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Comparative Performance Evaluation of Pavement Marking Materials at the NTPEP Test Facility

Final Report

Prepared for

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APPENDIXES

1 Background

The National Transportation Product Evaluation Program (NTPEP) was established in 1994 to assist the American Association of State Highway Transportation Officials (AASHTO) in providing cost-effective evaluations of materials, products and devices for the nation's transportation system. This is accomplished through combining the professional and physical resources of the AASHTO members to conduct the evaluations and provides a means to share the results of the evaluations to all members. The NTPEP Information and Operations Guide is included as Appendix 1, and it describes the objectives of NTPEP and the structure, policies and procedures. The outcome of the NTPEP's efforts is to help eliminate duplication of testing and auditing by states as well as significantly reducing the effort by the manufacturers that provide products for evaluation.

NTPEP has established Technical Committees in broad areas of interest to the AASHTO membership. These categories are Traffic Safety, Construction, Maintenance, and a DataMine Task Force. The NTPEP Committee Chair has the authority to establish Technical Committees as needed to evaluate materials, products or devices having potential benefit to the members. Each Technical Committee consists of both AASHTO member agency personnel and industry personnel having an interest in the subject and background knowledge of the committee subject matter. The Technical Committee develops a detailed work plan and provides oversight and guidance throughout the evaluation process. The Technical Committee also develops the evaluation procedures, identifies evaluation locations and chooses the agencies to perform the evaluations. The results of the evaluations are published by NTPEP.

One Technical Committee was established in the Traffic Safety category for Pavement Marking Materials. The materials included under the scope of this committee include either liquid or solid form and includes tapes, pre-formed plastics, durable paints, epoxies, methacrylates, polyesters, polymeric films, thermoplastics and paints. This committee's work plan, included as Appendix 2, utilizes test sites to evaluate the degradation of traffic marking materials under varying climatic conditions. Participating manufacturers place markings for field evaluation of daytime and nighttime color; dry/wet nighttime visibility (retroreflectance); and durability. Data from some of the temporary tape markings was obtained in both the transverse and longitudinal directions. The work plan describes the testing criteria and the reporting format. The data reported through this program allows state highway agencies to select products they believe will perform best on their pavements.

A comprehensive Best Practices Manual was also developed for use in establishing the test decks for evaluation of the various pavement markings. This detailed manual was designed to ensure that all test decks, regardless of location, were placed, evaluated, and results reported in a similar manner. This manual is included as Appendix 3.

2 Task Objective and Approach

Most of the pavement markings utilized transverse orientation for placement of the materials due to space restrictions and logistics. Concern exists that the transverse placement of these materials provides only an accelerated wear condition that is not necessarily related to actual field performance. The stated objective of this research is to provide statistically valid comparisons of the performance of the transverse lines in the 'skip' area with a longitudinally placed line of the same material on the test facility. From this information, a correlation will be used for the continued evaluation of pavement marking materials.

The approach to accomplish this was accomplished in four tasks as follows:

Task 1. Review and organize performance data in the NTPEP DataMine on traffic marking lines prepared with temporary tape and collected in both the transverse and longitudinal orientations.

Task 2. Develop and carry out a plan for statistical analysis of the Task 1 data to determine whether statistically significant differences in the measured performance of the transverse and longitudinal traffic marking lines can be attributed to the difference in their orientation to traffic.

Task 3. Based on the results of Task 2, propose (1) a method for correlating and predicting the performance of typical longitudinal field applications of traffic marking lines from the performance of transverse marking lines and (2) a plan to validate the method in future NTPEP product evaluations.

Task 4. Submit a project final report summarizing the results, findings, conclusions and recommendations of Tasks 1 through 3. As directed by AASHTO, present the results of the project to the AASHTO NTPEP Committee and Subcommittee on Materials.

3 Research Approach

All of the data related to the Pavement Marking Materials (PMM) test decks is located in a database on the NTPEP web site called the NTPEP DataMine. This data is housed in the NTPEP DataMine 1.0 portion of the NTPEP web site. A new version of DataMine has been developed that will be used in the future to collect and store all NTPEP data.

