FEDERAL HIGHWAY ADMINISTRATION POLICY

This report expresses the views of the Central/Western Field Test and Evaluation Center which is responsible for the facts and accuracy of the data presented. It does not necessarily reflect the official views or policies of the Federal Highway Administration, Department of Transportation; nor does the report constitute a standard, specification or regulation.

INTERPRETATION OF DATA

The calibration and correlation material reported for the Texas-Austin skid measurement system No. 2 is valid only if no modifications are made, and if no changes occur in the mechanical and electrical components. The validity of the material also requires that the system be operated in the same manner as it was at the time of evaluation at the Central/Western Field Test and Evaluation Center. Calibration tests should be performed on a periodic basis to maintain confidence in the measurement process.

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INTRODUCTION

The Central Field Test and Evaluation Center was established in 1971 at the Texas Transportation Institute by the Federal Highway Administration (FHWA) to reduce interstate variations in locked-wheel skid measurements of pavement surfaces. With the closing of the Western Field Test and Evaluation Center at the end of 1975, the Central Center was redesignated as the Central/Western Field Test Center (C/W FTC). In 1979 the C/W FTC became known as the Central/Western Field Test and Evaluation Center (C/W FT&EC) and currently serves central, western and southeastern states, Alaska, Hawaii and Puerto Rico. The Central/Western FT&EC also has the responsibility of calibrating and evaluating Mu-Meter systems. The Eastern FT&EC, located at East Liberty, Ohio and operated by Ohio State University, serves eastern and southern states.

This report results from the calibration, statistical correlation and evaluation of the Texas-Austin State Department of Highways and Public Transportation skid measurement system No. 2. The calibration, correlation and evaluation began October 12, 1982 and was completed October 15, 1982, a total of 4 working days.

Two dynamic skid number correlations were performed. The first correlation with the Texas-Austin skid measurement system compared skid number readings in the initial (as arrived) condition with those of the C/W FT&EC Area Reference Skid Measurement System (ARSMS) on three reference surfaces of various textures at three different test speeds. After calibration, water flow measurements and water distribution tests, the second correlation was conducted at the same speeds and on the same surfaces used during the first correlation.
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FIGURE 1. TEXAS-AUSTIN NO. 2 SMS PERSONNEL
(Curtis Goss and Douglas Chalman)

FIGURE 2. TEXAS-AUSTIN NO. 2 SMS
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FIGURE 3. INTERIOR VIEW OF TEXAS-AUSTIN NO. 2 SMS

FIGURE 4. NOZZLE VIEW OF TEXAS-AUSTIN NO. 2 SMS
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SUMMARY OF TESTS AND RESULTS

The following paragraphs summarize the various segments of the correlations, calibrations and evaluation of the Texas-Austin No. 2 skid measurement system by the Central/Western Field Test and Evaluation Center.

First Correlation

As soon as possible after arrival at the Center, a full scale skid number correlation was conducted between the Texas-Austin skid measurement system, in the as arrived condition, and the Area Reference Skid Measurement System (ARSMS). The correlation was conducted on three different test surfaces at speeds of 20, 40 and 50 mph.

A summary of the results of the first correlation is found in Tables A1 and A2 of Appendix A. The Texas-Austin system recorded higher average skid numbers than the ARSMS in 5 of the 9 speed-surface combinations. The differences ranged from -2.8 SN on surface SRS 1 at 50 mph to 3.9 SN on surface SRS 2 at 20 mph. The overall average absolute difference was 1.9 SN. The skid numbers measured by the Texas-Austin system were of the same level of variability as the values recorded by the ARSMS. The standard deviation for the Texas-Austin system, pooled over all surfaces and speeds, was 1.72 SN, whereas the pooled standard deviation for ARSMS was 1.64 SN. The two systems were highly correlated in their measurement of skid numbers at all three speeds.

