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16. Abstract

The primary objective of this study was to develop a "Measurement Strategy" for evaluating the relative degree of success of new hot mix asphalt (HMA) pavement construction specifications. The specific reason for developing a Measurement Strategy was for use in comparing relative performance as a function of time of HMA pavements constructed under Item 340 (sometimes called methods & materials, recipe, or prescription specifications) with pavements constructed using the newer quality control/quality assurance (QC/QA) specifications.

Researchers developed a paired analysis method and reported in Report 1877-5. In the event that pavement construction specifications are developed that, in the future, after the Pavement Management Information System (PMIS) data collection process and database are upgraded, it may be desirable to compare performance of all suitable pavements in the database. A second measurement strategy was developed and provided to Texas Department of Transportation (TxDOT) which uses a general analysis method, that is, it is designed to consider all the appropriate pavements in the PMIS database even if the number of pavements prepared using the different specifications are unequal.

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GENERAL MEASUREMENT STRATEGY TO ANALYZE THE EFFECTS OF CONSTRUCTION SPECIFICATION CHANGES ON QUALITY OF HMA SURFACE COURSES

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DISCLAIMER

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Steven G. Smith, director of construction for the Odessa District, served as Project Director. His insight and guidance were extremely valuable to the researchers during this study. His complete understanding of the objectives of this project and the problems anticipated and encountered during the pursuit of these objectives were key in assuring the study provided meaningful information to TxDOT.

The late Jose E. Morales, the first Project Coordinator, was instrumental in initiating this project. His guidance and assistance are gratefully acknowledged.

Special thanks are extended to Lauren D. Garduno, who served as Project Coordinator through most of the project, and Ken Boehme for their direction and assistance during the conduct of this work.

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INTRODUCTION

BACKGROUND

TxDOT began implementing new quality control/quality assurance (QC/QA) specifications in numerous pilot projects across the state in about FY1993. Full implementation on all state projects began in about FY1994. This was a major change for TxDOT and the contractors. The change was from the Item 340 specification to the Item 3063 or Item 3022 (QC/QA) specification. Shortly after implementation, TxDOT revised the QC/QA specification to make improvements. The QC/QA specification was again revised in about 1996-97 to increase TxDOT's control of the assessment of bonuses and penalties for pay purposes. The wording was also modified to give TxDOT more authority regarding identification of segregation. Additional changes may be forthcoming as a result of the findings and recommendations emanating from Project 1721, "Effectiveness Comparison of Former hot mix asphalt (HMA) Specifications and the Most Current QC/QA Specifications for HMA." It is anticipated that this periodic revision process will continue for the foreseeable future.

The last few generations of HMA pavement specifications need to be investigated to assure continued quality in management of construction testing and inspection. The results of these investigations will have a direct bearing on evaluation and development of improved specifications for HMA pavements and other highway construction products.

TxDOT recognized the need to develop a formal evaluation process for use in continuous improvement of their HMA pavement specifications. This evaluation process must quantify the changes in the level of pavement quality, if any, that the changes in specifications have had as they relate to the service life of HMA pavement surface courses. The measurement strategy should be capable of appraising subsequent generations of HMA pavement specifications for perpetual use by TxDOT.

OBJECTIVES

Near the end of this study, TxDOT requested that the researchers prepare a second Measurement Strategy using a general analysis method in addition to the paired approach reported in Report 1877-5. In the event that pavement construction specifications are developed, in the future, after the Pavement Management Information System (PMIS) data collection process and database are upgraded, it may be desirable to compare performance of specific types of pavements in the database. Therefore, researchers developed a second measurement strategy using a general analysis method which is designed to compare performance of all appropriate pavements in a database without identifying qualified pavement pairs. The general analysis method is valid even if the number of pavements constructed using each specification is different. However, this general analysis method measurement strategy was not tested as a part of this project.

The goal of this study was to develop a "Measurement Strategy" capable of evaluating essentially all appropriate pavements with performance measures recorded in a database to assess the degree of success of new HMA pavement construction specifications. Specifically, a measurement strategy was developed to compare the relative performance as a function of time of HMA pavement surface courses constructed using Item 340 (sometimes called methods & materials, recipe, or prescription specifications) with pavements constructed using the newer QC/QA specifications.

The measurement strategy consists of statistical processes for comparing the performance of Item 340 and QC/QA pavements in an automated format. The Measurement Strategy may subsequently be used by TxDOT to compare existing and future specifications.

