

Technical Report Documentation Page

|   |  |  |   |   |           |
|---|--|--|---|---|-----------|
| 1. Report No.<br>TX -97/0-1787-3  |  | 2. Government Accession No.                          |   | 3. Recipient's Catalog No.                          |           |
| 4. Title and Subtitle<br>Statewide Seal Coat Constructability Review  |  |  |   | 5. Report Date<br>March 2000                        |           |
|   |  |  |   | 6. Performing Organization Code<br>TECH             |           |
| 7. Author(s)<br>Sanjaya Senadheera, Douglas Gransberg, Tolga Kologlu  |  |  |   | 8. Performing Organization Report No.<br>1787-3     |           |
| 9. Performing Organization Name and Address<br>Texas Tech University<br>Civil Engineering<br>Box 43107<br>Lubbock, Texas 79409-3107   |  |  |   | 10. Work Unit No. (TRAIS)                           |           |
|   |  |  |   | 11. Contract or Grant No.<br>Project 0-1787         |           |
| 12. Sponsoring Agency Name and Address<br>Texas Department of Transportation<br>Research and Technology<br>P. O. Box 5080<br>Austin, TX 78763-5080  |  |  |   | 13. Type of Report and Period Cover<br>Final Report |           |
|   |  |  |   | 14. Sponsoring Agency Code                          |           |
| 15. Supplementary Notes<br>Study conducted in cooperation with the Texas Department of Transportation.<br>Research Project Title: "Statewide Seal Coat Constructability Review"   |  |  |   |   |           |
| 16. Abstract<br>The focus of this project is to conduct a formal constructability review of the construction and maintenance practices with respect to seal coat projects. The project's objective is to improve state-wide seal coat quality by identifying best practices. The researchers surveyed all 25 TxDOT districts to identify those practices that consistently produce successful seal coat projects throughout the State. Preparation and implementation of a comprehensive training plan on seal coat construction practices for use throughout the State was also done. Deliverables include a draft seal coat construction and maintenance specification, a final report, and district evaluations with individualized training to permit full implementation. This report identifies the changes recommended to the existing seal coat specifications based on the findings of this study. |  |  |   |   |           |
| 17. Key Words<br>constructability, seal coat, construction practices  |  |  | 18. Distribution Statement<br>No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161 |   |           |
| 19. Security Classif. (of this report)<br>Unclassified  |  | 20. Security Classif. (of this page)<br>Unclassified |   | 21. No. of Pages<br>110                             | 22. Price |

# **Statewide Seal Coat Constructability Review**

By

Sanjaya Senadheera, Ph.D  
Research Supervisor

Douglas D. Gransberg, Ph.D., P.E., C.C.E.  
Co-Principal Investigator

Tolga Kologlu  
Research Assistant

Final Report  
Project Number: 0-1787  
Report Number: TX-97/0-1787-3

Research Sponsor:  
Texas Department of Transportation

Texas Tech University  
Department of Civil Engineering  
Box 41023  
Lubbock, Texas 79409-1023

March, 2000

This page replaces an intentionally blank page in the original.

-- CTR Library Digitization Team

## IMPLEMENTATION STATEMENT

The practice of seal coating existing pavement surfaces is considered more as an art than a science. Good seal coats are a result of sound technical practice as well as the good judgment of field personnel during construction. Traditionally, TxDOT districts have conducted seal coat operations by relying heavily on the experience of their personnel. However, the economic prosperity enjoyed by the country has resulted in a higher rate of turnover among experienced seal coat personnel and it has become crucial for the Department to develop ways to educate new personnel on the intricacies of seal coat construction. Two important products developed in this research are district-customized seal coat workshops and an updated seal coat specification. The researchers have already conducted the seal coat workshops in each district, disseminating information gathered during the structured district interviews and field evaluations. The current seal coat specifications were developed a long time ago, and it was recognized that recent advances in the equipment technology and materials needs to be incorporated in the specifications. The updated seal coat specification published in Product Report TX-97/0-1787-P needs to be reviewed by the specification committee prior to its full implementation. This research project was extended into a third year to include two additional tasks. These tasks were for the development of a seal coat field guide and an aggregate-binder compatibility matrix. These two tasks will be completed by August 2000, and the findings will be presented in a manner that facilitates quick implementation.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

## **AUTHOR'S DISCLAIMER**

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view of policies of the Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

## **PATENT DISCLAIMER**

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

## **ENGINEERING DISCLAIMER**

Not intended for construction, bidding, or permit purposes.

## **TRADE NAMES AND MANUFACTURERS' NAMES**

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

## TABLE OF CONTENTS

|   |    |
|---|----|
| TABLE OF CONTENTS   | i  |
| LIST OF FIGURES   | ii |
| LIST OF TABLES  | iv |
| CHAPTER 1: PROJECT ABSTRACT                               | 1  |
| CHAPTER 2: PROJECT METHODOLOGY                            | 2  |
| CHAPTER 3: LITERATURE REVIEW                              | 5  |
| Seal Coat Design  | 5  |
| Use of Lightweight Aggregates                             | 12 |
| Constructability  | 13 |
| CHAPTER 4: STRUCTURED INTERVIEW                           | 15 |
| General Information on District Seal Coat Program         | 15 |
| Design  | 19 |
| Contract  | 24 |
| Materials   | 25 |
| Equipment   | 30 |
| Construction  | 32 |
| Quality Control   | 35 |
| Performance   | 37 |
| Continuous Improvement                                    | 39 |
| District Test Sections                                    | 40 |
| CHAPTER 5: SEAL COAT EQUIPMENT                            | 43 |
| Equipment Features  | 43 |
| Equipment Requirements                                    | 48 |
| CHAPTER 6: ANALYSIS OF THE STRUCTURED INTERVIEW DATA      | 58 |
| CHAPTER 7: CONCLUSION                                     | 68 |
| BIBLIOGRAPHY  | 70 |
| APPENDIX A: EXAMPLE TABLES TO DETERMINE SEAL COAT BINDERS | 73 |
| APPENDIX B: STRUCTURED INTERVIEW QUESTIONS                | 77 |
| APPENDIX C: DATA ON INDIVIDUAL SEAL COAT TEST SECTIONS    | 80 |
| APPENDIX D: ANALYSIS OF DISTRICT TEST SECTION DATA        | 83 |
| APPENDIX E: POWERPOINT SLIDES                             | 88 |

## LIST OF FIGURES

|  |    |
|--|----|
| Figure 3.1. Nomograph to Determine Asphalt Cement Application Rate in Seal Coats and One-Course Surface Treatments     | 6  |
| Figure 4.1. Percent Lane Miles with Seal Coat as Wearing Surface   | 15 |
| Figure 4.2. Percent Highway Lane Miles with Surface Treatments Directly over Base                                      | 16 |
| Figure 4.3. Planned Seal Coat Performance Cycle  | 16 |
| Figure 4.4. Districts Performing In-House Seals  | 17 |
| Figure 4.5. District Experience with In-House Seals  | 18 |
| Figure 4.6. Districts' Remarks on Contract Seal Coat Performance   | 18 |
| Figure 4.7. Common Contract Seal Problems  | 19 |
| Figure 4.8. Seal Coat Contract Letting Period  | 20 |
| Figure 4.9. Current Design Method  | 21 |
| Figure 4.10. Management of Seal Coat Design in Districts   | 22 |
| Figure 4.11. Period of Time Current Design Method has been in Use  | 22 |
| Figure 4.12. Binder Rate Distribution Across the Lane  | 23 |
| Figure 4.13. Level of Competition  | 24 |
| Figure 4.14. Aggregate Gradations Use  | 25 |
| Figure 4.15. Use of Pre-Coated Aggregates  | 26 |
| Figure 4.16. Availability of Aggregate Sources at Close Proximity  | 26 |
| Figure 4.17. No. of Different Binder Types Used  | 27 |
| Figure 4.18. Use of Asphalt Cement as Binder   | 28 |
| Figure 4.19. Use of Emulsified Asphalt as Binder   | 29 |
| Figure 4.20. Percent Use of Different Binder Types in the State  | 30 |
| Figure 4.21. Specification of Roller Types   | 31 |
| Figure 4.22. Start of Seal Coat Season   | 32 |
| Figure 4.23. End of Seal Coat Season   | 33 |
| Figure 4.24. Required Roller Type and Number   | 34 |
| Figure 4.25. Roller Passes Specified by Districts  | 35 |
| Figure 4.26. Inspection Team Size  | 35 |
| Figure 4.27. Stockpile Testing   | 36 |
| Figure 4.28. Common Distress Types   | 37 |
| Figure 4.29. Predominant Distress Type   | 38 |
| Figure 4.30. Methods Used to Rectify Seal Coat Problems  | 38 |
| Figure 4.31. Formal Post-Contract inspection   | 39 |
| Figure 4.32. Partnering of Seal Coat Projects  | 40 |
| Figure 5.1. Typical Seal Coat Roadway Geometry   | 48 |
| Figure 5.2. Staggered Pattern and Coverage for Three Medium Rollers  | 53 |
| Figure 5.3. Diagonal Pattern and Coverage with Four Medium Rollers   | 54 |
| Figure 5.4. Layout of Typical Seal Coat Shot   | 56 |
| Figure 6.1. District Satisfaction of its own Seal Coat Quality   | 59 |
| Figure 6.2. District Self-Evaluation of Quality vs. Extent of District Seal Coat Program                               | 60 |
| Figure 6.3. District Self-Evaluation of Quality vs. Use of Seal Coat as a Planned Preventive maintenance (PM) Activity | 60 |
| Figure 6.4. District Self-Evaluation of Quality vs. In-House Seal Coat Activity Level                                  | 61 |
| Figure 6.5. District Self-Evaluation of Quality vs. Design Method  | 61 |



|  |    |
|--|----|
| Figure 6.6. District Self-Evaluation of Quality vs. management of Seal Coat Design                 | 62 |
| Figure 6.7. District Self-Evaluation of Quality vs. Variable Binder rate Usage                     | 62 |
| Figure 6.8. Predominant Distress Type vs. Variable Binder Rate Usage                               | 63 |
| Figure 6.9. District Self-Evaluation of Quality vs. Level of Contractor Competition                | 63 |
| Figure 6.10. District Self-Evaluation of Quality vs. Number of Different<br>Binder Types Used      | 64 |
| Figure 6.11. District Self-Evaluation of Quality vs. No. of Different Aggregate<br>Gradations Used | 64 |
| Figure 6.12. District Self-Evaluation of Quality vs. Inspection Crew Size                          | 65 |
| Figure 6.13. District Self-Evaluation of Quality vs. Implementation of Post-Contract<br>Evaluation | 65 |
| Figure 6.14. District Self-Evaluation of Quality vs. Partnering                                    | 66 |
| Figure D.1. AC Rate in Wheel Path vs. ADT (Grade 4)  | 85 |
| Figure D.2. Emulsion Rate in Wheel Path vs. ADT (Grade 4)  | 85 |
| Figure D.3. AC Rate in Wheel Path vs. ADT (Grade 3)  | 86 |
| Figure D.4. Emulsion Rate in Wheel Path vs. ADT (Grade 3)  | 86 |
| Figure D.5. Binder Rate in Wheel Path vs. Aggregate Rate for AC15-5TR                              | 87 |

## LIST OF TABLES

|   |    |
|---|----|
| Table 3.1. Effect of Aggregate Gradation and Aggregate Treatment on Retention   | 8  |
| Table 3.2. Asphalt Application Rate Correction for Traffic  | 10 |
| Table 3.3. Asphalt Application Rate Correction for Existing Pavement Surface Conditions   | 10 |
| Table 3.4. Asphalt Application Rate Correction Factor for Existing Pavement Surface Condition as Recommended by The Asphalt Institute | 11 |
| Table 4.1. Percent Use of Different Binder Combinations by Each District  | 30 |
| Table 4.2. Number of Test Sections in Each District   | 41 |
| Table 6.1. Summary of the Relationship between Seal Coat Performance and Parameters Relating to Seal Coat Operation                   | 67 |
| Table A.1. Binder Base Rates  | 73 |
| Table A.2. Binder Rate Adjustment Factors for Traffic Level   | 73 |
| Table A.3. Alternate Binder Rate Adjustment factors for Traffic Level   | 73 |
| Table A.4. Binder Rate Adjustment for Truck Traffic   | 74 |
| Table A.5. Binder Rate Adjustment Factors for Truck Traffic   | 74 |
| Table A.6. Binder Rate Adjustment Factors for Pavement Condition  | 74 |
| Table A.7. Alternate Binder Rate Adjustment Factors for Pavement Condition on wheel path  | 74 |
| Table A.8. Alternate Binder Rate Adjustment Factors for Pavement Texture  | 75 |
| Table A.9. Binder Rate Adjustment Factors for Aggregate Gradation   | 75 |
| Table A.10. Binder Rate Adjustment Factors Based on Type of Rock  | 75 |
| Table A.11. Suggested Nozzle Configurations   | 76 |
| Table A.12. Lane Traffic Distribution Factors   | 76 |
| Table A.13. Typical Truck Percentages   | 76 |
| Table D.1. Binder Rates for Grade 4 Aggregate   | 83 |
| Table D.2. Binder Rates for Grade 3 Aggregate   | 84 |
| Table D.3. Average Rates for Grade 4 Aggregate  | 84 |
| Table D.4. Average Rates for Grade 3 Aggregate  | 84 |

## **CHAPTER 1. PROJECT ABSTRACT**

This research project conducted a formal constructability review of TxDOT seal coat practices. The essence of any constructability study is the identification of best practices and it is being widely implemented by the federal government, state DOTs and other public agencies. Areas for constructability review in seal coat construction include project selection, construction and maintenance processes. This project comprised of four phases. In Phase I, a comprehensive literature review on the subject was completed, and a structured interview process was conducted by visiting each district to determine their current seal coat practices. Each district was specifically asked to identify areas that need improvement. District were also asked to identify approximately five recently completed seal coat projects that are representative of the district seal coat practices. Data from these test projects were analyzed to identify factors that would possibly influence seal coat quality. Phase II involved the analysis of data from district interviews and test projects. This analysis was conducted with the focus of preparing a district training package. Phase III involved the development of training packages tailored to each district. Each package included an evaluation of district strengths as well as areas that require further improvement. In Phase IV, training workshops were conducted at each district. A draft seal coat specification was developed at the completion of all district training workshops and this was published in a separate interim report. Two additional tasks were added to the original work schedule. These tasks involved the development of (1) a seal coat field guide and (2) an aggregate-binder compatibility matrix. These two tasks are currently being conducted and their findings will be published at the completion of the research project in August 2000.

## CHAPTER 2. PROJECT METHODOLOGY

Many people involved in seal coat work consider it to be an art as much as it is a science. Such statements are a testament to the strong influence construction practices have on seal coat performance. Therefore, the development of a high quality seal coat program needs to begin and end with district construction and maintenance personnel who are directly involved with the process. A large body of research has already been done on seal coat design. TxDOT research project 0-1367 produced a performance-based seal coat specification (Elmore, 1995), but a specification alone cannot ensure consistent quality in a process. Field personnel who must both apply and enforce the terms of the specification must be trained to recognize good and bad construction procedures. More importantly, they must fully understand the capabilities of the equipment used in industry to complete seal coat projects. Such small observations as noticing a clogged spray bar nozzle and requiring the contractor to remedy the problem on the spot can make the difference between a successful seal coat and one that fails due to non-uniform application rates. Thus, the primary focus of this project was to identify those construction practices which consistently produce a good seal coat, and create a training program to implement throughout the Department which will propagate this collection of technical and anecdotal information to the TxDOT personnel who are responsible for the supervision, inspection, and acceptance of seal coat projects.

The methodology used for this purpose was a formal constructability review of the seal coat construction process. Constructability is a term of art which has come to encompass a detailed review of design drawings, specifications, and construction processes by a highly experienced construction engineer before a project is put out for bids. It is defined as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII, 1986). The purpose of the constructability review is to identify the following five items:

- Design errors, both material selection and dimensional
- Ambiguous specifications
- Project features which will be difficult or exceedingly costly to construct as designed
- Project features which exceed the capability of industry to properly build
- Project features which are difficult to interpret and will be hard to accurately bid

In 1994, The U.S. Army Corps of Engineers instituted a program of conducting formal constructability reviews on all projects before they are released for bids. This program has been extremely successful. While no effort has been made to capture and quantify the savings attributed to this program, virtually every review catches some factor that if it were left unchanged would have necessitated a construction change order during the project. This concept is easily applied to seal coat. Essentially, it is a review of the capability of industry to determine if the required level of tools, methods, techniques, and technology are available to permit an average construction contractor to build the project feature in question to the level of quality required by the contract. The constructability review also entails an evaluation of the ability of industry to understand the required level of quality and accurately estimate the cost of providing it. Thus, the level of risk due to misinterpretation that is inherent to a set of specifications or a project feature is reduced to a minimum. When a formal constructability review is combined

with a thorough economic analysis which springs from a current cost estimate, the final design as depicted by the plans and specifications is greatly enhanced, and the project is less susceptible to cost and time growth from change orders and claims. The benefits of a constructability review are (Gibson et al, 1996):

- Reduced cost
- Shorter Schedules
- Improved quality
- Enhanced safety
- Better control of risk
- Fewer change orders
- Fewer claims

The researchers picked apart piece by piece, the seal coat process from planning to construction completion looking for those portions of the process which are inherently variable and difficult to replicate in the field. The literature shows that seal coat performance is a function of the following factors (Elmore, 1995):

- Quality of design
- Quality and consistency of construction
- Quality and consistency of materials
- Environmental conditions
- Traffic conditions

The study focused primarily on construction and materials. These are the two factors that show the most promise for control through better training of field personnel. The quality of a seal coat project's performance is influenced by at least eight construction process variables (Elmore, 1995):

- Longitudinal and transverse variation in material application rates
- Uniform distribution of binder
- Time between applying binder and aggregate application
- Material variation
- Compaction method and duration
- Embedment of aggregate
- Climatic conditions prior to, during and after construction
- Interval between completion and opening to traffic

The project comprised of four phases. In Phase I, a comprehensive literature review on the subject was completed, and a structured interview process was conducted by visiting each district to determine their current seal coat practices. Each district was specifically asked to identify areas that need improvement. District were also asked to identify approximately five recently completed seal coat projects that are representative of the district seal coat practices. Data from these test projects were analyzed to identify factors that would possibly influence seal coat quality. Phase II involved the analysis of data from district interviews and test projects. This

analysis was conducted with the focus of preparing a district training package. Phase III involved the development of training packages tailored to each district. Each package included an evaluation of district strengths as well as areas that require further improvement. In Phase IV, training workshops were conducted at each district. A draft seal coat specification was developed at the completion of all district training workshops and this was published in a separate interim report. Two additional tasks were added to the original work schedule. These tasks involved the development of (1) a seal coat field guide and (2) an aggregate-binder compatibility matrix. These two tasks are currently being conducted and their findings will be published at the completion of the research project in August 2000.

## CHAPTER 3. LITERATURE REVIEW

Seal coats (or chip seals or surface treatments) have more than a 50-year recorded history in the United States. The first uses were limited to surface treatments as wearing courses in the construction of low volume roads. Since then, maintenance seal coats have become increasingly popular due to a number of factors including increased maintenance needs of existing pavements and the lack of sufficient funds earmarked for maintenance.

In 1960, McLeod provided definitions for surface treatments and seal coats. He defined a surface treatment as “a single application of asphalt binder, followed by a single application of cover aggregate, both placed on a prepared gravel or crushed stone base”. This definition is in line with what is currently being used by TxDOT. A seal coat is identified as a preventive maintenance (PM) activity. NCHRP defined preventive maintenance as “ a program strategy intended to arrest light deterioration, retard progressive failures, and reduce the need for routine maintenance and service activities” (NCHRP, 1989). On the other hand, routine maintenance was defined as “a program to keep pavements... in good condition by repairing defects as they occur”. As a PM activity, seal coats may provide a number of enhancements to the pavement performance including those listed below. The planned preventive maintenance activities are not expected to enhance the structural capacity of the pavement.

- Sealing of the pavement to moisture
- Enrichment of the surface
- Provide or restore adequate skid resistance
- Improve ride quality
- Preserve existing structural strength
- Improvement in visibility for night driving

### Seal Coat Design

The very early practitioners of seal coats appear to have used a purely empirical approach to design. Sealing a pavement was considered then, as it is now in many circles, an art. The design of a seal coat involves the calculation of correct quantities of a bituminous binder and a cover aggregate to be applied over a unit area of the pavement. Several design approaches outlined in available literature are briefly described below.

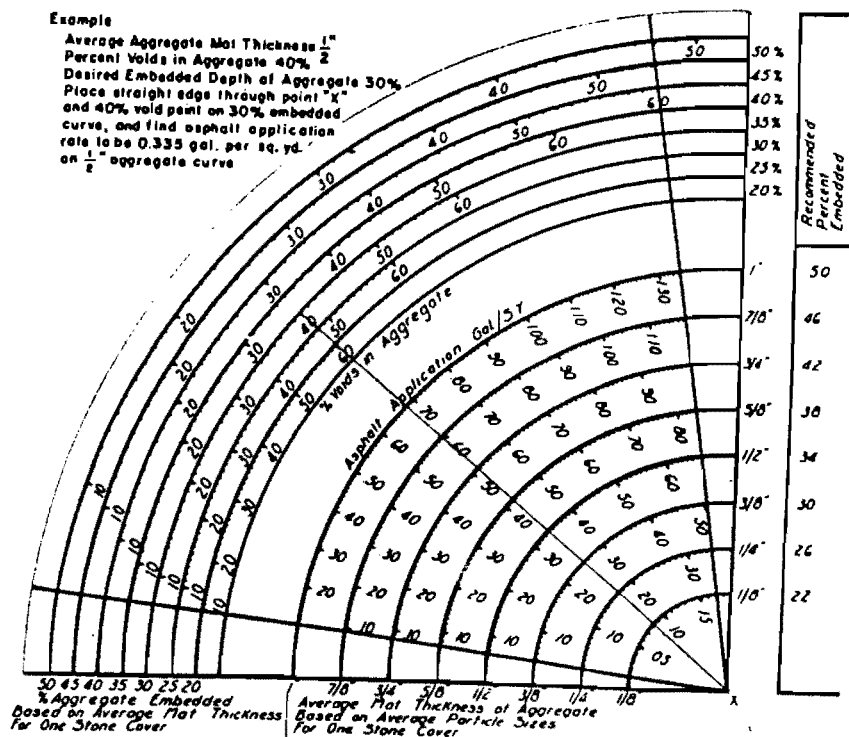
#### *Hanson Method*

The first recorded effort at developing a design procedure for seal coats appear to be made by Hanson (1934-1935) in New Zealand. His design method was developed primarily for liquid asphalt, particularly cutback asphalt, and was based on the average least dimension (ALD) of the cover aggregate spread on the pavement. Hanson calculated ALD by manually measuring the size of all aggregate particles in a representative sample to obtain the value for ALD that represents the thickness of rolled cover aggregate layer. He observed that when cover aggregate is dropped from a chip spreader on to a bituminous binder, the voids between aggregate particles is approximately 50 percent. He theorized that when it is rolled, this value is reduced to 30 percent and it further reduces to 20 percent when the cover aggregate is compacted by repeated

action of traffic. Hanson's design method involved the calculation of bituminous binder and aggregate spread rates to be applied to fill a certain percentage of the voids between aggregate particles. Hanson specified the percentage of the void space to be filled by residual binder to be between 60 and 75 percent depending on the type of aggregate and traffic level.

### Kearby Method

One of the first efforts at designing seal coat material application rates in the United States was made by Jerome P. Kearby, then Senior Resident Engineer at Texas Highway Department (Kearby, 1953). He developed a method to determine the type and quantity of asphalt and aggregate rates for one-course surface treatments and seal coats. The nomograph he developed (Figure 3.1) provided an asphalt cement application rate in gallons per square yard for the input data of average mat thickness, percent aggregate embedded and percent voids in aggregate. The percent voids in aggregate correspond to the percent voids in a bulk loose volume of aggregate and not to the aggregate spread on a pavement. If liquid asphalt were to be used, he recommended that the rate of bituminous material application should be increased such that the residual asphalt content is equal to the asphalt content given by the design nomograph. In order to determine the aggregate spread rate, for most aggregates, and especially for aggregates containing flat and elongated particles, Kearby recommended the "Board Test" method where aggregate is spread over a one square-yard area.



**Figure 3.1.** Nomograph to Determine Asphalt Cement Application Rate in Seal Coats and One-Course Surface Treatments (Kearby, 1953).

In addition to the nomograph, Kearby recommended the use of a uniformly graded aggregate by outlining eight grades of aggregate based on gradation and associated average spread ratios.



Each gradation was based on three sieve sizes. He also recommended that combined flat and elongated particle content should not exceed ten percent of any aggregate gradation requirement. Flat particles were defined as those with thickness less than half the average width of particle and elongated particles were defined as those with length greater than twice the other minimum dimension. Kearby was quick to point out that “computations alone cannot produce satisfactory results and that certain existing field conditions require visual inspection and the use of judgment in the choice of quantities of asphalt and aggregate”. He suggested that when surface treatments are applied over existing hard-paved surfaces or tightly bonded hard base courses, the percentage of embedment should be increased for hard aggregates and reduced for soft aggregates. He also mentioned that some allowance should be made for highway traffic. It was suggested that for highways with high counts of heavy traffic, the percent embedment should be reduced along with using larger-sized aggregates and for those with low traffic, it should be increased with the use of medium-sized aggregates. However, Kearby did not recommend any numerical correction factors at the time. Kearby also elaborated on the following construction aspects of surface treatments and seal coats based on his experience at the Texas Highway Department.

- Seal coats had been used satisfactorily on both heavy-traffic primary highways and low-traffic farm roads, with the degree of success largely depending on the structural strength of the pavement rather than the surface treatment itself.
- Thickness of the surface treatment range from ¼ in. to 1 in. with the higher thickness being preferred. However, lighter treatments have, in general, proven satisfactory when the pavement has adequate structural capacity and drainage.
- In general, most specification requirements for aggregate gradation are very broad, resulting in considerable variations in particle shape and size as well as percent voids in the aggregate.
- It is better to err on the side of a slight deficiency of asphalt to avoid a fat, slick surface.
- Considerable excess of aggregate is often more detrimental than a slight shortage.
- Aggregate particles passing the #10 sieve acts as filler, thereby raising the level of asphalt appreciably and cannot be counted on as cover material for the riding surface.
- Suitable conditions for applying surface treatments are controlled by factors such as ambient, aggregate, and surface temperatures as well as general weather and surface conditions.
- Rolling with both flat wheel and pneumatic rollers is virtually essential.

During the same period, two researchers from the Texas Highway Department (Hank and Brown, 1949) published a paper on their aggregate retention studies on seal coats. They conducted tests to determine the aggregate retention under a variety of conditions including source of asphalt cement, penetration grade of asphalt, number of roller passes, binder type (AC vs. cutback), aggregate gradation and binder application temperature. The authors concluded that aggregate retention was not significantly different in asphalt cements picked from five different sources commonly used by the Texas Highway Department at the time. A commentary made in the early 1950’s by the authors on the subject of asphalt quality strikes a familiar theme commonly used by practitioners even today.

“ There has long been a perhaps natural but unjustified tendency to attribute a large variety of job failures to the *quality* or source of the asphalt without adequate investigation of the other factors

involved. Ironically, this was as true back in the days of almost universal use of Trinidad natural asphalt ... now often referred to as standards of *quality* in demonstrating the inferiority of some *modern* product, as it is today”.

This study also highlighted the inter-relationships between the binder type, binder grade and pavement temperature during the asphalt shot and during rolling. In one set of laboratory experiments, the aggregate loss from an OA-230 penetration grade asphalt cement (close to an AC-2.5) reduced from 44 percent to 11 percent when the number of roller passes increased from one to three. In the same study, the effect of aggregate gradation on the performance of seal coats was investigated. OA-135 asphalt cement (close to an AC-5) applied at a rate of 0.32 gallons per square yard was used under different aggregate treatments and the corresponding aggregate loss values are reproduced in Table 3.1 below. These results highlighted the authors’ contention that increased #10-sized aggregate content pose aggregate retention problems in seal coats. In addition, Hank and Brown showed that a smaller portion of aggregate smaller than ¼-inch size results in better performance of the seal coat.

**Table 3.1.** Effect of Aggregate Gradation and Aggregate Treatment on Retention (Hank and Brown, 1949)

| Test Condition for Aggregate                       | Percent Aggregate Loss |
|--|------------------------|
| 12.6% passing #10 sieve                            | 72.0                   |
| 6.7% passing #10 sieve                             | 57.4                   |
| 0% passing #10 sieve                               | 30.5                   |
| 12.6% passing #10 sieve & rock pre-heated to 250°F | 17.7                   |
| 12.6% passing #10 sieve & rock precoated with MC-1 | 33.6                   |

In 1953, Texas Engineering Experiment Station published findings from an aggregate retention study on seal coats (Benson and Galloway, 1953). This study investigated the effects of field variables on surface treatment performance as an extension of the Kearby design method. A comprehensive laboratory test program was conducted to study the effects of factors including material application rates, aggregate gradation, aggregate moisture, aggregate dust and the elapsed time between the application of binder and aggregate. Some of the notable conclusions made by Benson and Galloway (1953) are listed below.

- To account for spreading inaccuracy, a 10 percent upward correction is needed to the aggregate quantity calculated from the Board Test as recommended by Kearby (1953).
- For average mat thickness less than 0.5 inches, a higher percentage embedment is needed to hold the smaller aggregate particles together. As a result, the authors proposed an alteration to the curve proposed by Kearby.
- When asphalt cement is used as the binder, aggregate should be spread as soon as possible after the asphalt is sprayed.
- Harder asphalt cements hold cover stone more tightly, but initial retention is more difficult to obtain.
- Cover stone with a limited variation in grading will give the highest retention.

- Wet aggregates give poor retention with asphalt cement.
- Dust in aggregate result in poor retention. However, wetting the dry aggregate before application and by allowing it to dry before rolling reduced the negative effect from dust.
- Aggregate retention increased with increased quantity of asphalt.
- When a 24-hour curing period was allowed, the retention of wet stone by RS-2 emulsion was slightly greater than that for dry stone. The retention of wet dusty stone was slightly less than for dry stone.

During the 1940's and 1950's, research work indicated that sufficient curing time is needed for seal coats constructed using liquid asphalt. The recommendation from researchers was that at least 24 hours of curing is required before opening the road for traffic. J. R. Harris (1955) of the Texas Highway Department proposed, based on his experience, that precoated aggregate should be used to improve the performance of the seal coat as well as to expedite the construction process. His contention was that precoated aggregates considerably shorten the required curing time by eliminating the problems associated with aggregate dust and moisture. He indicated that with precoated aggregate, traffic can be allowed to use the roadway within one hour after a seal coat is placed making the traffic control problem a lot more manageable.

#### *Modified Kearby Method*

In 1974, Epps et al. proposed a further change to the design curve developed by Kearby for seal coats using synthetic aggregates in Texas (Epps et al, 1974). Due to high porosity of synthetic aggregates, a curve showing approximately 30 percent more embedment than the Benson-Gallaway curve was proposed. The rationale for this increase was that high friction lightweight aggregate may overturn and subsequently ravel under the action of traffic.

In a separate research effort, Epps et al. (1980) continued the work done in Texas by Kearby (1953) and Benson and Gallaway (1953) by undertaking a research program to conduct a field validation of Kearby's design method. Actual pre-construction and post-construction data of 80 different projects were gathered and analyzed for this purpose (Holmgren et al, 1985). It was observed that Kearby design method predict lower asphalt rates than what is actually used by TxDOT and the study proposed two changes to the design procedures. First was a correction to the asphalt application rates based on level of traffic and existing pavement condition. Second correction was the shift of the original design curve proposed by the Kearby and Benson-Gallaway methods, as suggested for lightweight aggregates (Epps et al, 1974).

The following equation was used to calculate the asphalt application rate (in gallons per square yard) and included two correction factors for traffic level and existing surface condition.

$$A = 5.61 \frac{E}{d} \left( 1 - \frac{W}{62.6G} \right) T + V \quad \text{Eq. 3.1}$$

$W$  and  $G$  are the dry unit-weight and dry bulk specific gravity of the aggregate respectively, and the mat thickness ( $d$ ), can be measured in the laboratory.  $E$  is the depth of embedment and  $T$  and  $V$  are traffic correction factor and surface condition correction factor respectively for the asphalt application rate ( $A$ ). The correction factors were projected from the actual mat thickness-

embedment combinations that were proven to work well in the field. Tables 3.2 and 3.3 show correction factors corresponding to traffic level and existing surface condition respectively. Epps et al. (1980) also suggested that consideration should be given to varying the asphalt rate both longitudinally and transversely as reflected by the pavement surface condition. Since these modifications were introduced to the Kearby Method, the design method was commonly referred to as the “Modified Kearby Method”.

**Table 3.2.** Asphalt Application Rate Correction Factor for Traffic (Epps et al, 1980).

|                             | Traffic Level – Vehicles Per Day Per Lane |             |            |            |           |
|-----------------------------|---|-------------|------------|------------|-----------|
|                             | Over 1000                                 | 500 to 1000 | 250 to 500 | 100 to 250 | Under 100 |
| Traffic Factor ( <i>T</i> ) | 1.00                                      | 1.05        | 1.10       | 1.15       | 1.20      |

**Table 3.3.** Asphalt Application Rate Correction Factor for Existing Surface Condition (Epps et al, 1980).

| Description of Existing Surface            | Asphalt Application Rate Correction<br>(Gallons per Square Yard) |
|--|--|
| Flushed asphalt surface                    | -0.06  |
| Smooth, nonporous surface                  | -0.03  |
| Slightly porous, slightly oxidized surface | 0.00   |
| Slightly pocked, porous, oxidized surface  | +0.03  |
| Badly pocked, porous, oxidized surface     | +0.06  |

Since the publication of Modified Kearby design method, TxDOT Brownwood district has expanded on the asphalt application correction factors for ADT and existing surface condition. In addition, correction factors to incorporate the effects of truck traffic and aggregate gradation were also developed. These correction factors developed primarily for emulsified asphalts, are presented in Appendix A of this report.

A previous research study undertaken in 1981 by TxDOT also investigated the selection criteria for binder materials in seal coats (Holmgreen et al, 1985). Based on that research, recommendations were made to select the binder type based on the following factors. However, it does not appear that these recommendations were formally incorporated into TxDOT seal coat specifications at that time. These recommendations were incorporated in the TxDOT district seal coat training programs developed under this study.

- Prevention of low temperature cracking
- Existing pavement structural condition
- General climate of the location (cold, moderate or hot)
- Climatic season of construction
- Surface temperature at the time of (and just before) construction
- Compatibility with aggregate type

### *The Asphalt Institute Method*

The Asphalt Institute published ES-11 and ES-12 as its recommended procedure for the design and construction of surface treatments. These recommendations are in the form of aggregate gradations, binder types and grades for various aggregate gradations, and correction factors to the asphalt application rate based on existing surface condition. Table 3.4 shows the correction values recommended. These values are recommended for both asphalt cement and liquid asphalt.