Force Subsystem Calibration

An air bearing force plate which has been calibrated by using load cells calibrated at the National Bureau of Standards (NBS) was used to determine the actual vertical and traction force of the test wheel. The
vertical load of the left test wheel was stated to be 1077 lbs. on arrival; however actual measurement showed it to be 1085 lbs. The vertical load of the left test wheel remained at 1085 lbs. The vertical load of the right test wheel was stated to be 1004 lbs. on arrival; however actual measurement showed it to be 1020 lbs. The vertical load on the right test wheel remained at 1020 lbs. The tongue load was 126 lbs. on arrival and remained at 126 lbs.

The value of the left traction calibration signal was stated to be 500 lbs. and remained at 500 lbs. A comparison of the C/W FT&EC force plate with the Texas-Austin system transducer, found in Tables F2 through F4 of Appendix F, shows the transducer to be linear.

The skid number computer calibration value was 48. The value of the left vertical load calibration signal was measured at 490 lbs.

**Force Plate Calibration**

A force plate calibration fixture was used to calibrate the Texas-Austin force plate. All force plates and readout devices used in the calibration were calibrated at the NBS. Results of this calibration are found in Table F5 and F6.

The value of the R-cal for horizontal force was stated to be 500 lbs., and actual measurement showed it to be 500 lbs. The value of R-cal remained at 500 lbs. The value of the R-cal vertical force was stated to be 700 lbs. and actual measurement showed it to be 700 lbs. The value of the R-cal for vertical force remained at 700 lbs.

**Water Subsystem Evaluation**

The water flow rate was measured at equivalent speeds of 20, 40 and 50 mph. The Texas-Austin system arrived equipped with the non-divergent (OSU design) water nozzle. The nozzle was positioned as shown in Figure F1.
The results and analysis of these tests are shown in Table E1 and Figure E1.

**Speed Subsystem Calibration**

The speed readout device was compared to the calibrated reference fifth wheel. The results are given in Table F7.

**Tire Pressure Gage Calibration**

The Texas-Austin system tire pressure gage was calibrated using the C/W FT&EC reference air pressure gage. The results of the calibration are given in Table F8.

**Second Correlation**

After all calibrations and adjustments to the Texas-Austin system were completed, a second correlation with the ARSMS was performed. The results of the second correlation are found in Tables B1 and B2 of Appendix B. The Texas-Austin system recorded higher average skid numbers in 3 of the 9 speed-surface combinations. The differences were less than in the first correlation, ranging from -1.4 SN on surface SRS 1 at 20 mph to 0.9 SN on SRS 2 at 40 mph with an overall average absolute difference of 0.6 SN.

The variation in skid number measurements was slightly larger for the Texas-Austin system than for the ARSMS in 5 of 9 cases. The overall pooled standard deviation was 1.80 SN for Texas-Austin system and 1.81 SN for the ARSMS. Again, the two systems displayed a high correlation in their measurement of skid numbers.

**Correlation Overview**

There was a decrease in the absolute difference in average skid numbers between the two correlations in 8 of the 9 cases. The average
The absolute difference was 1.9 SN during the first correlation and 0.6 SN during the second correlation.

The skid numbers measured by the Texas-Austin system showed an increase in their level of variability; a standard deviation of 1.72 SN was recorded during the first correlation while a value of 1.80 SN was recorded for the second correlation. The standard deviations pooled over both correlations were 1.72 SN for the ARSMS and 1.76 SN for the Texas-Austin system.

The correlation between the measured skid numbers was 0.98 for the first correlation and 0.99 for the second correlation reflecting a high degree of linearity between the two systems in their measurement of skid numbers for both correlations.

General Recommendations

1. Monthly estimates of the Texas-Austin skid measurement system variability should be made using the procedures outlined under "Procedures for Estimating System Variability" in Appendix D. If a significant change in variability is noted, the system should be investigated to determine the cause of the change and restored to a satisfactory condition.

2. A detailed checklist should be devised and used periodically in a regular maintenance program to monitor the condition of the skid measurement system components. The list should include such items as condition of brakes, speed measuring instrument, position and condition of water nozzle, water flow rate, force transducer, suspension and loose or leaking water connections.

