed those of Grade 4 seal coats by 1.54 years, 1.38 years, and 1.34 years for Excellent, Good, and Fair road conditions, respectively. All these differences are statistically significant, as shown in the non-overlapping 95 percent confidence intervals in Table 23. Figure 49 shows that the greatest service lifetimes for both seal coat grades occur for the Excellent pre-existing pavement condition, which would be expected. Seal coats applied to Good and Fair pavement sections exhibit approximately one year less median service lifetimes, and within each grade the differences in median service life between these conditions of pavement are not considered statistically significant.

Table 23. Amarillo Estimated Median Service Lifetimes.

Road Condition	Seal Coat Grade	Median Service Life	Lower 95% C.I.	Upper 95% C.I.
Excellent	3	9.18	8.49	9.93
	4	7.64	7.11	8.20
Good	3	8.19	7.80	8.59
	4	6.81	6.50	7.13
Fair	3	7.96	7.47	8.50
	4	6.62	6.26	7.00

Separate analyses were performed for two categories of traffic within the Paris District data set. For low traffic (AADT < 501) sections, survival analysis results indicate the estimated median service lifetimes for Grade 3 seal coats exceed those of Grade 4 seal coats by 1.46 years, 1.54 years, and 1.40 years for Excellent, Good, and Fair road conditions, respectively. Figure 46 graphically displays these results. The differences found in all three pre-existing pavement condition data sets are statistically significant, as evident in the non-overlapping 95 percent confidence intervals in Table 24. Figure 50 reveals that the greatest service lifetimes for both seal coat grades occur when the pre-existing pavement condition is in the Good category. Seal coats applied to pavement sections in the Fair pre-existing condition category exhibit approximately 9 months less median service lifetimes. Meanwhile, the median service lifetimes for seal coats applied to pavement sections in the Excellent pre-existing pavement condition category are shorter by less than 4 months. However, there are no statistically significant differences in median service life between different pavement conditions within the same seal coat grade.

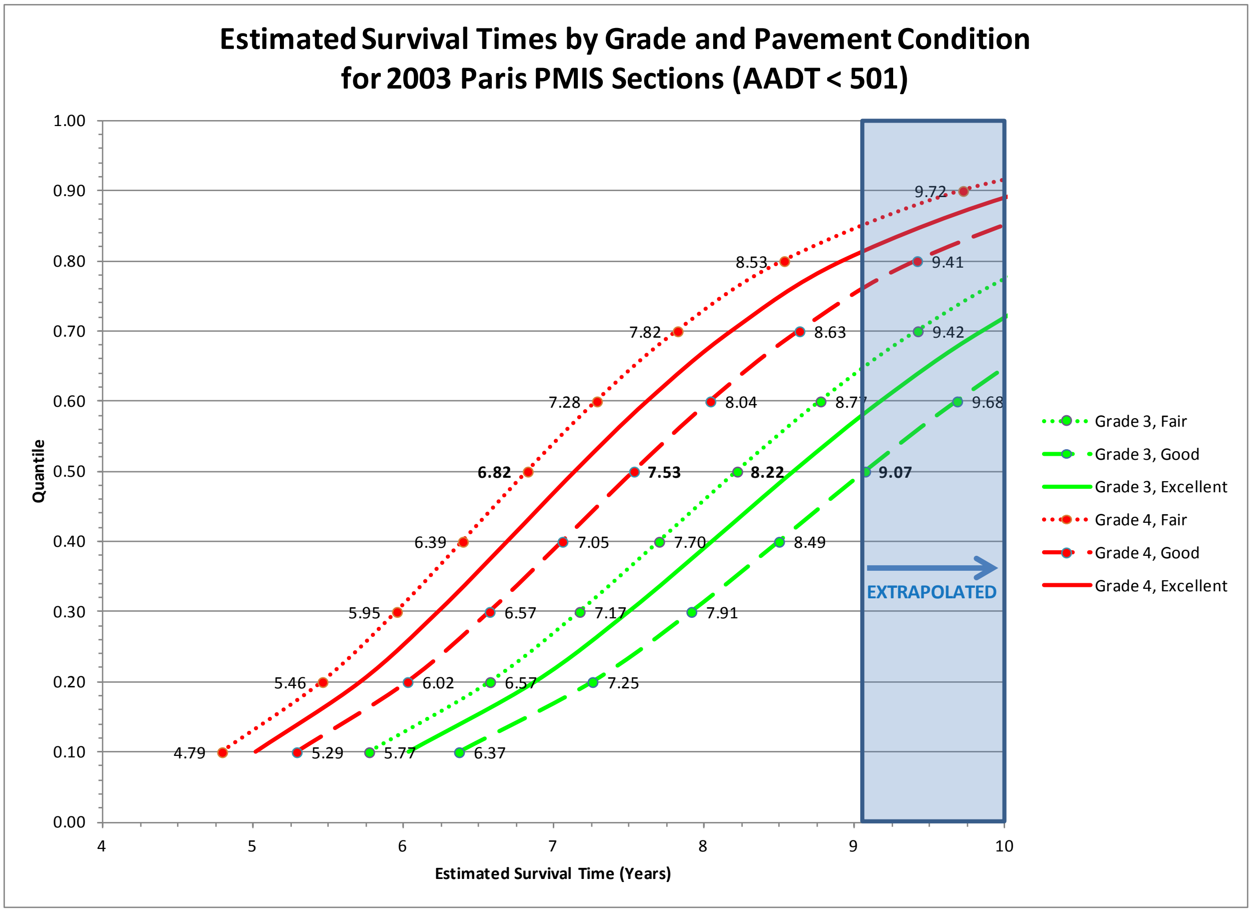

Figure 50. Paris Estimated Survival Curves, AADT < 501.

Table 24. Paris Estimated Median Service Lifetimes, AADT < 501.

Road Condition	Seal Coat Grade	Median Service Life	Lower 95% C.I.	Upper 95% C.I.
Excellent	3	8.60	8.12	9.10
	4	7.14	6.69	7.62
Good	3	9.07	8.56	9.60
	4	7.53	7.16	7.92
Fair	3	8.22	7.74	8.72
	4	6.82	6.48	7.18

For medium traffic sections (AADT between 500 and 2000) in the Paris District, survival analysis results indicate the estimated median service lifetimes for Grade 3 seal coats exceed those of Grade 4 seal coats by 1.31 years, 1.38 years, and 1.24 years for Excellent, Good, and Fair pre-existing road conditions, respectively. All these differences are statistically significant, as the non-overlapping 95 percent confidence intervals in Table 25 show. As with the case for low traffic sections, Figure 51 shows that the greatest service lifetimes for both seal coat grades occur for Good pre-existing pavement conditions. Once again, there are no statistically significant differences in median service life between different pavement conditions within the same seal coat grade.

Seal coats applied to Fair pre-existing pavement sections exhibit approximately 9 months less median service lifetimes, while the median service lifetimes for seal coats applied to Excellent pavement are shorter by less than 4 months. However, there are no statistically significant differences in median service life between different pavement conditions within the same seal coat grade.