Performance Data spreadsheets were downloaded for all locations in the DataMine as of mid-year 2010 and used as the beginning point for data analysis. These spreadsheets from 25 test decks representing five different states were very detailed and included data from all types of pavement markings, most of which were only in the transverse direction and therefore outside of the scope of this project. The spreadsheets, which can be seen in Appendix 4, titled Raw Pavement Marking Data, represented the following test states, pavement types and years:

State	Pavement Type	Year
Florida	Asphalt	2009
Florida	Concrete	2009
Mississippi	Asphalt	2002
Mississippi	Asphalt	2004
Mississippi	Asphalt	2006
Mississippi	Concrete	2002
Mississippi	Concrete	2004
Mississippi	Concrete	2006
Pennsylvania	Asphalt	2000
Pennsylvania	Asphalt	2002
Pennsylvania	Asphalt	2005
Pennsylvania	Asphalt	2008
Pennsylvania	Asphalt	2010
Pennsylvania	Concrete	2000
Pennsylvania	Concrete	2002
Pennsylvania	Concrete	2005
Pennsylvania	Concrete	2008
Utah	Asphalt	2001
Utah	Asphalt	2005
Utah	Concrete	2001
Utah	Concrete	2005
Wisconsin	Asphalt	2004
Wisconsin	Asphalt	2007
Wisconsin	Concrete	2004
Wisconsin	Concrete	2007

The data for each individual test deck was contained in 12 different worksheets that provided varying data about the markings within that deck and the data collected. The titles of the individual worksheets were as follows:

PMM Site	PMM Line	PMM Lab Epoxy MMA
PMM Product	PMM Inspection	PMM Lab Traffic Paints
PMM Installation	PMM Weather	PMM Lab Thermoplastic
PMM Deck	PMM Weather – Winter	PMM Lab Traffic Striping Tape

Within each of these datasets, each product had a unique PMM number which was used across the individual spreadsheets to tie the data to the product being evaluated. The data was reduced to only those PMM numbers that included readings in both the transverse and longitudinal directions. This was accomplished by first using the PMM Line spreadsheet to determine which PMM Numbers had data from both orientations, using the PMM Inspection spreadsheet to capture the retroreflective data and using the PMM Product spreadsheet to tie the data to a particular product. Eighteen (18) of the original 25 test decks were found to have individual PMM Numbers with data in both the transverse and longitudinal directions. Out of these remaining 18 test decks, 184 individual PMM Numbers indicated that data existed in both the longitudinal and transverse orientations.

It is important to describe how the test decks were constructed and the data obtained to understand the data. The Best Practices Manual describes how the removable tapes are to be applied and data collected. Removable tapes were to be applied in sets of six transverse and six longitudinal lines of markings as shown in Photo 1 from the Best Practices Manual. The six transverse markings were to be placed parallel to one another on the same sub-deck and were to be 12 feet long each as shown in Photo 2 from the Best Practices Manual. The six longitudinal markings were to be placed in pairs, with two inches of separation, in 10 foot lengths, parallel to existing skip lines as shown in Photo 3 from the Best Practices Manual.

The evaluation of removable tapes were planned to last for six months. After each of the six, thirty-day periods, each line was to be evaluated for retroreflectivity, color (day and night), durability, and photo logging. After the data was collected, one longitudinal line and one transverse line was to be removed and data collected about the ease of removal and discernability of the markings left after the line was removed. This should result in six data points for each orientation for the first set of readings, five data points for each orientation for the second set of readings, four data points for each orientation for the third set of readings, etc., until only one data point for each orientation for the last time interval.

Photo 1. Removable Tapes (longitudinal parallel to existing skip lines, transverse between skip lines)

