APPENDIX A

CORRELATION OF CONSTRUCTION QUALITY CRITERIA WITH PERFORMANCE OF ASPHALTIC CONCRETE PAVEMENTS

FINAL REPORT

By

S. C. SHAH
RESEARCH & DEVELOPMENT ENGINEER

Research Report No. 208
Research Project No. 79-2G

Conducted by
LOUISIANA DEPARTMENT OF TRANSPORTATION
AND DEVELOPMENT
Louisiana Transportation Research Center
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

AUGUST 1987

This report is concerned with the determination of relationship between asphaltic concrete surface course specifications and the level of performance of pavements constructed under these specifications. The relationship was investigated through comparative evaluation of deficient (in specification) and non-deficient sections using a combination of pavement condition rating and ride rating as the criteria for evaluation. The analysis and evaluation of the data indicated (1) a recognizable difference in the level of performance between the 100 percent pay or non-deficient sections and the deficient sections for stability and surface tolerance criteria of acceptance; (2) little difference in the performance level between the two groups of sections for compaction criteria deficiency; (3) pot hole patching for test or deficient sections to be much more than the corresponding control or non-deficient section (4) that majority of the sections (control or test) have not reached end of life according to PSI measure of serviceability.

ABSTRACT

This report is concerned with the determination of relationship between asphaltic concrete surface course specifications and the level of performance of pavements constructed under these specifications. The relationship was investigated through comparative evaluation of deficient (in specification) and non-deficient sections using a combination of pavement condition rating and ride rating as the criteria for evaluation. The analysis and evaluation of the data indicated (1) a recognizable difference in the level of performance for the 100 percent pay or non-deficient sections and the deficient sections for stability and surface tolerance criteria of acceptance; (2) little difference in the performance level between the two groups of sections for compaction criteria deficiency; (3) pot hole patching for test or deficient sections to be much more than the corresponding control or non-deficient section (4) that majority of the sections (control or test) have not reached end of life according to PSI measure of serviceability.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Most highway construction specifications prescribed can be categorized as design requirements or material requirements, as opposed to the current emphasis on performance requirements. The issue of quality with respect to performance has been the most complex and little, if any, information is available about the relationship between the presently used material 'quality indicator' type specifications and the real-life service performance.

Louisiana has been actively engaged in the development and implementation of statistically oriented end-result specifications (ERS) since the late 1960's (1, 2, 3, 4). Since implementation of the original ERS in 1971, changes have been made to accommodate material and equipment changes without affecting the basic concept of these specifications. Conceptually, the specifications contain the following features:

1. Definition of responsibilities of the contractor and the Department for control and/or acceptance of the product (who is required to do what?).

2. Identification of quality criteria for control and acceptance and their respective limiting values.

3. Random sampling techniques and statistically oriented acceptance sampling plans.

4. Disposition of non-conforming product (price adjustments).

Underlined numbers in parentheses refer to list of references.

After almost two decades of implementation of these specifications, the question as to what relationships, if any, exist between these specifications and long term performance still remains to be answered. This report attempts to answer this question through field evaluation of projects constructed under these specifications. However, in seeking this answer, there is an implied assumption that the construction criteria are performance oriented. Furthermore, the disincentives, or reduction in pay imposed on the producer or contractor due to non conforming product, are believed to offset a reduction in design life which may necessitate early maintenance and/or rehabilitation effort due to early manifestation of pavement surface distress.

OBJECTIVE & SCOPE

The specific objective of the study reported herein was to determine the relationships between construction acceptance criteria for asphaltic concrete pavements and the performance of such pavements.

The scope was limited to evaluation of the lots, deficient or otherwise, and not the individual subsections within these lots that may have contributed to the deficiency or non-deficiency. Thus, the non-deficient section may have a real low value and yet receive 100 percent pay because of higher than the required average values for the remaining samples. Likewise, a single low value may also render the entire lot defective because of the remaining sample values very close to the required average for conformance. This inability to delineate the subsections was a major constraint in the study.