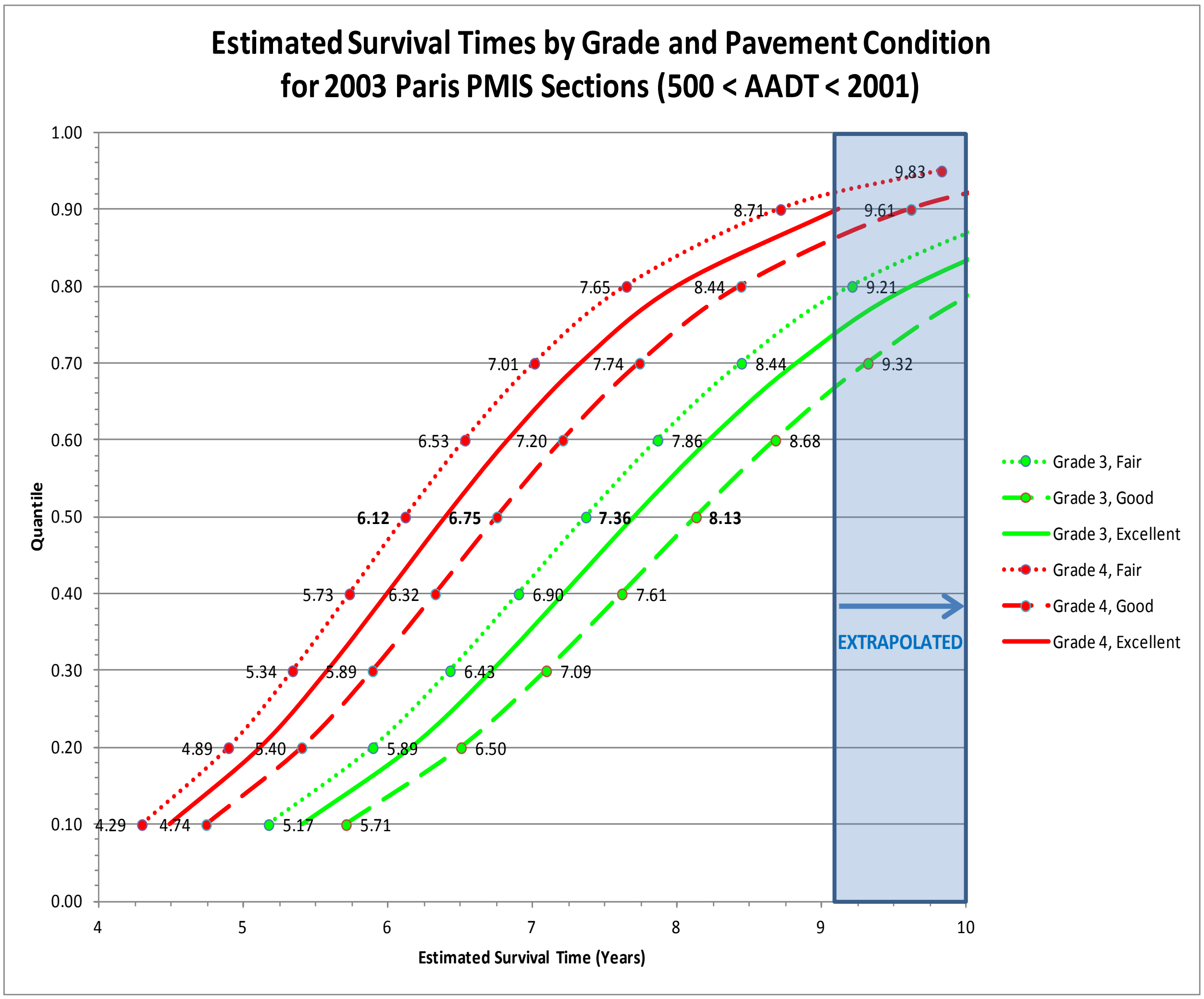

Figure 51. Paris Estimated Median Service Lifetimes, 500 < AADT < 2001.

Table 25. Paris Estimated Median Service Lifetimes, 500 < AADT < 2001.

Road Condition	Seal Coat Grade	Median Service Life	Lower 95% C.I.	Upper 95% C.I.
Excellent	3	7.71	7.36	8.07
	4	6.40	6.00	6.82
Good	3	8.13	7.74	8.53
	4	6.75	6.42	7.10
Fair	3	7.36	6.96	7.79
	4	6.12	5.78	6.47

As shown in Table 26, there are statistically significant differences in estimated median service lifetimes across traffic levels in the Paris District. Within the Grade 3 group of seal coat sections, low traffic sections with Excellent condition had 0.89 years greater median service lifetimes compared to medium traffic sections, while low traffic sections in Good condition exhibited 0.94 years greater median service lifetimes compared to medium traffic sections. For the Grade 4 sections, low traffic sections in Good condition showed 0.78 years greater median service lifetimes over comparable medium traffic sections, while low traffic Fair condition sections had an additional 0.7 years median service life compared to medium traffic sections.

Table 26. Paris Estimated Median Service Lifetimes, All Traffic Levels.

Seal Coat Grade	Road Condition	Traffic Level	Median Service Life	Lower 95% C.I.	Upper 95% C.I.
3	Excellent	Low	8.60	8.12	9.10
		Medium	7.71	7.36	8.07
	Good	Low	9.07	8.56	9.60
		Medium	8.13	7.74	8.53
	Fair	Low	8.22	7.74	8.72
		Medium	7.36	6.96	7.79
4	Excellent	Low	7.14	6.69	7.62
		Medium	6.40	6.00	6.82
	Good	Low	7.53	7.16	7.92
		Medium	6.75	6.42	7.10
	Fair	Low	6.82	6.48	7.18
		Medium	6.12	5.78	6.47

Note: For Traffic Level, L is AADT < 501 and M is 500 < AADT < 2001

The survival analysis results for Yoakum District data indicate the estimated median service lifetimes for Grade 3 seal coats exceed those of Grade 4 seal coats by 1.71 years, 1.78 years, and 1.99 years for Excellent, Good, and Fair pre-existing road conditions, respectively. However, only the difference for Good pre-existing condition sections was found to be statistically significant (see Table 27). The contradiction between large differences and their lack of statistical significance is explained in large part by the very high percentage of right-censored service lifetimes; out of the 396 Yoakum District pavement sections, 272 were still in service after the 9-year period, leaving only 124 uncensored observations. Note also that the greatest median service lifetimes for both seal coat grades occur in the Fair pavement condition category, while the shortest median service lifetimes are found for Excellent pre-existing pavement conditions. This suggests the possibility of a district policy of assuring truly preventive maintenance timing of resurfacing on selected roadways.