SCOPE

The main focus of this project was to develop and test a paired analysis method. The element of work described herein is limited to the development of the general analysis method.

DEVELOPMENT OF THE GENERAL ANALYSIS METHOD

MEASUREMENT STRATEGY—GENERAL ANALYSIS METHOD

This measurement strategy involves analyzing a large number of PMIS evaluations to statistically compare essentially all pavements constructed with the two different specifications. An initial sort of the data is necessary to categorize the pavements. Pavements may be segregated with regard to function or type (e.g., farm-to-market road, state highway). Pavements may be further grouped by climate, subgrade soil, grade, and other such criteria available to the researchers, such as grouping by district. Having grouped the data, an analysis would then be conducted to examine the quality ratings obtained from PMIS data for pavements as a function of age. Pavement "age" may need to depend upon age in years or exposure to traffic (KESALs) or be related to design life or, more specifically, design period to first overlay.

Logical adjustments may need to be made to compare pavements on an equal basis for a statistical robust analysis. For example, it would be possible to statistically compare the mean "distress score" between the two specification methodologies, taken over a large sample, for 5-year old pavements that have common geological and climatic conditions and similar traffic exposure.

If sufficient data can be gathered, it would be possible to statistically compare the mean scores for *each* of the quality-related evaluations summarized in PMIS data. Evaluations with regard to average ratings for distress, ride, deflection, skid, and condition score are possible. Further, the variability, or statistical spread, of the individual scores could be compared. The scores would be compared for each of the years for which sufficient data is available. This allows some inference to be made about quality "trends" as a function of time resulting from the two different specification types.

This general approach is data intensive and will likely require substantial effort in obtaining essential information not currently included in the PMIS database. Further, this approach has the added disadvantage of comparing the two pavement types over such a wide database of values that significant variability in PMIS quality values (ratings or scores) is inevitable. As a result, there is some probability that statistical differences between the scores is not wholly attributable to the different specifications used during construction. This analysis, while useful in identifying broad trends of performance, will need to be carefully evaluated to determine the appropriateness and practicality of eventually applying the procedure on a state-wide scale.

PROCEDURES—GENERAL ANALYSIS METHOD

Randomized experiments are frequently impossible to implement within a field study. In particular, when one compares the effects of old and new standards for pavement construction, randomized studies are not practical. Instead, one needs to compare existing pavements that were not randomly applied. This means that the degree of control and, hence, the interpretation of the results of the study, will be inferior to that which would have been obtained if a randomized study was possible.

The results of field studies or quasi-experiments, while not as easily interpretable as random experiments, still often provide useful information. One must pay careful attention to the likely threats to the interpretation of the findings that occur due to lack of randomization. It should be noted that field studies have some advantages over controlled randomized laboratory experiments. These advantages of field studies include wear that is achieved under normal loading and environmental conditions.

This exposition draws heavily from the pioneering work of Campbell and Stanley. Following Campbell and Stanley (1963), the authors have listed below 12 factors that potentially jeopardize the results of a study of pavement standards. These will be broken into two categories: internal validity and external validity. Internal validity is the basic minimum a field study needs for interpretability: Did the old standard perform as well as the new standard on the specific road segments in our study? External validity is concerned with extrapolation: If the old standard were reinstated would pavement quality improve?

There are at least six relevant variables that will affect internal validity, if not carefully controlled:

1. History: What events such as traffic, weather, and/or repairs affected each pavement section in the study? The number of times a road segment has been overlaid may affect its performance.
2. Maturation: The process that happens regardless of the standard. Does pavement strength change with age? Do different standards lead to different maturation rates?
3. Instrumentation: Will the measurement instruments behave differently on different pavements? For example, nuclear gauges should be calibrated for each pavement type and thickness.
4. Statistical Regression: When trying to match pavement types, the matching will involve measurement error. It will turn out that the performance of the standards does not depend on the measurement error so that the pavement types may not really be matched in the desired fashion.
5. Biases: Those resulting from nonrandom assignment of pavement sections.
6. Experimental Mortality: Some roads paved by the old standard will have been overlaid using the new standard and others may have received major maintenance or rehabilitation.

There are also at least two relevant factors that affect external validity:

1. Selection biases that choose particular pavements that are not typical.
2. Interaction effects of biased selection and controlling variables. For example, it may be convenient to over-represent road segments in southern Texas, thus, the results would not be typical of northern Texas.