3. The friction factor on wet pavement is speed dependent. Therefore, emphasis should be placed on maintaining the appropriate test speed in accordance with the speed calibration provided by the C/W FT&EC.
4. With the non-divergent water nozzle, it is even more important that flow from the nozzle be checked periodically to ascertain that the 1/8" and 1/4" holes have not been obstructed by trash, scale, etc., from the water tank. In the case of one system visiting the C/W FT&EC (Figure 5), the nozzle was partially clogged by the wire from a deteriorated wire reinforced water hose leading to the nozzle.

FIGURE 5. PARTIALLY CLOGGED NOZZLE.
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APPENDIX A

FIRST CORRELATION
FIRST CORRELATION

The first correlation consisted of 12 skids on surface SRS 2, 12 skids on surface PRS 4, and 12 skids on surface SRS 1. This pattern was repeated for 20, 40 and 50 mph.

The results of the first correlation are given in Tables A1 and A2. Considering all speed-surface combinations, the Texas-Austin system recorded higher average skid numbers in 5 of the 9 speed-surface combinations; the average absolute difference being 1.9 SN. Furthermore, it was observed that the Texas-Austin system had a slightly larger pooled standard deviation than the ARSMS, 1.72 SN versus 1.64 SN.

The linear regression equations relating the measurements of the Texas-Austin system to those of the ARSMS are graphed in Figure A1. None of the lines had a slope which was significantly different from 1.0. This indicates that the ARSMS and Texas-Austin system differed by no more than a constant amount in their measurement of skid numbers. The regression lines at 20, 40 and 50 mph were essentially the same lines since neither their slopes nor intercepts were significantly different. This indicates that the two systems were consistent across the range of speeds in their measurement of skid numbers. The measured skid numbers of the two systems were highly correlated. A value of 0.98 was recorded for the correlation coefficient at all three speeds.

If the regression equations are used to estimate the results that would have been obtained by the ARSMS, Figures A2 through A5 may be used to indicate the range of confidence. That is, if the Texas-Austin system is used to obtain an average skid number of a given surface based on K measurements, then these measurements have a variance of $SD^2/K$ and refer to the left-hand scale of the appropriate figure to find the range which indicates 90% confidence limits that would have been obtained by ARSMS.
<table>
<thead>
<tr>
<th>REFERENCE SURFACE</th>
<th>20 MPH</th>
<th></th>
<th>40 MPH</th>
<th></th>
<th>50 MPH</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARSMS</td>
<td>TEXAS-AUSTIN No. 2</td>
<td>ARSMS</td>
<td>TEXAS-AUSTIN No. 2</td>
<td>ARSMS</td>
<td>TEXAS-AUSTIN No. 2</td>
</tr>
<tr>
<td>SRS 2</td>
<td>19.6</td>
<td>23.5</td>
<td>14.3</td>
<td>16.6</td>
<td>13.2</td>
<td>12.8</td>
</tr>
<tr>
<td>PRS 4</td>
<td>24.1</td>
<td>26.4</td>
<td>18.8</td>
<td>21.3</td>
<td>17.9</td>
<td>17.9</td>
</tr>
<tr>
<td>SRS 1</td>
<td>49.8</td>
<td>51.9</td>
<td>45.5</td>
<td>45.0</td>
<td>44.0</td>
<td>41.2</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>31.2</td>
<td>33.9</td>
<td>26.2</td>
<td>27.6</td>
<td>25.1</td>
<td>23.9</td>
</tr>
<tr>
<td>POOLED STANDARD DEVIATION</td>
<td>2.00</td>
<td>1.87</td>
<td>1.28</td>
<td>1.84</td>
<td>1.55</td>
<td>1.42</td>
</tr>
</tbody>
</table>