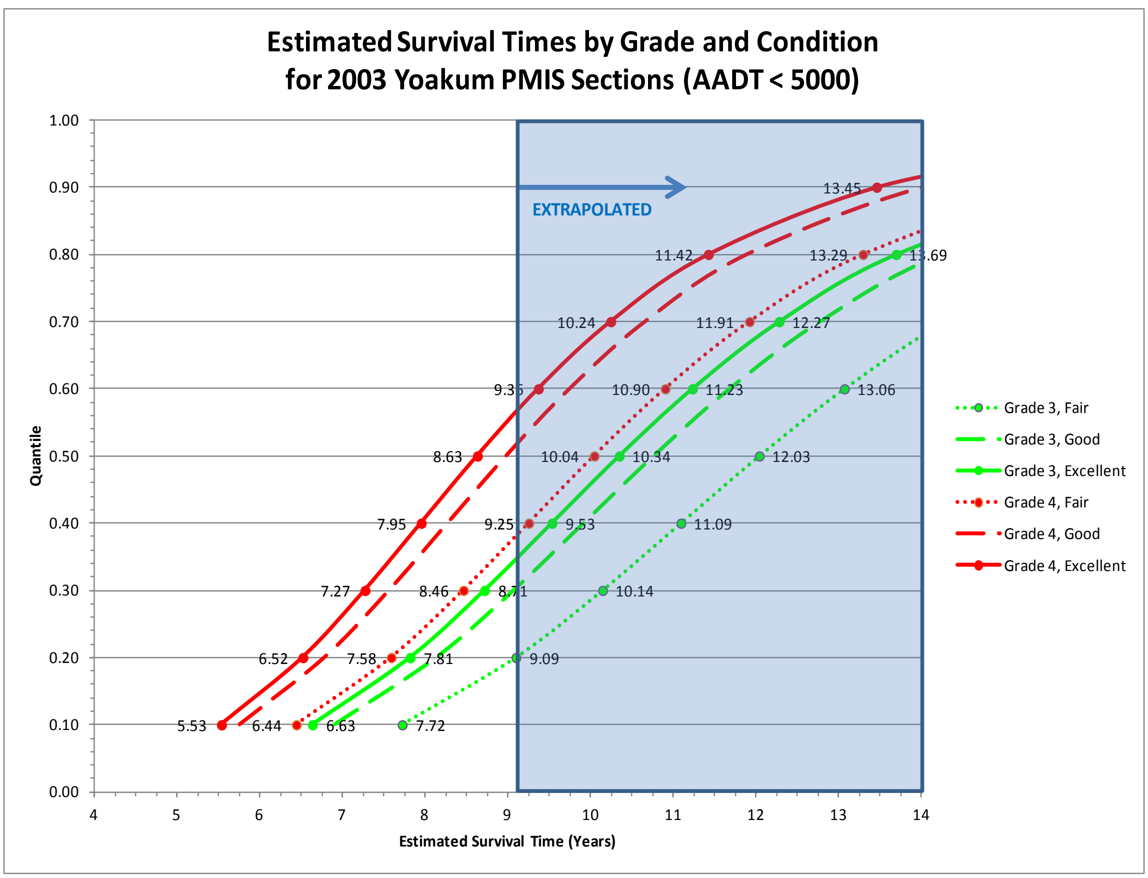

Figure 52. Yoakum Estimated Survival Curves.

Table 27. Yoakum Estimated Median Service Lifetimes.

Road Condition	Seal Coat Grade	Median Service Life	Lower 95% C.I.	Upper 95% C.I.
Excellent	**3**	10.34	9.47	11.30
	4	8.63	7.80	9.54
Good	**3**	10.75	9.87	11.72
	4	8.97	8.21	9.81
Fair	**3**	12.03	10.84	13.37
	4	10.04	9.15	11.01

Table 28 summarizes the results of the statistically modeled analysis of seal coat performance lifetimes based on PMIS performance data for seal coats constructed in 2003 in the Amarillo, Paris, and Yoakum Districts. The bold print value in each table box is the average anticipated performance prior to resurfacing, based on the collective practices and history of resurfacing seal coated pavements in these three districts. The values in parentheses below the bold values are the 95 percent Confidence Intervals associated with value above.

In the Amarillo District and in the Paris District for AADTs below 501, the model predicts between 1.4 and 1.6 years of additional performance from Grade 3 seal coats over Grade 4 seal coats.

In the Paris District, for AADTs between 501 and 2,001, the model predicts 1.3 years of additional performance of Grade 3 seal coats over Grade 4 seal coats.

In the Yoakum District, 1.7 to 2.0 years of additional performance is anticipated from Grade 3 seal coats over Grade 4 seal coats.

The consensus finding of the statistical analysis of performances of seal coats constructed in three districts in 2003 is that Grade 3 seal coats should be expected to serve one to two years longer before resurfacing than Grade 4 seal coats, all other roadway and environmental factors being equal. However, as decisions to apply preventive maintenance resurfacing has in the past been based on age, as well as other non-distress-related factors, this difference in performance life potential may be understated.

Table 28. Estimated Median Service Life prior to Resurfacing and 95% Confidence Intervals.

District	Seal Coat Grade	Prior 3-year Average Pavement Condition		
		Fair	Good	Excellent
Amarillo	3	**8.0** (7.5, 8.5)	**8.2** (7.8, 8.6)	**9.2** (8.5, 10.0)
	4	**6.6** (6.3, 7.0)	**6.8** (6.5, 7.1)	**7.6** (7.1, 8.2)
Paris (AADT < 501)	3	**8.2** (7.7, 8.7)	**9.1** (8.6, 9.6)	**8.6** (8.1, 9.1)
	4	**6.8** (6.5, 7.2)	**7.5** (7.2, 7.9)	**7.1** (6.7, 7.6)
Paris (500 < AADT < 2001)	3	**7.4** (7.0, 7.8)	**8.1** (7.7, 8.5)	**7.7** (7.4, 8.1)
	4	**6.1** (5.8, 6.5)	**6.8** (6.4, 7.1)	**6.4** (6.0, 6.8)
Yoakum	3	**12.0** (10.8, 13.4)	**10.8** (9.9, 11.7)	**10.3** (9.5, 11.3)
	4	**10.0** (9.1, 11.0)	**9.0** (8.2, 9.8)	**8.6** (7.8, 9.5)

Experimental Limitations of the 2003 Seal Coat Performance Statistical Analyses

Distress Analysis

Average distress score of the pavement sections remaining in service was largely unhelpful in determining long-term pavement condition. Progressive censoring of pavement sections occurred over time as failing sections were replaced. For the Amarillo and Paris Districts, this censoring reached nearly 80 percent of sections eight years after initial seal coat application. The bias induced by this process acted to increase the average distress scores over what would be observed in the absence of censoring. This was readily apparent for Grade 4 seal coats, where the average distress score of the remaining sections actually increased beginning seven years after initial seal coat application.

The researchers consider it likely that the progressive survivorship bias in distress scores acted to obscure what would otherwise appear to be a typical exponential degradation process. That is, in the absence of such censoring, the distress scores of the sections would decrease first slowly and then precipitously past a certain time. In the presence of substantial late-time censoring, however, any inferences for prospective distress scores over time could only be confined to the more linear region of distress score declines. The estimates for time until a given distress level is reached in Tables 18, 20, and 22 should therefore be considered suspect for times greater than seven years, as these estimates are based on linear extrapolation in a region whose trend is probably polynomial or exponential. Figure 53 illustrates an example of this type of bias, where one can see the progressively increasing error of linear approximations once deterioration begins to accelerate in later time periods.