Campbell and Stanley (1963) call the design proposed herein "the static group comparison." The old specification was used until a given time. Then, afterwards, all new roads use the new specification. Researchers then will compare equivalent roads that were paved using different specifications. A problem here is that the roads are really not equivalent. One does not know, for example, if the truck traffic on both roads had equivalent loads and other characteristics. One will not know if drainage was the same for both. Weather during the two construction and/or performance periods may have been different enough to affect performance. While one can carefully select road sections that are similar, it is not likely that these roads will really be equivalent. The fact that the different pavements were paved at different times is an indication of different historical events leading to rehabilitation. So, an important issue really is: Given the observed or estimated differences between the two pavement standards, is the difference in performance really due to the standards or are they different for other reasons? This issue will be discussed in some detail later.

MEASURING DIFFERENCES BETWEEN PAVEMENTS

It is assumed that pavements are matched regarding type and age. Thus, researchers compared pavements from the old and new standard based upon the same number of years of wear, the same traffic patterns, and the same composition. In this particular type of comparison (Item 340 versus QC/QA), it was impossible to match pavement weather exposure and pavement raters, among other things. Thus, these effects will be confounded along with the effects of the standards. In general, a form of statistical adjustment called covariance analysis can be used to adjust for known mismatched properties. In order to implement the covariance analysis, statisticians would have to know, for example, both the weather that each type of pavement was subjected to and a reasonable model for the relationship between weather and damage. Herein, researchers will use a form of regression discontinuity design from Campbell and Stanley (1963) to analyze these data.

It is assumed that data are available from each type of pavement specification at equally spaced intervals. At first, researches also assume that wear measurements are available at several different times for a few years for each type of pavement specification. Then, a line will be fitted to each measurement set using time, since the pavement type was created as the x variable and the wear measurement as the y variable.

Suppose it is desirable to compare two treatments. The data are measured in the same units and over time units that are comparable, such as years since treatment was applied. The form of the data is shown in Table 1. A plot of a data set might appear as Figure 1.

Table 1. Example Data for Comparing Cracking for Two Treatments as a Function of Age**.**

Age	**Treatment1 (T1)**	**Treatment 2 (T2)**
1	X_1	Y_1
2	•	•
3	•	•
4	X_{n1}	Y_{n2}

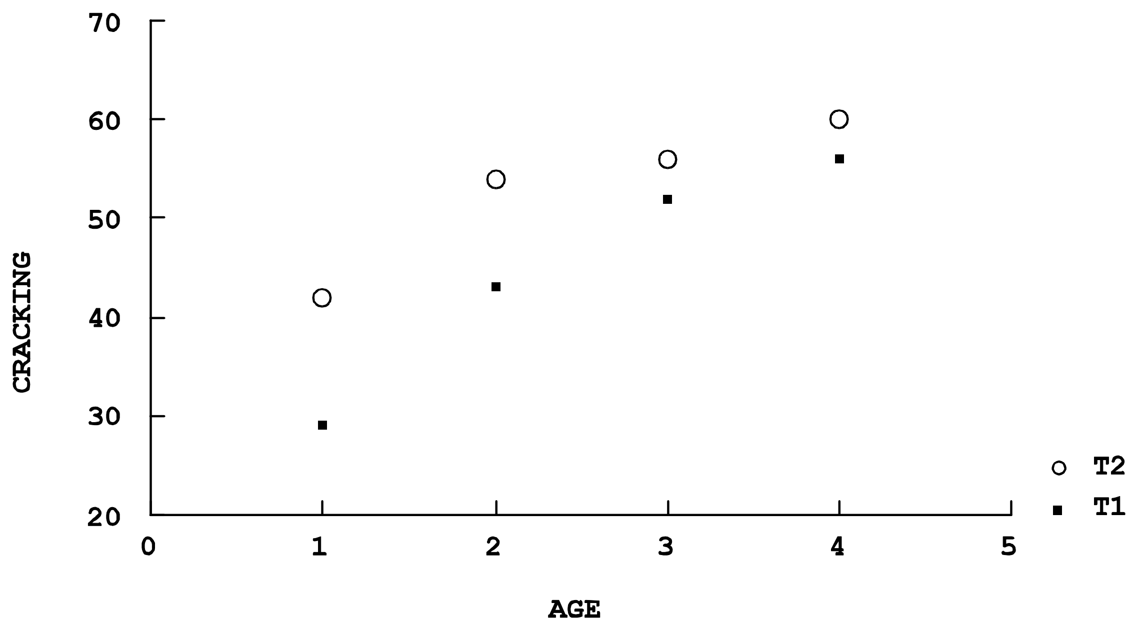

Figure 1. Example Plot of Hypothetical Cracking vs. Pavement Age (from Table 1).