**TABLE A1. RESULTS OF FIRST CORRELATION**
<table>
<thead>
<tr>
<th>REFERENCE SURFACE</th>
<th>20 MPH</th>
<th>40 MPH</th>
<th>50 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARSMS</td>
<td>TEXAS-AUSTIN No. 2</td>
<td>ARSMS</td>
</tr>
<tr>
<td>SRS 2</td>
<td>2.47</td>
<td>2.43</td>
<td>0.99</td>
</tr>
<tr>
<td>PRS 4</td>
<td>2.14</td>
<td>1.68</td>
<td>1.33</td>
</tr>
<tr>
<td>SRS 1</td>
<td>1.16</td>
<td>1.31</td>
<td>1.47</td>
</tr>
<tr>
<td>POOLED</td>
<td>2.00</td>
<td>1.87</td>
<td>1.28</td>
</tr>
</tbody>
</table>

TABLE A2. STANDARD DEVIATION OF SKID NUMBER - FIRST CORRELATION
\[ SN_{20} (\text{ARMS}) = -3.407 + 1.019 \quad \text{SN}_{20} \quad (\text{TEXAS-AUSTIN NO. 2}) \]

\[ SN_{40} (\text{ARMS}) = -3.934 + 1.091 \quad \text{SN}_{40} \quad (\text{TEXAS-AUSTIN NO. 2}) \]

\[ SN_{50} (\text{ARMS}) = -0.866 + 1.083 \quad \text{SN}_{50} \quad (\text{TEXAS-AUSTIN NO. 2}) \]

\[ SN_{\text{ALL}} (\text{ARMS}) = -1.632 + 1.021 \quad \text{SN}_{\text{ALL}} \quad (\text{TEXAS-AUSTIN NO. 2}) \]

FIGURE A1. FIRST SKID NUMBER CORRELATION
FIGURE A2. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (20 MPH)
FIGURE A3. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (40 MPH)
FIGURE A4. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (50 MPH)
FIGURE A 5. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (ALL SPEEDS)
APPENDIX B
SECOND CORRELATION
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SECOND CORRELATION

The second correlation was performed after the calibration of all subsystems of the Texas-Austin system were completed. The skid number evaluation procedure was the same as that used in the first correlation.

The results of the second correlation are given in Tables B1 and B2. The Texas-Austin system recorded higher skid number values in 3 of the 9 speed-surface combinations. The differences ranged from -1.4 to 0.9 SN with an overall average absolute difference of 0.6 SN. The Texas-Austin system had a lower standard deviation, 1.80 for the system versus 1.81 SN for the ARSMS.

The linear regression equations relating the measurements of the Texas-Austin system to those of the ARSMS are displayed both algebraically and graphically in Figure B1. During the second correlation, none of the lines had slopes which were significantly different from 1.0. The three lines were essentially the same lines, since the slopes and intercepts were not significantly different. Thus, two systems were consistent in their measurement of skid numbers across the three speeds. The validity of using a linear relationship to relate the skid measurements of the two systems is reflected in the very high correlation in their measurement of skid number. There was a 0.99 correlation between the skid numbers of the ARSMS and the Texas-Austin system at 20, 40 and 50 mph.
<table>
<thead>
<tr>
<th>Reference Surface</th>
<th>20 MPH</th>
<th>40 MPH</th>
<th>50 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARSMS</td>
<td>TEXAS-AUSTIN No. 2</td>
<td>ARSMS</td>
</tr>
<tr>
<td>SRS 2</td>
<td>20.6</td>
<td>19.8</td>
<td>13.1</td>
</tr>
<tr>
<td>PRS 4</td>
<td>24.4</td>
<td>23.5</td>
<td>17.4</td>
</tr>
<tr>
<td>SRS 1</td>
<td>51.1</td>
<td>49.7</td>
<td>42.9</td>
</tr>
<tr>
<td>Average</td>
<td>32.1</td>
<td>31.0</td>
<td>24.5</td>
</tr>
<tr>
<td>Pooled Standard Deviation</td>
<td>1.74</td>
<td>1.85</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Table B1. Results of Second Correlation
<table>
<thead>
<tr>
<th>REFERENCE SURFACE</th>
<th>20 MPH</th>
<th>40 MPH</th>
<th>50 MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARSMS</td>
<td>TEXAS-AUSTIN No. 2</td>
<td>ARSMS</td>
</tr>
<tr>
<td>SRS 2</td>
<td>1.62</td>
<td>1.80</td>
<td>2.06</td>
</tr>
<tr>
<td>PRS 4</td>
<td>2.30</td>
<td>2.43</td>
<td>1.69</td>
</tr>
<tr>
<td>SRS 1</td>
<td>1.08</td>
<td>1.07</td>
<td>0.83</td>
</tr>
<tr>
<td>POOLED</td>
<td>1.74</td>
<td>1.85</td>
<td>1.61</td>
</tr>
</tbody>
</table>