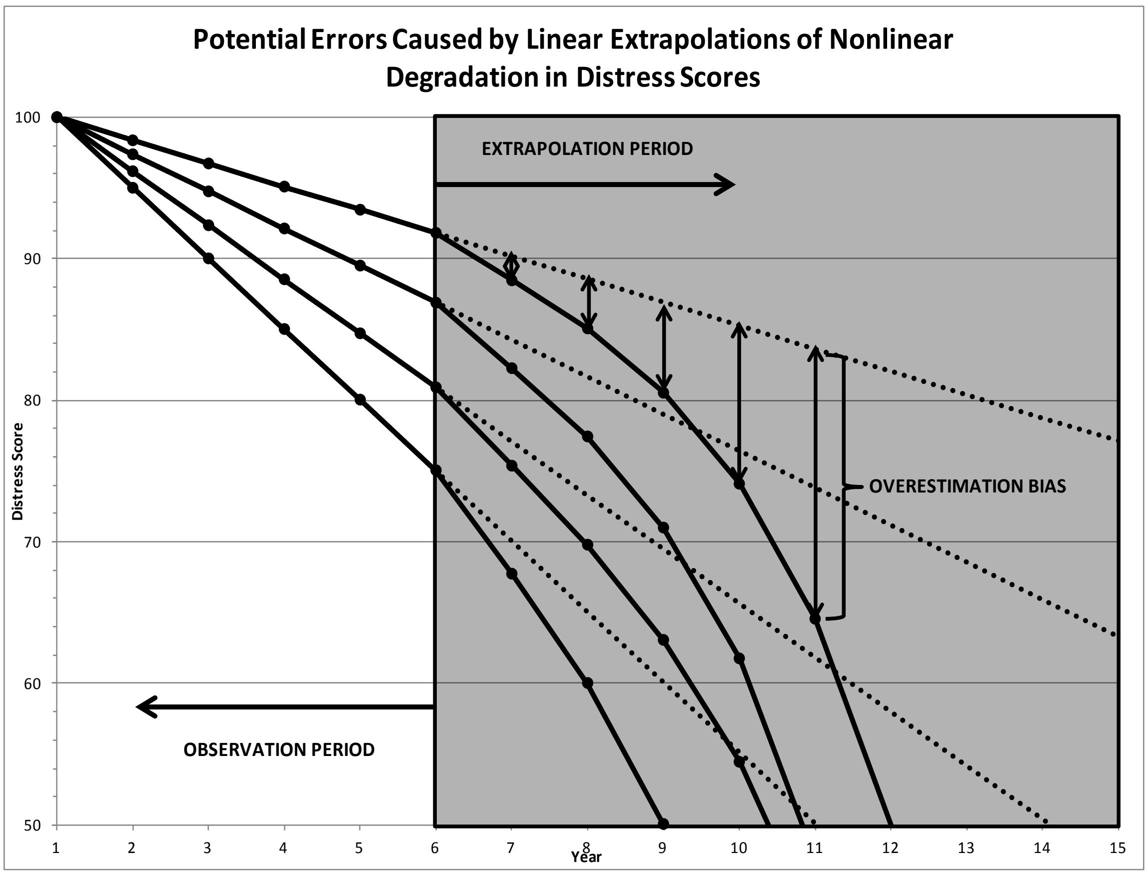

Figure 53. Errors Resulting from Linear Extrapolation.

An additional limitation of the estimates of distress versus time is that these were obtained by inverse regression. In particular, the slopes of the linear trends for excellent pre-existing condition sections were very shallow relative to the slopes of the linear trends for pavement sections in worse condition at time of seal coat construction. Thus, estimates of time based on inverse regression of these sections have exceptionally large error terms.

The PMIS data also appears to violate certain assumptions underlying the survival analysis models; one of these being the assumption of failure-at-random. Often, clusters of contiguous pavement sections are resurfaced, with a number of 0.5-mile pavement sections in considerably better condition than the intermittent sections causing the resurfacing decision. In consequence, this unavoidably creates outliers in the data population.

A major limitation of the survival analysis is the fact that the service lifetimes being obtained in the field, and which the research team captured and modeled, are not in actual practice purely a function of degree of visually evident roadway deterioration. As the optimal use of seal coat surfacing is as a preventive maintenance tool, districts have historically tried to use it just prior to the appearance of visually observable distresses. Also, districts must consider numerous other factors, in addition to distress levels, when prioritizing candidate roadways for preventive maintenance seal coat resurfacing. These other factors can include proximity to schools, crash history, and major project planning, to name a few. This situation gives rise to anomalous hazard functions, complicating model fit and hindering accuracy of model output.

2003 PMIS Data Analyses Conclusions

The conclusions that can be drawn from the statistical analyses of PMIS performance data for seal coats constructed in 2003 include that Grade 3 seal coats will not show visually observable distress as quickly as Grade 4 seal coats placed in the same roadway environment. The difference in performance to be expected between these two grades of seal coat is *at least* one to two years, depending on the traffic level, pre-existing condition of the roadway, and possibly other factors. A more definitive conclusion regarding how long each grade of seal coat should be expected to serve and the difference in these service life expectations cannot confidently be drawn from this study of historical service life records. This is because 1) districts vary in philosophies on timing of preventive maintenance resurfacing and 2) factors other than pavement distress sometimes necessitate resurfacing earlier than otherwise required.

Economic Considerations – Performance versus Cost

The difference in construction cost for Grade 3 and Grade 4 seal coats is basically equal to the difference in volumes of asphalt and aggregate used for each. While aggregate application rates vary based on the seal coat design and district policies and practices, Grade 3 aggregate rates will generally fall between 1CY/85SY and 1CY/95SY. For Grade 4 aggregate, rates generally vary between 1CY/115SY and 1CY/125SY. Asphalt application rates vary to an even greater extent, roadway to roadway, but are generally in the area of 0.42Gal/SY to 0.47Gal/SY for Grade 3 seal coats and between 0.32Gal/SY and 0.38Gal/SY2 for Grade 4 seal coats. Collectively, considering these ratios, Grade 3 seal coats should generally cost 25 percent to 35 percent more than Grade 4 seal coats, all other factors being equal.

If we apply this percentage to seal coat service life, and if Grade 4 seal coats are providing six years of performance, on average, in a specific type of application, then Grade 3 seal coats must provide an average of eight years of service life to match if not slightly exceed the cost-effectiveness of the Grade 4 seal coat option. If Grade 4 seal coats are providing eight years of service life for another type of application, then Grade 3 seal coats would need to provide 10 or 11 years of performance life to match or exceed the cost effectiveness of using Grade 4. There are also some reductions in annual average departmental operational costs when an operation such as seal coating is required less frequently. The above calculations do not include those reductions or the value of reduced user costs and inconveniences when seal coat construction occurs less frequently.

CHAPTER 7:
CONCLUSIONS AND RECOMMENDATIONS

This study encompassed a broad array of activities designed to capture much-needed additional knowledge about seal coat pavement performance as practiced in Texas. The following conclusions and recommendations are drawn from the various activities included in the study.

CONCLUSIONS

Literature Review Findings

The review of available literature revealed very few publications specifically addressing the issues of either relative cost-effectiveness or relative expected performances of seal coats of varying grades. The following information of interest to the objectives of Project 0-6496 was gleaned from published literature.