This plot shows a typical difficulty. Even though Treatment 1 shows less cracking in the first year after the initial treatment, both treatments have similar cracking patterns in the long term. No treatment will last forever, and one needs to look not only at initial quality differences but also at the rate of change over time. Thus, for wear measured in absolute units (not percentages) the researchers recommend using regression analysis, see Draper and Smith (1966). In particular, statisticians will often fit a straight line to both sets of treatment data. A comparison of intercepts compares the initial quality of the treatments, and the slopes indicate the decay rate.

Both types of comparisons are important. The formulas for the least squares intercept and slope and their standard errors are found in the Appendix. Let the estimated intercepts and slopes for the Treatment 1 and Treatment 2 data be denoted by a_{T1}, b_{T1}, a_{T2}, and b_{T2}, respectively. Similarly, let their standard errors be denoted by $SE(a_{T1})$, $SE(b_{T1})$, $SE(a_{T2})$, and $SE(b_{T2})$. Instead of performing a test of hypothesis to determine if there is a difference between the intercepts and slopes for the two treatment groups, the researchers recommend calculating confidence intervals (say, at 95 percent) for the differences. Thus, the confidence interval for the difference of the intercepts is:

$$(a_{T1} - a_{T2}) \pm t_{(1-\alpha)}(DF)\left(SE(a_{T1})^2 + SE(a_{T2})^2\right)^{½}$$

Calculation of $t_{(1-\alpha)}(DF)$, the t percentile, is discussed in the Appendix.

Similarly, the confidence interval for the differences of the intercepts is:

$$(b_{T1} - b_{T2}) \pm t_{(1-\alpha)}(DF)\left(SE(b_{T1})^2 + SE(b_{T2})^2\right)^{½}$$

Again, the calculation of $t_{(1-\alpha)}(DF)$, the t percentile (perhaps a different value from the percentile above), is discussed in the Appendix.

If these confidence intervals include 0, one could say that there is no statistically significant difference, and any value within the confidence interval is a plausible value for the difference. As an example, suppose that the following data (Table 2) used.

Table 2. Example Data for Treatments 1 and 2.

Treatment 1	**Treatment 2**	**Date (Days from 1/1/93)**
92.2	114.6	65
88.2	75.7	526
122.8	96.8	897
150.6	131.8	1250
155.0	137.4	1562
173.1	155.8	1952
186.9	169.0	2364

In this case, a_{T1} = 81.269, SE(a_{T1}) = 7.418, a_{T2} = 83.825, SE(a_{T2}) = 14.173, b_{T1} = 0.046, SE(b_{T1}) = 0.005, b_{T2} = 0.034, and SE(b_{T1}) = 0.010.

The 95 percent confidence intervals are: $(81.269 - 83.825) \pm 2.571\ (7.418^2 + 14.173^2)^{½} \approx -2.55 \pm 41.128$, and $(0.046 - 0.034) \pm 2.571\ (0.005^2 + 0.010^2)^{½} \approx 0.012 \pm 0.0001$.

Thus, the two treatments do not have significantly different initial quality but do have slightly different decay rates. Treatment 1 decays faster than Treatment 2. It remains to be seen whether or not these differences are practically different.

In this description so far, it has been assumed that the measurement error for the two treatments are independent. It could be that the measurement errors are dependent. This could happen, for example, if the same rater rated each pavement treatment in each year, but the raters changed from year to year. In this case, researchers recommend regressing the difference, difference(i) = $Y_i - X_i$, i=1,…,n of the two performance measures on time. Typically, a positive intercept will mean that the second treatment has worse initial quality; a negative intercept means that the first treatment has worse initial quality. Similarly, a positive slope means that the second treatment has faster quality decay; a negative slope means that the first treatment has a faster decay rate.

In this case, the estimated intercept for the difference is denoted by a_d, and the estimated intercept for the difference is denoted by b_d. Their standard errors are denoted by SE(a_d) and SE(b_d), respectively. The formulas for the corresponding confidence intervals are: $a_d \pm t_{(1-\alpha)}$ (DF) SE (a_d) and $b_d \pm t_{(1-\alpha)}$ (DF) SE (b_d), respectively. The formulas are given in the Appendix.