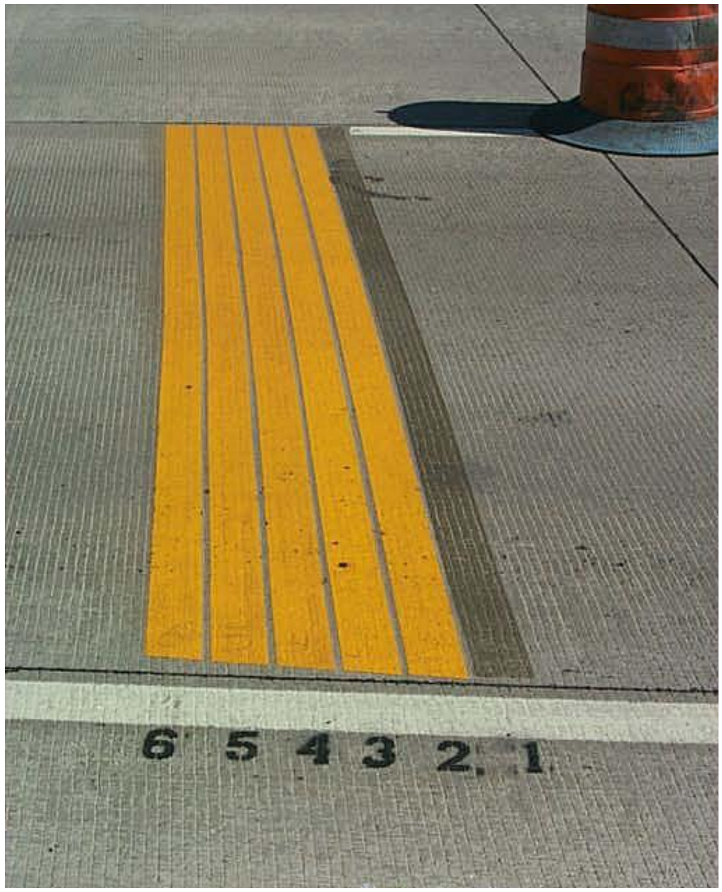


Photo 2. Removable Tapes - Transverse

Photo 3. Removable Tape – Longitudinal parallel to existing skip lines

Apparent inconsistencies about how the detailed data was recorded were discovered after the data organization effort was underway. It was not clear which data from a particular interval represented the transverse orientation and which data represented the longitudinal direction with any degree of consistency. The NTPEP DataMine had functionality to determine the average retroreflectivity for both longitudinal and transverse directions for each inspection interval for each PMM Number in each of the test decks, and the interpretation of the detailed data for the 184 PMM Numbers did not agree with the averages in some cases. The average performance data could be used, but a more statistically sound correlation was likely if all data points are considered rather than using average data. After consultation with NTPEP and the advisory panel, an agreement about how to proceed was reached and the data organization in preparation for statistical analysis continued, which required additional detailed analysis of all data points to ensure that the correct data was being used for the respective orientation.

The data was again reviewed and sorted by PMM number and orientation for each inspection interval. Inconsistencies still appeared to exist after sorting through all of the data again in preparation for making the statistical comparisons when compared to the average performance data in the DataMine system. Attempts were made to determine how the original data was entered, but we still did not have confidence that the approach to organizing the data in the system accurately represented the true orientation of the marking data. The data seemed to be reported in different columns in some of the test decks. For instance, some data for both orientations consistently resided in the Skip Retroreflectivity column with the first series of readings representing the transverse orientation data and the second portion of each interval representing the longitudinal orientation. Decreasing numbers of readings existed with each of the intervals because of the removal of one line each time. In some cases the longitudinal data appeared to be the first series of readings and the transverse data was the second series of readings within a given interval, making it difficult to consistently be assured that the orientation was correct. Other test decks appeared to have the transverse data listed under the Skip Retroreflectivity column for each interval and the longitudinal data listed under the Left Wheel Retroreflectivity for each interval. Still other PMM Numbers within other test decks appear to use both the Skip Retroreflectivity column data and either the Wheel Retroreflectivity column data or Left Wheel Retroreflectivity column data to arrive at the averages shown in the NTPEP DataMine. These inconsistencies were again reviewed with the panel and an agreement was reached to proceed with the data in the following manner:

- Identify data sets from the various states and years that exhibit both transverse and longitudinal data.
- Delete all PMM numbers within a data set that do not exhibit data in both orientations.
- Within each PMM number, sort by interval. Each resulting PMM file should reflect decreasing numbers of observations for each subsequent interval.
- Ignore the Wheel Retroreflectivity column data.
- Use only Skip Retroreflectivity data for analysis.
- Within the data for each PMM number, assume that the first half of the