1. Based on a study performed in Texas and reported in 2011, Grade 3 seal coat aggregate provide distinctly superior resistance to return of surface flushing when compared to the performance of Grade 4 seal coat aggregate placed on previously flushed pavements.
2. A panel of New Zealand pavement engineers reached a consensus opinion that their Grade 3 aggregate should provide an additional two years of service over their Grade 4 aggregate if all other factors were equal. For Grade 3, between traffic levels of 500 to 10,000 ADT, expected service lives were 10 years to eight years, respectively. For Grade 4 traffic levels of 500 to 10,000 ADT, expected service lives were eight to six years, respectively.
3. Generally, the larger the aggregate size, the greater the resulting tire-noise to be emitted by traffic.

District Survey Conclusions

The following conclusions can be drawn from the survey responses and discussions in the field with district personnel across the state.

1. Eleven districts planned to use Grade 4 seal coats exclusively in their 2010 seal coat programs. Only one district specified Grade 3 exclusively in 2010.
2. Twelve districts continued to use Grade 3 seal coats within their 2010 district seal coat preventive maintenance programs.
3. In districts specifying both Grade 3 and Grade 4 seal coats, roadway traffic level, proximity to dwellings, and potential for windshield breakage are considered in making seal coat grade selections.
4. Two districts reported using Grade 5 seal coats on travel lanes in specific situations. Inadequate performance information exists to determine if and under what circumstances Grade 5 seal coats should be used on travel lanes in lieu of larger aggregate grades.
5. Several additional districts are placing Grade 5 seal coats on shoulders for both economic and/or bicyclist preference reasons. The most common use of Grade 5 seal coat is for strip seals and spot seals placed by department maintenance forces.
6. District personnel offering opinions on expectations for service life to be obtained from Grade 3 and Grade 4 seal coats stated the belief that Grade 3 seal coats would perform at least one year longer than Grade 4 seal coats in most application situations.
7. Selections of seal coat grade for given roadway locations are in some cases being driven by the current funding shortage for preventive maintenance.
8. There is near-universal consensus that the larger the seal coat aggregate being used, the louder the noise to be generated by traffic.
9. Based on numerous interview comments, district seal coat decision makers are generally aware of and consider the needs of cyclists when making material selections.

Noise Testing Conclusions

A number of conclusions can be reached based on the noise testing of seal coats performed.

1. Tire-pavement interface noise intensity generally increases with increasing aggregate size. Average noise intensity levels for all Grade 3, Grade 4, and Grade 5 seal coats tested in this study were 106.2 dBA, 105.5 dBA, and 104.5 dBA, respectively. However, these average noise intensity levels do not differ adequately for the differences to be easily perceivable to the human ear.
2. The range of possible noise intensity levels generated by each of the various aggregate grades is large enough that some Grade 4 aggregate seal coats will produce higher tire-pavement interface noise intensity than some Grade 3 aggregate seal coats. Likewise, some Grade 5 aggregate seal coats will have a higher tire-pavement interface noise level than some Grade 4 aggregate seal coats.
3. The possibility exists that aggregate mineral type has a small but measurable effect on the noise intensity level generated at the tire-pavement interface. However, based on the testing performed during this study, other roadway surface factors likely supersede any effect potentially imposed by aggregate mineral type.
4. While texture depth testing was not included in this study, photography of the loudest and quietest Grade 3 seal coats indicate that macro-texture characteristics may be a significant factor affecting noise level being generated from the tire-pavement interface.
5. No consistent trend between seal coat age and noise level generated at the tire-pavement interface was observed from the pavements testing during this study.
6. A minor reduction in noise level generated at the tire-pavement interface was obtained when aggregate application rates were reduced. The amount of difference should not be discernible to the human ear.
7. Precoating aggregate with asphalt prior to seal coat construction does not appear to have a measurable effect on noise level generated at the tire-pavement interface.
8. Based on the OBSI test results of this and other TxDOT-sponsored projects, *average* tire-pavement interface noise intensity levels that seal coats generated are higher than

the *average* noise intensity levels of the other commonly used pavement surface types. However, the ranges of possible noise levels that seal coats and other pavement surface types generate are so large that considerable overlap exists between many pavement surface types.

1998 and 2003 PMIS Distress Level and Service Life Analyses Conclusions

1. A statistically significant difference in performance was obtained from Grade 3 and Grade 4 seal coats placed in both 1998 and 2003. Grade 3 seal coats begin to exhibit visually observable distress at a significantly slower pace than Grade 4 seal coats. The extent of the average difference in distress score decline between service year 1 and service year 5 for seal coats placed in 1998 is depicted below (Table 12, Chapter 6, page 50).

Grade	Average Difference in Distress Scores (D1-D5)	N
3	3.56	776
4	5.71	2,351

2. The average difference in performance life to be expected between Grade 3 and Grade 4 seal coats is *at least* one to two additional years when Grade 3 is used.
3. Here are two facts about seal coat use in Texas: first, they are used as a preventive maintenance tool; and second, districts differ in policies and procedures in determining the optimal time to resurface them. Together, these two facts have caused the study of PMIS historical pavement service life records to fall short of a more definitive conclusion regarding how long each grade of seal coat should be expected to serve on the roadway.

Economic Conclusion

1. A Grade 3 seal coat must be able to perform 25 to 35 percent longer than a Grade 4 seal coat in a specific location, and all other service life costs being equal, for the Grade 3 seal coat to meet or exceed the cost-effectiveness of the Grade 4 seal coat option.

RECOMMENDATIONS

1. The Seal Coat Grade Selection and Use Guidelines should be distributed to the districts for their information and application.
2. The findings of this study should be incorporated into TxDOT's seal coat training courses.
3. Texture and possibly other types of surface testing should be performed on selected seal coats noise tested during this project, particularly those emitting the highest and lowest noise intensity levels, in efforts to better identify the factors leading to quieter pavements.
4. TxDOT should continue to monitor both the test sections placed during this research project and performance at large of seal-coated pavements to better define expectations for performance lives from the various seal coat grades.
5. TxDOT should consider developing technical criteria to assist in determining when to reseal seal-coated pavement surfaces.

SEAL COAT GRADE SELECTION AND USE GUIDELINES

One of the major objectives of this project was to develop guidelines for optimally selecting seal coat grade and thereby maximizing cost effectiveness in future use of limited preventive maintenance funding. Individual distress type information was collected from historical PMIS records, as well as traffic volume information, in efforts to provide seal coat guidelines based on these visually observable roadway conditions. Development of guidelines based on individual distress types and traffic levels proved unsupportable from the statistical analyses of PMIS historical performance records of seal coats placed in 1998 and 2003. However, these analyses combined with the noise testing performed, the insights gained from interviews of experienced TxDOT field engineers, and the review of recent technical literature allow strong support for the following guidance.

Reseal Timing

- If seal coat age is a heavy consideration in selecting roadways to be resealed, as broadly considered good practice for preventive maintenance applications, a Grade 3 seal coat should be expected to perform *at least* one to two years longer than a Grade 4 seal coat placed in a given service environment.

Grade 3 Seal Coat Selection

- Grade 3 seal coats should be used in lieu of finer seal coat grades whenever wheel paths are heavily flushed and no other positive treatment is being used to mitigate early return of texture loss.
- Grade 3 seal coats should be used in lieu of Grade 4 in situations where obtaining an additional several years of service prior to resealing is an overriding consideration.