**Table 3.4.** Asphalt Application Rate Correction Factor for Existing Surface Condition as Recommended by The Asphalt Institute (Finn and Epps, 1980).

| Texture                                       | Asphalt Application Rate Correction<br>Gallons per Square Yard |
|---|--|
| Black, flushed asphalt                        | -0.01 to -0.06   |
| Smooth, nonporous                             | 0.00   |
| Absorbent - Slightly porous, oxidized         | 0.03   |
| Absorbent - Slightly pocked, porous, oxidized | +0.06  |
| Absorbent - Badly pocked, porous, oxidized    | +0.09  |

### *TRL Method*

Transportation Research Laboratory (TRL) of the United Kingdom developed a comprehensive design procedure for chip seals along with a computer program (Colwill et al, 1995). This design procedure includes the following steps.

- Selection of the type of dressing: The selection of surface dressing (surface treatment) is made from 5 treatments. These are single dressing, pad coat plus single dressing, racked in dressing, double dressing and sandwich dressing.
- Selection of binder: Binders are selected from either emulsion or cutback asphalt specified based on viscosity. Modified binders such as polymer-modified binders are also recommended if their need and additional cost can be justified. The grade of binder is selected based on the road traffic category and construction season.
- Selection of aggregate: The nominal size of aggregate is selected based on traffic and hardness of existing surface. 20, 14, 10, 6 and 3 mm nominal size aggregates are specified. 20 mm size is not commonly used due to windshield damage.
- Binder spread rate: The required rate of binder spread depends on the size and shape of aggregates, nature of existing road surface and the degree of embedment of aggregate by traffic. The rate of binder spread should not vary by more than 10 percent from the target figure.
- Aggregate spread rate: The aggregate spread rate is determined based on “tray test” and will depend on the size, shape and relative density of the aggregate.

The design factors recommended TRL are listed below.

- Traffic level (personal and commercial traffic)
- Road hardness measured using a probe (from very hard to very soft)
- Surface condition (very binder rich, binder rich, normal, porous, very porous & binder lean)
- Location and geometry of site (radius of curvature, gradient, altitude, shade)
- Site requirements for skid resistance
- Seasons and likely weather conditions

### *South African Method*

The approach taken by the South African design method proposed in 1971 by the National Institute for Road Research is very similar to the TRL method (CSIR, 1971). The following is an outline of this design method.

- Selection of the type of surfacing: The selection of surfacing is made between single, double or triple surface treatments. This decision is primarily based on the traffic level and pavement condition.
- Selection of binder: Binders are selected from either asphalt cement, emulsion, cutback asphalt and tar. The grade of binder is selected based on traffic level, road surface temperature, climatic region and aggregate condition (dusty, precoated etc.)
- Selection of aggregate: Nominal size of aggregate is selected based on traffic, surface condition and type of treatment. 13 mm or 10 mm nominal size aggregates are specified for single treatments. Precoated aggregate is allowed and a number of materials including cutback asphalt, asphalt cement, tar and emulsion are included in the specifications for precoating materials.
- Rate of binder spread: The required rate of binder spread is determined using charts that incorporate aggregate spread rate, traffic level and ALD.
- Rate of aggregate spread: The aggregate spread rate is determined based on a design chart that uses the average least dimension (ALD) of aggregate.

### **Use of Lightweight Aggregates**

TxDOT first used lightweight aggregate seal coats in the Abilene district where a 1000 ft. test section was constructed in 1962. Around the same time, Brownwood district also started using it in surface treatment work. A study undertaken at the Texas Transportation Institute (TTI) investigated the suitability of lightweight aggregate as coverstone for seal coats and surface treatments (Epps et al, 1974). Findings from this study showed that “ under a variety of construction and service conditions, the lightweight material under study has, so far, proved to be highly successful cover aggregate for seal coats and surface treatments”. Lightweight aggregate did not show potential for significant degradation under freeze-thaw conditions and an accelerated freeze-thaw test was recommended in place of the magnesium sulfate soundness test. Of particular interest were the definite advantages of lightweight aggregate regarding windshield breakage problems, skid resistance and its uniform gradation.

## **Constructability**

Two extensive studies on the constructability of seal coats or chip seals are recorded in available literature. These were conducted in the states of Washington and Minnesota and a brief outline of the recommendations from those studies are given below.

### *Washington DOT Study*

Washington State DOT undertook a constructability review of its seal coat practices that was published in 1990 (Jackson et al, 1990). It was reported that approximately 50 percent of their highway system has bituminous surface treatments. The research study included project-level investigation of nine chip seal projects. The investigation focused on the distresses (flushing and raveling), impact of traffic and trucks, inspection procedures, political pressures and public relations. Washington State almost exclusively uses emulsified asphalt as chip seal binder.

Flushing and raveling were the primary seal coat distresses in Washington State. The main causes of flushing were identified as sealing over existing flushed pavements and cold mix patches, allowing emulsion to break before applying aggregate and use of too much crack seal material. The study recommended pre-paving evaluation of pavement surface (video road logs or field reviews), embedment checks and judicious use of fog seals as ways to mitigate flushing. A 50 percent embedment after initial rolling and a 70 percent embedment after two or more weeks of traffic application were recommended as typical values to look for in performance monitoring. Causes of raveling were identified as sealing over dry pavements and recent hot mix patches, sealing in shaded areas, aggregate too wet or dirty, use of too much aggregate, late season work and allowing emulsion to break before applying aggregate. In order to overcome raveling, the study recommended the use of thin preseals, embedment checks, prepaving evaluations, use of fog seals, timely application of aggregates and timing of contracts.

Chip seals were not recommended for highways with over 5000 ADT and/or truck percentages over 15 percent when ADT is between 2000 and 5000. Routes that fall into these categories were considered as requiring better construction quality and typically result in more construction related problems in traffic control and windshield damage.

The study also identified that skilled and experienced inspectors are a key element in a quality chip seal program and listed the following recommendations. The recommendations under political issues included reduction in dust generation, use of smaller aggregate where smoothness is required (such as in high bicycle traffic areas), use of polymer-modified binders for better performance and enhanced traffic control operations.

- Consider using maintenance personnel with extensive experience as inspectors.
- Provide pre-construction training to inexperienced personnel.
- Team up inexperienced inspection personnel with experienced inspectors at least for the first few days on the job.
- Continue with centralized support and review of chip seal program.

### *Minnesota DOT Study*

This study involved the identification of factors that would lead to high quality seal coats (MinnDOT, 1991). It appears that Minnesota DOT recommends the use of a design procedure similar to the modified Kearby method. The primary binder types mentioned in the study are cutback asphalt and emulsion. The primary recommendations of the study are given below.

- Seal coats should be designed instead of based simply on previous experience.
- Binder application rates should be changed according to traffic and surface conditions.
- Representative stockpile checks of aggregate should be conducted.
- Calibration of equipment, particularly the chip spreader is crucial to the satisfactory performance of seal coats.
- Dirty aggregate should not be used and if percent passing #200 sieve is 2 percent or higher, aggregate should be washed.
- Sweeping (brooming) should be conducted as soon as possible after construction, preferably the day after sealing.



## CHAPTER 4. DISTRICT SEAL COAT EVALUATION

### STRUCTURED INTERVIEW

The structured interview was designed with emphasis on constructability to reveal the best practices of district seal coat programs. This approach was selected to facilitate interactive communication between TxDOT experts and researchers, thus resulting in enhanced reliability of collected data. Each district interview was attended by district personnel involved in contract administration, design, materials, inspection and maintenance of seal coat work. The discussions often generated a wealth of information which would not have been collected with a mail-in questionnaire. The structured interview questionnaire comprised of 66 questions in divided into 9 categories listed below. A copy of the questionnaire is included in Appendix B of this report.

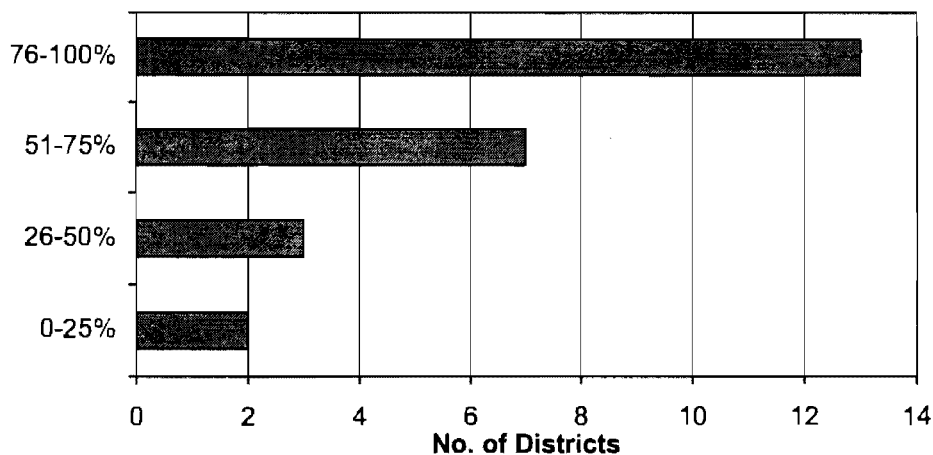
- General information on district seal coat program
- Design
- Contract
- Materials
- Equipment
- Construction
- Quality control
- Performance
- Continuous improvement

An in-depth analysis of district responses to the structured interview questions, are presented in the following sections under each category identified in the questionnaire. Numerous charts illustrate district responses to key interview questions.

#### General Information on District Seal Coat Program

This first category of interview questions highlighted the scope of district seal coat program and whether the district uses seal coats strictly as a preventive maintenance tool.

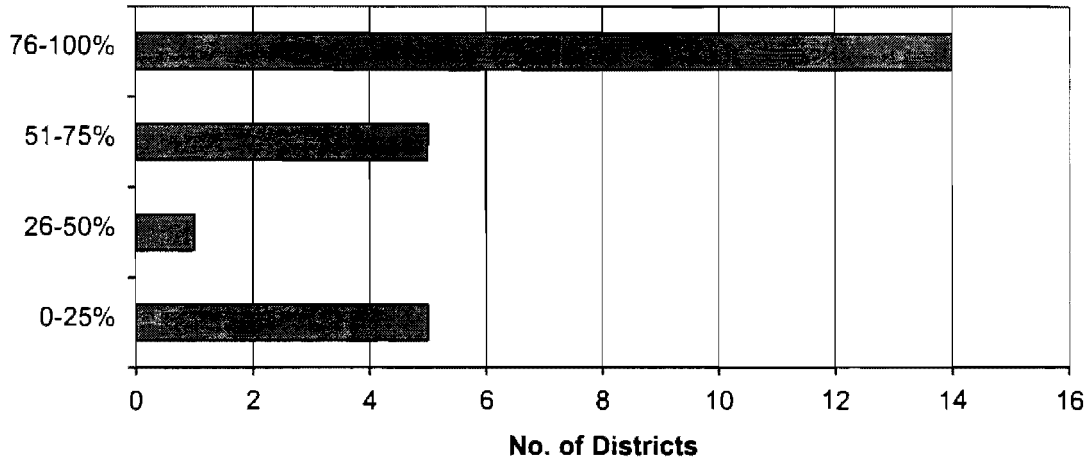
*Question 1. What percentage of district roads has seal coats as wearing surface?*



**Figure 4.1.** Percent Lane Miles with Seal Coat as Wearing Surface.

Figure 4.1 shows that 19 out of 25 districts have over 50 percent of their pavement lane miles covered with seal coat surfaces. As expected, districts with more rural highways have a much higher proportion of their pavement lane miles covered with seal coats. In districts with a significantly high volume of urban, interstate, state, and US highways (i.e. Houston), the percentage of seal coated lane miles was low.

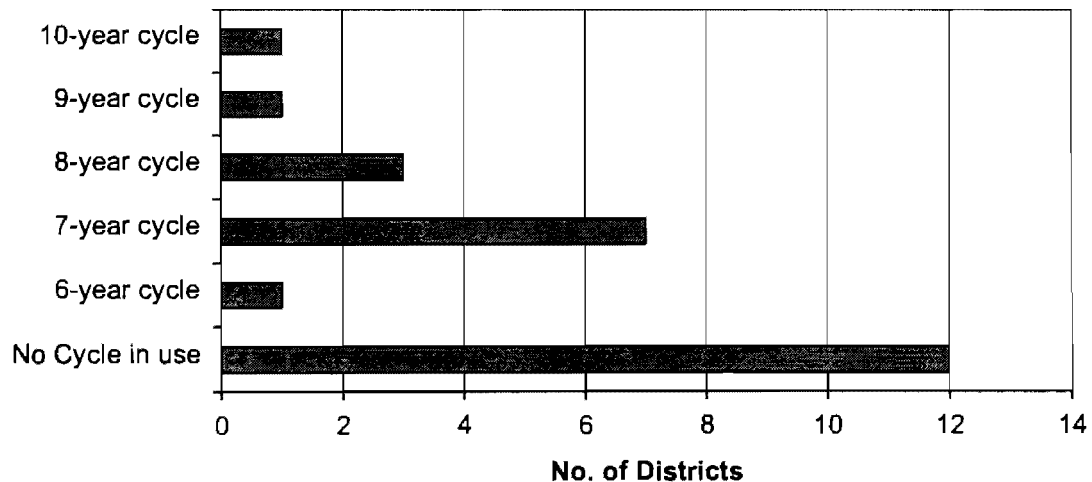
*Question 2. What percentage of district flexible pavements use surface treatments over base?*



**Figure 4.2.** Percent Highway Lane Miles with Surface Treatments Directly Over Base.

This question specifically refers to surface treatments used as a part of the initial construction where it is applied directly over base. Figure 4.2 shows that 19 districts make significant use (over 50%) of surface treatments directly over base. Such surface treatments may be used either as a wearing course or as an interlayer.

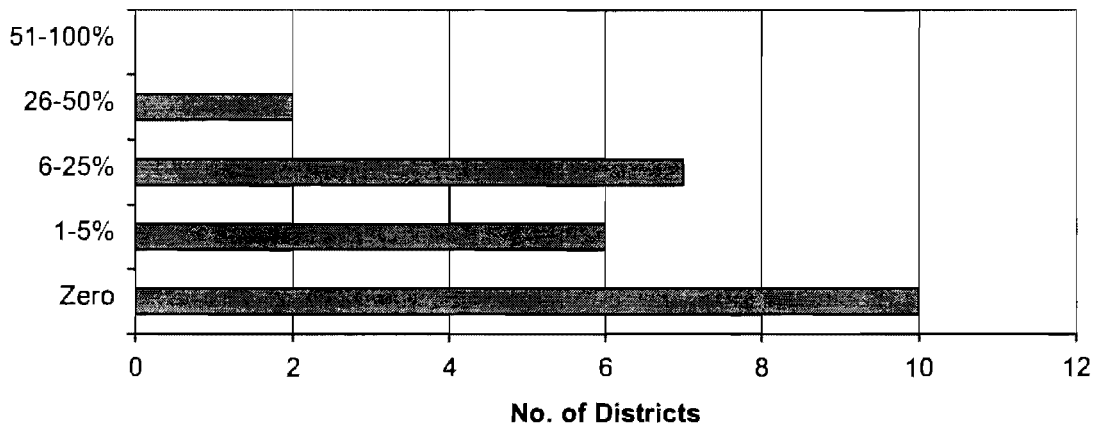
*Question 3. Does the district follow a preventive maintenance cycle for seal coats?*



**Figure 4.3.** Planned Seal Coat Performance Cycle.

Generally, seal coats are used as a preventive maintenance tool. The structured interview revealed that there is one district in the state that uses seal coats strictly as a preventive maintenance treatment. Odessa district seals each pavement section every seven years with only a few exceptions. However, 13 districts indicated that they try to achieve a uniform preventive maintenance cycle, but regular shortages in preventive maintenance funds prevents them from following that desired practice. It was also surprising that 12 districts perform seal coats on an as-needed basis. Such a practice would prevent districts from having a well coordinated preventive maintenance plan.

*Question 5. What percentage of seal coat work done with in-house crews*



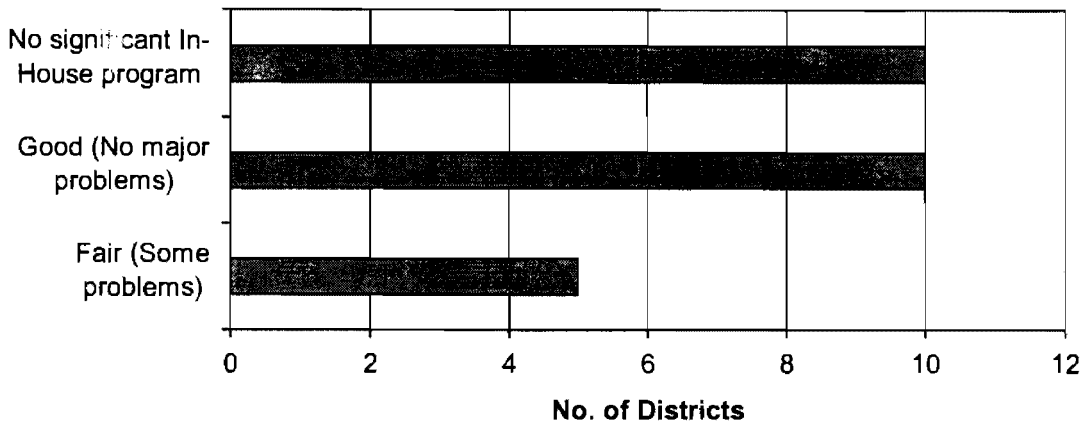
**Figure 4.4.** Districts Performing In-House Seals.

Figure 4.4 presents the percentage of in-house work performed in the districts. The general trend among the districts is to contract out a major portion of the seal coat work. The reasons given by districts for limited in-house seal coat operations include inadequate resources, lack of seal coat expertise and the competitiveness of contractor bid prices compared to cost of in-house work.

Districts that perform 1-5% of their seal coat work in-house typically have special job crews to perform small sections of seal coats, urgent work or winter seals. In many of these districts, materials used in contract seal coat operations differ from in-house seals. Special crews primarily use emulsion as the binder since most their work is performed during winter. Also they tend to select materials according to their availability at that time.

Districts that perform 6-25% of their seal coat work in-house typically have limited seal coat expertise within districts and use in-house crews to perform small to medium size sections and those sections that are typically isolated and would increase contractor bid prices if they were included. The two districts that does 26-50% of seal coat work in-house are Lubbock and Pharr where approximately half of their seal coat work is done in-house. These two districts attribute this to low turnover of experienced seal coat personnel.

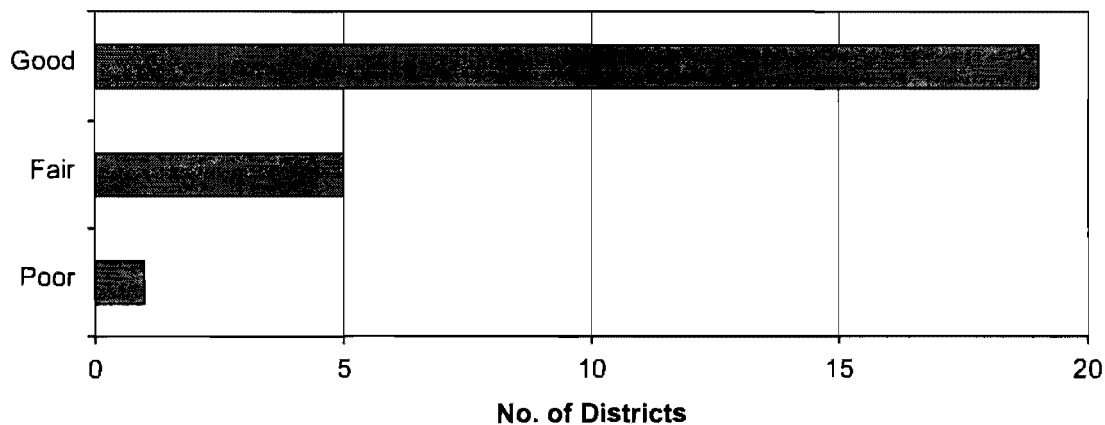
*Question 6. How is district experience with in-house seals rated?*



**Figure 4.5.** District Experience with In-House Seals.

Districts with larger in-house seal coat programs appear to be satisfied with the quality of their work. Districts with smaller in-house seal coat programs tend to have problems with in-house seals. These problems may be attributed to a number of factors including staff turnover and a lack of equipment.

*Question 7. How is district experience with contract seals rated?*

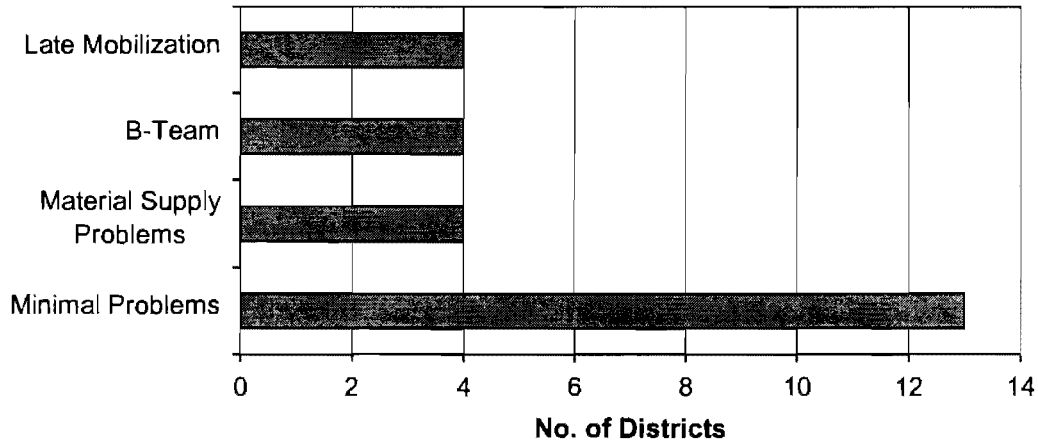


**Figure 4.6.** Districts' Remarks on Contract Seal Coat Performance

According to Figure 4.6, most districts appear to be pleased with the contractors' work. Districts with a longer working relationship with a particular contractor appear to have fewer problems due to a better understanding developed between TxDOT and contract personnel. Most districts did identify some problem areas. It would be unrealistic to expect a district to experience no problems since success, or consistency, of quality seal coat can only be achieved with time.

The only district that rated its contractor performance as “poor” attributed the rating to lack of experience of contractor seal coat crew and getting persistent late mobilization by the contractor.

*Question 8. What problems does your district typically experience with contract seals?*



**Figure 4.7.** Common Contract Seal Problems.

Figure 4.7 summarizes the common problems observed in the contracts from the district perspective. Thirteen out of 25 districts indicated no significant problems with their contract seals. Some northern districts have problems with late mobilization by contractors since contractors typically begin their seal coat work for the season in the southern districts where warm weather starts early, then proceed north and then move back to the southern part of the state to complete the season. There is competition among districts to attract the contractors early in the season since the overall quality of seal coats shot early in the season appear to be better. On the other hand, districts in the far south complain about contractors moving in so quickly leaving them with little time to make necessary arrangements.

Another significant problem, particularly over the last few years, has been the material shortages that impacted the seal coat program. The increasing demand for construction materials appears to have caused this problem.

Smaller districts seem to have problems with the poor performance of established contractors. These districts typically have small seal coat contract that does not get the full attention from big contractors, and they may end up with less experienced sub-contract crews (B-Team) that perform poorly.

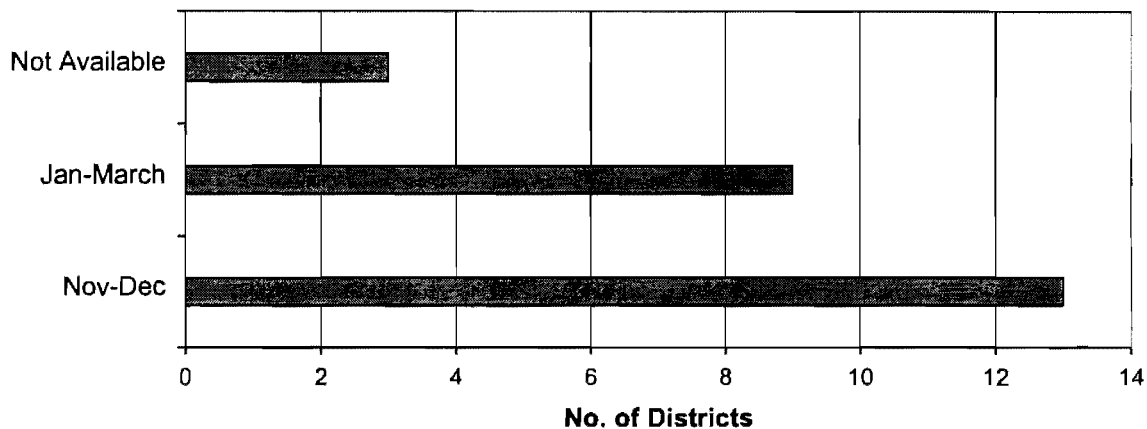
## **Design**

This section of the structured interview deals with questions related to seal coat design starting from the call made to identify candidate seal coat projects up to contract letting. Topics covered in this section included project selection process, design methods, material selection and design variables.

Project selection process is an important milestone in the design process. It typically starts with the district office calling for Area Engineers to submit candidate projects for next year's seal coat program. Once these projects are submitted, each district appears to be handling the project selection process in their own unique way. Some districts adopt a more centralized approach to project selection where the district office makes its evaluation of candidate projects and select a district-wide list earmarked for funding. Centralized project selection is done in different ways. It may be based either on qualitative assessment of each project by an experienced person or using a more sophisticated ranking procedure using pavement condition information. A few districts adopt a totally decentralized approach where each area office is allocated a certain portion of the preventive maintenance budget leaving the areas office with total discretion on how to spend it.

The primary candidates for seal coat work appear to be pavement sections that show cracking, oxidation, flushing and lack of skid resistance. Some districts resort to seal coat application on severely distressed surfaces in order to seal the pavement until funds for rehabilitation become available. However, in general, districts do not apply seal coats to pavements with structural deficiencies.

*Question 10. What is the sequence of events in your seal coat decision making process?*



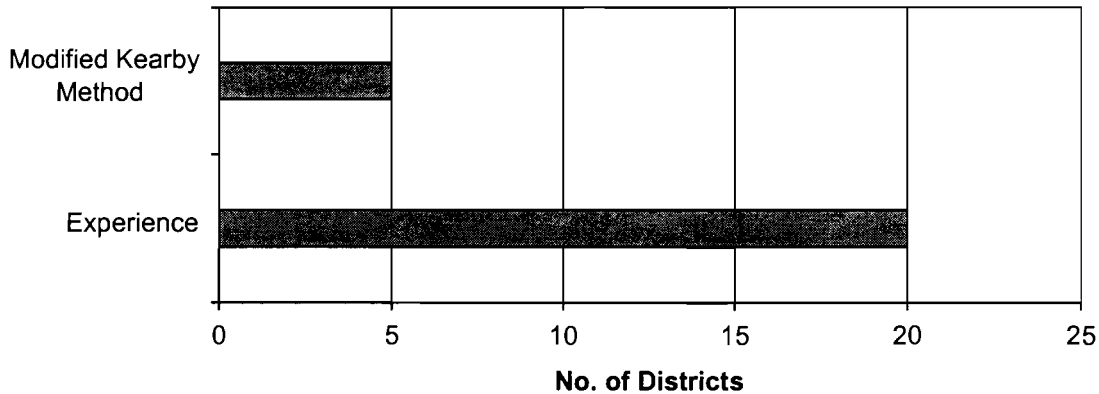
**Figure 4.8.** Seal Coat Contract Letting Period

This question addressed the sequence of events including the calls made for candidate projects, selection of projects, design of the seal coat work and contract letting. The dates for these events were closely examined to relate the seal coat performance to the timing of district seal coat program, if such a relationship exists. Figure 4.8 summarizes the letting date for district seal coat contracts. Since all districts appear to compete for the services of a small group of contractors, letting time appears to be an important parameter from the contract management point of view to ensure that an adequate number of quality contractors bid on projects. There appear to be a strong tendency for districts to let their seal coat contracts as early as possible.

As Figure 4.8 indicates, most districts prefer to let their seal coat contracts early in the fiscal year around November or Decemoer. By doing this, the number of contractors to bid to the seal coat job of the district can be maximized because contractors tend to get busy and bid less late in the

fiscal year. On the other hand, districts that let seal coat contracts late in the season point out that there are advantages for letting late because during most years, additional funding becomes available late in the year allowing them to include more projects in the seal coat program.

*Question 11. What is the design procedure and the design criteria used?*



**Figure 4.9.** Current Design Method

Figure 4.9 shows the design method preferred by districts. There are two primary design methods; modified Kearby method and the experience-based method. The modified Kearby method is based on a desired level of aggregate embedment combined with adjustments made to the binder rate for existing roadway conditions. The experience-based design method relies on a person with experience in seal coat work to establish the material application rates. In both these methods, selection of the binder type/grade and rock type is made based on past district experience.

Figure 4.9 indicates that experience-based design method is dominant throughout the state. The primary reason for the popularity of experience-based design method is because the success of a seal coat depends to a large extent on the adjustments that are made at the field during construction activity. These adjustments include changing the binder rates for existing surface condition of the pavement and altering the construction sequence based on pavement temperature and aggregate surface condition. Due to the critical nature of field adjustments, some districts argued that a sophisticated design procedure is a futile effort. However, the modified Kearby method appears to be gaining acceptance among districts and during the training workshops, several districts that use the experience-based design method showed strong interest in the modified Kearby method. The modified Kearby method starts with a base rate for a particular binder type and makes adjustments for existing surface and traffic conditions. Districts that use modified Kearby method are strong proponents of it and some of its positive aspects include its scientific basis and the ability to use it as a training tool to train personnel who are new to seal coat work. This is particularly important in the light of high turnover among experienced seal coat personnel.

Question 12. Who performs the design and when is it performed?

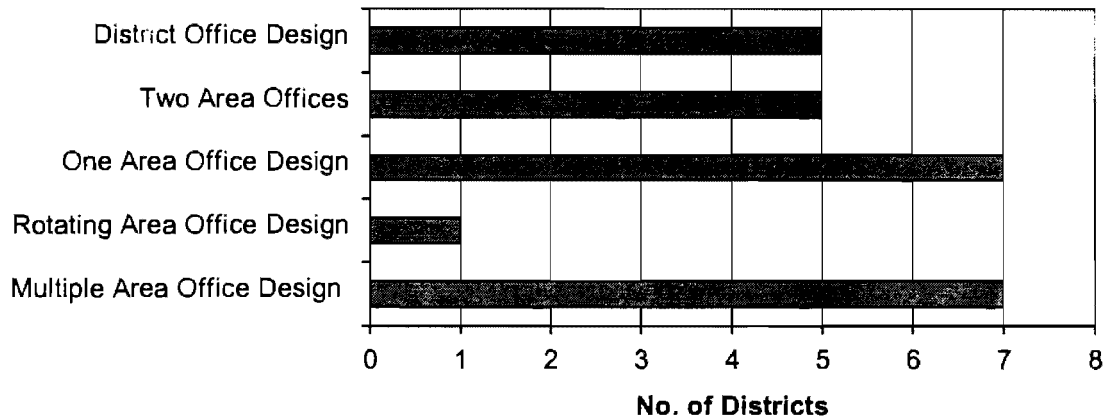


Figure 4.10. Management of Seal Coat Design in Districts

Figure 4.10 shows the different design management practices adopted by districts. There are 5 design management practices for seal coat projects varying between totally centralized and totally decentralized approaches. Except for rotating area office design, other four approaches appear to be almost equally popular among districts. When design is done by one area office, binder type/rate and aggregate type/rate are determined for the whole district by that office. However, the common practice among districts is to fix a preliminary rate for plan preparation and leave area engineers to establish final rates according to field conditions.

In the past, districts have rotated the seal coat design responsibility among all area offices. There is only one district that currently follows this policy, and its reason is to make every area office acquainted with the seal coat design and construction activities. This way, districts can overcome staff turnover problems by having a group of experienced personnel. Preliminary observations suggest that districts adopting a central approach (having either one or two offices responsible for the design) may have better control and less variability in their product quality.

Question 13. How long has the current design procedure been used?

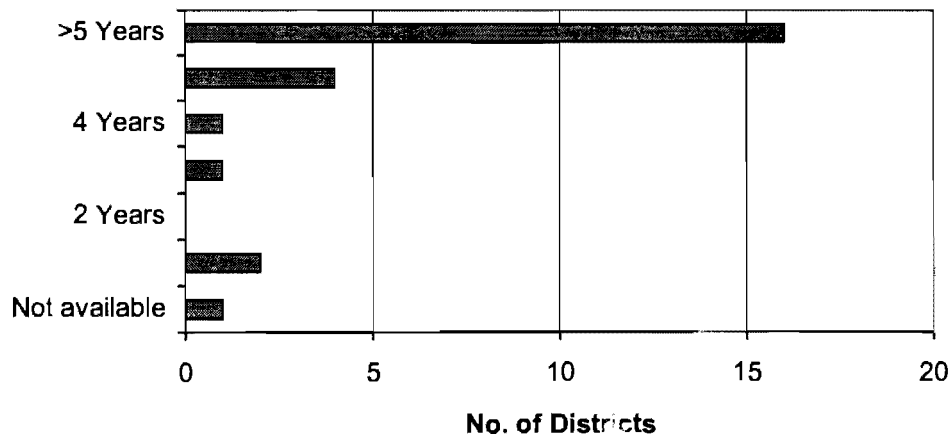
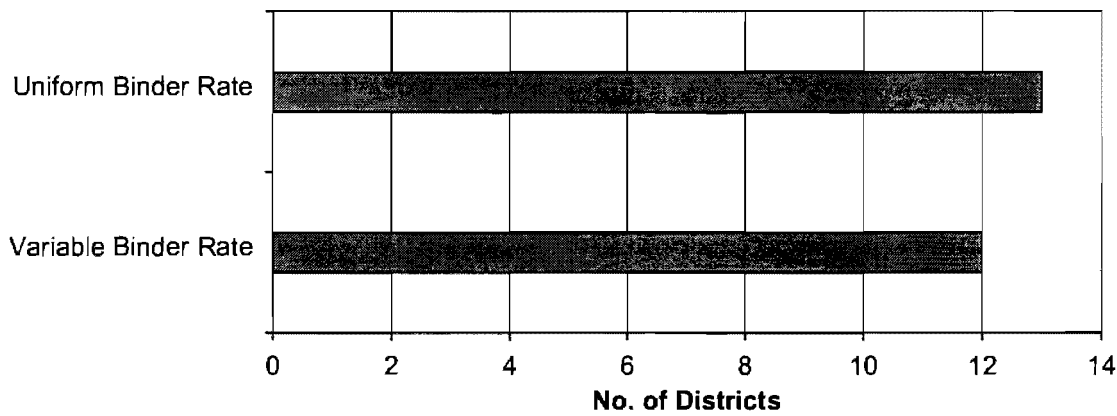


Figure 4.11. Period of Time Current Design Method Has Been in Use



Under this question, district experience with the current design procedure was examined. As shown in Figure 4.11, most districts have been using their current design procedure for over five years. Many districts could not even recall the last time when they changed the design procedure. The longevity of design procedure may be attributed to the district satisfaction with the seal coat program. Most districts with longstanding design procedures also use the experience based design procedure. It appears that these districts have a good grasp of the material types/rates that have historically worked well for them and hence do not see a need to change the design procedure.