TABLE B2. STANDARD DEVIATION OF SKID NUMBER - SECOND CORRELATION
SN_{20} (ARSMS) = 0.936 + 1.004 SN_{20} (TEXAS-AUSTIN NO. 2)

SN_{40} (ARSMS) = -0.499 + 1.004 SN_{40} (TEXAS-AUSTIN NO. 2)

SN_{50} (ARSMS) = 0.519 + 0.994 SN_{50} (TEXAS-AUSTIN NO. 2)

SN_{ALL} (ARSMS) = 0.121 + 1.008 SN_{ALL} (TEXAS-AUSTIN NO. 2)

---

**FIGURE B1. SECOND SKID NUMBER CORRELATION**
Figure B2. Determination of range of the value of average SN which would have been determined by ARSMS (20 MPH)
FIGURE B3. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (40 MPH)
FIGURE B4. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (50 MPH)
FIGURE B5. DETERMINATION OF RANGE OF THE VALUE OF AVERAGE SN WHICH WOULD HAVE BEEN DETERMINED BY ARSMS (ALL SPEEDS)
APPENDIX C

COMPARISON OF FIRST AND SECOND CORRELATIONS
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COMPARISON OF FIRST AND SECOND CORRELATIONS

The average absolute difference in measured skid numbers between the two systems decreased by 1.3 SN from the first to the second correlations. There was a decrease in the difference between the two systems in 8 of the 9 speed-surface combinations.

The skid number variation of each system was approximately the same during both correlations. The ARSMS showed a slight increase between the two correlations, 1.64 SN versus 1.81 SN with an overall pooled standard deviation of 1.72 SN. The Texas-Austin system also showed a slight increase in variability, 1.72 SN versus 1.80 SN with an overall pooled standard deviation of 1.76 SN.

The linear regression equations relating the measurements of the Texas-Austin system to those of the ARSMS are graphed by speed in Figures C1 through C4. A comparison of the regression lines from the first and second correlations yielded the following results. The 20 and 40 mph lines were essentially parallel since they differed in intercept but not in slope. The two lines at 50 mph were essentially the same line since no significant difference was found in their slopes or intercepts. During both the first and second correlations, the lines were essentially the same lines at all speeds, so the systems were measuring skid numbers in a similar relationship across speeds.
1982 As Arrived
\[ SN_{20}^{(ARSMS)} = -3.407 + 1.019 \cdot SN_{20} \quad \text{(Texas-Austin No. 2)} \]

1982 Departing
\[ SN_{20}^{(ARSMS)} = 0.936 + 1.004 \cdot SN_{20} \quad \text{(Texas-Austin No. 2)} \]

**Figure C7. Comparison of 1982 As Arrived and Departing Regression Equations at 20 MPH**
FIGURE C2. COMPARISON OF 1982 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT 40 MPH
1982 As Arrived

\[ SN_{50} (\text{ARSMS}) = -0.866 + 1.083 \times SN_{50} \text{ (TEXAS-AUSTIN NO. 2)} \]

1982 Departing

\[ SN_{50} (\text{ARSMS}) = 0.519 + 0.994 \times SN_{50} \text{ (TEXAS-AUSTIN NO. 2)} \]

FIGURE C3. COMPARISON OF 1982 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT 50 MPH
1982 As Arrived
\[ SN_{\text{ALL}}(\text{ARSMS}) = -1.632 + 1.021 SN_{\text{ALL}}(\text{TEXAS-AUSTIN NO. 2}) \]