Grade 4 Seal Coat Selection

- Grade 4 seal coats should generally be used in lieu of Grade 3 unless district experience indicates a Grade 3 seal coat is likely to provide 25 to 35 percent longer service life with similar total life maintenance expenditures for the application being considered.
- Grade 4 seal coats should be used in lieu of Grade 3 in all locations where concerns for windshield damage are overriding considerations.
- Grade 4 seal coats are recommended in lieu of Grade 3 when roadside noise level is a primary consideration. However, use of Grade 4 cannot be relied on to provide noticeably quieter roadside environments than would have been provided using Grade 3.

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APPENDIX A – TELEPHONE SCRIPT – SEAL COAT GRADE QUESTIONS FOR DISTRICTS

Project 0-6496: Quantifying the Effects in Order to Optimize
The Use of Grade 3 and Grade 4 Seal Coats

Telephone Script - Seal Coat Grade Questions for Districts

(TASK 2: Evaluation of Reasons Districts Use Various Grades of Seal Coats)

Confirmation and Clarification of Aggregate Grades and Mineral Types Used Recently

1. Your 2010 district seal project plans specify Type ___ Grade ___ (and Type ___ Grade ___) seal coat aggregates for this summer. Approximately how long has your district been specifying this type and grade (or these types and grades) of seal coat aggregate?

2. At this point do you know the contractor's aggregate source(s) and mineral type(s) for this summer's seals?

   Producer/Quarry Name: ______________________
   Mineral Type:
   a. Crushed limestone
   b. Crushed siliceous gravel
   c. Crushed sandstone
   d. Lightweight
   e. Other _________________

3. What was the source and mineral type of aggregate used last summer?

   Producer/Quarry Name: ______________________
   Mineral Type:
   a. Crushed limestone
   b. Crushed siliceous gravel
   c. Crushed sandstone
   d. Lightweight
   e. Other _________________

4. Have other seal coat types and grades been specified for your district seal projects over the last 8 to 10 years? If so, why were changes made? Have mineral types other than those used last summer been used in your district over the last 8 to 10 years?

5. Has your district used Grade 5 seal coats in the past for in-house or contract seal coats? If so, for what purpose(s) was the Grade 5 used? In your opinion did it turn out to be a good choice from a long term cost effectiveness perspective?

6. Has your district tried either of the single-size grades, Grade 3S or Grade 4S? If so, how have they performed in comparison to standard Grade 3 or Grade 4?

Additional question for districts whose plans allowed optional asphalt types:

7. If optional asphalt types were allowed on the plans last summer, which did the contractor choose to use? Did his choice work out well from your view of construction and seal coat performance so far?

(Rev. February 11, 2010)

Grade Selection Choice Questions

If the district's 2009 or 2010 seal coat plans specified only one type and grade of seal coat aggregate:

1. Why was this single grade selected? Why was this type selected?
   a. Economic considerations (Yes/No – and comments)
   b. Simplicity in construction (Yes/No – and comments)
   c. Aggregate availability considerations (Yes/No – and comments)
   d. Performance considerations (Yes/No – and comments)
   e. Other reasons (Identify – and comments)

2. Looking back at your 2009 seals, were there roadways where you believe using a different aggregate grade might have performed better? If so, what were those conditions and what grade of aggregate would you have chosen instead of the one used?

3. If you have used this single grade for a number of years, under what roadway and traffic conditions has it performed the best, and under what conditions has it struggled to perform well?

If the district's 2009 or 2010 seal coat plans specified or allowed more than one type and/or grade of seal coat aggregate:

1. What are the factors you consider when deciding which aggregate grade (or type) to specify for a given roadway?
   a. AADT (Yes/No – and comments)
   b. % Trucks (Yes/No – and comments)
   c. Posted speed limit (Yes/No – and comments)
   d. Roadway geometric considerations (Identify – and comments)
   e. Level of pavement cracking (Yes/No – and comments)
   f. Level of pavement flushing (Yes/No – and comments)
   g. Level of rutting (Yes/No – and comments)
   h. Level of other pavement distresses (Yes/No – and comments)
   i. Other considerations? (Identify – and comments)

2. Are there roadway conditions and traffic levels where only one aggregate grade (i.e. Grade 3, Grade 4, or Grade 5) is appropriate to use based on your experience?

3. Are there other grades or types of aggregate that you would prefer to use in addition to or instead of those used the last two summers? If so, for what types of roadway situations?

Modified Gradation Questions

If the district's 2009 or 2010 seal coat plans specified a modified gradation:

1. How long has your district used this modified gradation?
2. What advantages are there to using this modified gradation?

If the district's 2009 or 2010 seal coat plans did ***not*** *specify a modified gradation*:

1. Has your district specified modified gradations in the past? If so, what was used and why was a change made to move away from it? In your opinion was performance of the modified gradation better than the standard gradation used now? If so, how?

Relative Performance Questions

1. Based on your experience in your area of the state, would you expect a Grade 3 seal coat to perform its function one or more years longer than a Grade 4 seal coat would have performed if placed on that same roadway? If so, how much longer?

2. In the same manner, would you expect a Grade 4 seal coat to perform its function longer than a Grade 5 seal coat would have performed if placed on that same roadway? If so, how much longer?

Noise Questions

1. Considering noise is a part of this study of seal coat. Is there a seal coat in your district that in your opinion is considerably louder than other seal coats of the same Grade of aggregate? Is there one that in your opinion is considerably quieter?

Test Section Experience Questions

1. Has your district constructed a seal coat test section in recent years that included comparing aggregate grades or types?

   If yes:

   When and where was it placed?
   What were the variables?
   What types of data have been gathered on it to date?
   About how long are individual sections?
   Who would be the best contact in your district to learn more about it?

2. Would your district be willing to consider building a seal coat test section as part of this research project? If yes, might it be possible to arrange this through a change order to next summer's seal project?

APPENDIX B – SURVEY RESPONSE SUMMARY

The CD-ROM enclosed in a jacket inside the cover of this report contains a large table summarizing all district responses.

APPENDIX C – NOISE TEST PLAN

The noise testing plan for existing pavement sections is necessarily an observational study. Unlike a designed experiment, where treatments (combinations of variables thought to affect the measured response) are independently applied to the experimental units (pavement sections), an observational study cannot "preset" the values of the various factors for a given segment—the experimental units here are essentially "come as you are." Under these circumstances, important additional factors/variables affecting the response may be ignored or left uncontrolled simply because they cannot be known (so-called "unknown unknowns"). Failure to control factors that can potentially affect the response often results in inflated experimental error; i.e., the variation between nominally identical road segments may be disproportionately large due to the effects of unsuspected variables/factors.

As such, proper implementation of a testing plan requires identification of testing objectives, test variables, and consideration of the level of sensitivity desired in findings. These must be weighed against the resources available for the testing exercise.

<u>Noise Testing Objectives.</u> Knowledge objectives of the noise test plan are delineated on page 13 in the project agreement. These objectives are listed below.

1. Determine extent that noise levels change over normal seal coat service lives.
2. Determine degree of inherent difference in noise levels of Grade 3 and Grade 4 seal coats.
3. Determine if aggregate mineralogy has an effect on seal coat noise level.
4. Determine effect of aggregate gradation, particularly single sizing, on noise level.
5. Determine effect of aggregate spread rate on noise level.
6. Determine effect of aggregate shape on noise level.