*Question 15. Do you vary the asphalt spray rate across the lane?*



**Figure 4.12.** Binder Rate Distribution across the Lane

Figure 4.12 shows the extent to which variable binder spray rates are adopted across the state. The number of districts using variable and uniform rates is almost equal. The justification of using variable spray rates is to adjust the binder application rates depending on variation across the lane due to reasons such as flushed wheel paths. Districts using variable spray rates appear to be satisfied with the performance of their seals. They typically require contractors to provide their own nozzles. However, a few districts including Brownwood fabricate their own nozzles.

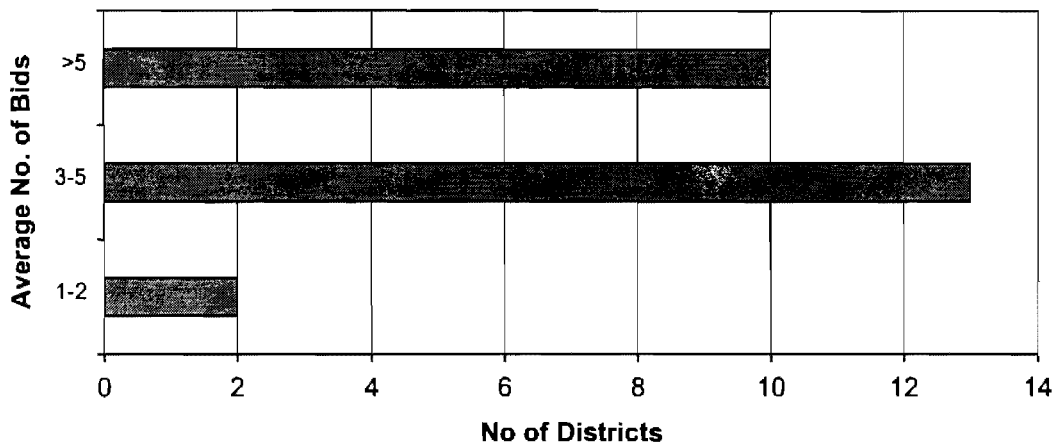
During the district seal coat training workshops conducted during this study, many districts that does not use variable spray rates across the lane showed a willingness to try it. It appeared that most districts depend on the equipment technology introduced by contractors before trying a new construction technique. Variable binder spray rates could be effectively used only when uniform flushing is present along a relatively long pavement section. This study indicated that such distresses are common in most districts.

A recent addition to available equipment is a distributor with two spray bars that enable variable spray rates across the lane without using variable size nozzles. A couple of districts have tried this type of distributor and it appears that it will become more popular with time.

## Contract

The third section of structured interview deals with contract management. Some of the issues discussed include the availability of good contractors, contract size and the type of contract. All districts were quick to point out that State law requires for them to award contracts to the lowest bidder. Most districts also indicated that contract price is not related to the quality of seal coat the district get because of strict adherence to the specifications. Districts keep the size of a typical seal coat job as large as possible. Both the districts and the contractors appear to prefer longer sections. Districts indicated that longer sections tend to give a better bid price from the contractors. Therefore, smaller sections and isolated sections are typically not included in seal coats contracts and are handled by the in-house special crew.

*Question 18. Do you feel that an adequate number of quality contractors bid on seal coat jobs?*



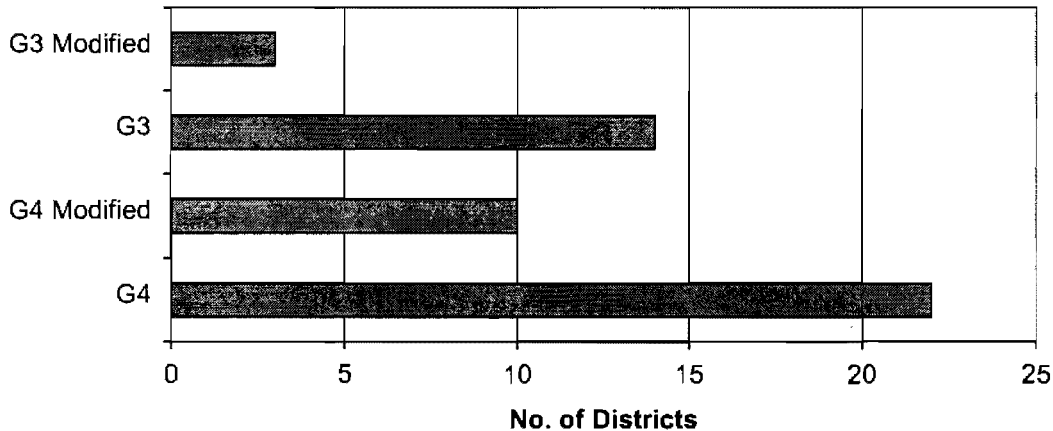
**Figure 4.13.** Level of Competition

Figure 4.13 shows the availability of an adequate number of bidders in the state. There are a couple of districts where one contractor got the seal coat contract year after year. This may be due to the familiarity that contractor has, about the conditions in that district. All except two districts indicated that typically, an adequate number of contractors bid on seal coat jobs. The two exceptions were districts with smaller contract size that may be turning away more established contractors. Even larger districts may face a shortage of bidders if the district puts out several smaller contracts. When asked about this question, several contractors agreed that contract size plays a significant role when they decide to bid on a job.

## Materials

Issues raised in questions under this category include selection of material type and grade, material availability and cost. The districts were also asked about their strategy for material selection because of its relevance to constructability. Two approaches were observed in material selection. Some districts select materials to maximize seal coat performance whereas others were interested in maximizing the number of lane miles sealed for the funds available.

*Question 24. What aggregate specifications do you use for seal coat jobs?*



**Figure 4.14.** Aggregate Gradations Used

Figure 4.14 shows the number of districts that use the aggregate gradations included in the specifications. Primarily, two aggregate gradations, Grades 3 and 4, are specified with Grade 3 being the coarse gradation. The most popular gradation is Grade 4, which is used by 22 districts. Grade 4 is preferred over Grade 3 because of its smoother surface finish, less susceptibility of windshield damage by loose rocks and the lower binder requirement. Many districts indicated that use of Grade 3 aggregate increases public complaints due to rough ride surface and windshield damage. The likelihood of windshield damage is reduced by lightweight aggregate use. However, the number of lightweight aggregate suppliers in the state is now reduced to one, and only districts in close proximity to Corsicana, where that one plant is located, are able to use it economically. Proponents of the Grade 3 aggregate argue that it is more "forgiving" for variations in the binder rate because of the larger aggregate size and cause much less flushing and bleeding problems. From a seal coat performance standpoint, most experienced seal coat personnel appear to prefer the Grade 3 aggregate. Grade 3 aggregate appears to be a good choice for low volume rural roads where aggregate loss can pose a problem due to less compaction by public traffic. The larger size grade 3 aggregate allows the districts to use a higher asphalt content to retain the aggregate without increasing incidence of flushing and bleeding.

The modified gradations are designed to provide a more uniformly graded aggregate, which has been shown to be desirable for seal coats. However, the price of modified graded aggregate is typically higher than the regular Grade 3 and Grade 4 aggregates. Most district personnel seemed to be satisfied with the performance of modified gradations. However, some thought it would not be worth the additional cost.

Question 26. Do you use precoated aggregates?

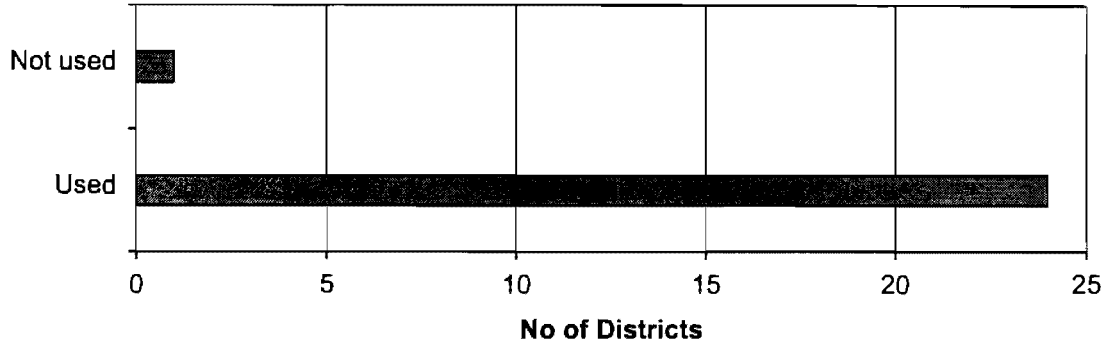


Figure 4.15. Use of Precoated Aggregates

Figure 4.15 clearly shows the popularity of precoated aggregates among the districts. Use of precoated aggregate is popular because it controls the dust in aggregate particle surfaces. Research has shown that presence of dust in aggregate surfaces is extremely detrimental to the bonding between aggregate and asphalt binder. Some districts like precoated aggregate because it provides a darker seal coat surface making the lane markings more clearly visible. Typically, softer asphalt cements such as AC-3 and AC-5 are used as the precoating binder. Precoating material should also be compatible with the asphalt cement used in the seal coat. Most districts indicated that precoated aggregate is effective only when asphalt cement is used as the seal coat binder. Most districts perform binder extraction tests to ensure that an adequate coating of binder is available.

Question 27. What approved aggregate sources are used in your district?

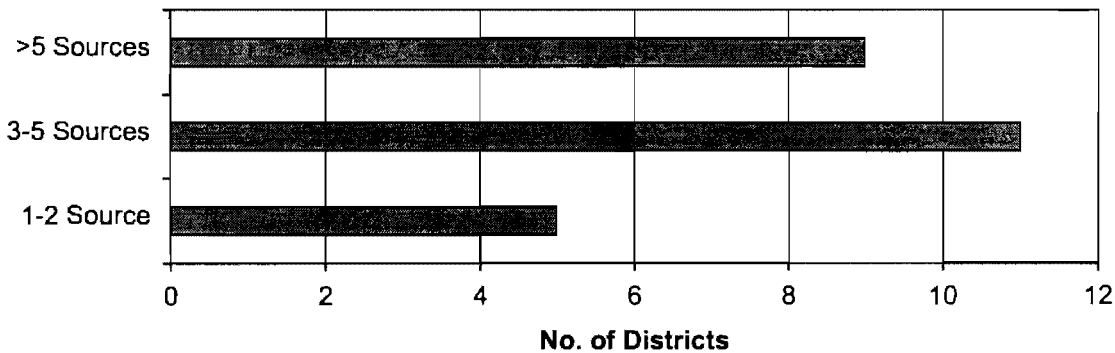
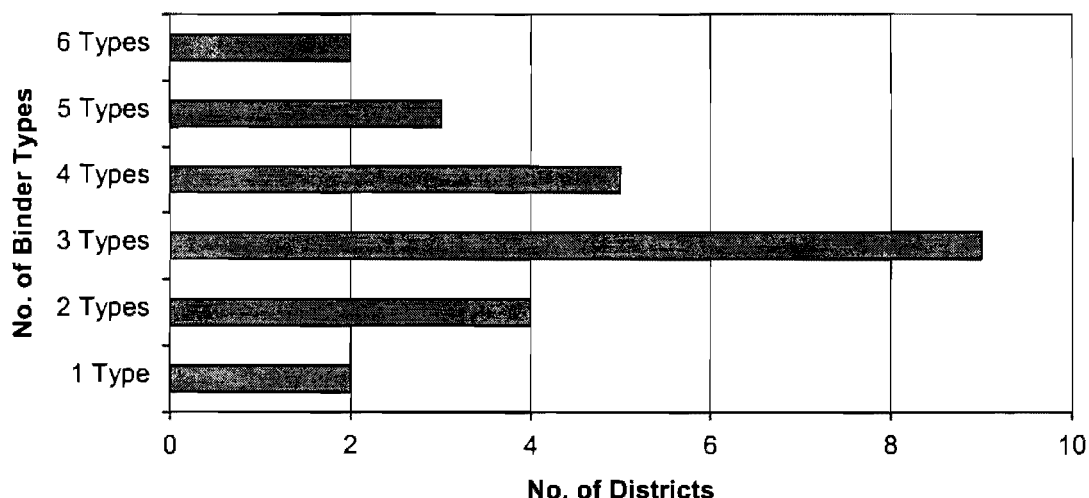


Figure 4.16. Availability of Aggregate Sources at Close Proximity

Figure 4.16 shows 20 out of 25 districts can choose from at least 3 aggregate sources. The east Texas districts appear to have the biggest problems with aggregate availability. Some of these districts reported that aggregate shortages prevented them from completing their seal coat contracts over the past two years. One important issue related to aggregate availability is the compatibility between available aggregate and the binders to be used in seal coats. Particularly

in relation to emulsified asphalt, selection of emulsion type and grade should be made carefully after taking the aggregate availability into account.

*Question 29. What binder types do you normally use in the district?*



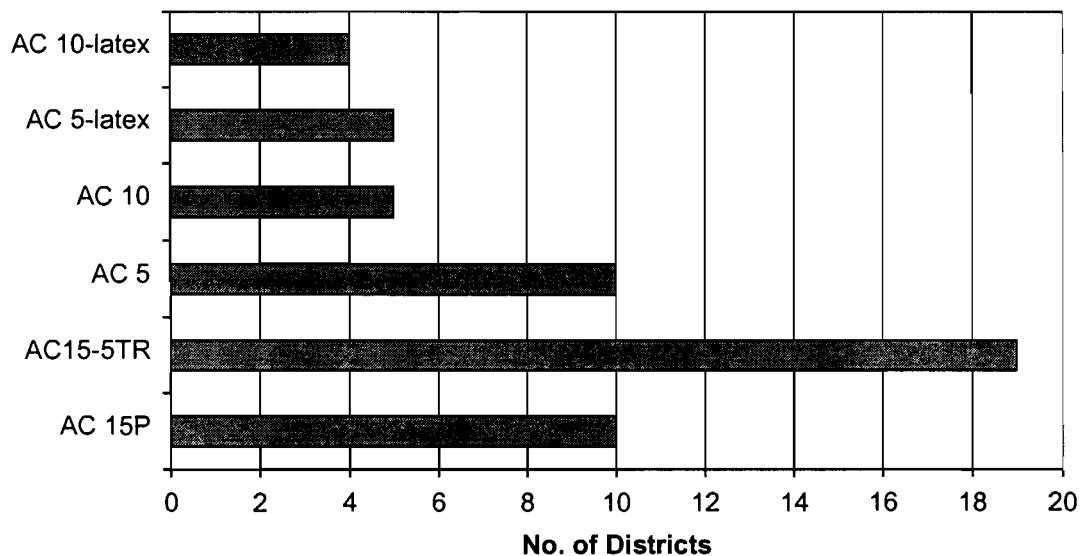
**Figure 4.17.** Number of Different Binder Types Used

Figure 4.17 reflects the district practice on the number of binder types used in seal coat contracts, and three binder types appear to be the most common number. Districts with significant in-house seal coat activity typically use more binder types because of winter seal work. Several districts using a fewer number of binder types (one or two) indicated that they are able to better manage the quality of their seal coats by gaining experience with the few binders and then continue to use them year after year. On the other hand, districts using a higher number of binders (such as 5 or 6) were found to experience problems with their seal coats. Since the field personnel have to focus on several different binder types, it may be difficult for them to develop sufficient experience with a particular binder to perfect its use to conditions in the district. This is a good illustration of how good constructability practices can be used to feedback experience to improve the performance of seal coats. The interview process revealed that there are several approaches used in the selection of binder types used in seal coats within a district and they are listed below.

- Divide district seal coat jobs based on ADT and use a higher quality binder on high ADT roads and a lower quality binder on others.
- Binder selection based purely on prices in the area.
- Identify a short list of binder types in general notes, this allowing the contractor to use the most economical one.

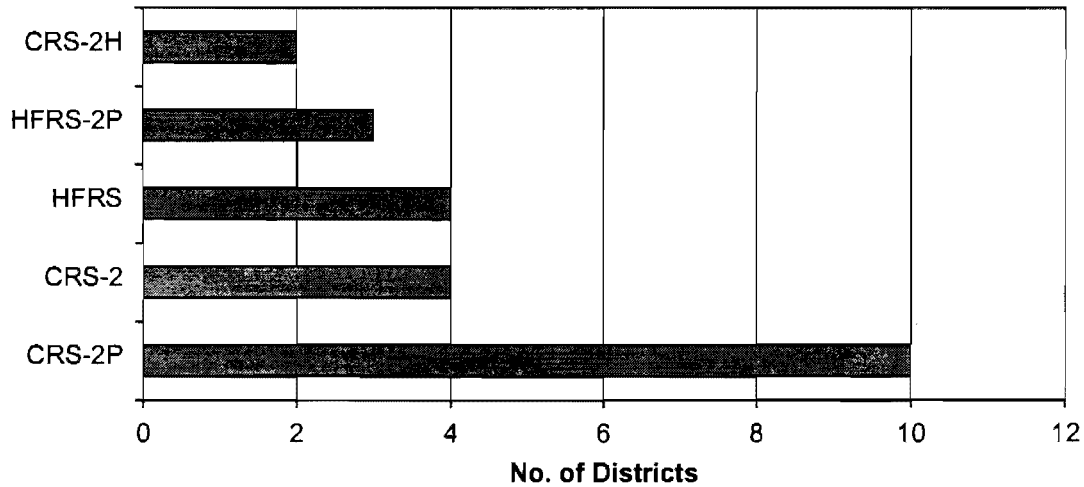
On the subject of market price, urban districts appear to be at an advantage, because prices of different binders did not appear to be significantly different from one another. In rural districts, typically, the higher quality binders were priced significantly higher than the others.

In order for districts to keep up with the latest developments, it is important for them to try out promising new binder types when they are introduced into the market. However, it was interesting to note that in some instances, the same binder type coming from the same source when used in different districts, have resulted in totally different outcomes. This may create confusion among TxDOT personnel and it can be overcome only by using new products under carefully controlled conditions. This way, experience with the new binder can be easily correlated with the conditions under which the project was constructed.



**Figure 4.18.** Use of Asphalt Cement as Binder

Figure 4.18 shows the common asphalt cement binder types used by districts. The most widely used asphalt cement is AC-15 5TR, and the others are AC-15P and AC-5. Most of these binders are used in combination with precoated aggregates. Asphalt cements are almost exclusively used in warm or hot weather construction. They appear to provide satisfactory seals with good adhesion between the aggregate and binder. Tire rubber modified asphalt cement (AC-15 5TR) has gained immense popularity over a relatively short period of time and almost all districts were satisfied with its performance, particularly its superior ductility characteristics. Even the polymer and latex modified asphalt cements appear to have fared well. Districts that use softer asphalt such as AC-5 appear to have significant bleeding problems, based on the amount of money spent in rectifying bleeding pavements.



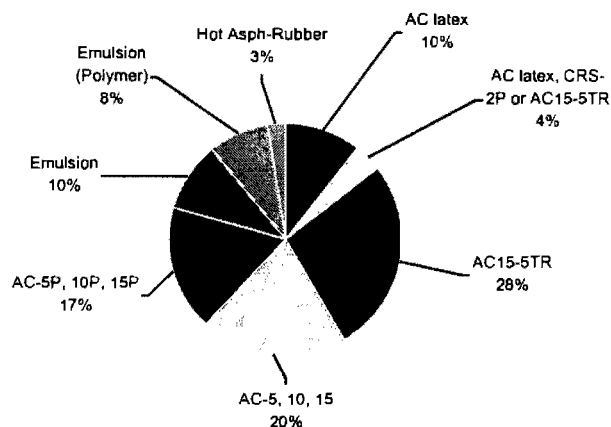
**Figure 4.19.** Use of Emulsified Asphalt as Binder

The statewide use of emulsified asphalt is illustrated in Figure 4.19. CRS-2P is by far the most popular of the emulsified asphalt types. Emulsified asphalt is generally preferred for seal coat work during cooler weather conditions and when there is a higher probability of rain during construction. A primary concern with emulsified asphalt is when to spread the aggregate. According to the Asphalt Institute, aggregate should be placed as soon as possible after the binder is sprayed. However, most districts appear to follow the practice of waiting until the emulsion breaks before spreading the aggregate. Sticking of the binder on chip spreader tires appears to be the main reason for delaying the aggregate spreading operation. The other problem area with emulsified asphalt is the long traffic delay due to curing time. However, public complaints often force the field personnel to open the seal for traffic before it is ideally prepared. The use of pilot cars, which forces the drivers to travel slowly over the new seal coat may significantly help reduce damage to the seal.

Table 4.1 and Figure 4.20 show the percent use of different binder types by each district. This information is based on available data collected from 23 districts. It clearly shows the variability in binder use among districts that range from 100 percent asphalt cement use to 100 percent emulsified asphalt use.

**Table 4.1. Percent Use of Different Binder Combinations by Each District**

| Combinations of Binders and Percent Use          | No. Districts |
|--|---------------|
| 100% AC-5,10,15                                  | 2             |
| 95-100% AC-5P,10P,15P                            | 4             |
| 100% Emulsion                                    | 1             |
| 100% AC Latex                                    | 1             |
| 75-85% AC-5,10,15 and 15-25% AC latex            | 2             |
| 50-75% AC-15-5TR and 25-50% Emulsion(Polymer)    | 2             |
| 35-45% AC-15-5TR and 55-65% Emulsion             | 2             |
| 75% AC-5P,10P,15P and 25% AC-15-5TR              | 1             |
| 70% AC-15-5TR and 30% AC-5P,10P,15P              | 1             |
| 80% AC-5,10,15 and 20% AC-5P,10P,15P             | 1             |
| 50% AC latex and 50% AC-15-5TR                   | 1             |
| 50% AC-15-5TR, 35% AC-5,10,15, 15% AC-5P,10P,15P | 1             |
| 65% Emulsion and 35% AC latex                    | 1             |
| 60% AC-5P,10P,15P and 40% Asp.Rubber             | 1             |
| 50% AC-5,10,15, 30% AC latex, 50% AC-5,10,15     | 1             |
| 60% AC latex, 30% Asp. Rubber, 10% AC-5,10,15    | 1             |



**Figure 4.20. Percent Use of Different Binder Types in the State**

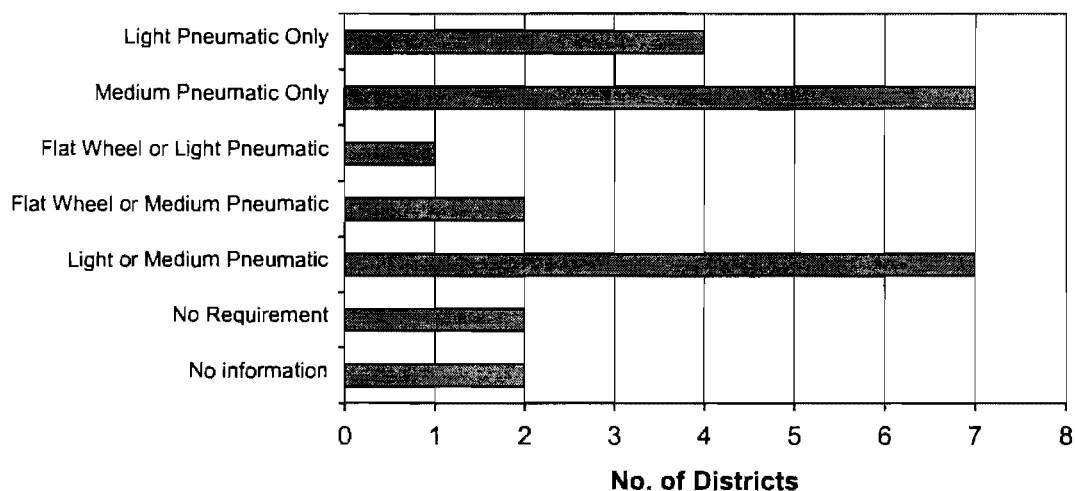
### Equipment

TxDOT standard specification for construction activities stipulates the criteria to be met by all types of seal coat construction equipment including binder distributors, aggregate spreaders, rollers and sweeping brooms. The primary issue that was raised on equipment during district interviews was the need to update specifications to include the latest equipment technology available in the market. Districts generally showed a willingness to improve seal coat



construction practices by using the latest equipment. It was observed that all districts use computerized distributors and a few districts use the latest two-spray bar distributor to spray variable rates across the lane. Several districts also use computerized aggregate spreaders. One issue of contention related to computerized equipment is the necessity to calibrate the computer displays periodically to verify if they read the actual material spray rates, and all districts appear to be following the correct approach in this regard. It was noted that many districts tend to rely on contractors to introduce new technologies rather than looking for new equipment technologies on their own. The district interviews and field visits showed that rolling of seal coats is an area that require some attention under the constructability review.

*Question 34. What roller types are considered appropriate for the contractor to use?*



**Figure 4.21.** Specification of Roller Type

Figure 4.21 illustrates the use of roller types by districts. There are two main types of rollers used in seal coat operations; light pneumatic and medium pneumatic. Medium pneumatic rollers appear to be the most popular when only one type of roller is specified. A third type, flat steel wheel roller, is used by two districts and does not appear to be a popular statewide choice. These two districts are able to use them because they use harder aggregates such as siliceous gravel that does not pose crushing problems under the roller. In many districts, rollers are specified as one or a combination of the following.

- Roller type
- Number of roller passes
- Rate of rolling (area per hour)

Under the constructability review, particular emphasis was given to the rolling operation including roller specifications, rolling patterns and rolling rates since it was found that sufficient attention was not given to it. Rolling operation is directly related to aggregate embedment and lack of rolling may result in widespread loss of aggregate. Districts were asked to describe their rolling operations and the specific reasons why they require certain types of rollers. Due to their lower tire inflation pressure, lightweight rollers result in less crushing of aggregate, but require

more rollers to get adequate roller coverage. Rolling time requirements are different for light and medium pneumatic rollers but these do not appear to be closely monitored by many districts.

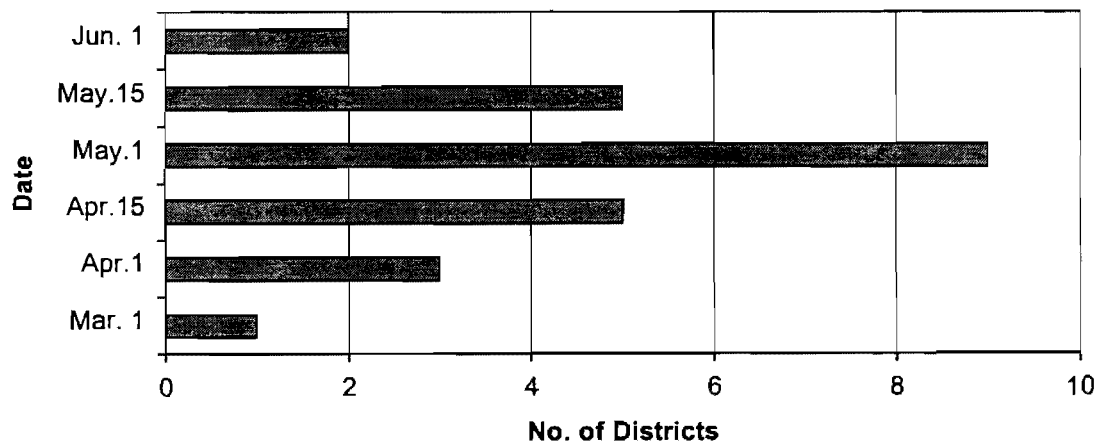
### Construction

Construction related questions of the interview focused on seal coat season, surface preparation methods, traffic control, material application, rolling and brooming. Even though surface preparations such as crack sealing and patching have significant influences on seal coat performance, most districts have difficulties with performing them sufficiently early to minimize their negative influence.

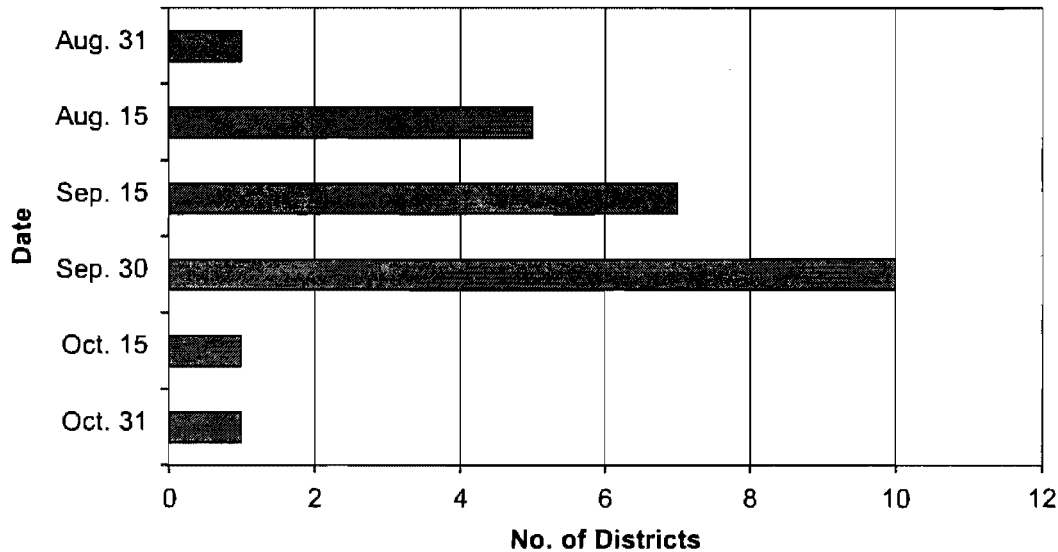
Under activities related to traffic control, the following issues were discussed.

- Use of pilot cars: Even though most districts agree that use of pilot cars is a good way to reduce vehicle speeds over the new seal coat thus reducing its damage, only a few districts actually follow that practice.
- Time elapsed before opening the road to traffic: This issue is particularly important when emulsified asphalt is used as the seal coat binder because it requires more curing time. However, public complaints often force the field personnel to open the road to traffic earlier than desired.
- Reduced speed policy: TxOT does not have a reduced speed policy on new seals.

*Question 37. What is your typical seal coat season?*



**Figure 4.22.** Start of Seal Coat Season



**Figure 4.23.** End of Seal Coat Season

Figures 4.22 and 4.23 show the distribution of start and end dates of the district seal coat season. It has been established that pavement temperature at the time of construction closely affects the seal coat quality. Therefore, seal coat season directly contributes to the quality of the seal coat program and the ideal seal coat season for districts differ significantly based on climatic conditions. Although some district seal coat seasons may start earlier and finish later, there is general consensus among districts that summer months are the best time for seal coat operations. However, this season can be reasonably extended for warmer districts. Another important consideration is that seal coats should be subjected to a reasonable period of warm weather before the first cold spell arrives. Therefore, ideally, districts prefer to complete seal coat work much earlier than the first cold spell. However, factors such as contractor schedules and volume of work planned for that year may not allow them to do so. This issue is particularly important to the northern districts where the first cold spell arrive a lot sooner.

The start and end dates of the seal coat season were obtained from district general notes. However, most districts allow exceptions for the end date to allow for unforeseen delays. Start and end of seal coat season exhibit a variation similar to normal distribution between April 1-June 1 and August 31-October 31, respectively.

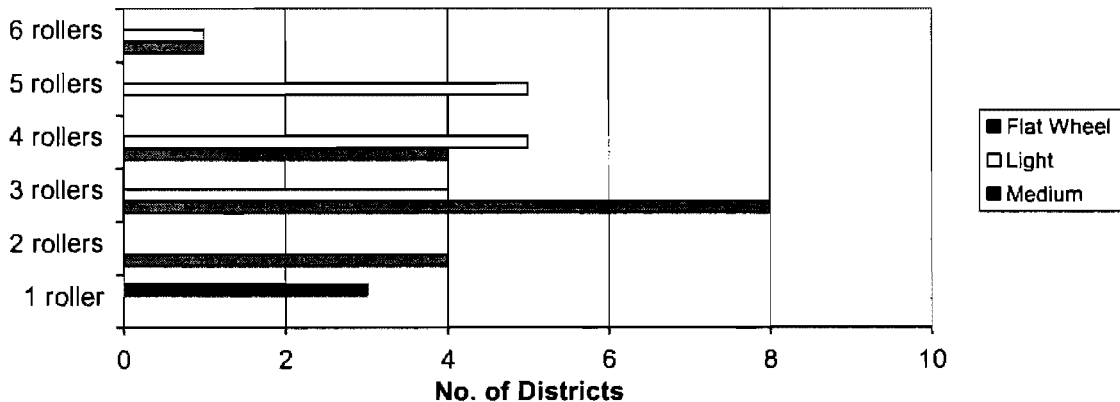
Seal coats need a reasonable duration of warm weather to attain its desired adhesion level between aggregate and binder before the onset of cold weather. Seal coats applied during cooler weather experience a high probability of shelling. For this reason, districts generally prefer to start their seal coat season as early as possible. One method used to facilitate this is to include a general note in the plans for a latest start/mobilization date. However, it is evident that not all of the districts can begin seal coat work early given the competition between districts and the capacity of the contractors. To understand this issue better, attention should be given to the mobilization pattern of established seal coat contractors. These contractors start their seal coat contracts from the southern districts and proceed towards north during the season. As a result, it is the districts in the north that often complain about late mobilization and related shelling.

*Question 39. Prior to seal coating, what surface preparation methods are adopted?*

The desired seal coat quality can be best achieved if existing surface is prepared and brought to a uniform condition. Common surface preparation methods are crack seals and patches. Crack seals prevent loss of seal coat binder through existing cracks and patches are intended to level-up the pavement surface. Not only are these important, but the time between the preparation activity and seal coat application is also crucial. As a rule of thumb, patches should be completed at least 6 months prior to and crack seals should be applied at least 3 prior to the application of seal coats. This is essential in order to allow curing time for the patches. If seal coat binder is applied over an old patch, the patch mix may absorb the binder and cause aggregate loss. As a remedy for such situations, fog seals are used. However, the effectiveness of fog seals is subject to debate.