1982 Departing
\[ SN_{\text{ALL}}(\text{ARSMS}) = 0.121 + 1.008 SN_{\text{ALL}}(\text{TEXAS-AUSTIN NO. 2}) \]

FIGURE C4. COMPARISON OF 1982 AS ARRIVED AND DEPARTING REGRESSION EQUATIONS AT ALL SPEEDS
APPENDIX D
PROCEDURE FOR ESTIMATING SYSTEM VARIABILITY
AND
STATISTICAL INTERPRETATION OF SYSTEM VARIABILITY
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PROCEDURE FOR ESTIMATING SYSTEM VARIABILITY

In order to estimate the variability of a skid measurement system defined as Situation I, Figure D2, it is necessary to run a number of skid tests on the same spot or strip of pavement. The operator should make every effort to maintain the same lateral position on the pavement and the same initial starting point of the skid. A suitable pavement section should be selected based on uniformity of skid resistance in both lateral and longitudinal directions. The pavement should have a SN value between 20 and 50. One or more passes should be made to wet the pavement without locking the test tire. At least 20 duplicate tests should be conducted each time the variability of the system is determined. The time between tests should be minimized so that all tests are made under approximately the same environmental conditions. A stoppage of 5 minutes or more will cause this test to be invalid. Experience has shown that twenty tests can be performed in approximately one hour. The same tire should be used on all tests and all tests should be run in the same direction.

The procedure for determining if significant changes in the variability of the skid measurement system occurred is as follows:

(1) Plot the 20 skid numbers versus run number. Construct a straight line through the calculated average (x) of the data points. Determine the deviation of each point from the average. Variability is computed by the following expression:

\[ SD^2 = \frac{\Sigma(d_i^2)}{N - 1} \]

Where: The \( \Sigma(d_i) \) should equal 0, within roundoff error.

\( SD^2 \) = Variance

\( d_i \) = Algebraic value of vertical deviation from the average.

\( N \) = Total number of tests.
(2) Investigate possible changes in the variability of the system at a later date by conducting the same number of tests on the same spot on the pavement and comparing the new variability with that previously established. The variability for the second set of tests is computed as shown in step (1). Significant changes in the two values of variance can be established by comparing the ratio of the larger to the smaller with values for this ratio given in Figure D1. If the computed ratio of the variance exceeds that given in Figure D1, it can be concluded that significant changes in the variability of the system have occurred. If the number of tests used to determine the two values of variance are not the same, then Figure D1 is not valid. However, comparison can be made using the appropriate values from the statistical table of F values.

The procedure is illustrated by the following:

Assume twenty tests, on the left wheel, were conducted in this manner by the Texas-Austin system at the Central/Western FT&EC. The variance, $SD^2$, for the system is found to be 1.35 for the left wheel. At a later date, it is desired to check the variability of the system to determine if it has changed significantly. Assume twenty tests are again conducted on the same place on the selected pavement on the left wheel. The new variability computed for the left wheel is 2.27. The ratio of these two variabilities computed for the left wheel is:

$$\frac{SD^2_{\text{max}}}{SD^2_{\text{min}}} = \frac{2.27}{1.35} = 1.68$$

The value from Figure D1 for 20 tests is 2.15. The computed value of 1.68 for the left wheel from the test data is less than the value given in Figure D1. Therefore, it can be concluded that no significant changes in the variability of the system have occurred.
FIGURE D1. DETERMINATION OF CHANGES IN SYSTEM VARIABILITY
STATISTICAL INTERPRETATION OF SYSTEM VARIABILITY

Variability, expressed in terms of standard deviation, must be considered in the interpretation of SN values obtained using any skid number measurement system. Three methods of illustrating the significance of SN variability are shown in Figure D2.

The standard deviation values reported in Table B1 of the previous section include the combined variation effects of the correlation pavement, operator and the skid number measuring system. This condition is defined as Situation II in Figure D2.