The study involved evaluation of asphaltic concrete wearing course mixes only. Furthermore, no attempt was made to delineate the material and section layer characteristics underneath the surface course layer. However, care was exercised to assure that the binder course layer directly beneath the surface course sections was free of any specification deficiencies. In essence, to accomplish the stated objective, it was assumed that the pavement section is homogeneous in all respects except the deficient hot mix surface layer.

The scope did not include determination of the validity of the pay schedule. Furthermore, no control or constraint was placed on carrying out any routine maintenance of the sections during the evaluation period as was deemed appropriate by the districts.

STUDY METHOD

Selection of Projects

Two sources were used for selection of projects for data collection. One was reference 2 and the other was the Department's computerized material and construction test data file (MATT system). Although not much choice was available in the selection procedure, a combination of these two sources provided twenty-one projects across the state that had some deficiency in construction acceptance criteria as defined in Appendix Table 6, 7 and 8. Figure 1 on page 5 shows the location of the selected projects.

Appendix A contains excerpts from the Louisiana Standard Specifications for Roads and Bridges, 1977 which indicate levels of pay adjustment for the specified acceptance criteria of stability, compaction and surface tolerance for each lot. A lot was defined as one day's production in these specifications. In cases where a lot may be deficient in several criteria, the lowest percentage of contract price is used for final adjustment.

The selected projects represent new and overlay construction. Furthermore, most of these projects were at least three years old at the time. This was considered necessary in order to minimize the time to identification of recognizable (significant) distress. The ages of these projects varied from six to eleven years at the conclusion of the study. Table 1 on page 6 is a listing of the selected construction projects by type of construction and number of control and test sections available for evaluation. A control section is one which has met all construction acceptance requirements and thus merited full (100%) pay. A test section is one which failed to meet one or more construction acceptance requirements (as specified in Appendix A) and therefore merited less than 100% of scheduled pay.

The projects were distributed almost evenly between new construction, overlays over rigid pavements and overlays over flexible pavements. These projects provided 52 control sections and 140 test sections for a total of 192 sections. The projects marked with an asterisk are those that had to be dropped sometime during the evaluation period because of heavy maintenance and/or rehabilitation.

Table 2 on page 8 shows the distribution of project test sections according to the acceptance criteria and percent of contract pay. Of the 140 test sections, more than half had deficiencies in compaction criteria. Some sections had multiple deficiencies.

<u>Field Identification of Sections</u>

The physical limits of construction lots, with and without deficiencies in acceptance criteria, were located and marked for identification. Random 1000-foot sections were then selected from these deficient and non-deficient lots. It was not possible to assign a control section for each test section as was originally planned for pairwise comparison. On the average, for every three test sections, a control section was available for comparison.

<u>Data Collection</u>

Data collection on the projects and sections consisted of the following:

> <u>Construction Information</u>
>
> The basic project information on asphaltic concrete mixes for the sections and other associated information is listed in Appendix B, Table 9.
>
> <u>Traffic Histories</u>
>
> Traffic data consisted of yearly ADT and 18k ESAL since hot mix construction. Table 3 on page 9 is a listing of the traffic history of the sections.

Field Measurements

Field measurements basically involved four separate condition evaluation of sections over a five year period; specifically in 1980, 1982, 1984 and 1985. Pavement condition indicators selected for evaluation were those hypothesized to relate to the acceptance criteria defined in the specifications (mix strength, density and surface profile). In essence, performance was measured by evaluating pavement condition indicators such as cracking, patching, rutting and roughness. Figure 2 on page 11 is an example of the condition survey form that was developed for the evaluation. The final rating, termed Basic Rating, is a combination of defect rating and ride rating. The rating ranges from zero (worst pavement condition) to 100 (best). The cracking and patching defects were noted by walking the entire length of the sections. The rutting defect was measured every 100 feet with the AASHO A-frame rut depth device in both wheel paths. The roughness defect was measured with the Mays Ride Meter.

Data Storage

All project and section data were stored in the computer for easy accessibility and analysis. Appendix B, Table 10 is a record layout of the stored data.