<u>Test Variables.</u> As with any observational study of construction-related activity, a myriad of potential variables exist. Since virtually no seal coat noise testing has been performed prior to this research project, seal coat characteristics thought to be significant variables have not been validated. The opinions of experienced TxDOT personnel gathered during Task 2 allowed development of the following list of seal coat factors with good probability to affect seal coat noise levels. There are a number of additional factors that may also have an effect on noise levels, including construction techniques, but the ones listed below are considered more likely to have considerable impact.

1. Aggregate top size
2. Aggregate gradation
3. Mineral type
4. Coating
5. Age of seal coat
6. Aggregate spread rate
7. Surface unevenness
8. Percent embedment
9. Aggregate shape

Table 1 shows the prospective test variables and lists ranges of conditions suggested to fully examine the seal coat noise question. If all possible combinations of the different test variables were to be investigated in a full factorial arrangement, this would entail data collection on 4800 sets of conditions.

Considering the limited testing resources, as described further below, the test plan to be developed cannot practically address this broad study area with certainty in findings. Therefore, a test plan is proposed focused on providing TxDOT with sorely needed, basic seal coat noise test results that largely, if not completely, address the stated objectives of the approved project agreement. It is reasonable to expect these results to provide an approximate quantification of inherent underlying measurement variability between qualitatively similar road segments, and indicate the magnitude of the effects of a small subset of potential test variables thereon. Primary emphasis of the plan focuses on variation in noise level due to the combination of effects of aggregate top size and gradation, mineral type, age, and selection of aggregate spread rate. Study of aggregate spread rate will require construction of a set of end-to-end test sections. It is proposed for age to be characterized in terms of accumulated vehicle passes.

Sensitivity Level Consideration. Most inferential studies proceed from consideration of both:

1. The smallest measurement difference of real concern; i.e., the required sensitivity level.
2. A prior estimate of the expected experimental error; i.e., the inherent measurement variability expected to be encountered among otherwise identical experimental units.

Unfortunately, prior seal coat noise test data are virtually nonexistent, making knowledge about expected magnitude of experimental error virtually nonexistent as well. A quantitative assessment of the measurement variability between qualitatively similar road segments is therefore recommended. This is especially pertinent in a groundbreaking observational study, where the possible increased variability among pavement sections, arising from possibly unknown and uncontrolled factors, necessarily impairs the level of sensitivity that can be achieved in findings.

Resources Available. The project agreement proposes noise testing as a joint TxDOT and TTI effort. Meetings with TxDOT noise testing personnel determined that TxDOT and TTI personnel time and equipment availability will allow up to 50 noise tests to be included in this study. These locations are to include both existing pavements and test sections to be constructed.

Proposed Noise Testing Plan. Table 2 is the proposed noise testing plan, as developed jointly between TTI and Mr. John Wirth, TxDOT's leading noise testing expert and a project advisor on this study. TTI and Mr. Wirth recommend this plan as the means of maximizing useful information obtainable within the resources available. It is believed that this plan will largely meet the previously stated noise testing project objectives. With the approval of the PMC, the research team will make contacts with districts in attempts to line up the test sections shown on the plan. Existing seal coat locations will be identified through the study of historical construction plans and records. The geographical distribution of locations mentioned in Table 2 is further described in Table 3.

Noise Testing Protocol. Noise testing will be performed using TxDOT OBSI noise testing equipment and vehicle. John Wirth has expressed an interest in participating in all roadway noise testing. TTI will participate in all noise testing except when Mr. Wirth needs to train other TxDOT personnel.

The test procedure used for noise testing will be the one that TxDOT normally used, i.e., AASHTO Designation: TP 76-09, “Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method.” A minimum of three sampling locations will be tested per test site unless an uncommonly short test section precludes that possibility. Each sampling location will be tested three times. The average of all test results will represent the noise level from a given test site. Test results will be in terms of Overall Sound Intensity Level, measured in dB(A).

Table C1. Major Variables for Full Experimental Design.

Seal Coat Characteristic	**Conditions Reasonable to Include in a Full Factorial Experiment**					
Aggregate Top Size and Gradation	3	3S	4	4S	5	
Mineral Type	Limestone	Siliceous	Lightweight	Blend	Sandstone	Igneous
Coating	Plain	Precoated				
Age	Initial	3-6 months	1 year	3 years	6 years	
Aggregate Spread Rate	Normal	100% coverage				
Surface Unevenness	Rough	Smooth				
Initial Embedment	~35%	~50%				
Aggregate Shape	AIMs #1 level	AIMs #2 level				

Table C2. Noise Testing Plan.

Noise Testing Objectives	Aggregate	Probable Aggregate Sources	Probable District Roadway Locations	Existing Pavement or Side-by-Side Test Section	Desired Roadway Characteristics	Testing Year	Desired Individual Test Sections			Age for OBSI Noise Testing				
										Within 2 weeks	3 to 6 Months	1 year	3-4 years	6-8 years
1. Determine degree of inherent difference in noise levels of Grade 3 and Grade 4 seal coats in Texas. 2. Determine affect of aggregate mineralogy on seal coat noise level. 3. Determine extent that noise levels change over normal seal coat service lives.	Limestone - Grade 3	CSA, Colorado Materials, Vulcan (Bwd)	San Angelo, San Antonio, Yoakum, Brownwood	Existing	Condition: No history of flushing and good IRI. Traffic Volume: High to moderately high. Posted Speed: 60 mph or higher. Design: No curb, limited guard rail and median barriers.	2010 and 2011						3 sites (summer of 2009 seals)	1 site* (summer of 2006 and 2007 seals)	1 site* (summer of 2002 thru 2004 seals)
	Limestone - Grade 4	Vulcan (Bwd), Hanson (Servtex), Jones Bros., Colorado Materials, Vulcan (Weatherford)	Brownwood, Austin, Odessa, Yoakum, Bryan, Fort Worth	Existing	As above.							As above.	As above.	As above.
	Gravel - Grade 3	Capitol Aggr. (Hoban)	Odessa	Existing	As above.							As above.	As above.	As above.
	Gravel - Grade 4	Capitol Aggr. (Hoban), J. Lee Milligan	Lubbock, Odessa	Existing	As above.							As above.	As above.	As above.
	Lightweight - Grade 3	TXI	Dallas, Waco, Lufkin, Tyler, Bryan	Existing	As above.							As above.	As above.	As above.
	Lightweight - Grade 4	TXI	Waco, Bryan, Lufkin	Existing	As above.							As above.	As above.	As above.
4. Determine early age noise levels characteristic of Grade 3, Grade 4, and Grade 5 seal coats.	Limestone	Central Texas limestone	San Antonio	Test Sections	Condition: Considerable sealed cracking and uniformity throughout test length Traffic Volume: Low to Moderate Posted Speed: 60 or higher Location: Rural preferred Design: No curb, limited guard rail and median barriers. Length: 1.5 miles minimum total length (minimum of 0.5 miles/test section). Prefer minimum of 1.0 mile section lengths.	2010 and 2011	Grade 3	Grade 4	Grade 5	X	X	X	Option**	Option**
	Lightweight or Contractor's other choice	TXI	Lufkin	Test Sections	As above.		Grade 3	Grade 4	Grade 5	X	X	X	Option**	Option**
5. Determine affect of rock spread rate on noise.	Grade 3	Central Texas limestone	Yoakum	Test Sections	Condition: Considerable sealed cracking and uniformity throughout test length Traffic Volume: Low to Moderate Posted Speed: 60 or higher Location: Rural preferred Design: No curb, limited guard rail and median barriers. Length: 2.0 miles minimum total length (minimum of 1.0 miles/test section).		Grade 3 normal rock rate	Grade 3 heavier rock rate (adjust AC rate as needed)		X	X	X	Option**	Option**
	Grade 4	Central Texas limestone	Brownwood, Yoakum	Test Sections	As above.		Grade 4 normal rock rate	Grade 4 heavier rock rate (adjust AC rate as needed)		X	X	X	Option**	Option**
6. Determine affect of single sizing aggregate on noise.	Grade 3 and 3S and/or Grade 4 and 4S	Oklahoma sandstone, North Texas limestone	Laredo	Test Sections	Condition: Considerable sealed cracking and uniformity throughout test length Traffic Volume: Low to Moderate Posted Speed: 60 or higher Location: Rural preferred Design: No curb, limited guard rail and median barriers. Length: 2.0 miles minimum total length (minimum of 1.0 miles/test section).	2010 or 2011	Grade 3 or Grade 4	Grade 3S or Grade 4S		X	X	Option**	Option**	Option**
7. Document noise level of seal coats reported as particularly loud or quiet by districts during survey. Test up to six locations.	Any	Any	Statewide	Existing	Particularly loud or quiet seal coated pavements.	2010 and 2011				Current Pavement Age				