Thus, for the data above, the corresponding 95 percent confidence intervals are:

$a_d \pm t(_{1-\alpha})$ (df) SE (a_d) ≈ 2.556 ± 2.571 (9.986) = 2.556 ± 25.674, and $b_d \pm t_{(1-\alpha)}$ (df) SE (b_d) ≈ -0.012 ± 2.571 (0.007) = - 0.012 ± 0.018, respectively.

Now, consider the case of many treatments of the sort that was considered above. Typical data are represented in Table 3.

Table 3. An Example of Typical Data.

BLEEDING Compared to Control							
Inspection Date	**Conventional**	**Polymer Modified Emulsion**	**Fog Seal**	**Rubber Modified**	**Latex Mod**	**Micro**	**Pre Con-struction**
3/6/93	92.2	114.6	105.9	73.0	104.4	87.8	
6/10/94	88.2	75.7	99.1	129.0	91.2	53.2	p.1
6/16/95	122.8	96.8	100.4	136.7	126.7	52.3	p.2
6/3/96	150.6	131.8	103.5	173.7	158.6	63.7	p.3
4/12/97	155.0	137.4	103.6	159.9	158.8	62.2	p.4
5/7/98	173.1	155.8	96.4	183.2	180.1	68.3	p.5
6/23/99	186.9	169.0	96.1	192.7	194.6	70.9	p.6

There are two important cases. The first is where each treatment is only to be compared to the standard treatment and the second is where every treatment is compared to every other treatment.

Regardless of which case is used, the fact that there are more than one comparison implies that there is a greater chance to find a false positive. That means, for example, that there may be a confidence interval for the difference of intercepts that does not include zero simply due to the fact that many comparisons were made. The more comparisons that are made, the greater the chance of an error. Thus, the chance of error, α, must be adjusted to account for the number of comparisons. Using the table above, if each treatment is compared to the conventional treatment, five pairwise comparisons will be made. Thus, instead of a $\alpha = 0.05$, one chooses $\alpha = 0.05/5 = 0.01$. If one compares every treatment to every other treatment then there are 15 pairwise comparisons and $\alpha = 0.05/15 = 0.0033$. The relevant tabled t-value changes from 2.571 to 4.032 if five pairwise comparisons are made and to 5.247 if 15 pairwise comparisons are made (for this example).

A straight-line model has been assumed for the time trends. There is no physical theory that one can rely on to guarantee that a straight-line model will work in all cases. However, with small data sets over limited time periods, it is hard to justify fitting complex models. Nonetheless, standard diagnostic procedures and exploratory analysis should be performed to determine that the conclusions emanate from the actual highway conditions and not the model that was imposed. The exploratory analysis is beyond the scope of this report but excellent treatments of these issues can be found in Box et al. (1978).

USING THE ANALYSIS PROGRAM

The analysis program developed by Texas Transportation Institute (TTI) is a simple, easy-to-use, executable computer program written for MINITAB. The complexity of writing an effective program for downloading data from the TxDOT mainframe PMIS data was beyond the scope of this project and the decision was made to require the data be prepared in an Excel spreadsheet format. This greatly increases the utility of the program in that it can now be used to compare other measures besides PMIS data.

The procedure for comparing PMIS sections is to:

1. Identify the pair, or pairs, of pavements to be analyzed, making sure that they are indeed a valid pair.
2. Determine the years over which the analysis is valid. For example, if a pavement has been overlaid or seal coated, and the analysis is not a study of these treatments, only the years prior to the rehabilitation are valid. For studies of older pavements, this step will be critical.
3. Execute the multi-year ratings and scores report from either the PMIS or ROSCOE system (for ROSCP, 1 - Standard Reports, 1 - Class 1 Reports Menu - Section Lists and Data, 3 - Ratings and Scores Reports Menu, 7 or 8 - Multi-year Ratings and Scores).
4. Enter the appropriate data including years for the analysis (see step 2), district, county, highway, and appropriate beginning and ending reference markers. These data, especially the reference markers should be as specific as possible, since extraneous data will need to be deleted manually.

Note - Craig Cox, TxDOT Design Division, is developing a program to extract the data from standard reports directly into the Excel program which will greatly facilitate this transfer. For now, this procedure will work, but it is time consuming.