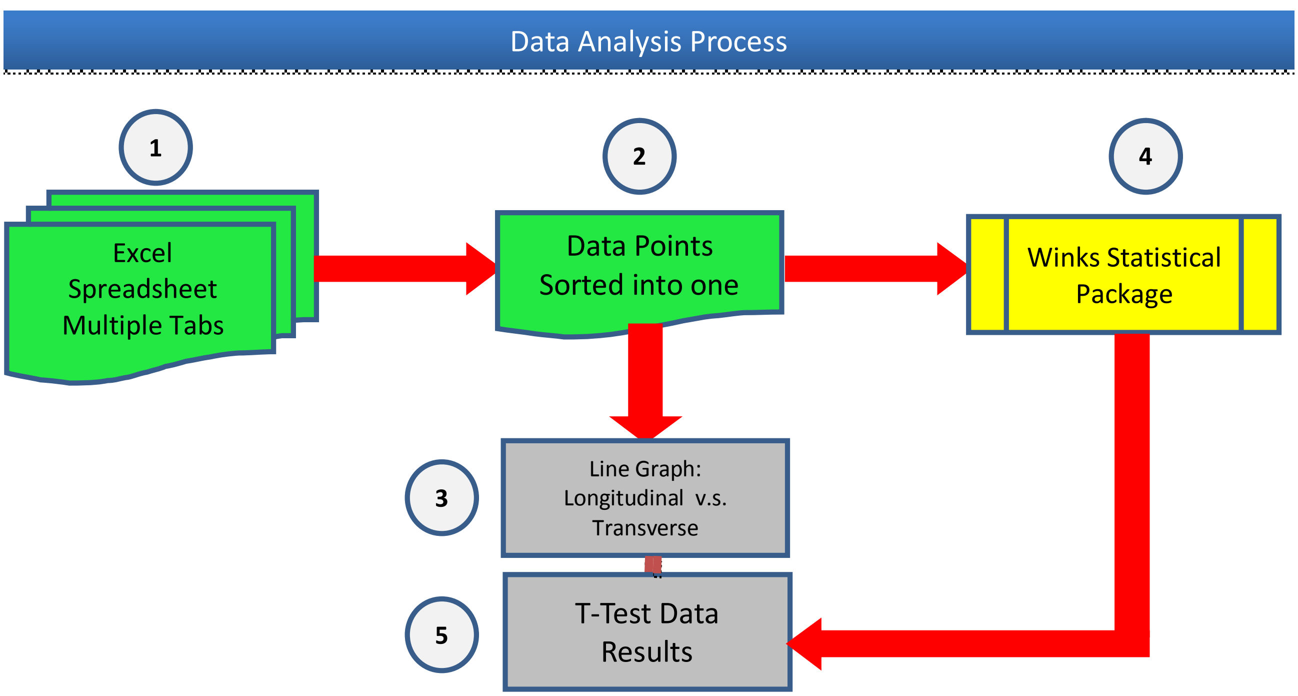
observations within each interval are longitudinal data and the second half of the observations within each interval are transverse.

- Where data exists in the Left Wheel Retroreflectivity column, assume the corresponding data in the Skip Retroreflectivity column represents the transverse orientation. This rule helps clarify data sets where the above assumption appears to not be valid, which was the cause of the concerns about the validity of the data.
- Proceed with the statistical comparisons based on the resulting longitudinal and transverse data.

The data was reviewed and organized yet again following this procedure, and several more inconsistencies still came to light. These were pointed out to the chair of the Pavement Marking Materials Technical Committee, who went back to the original data used to populate the NTPEP database and corrected on a case by case basis. The guidance by the panel and Mr. Dave Kuniega was instrumental in developing a confidence level in the data finally used for the statistical analysis. Once this procedure was followed, the original 184 PMM data sets was reduced to 71 sets having data that we were confident accurately represented both orientations correctly.

4 Data Analysis Approach

The approach to the analysis data is described as follows:



1. The spreadsheet from where the Longitudinal and Transverse data was selected contained 12 tabs. For the purposes of the analysis, only two of the tabs were needed: PMM_Line, and PMM_Inspection.