Table C3. Geographical Distribution of Tentative Noise Test Locations.

	Grade 3			Grade 4			Gr 3		Gr 4		Gr 5		Grade 3		Grade 4		Grade 3		Grade 4		Grade 3s		Grade 4s	
	LS	GR	LTWT	LS	GR	LTWT	LS (CT)	LTWT/Oth	LS (CT)	LTWT/Oth	LS (CT)	LTWT/Oth	LS Norr	LS Hvy	LS Norr	LS Hvy	LS (NT)	SS (OK	LS (NT)	SS (OK	LS (NT)	SS (OK	LS (NT)	SS (OK)
Austin				1																				
Brownwood	1			1											3	3								
Bryan			1	1		1																		
Dallas			1																					
Fort Worth				1																				
Laredo																	4	4	4	4	4	4	4	4
Lubbock					1																			
Lufkin			1			1		2		2		2												
Odessa		1		1	1																			
San Angelo	1																							
San Antonio	1			1			2		2		2													
Tyler			1																					
Waco			1			1																		
Yoakum	1			1									3	3	3	3								

APPENDIX D – SOUND FREQUENCY DATA

Figure D1 displays the noise frequency range as determined on FM 1704. All noise frequency ranges are graphically provided in the CD-ROM enclosed in a jacket inside the cover of this report.

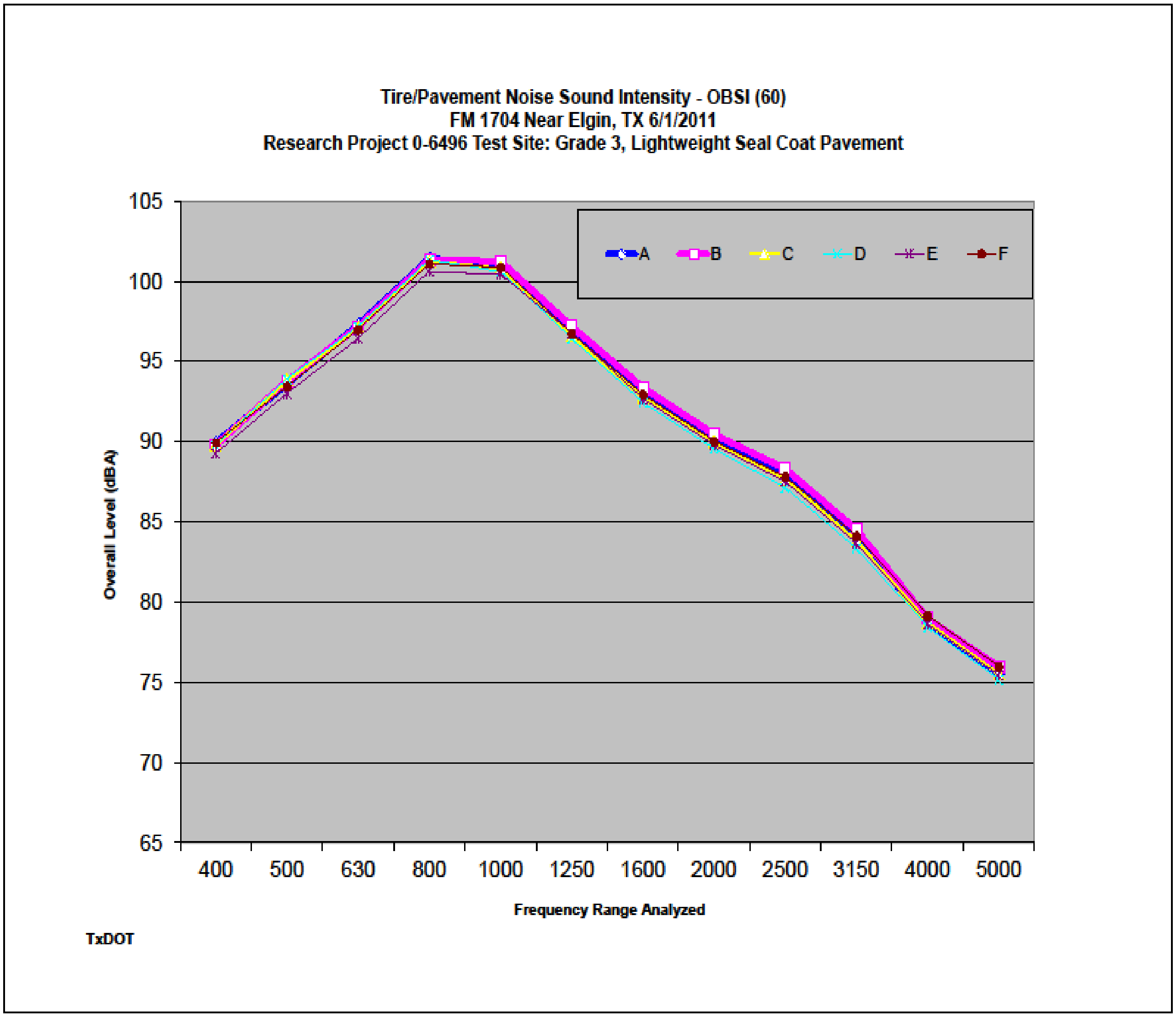

Figure D1. FM 1704 Sound Frequency Range.

APPENDIX E – NOISE TEST LOCATION PHOTOGRAPHY

The noise test location on FM 1704 is seen in Figure E1. Figure E2 is a close up photograph of the wheel path condition at the same location. Similar photography of all roadways included in OBSI noise testing is provided in the CD-ROM enclosed in a jacket inside the cover of this report. Photography is courtesy of John Wirth, TxDOT.

Figure E1. FM 1704 Roadway Noise Test Location.

Figure E2. FM 1704 Wheel Path.