5. After running the report for the sections to be analyzed, download the report as a text file (extension .TXT).
6. Open the Excel program, select File, Open (or select the icon of an open folder), change to the appropriate directory, then change "Files of Type" to "Text Files (*.prn, *.txt, *.csv)" and select the file you want to analyze.
7. The import wizard will assist in parsing the data into the appropriate columns. The needed columns are the year and the data to be analyzed. For most cases, this will be the pavement condition score, which is the last column.
8. Once the data is parsed, the data needs to be formatted and put into the appropriate columns. The proper format is to have the data for the first section in the pair in column 2 and the data for the second pair in column 3. Column 1 should contain the normalized year. For example, the data in Table 16 represents pair 1. A similar table would be prepared for pair 2. For this example, the average distress score will be used. Averages of the year and distress columns would be calculated and placed in the format listed in number 9.
9. Column 1 - Average Year, column 2 - Normalized Year (year - average of years), column 3 - Average Distress for Pair 1. Table 17 is an example of the data.
10. Columns 2 and 3 (Normalized Year and Average Value) would be used in the analysis.
11. After all sets of data are prepared as above, the statistical computer program MINITAB is used. After the program is loaded, the data from the data file is copied into column 1 for the date, column 2 for pair 1, and column 3 for pair 2. Then select File, Other files, Run an Exec, and select the directory where the TTI file named TTI1DOS.MTB is located.

Table 4. Raw Data Table.

<table>
<tr><th>Year</th><th>Other Data - To Be Deleted</th><th>Distress</th></tr>
<tr><td>1996</td><td>US0190 K1 0770 +00.0 0770 +00.5 08 |* 0|* 0| 0| 0| 0| 0| 0| 0| | | 4300 2101</td><td>100</td></tr>
<tr><td>1998</td><td>US0190 K1 0770 +00.0 0770 +00.5 08 | included in comparative analyses, at least as an indicator of “time to first treatment.” Evaluation of | | 0| 0| 0| 0| 0| 0| 0| 0| 4600 2101</td><td>100</td></tr>
<tr><td>1999</td><td>US0190 K 0770 +00.0 0770 +00.5 08 |* 0|* 0| | | | | | | | | 5000 1555</td><td>99</td></tr>
<tr><td>2000</td><td>US0190 K 0770 +00.0 0770 +00.5 08 |* 0|* 0| | | | | | | | | 5000 1673</td><td>98</td></tr>
<tr><td>2001</td><td>US0190 K1 0770 +00.0 0770 +00.5 08 |* 0|* 0| 0| 0| 0| 0| 0| 0| 0| 0| 5100 1673</td><td>100</td></tr>
<tr><td>1996</td><td>US0190 K1 0770 +00.5 0770 +01.0 08 |* 0|* 0| 0| 0| 10| 70| 5| 0| | | 4300 2089</td><td>83</td></tr>
<tr><td>1997</td><td>US0190 K 0770 +00.5 0770 +01.0 08 | | | | | | | | | | | 4300 2089</td><td>65</td></tr>
<tr><td>1998</td><td>US0190 K1 0770 +00.5 0770 +01.0 08 |* 0|* 0| 0| 0| 0| 0| 48| 3| 0| 0| 4600 2089</td><td>96</td></tr>
<tr><td>1999</td><td>US0190 K6 0770 +00.5 0770 +01.0 08 |* 0|* 0| 0| 0| 40| 0| 0| 0| 0| 0| 5000 1563</td><td>78</td></tr>
<tr><td>2000</td><td>US0190 K 0770 +00.5 0770 +01.0 08 |* 0|* 0| | | | | | | | | 5000 1689</td><td>70</td></tr>
<tr><td>2001</td><td>US0190 K1 0770 +00.5 0770 +01.0 08 |* 0|* 0| 0| 0| 36| 0| 0| 0| 0| 0| 5100 1689</td><td>79</td></tr>
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<tr><td>1997</td><td>US0190 K 0770 +01.0 0770 +01.5 08 | | | | | | | | | | | 4300 2089</td><td>88</td></tr>
<tr><td>1998</td><td>US0190 K1 0770 +01.0 0770 +01.5 08 |* 0|* 0| 0| 0| 0| 0| 89| 6| 0| 0| 4600 2089</td><td>84</td></tr>
<tr><td>1999</td><td>US0190 K6 0770 +01.0 0770 +01.5 08 |* 0|* 0| 0| 0| 73| 2| 31| 1| 0| 0| 5000 1563</td><td>74</td></tr>
<tr><td>2000</td><td>US0190 K 0770 +01.0 0770 +01.5 08 |* 0|* 0| | | | | | | | | 5000 1689</td><td>85</td></tr>
<tr><td>2001</td><td>US0190 K1 0770 +01.0 0770 +01.5 08 |* 0|* 0| 0| 0| 0| 0|241| 8| 0| 0| 5100 1689</td><td>69</td></tr>
<tr><td>1996</td><td>US0190 K1 0770 +01.5 0772 +00.0 08 |* 0|* 0| 0| 0| 15| 0|702| 0| | | 4300 2089</td><td>81</td></tr>
<tr><td>1997</td><td>US0190 K 0770 +01.5 0772 +00.0 08 | | | | | | | | | | | 4300 2089</td><td>91</td></tr>
<tr><td>1998</td><td>US0190 K1 0770 +01.5 0772 +00.0 08 |* 0|* 0| 0| 0| 0| 1| 83| 4| 0| 0| 4600 2089</td><td>89</td></tr>
<tr><td>1999</td><td>US0190 K6 0770 +01.5 0772 +00.0 08 |* 0|* 0| 0| 0| 97| 5| 12| 1| 0| 0| 5000 1563</td><td>72</td></tr>
<tr><td>2000</td><td>US0190 K 0770 +01.5 0772 +00.0 08 |* 0|* 0| | | | | | | | | 5000 1689</td><td>75</td></tr>
<tr><td>2001</td><td>US0190 K1 0770 +01.5 0772 +00.0 08 |* 0|* 0| 0| 0| 0 | 0|193| 7| 0| 0| 5100 1689</td><td>73</td></tr>
</table>