Another common method of defining SN variability is illustrated as Situation I in Figure D2. In this case, SN values are obtained on a single strip of pavement. Under perfect test control conditions, the variability of the pavement would approach zero and a good estimate of the skid measurement system variability could be achieved. However, under actual test conditions, a portion of the SN variability will be due to the pavement, as shown in Figure D2, largely caused by: (1) variations in the starting point and lateral displacement of the locked wheel; (2) pavement polishing; (3) variations in water distribution due to changes in wind speed and direction, and changes in the speed of the pumping unit; and (4) the practical necessity of making a number of determinations over a reasonable time period which requires that tests be repeated before the pavement can return to the dry condition. In conclusion, a valid test of the entire skid number measurement is not accomplished under the conditions of Situation I.

As illustrated in Figure D2, Situation III is typical of field surveys in which the total SN variability is unknown until a number of tests have been made and the data analyzed. In general, highways will have a SN
Situation I
Skid Numbers on a Single Strip of Pavement*

Situation II
Skid Numbers Over a System Correlation Pad

Situation III
Skid Numbers Over a Highway Surface of Unknown Variability

* Even with a maximum effort toward repeating a number of skids on the same strip of pavement, there will be some pavement variation due to variations in the starting point and lateral placement.
variability both above and below that of Situation II; and in most cases
the variability will be above that of Situation I.

The SN variability obtained under the test condition of Situation I or
Situation II can be used to determine the appropriate number of skid tests
required to evaluate an actual highway pavement surface. Figure D3 illus­
trates a graphical relationship available for this purpose. Because of the
previously listed influences on variability in Situation I, the SN standard
deviceation (SD) from Situation II is more useful when using the curves in
Figure D3.

Another alternative, which neglects the possibility of variations due
to water distribution and other elements discussed above, is the use of a
value of SD determined by data taken under Situation I with an approxima­
tion of the influence of the pavement SD. An estimate of the composite SD
variability corresponding to Situation III is calculated using the follow­
ing relationship presented by Gillespie.*

\[(SD_c)^2 = (SD_t)^2 + (SD_p)^2\]

Where:
- \(SD_t\) = Standard Deviation of the SN Test System
  (Corresponding to Situation I)
- \(SD_p\) = Standard Deviation of the pavement
- \(SD_c\) = Composite Standard Deviation (Corresponding to
  Situation III)

Data from NCHRP Report 151 shows that the values of \(SD_t\) and \(SD_p\) are of
the same order of magnitude, and on some of the more uniform highways

---

Testing from a Statistical Viewpoint." Highway Research Record No. 471,
presented at the 52nd Annual Meeting of the Highway Research Board,
may be approximately equal. In any case, an estimate of variability is required before a testing program can be planned.

An example is presented to illustrate the use of Figure D3 to determine the number of tests required based on an estimate of the SN variability.

Consider the hypothetical problem of determining the average value of SN on one lane for a one mile section of highway. In order to determine the number of tests that will be necessary, the variability of the combined tester-operator-highway system is required in conjunction with the accuracy of the mean SN value.

The skid number must be determined within ±3. Assume that the SN variability of the highway pavement is approximately the same as the variability of the reference surfaces defined as Situation II in Figure D2.

From Table B2, a value of 2.02 is obtained for pooled standard deviation at 40 mph. Projecting from the ±3 SN range on the abscissa to the SD = 2.02 curve, a value of approximately four required tests can be read from the ordinate of Figure D3.

In order to interpret the values of the mean SN for a section of highway pavement, the use of Figures B1 through B5 is recommended. Figure B1 is a graphical representation of the equations which were statistically derived relating the Texas-Austin system and the ARSMS. Figures B2 through B5 give the range of 90 percent confidence limits. These limits provide an estimate of the upper and lower boundaries of the mean SN which would have been determined by ARSMS in performing the same number of tests. The confidence limit boundaries are based on the ratio of variance, SD², to the number of skid tests performed, K. An example is presented to illustrate the use of the 90 percent confidence limit graphs.