   From PMM_Line, we were able to determine which of the many PMM-Numbers had both Longitudinal and Transverse data.
   From PMM_Inspection, all the PMM-Numbers which contained Longitudinal and Transverse data were selected. Since the sort characteristics were Deck **à** Line **à** Interval, this was re-sorted by Inspection Date **à** Interval **à** Orientation Measurements.
2. For each PMM-Number, a new spreadsheet was created that contained the Longitudinal and Transverse in the **order specified by the Interval-No.**

   In addition, for each PMM-Number, for each interval number N (if even), the first N/2 pair was determined to be Longitudinal data, and the second N/2 pair was the Transverse data. If N was odd, the entire data set was not tested.
   Further the data was used to generate in Excel a line graph comparing the two data sets.

3. The graph was then copied to MS-Presentation. This was done so that selected data analysis from the T-test, could also be included with the graph.

4. All analysis was performed using the *'TexaSoft, WINKS SDA Software, 6th Edition, Cedar Hill, Texas, 2007'.*

   The statistical test used was the Independent Group T-Test. That is comparing the grouped Longitudinal Data Points with the grouped Transversal Data.
   The analysis was a two-tail test with a 95% Confidence Interval (CI).
   In all cases, the Null-Hypothesis was that there was no significant difference between the two groups, that is: H_0: $\mu_L = \mu_T$, with the alternative hypothesis that the means were not equal.

   To determine the particular T-Distribution to use – T(df), the Variances of the two grouped Data Points was calculated. If the variances were statistically equal, then

   $$d.f. = Data\ Points_L + Data\ Points_T - 2$$

   When the variances are statistically unequal, df is a pooled value using the Welch-Satterthwaite method :

   $$\frac{(\frac{s_1^2}{n_1}+s_2^2/n_2)^2}{\left(\frac{1}{n_1}-1\right)(\frac{s_1^2}{n_1})^2+\left(\frac{1}{n_2}-1\right)(s_2^2/n_2)^2}$$

   where n_1 and n_2 are the number of data points for each grouped data and s_1 and s_2 are the respective standard deviations.

Since, all tests used a CI = .05, the null hypothesis was rejected if P <= .05, and accepted if P>.05. (The P-value is explained in more detail elsewhere).

Three key requirements are necessary to ensure the credibility of the analysis:

a. The Longitudinal measurements and the corresponding Transverse measurements used the same measurement tool and were measured at the same time.
b. There is a direct 1-1 measurement between each Longitudinal and Transverse data.
c. When grouping the data, if the Transverse Data Points were fewer than the corresponding Longitudinal Data Points for a particular grouping, the missing Data Points must be at the end of the Set. (There was no case where the Transverse Data Points were greater than the corresponding Longitudinal Data Points.)

All of the Wisconsin Asphalt data, and Wisconsin Concrete data were not tested as they did not meet point b above.

5. The Winks package recommends a possible write-up. The recommendations concerning whether to accept or reject the Null Hypothesis, the t-distribution used, and the sample means and standard deviations for each of two data sets were added to each graph. Examples of the complete analysis and write-up for four different examples of the complete analysis for PA05A-5 (failed with unequal variances), PA05C-4 (passed with unequal variances), UT01C-27 (Passed with equal variances), and UT01C-26 (failed with equal variances) are shown in Appendix 5.

5 Findings

The results of the statistical analysis are shown in Appendixes 6 and 7. Appendix 6 includes the results of the statistical analysis for the individual PMM Numbers that met the requirements of the grouped Independent T-Test, and Appendix 7 includes the results for those that did not. The end result is that very few data sets met the requirements of the grouped Independent T-Test indicating that the longitudinal and transverse data represented the same population. As noted earlier, 25 test decks were included in the DataMine database. Of these 25 decks, 18 (72%) included individual PMM Numbers with data in both the longitudinal and transverse directions. A total of 184 individual PMM data sets included data that could potentially be statistically analyzed. Because of the inconsistencies in the data previously discussed, only 71 individual PMM data sets were initially included in the data sets to be analyzed. Of the 71 sets, a total of 51 data sets contained sufficiently credible data with which to conduct the statistical analysis. (The Wisconsin data was excluded). After conducting the analysis, only 22 of the individual PMM data sets (43% of the 51 data sets we were comfortable in beginning to conduct the analysis) had statistically equal means. This represents only 12% of the total PMM Numbers that exhibited data in both the longitudinal and transverse directions. One additional issue arose when attempting to construct a legend to connect the individual PMM Numbers to a product name. For both the Utah and Wisconsin data, no clear tie between the PMM Product, PMM Line, and PMM Inspection worksheets existed making it unable to identify the product used for the PMM Numbers included. This is shown in Appendix 8 titled PMM Legend. In summary, attempting to interpret data that only represents 12% of the original population does not give a high level of confidence in the results, or put us in a position to make meaningful recommendations that could be used to predict performance of all markings.