Table 5. Data Ready for Input.

Average Year	Normalized Year	Average Value
1996	-2.5	85.5
1997	-1.5	81.3
1998	-0.5	92.3
1999	0.5	80.8
2000	1.5	82.0
2001	2.5	80.3
1998.5 - Average of years		

CONCLUSIONS

TxDOT Research Project 1877 developed two types of "measurement strategies" specifically to evaluate relative performance of asphalt overlays placed using either Item 340 or QC/QA specifications. These measurement strategies are described as a general approach (reported herein), wherein essentially all suitable pavements in a database can be evaluated, and a paired approach (reported in Report 1877-5), wherein only selected pairs of pavements with specified attributes are evaluated.

Two measurement strategies were developed that have the potential to provide useful insight into the effects on HMA pavement quality resulting from changing the construction specification or any other factor that may affect pavement performance. The analysis programs or measurement strategies are versatile and can be used to compare other measures besides HMA performance from PMIS.

REFERENCES

Campbell, D.T. and Stanley, J.C., *Experimental and Quasi-Experimental Designs for Research*, Houghton Mifflin Co., Boston, MA, 1963.

Box, G.E.P., Hunter, W.G., and Hunter, J.S., Statistics for Experimenters, Wiley, New York, 1978.

APPENDIX:

FITTING A STRAIGHT LINE TO DATA

It is assumed that Y (called the dependent variable) is related to a predictor x by an equation:

$$= \beta_0 + \beta_1 t + e$$

The expression $\beta_0 + \beta_1 t$ represents the time trend and e represents random error or noise.

Let

$$S_{ty} = \sum_{i=1}^{n} (t_i - \bar{t})(Y_i - \bar{Y}),$$

and let

$$S_{tt} = \sum_{i=1}^{n} (t_i - \bar{t})^2.$$

Then, the estimate of β_0 is $b_0 = \bar{Y} - (S_{ty} / S_{tt})\, \bar{t}$ and the estimate of slope is $b_1 = S_{ty} / S_{tt}$.

The estimated variance for e is $S_e^2 = \dfrac{\sum_{i=1}^{n} (Y_i - b_0 - b_1 t_i)^2}{n-2}$. The standard errors for the estimated

intercept and slope are $S_e \dfrac{\sqrt{\sum_{i=1}^{n} t_i^2}}{nS_{tt}}$, and $S_e \sqrt{\dfrac{1}{S_{tt}}}$, respectively.

The value from the t table is t(1-α, DF). This value is the upper α/2 percent point from a t-distribution with degrees of freedom DF.