Method of Data Analysis

The study was not a statistically designed study in that not much choice was available in selection of either the projects with non conforming product, or the sections within the projects with specific reduction in pay category. The availability was the governing factor in selection. If a project had non conforming lots, it was in. Because of this scarcity of project sections for one-to-one comparison (a control section for each test section), graphical and/or numerical method using averages were applied to compare trends in performance between the control and test sections. Whenever possible, statistical methods were used to determine the significance of the performance trends between the sections.

ANALYSIS & EVALUATION OF TEST RESULTS

The first condition evaluation was made in the fall of 1980 with subsequent ones in 1982, 1984 and 1985, all approximately the same time of the year. As was shown in Figure 2, the condition evaluation is expressed as Basic Rating which is a quantitative composite of ride and pavement distress values. Pavement distresses are in terms of cracking, patching and rutting. The final rating ranges from zero (worst pavement condition) to 100 (best).

All field data appear in Appendix B, Table 11. Table 4 on pages 14-16 lists the condition ratings by projects averaged over sections and specific deficiency. Only initial (1980) and final (1985) data are listed in this table and the associated percent change during the period. Several projects had to be taken off the evaluation during the study period because of major maintenance overlay. For these projects the final represents the last data available prior to maintenance overlay or other rehabilitation. These projects were identified with an asterisk in Table 1.

Performance Evaluation - Individual Projects

The data for Basic Rating and Mays PSI listed in Table 4 on pages 14-16 are graphically presented in Figures 3 and 4 on pages 17-28, respectively. The tabulated and charted values indicate the following:

+ Using Basic Rating as the performance evaluation criteria, more than two thirds of the projects show sections with no deficiency (control) to perform slightly better than the corresponding deficient sections (test). However, with the exception of project 263-01-09, the difference in the mean performance between the control and test section for the projects was not statistically significant as determined by the T-Test at a 0.05 significance level.

- + The Mays Ride Meter data do not show any discernible difference between the sections, either graphically of statistically.

- + Rutting does not seem to be an overall problem and, therefore, fails to indicate any recognizable differences. The largest magnitude of this distress was less than one centimeter or one-half inch.

- + On some projects, extensive pot hole patching on the deficient sections required major maintenance to bring the project to an adequate serviceability standard.

- + The majority of the projects show decay in performance during the period of evaluation. The rate of decay is more pronounced in half of the project test sections than the corresponding control sections.

<u>Discussion</u> - <u>Individual Project Analysis</u>

Lack of observed definitive trend in some cases can be attributed to several extraneous factors, the predominant being the performance of the section layers below the surface layer evaluated (although assumed to be uniform) and the interdependency of the materials and construction variables. Furthermore, the confounding of 'good' subsections in overall deficient lots and 'bad' subsections in non-deficient lots within the sections can not be overlooked. As was pointed out in the scope section of this report, the selection procedure for the control or the test sections did not (and could not) attempt to delineate the individual deficient mix (stability) and/or roadway cores (compaction) that may have contributed to the overall conformance or non conformance of the lot.

Although the 1000-foot section for evaluation was randomly selected, it could not be ascertained that the particular segment did indeed represent all conformed material or all non conformed material.

The specifications applicable at the time of this study (Appendix A) did not have any provision for disposition of individual samples that may have undesirable low value or values. A single value in a sample size of four (such as for stability) or five (for roadway compaction) may render the lot acceptable or unacceptable depending on the magnitude of the remaining individual samples. (100 percent pay if the remaining values are considerably larger than the required average or reduction in pay if these values are close to the average). To circumvent this confounding it is necessary to specify acceptance limits on individual samples (in addition to limits on average) that make up the lot average.

Performance Evaluation - Pooled Data

In order to smooth out the erratic trends indicated by some of the project sections, analysis was performed on data averaged over certain variables. The data from Appendix B, Table 11 were used for this analysis.

Figure 5 is a comparison of the performance of the control section and the test section for various distress criteria averaged over all sections. Table 5 on page 32 is the result of the statistical T-Test. The missing data indicate either obvious erratic trends and/or lack of valid sample size for variables used in the hypothesis testing.

The differences in mean values between test and control sections as of 1.8 in Basic Rating and 0.13 in Mays PSI is not statistically significant at a 0.05 significance level (Table 5). Likewise, the rutting for both sections is less than 0.25 inches. The patching was seven times more for the test sections than the control section.