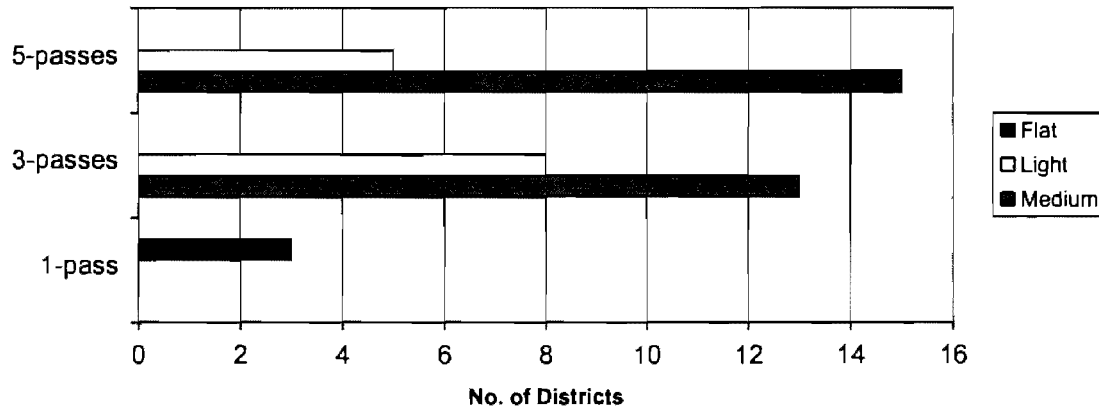
The main problem encountered by districts on surface preparation seems to be the apparent lack of coordination between maintenance crew responsible for surface preparation and the contract seal operations. Most districts cannot finish the preparation work sufficiently early. The study also found out that crack seals paid by pound have a tendency to be thicker than the ones paid by linear foot. Such crack seals are reflected through the seal coat surface and cause flushing /bleeding problems.

*Question 43. What is the typical number of roller passes?*



**Figure 4.24.** Required Roller Type and Number

Another key factor in construction is the number of rollers used. The distribution of responses for this question is shown in Figure 4.24. A wide variation exists in the number of rollers specified and/or used by districts. Roller width and tire inflation pressure values indicate that a lesser number of medium weight pneumatic rollers are required to achieve the same level of compaction compared to lightweight rollers. Some districts do not specify a number of rollers even if they may specify a roller type. From Figure 4.24, it can be seen that typically, 3 to 5 lightweight rollers and 3 medium weight rollers are specified. Field observations indicated that two lightweight rollers are inadequate to provide coverage to a typical 12 ft. wide lane.



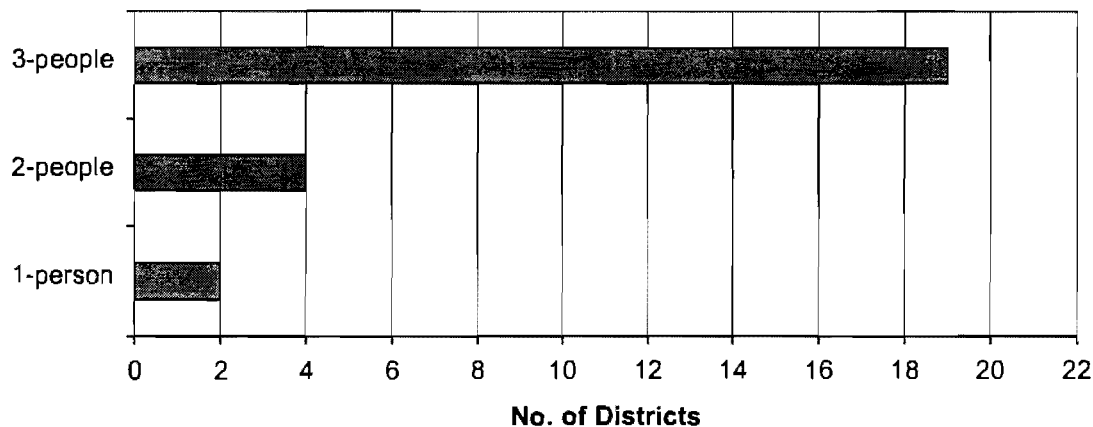
**Figure 4.25.** Roller Passes Specified by Districts

Figure 4.25 shows district practices regarding the number of roller passes required, which ranges from 3 to 5 passes for pneumatic rollers. However, not all districts specify a number of roller passes. Districts that require a specific number of passes do not appear to closely monitor the actual speeds of the rollers. In such situations, the number of roller passes can be attained, but the minimum rolling time may be sacrificed. Typically, the chief inspector decides on the adequacy of the rolling requirement.

### Quality Control

Quality control section of the structured interview emphasized the district policies on checking the conformance of the construction operation to specifications. The inspection team size and composition were particularly examined to relate to seal coat quality. The methods used to check the application rates were also analyzed together with the tolerances allowed for these values.

*Question 51. Who does the inspection, a team or an individual?*



**Figure 4.26.** Inspection Team Size

Figure 4.26 shows the number of inspection personnel used by the districts. An overwhelming majority of the districts use 3 people (in a few cases 4) to inspect their seal coat operations. An adequate number of experienced inspectors is essential to achieve success in the seal coat program since seal coat construction is highly dependable on field conditions during the construction and often adjustments need to be made for material application rates at site. The main responsibility of the inspection team should be to verify if the binder and aggregate rates are applied and compacted according to the design and specifications. Also, the chief inspector should keep an eye on the overall progress at the job site.

The ideal and most commonly used inspection team consists of three persons (one chief inspector and two others). The chief inspector should be free of specific inspection duties to keep track of the overall quality of the project. The other two inspectors can keep the track of the asphalt distributor, aggregate trucks, aggregate spreader, and rolling. The few districts that use only one person for inspection appear to be experiencing problems in their seal coat quality. This small inspection team size is due to decentralized seal coat operations in these districts which results in the thinning of experienced district inspection forces. It is the opinion of the research team that steps need to be taken to increase their inspection size.

*Question 53. How do you control the quality of the aggregate?*



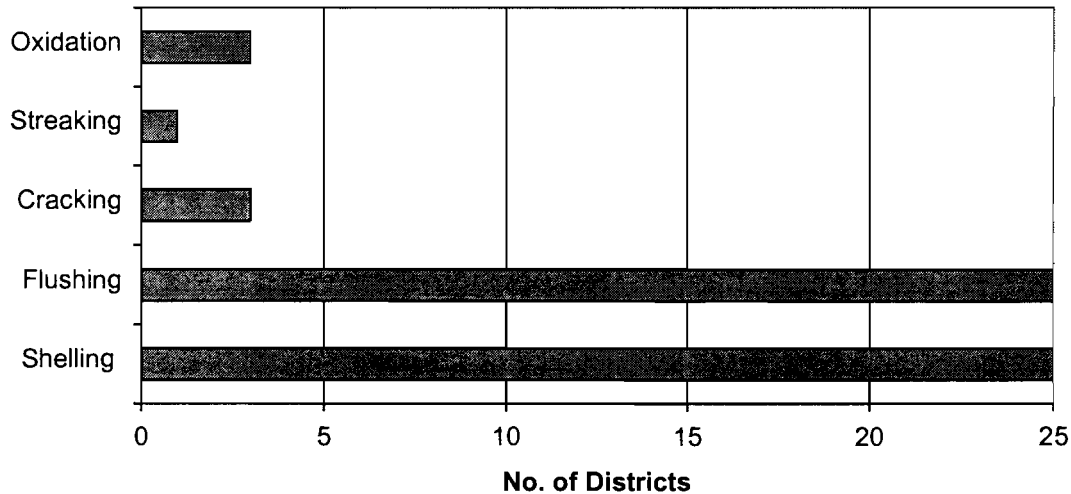
**Figure 4.27. Stockpile Testing**

Stockpile testing information is presented in Figure 4.27. Testing at stockpiles is particularly important if stockpiles are kept at the roadside. Due to repeated handling of aggregates, original gradation of the stockpile can adversely change. Also, if the stockpile is exposed to dust, problems may arise with the binding between aggregate and binder. In addition, some vegetation may also be present among the aggregates if the stockpiles are around for a long time. Non-conforming gradations would decrease the final product quality in terms of flushing. Therefore, stockpiles should be checked prior to the application of seal coat.

## Performance

This section of the structured interview dealt with the performance of seal coats. It addressed issues such as common distress types and rectification methods. Districts were encouraged to comment if they ever observed a performance difference between maintenance seal coats and the surface treatments that are directly applied over base courses. In addition, districts were asked if they have instituted a formal performance monitoring system for seal coats.

*Question 58. What common distresses are observed in seal coats?*



**Figure 4.28.** Common Distress Types

Figure 4.28 shows the common distress types observed in seal coats. It is obvious that all districts experience shelling and flushing problems in addition to some other distresses. Flushing is generally associated with high binder rates and non-uniform aggregate gradations and accelerated by high temperatures. On the other hand, shelling is observed with low binder rates and inadequate rolling. Shelling is accelerated by cooler weather and is generally observed during the first cold season the seal coat is exposed to.

Question 59. What distresses are most predominant?

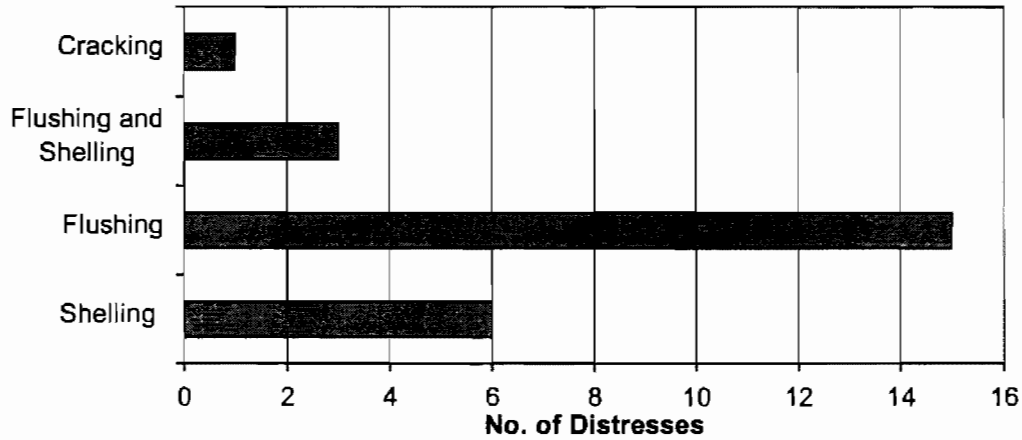
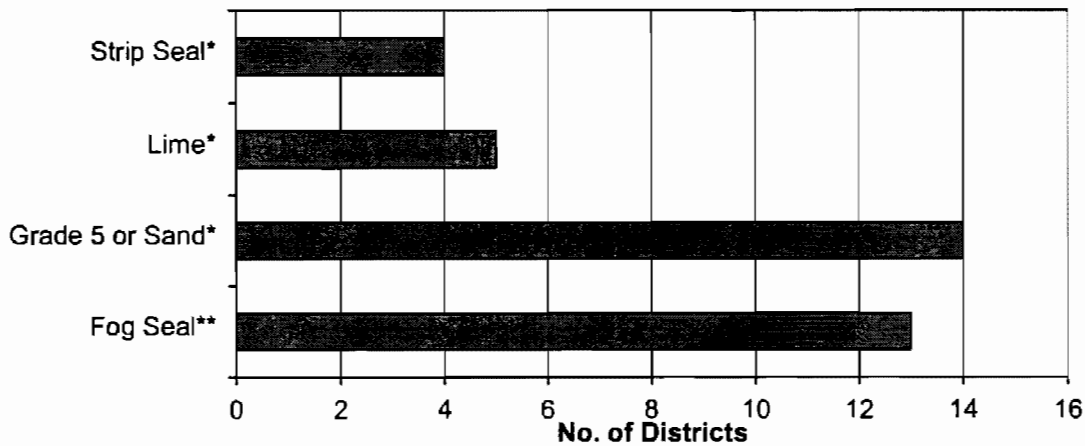


Figure 4.29. Predominant Distresses Type

Figure 4.29 indicates that flushing, by far, is the predominant distress and it appears that more effort should be spent to minimize it. Some districts equally experience both flushing and shelling problems. One district responded saying that their predominant stress is cracking. The severity of distresses changes from district to district. Some districts indicated that flushing is more critical since it significantly decreases skid values. Others expressed that they would prefer flushing instead of shelling.

Question 60. How do you rectify the distresses?



\* methods to rectify flushing  
 \*\* methods to rectify shelling

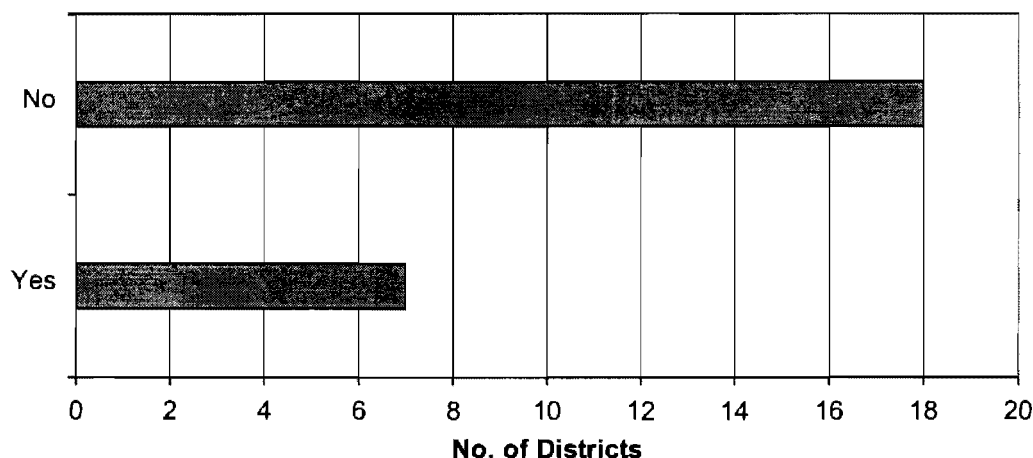
Figure 4.30. Methods Used to Rectify Seal Coat Problems

Figure 4.30 presents the methods used to rectify flushing and shelling problems. The only method used against shelling is the application of fog seal. The most popular rectification method used against flushing appears to be the application of sand or Grade 5 rock on the existing surfaces. However, some districts expressed their doubts about the effectiveness of this



method since additional particles may further go down resulting in even more flushing. Another treatment against flushing or bleeding is the application of lime-water, which is sprayed on flushed sections. If flushing is severe, some districts adopt strip sealing practices for wheel path areas.

*Question 62. How often do you inspect the performance of your seal coats?*



**Figure 4.31. Formal Post-Contract Inspection**

Figure 4.31 shows the districts that conduct a formal post-construction inspection just after the completion of the project. This would enable the districts to find out what worked and what did not. Eventually, best practices can be replicated to attain a consistent seal coat program. Figure 4.31 shows that it is not common for districts to have such an evaluation. However, this is easy to implement and it may enable the district personnel to have better control over the final product, particularly if it were done by the chief inspector. The design team would also benefit from such a constructibility approach. This practice can also help maintenance personnel since they are responsible for the maintenance of the road after the seal coat operation.

**Continuous Improvement**

The last section of the structured interview addressed continuous improvement efforts of the seal coat program such as partnering or periodic seal coat program evaluation meetings. One of the most informative questions in the interview encouraged the district personnel to express their individual opinions on the binder and aggregate selection if money were not a problem. In addition comments on the how to improve the seal coat program were made at this stage of the interview. The recommendations included, among others, remarks on design and road selection processes and construction related issues.

Finally, district personnel were requested to state their particular interest areas they would like to be emphasized during the planned seal coat seminar during the second year of the study.

Question 64. What CI methods are used (or planned) to improve the quality of your seal coats?

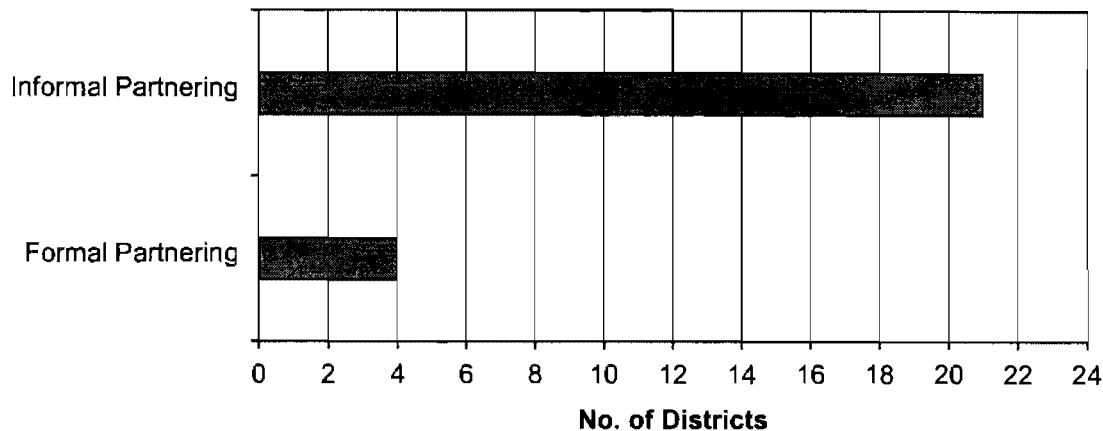


Figure 4.32. Partnering of Seal Coat Projects

Figure 4.32 shows that only four districts adopted formal partnering methods for seal coat projects. These districts use formal partnering with new contractors who conduct business for the first time in the district. The most common practice appears to be the conduct of informal partnering sessions similar in many ways to the conventional preconstruction meeting. This method is highly effective if the district and contractor have past experience together. In such a situation, the two parties have a better understanding of each other's expectations and business methods. District personnel recommended that as a part of preconstruction meeting, the inspector and the contractor's superintendent should drive the roadway with the contractor prior to the construction. This way, parties would be able to see the actual situation on the site and agree on action to be taken in an informal setting. Road preparation activities, traffic control and variation of at site can be discussed in such a meeting.

### District Test Sections

As a part of the district seal coat program evaluation, a survey of several test sections within each district was performed. Typically, the research team spent one full day in each district with the morning session consumed by the structured interview, and the survey of test sections was conducted in the afternoon. The objective of the test section survey was to study a representative sample of the district seal coat work. Each district was given guidelines based on which the test sections were to be selected. It was requested that factors such as ADT, climatic conditions, binder type & grade, rock type & grade and the contractor be used in selecting sections. Districts were requested to strongly consider recently constructed seal coat sections so that the performance of these sections could possibly be monitored during the course of study. Each district typically provided a list of candidate sections from which 3-5 test sections were selected by the research team for a detailed analysis. However, the research team was able to look at other pavements around the districts while driving to test section locations. Typically, selected test sections were one or two years old, but there were also sections that were more than eight years old. The number of test sections surveyed from each district is shown in Table 4.2.

**Table 4.2.** Number of Test Sections in Each District

| Districts      | Number of Test Sections |
|----------------|-------------------------|
| Abilene        | 5                       |
| Amarillo       | 5                       |
| Atlanta        | 6                       |
| Austin         | 6                       |
| Beaumont       | 5                       |
| Brownwood      | 4                       |
| Bryan          | 4                       |
| Childress      | 4                       |
| Corpus Christi | 3                       |
| Dallas         | 4                       |
| El Paso        | 4                       |
| Fort Worth     | 6                       |
| Houston        | 3                       |
| Laredo         | 3                       |
| Lubbock        | 4                       |
| Lufkin         | 4                       |
| Odessa         | 4                       |
| Paris          | 6                       |
| Pharr          | 5                       |
| San Angelo     | 4                       |
| San Antonio    | 3                       |
| Tyler          | 3                       |
| Waco           | 6                       |
| Wichita Falls  | 6                       |
| Yoakum         | 6                       |

These site visits provided the research team with a valuable opportunity to see firsthand, the performance of the district seal coats. During most visits, the researchers were accompanied by at least one district representative. This enabled the research team to obtain the district perception of the quality of each seal coat section by asking the district representative(s) to rate the seal coat quality and performance on a scale from 1 to 5, with 5 being the best. This ranking was recorded along with data relating to the test section including digital images of the pavement. Pavement surface condition was recorded for posterity using a digital camera. Data requested on each test section included details on section location, design, materials, and the construction process. This information was entered in a Microsoft Access<sup>®</sup> database for further analysis.

Typically, five images were recorded for each test section. These included a macro image of the roadway, a sectional close-up of the roadway and close-up images of the shoulder, wheel path and the area between wheel paths. These images are intended to serve two functions. First, they served as the record of actual surface conditions at the time of visit. Secondly, these images

were processed to quantify the condition of the seal coat section. It should be noted that this portion of the study was not an integral part of the current research program. However, the research team used the opportunity to leverage technology already developed as a part of another TxDOT research study to improve seal coat condition evaluation procedures without significantly diverting the resources assigned to this project. This image analysis was aimed at providing a quantitative measure of the seal coat quality. The overall quality of a seal coat section is highly variable and the images that were taken by the research team represented the condition of only a small portion of the pavement. Therefore, an overall assessment of the whole seal coat section will only be possible after a statistically significant number of images are processed within a specific seal coat job. Preliminary processing of the image data using an edge detection algorithm showed that these images could be used to objectively quantify the seal coat condition by developing a metric (a number) for each processed image. These numbers were compared with the visual observations recorded from that seal coat section during field visits. It was also observed that quantitative measures obtained from the analysis pavement images from seal coats with different performance levels showed a significant difference. In other words, using this image analysis technique, one could classify the seal coat quality into categories such as satisfactory, flushed, or shelled seal coats. Such information can be used effectively during the prioritization of candidate roadway surfaces to be sealed.

The image processing part of the study was only extended up to a point where it did not interfere with the activities listed under this research. This research team is confident that an automated image analysis technique such as the one described above could be developed to evaluate the seal coat condition that, in turn, can be used in a seal coat performance monitoring program. This could save valuable time of maintenance supervisors and seal coat inspectors.

A preliminary analysis was conducted using the data collected from test sections, and its results are included in Appendix D.

## CHAPTER 5. SEAL COAT EQUIPMENT

### EQUIPMENT FEATURES

Seal coat quality is depends heavily on the availability and proper usage of appropriate equipment. Understanding the capabilities and limitations of each piece of equipment helps to attain a quality seal coat product. The following types of equipment are used in a seal coat construction project:

- Asphalt distributor
- Aggregate spreader
- Haul trucks
- Rollers
- Rotary broom
- Asphalt Transporter
- Heater and storage unit
- Miscellaneous equipment

#### **Asphalt Distributor**

The asphalt distributor is the most complex piece of equipment in seal coat work. An asphalt distributor is a truck-mounted, insulated tank, with numerous special purpose attachments. Its major components are:

- Asphalt tank
- Heating system
- Circulation and pumping system
- Spray bar
- Hand sprayer
- Controls and gauges

#### *Asphalt tank*

The most common tank sizes used in seal coat work are between 1,000 and 2,000 gallons. The tank is insulated to prevent the asphalt from cooling since the correct temperature of asphalt binder is important especially when dealing with asphalt cements that require a temperature of at least 300°F. The stabilization of liquid asphalt in the tank while the distributor is in motion is assured with the help of two or three baffle plates. This is particularly important because a constant spray pressure across the bar is necessary.

In addition to the baffle plates, the tank is equipped with one or two flues – heat ducts running lengthwise of the tank. These flues in conjunction with a burner system allow uniform heating of the asphalt. The temperature level of asphalt can be closely monitored using a thermometer installed in the side of the tank. Most thermometers have a range from 100-400°F and fit most seal coat project needs.

One particularly important measuring activity is strapping the distributor with a calibrated dipstick to measure the asphalt level in the tank. This measurement sets the basis for asphalt quantities used in a particular seal coat shot.

#### *Heating system*

Asphalt temperature is critical for the success of a seal coat. It is recommended that asphalt temperature should be kept within 15°F of the temperature specified by the Engineer. To maintain these close tolerances, a heating system is necessary. Depending upon the make and size of distributor, one or two gas or oil fired burners are used. These burners are mounted on the platform at the rear of the tank, and are positioned so the flame is directed into the flues that pass through the tank.

The need for heating the asphalt depends on the type of the asphalt, weather conditions, whether the tank was filled directly from heated storage and the time asphalt spent in the tank before it was shot if asphalt was carried some distance in an insulated transporter. For example, most emulsions may not require heating if used within a few minutes.

#### *Distributor circulation and pumping system*

All asphalt distributors are equipped with a power-driven pump to spray asphalt under pressure onto the roadway. The pumps also serve as a circulation system. The circulation and pumping system can be powered by either a separate diesel engine mounted on the platform at the rear of the tank or directly from the truck engine to operate the pump.

Asphalt is circulated and pumped throughout the tank for several purposes including uniform heating of asphalt, preventing the cooling and hardening of the asphalt remaining in the distributor bar, pumping the remaining asphalt in the tank and filling the distributor tank in case the transporter is not equipped with a pump.

#### *Distributor spray bar*

The spray bar is an extremely important component of the asphalt distributor because the bar height and spray nozzles regulate the amount of asphalt sprayed and the spray pattern. It is composed of a series of spray nozzles evenly spaced along the width of bar. Asphalt circulation within the distributor is facilitated by the use of a return bar that takes asphalt from the end of spray bar back to the tank. In some cases chains may be attached to both ends of the spray bar to stabilize it while the distributor is in motion.

Spray nozzles are manufactured with different sized openings to permit different amounts of asphalt to pass through in a given amount of time. The apertures on the bar ensure a fan shaped spraying pattern rather than a circular one. Moreover, the nozzle angle is crucial to attain the desired angle between the fan shaped spray and the axis of spray bar. This angle may vary among different spray bar manufacturers, but generally it is between 15° and 30°. All nozzles must be set at the same angle to avoid distortion of the spray pattern.

Another important factor to attain the desired pattern of asphalt is the height of the spray bar. The height of bar above the roadway surface determines how wide the fan spreads. Seal coat jobs require either double or triple lap coverage; double lap being pattern from one nozzle overlaps half of the spray pattern of the nozzles on both sides of it. In a triple lap, however, the pattern from one nozzle overlaps two thirds of the pattern of the nozzles on both sides of it plus one third of the pattern put out by the nozzles two positions away.

The stabilization of the distributor springs is very important because same spray rate is desired when the tank is both full and empty. If not stabilized, the spray bar would rise with the decreased weight on the springs. To avoid inconsistency of the spray bar coverage, most distributors are equipped to either prevent springs from compressing under a load or to prevent them from arching back with a near-empty tank. Most of the time, stabilization is achieved with compressed air.

### *Distributor controls and gauges*

The distributor controls and gauges must function accurately because the precise amount of asphalt delivered onto the roadway is a key element to obtain quality seal coat. Many controls and gauges are used to assure the consistency and accuracy of the asphalt rates. Included among them are the thermometer, volume gauge, dipstick, pump pressure and bitometer. Although it is possible to monitor asphalt quantity in the tank with the volume gauge, this should never be used as a basis for payment due to low reliability of such devices. Instead a calibrated dipstick for each distributor tank should be used to measure the volume. The pump pressure and speed gauges are critical devices since asphalt pressure will greatly influence the uniformity of the job. If the pressure is too low, asphalt tends to streak. If the pressure is too high, asphalt will atomize and the pattern will be distorted. As a rule of thumb, the pump should be operated at the highest pressure without atomizing the asphalt.

The bitometer is used to maintain the desired distributor speed. It consists of a small wheel mounted behind the driver's door and it measures feet per minute that is converted from the number of revolutions per minute. An instrument in the cab is attached to the wheel that displays the speed of the vehicle. The distributor driver is responsible to ensure consistent performance of pump pressure as well as distributor speed.

### **Aggregate Spreader**

Another important piece of equipment used in seal coat work is aggregate spreader or "spreader box". This piece of equipment is self-propelled and has a continuous feed feature. The spreader box receives aggregate from a haul truck, which dumps the aggregate into a receiving hopper at the rear of the spreader. A conveyor system transports the aggregate to another bin at the front of the vehicle. Gravity spreads the aggregate evenly across adjustable gates. The gates allow precise amounts of aggregate to pass through. The major components of the aggregate spreader are the truck hitch, receiving hopper, belt conveyors, spreading hopper, discharge gates and the discharge roller.

### *Truck hitch*

To be operated properly, the haul truck should back up to the spreader, and a coupling on the spreader should engage one on the rear of the truck. The coupling should lock securely together and the spreader box should pull the truck. Therefore, the truck should not push the spreader box. This is particularly important because the amount of aggregate spread onto fresh asphalt is a function of the spreader speed. The hitch must be able to lock securely with the truck hitch, and the spreader box operator must be able to release it easily.

### *Receiving hopper*

Receiving hopper is filled with rock from the truck bed once the hitch is engaged. At the bottom of the hopper, there are openings which the belt conveyors must pass in a continuous loop.

### *Belt conveyors*

Two belt conveyors carry the rock load from the receiving hopper to the spreading hopper.

### *Spreading hopper*

The spreading hopper receives aggregate from the belt conveyors and distributes it laterally in the hopper. This is realized by the aggregate falling over two angular (pyramid-shaped) devices at the top of the spreading hopper.

### *Discharge gates*

At the bottom of the discharge hopper are a series of discharge gates that can be opened by the operator controlling the aggregate discharge. Each gate can also be opened or closed individually by levers located at the top and in front of the discharge hopper.

### *Discharge roller*

A roller at the bottom of the discharge gate spins to assure an even flow of aggregate onto the asphalt. This is to ensure an even amount of aggregate is spread laterally across the pavement.

## **Rollers**

Once the asphalt has been sprayed and covered with a layer of aggregate, the seal coat must be rolled. This is important to adjust the orientation of the aggregate such that its flattest dimension is vertical and that the aggregate is seated firmly into the asphalt binder. Therefore, rolling equipment is important to the final outcome of the project. This discussion will focus only on pneumatic rollers although flat wheel rollers are also being used by a couple of districts. Steel wheel rollers are avoided in most of the seal coat projects because steel drums tend to crush the aggregate on the high spots across the lane. This crushing may be much more severe if a lightweight aggregate is used. In addition, the steel wheel rollers may not seat the aggregate that



is placed lower parts of ruts. However, it should be reminded that seal coat is not a recommended alternative if rutting is observed on the existing roadway surface, in the first place.

Pneumatic rollers operate on rubber air-inflated (pneumatic) tires. The tires, themselves, provide the force needed to seat the aggregate firmly in the asphalt binder in a uniform arrangement. Pneumatic rollers should be self-propelled and should also be capable of operating in both forward and reverse. There are two types of pneumatic rollers, lightweight and medium-weight, that are grouped in terms of their weight.

Rollers should be capable of ballast loading to uniformly vary the total vehicle weight from 9,000 pounds or less to 18,000 pounds or more. Contact pressure exerted by each tire on the roller is a more accurate measure than the total roller weight. Contact pressure is a function of the following combination of factors:

- Total vehicle weight
- Number of tires on the roller
- Tire size and ply rating
- Tire inflation pressure

TxDOT specifications require that for a light pneumatic roller, a minimum contact pressure of 45 pounds per square inch is required. All tires must have a uniform and smooth contact area with the ground. In addition, all tires must be inflated so that variation in inflation pressure is no more than 5 psi from one tire to the next. Maintaining a uniform and desired inflation pressure is very crucial to obtain quality seal coat because if the tire is soft, it will not seat the aggregate as firmly as the other tires, and this could result in the aggregate in that path stripping away under traffic.

Specifications require that light pneumatic rollers have a minimum of nine tires. Most are manufactured with 5 wheels in the front and 4 in the rear. The rear wheels are the drive wheels whereas the front wheels are the steering wheels. Another requirement for light rollers is to cover an area approximately 60 inches on each pass. The rear tires must be offset to provide coverage of the areas between the front wheels.

Another important operating factor is the wobble-free operation of the wheels. All rollers must be capable of smooth operation, especially when turning, stopping and starting. Such inconsistencies in seal coat rolling operations would directly impact the end quality.

Medium rollers are required to have a gross weight between 23,500 and 50,000 pounds. There must be no less than 7 wheels, with contact pressure specified at either 85 or 90 psi depending on roller type. The effective rolling width must be approximately 84 inches.

## EQUIPMENT REQUIREMENTS

Three of the seal coat equipment mentioned in the previous section play a crucial role in determining the efficient and sustained production of the seal coat system. These are the distributor, aggregate spreader and the rollers. To achieve maximum rate of production, the production rates of the spreader and the rollers must be greater than that of the distributor. The distributor controls the overall production because no other piece of equipment can begin to produce its function until the distributor has applied the binder to the surface. Therefore, to ensure a high standard of quality control, all other equipment systems must be able to keep up with the production rate of the distributor. Observations in the field confirm that distributor sets the pace for the rest of the equipment spread. If the production rate of any other equipment is less than that of the distributor, the seal coat quality will suffer.

Both the structured interview and the field observations indicated that seals coats may not be getting sufficient rolling in many projects. In the districts that adopted a rolling rate requirement, general notes indicated that the rolling rate varied from a high of 1000 square yards per hour to a low of 5000 square yards per hour. Interview data showed that the average equipment spread contained three medium pneumatic rollers. Manufacturer data sheet for Dynapac Model CP132 medium-weight pneumatic roller indicated that it is a nine-wheel roller with an effective rolling width of 69.3 inches. Assuming a shot width of 12 feet, the following equipment requirement analysis was conducted for the critical equipment in the seal coat process.

In this analysis, as it is observed in practice, production rates of the aggregate spreader and the distributor are taken to be equal. Since the distributor dictates the overall seal coat production rate, its production rate can be used as the overall system production rate. If there is a minimum rolling time requirement stipulated for a seal coat project, if sufficient rollers are not provided, the rollers will lag behind the asphalt distributor and aggregate spreader. The rollers will eventually complete the job, but the delay may result in lower embedment of the aggregate. The following computational procedure illustrates how the roller requirement can be calculated for efficient system production without compromising the quality. Figure 5.1 shows the plan view of a typical rural two-lane roadway (with shoulders) section that will be used to illustrate the computational procedure.

### Calculation of Roller Requirement

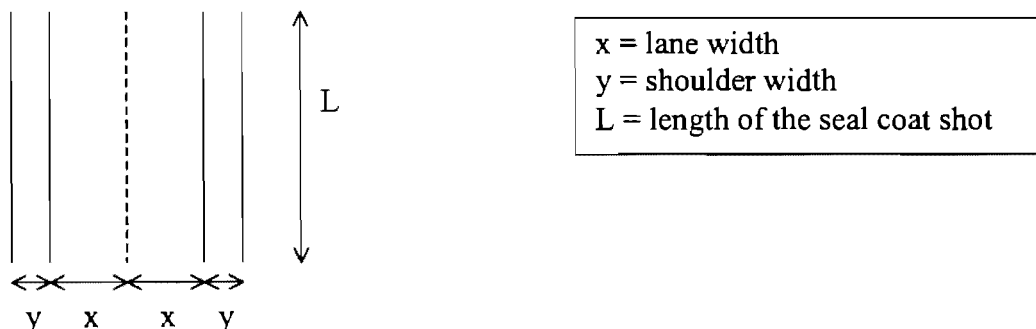


Figure 5.1. Typical Seal Coat Roadway Geometry

Considering that required rolling rate per hour is  $A$ , the following relationship can be established for the area to be rolled.

$$A = xL \quad \text{Eq. 5.1}$$

The time,  $t$ , it takes for each roller pass to cover the distance  $L$  can be calculated using Eq. 5.2, where  $V_r$  is the roller speed. Rollers typically have dual gears and the desired speed can be used in the calculation. The roller requirement would indicate the minimum number of rollers, traveling at a fixed speed, needed to meet the rolling rate requirement established by the distributor production rate.

$$t = \frac{L}{V_r} \quad \text{Eq. 5.2}$$

Using the rolling time for one pass,  $t$ , calculated above, total time spent by all rollers per single pass,  $T$ , can be calculated by simply multiplying the rolling time for one roller,  $t$ , by the number of rollers,  $N$ , that are utilized in the rolling process (Eq. 5.3).

$$T = tN \quad \text{Eq. 5.3}$$

The required number of passes,  $NP$ , can be calculated using Eq. 5.4 where  $H$  is the rolling time unit. Since, typically, the rolling time requirement is specified per one hour,  $H$  would be 1 hour.

$$NP = \frac{H}{T} \quad \text{Eq. 5.4}$$

Production rate of the rollers,  $P_r$ , can be expressed in linear miles per hour, and it will be a function of the number of passes made by the each roller, as shown in Equation 5.5.

$$P_r = \frac{V_r}{NP} \quad \text{Eq. 5.5}$$

By combining Eqs. 5.1 through 5.5, the roller production rate,  $P_r$ , can be expressed as a function of the number of rollers,  $N$ , as shown in Eq. 5.6.