Beyond the reduction in total data sets available to analyze, it is of concern that only 22 of the individual PMM data sets (which represents 43% of the 51 data sets that were actually analyzed) met the requirements of the grouped Independent T-Test at a 95% Control Interval level. In addition, within these 22 individual PMM data sets, no clear trends were discernable. From the graphs in Appendix 6, there was no clear indication of a consistent relationship between the longitudinal and transverse orientations. The transverse data indicated higher retroreflectivity readings in some cases throughout the exposure times, in other cases, the opposite was exhibited and in other cases there was no consistent relationship between the readings.

6 Future Recommendations

Data collection is the most critical part of any statistical analysis project. The collection and recording of the wide variety of information from the NTPEP test decks is a complex and time consuming task. The NTPEP Best Practices Manual was a good comprehensive description of what was to be done, how the data was to be obtained, and reported. However, it was a large undertaking with many different facets. During the early stages of this work, it became apparent that some data was corrupted and significant time and effort was exhausted attempting to understand, interpret and attempt to ensure that the data used accurately represented the correct interval and orientation. Due to the overwhelming amount of data that was eventually excluded because either questions about its validity or the fact that most of the observations within an individual PMM Number failed to statistically represent the same population, considerable effort into the data collection and reporting phases would be appropriate in future NTPEP product evaluations.

The new version of the DataMine data entry spreadsheets for Pavement Marking Materials located on the NTPEP website have been revised and seem to provide an improved data recording process, but it still seems to be very comprehensive and may be attempting to collect too much information at one time. As noted previously, we had to search across several different worksheets within the data spreadsheet to attempt to capture the correct data for evaluating the markings. It is noted that the new data collection sheet separates temporary markings from permanent markings and has fields specifically indicating transverse (T) or longitudinal (L) orientations. This is certainly an improvement and should help with the organization of data in the future. The more focused the data collection is on the final results, the higher probability that the error in data collection will be minimized. Although the coordination of effort and hazards of the field collection of data are appreciated, it might be advisable to have multiple teams focusing on specific data collection tasks, such as temporary markings in both orientations, and other teams collecting data for other portions of the overall portions of the test deck experiment.

While recognizing that a tremendous amount of data was obtained for a wide variety of reasons in each of the test decks, focusing the data to fit the individual needs of the specific data analysis tasks would be of great benefit after the memory of the data collection has grown cold. Having to rely on individuals who were intimately involved with the data collection, and who had the ability to return to the original data collection documents before it was entered into the NTPEP DataMine was of great benefit to us when attempting to clear up apparent inconsistencies, but is not the best way to preserve data for the future.

In its simplest form, data to evaluate the relationship between the two orientations should exist on a single workbook within a spreadsheet and include the basics of what is needed to accomplish the task. For instance, the PMM Number (with some type of tie to the actual product name) is needed, the clearly labeled longitudinal and transverse retroreflective readings for each interval is needed, as is a date/time stamp to assure that the readings were all, in fact, taken from the same time interval. One possible example to exhibit this is shown in Appendix 9, titled Data Collection Sample which is an adaptation from the new version of the DataMine data entry spreadsheets for Pavement Marking Materials shown on the NTPEP website.

Simplifying terminology is also advisable. Although those familiar with pavement markings generally understand the terminology, using clear descriptions of the line being measured would help assure the data is correct. For instance, both longitudinal and transverse data was reported in the “skip” column of the spread sheet. This likely caused confusion for those collecting and reporting data. Perhaps using “Transverse” (or T) and “Longitudinal (or L) Adjacent to Existing Skip” could have resulted in more data being correctly reported.

7 Summary

In conclusion, no clear relationship between the NTPEP data for temporary pavement markings was found to allow correlation between the transverse and longitudinal retroreflective data. Because of this, it is not possible to make predictions for the performance of longitudinal traffic marking lines from existing transverse data. The possibility exists that with data having a higher confidence level of accuracy, then such a correlation might be possible.