Further breakdown of the above data by various acceptance criteria (deficiency), developed Figure 6. With the exception of compaction deficient sections, there is a recognizable difference in the performance criteria between the non-deficient control sections and sections with stability and surface tolerance deficiency. Likewise, the difference was significant at .05 level as determined by the T-Test and shown in Table 5.

The average patching for the deficient sections was five to ten times more than the corresponding non-deficient sections. The rutting trend, although erratic, is of minor consequence, being less than 0.25 inches or 6.3 millimeters on most of the projects.

The data in Figure 6 was further broken down to show the relationship of each individual acceptance deficiency according to their level of pay. Figure 7 on pages 35-38 is the result of this analysis by level of pay. Table 5 shows results of the statistical T-Test.

The reduced pay level sections due to compaction deficiency are performing as good as the 100 percent pay section using the Basic Rating and Mays PSI criteria of performance evaluation. However, the patching on the 80 and 95 percent pay level sections is more than five times the 100 percent pay sections. The magnitude of rutting on all sections is too small to be of any significance.

The stability and surface tolerance deficient sections show more noticeable trend in performance with the latter showing the most pronounced difference in the test and control sections. The 80 percent level of pay for surface tolerance was statistically significant for both the Basic Rating and PSI criteria. The patching was quite pronounced on all deficient sections with reduced pay level than the corresponding full pay sections.

A final analysis of the data on the basis of construction type is provided in Figure 8 on pages 39-40. The bar charts in the figure clearly indicate the negligible effect of the construction type on the level of performance between the control and test sections. The average difference in Basic Rating for control sections (for the three construction types) was 1.5 and that for test sections was 1.4. Likewise, the average PSI difference for control and test section was 0.1 and 0.2, respectively.

The overall rate of deterioration in the measured performance for control and test sections is shown in Figure 9 on page 42. This overall rate is slightly lower for the control sections than the test sections with respect to Basic Rating and Mays. Again, the levels of rutting are generally less than 0.25 inch indicating additional compaction due to traffic and thus are insignificant. The apparent higher rate of rutting on control sections is misleading. As the deficient sections had higher initial void levels, those sections compacted more readily in the earlier years thus demonstrated a lower percentage change from the initial to final readings. Generally, the final amount of rutting within each project was the same at the final evaluation.

<u>Supplementary Analysis of Pooled Data</u>

The decay of PSI with time is shown in Figure 10 on page 43. Projects were pooled according to age groups to derive this figure. The effect of traffic since hot mix construction, expressed as log summation of 18-kip ESAL, on PSI is shown in Figure 11 on page 43. The fair to good PSI level, after almost 10 years or one million ESAL, should be attributed to adequate maintenance on the projects to maintain the level of service deemed appropriate. This fact is further demonstrated in Figure 12 on page 44 which show defect rating relationship to PSI. The data represents 1984 data. If the pavement is maintained around a defect value of 70-75, fair to good serviceability can be retained. The majority of the projects falling in the upper right quadrant show this to be the case.

Discussion - Pooled Analysis

Pavement performance is generally categorized into two classes: functional and structural. The former is usually defined in terms of pavement condition indicators such as roughness and skid resistance. Structural performance generally relates to deterioration in structural condition over time (or load). Examples of this class are cracking, patching and rutting.

Variables associated with materials and construction affect the above two classes of performance. Both roughness and cracking and rutting may be influenced by materials and construction variables. However, construction may have more pronounced effect in the long run than materials. This has been observed in this investigation. In fact, this particular criteria of acceptance indicated a pronounced difference in PSI roughness in the two systems, deficient and non-deficient.

The fact that the surface tolerance criteria showed a definitive trend can be attributed to the sampling plan used for its acceptance. The entire lot is tested for conformance rather than several segments of the lot as is done for compaction acceptance. Testing the entire lot provides a continuous longitudinal profile of the pavement lot. Thus a full pay lot assures its acceptability over the entire lot. There is very little confounding of 'good' segments in deficient lots or 'bad' segments in non-deficient lots as is generally encountered in acceptance of lots on the basis of compaction or stability.