From Eqs. 5.4 and 5.5,

$$P_r = \frac{V_r T}{H}$$

Combining with Eq. 5.3,

$$P_r = \frac{V_r t N}{H}$$

Combining with Eq. 5.2,

$$P_r = \frac{V_r LN}{HV_r} = \frac{LN}{H}$$

Combining with Eq. 5.1,

$$P_r = \frac{AN}{xH} \tag{Eq. 5.6}$$

### *Distributor Speed, $S_f$*

Distributor speed,  $S_f$ , in feet per minute, for the desired binder rate can be calculated from Eq. 5.7 where  $G_t$  is the spray bar output (gal/min),  $W$  is the shot width (ft) and  $R$  is the rate of binder application (gal/sy).

$$S_f = \frac{9G_t}{WR} \tag{Eq. 5.7}$$

Distributor speed,  $S_f$ , can be used to represent the distributor production rate if production is considered in terms of length per unit time. This works well for matching the roller production rate to compute system production. In practice, the distributor controls production of all other components in the system. Therefore, the production rates of the chip spreader and the roller fleet must be greater than or equal to the production of distributor. If this is not the case, either the distributor will have to reduce its production or other equipment will not be able to produce the required level of quality. Observations in the field confirm that the distributor actually sets the pace for the entire system. Therefore, the relationship between roller and distributor production rates can be expressed by Eq. 5.8.

$$P_r \geq P_D \tag{Eq. 5.8}$$

If the system production is defined in terms of linear miles per hour, distributor production,  $P_D$ , is equal to distributor speed,  $S_f$ . It should be noted that production rates shown in Eq. 5.8 are instantaneous production rates. In other words, this is an ideal condition for both the distributor and the roller. Using instantaneous production as the parameter of comparison yields a conservative solution by ensuring that the “best” production of the roller is greater than or equal to the “best” production of the distributor.

### *Case Study*

The following case study illustrates the above procedure by using actual values for parameters. Some of the parameters used in the illustration are given below. The parameter list is followed by the calculation steps.

- Dynapac CP 132 type roller is used. This roller has two gears producing speeds of 6.2 and 12.4 miles per hour, and the lower speed of 6.2 mph is used for calculations. Roller width is 69.3 inches.
- Roadway lane width,  $x$ , is 12 feet and shoulder width,  $y$ , is 10 feet.
- Rolling time requirement is 5000 square yards per hour. This value is the least restrictive rolling time requirement used by districts.
- Number of rollers is three.
- Distributor production rate is calculated based on a spray bar output of 90 gal/min.
- Design binder application rate is 0.33 gal/sy.

$$L = \frac{A}{x} = \frac{5000 \frac{yd^2}{hour}}{4 \text{ yards}} = 1250 \text{ yards}$$

$$t = \frac{L}{V_r} = \frac{1250(yd)}{6.2(mph)1760 \frac{yd}{mile}} = 0.115 \text{ hours}$$

$$T = tN = 0.345 \text{ hours}$$

$$NP = \frac{H}{T} = \frac{1(hr)}{0.345(hr)} = 2.17 \text{ passes}$$

Therefore, NP can be rounded up to 3, which is the nearest odd number and the number of passes has to be an odd number.

$$P_r = \frac{V_r}{NP} = \frac{6.2}{3} = 2.07 \text{ linear miles per hour}$$

It should be noted that the roller production rate of 2.07 miles per hour, obtained using 3 passes of 3 rollers, should provide the required rolling rate of 5000 square yards per hour. Using this value, the distributor production rate can be calculated as shown below.

$$S_f = \frac{9G_t}{WR} = \frac{(9)(90)}{(12)(0.33)} = 2.33 \text{ linear miles per hour}$$

Therefore, the roller production rate,  $P_r$ , is less than the distributor production rate,  $S_f$ . Since this is not the desired outcome, the required number of rollers,  $N$ , can be calculated using Eq. 5.6.

$$N = \frac{P_r x H}{A} = \frac{2.33 \frac{miles}{hour} \cdot 4 \text{ yards} \cdot 1760 \frac{yards}{mile}}{5000 \frac{yards}{hour}} = 3.28 \text{ rollers}$$

Therefore, 3.28 can be rounded up to give a roller requirement of 4 rollers. The above calculations show that production rate of three medium pneumatic rollers is less than the production rate of the distributor, and therefore, the rollers would lag behind the distributor. This situation will be observed if the rollers strictly travel at 6.2 mph in order to comply with the required rolling requirement. On the other hand, rollers may accelerate to keep up with the distributor by shifting to the higher gear. However, this may reduce the rolling efficiency and the required aggregate embedment may not be achieved. This could lead to aggregate loss.

Looking at this production mismatch between the rollers and the distributor when three rollers are used, every hour, the rollers would fall behind the distributor by about a quarter mile. At the end of a typical 12-hour workday, the rollers should be three miles behind the rest of the equipment if they are strictly adhering to the rolling time requirement, and they would have to continue to roll for another hour and a half before they could shut down for the night. Obviously, this is not happening in the field. The rollers are expected to keep up with the distributor, and the distributor is allowed to achieve its maximum sustained production. During one district interview, a seal coat contractor stated that if he shot 50,000 gallons or 100,000 gallons in one day, the same number of rollers would somehow keep up with the distributor, probably at the expense of rolling efficiency and coverage. TxDOT personnel present at that interview agreed that this happens often due to the inspection forces being busy and not being able to keep a close eye on the rolling operation. Therefore, it is extremely important to have a sufficient number of rollers available to provide a rolling production rate that matches or exceeds the production of the distributor. In the above example, four medium pneumatic rollers are required to achieve a production rate equal to the distributor. Thus, the roller team will be able to keep up with the distributor without violating the rolling time requirement.

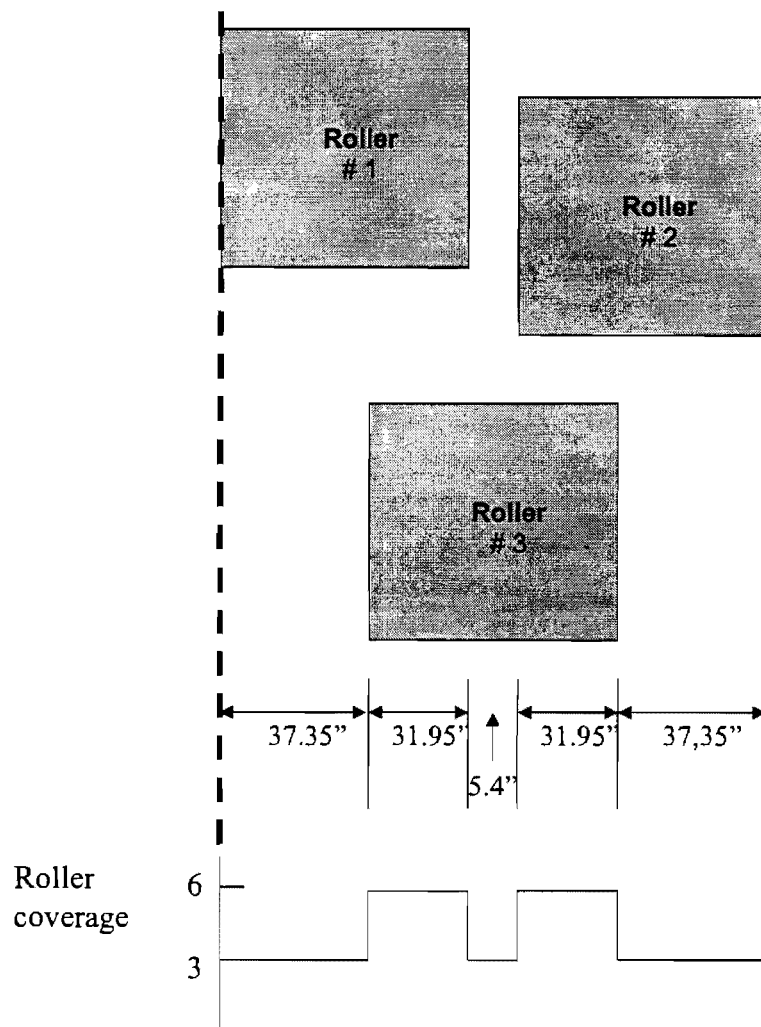
When one considers that some districts have more restrictive rolling time requirements, the value of the above set of calculations is greatly enhanced. A point to be made is that the purpose of rolling is to achieve the desired aggregate embedment depth. It achieves this by redistributing the aggregate and seating it in the binder. During one interview, it was aptly pointed out that the roller moves individual rock particles around such that their center of gravity is in its lowest position.

### **Roller Patterns**

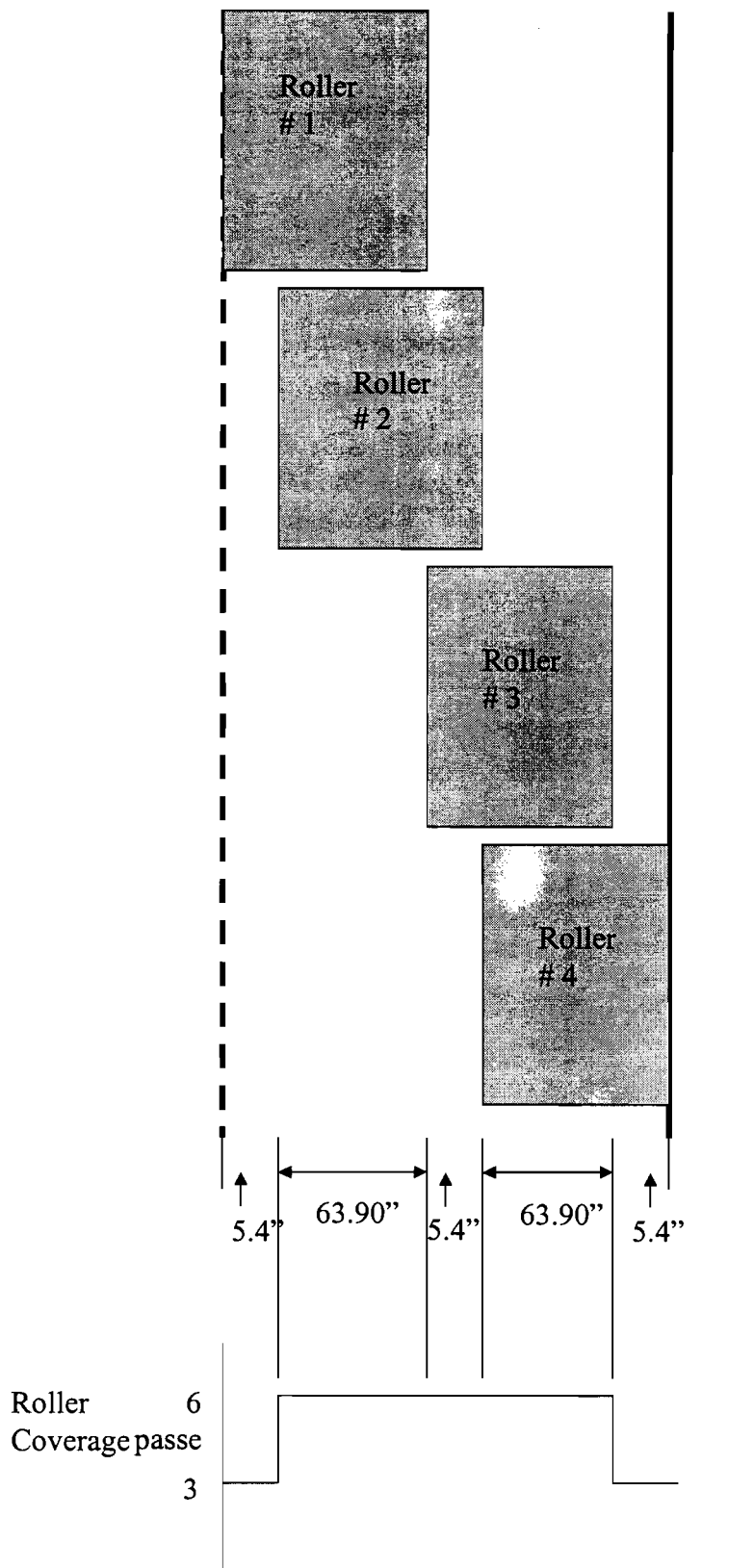
The above case study showed that a minimum of four medium-weight pneumatic rollers are required to match the distributor production rate for a rolling requirement of 5000 yd<sup>2</sup> per hour. This leads to a discussion of rolling patterns. The structured interview showed that the most common number of medium-weight rollers in use was three. The common rolling pattern was described as a staggered pattern with one roller on the centerline, one roller on the outside edge, and the third bringing up the center. Using the Dynapac CP132 roller from the previous example, the resultant roller pattern for three rollers in a staggered formation is shown in Figure 5.3. It can be seen that there are three regions across the lane that receive only three roller passes, two of which are roughly 37 inches wide on the outskirts of the lane and the third is about five inches wide between the wheel paths. The wheel path areas receive six passes. Field observations made by the research team showed that shelling is most prevalent in the areas between and outside of the wheel paths.

Additionally, considering the staggered rolling pattern, the first two rollers will tend to work excess aggregate to the center whereas the third roller flattens it out. This may tend to increase the aggregate density in the middle of the lane and further encourages shelling in the area between the wheel paths. On the other hand, a diagonal roller pattern working from one edge of the lane to the other, will work excess aggregate toward the shoulder of the road, and thus, should keep shelling problems between the wheel paths to a minimum.

As four rollers are required to achieve the necessary production rates, it is interesting to see the change in roller coverage going from 3 to 4 rollers. Figure 5.4 shows that by carefully stationing the four rollers, the coverage can be dramatically increased. In fact, it will result in six uniform passes across virtually the entire width of the lane. It only drops to three passes for two 5.4-inch strips at the center line and the outside edge of pavement. Thus, not only does the addition of one roller enable sufficient rolling time without sacrificing system production or seal coat quality, it also produces a superior roller pattern which virtually doubles the number of passes across the width of shot.



**Figure 5.2.** Staggered Pattern and Coverage for Three Medium Rollers



**Figure 5.3.** Diagonal Pattern and Coverage with Four Medium Rollers



## Conclusions Related to Rolling

The preceding analysis on rolling clearly presents how important it is to specify a minimum number of rollers in order to attain the required production level with desired seal coat quality. If the number of rollers is not specified, then either the rollers may lag the distributor in order to attain the desired rolling time or for the sake of keeping up with the distributors, they roll less amount of time on the roadway section.

Rolling is particularly important because it ensures the seating of the aggregate in place. It is evident that shelling is observed in the regions where aggregate embedment is typically poor, i.e. areas such as between wheel paths. With the diagrams that show three-roller and four-roller patterns (Figures 5.3 and 5.4), it was shown that four rollers produce a more uniform rolling distribution across the lane. The use of four rollers gives twice as much rolling than three rollers.

Therefore, in order not to sacrifice from quality and production rate, the district personnel should calculate equipment requirements such as minimum number of rollers and aggregate trucks. This can be easily handled during pre-construction meetings in coordination with the contractor.

## Calculation of Aggregate Supply Truck Requirement

The other equipment production issue that could potentially cause quality control problems is the dump truck/chip spreader relationship. As the chip spreader generally follows the distributor, its production can easily match that of the distributor if sufficient trucks are available to feed it. If there are not enough trucks, the chip spreader will lag the distributor allowing the binder to cool before application of aggregate, which may result in shelling due to lack of sufficient adhesion between the aggregate and the binder. The required number of trucks to maintain maximum sustained production can be calculated as follows.

*Length of Shot,  $L_A$*

Length of a seal coat shot is a function of the distributor capacity,  $T$ , width of the lane,  $W$ , and the design asphalt application rate,  $R$ . Equation 5.9 gives calculates the shot length.

$$L_A = \frac{9T}{WR} \quad \text{Eq. 5.9}$$

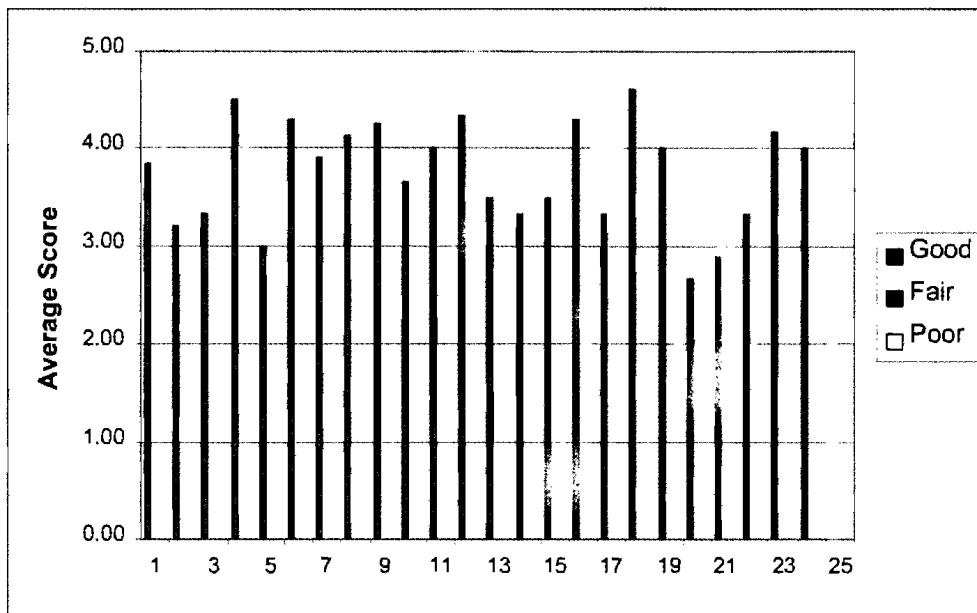
*Aggregate Spread Rate,  $L_R$*

The length of aggregate spread by a single truck load is a function of the truck capacity,  $Q$ , aggregate spread rate,  $S$ , and lane width,  $W$ , and can be calculated using Equation 5.10 where  $Q$  is expressed in cubic yards and  $S$  in square yards per cubic yard.

$$L_R = \frac{9QS}{W} \quad \text{Eq. 5.10}$$

*Case Study*

- Design method
- Use of variable binder rates across the lane
- Binder type
- Aggregate gradation
- Seal coat season
- Inspection crew size
- Post-contract evaluation



**Figure 6.1.** District Satisfaction of its Own Seal Coat Quality

Figure 6.2 shows the relationship between the district seal coat program size and the district self-evaluation of seal coat quality. It is clear that a larger seal coat program size does not necessarily translate into a system with better quality. Approximately a third of the districts with over 75 percent of their lane miles surfaced with seal coats indicated that they are not able to achieve the desired seal coat quality year after year. District interviews highlighted that due to the low-bid contract award system, it is impossible for districts to maintain a high quality seal coat program year after year even if the district personal are dedicated to quality.

Figure 6.3 shows a possible relationship between seal coat performance and the use of seal coats as a planned preventive maintenance activity. As stated earlier, there is only one district that strictly applies seal coat as a preventive maintenance activity. However, 12 other districts indicated that they strive hard to attain a PM cycle whenever funding is available. It can be seen from Figure 6.3 that with the exception of one district, all twelve other districts that follow a preventive maintenance cycle for seal coats are happy with their seal coat quality.

that the last truck in line travels the longest path. Therefore, Eq. 5.13 can be used to calculate the time it takes for the last truck to travel the distance  $X_{NT}$ , which is the most critical distance to be traveled.  $V_{tr}$  is the travel speed of the truck.

$$T_{\max} \geq \frac{X_{NT}}{V_{tr}} + T_{load} \quad \text{Eq. 5.14}$$

By substituting Eq. 5.12 to Eq. 5.14, number of trucks,  $NT_{\min}$ , can be solved using Eq. 5.15, which shows that required number of trucks is a function of truck speed, distributor production rate, rock land length and truck loading time. The loading time for each truck is assumed to be a constant.

$$NT_{\min} = \frac{L_R(V_{tr} - S_f) + T_{loading}(S_f)(V_{tr})}{L_R(V_{tr} - 3S_f)} \quad \text{Eq. 5.15}$$

These equations can be used to ensure that seal coat quality is not sacrificed through a lack of equipment at site. The rule to remember is that all equipment must have the ability to equal or exceed the sustained production of asphalt distributor. Field observations show that insufficient dump trucks, is not a common problem. However, as shots get farther from the stockpile, the required number of trucks increases. Therefore, it behooves inspection personnel to check to see if the trucks are able to adequately feed the chip spreader.

## CHAPTER 6. ANALYSIS OF STRUCTURED INTERVIEW DATA

This chapter identifies the possible relationship between various constructability parameters and seal coat quality. The biggest challenge in such an analysis is in the evaluation of a district's seal coat quality. In general, seal coat quality shows considerable variation between districts. However, the overall seal coat quality in a district was evaluated using three quality levels; poor, fair and good.

This seal coat performance evaluation was based on the level of consistency in district seal coats. If a district seal coat program consistently produces poor seal coats with only a few exceptions, that district was classified as having poorly performing seal coats. On the other hand, if a district seal coat program consistently produces good seal coats with only a few exceptions, that district was classified as having high performing seal coats. A district with a good seal coat program may occasionally have failures. However, such failures take place despite having construction and quality control methods similar to those seal coats that consistently produced quality seals. The third performance category, districts with fair seal coat performance, includes those districts that do not consistently produce seal coats that are either good or poor.

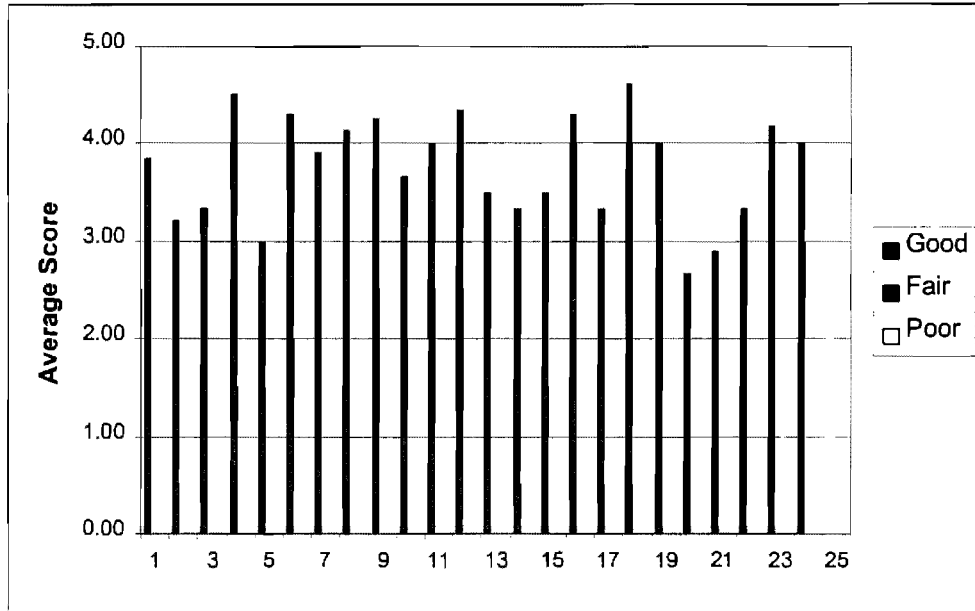
It should be noted that, the critical word used in the preceding set of definitions is consistent. District seal coat quality was evaluated based on qualitative visual examination. During structured interviews, districts were urged to make a self-evaluation of their seal coat quality. In addition, the research team was able to evaluate the district seal coats by observing the seal coat quality along the roadways they drove on. In Figure 6.1, district evaluation of its own seal coats is adopted as the basis for this analysis.

In order to decrease the subjectivity and bias of this evaluation, district self evaluation (poor, fair, good) is combined with the average score (on a scale from 1 to 5) assigned by the research team. Figure 6.1 shows the average scores of the 25 districts together with their self-evaluations. Only one district that evaluated its own seal coat program as *poor*. However, its score is not significantly lower than some other districts that have evaluated their seal coat as *fair*. Therefore, for the purpose of data analysis, the district self-evaluation was changed to *fair* that increased the number of *fair* answers to six. This data modification is in accordance with the researchers' perception of quality of seal coats in this district. In general, the districts that had a self-evaluation of *fair* had lower scores than the ones that classified their seal coat program as *good*.

Using the self-evaluations of district seal coat quality, charts were developed to relate the seal coat quality to important parameters that are likely to affect seal coat quality. These parameters include the following. Results of the analysis of seal coat quality based on these variables, is presented in the following pages.

- Extent of seal coat surfaces in district
- Use of seal coat as a preventive maintenance tool
- Size of in-house seal coat program
- Level of decentralization
- Level of contractor competition

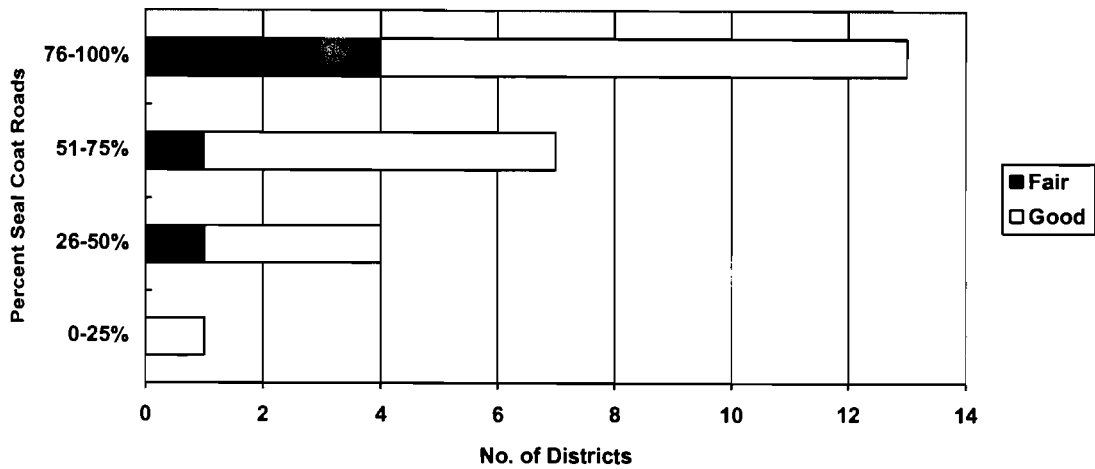
- Design method
- Use of variable binder rates across the lane
- Binder type
- Aggregate gradation
- Seal coat season
- Inspection crew size
- Post-contract evaluation



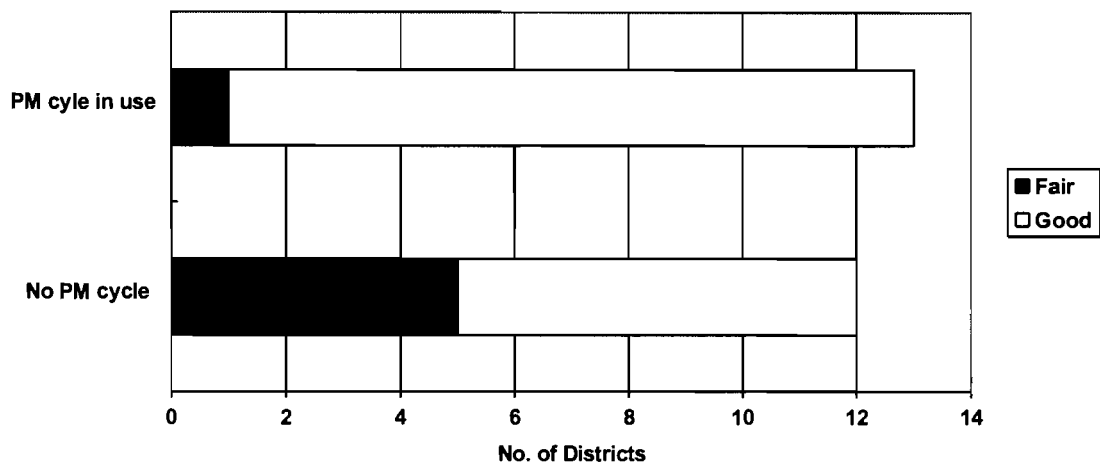
**Figure 6.1.** District Satisfaction of its Own Seal Coat Quality

Figure 6.2 shows the relationship between the district seal coat program size and the district self-evaluation of seal coat quality. It is clear that a larger seal coat program size does not necessarily translate into a system with better quality. Approximately a third of the districts with over 75 percent of their lane miles surfaced with seal coats indicated that they are not able to achieve the desired seal coat quality year after year. District interviews highlighted that due to the low-bid contract award system, it is impossible for districts to maintain a high quality seal coat program year after year even if the district personal are dedicated to quality.

Figure 6.3 shows a possible relationship between seal coat performance and the use of seal coats as a planned preventive maintenance activity. As stated earlier, there is only one district that strictly applies seal coat as a preventive maintenance activity. However, 12 other districts indicated that they strive hard to attain a PM cycle whenever funding is available. It can be seen from Figure 6.3 that with the exception of one district, all twelve other districts that follow a preventive maintenance cycle for seal coats are happy with their seal coat quality.



**Figure 6.2.** District Self-Evaluation of Quality vs. Extent of District Seal Coat Program

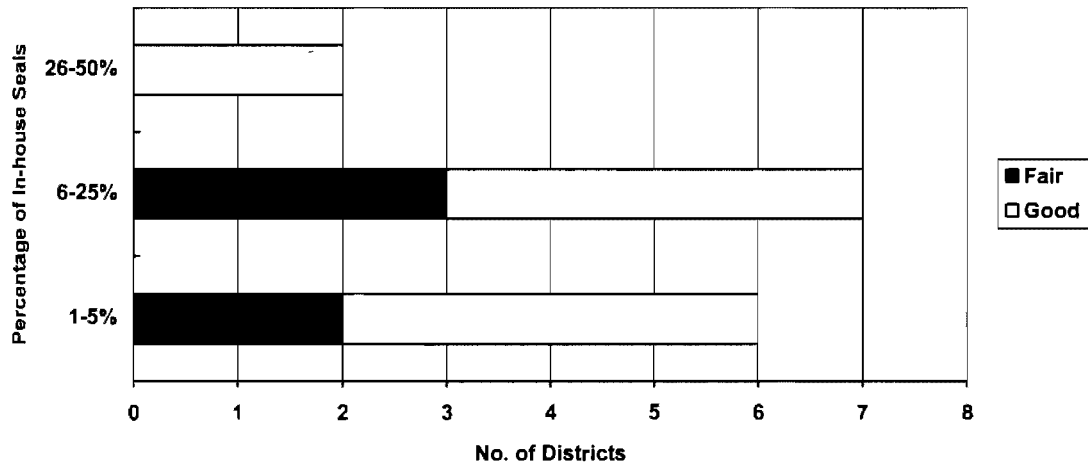


**Figure 6.3.** District Self-Evaluation of Quality vs. Use of Seal Coat as a Planned Preventive Maintenance (PM) Activity

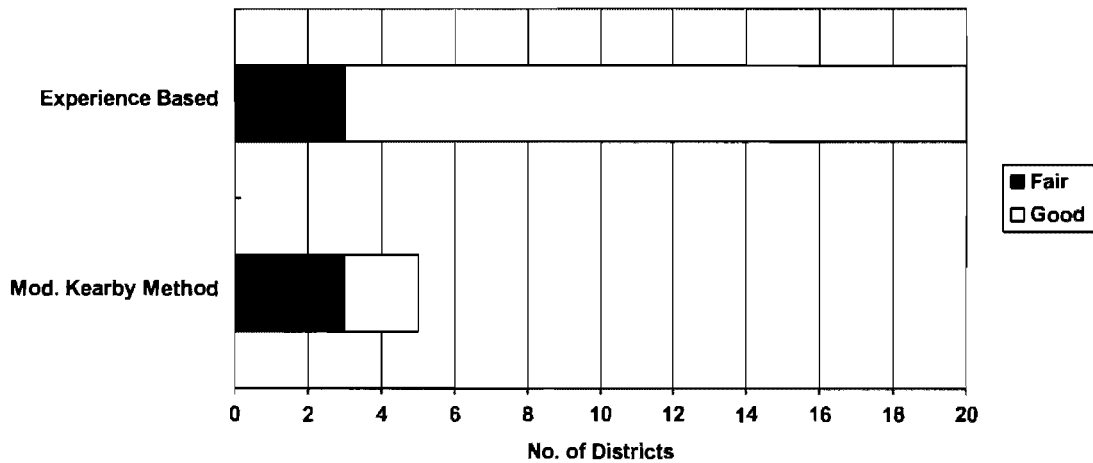
Figure 6.4 shows district self-evaluations on in-house seal performance. The two districts that conduct almost half their seal coat work in-house (Lubbock and Pharr) are satisfied with in-house seal coat quality and they appear to be happy to continue with that practice. On the other hand, districts which conduct less than 25 percent of their seal coats in-house does not appear to have a clear perception of good quality in-house work. Several reasons, including a lack of experienced seal coat personnel and equipment appear to have contributed to this perception.

Figure 6.5 shows how district seal coat quality relates to the design method used, and two things stand out. Most districts using experience-based design methods appear to be satisfied with their seal coat quality. Three out of the five districts that use modified Kearby method does not appear to be satisfied with their seal coat quality. Therefore, there is no clear evidence to suggest that the more scientific modified Kearby method would lead to better seal coats. However, this

may reinforce the notion that seal coat quality is significantly influenced by the construction-related factors, i.e. experience of contractor and the inspection personnel.



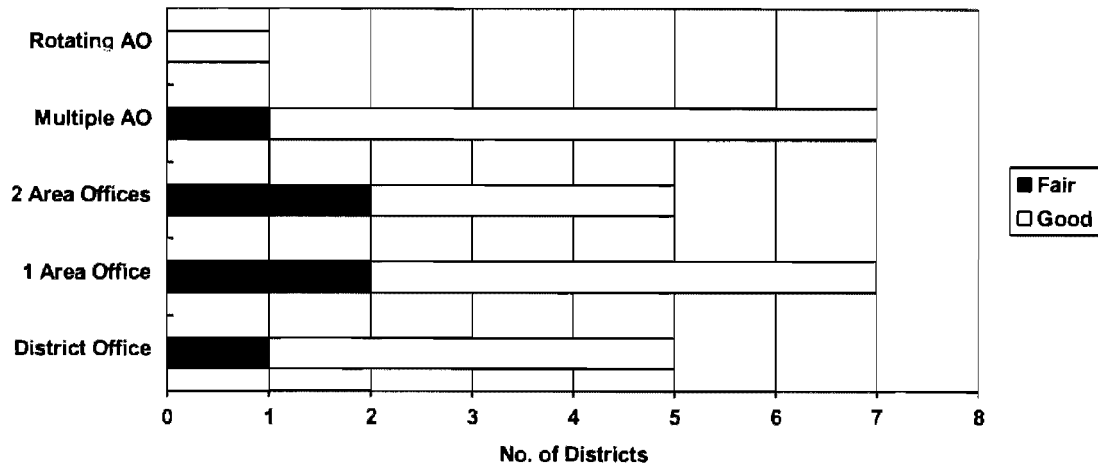
**Figure 6.4.** District Self-Evaluation of Quality vs. In-House Seal Coat Activity Level



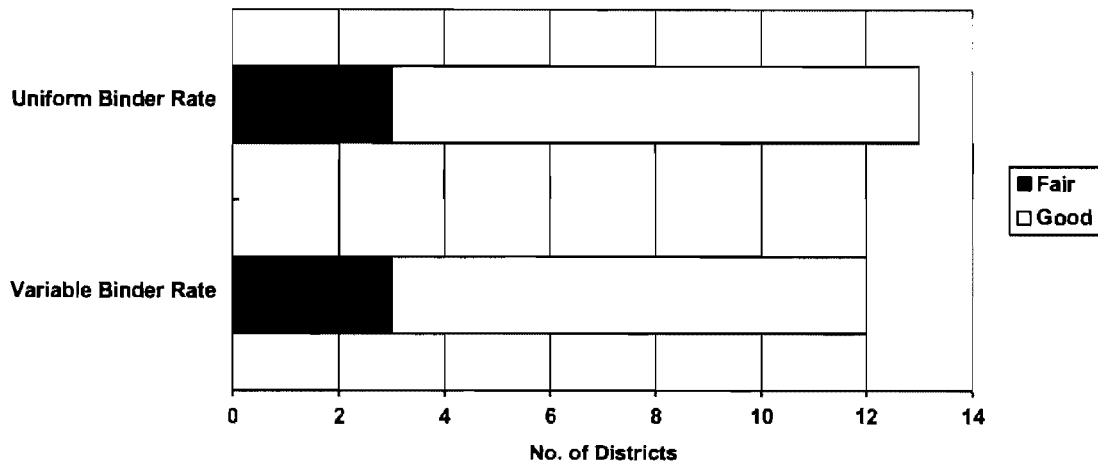
**Figure 6.5.** District Self-Evaluation of Quality vs. Design Method

Figure 6.6 shows how district seal coat quality may relate to how the districts handle design duties. There are two main approaches for the management of design among districts; centralized and decentralized. The data does not seem to provide any clear relationship between these seal coat quality and the way districts manage their design operations.

Figure 6.7 illustrates the relationship between seal coat quality and the variation of binder rate across the lane. It does not show any clear distinction in performance between the two practices. Each group, with approximately same number of districts, has three districts that are not pleased with the quality level of their seal coat.



**Figure 6.6.** District Self-Evaluation of Quality vs. Management of Seal Coat Design

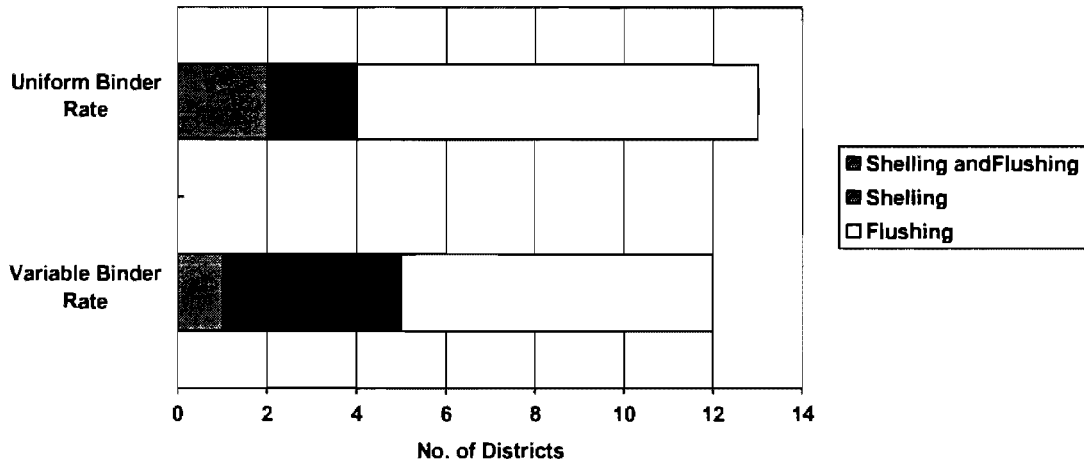


**Figure 6.7.** District Self-Evaluation of Quality vs. Variable Binder Rate Usage

Figure 6.8 relates the binder rate variation to the predominant type of seal coat distress. It does seem to suggest that districts that use variable binder rates have less flushing/bleeding problems than those using a uniform binder rate. However, those same districts with less flushing show more shelling/raveling. This may be due to interaction with other factors such as climate within district and the rolling practices. However, this may be one area where further investigations could be made.

Figure 6.9 shows that most districts are satisfied with the level of competition for seal coat contracts. Over 20 percent of districts that have adequate competition are not satisfied with their seal coat quality. This may further reinforce the notion that low-bid contract award method does make it difficult for districts to maintain a uniform level of quality year after year.





**Figure 6.8.** Predominant Distress Type vs. Variable Binder Rate Usage

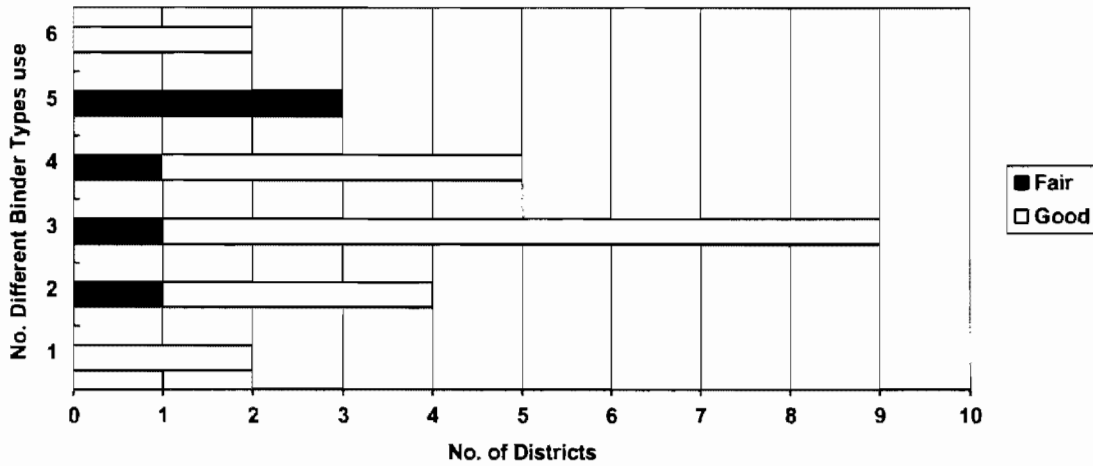


**Figure 6.9.** District Self-Evaluation of Quality vs. Level of Contractor Competition

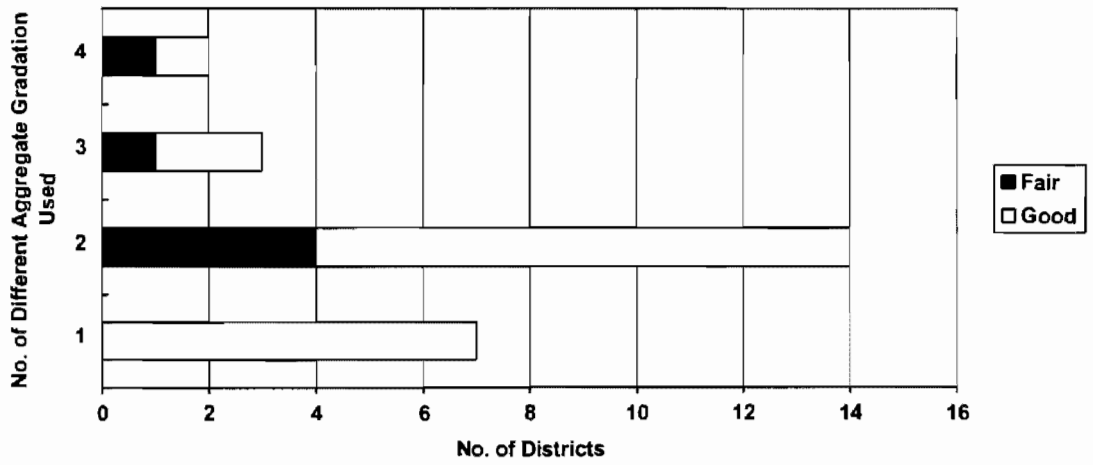
Figure 6.10 shows how the district self-evaluation of seal coat quality may be related to the number of binder types used in district seal coats. No data is available on the extent of usage for each binder type. Some districts may use one type of asphalt cement for most of their seal coat work and use different emulsion grades for small-scale in-house seals. However, this chart paints a general picture of district practice regarding the use of binder types. Many districts appear to be experimenting with a number of binder types. During the district interviews, it was revealed by several districts that it is much easier to manage seal coat quality with a smaller number of binders. Figure 6.10 appears to support this thinking because the higher the number of binders, the number of districts not fully satisfied with their seal coat quality increases.

Figure 6.11 shows how the seal coat quality is related to the number of different aggregate gradations used in each district. All districts that use one aggregate gradation are satisfied with the quality of their seals. During district visits, the researchers observed that all four gradation types – Grade 3, Grade 4, Grade 3 single size and Grade 4 single size – are all capable of

providing satisfactory seal coat performance under the right circumstances. However, as the number of used aggregate gradations increases, the number of different binders and binder rates also increase. This could decrease the degree of control seal coat inspectors have on final product quality and furthermore, the constructability learning process is also restricted.



**Figure 6.10.** District Self-Evaluation of Quality vs. No. of Different Binder Types Used

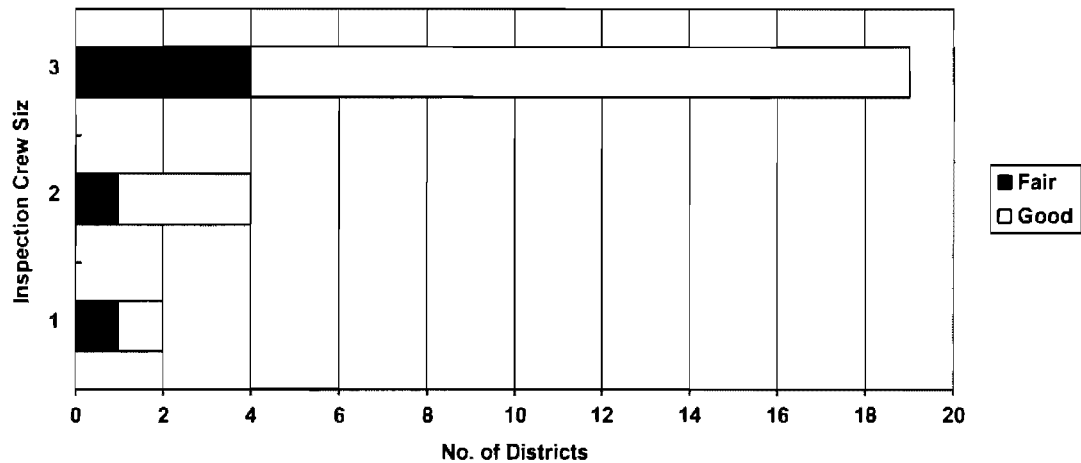


**Figure 6.11.** District Self-Evaluation of Quality vs. No. of Different Aggregate Gradations Used

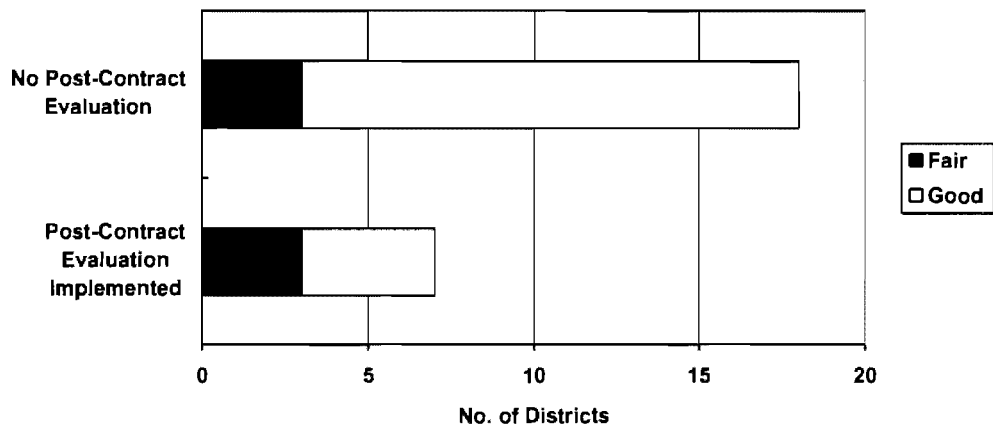
Figure 6.12 shows district seal coat performance when grouped by the size of inspection crew. Based on the information gathered from districts, the researchers strongly believe in the positive effect an experienced crew of at least three inspectors has on the seal coat quality. Since the success of a seal coat is mostly determined by construction practices and field adjustments, consistent allocation of at least 3 people to the inspection crew is essential.

Figure 6.13 shows that implementation of a post-contract evaluation process does not necessarily result in a quality seal coat. It should be noted that a post-contract evaluation does not

automatically guarantee quality seal coats unless a system is in place to facilitate the feedback of lessons learned. There was no evidence to suggest that all districts using post-contract evaluation had such a system in place. It can be concluded that generally, districts that are not satisfied with the seal coat quality is inclined to establish a contract evaluation process in order to better their seal coat quality. Throughout the survey, the importance of learning from past experiences was mentioned at several districts, along with the idea of continuous improvement.

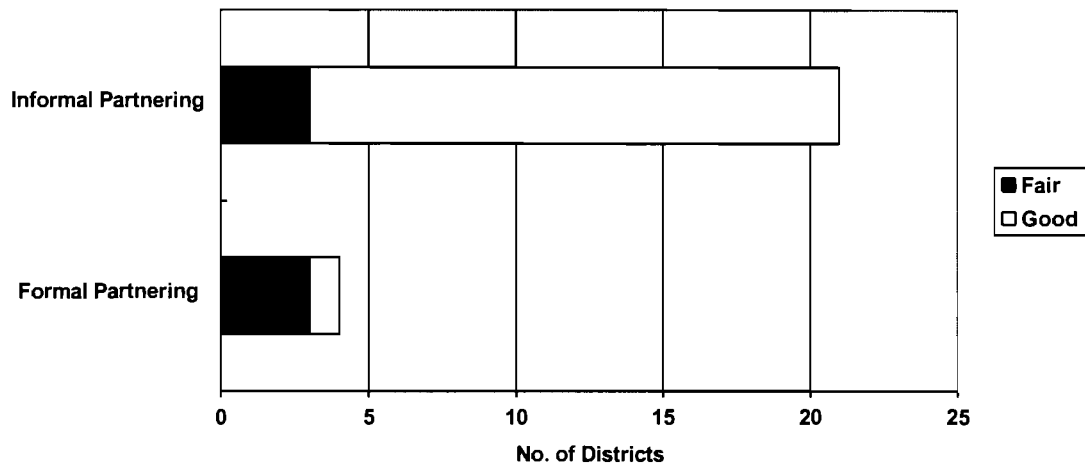


**Figure 6.12.** District Self-Evaluation of Quality vs. Inspection Crew Size



**Figure 6.13.** District Self-Evaluation of Quality vs. Implementation of Post-Contract Evaluation

Figure 6.14 indicates that three out of four districts that formally partner their seal coat projects are not satisfied with their seal coat quality. This is particularly interesting because these districts seem to partner their seal coat projects to enhance their overall seal coat quality. Districts appear to implement a formal partnering scheme to improve inconsistent or poor seal coat performance.



**Figure 6.14.** District Self-Evaluation of Quality vs. Partnering

In addition to the factors whose influence on seal coat quality were presented in this chapter, several other parameters were also evaluated and the relationships between these parameters and seal coat quality was non-conclusive at best. Table 6.1 summarizes the relationships established in previous chapters between seal coat performance and various parameters related to the seal coat operation. These relationships ranged from *weak* to *strong*. All findings reflect statewide trends that were captured during visits to all twenty-five districts that included structured interviews and visits to survey sections.

**Table 6.1. Analysis Summary of Relationships Between Seal Coat Performance and Parameters Related to Seal Coat Operation**

| Policy/Decision Parameter                                   | Relationship to Performance Level                                | Relationship to Predominant Distress Type                    |
|---|--|--|
| Percent lane miles with seal coat as wearing surface        | No relationship  | No relationship  |
| Seal coats used as preventive maintenance (PM) activity     | Existence of PM cycle enhances seal coat performance             | No relationship  |
| Percentage of seal coats done in-house                      | High in-house quality may increase percentage of in-house seals. | No relationship  |
| Management of seal coat design                              | Centralized Design increases learning pace.                      | No relationship  |
| Use of variable binder rates across the lane                | No relationship  | Reduces shelling between wheel paths                         |
| Level of contractor competition                             | No relationship  | No relationship  |
| Aggregate gradations used                                   | No relationship  | Careful control of binder rate with Gr. 4 to reduce flushing |
| Use of precoated aggregates                                 | Enhanced performance through reduced dust & increased adhesion   | Use with emulsion may cause shelling                         |
| Number of different binder types used                       | Large number of binder types may slow down learning curve        | No relationship  |
| Type of asphalt cement used                                 | No relationship  | No relationship  |
| Type of emulsion used                                       | No relationship  | No relationship  |
| Specified roller type                                       | No relationship  | Lightweight rollers may cause more shelling                  |
| Specified number of rollers and the number of roller passes | Rolling effort determines how good the aggregate is seated.      | Uneven rolling patterns and less rolling cause shelling      |
| Start and end dates of seal coat season                     | Rainfall and temperature affect seal coat quality                | Sealing in later & earlier part of season may cause shelling |
| Inspection team size  | Minimum of 3 inspectors recommended for better quality.          | No relationship  |
| Formal post-contract inspection                             | Implemented due to unsatisfactory seal coat performance          | No relationship  |
| Partnering of seal coat projects                            | Implemented due to unsatisfactory seal coat performance          | No relationship  |

## CHAPTER 7. CONCLUSION

The key findings from this seal coat constructability review study can be summarized as follows. These findings were based on information gathered during district visits and the data analysis that followed.

1. Using seal coats as a part of a broader preventive maintenance effort increases the probability of having better performing pavements.
2. Districts with high in-house seal coat activity are pleased their product because they have experienced in-house teams, good equipment and sufficient personnel to sustain their production levels.
3. The most common problems identified by districts include late mobilization by contractors, use of subcontractors when established contractors get overloaded (B-Team) and material supply/quality problems. In order to eliminate the late mobilization problem, districts specify latest start dates in the contract. However, if the contractor starts work too early when the cold weather is still around, it may cause shelling/raveling problems. The problem with subcontracting (B-team) may be eliminated by letting larger seal contracts that attract bigger and better contractors. Material problems on the other hand, are harder to overcome.
4. Use of a minimum number of aggregate gradations and binder types are highly recommended to increase the level of control on application rates and to quicken the learning curve.
5. Modified Kearby method does not necessarily result in better seal coats. However, it is a very effective as a tool to train inexperienced personnel and each district is encouraged to develop their own base rates and correction factors. Experience-based design is very successfully used throughout the state as long as the districts are able to retain their experienced seal coat personnel.
6. Seal coat design is best when handled by a single seal coat team. Such a policy will enable the accumulation of experience within one group and as a result, districts will be able to reap benefits of having a better-trained group.
7. Each district appears to select projects for seal coat work in its own unique way. These methods range from totally subjective to objective. Objective methods can incorporate factors such as pavement condition, distress types and traffic level, and it can reduce the subjectivity of the process.
8. Variable binder rates across the lane may be better suited for pavement sections where there is continuous flushing on the wheel paths.
9. Each aggregate gradation has its own benefits. A single size aggregate gradation gives better performance but its availability and cost pose problems for most districts. Quality seal coats can be attained with either Grade 3 or Grade 4 aggregates as long as the district uses them judiciously. Grade 3 aggregates may increase windshield damage complaints and care should be taken to eliminate loose gravel by using higher binder rates.
10. Almost all districts are in favor of using precoated aggregates. It results in better seal coats because it eliminates dust and enhances adhesion between the aggregate and binder. However, use of precoated aggregates with emulsified asphalt, is not recommended by many districts.

11. Compatibility between the binder and aggregate should be considered during the material selection process.
12. The number of different binder types used by a district, or a seal coat crew, should be minimized because it can increase the control of product quality through better constructability practices.
13. A detailed investigation of the rolling operation has been performed in this study. It showed that given a rolling time requirement, the number of rollers and roller passes can be calculated. In addition, different types of rollers give different levels of rolling effort due to their tire pressure and width.
14. Start and end of seal coat season should be determined based on district climatic pattern. However, late mobilization problems may force the districts to extend their seal coat season and this may result in shelling problems.
15. Number of inspectors and their experience level are extremely important since seal coat quality depends on a number of key adjustments that needs to be made in the field. These adjustments include changing material application rates based on climate and existing surface condition.
16. Stockpile testing is recommended, particularly for those districts where a significant amount of dust is present in the atmosphere.
17. Concrete decant test is recommended for the testing of seal coat aggregate since it reflects the dust level on the particles more realistically compared to asphalt decant test.
18. There is not effective long-term treatment available for flushed pavements. However, the problem can be alleviated over the short term by treating with a lime-water solution and by spreading a finer aggregate (Grade 5-6 or sand).
19. Post-contract evaluation is very important to capture the lessons learned from previous projects. This will improve the seal coat quality by developing better seal coat expertise.
20. There is no evidence to suggest that formal partnering increases the seal coat project quality. However, informal partnering may create a better working environment between the contractor and TxDOT personnel that is key to achieving good quality seal coats. Informal partnering can be facilitated within the framework of a preconstruction meeting. Of particularly benefit is for the chief inspector to drive the project roadway section with the contractor's representative to exchange ideas on existing road conditions.
21. Surface preparation activities such as crack sealing and patching should be performed sufficiently early. Patching should be completed at least 6 months prior to the seal coat operation and crack sealing should be completed at least 3 months before. This would increase the likelihood of attaining more uniform surface conditions.
22. The pay unit for crack sealing should be a pavement length unit (such as a lane mile) rather than by weight because the contractor may be inclined to put as much crack seal as he could to maximize their profits. This would cause the seal coat to deteriorate early.

## BIBLIOGRAPHY

Anderson, S.D., and D.J. Fisher, (1997). "Constructability Review Process of Transportation Facilities," *National Cooperative Highway Research Program Report 390*, TRB, National Research Council, Washington, D. C.

Anderson, S.D., and D.J. Fisher, (1997). "Constructability Review Process of Transportation Facilities Workbook," *National Cooperative Highway Research Program Report 391*, TRB, National Research Council, Washington, D. C.

The Asphalt Institute, "Asphalt Surface Treatments – Specifications," *Educational Series No. 11 (ES-11)*, Lexington, Kentucky.

The Asphalt Institute, "Asphalt Surface Treatments – Construction Techniques," *Educational Series No. 12 (ES-12)*, Lexington, Kentucky.

Benson, F.J and Galloway, B.M. (1953). *Retention of Cover Stone by Asphalt Surface Treatments*, Bulletin 133, Texas Engineering Experiment Station, Texas A&M University System.

Colwill, D.M., Mercer, J., and Nicholls, J.C. (1995). *UK Design Procedure for Surface Dressing, in Seal Coats and Asphalt Recycling*, Transportation Research Board, Washington, D.C.

Connor, B.G., (1984). *Asphalt Surface Treatment and Sealing Parameters*, Alaska Department of Transportation and Public Facilities, Fairbanks, Alaska.

The Construction Industry Institute (CII). (1986). *Constructability: A Primer*. Publication 3-1 (July), CII, Austin, Texas.

Council for Scientific and Industrial Research (1971) Bituminous Surface Treatments for Newly Constructed Rural Roads, Technical Recommendations for Highways, TRH 3, National Institute for Road Research, Pretoria, South Africa.

Elmore, W.E., M. Solaimanian, R.B. McGennis, C. Phromson, and T.W. Kennedy, (1995). "Performance-Based Seal Coat Specifications," CTR Research Report 1367-1, CTR, Austin, Texas.

Epps, J.A., Chaffin, C.W., and Hill, A.J. (1980) *Field Evaluation of a Seal Coat Design Method*, Research Report 214-23, Texas Transportation Institute, Texas A&M University System, College Station.

Epps, J.A., Galloway, B.M, and Brown, M.R (1974) *Synthetic Aggregate Seal Coat Research Report No. 83-2F*, Texas Transportation Institute, Texas A&M University System, College Station.



Finn, F.N. and Epps, J.A. (1980) *Selection of Asphalt Grade to Optimize Performance of Asphalt Surfaced Pavements*, Research Report 214-27, Texas Transportation Institute, Texas A&M University System, College Station

Galloway, B.M. and Harper, W.J. (1966) *A Laboratory and Field Evaluation of Lightweight Aggregates as Coverstone for Seal Coats and Surface Treatments*, Research Report 51-2, Texas Transportation Institute, Texas A&M University System, College Station.

Garcia-Diaz, A. and F. Cediél-Franco,(1988). "Evaluation of In-House Maintenance Contract Costs for Guardrail, Rest Areas, Pavement Marker, Striping, and Seal Coats," Texas Transportation Institute, College Station, Texas.

Gibson, G.E., C.I. McGinnis, W.S. Flanigan, and J.E. Wood, (1996). "Constructability in the Public Sector," *Journal of Construction Engineering and Management*, ASCE, 122 (3), New York, NY, 274-280.

Hank, R.J and Brown, M. (1949). "Aggregate Retention Studies of Seal Coats," *Proceedings*, Association of Asphalt Paving Technologists, Volume 18.

Hanson, F.M. (1934-35). "Bituminous Surface Treatments of Rural Highways", *Proceedings*, New Zealand Society of Civil Engineers, Volume 21.

Harris, J.R. (1955). "Surface Treatments of Existing Bituminous Surfaces," *Proceedings of the Symposium on Seal Coats and Surface Treatments for Existing Bituminous Surfaces*, Technical Sessions of the Associations of Asphalt Paving Technologists held at New Orleans, Louisiana, Volume 24.

Holmgreen, R.J., Epps, J.A., Hughes, C.H., and Galloway, B.M. (1985). "Field Evaluation of the Texas Seal Coat Design Method", *Research Report 297-1F*, Texas Transportation Institute, Texas A&M University System, College Station.

Jackson, D.C., Jackson, N.C., and Mahoney, J.P. (1990) *Washington State Chip Seal Study, in Chip Seals, Friction Course and Asphalt Pavement Rutting* , Transportation Research Record 1259, Transportation Research Board, Washington, DC.

Janisch, D.W. (1995) *Reevaluation of Seal Coating Practices in Minnesota, in Seal Coats and Asphalt Recycling*, Transportation Research Record 1507, Transportation Research Board, Washington, DC.

Kearby, J.P. (1953) Tests and Theories on Penetration Surfaces, *Proceedings*, Highway Research Board, Volume 32.

Ksaibiti K., M. Cole, and M. Farrar, (1996). "Evaluation of Surface Treatment Practices in the United States," *Transportation Research Record 1545*, TRB, National Research Council, Washington, D.C., 26-34.

McLeod, N.W. (1960) *Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalts and Asphalt Cements*, Supplement to Volume 29, Proceedings of the Technical Sessions, The Association of Asphalt Paving Technologists, Memphis.

Minnesota Department of Transportation, (1991). *Design and Construction of Seal Coats*, MDOT, Materials and Research Lab, Maplewood, Minnesota.

NCHRP (1989). "Evolution and Benefits of Preventative Maintenance Strategies," *Synthesis of Highway Practice No. 153*, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC.

Texas Transportation Institute (1981). "Field Manual on Design and Construction of Seal Coats", *Research Report 214-25*, Texas A&M University System, College Station.

U.S. Army Corps of Engineers, (1994). *Engineer Regulation 415-1-11: Biddability, Constructability, Operability, and Environmental Review*, Department of the Army, Washington, D.C.

## APPENDIX A. EXAMPLE TABLES TO DETERMINE SEAL COAT BINDER RATES

These binder adjustment factors were developed for Modified Kearby Method for specific conditions in Brownwood and Abilene districts. All binder rates are in gallons per square yard.

**Table A.1.** Binder Base Rates (AC)

| Aggregate Gradation | GR3  | GR4  | GR5  |
|---------------------|------|------|------|
| <b>Binder Rate</b>  | 0.37 | 0.32 | 0.22 |

**Table A.2.** Binder Rate Adjustment Factors for Traffic Level

| ADT per Lane | GR3   | GR4     | GR5     |
|--------------|-------|---------|---------|
| 0-50         | +0.07 | +0.05   | +0.04   |
| 50-100       | +0.06 | +0.04   | +0.02   |
| 100-300      | +0.04 | +0.03   | 0       |
| 300-500      | +0.03 | +0.02   | * -0.02 |
| 500-700      | 0     | 0       | N/A     |
| 700-1000     | -0.01 | -0.01   | N/A     |
| 1000-1500    | -0.02 | -0.02   | N/A     |
| 1500-2000    | -0.03 | * -0.03 | N/A     |
| >2000        | -0.04 | * -0.04 | N/A     |

\* This grade aggregate not recommended for traffic volumes shown

**Table A.3.** Alternate Binder Rate Adjustment Factors for Traffic Level

| ADT/Lane  | Adjustment | Highway Description             |
|-----------|------------|---------------------------------|
| 0         | + .10      | Shldrs                          |
| 0-100     | + .05      | Very low vol FM                 |
| 100-250   | + .04      | Low vol FM                      |
| 250-400   | + .03      | Med vol FM or                   |
| 400-600   | + .01      | Low vol US or SH                |
| 600-800   | 0          | Med vol US or SH or High vol FM |
| 800-1000  | - .02      | High vol US or SH               |
| 1000-1500 | - .03      | High vol US or SH               |
| 1500-2000 | - .04      | Very high vol US                |
| >2000     | - .06      | Key ave etc...                  |

**Table A.4. Binder Rate Adjustment Factors for Truck Traffic**

| <b>% Trucks</b> | <b>GR3</b> | <b>GR4</b> | <b>GR5</b> |
|-----------------|------------|------------|------------|
| 5%              | 0          | 0          | 0          |
| 15%             | -0.01      | -0.01      | N/A        |
| 30%             | -0.02      | -0.02      | N/A        |
| 40%             | -0.03      | -0.02      | N/A        |

**Table A.5. Alternate Binder Rate Adjustment Factors for Truck Traffic**

|          | <b>GR5</b> | <b>GR4</b> | <b>GR3</b> |
|----------|------------|------------|------------|
| High %   | - .02      | - .04      | - .05      |
| Medium % | - .01      | - .02      | - .03      |
| Low %    | 0          | 0          | 0          |

**Table A.6. Binder Rate Adjustment Factors for Pavement Condition(existing or new pavement-wheel path conditions)**

| <b>Surface Type</b> | <b>Surface Condition</b>          | <b>GR3</b> | <b>GR4</b> | <b>GR5</b> |
|---------------------|-----------------------------------|------------|------------|------------|
| ACP                 | Very dry ACP with many cracks     | +0.08      | +0.06      | +0.05      |
|                     | Dry ACP with some cracks          | +0.05      | +0.04      | +0.03      |
|                     | Good ACP with few cracks          | +0.02      | +0.02      | +0.01      |
|                     | Flushed seal                      | -0.02      | -0.02      | -0.01      |
|                     | Bleeding ACP                      | -0.04      | -0.04      | -0.03      |
| SEAL                | Very dry seal with many cracks    | +0.06      | +0.06      | +0.04      |
|                     | Dry seal with few cracks          | +0.03      | +0.03      | +0.02      |
|                     | Good seal with few cracks         | 0          | 0          | 0          |
|                     | Flushed Seal                      | -0.02      | -0.02      | -0.01      |
|                     | Bleeding seal                     | -0.04      | -0.04      | -0.02      |
| PATCHES             | Dry or fresh patch                | +0.03      | +0.03      | +0.02      |
|                     | Flogged patch                     | 0          | 0          | 0          |
|                     | Flushed patch                     | -0.03      | -0.03      | -0.03      |
| PRIME               | Dry surface, light rate           | +0.02      | +0.02      | +0.02      |
|                     | Penetrated well, good rate        | 0          | 0          | 0          |
|                     | Waxy and wet, not penetrated well | -0.03      | -0.03      | -0.02      |

**Table A.7.** Alternate Binder Rate Adjustment Factors for Pavement Condition on wheel path (Hunger Factor)

| Surface Condition             | Adjustment |
|-------------------------------|------------|
| Very dry ACP with many cracks | + .10      |
| Dry ACP with some cracks      | + .06      |
| Good ACP with few cracks      | 0          |
| Flushed ACP                   | - .05      |
| Bleeding surface              | - .10      |
| Dry seal with many cracks     | + .08      |
| Dry seal with few cracks      | + .05      |
| Good seal with few cracks     | 0          |
| Flushed seal                  | - .05      |
| Fogged patch                  | 0          |
| Dry patch                     | + .08      |
| Flushed patch                 | - .06      |

**Table A.8.** Alternate Binder Rate Adjustment Factors for Pavement Texture (wheel path only)

| Existing Surface Texture                                      | Aggregate Gradation |       |     |
|---|---------------------|-------|-----|
|   | GR5                 | GR4   | GR3 |
| Very coarse seal  |                     | + .04 |     |
| Coarse seal or premix patch                                   |                     | + .02 |     |
| Good seal or premix patch; texture with little or no flushing |                     | + .01 |     |
| Flushed or smooth surface                                     | 0                   | 0     | 0   |

**Table A.9.** Binder Rate Adjustment Factors for Aggregate Gradation

|        | GR5   | GR4   | GR3   |
|--------|-------|-------|-------|
| Coarse | + .02 | + .05 | + .08 |
| Fine   | - .02 | - .03 | - .05 |

**Table A.10.** Binder Rate Adjustment Factors Based on Type of Rock

| Type of Aggregate | Binder Rate Adjustment |
|-------------------|------------------------|
| Light weight      | + .02                  |
| Limestone, etc... | 0                      |

**Table A.11. Suggested Nozzle Configurations**

| Lane Width (ft) | Nozzle Configuration |     |    |     |    |     |            | Total Nozzles | Comments         | Uniform Binder Rate Factor (20% Variance) | Uniform Binder Rate Factor (30% Variance) |
|-----------------|----------------------|-----|----|-----|----|-----|------------|---------------|------------------|---|---|
|                 | DEFL (BIG)           | BIG | SM | BIG | SM | BIG | DEFL (BIG) |               |                  |   |   |
| 9               | 1                    | 0   | 9  | 6   | 9  | 2   | 1          | 28            |                  | 1.072                                     | 1.108                                     |
| 10              | 1                    | 2   | 9  | 6   | 9  | 3   | 1          | 31            |                  | 1.084                                     | 1.126                                     |
| 11              | 1                    | 4   | 9  | 6   | 9  | 4   | 1          | 34            |                  | 1.094                                     | 1.141                                     |
| 12              | 1                    | 5   | 9  | 8   | 9  | 4   | 1          | 37            |                  | 1.102                                     | 1.153                                     |
| 13              | 1                    | 6   | 9  | 8   | 9  | 6   | 1          | 40            |                  | 1.110                                     | 1.165                                     |
| 14              | 1                    | 6   | 9  | 8   | 9  | 9   | 1          | 43            | Outside shoulder | 1.117                                     | 1.175                                     |
| 14              | 1                    | 9   | 9  | 8   | 9  | 6   | 1          | 43            | Inside shoulder  | 1.117                                     | 1.175                                     |
| 15              | 1                    | 6   | 9  | 8   | 9  | 12  | 1          | 46            | Outside shoulder | 1.121                                     | 1.182                                     |
| 16              | 1                    | 6   | 9  | 8   | 9  | 15  | 1          | 49            | Outside shoulder | 1.126                                     | 1.189                                     |
| 16              | 1                    | 16  | 9  | 8   | 9  | 5   | 1          | 49            | Inside shoulder  | 1.126                                     | 1.189                                     |

\* Configuration of 1-5-9-8-9-4-1 may be shown as 6-9-8-5 etc. on design and application reports

**Table A.12. Lane Traffic Distribution Factors**

| Total Number of Lanes   | Lane Traffic Distribution Factor |
|-------------------------|----------------------------------|
| 2 lane                  | ADT x 0.5                        |
| 4 lane rural outside ln | ADT x 0.35                       |
| 4 lane rural inside ln  | ADT x 0.15                       |
| 4 lane urban (all) ln   | ADT x 0.25                       |
| Shoulder                | 0                                |

**Table A.13. Typical Truck Percentages**

| Highway Description               | Typical Truck Traffic Level (Percent of ADT) |
|-----------------------------------|--|
| Low volume FM's, ADT 250 or less  | 5  |
| Moderate volume FM/SH/US Highways | 15   |
| High Volume US Highways           | 30   |
| Interstate Highways               | 40   |

Note: Seal coat not recommended for 40% truck volumes

## APPENDIX B. STRUCTURED INTERVIEW QUESTIONS

During the district visit, the researchers will interview TxDOT personnel involved in the district seal coat program and the interview will include the following questions.