Pavement condition indicators that define the structural integrity of the pavement are in most cases, influenced by materials variables relative to asphalt grade, content, and source, aggregate gradation and air voids. The construction variables that are assumed to influence rutting and cracking can be defined in terms of roadway density and thickness.

Most of the material and construction variables are hierarchical in nature and are often not independent of each other. In the present case, stability is used as an indirect measure of material variables defined above. This means that any deficiency in asphalt and/or aggregate material would be reflected in the stability. Likewise, air voids in the roadway compacted mix are determined largely by gradation, asphalt content and compactive effort. Thus, air voids in pavement would be an influential variable in the determination of performance. However, this hierarchical and interdependency of materials coupled with routine maintenance (not controlled on these projects) complicates the consideration of the materials and construction variables that may singly influence performance as has been the case in the study. The lack of specific trends in compaction criteria may be the result of the masking effects of these interpendencies.

SUMMARY, CONCLUSIONS, & RECOMMENDATIONS

In the preceding sections an attempt was made to present relationships, if any, between asphaltic concrete acceptance specifications for surface course and performance of pavements constructed under these specifications. This relationship was investigated through comparative evaluation of deficient (in specification compliance) and non-deficient segments of several projects throughout the state. Deficient sections were defined as those that failed to meet the specification requirement for Marshall stability, roadway compaction and surface tolerance. The performance criteria used for comparative evaluation of these sections related to a combination of condition rating and ride rating and expressed as Basic Rating. The following represent key findings from the statistical and graphical analysis of individual and pooled project data and are within the confines of the projects evaluated in this study.

1. The majority of the projects showed better performance, in terms of overall Basic Rating, of the control or non-deficient sections than the test or deficient sections. However, this difference was not statistically significant at a 0.05 level.

2. The magnitude of the rate of deterioration of the Basic Distress Rating and Mays Ride Meter was evenly distributed between the control and test sections. Generally, rutting was non-existent in the projects evaluated.

3. Analysis of pooled data according to acceptance criteria and level of pay showed better level of performance of the control sections (100 percent pay) than the sections with deficiency in stability and surface tolerance and the associated reduction in level of pay. This

difference was also shown to be statistically significant at the 0.05 level. However, the level of performance between the compaction deficient sections and the non-deficient sections was basically the same.

4. The extent of pot hole patching on the deficient sections was much more than the control sections.

5. The magnitude of rutting was too small to show any difference between the sections.

6. Construction type (overlay of flexible or rigid pavements and new construction) did not show any difference in the level of performance between the sections.

7. Most of the sections, control and test, have not reached end of life, based on magnitude of PSI, as of the last rating survey. Likewise, after almost ten years and close to an average application of one million 18-kip ESAL, the average PSI is 3.0 or better.

8. All in all, the findings seem to indicate a better level of performance of the non-deficient sections than the deficient sections. Lack of this difference for any specific specification criteria should be attributed to interpendencies of the several material and construction variables and routine maintenance. A possible confounding effect of individual 'good' samples in unacceptable lots and 'bad' samples in acceptable lots may have further masked the presence of the difference between the sections.

9. In view of the above last statement, the specifications should include a provision for acceptance limits on individual samples in the lot.

REFERENCES

1. Shah, S.C., "Asphaltic Concrete Pavement Survey," Research Report No. 3, Louisiana Department of Highways, Baton Rouge, April 1963.

2. Shah, S.C., "Quality Control Analysis, Part I -Asphaltic Concrete," Research Report No. 15, Louisiana Department of Highways, Baton Rouge, November 1964.

3. Shah, S.C., "Quality Control Analysis, Part IV - Field Simulation of Asphaltic Concrete Specifications," Research Report No. 36, Louisiana Department of Highways, Baton Rouge, March 1969.

4. Shah, S. C. and Yoches, V., "Quality control Analysis, Part V - Review of Data Generated by Statistical Specifications on Asphaltic Concrete," Research Report No. 94, Louisiana Department of Highways, Baton Rouge, December 1975.