### General:

1. At this time, what percentage of your highway lane miles has seal coats or surface treatments as the wearing course (Rural FM/Rural State or US/Urban)?
2. What percentage of your highway lane-miles has surface treatments directly over base?
3. Do you follow a preventive maintenance cycle for seal coats? What is the cycle length?
4. What is the typical life span (age/traffic applications) of a seal coat in your district?
5. What percentage of your seal coat work is done with in-house crews?
6. How do you rate your district experience and the performance of in-house seal coats?
7. How do you rate your district experience and the performance of contract seal coats?
8. What are the primary problems associated with in-house and contract seal coat work?

### Design:

9. What existing pavement conditions are considered appropriate for seal coat application?
10. What is the sequence of events in your seal coat decision making process?
11. What is the design procedure and what are the design criteria used?
12. Who performs the design and when is it performed?
13. For how long has the current design procedure been used?
14. How do you determine the asphalt and aggregate rates?
15. Do you vary the asphalt spray rate across the lane?
16. How do you characterize the subgrade type(s) in your district?

### Contract:

17. Who are the contractors that bid on your seal coat jobs?
18. Do you feel that an adequate number of quality contractors bid for your jobs?
19. Do you require different quality levels for seal coats in different types of highways?
20. In your experience, is the contract price related to the quality of seal coat?
21. Do you adopt unit price-low bid contracts for seal coat jobs?
22. What is the range for the length of a typical seal coat job (in lane miles)?
23. What general notes would you include in seal coat plans?

**Materials:**

24. What aggregate specification(s) do you use for seal coat jobs? (Grade 3, 4, etc.)
25. Are any special gradations used?
26. Do you use pre-coated aggregates? If so, how do you control its quality in terms of aggregate type and coating?
27. What approved aggregate sources are used in your district?
28. What are the most commonly used aggregate sources and the corresponding percentages?
29. What binder types do you normally use in the district? What is the percent usage and average unit price for each type?
30. How do you select the binder type for seal coat jobs and who makes the decision?
31. Do you adopt any special tests to check the suitability of materials?

**Equipment:**

32. What binder spray equipment types and models are considered appropriate for the contractor to use?
33. What aggregate spreader equipment types and models are considered appropriate for the contractor to use?
34. What roller types and models are considered appropriate for the contractor to use?
35. What types and models of brooms are considered appropriate for the contractor to use?
36. Would you be able to provide us with specs of the equipment used in the district?

**Construction:**

37. What is your typical seal coat season?
38. What are your specifications for ambient temperature to do seal coat work?
39. Prior to seal coating, what preparation methods are adopted for the existing surface? How early before the seal coat operation are these preparations done?
40. How soon after the binder spray operation is aggregate spread? Is this different for AC and emulsion?
41. When emulsion is used, how soon after the emulsion spray is aggregate spread? (Immediately/When emulsion breaks/When Emulsion turns black)
42. What is the typical time span between aggregate spread and initial rolling?
43. What is the typical number of roller passes?
44. Do you lap between roller passes and by how much?



45. What is the typical time span between final rolling and brooming?
46. What is the typical number of broom passes?
47. After the seal coat is placed, do you open the road to reduced speed traffic first?
48. What is the typical maximum reduced speed allowed?
49. What is the typical time span between final rolling and opening to reduced speed traffic?
50. What is the typical time span between final rolling and opening to full speed traffic?

**Quality Control:**

51. Who does the inspection, a team or an individual?
52. Who keeps the records and in what form?
53. How do you control the quality of the aggregate?
54. What verification methods are used to check material application rates?
55. For computerized distribution methods, do you strap the distributor to check flow rate?
56. What tolerances are allowed for binder spray and aggregate spread rates?
57. Are any special tests used to control quality?

**Performance:**

58. What common distresses are observed in seal coats? When do you notice them?
59. What distresses are the most predominant?
60. How do you rectify them?
61. Do you think there is a difference in performance between maintenance seal coats and surface treatments?
62. How often do you inspect the performance of your seal coats?
63. Who does this inspection and where is it recorded?

**Continuous Improvement:**

64. What CI methods are used (or planned) to improve the quality of your seal coats?
65. Do you have any suggestions for improvement of seal coat quality? In other words, if money is not a problem, how would you do your seal coats?
66. Other pertinent information not covered above.

## APPENDIX C. DATA ON INDIVIDUAL SEAL COAT TEST SECTIONS

### A. Project

District :  
County :  
Highway :  
Direction :  
Length of section :  
TRM Limits : From \_\_\_\_\_ To \_\_\_\_\_  
C-S-J. :  
Date sealing began :  
Date sealing ended :  
Date of opening for traffic :

### B. Road geometry and traffic details

Number of lanes : 2 lanes  4 lanes  > 4 lanes   
Lane width :  
Divided highway ? : Yes  No   
Speed limit :  
Topography : Level  Hor.curve  Vert.curve   
Traffic level(ADT) : <1K 1K-2K 2K-5K  
5K-10K 10K-15K 15K-20K > 20K  
Percent Trucks :  
Sub-surface drainage provided ? : Yes  No

### C. Design

Type (and thickness) of previous friction course:  
Binder type and grade:  
Target temperature for binder:  
Target binder spray rate in WP:  
Target binder spray rate outside WP:  
Target aggregate spread rate in WP:  
Target aggregate spread rate outside WP:

### D. Material

Type of subgrade in the area:  
How do you rate the subgrade? Good / Fair / Poor  
Type of aggregate :  
Gravel  Limestone  Sandstone  Lightweight  Other   
Source of aggregate : Company: \_\_\_\_\_ Pit: \_\_\_\_\_  
Source(s) of other aggregates:  
Type of binder : AC  Emulsion  Cutback   
Binder grade :  
Binder additive used :

**E. Roller data**

Brand:    Model:    Gross Wt:  
Tire pressure:    Width:    Speed:

**F. Binder spray equipment**

Brand:    Model:    Year:  
Nozzle angle:    Spray bar ht.:    Nozzle spacing:  
Nozzle brand:    Nozzle model:  
Bitumeter available ?    :  
Pump tachometer available ?    :  
Equipped with heaters ?    :  
Laps    :    Double/Triple

**G. Aggregate spreader**

Brand:    Model:    Capacity:    Self-propelled?

**H. Existing surface**

Cleanliness of surface before sealing: Clean / Mostly clean / Somewhat dirty / Dirty  
Surface moisture condition: Dry / Mostly dry / Somewhat moist / Wet  
Surface condition: Badly oxidized / Slightly oxidized / Normal / Slightly flushed / Flushed /  
Flushed only in WP / Other (specify)  
Average crack severity level: Low / Moderate / High  
Primary type of cracks:  
Existing surface preparation methods:  
Condition prior to surface preparation:  
Condition prior to surface treatment:

**I. Binder application**

Binder spray rate adjusted at site?  
Actual temperature for binder:  
Actual binder spray rate in WP (from distributor readings):  
Actual binder spray rate in WP (from other measurements - specify):  
Actual binder spray rate outside WP (from distributor readings):  
Actual binder spray rate outside WP (from other measurements - specify):  
Spray uniformly applied?  
Was atomization noticed?  
Missed spots noticed?  
Hand sprayer used on missed spots?  
Asphalt streaking noticed?  
Overlap allowed on adjacent lane?

**J. Aggregate spreading**

Aggregate moisture condition prior to use :  
Actual aggregate spread rate in WP:  
Actual aggregate spread rate outside WP:  
Estimated time between the binder spray and the aggregate spread:  
Aggregate spread uniformly?  
Streaking of aggregate noticed?

**K. Rolling and Brooming**

Estimated time between the aggregate spread and initial rolling:  
Number of roller passes:  
Estimated time between final rolling and brooming:  
Estimated time between final rolling and opening to reduced speed traffic :  
Maximum reduced speed allowed:  
Estimated time between final rolling and opening to full speed traffic:  
Number of passes with broom:  
Est. loss of material from brooming: <1% / 1-3%../ 3-5% / >5%  
Est. percent of loose material remaining after brooming: <1% / 1-3% / 3-5% / >5%  
Agg. embedment depth :

**L. Climatic conditions during construction**

Ambient temperature:  
Relative humidity:  
General climatic description (Cloudy/Sunny/Windy etc.):

**M. Quality control/Quality assurance**

Inspection team members:  
Chief inspector:  
Chief inspector's experience:  
Where was experience obtained?  
Binder spray rate control method:  
Aggregate spread rate control method:  
In-situ tests (if any):

**N. Contract**

Contractor:  
Unit price:  
Date of award:  
Scheduled completion:  
Time of extension (if any):  
Original contract amount:  
Final contract amount :  
Liquidated damages (if any):

**APPENDIX D. ANALYSIS OF DISTRICT TEST SECTION DATA**

**Table D.1 Binder Rates for Grade 4 Aggregate**

| <b>Binder Grade</b> | <b>ADT</b> | <b>Binder Rate<br/>on WP<br/>(gal/sy)</b> | <b>Binder Rate<br/>Outside WP<br/>(gal/sy)</b> | <b>Rock Rate<br/>on WP<br/>(sy/cy)</b> | <b>Aggregate Type</b> |
|---------------------|------------|---|--|--|-----------------------|
| <b>AC10</b>         | 1500       | 0.40                                      | 0.40   | 114                                    | Gr 4 (LS)             |
|                     | 2200       | 0.25                                      | 0.25   | 100                                    | PE Gr. 4 (LS)         |
|                     | 1100       | 0.25                                      | 0.25   | 100                                    | PE Gr. 4 (LS)         |
|                     | 1000       | 0.25                                      | 0.25   | 100                                    | PE Gr. 4 (LS)         |
|                     | 340        | 0.25                                      | 0.25   | 100                                    | PE Gr. 4 (LS)         |
| <b>AC15-5TR</b>     | 10800      | 0.35                                      | 0.35   | 119                                    | Gr. 4 pre-coat (LW)   |
|                     | 14400      | 0.32                                      | 0.35   | 112                                    | Gr. 4 LW              |
|                     | 7500       | 0.35                                      | 0.35   | 113                                    | Gr. 4 PB              |
|                     | 15000      | 0.35                                      | 0.35   | 113                                    | Gr. 4 PB              |
|                     | 20000      | 0.33                                      | 0.33   | 124                                    | Ty PB GR 4            |
|                     | 4500       | 0.30                                      | 0.33   | 112                                    | PL Gr. 4 (LW)         |
|                     | 80         | 0.36                                      | 0.40   | 123                                    | PB Ty B Gr 4 (gravel) |
|                     | 1100       | 0.37                                      | 0.32   | 123                                    | PB Ty B Gr 4 (gravel) |
| <b>AC5</b>          | 650        | 0.35                                      | 0.35   | 100                                    | Gr. 4 gravel          |
|                     | 1300       | 0.35                                      | 0.35   | 100                                    | Gr. 4 gravel          |
|                     | 7600       | 0.33                                      | 0.33   | 100                                    | Gr. 4 gravel          |
|                     | 2000       | 0.35                                      | 0.35   | 100                                    | Gr. 4 gravel          |
|                     | 5000       | 0.33                                      | 0.33   | 118                                    | Ty PB Gr. 4 (LS)      |
|                     | 1450       | 0.33                                      | 0.33   | 118                                    | Ty PB Gr. 4 (LS)      |
|                     | 1600       | 0.33                                      | 0.33   | 118                                    | Ty PB Gr. 4 (LS)      |
|                     | 10500      | 0.34                                      | 0.34   | 108                                    | Ty PB Gr. 4 (LS)      |
|                     | 70         | 0.40                                      | 0.40   | 123                                    | PB Ty B Gr 4 (gravel) |
| <b>AC5 w/ latex</b> | 2900       | 0.40                                      | 0.40   | 110                                    | PB Gr. 4 (LS)         |
|                     | 340        | 0.35                                      | 0.35   | 110                                    | Ty E Gr. 4            |
|                     | 650        | 0.35                                      | 0.35   | 100                                    | Gr. 4 LS              |
|                     | 1100       | 0.31                                      | 0.31   | 118                                    | Ty PB Gr. 4 (LS)      |
| <b>CRS-2</b>        | 960        | 0.50                                      | 0.61   | 125                                    | Gr. 4 LW              |
|                     | 1500       | 0.57                                      | 0.75   | 90                                     | Gr. 4M LS             |
| <b>CRS-2H</b>       | 170        | 0.65                                      | 0.85   | 90                                     | Ty B Gr. 4 LS         |
| <b>CRS-2P</b>       | 1500       | 0.45                                      | 0.59   | 125                                    | Gr. 4 Sandstone       |
|                     | 1600       | 0.43                                      | 0.43   | 112                                    | Gr. 4 LW              |

(WP = Wheel Path; LS = Limestone aggregate; LW= Lightweight aggregate)

**Table D.2. Binder Rates for Grade 3 Aggregate**

| Binder Grade | ADT  | Binder Rate on WP (gal/sy) | Binder Rate Outside WP (gal/sy) | Rock Rate on WP (sy/cy) | Aggregate Type  |
|--------------|------|----------------------------|---------------------------------|-------------------------|-----------------|
| AC10         | 3900 | 0.38                       | 0.38                            | 98                      | Gr 3 PB (LS)    |
|              | 1100 | 0.38                       | 0.38                            | 98                      | Gr 3 PB (LS)    |
| AC5 w/ latex | 950  | 0.38                       | 0.38                            | 100                     | Gr 3 PB (LS)    |
|              | 7100 | 0.38                       | 0.38                            | 100                     | Gr 3 PB (LS)    |
| CRS-2P       | 1050 | 0.44                       | 0.44                            | 100                     | Gr. 3 (LW)      |
|              | 7800 | 0.44                       | 0.44                            | 100                     | Gr. 3 (LW)      |
|              | 7800 | 0.44                       | 0.44                            | 100                     | Gr. 3 (LW)      |
|              | 6200 | 0.44                       | 0.44                            | 100                     | Gr. 3 (LW)      |
|              | 1500 | 0.52                       | 0.58                            | 90                      | Gr 3M Sandstone |
|              | 7800 | 0.44                       | 0.44                            | 100                     | Gr. 3 (LW)      |

**Table D.3 Average Rates for Grade 4 Aggregate**

| Binder Grade | ADT  | Binder Rate on WP (gal/sy) | Binder Rate Outside WP (gal/sy) | Rock Rate on WP (sy/cy) |
|--------------|------|----------------------------|---------------------------------|-------------------------|
| AC10         | 1228 | 0.28                       | 0.28                            | 103                     |
| AC15-5TR     | 8340 | 0.34                       | 0.35                            | 117                     |
| AC5          | 3352 | 0.35                       | 0.35                            | 109                     |
| AC5 w/ latex | 1248 | 0.35                       | 0.35                            | 110                     |
| CRS-2        | 1230 | 0.54                       | 0.68                            | 108                     |
| CRS-2H       | 170  | 0.65                       | 0.85                            | 90                      |
| CRS-2P       | 1550 | 0.44                       | 0.51                            | 119                     |

**Table D.4 Average Rates for Grade 3 Aggregate**

| Binder Grade | ADT  | Binder Rate on WP (gal/sy) | Binder Rate Outside WP (gal/sy) | Rock Rate on WP (sy/cy) |
|--------------|------|----------------------------|---------------------------------|-------------------------|
| AC10         | 2500 | 0.38                       | 0.38                            | 98                      |
| AC5 w/ latex | 3110 | 0.38                       | 0.38                            | 100                     |
| CRS-2P       | 5358 | 0.46                       | 0.47                            | 98                      |

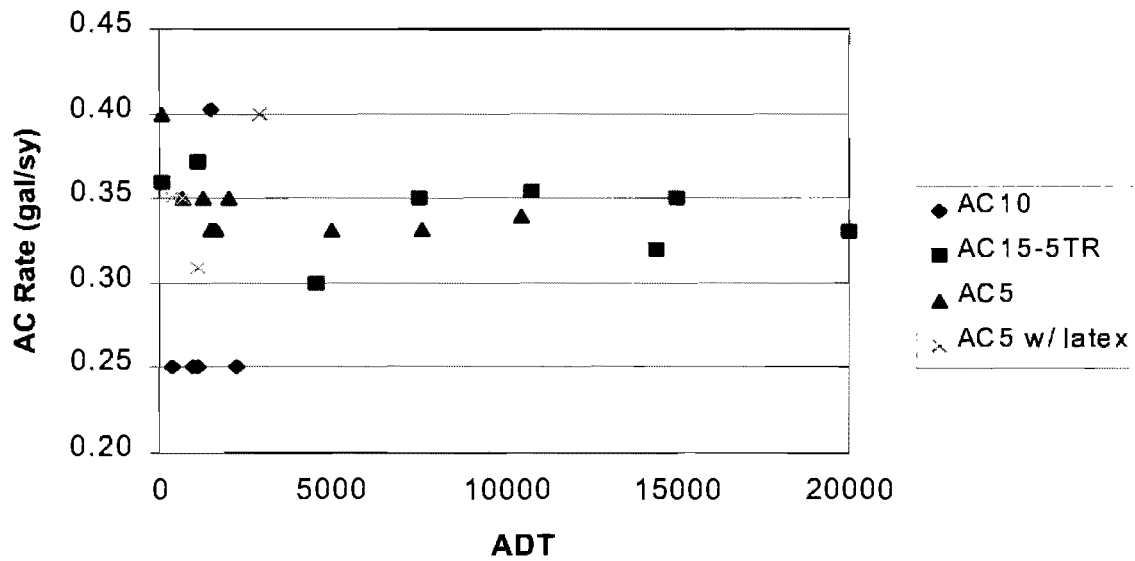


Figure D.1 AC Rate in Wheel Path vs. ADT (Grade 4)

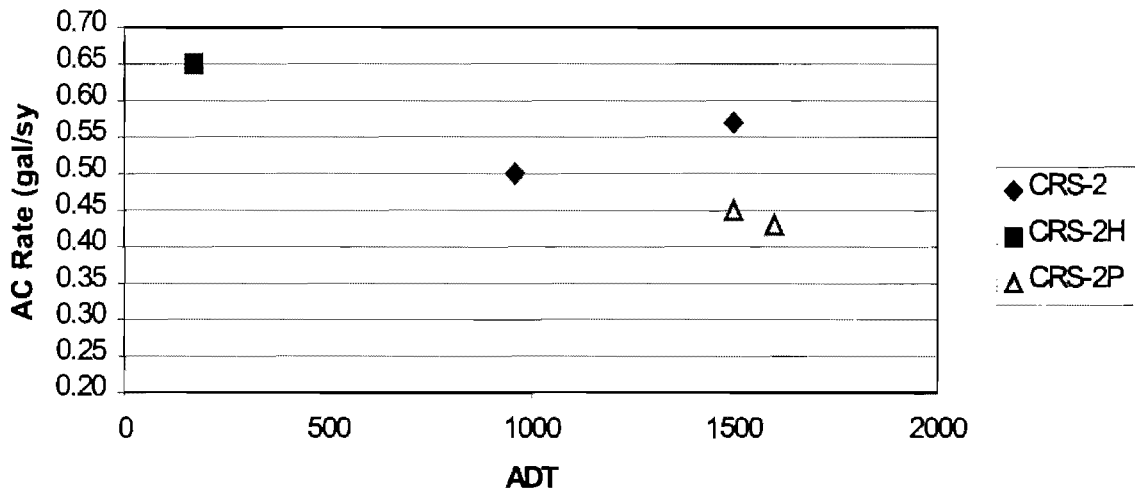


Figure D.2 Emulsion Rate in Wheel Path vs. ADT (Grade 4)

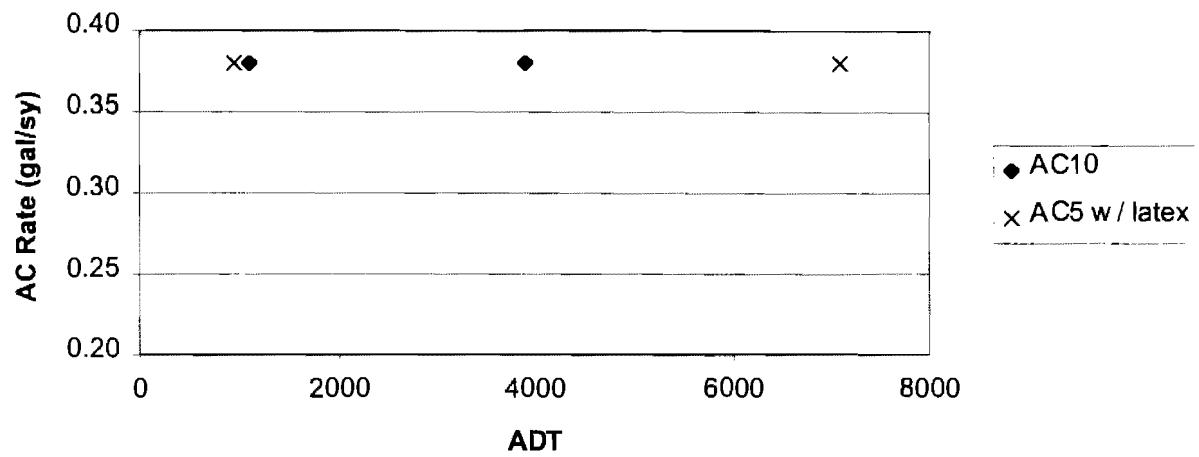


Figure D.3 AC Rate in Wheel Path vs. ADT (Grade 3)

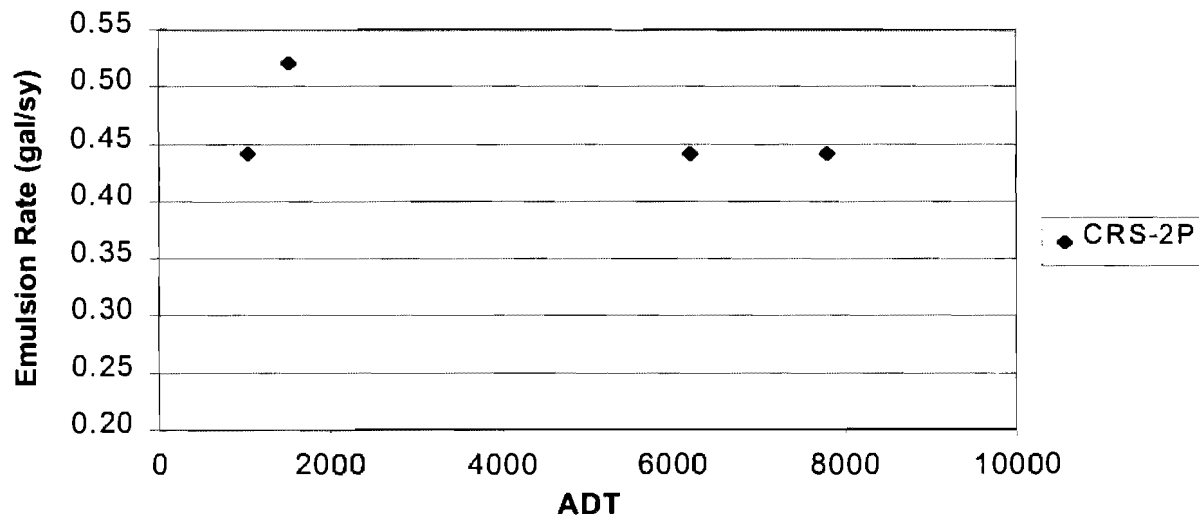


Figure D.4 Emulsion Rate in Wheel Path vs. ADT (Grade 3)



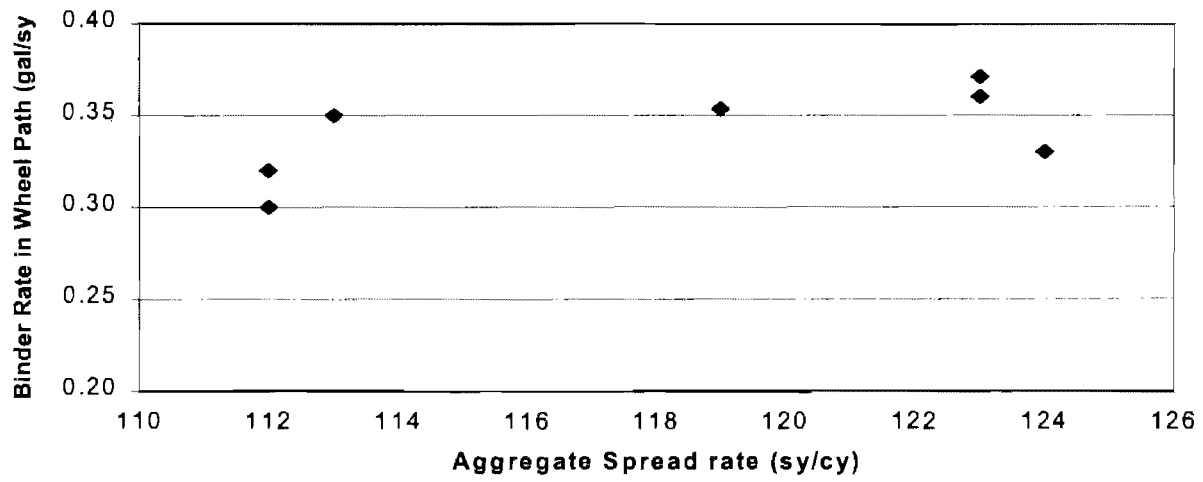


Figure D.5 Binder Rate in Wheel Path vs. Aggregate Rate for AC15-5TR

## APPENDIX E: POWERPOINT SLIDES

### Seal Coat Constructability Review

TxDOT Research Project 0-1787  
Texas Tech University

Project Coordinator : Thomas Bohuslav P.E.  
Project Director : Richard Walker  
Principal Investigator: Douglas D. Gransberg, Ph.D., P.E.  
Co-Principal Investigator: Sanjaya Senadheera, Ph.D.

1

### Presentation

- Statewide Seal Coat Constructability Review
- Seal Coat Design
- Seal Coat Construction
- Constructability Review for Beaumont District

2

### State Seal Coat Program

- \$220 m. Annual Preventive Maintenance
- \$20 m. Maintenance Seal Coat
- Over 50% lane miles have Seal Coat surface
- Therefore, this is what the public sees

3

### Definition of a Seal Coat

*"an application of asphalt binder followed by a single application of cover aggregate, both placed on an existing bituminous surface"*

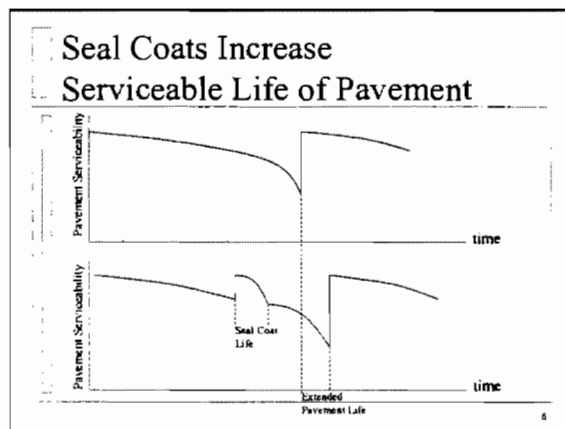
McLeod (1960)

4

### Effective Preventive Maintenance (PM) Measure

- Arrests light deterioration
- Retards progressive failures
- Reduces the need for routine maintenance
- Seals cracked surface against air and water intrusion
- Protects underlying surface from oxidation
- Improves skid resistance
- Reduces annualized life cycle cost

5



## As a PM tool, seal coats are not suitable for:

- Pavements with structural failures
- Badly cracked surfaces (e.g. alligator cracks, wide cracks)
- Irregular surfaces (potholes, rutting, etc.)
- Improvement of ride or smoothness

7

## Purpose of Constructability

- Identify areas for Constructability Review
- Capture lessons-learned

8

## Benefits of Constructability

- Reduced Cost
- Shorter Schedules
- Improved Quality
- Enhanced Safety
- Better Control of Contract Risk
- Fewer Change Orders
- Fewer Claims

9

## Focus of the Project

- Constructability
  - Planning and Project Selection
  - Design
  - Specifications
    - materials
    - equipment
    - construction process

10

## Focus of the Project

- Contract Management
  - Equipment
  - Construction
    - Process
    - Quality control/Quality assurance
  - Environmental Conditions
  - Performance Monitoring - closing the loop

11

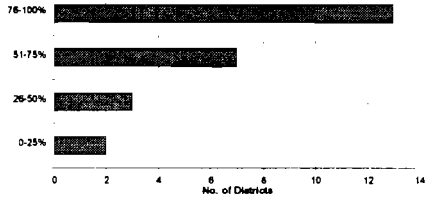
## Structured Interview

### 66 questions in 9 categories

- |             |                          |
|-------------|--------------------------|
| ■ General   | ■ Construction           |
| ■ Design    | ■ Quality Control        |
| ■ Contract  | ■ Performance            |
| ■ Materials | ■ Continuous Improvement |
| ■ Equipment |                          |

12

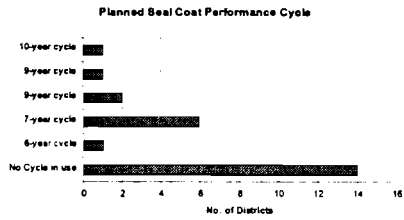
What percentage of roads has seal coats as wearing surface?



Beaumont: Rural: 90%FM,70%TX,30%US  
Urban: 5%

13

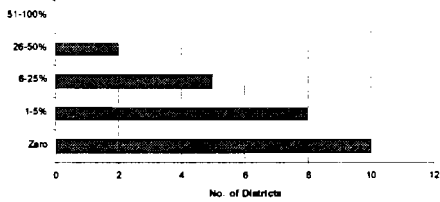
Do you follow a preventive maintenance cycle for seal coats?



Beaumont= No cycle in use

14

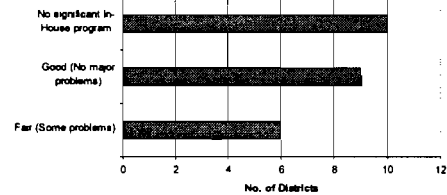
What percentage of Seal Coat Work is done in-house?



Beaumont= 0-1% (spot seals)

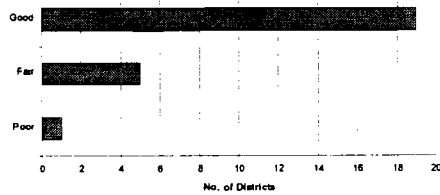
15

How do you rate your district experience with in-house seals?



16

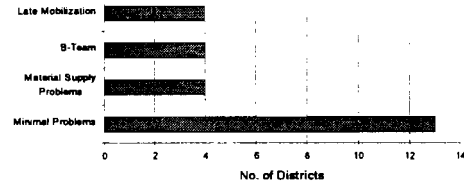
How do you rate your district experience with contract seals?



Beaumont=Good to Excellent

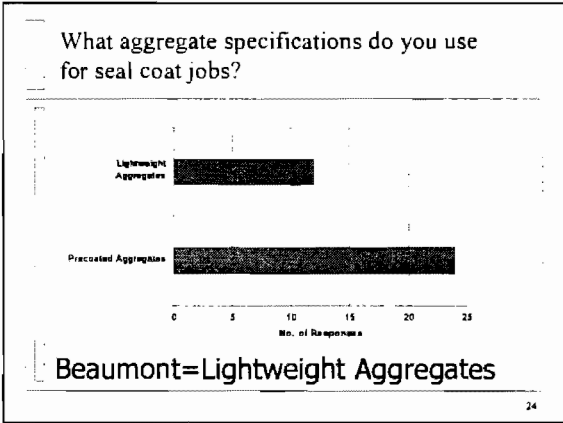
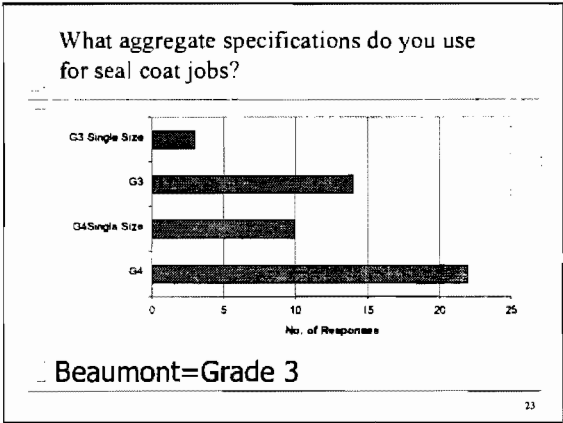
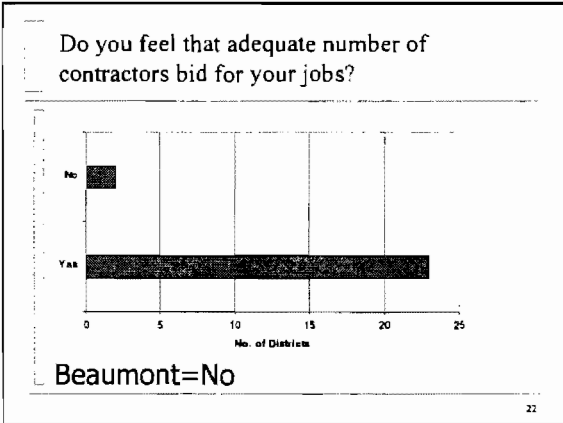
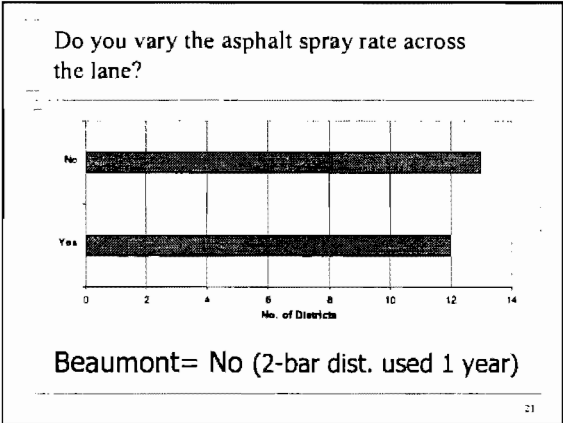
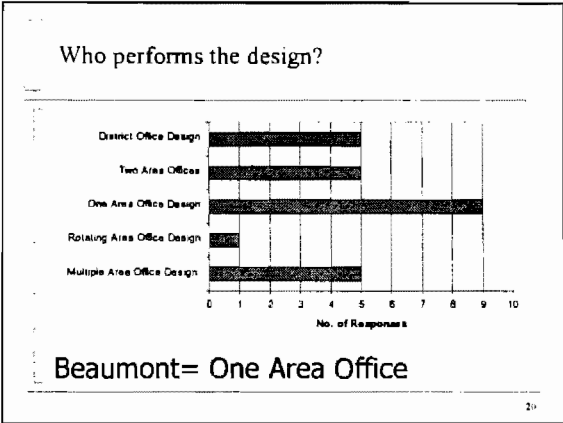
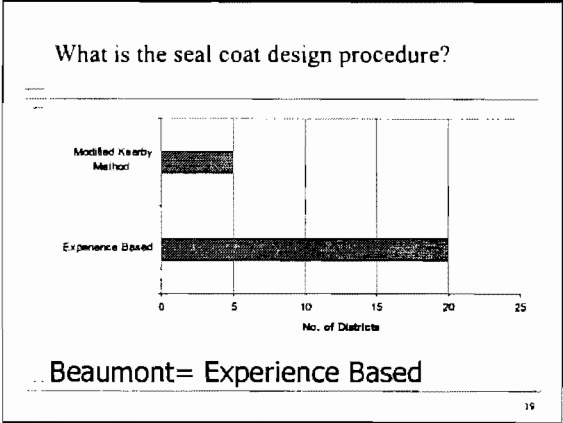
17

What problems does your district experience with contract seals?

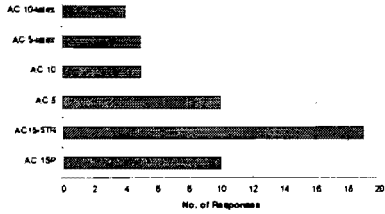


Beaumont= Minimal Problems

18



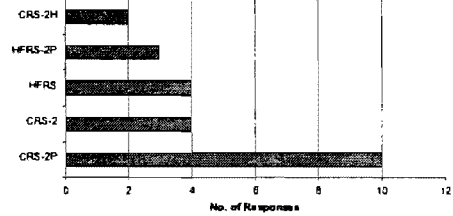
What grades of Asphalt Cement do you use in the district as seal coat binder?



Beaumont= AC's not used

25

What grades of Emulsion do you use in the district as seal coat binder?



Beaumont=CRS-2P

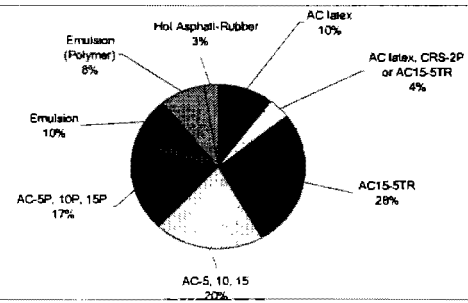
26

Percent Use of Different Binder Combinations by Each District

| Combinations of Binders and Percent Use              | No. Districts |
|--|---------------|
| 100% AC-5, 10, 15                                    | 2             |
| 95-100% AC-SP, 10P, 15P                              | 4             |
| 100% Emulsion  | 1             |
| 100% AC Latex  | 1             |
| 75-85% AC-5, 10, 15 and 15-25% AC latex              | 2             |
| 50-75% AC-15-5TR and 25-50% Emulsion(Polymer)        | 2             |
| 35-45% AC-15-5TR and 55-65% Emulsion                 | 2             |
| 75% AC-SP, 10P, 15P and 25% AC-15-5TR                | 1             |
| 70% AC-15-5TR and 30% AC-SP, 10P, 15P                | 1             |
| 80% AC-5, 10, 15 and 20% AC-SP, 10P, 15P             | 1             |
| 50% AC latex and 50% AC-15-5TR                       | 1             |
| 50% AC-15-5TR, 35% AC-5, 10, 15, 15% AC-SP, 10P, 15P | 1             |
| 85% Emulsion and 15% AC latex                        | 1             |
| 80% AC-SP, 10P, 15P and 40% Asp. Rubber              | 1             |
| 50% AC-5, 10, 15, 30% AC latex, 50% AC-5, 10, 15     | 1             |
| 60% AC latex, 30% Asp. Rubber, 10% AC-5, 10, 15      | 1             |

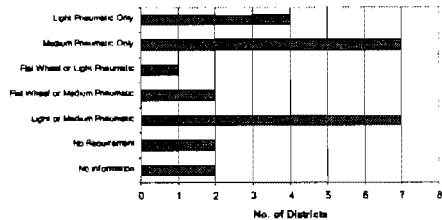
27

Statewide Usage of Binder Types by Quantity



28

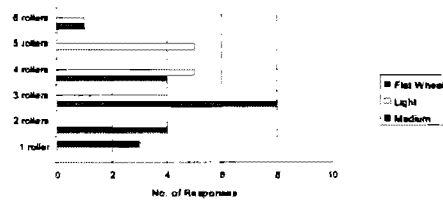
What roller types are considered appropriate for the contractor to use?



Beaumont= Light Pneumatic only

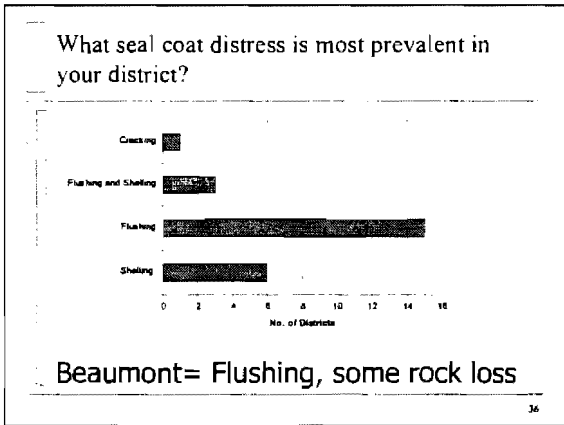
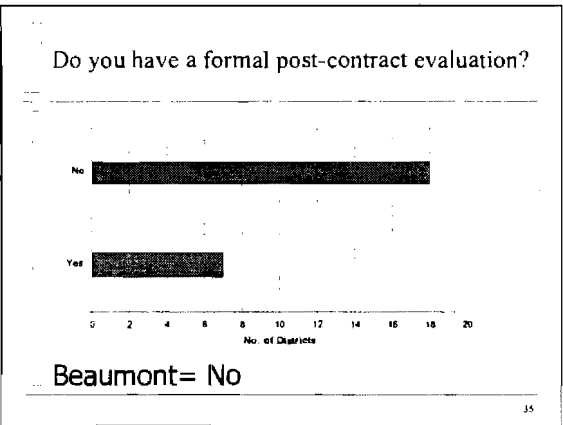
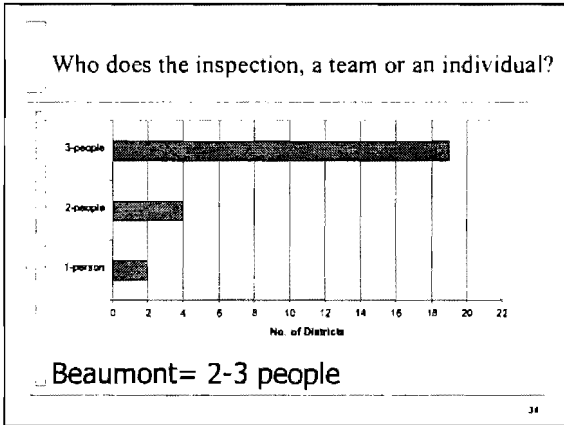
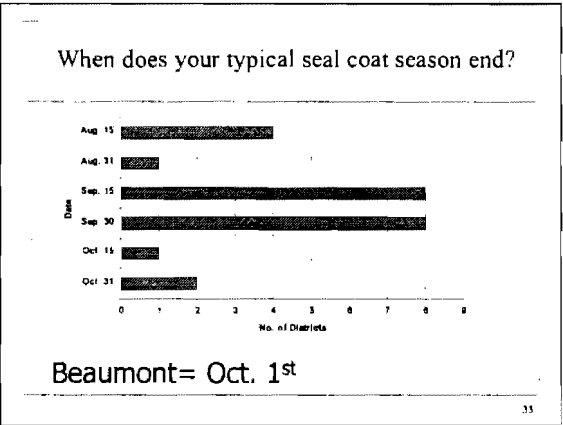
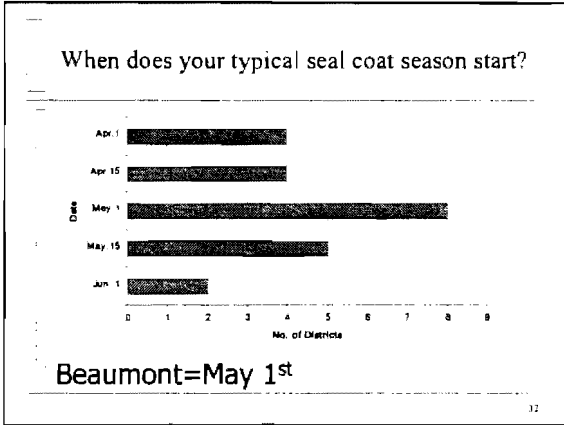
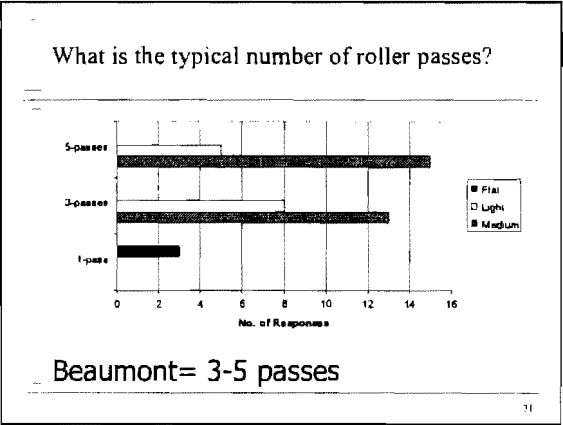
29

What is the typical number of rollers?

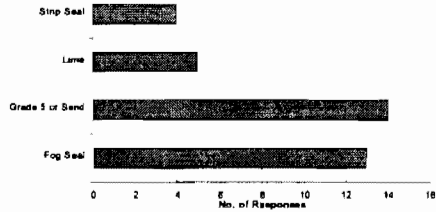


Beaumont= Minimum 6

30



### How do you rectify the distresses?



Beaumont= Grade 5 or Sand for flushing

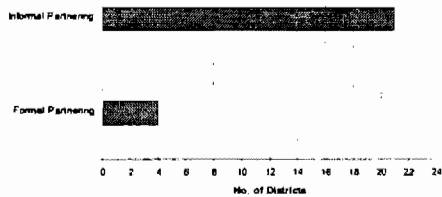
37

### Costs to Rectify Bleeding Pavements

| Cost (\$)       |           |                |        |                   |     |
|-----------------|-----------|----------------|--------|-------------------|-----|
| Statewide Total |           | Statewide Avg. |        | Beaumont District |     |
| 97              | 98        | 97             | 98     | 97                | 98  |
| 1,405,547       | 2,112,213 | 56,222         | 84,489 | 6,372             | 215 |

38

### What CI methods are used to improve the quality of your seal coats?



Beaumont= Informal Partnering

39

### Statewide Constructability Review Findings

- Planning and Design
- Materials and Specs
- Contract Administration
- Equipment and Construction

40

### Planning and Design

- Project selection and prioritization
  - objective
  - subjective
- Design method
  - Modified Kearby Method
  - Past experience basis
- Surface preparation
  - crack sealing - linear unit pay item
  - patching - timing
- Multiple binders on the same contract

41

### Materials and Specs

- Concrete aggregate decant test
- Encourage stockpile testing
- Revisit the specs for asphalt binders
- Minimize the binder-aggregate combination for each contract and stay with it
- Study aggregate-binder compatibility and precoating effectiveness

42



## Contract Administration

- Keep contract size at or above \$2 m.
- Designate a permanent seal coat team
- Pay for binder by weight
- Post-contract evaluation

43

## Equipment and Construction

- Develop a Seal Coat Field Guide
- Standardize technical seal coat vocabulary
- Require contractors to provide calculated number of rollers based on minimum rolling time and distributor production
- Have minimum 3 people in inspection team

44

## Seal Coat Design

## Design Management

- Project identification
- Project selection methodology
- Material selection (binder & aggregate)
- Experimentation with new products

## Project Selection Process

- Funds available
- Pavement condition (PMIS)
- Time since last seal
- Prioritization
  - Objective methods
  - Subjective methods

## Objective Project Selection - Example

### San Angelo District Project Selection Process

1. Area Engineers prioritize area's list with input from maintenance offices and submits the list to design office
2. Collect project data for all projects on the AE's list, e.g. PMIS, cracking, flushing, ADT
3. Quantify all factors
4. Form a preliminary list
5. Modify the preliminary list
6. Finalize the list and prepare PS & E

## San Angelo District Project Selection

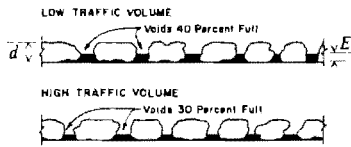
### ■ Relative Weight of the Factors

|                      |                  |
|----------------------|------------------|
| AE's prioritization: | 40 points        |
| Cracking (PMIS):     | 20 points        |
| Flushing (PMIS):     | 10 points        |
| Traffic:             | 20 points        |
| Age:                 | <u>10 points</u> |
|                      | 100 points       |

## Subjective Project Selection Methods

- Decentralized
  - split funds between AE's
- Centralized
  - Prioritize at District office
  - Evaluate & prioritize at District office

## Embedment Depth (E) \*



$$E = e \cdot d$$

- $e$  = percent embedment
  - Based on Agg. Type/Grade, Binder Type/Grade
- $d$  = average mat depth (in)

\*Galloway, et. al. Field Manual on Design and Construction of Seal Coats, TTI, 1981

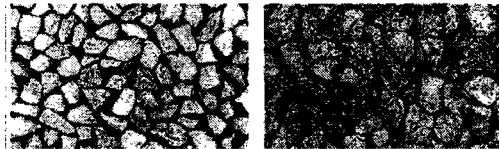
## Design Approach

- Design method
  - Experience-based
  - Other
- Select binder(s)
- Select aggregate grade
- Design material application rates

## Material Application Rates

- Binder rate
  - Experience-based
  - Modified Kearby method
- Rock rate
  - Experience-based
  - Board Test

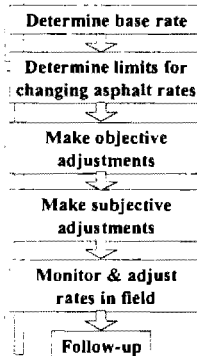
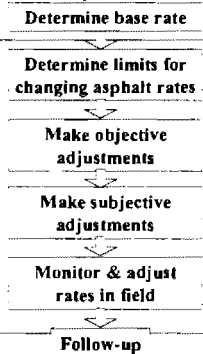
## Rock Rates



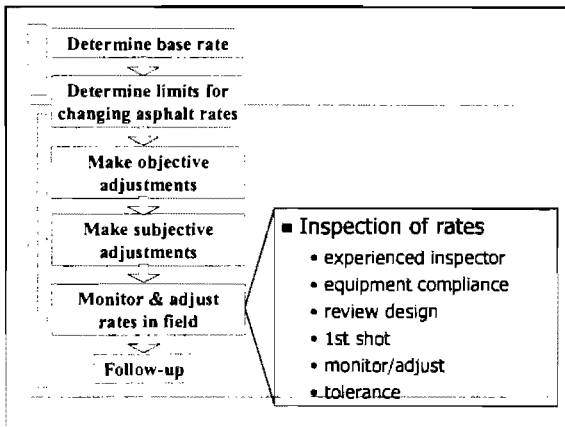
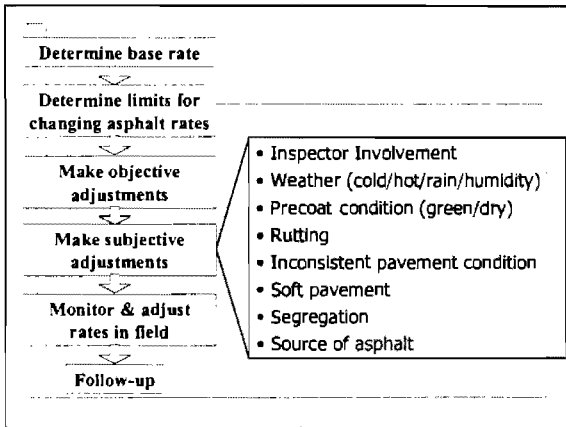
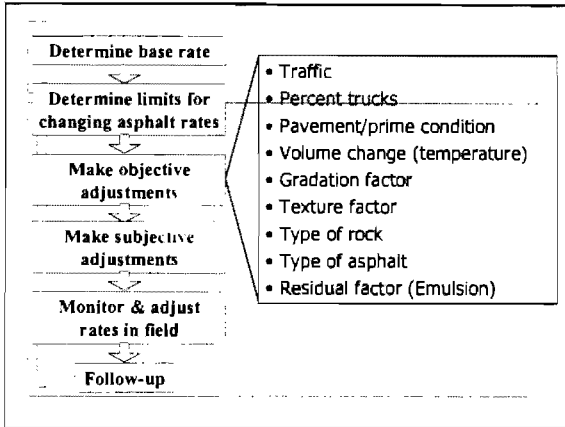
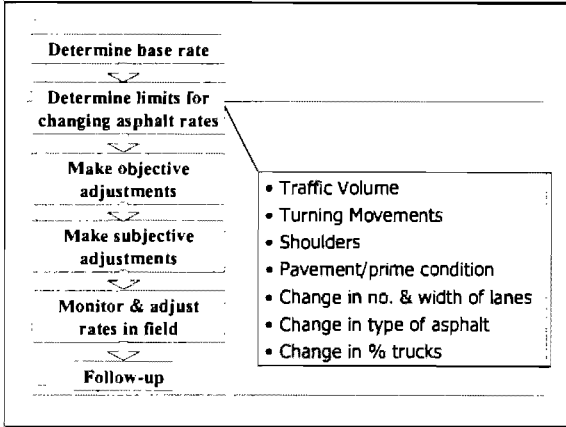
Open

Dense

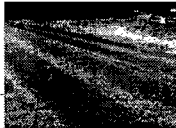
## Modified Kearby Method



- Past Experience Basis
- Type & grade of Binder
- Rock rate
- Type & Grade of Aggregate
- Traffic



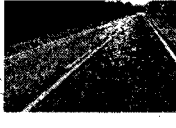
### Design Example for a Flushed Pavement



- AC-10, Type B Gr. 3, ADT=6000 (VPL=1800), 25% Trucks, Flushed Seal

|   |                    |
|---|--------------------|
| Base rate                               | 0.37 gal/sy        |
| Traffic adjustment (Table 1)            | -0.03 gal/sy       |
| Truck adjustment (Table 2)              | -0.01 gal/sy       |
| Existing surface condition (Table 3)    | -0.02 gal/sy       |
| <b>Wheel path binder rate</b>           | <b>0.31 gal/sy</b> |
| <b>Outside WP binder rate(1.2*0.31)</b> | <b>0.37 gal/sy</b> |

### Design Example for a Uniform Pavement Condition



- AC-10, Type B Gr. 3 Lightweight, ADT=6000 (VPL=1800), 25% Trucks, Uniform Seal

|   |                    |
|---|--------------------|
| Base rate                               | 0.37 gal/sy        |
| Traffic adjustment (Table 1)            | -0.03 gal/sy       |
| Truck adjustment (Table 2)              | -0.01 gal/sy       |
| Existing surface condition (Table 3)    | 0.00 gal/sy        |
| Lightweight aggregate (Table 8)         | +0.02 gal/sy       |
| <b>Wheel path binder rate</b>           | <b>0.35 gal/sy</b> |
| <b>Outside WP binder rate(1.2*0.35)</b> | <b>0.42 gal/sy</b> |

## Design Example for a Shelled Pavement



- AC-10, Type B Gr. 3, ADT=6000 (VPL=1800), 25% Trucks, Dry (hungry) seal with cracks

|  |                     |
|--|---------------------|
| Base rate                                | 0.37 gal/sy         |
| Traffic adjustment (Table 1)             | -0.03 gal/sy        |
| Truck adjustment (Table 2)               | -0.01 gal/sy        |
| Existing surface condition (Table 3)     | +0.03 gal/sy        |
| Finer material in agg. (Table 6)         | -0.005 gal/sy       |
| <b>Wheel path binder rate</b>            | <b>0.355 gal/sy</b> |
| <b>Outside WP binder rate(1.2*0.355)</b> | <b>0.426 gal/sy</b> |

## Aggregate Issues

- Availability and cost
- Gradation
  - Uniform size preferred (minimize - #10 size)
- Particle Surface Condition
  - Dusty aggregate
  - Wet aggregate
- Compatibility with binder

## Aggregate Gradation

- |  |   |
|--|---|
| <ul style="list-style-type: none"> <li>■ Grade 3                             <ul style="list-style-type: none"> <li>- Larger particles</li> <li>- Noisy</li> <li>- rougher riding surface</li> <li>- higher mat thickness</li> <li>- windshield complaints</li> <li>- higher price</li> <li>- Better drainage</li> <li>- more "forgiving"</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>■ Grade 4                             <ul style="list-style-type: none"> <li>- Smaller particles</li> <li>- Less noisy</li> <li>- smoother riding surface</li> <li>- lower mat thickness</li> <li>- widely used</li> <li>- no room for error in binder rate</li> </ul> </li> </ul> |
|--|---|

## Aggregates

- Use of Precoated aggregates
  - precoating material
  - reduction in dust
- Lightweight aggregates
  - very good skid resistance
  - abrasion may be a problem
  - less windshield damage

## Binder Selection

- 3 binder types (AC, emulsions, cutbacks)
- "Can make any binder work"
- Selection criteria
  - Availability & cost
  - Climatic factors (temperature, rainy days)
  - Past experience
- Better quality binder gives higher probability of success

## Variation of Binder Rate

- Across the lane
  - Asphalt rate corrected outside the wheel path
  - Some districts provide nozzles to the contractor
  - Nozzle configuration
 

|     |       |     |       |     |
|-----|-------|-----|-------|-----|
| Big | Small | Big | Small | Big |
|-----|-------|-----|-------|-----|
  - May be appropriate for
    - pavements with continuous flushing/shelling on WP
    - districts with consistent flushing & shelling problems
- Along the lane(Adjusted in-situ, depending on existing surface)

## Seal Coat Construction



Equipment Patterns

## Construction

- Contractors
  - size of the contract
  - level of competition
  - contractor's experience
  - past experience with the contractor

## Construction

- Construction season
  - temperature is the most crucial factor
  - rainfall
- Proper Equipment Selection
  - distributors
  - chip spreaders
  - rollers
  - brooms

## Construction

- Quality Control Program
  - inspection crew
    - number of inspectors
    - experience
  - field adjustment of binder rate
  - rock lands, strapping the distributor, marking aggregate trucks
  - control of rolling time and pattern

## Asphalt Distributor

- Heating System
  - necessary to keep binder at desired application temperature
  - need for heating depends on type of binder, weather and length of time in the tank
  - flame from burners is directed into flues that pass through tank
  - Care must be taken with asphalt cements

## Asphalt Distributor



- Major Components
  - Tank
    - 1000 to 2000 gallon capacity.
    - tank is insulated to prevent the binder from cooling
    - baffle plates stabilize the load while in motion
    - asphalt is heated with flues or heat ducts running lengthwise of the tank

## Asphalt Distributor

- Circulation and pumping system
  - circulates asphalt throughout the tank
  - circulates asphalt through spray bar
  - pump unused asphalt out of the distributor
- Spray bar
  - regulate the amount of asphalt and spray pattern
  - nozzles should be set at proper angle
  - spray bar height determines lap pattern
  - springs of the truck should be stabilized to ensure the same bar height when tank is full and empty

## Controls and gauges

- thermometer
- volume gauge
  - not to be used as a basis for payments
- dip stick
- pump pressure gauge
  - critical for the uniformity of the spray.
  - low pressure causes streaking
  - high pressure atomizes asphalt and distorts the pattern
- valve control
- tachometer

## Asphalt Distributor Calibration

- Perform under the supervision of a Registered Professional Engineer
- Distributor tank calibration
  - Strapping rod used to calibrate by filling in increments
  - Depth vs. volume data prepared
- Spray bar calibration
  - Bucket test
  - Spray bar height for coverage
  - Even fan widths
  - Nozzles (angle, arrangement, deflectors, cleanliness)

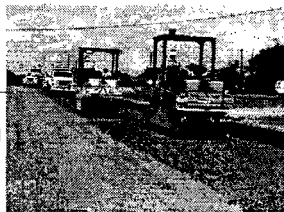
## Aggregate Spreader

- spreader box receives aggregate from a haul truck, which dumps the aggregate into a receiving hopper
- a conveyor system transports the aggregate to another bin (spreader hopper) at the front of the vehicle
- gravity spreads aggregate evenly across adjustable gates
- the gates with a discharge roller allow precise and uniform amounts to pass through



## Pneumatic Rollers

- Contact pressure is critical for seating the aggregate
- tires should have uniform contact pressure
- either 7 or 9 wheel rollers
- tires should not wobble during operation
- speed/gear relationship determines rolling time



## Pneumatic Rollers

- Lightweight rollers
  - must be capable of ballast loading, to uniformly vary the total vehicle weight from 9,000 lbs or less to 18,000 lbs or more
  - minimum tire contact pressure should be 45 psi
  - 60" rolling width
- Medium rollers
  - must uniformly vary the weight from 23,500 lbs or less to 50,000 lbs or more
  - contact pressure must be at least 85 or 90 psi
  - 84" rolling width

## Steel-Wheeled Rollers

- Types: single drum, two-axle tandem or three-wheeled
- Weigh between 3 to 6 tons
- Wheels must be flat and free of gouges or pits, visible wobble and excessive vibration
- Use only with hard aggregate
- One pass only

## Preparation of Existing Surface

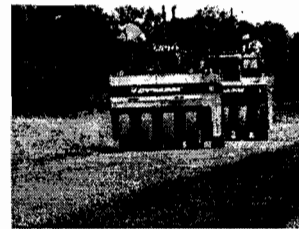
- Timeliness of preparation
  - coordination with maintenance crew
- Repairs
  - Level-ups
  - Patches (asphalt absorption capacity)
  - Crack seals (cold pour, pay unit)

## Determination of Minimum Number of Rollers

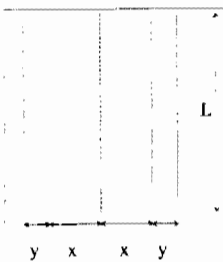
- If a minimum rolling time is stipulated in the contract, the required minimum number of rollers can be calculated
- Aggregate retention depends on embedment
- Roller is a tool to seat rock - achieve least dimension vertically
- The specified minimum rolling time varies among districts

## Example Roller Patterns

CP 132 type medium rollers



## Typical Roadway Geometry



Requirement:  
 1 hr. rolling time / 5000 sy  
 $x = 12 \text{ ft.} = 4 \text{ yd}$   
 $y = 10 \text{ ft.}$   
 $A = x.L$   
 $L = 5000 \text{ sy} / 4 \text{ yd}$   
 $L = 1250 \text{ yd.}$

## Travel Time of a Roller (t)

$$t = \frac{L}{V_r} \quad V_r = 6.2 \text{ mph for CP 132 type roller}$$

$$t = \frac{1250(\text{yd})}{6.2(\text{mph})1760 \frac{\text{yd}}{\text{mile}}}$$

$$t = 0.12 \text{ hr}$$



### Number of Passes (NP)

$$NP = \frac{H}{T}$$

H = 1 hr  
T = total rolling time  
N = number of rollers

$$T = tN$$

$$T = (0.115)(3)$$

$$NP = \frac{1(hr)}{0.345(hr)} = 2.17$$

NP = 2.17 passes;  
therefore NP = 3

because you must have an odd number of complete passes

### Production Rates of Rollers ( $P_r$ ) & Distributor ( $S_f$ )\*

$$P_r = \frac{V_r}{NP}$$

$$S_f = \frac{9G_s}{WR}$$

$G_s$  = spray bar output (gal/min)  
 $W$  = sprayed width (ft)  
 $R$  = rate of binder application (gal/sy)

$$P_r = \frac{6.2}{3}$$

$$S_f = \frac{(9)(90)}{(12)(0.33)} = 2.33 \text{ mph}$$

$$P_r = 2.07 \text{ mph}$$

$$S_f = 2.33 \text{ mph}$$

$P_r < S_f$

(\*) Galloway, 1981

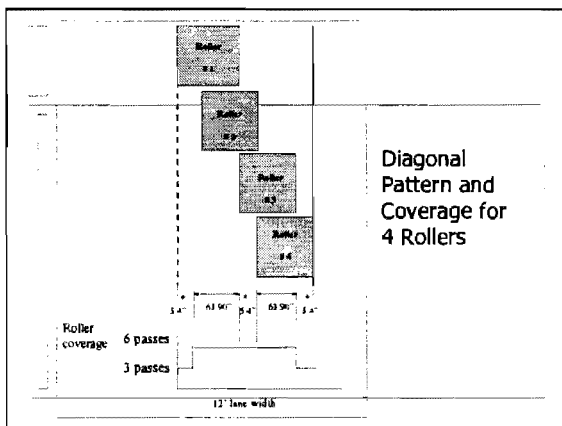
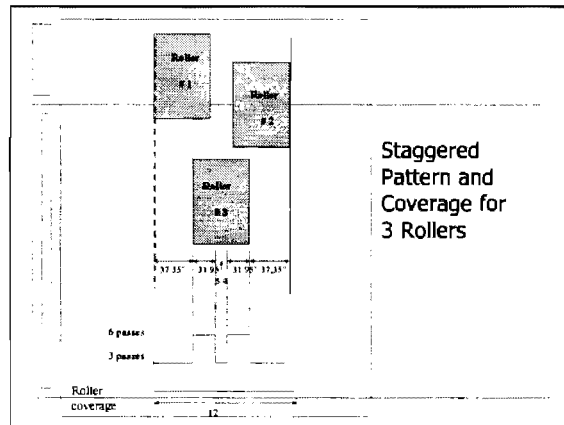
### Minimum Number of Rollers

$$N = \frac{P_r x}{A}$$

$$P_r = S_f$$

$$N = \frac{2.33(\text{mph})4(\text{yd})1760(\text{yd} / \text{mi})}{5000 \text{ sy} / \text{ hr}}$$

$$N = 3.28 \rightarrow 4 \text{ rollers}$$



### Conclusions on Rolling Patterns

- Production of distributor controls the system
- All other equipment production rates must be greater than or equal to the distributor
- If not, quality control may suffer

## Continuous Improvement

---

- Partnering
    - formal
    - informal
  - Preconstruction meeting
  - Periodic seal coat meetings
    - evaluation
    - improvement
-

## Seal Coat Constructability Review for Beaumont District

Discussion of Findings & Recommendations

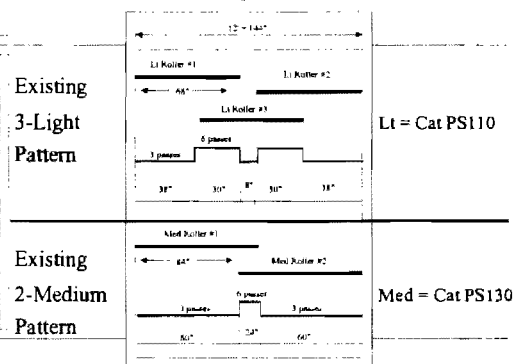
## Program Strengths

- Central Design
- Single Binder
- Inspection Team
- Informal Partnering

## Things to Consider

- Single Seal Coat Team
  - learning curve
  - lessons learned
- Rolling
- Design method
- Variable binder rates across lane
- Methods to Rectify Flushing
- Post-Contract Evaluation

## Roller Patterns: 3-Light or 2-Medium Rollers



## Rolling Considerations

- Minimum number of rollers to keep up with Distributor production without sacrificing rolling time requirement.
- Consider size(s) of rollers to be used
  - Calculate rolling pattern
  - Evenly distribute roller coverage
- Inspector aware of rollers during construction.

## Additional Equipment-Related Submittals

- Distributor production rate
- Actual width of rollers to be used
- Roller tire pressure
- Rolling plan for each shot to ensure adequate coverage

## Methods to Rectify Flushing

- Chatting
  - adding finer aggregate (Gr. 5)
  - may only postpone the problem
- Lime Slurry Spray
  - timing is critical
  - makes binder stiffer
  - makes binder cooler (temporary)
  - Lightens pavement color so less heat is absorbed

## Post-Contract Evaluation

- Compare actual rates to performance
- Period between completion and evaluation
  - After minimum amount of traffic passed
  - After first cold spell
- Construction-related documentation needed to facilitate evaluation
- Post-Contract Evaluation documentation to be used in next year's seal coat work