On a section of highway, assume ten 40 mph tests were made using the Texas-Austin system. The SN values were 41, 42, 41, 45, 42, 48, 47, 45, 42 and 44. The average of these values is 43.7. Using the following equation, the variance is computed to be SD² = 6.23.

\[ \text{SD}^2 = \frac{\Sigma (SN_i)^2 - (\Sigma SN_i)^2}{K - 1} \]
Where:  
\[ SD^2 = \text{Variance} \]
\[ K = \text{Number of Tests} \]
\[ SN_i = \text{Individual Skid Numbers, } i = 1 \text{ to } K \]

The appropriate equation from Figure B1, can be used to solve for the ARSMS value of SN when the state system SN is 43.7. In this case, the ARSMS skid number is 43.4.

Entering Figure B3 at a point on the abscissa of 43.7, project vertically to the intersection with the 40 mph correlation line. Projecting a line from this point horizontally to the ordinate yields the estimate of the SN for ARSMS of 43.4. This can be used to check the regression equation calculation.

Now entering Figure B3 at the abscissa point of 43.7 and projecting vertically to the position of the \( SD^2/K = 0.6 \) curve (\( SD^2 = 6.23, K = 10 \)), one finds that the range of confidence limits is equal to \( \pm 1.7 \). Thus, the confidence limits of the mean SN lie between 43.4 - 1.7 and 43.4 + 1.7.

The interpretation is as follows: One is now 90 percent confident that the value of the SN mean determined by ARSMS in performing the same number of tests on the same section of highway would lie between 41.7 and 45.1. The best estimate of the SN value is 43.4.
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<table>
<thead>
<tr>
<th>EQUIVALENT SPEED (MPH)</th>
<th>TOTAL QUANTITY (GAL)</th>
<th>TIME (SEC)</th>
<th>FLOW RATE (GPM)</th>
<th>AVERAGE FLOW RATE (GPM)</th>
<th>TRACE WIDTH (INCH)</th>
<th>GALLONS PER WETTED INCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>14.5</td>
<td>60</td>
<td>14.5</td>
<td>14.4</td>
<td>7</td>
<td>2.1</td>
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<td>20</td>
<td>14.3</td>
<td>60</td>
<td>14.3</td>
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<td></td>
<td></td>
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<tr>
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<td>60</td>
<td>28.0</td>
<td>28.0</td>
<td>7</td>
<td>4.0</td>
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<td>28.0</td>
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<td>24.0</td>
<td>40</td>
<td>36.0</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE E1
FIGURE E1. FLOW RATE PER UNIT WIDTH - TEXAS-AUSTIN NO.2
FIGURE E2. TYPICAL RESULTS OF STATIC DISTRIBUTION GAGE
TEXAS-AUSTIN NO. 2 LEFT WHEEL, 20 MPH
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FIGURE E3. TYPICAL RESULTS OF STATIC DISTRIBUTION GAGE
TEXAS-AUSTIN NO.2 LEFT WHEEL, 40 MPH

RUN 6  50 MPH
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FIGURE E4. TYPICAL RESULTS OF STATIC DISTRIBUTION GAGE
TEXAS-AUSTIN NO. 2 LEFT WHEEL, 50 MPH

RUN 4  40 MPH
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APPENDIX F

REPAIRS, MODIFICATIONS, CALIBRATIONS AND MEASUREMENTS
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REPAIRS AND ADJUSTMENTS SINCE PREVIOUS CALIBRATION AT C/W FT&EC
October, 1981

Repairs to Tow Vehicle:

- Rear end overhaul
- New brake linings/pads
- New tires
- Air conditioner

Repairs to Skid Trailer:

None

Since last visit to C/W FT&EC

<table>
<thead>
<tr>
<th>Approximate number of skid miles/yr</th>
<th>6,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate number of skids/yr</td>
<td>18,000</td>
</tr>
<tr>
<td>Total miles accumulated/yr</td>
<td>7,016</td>
</tr>
<tr>
<td>Present odometer reading</td>
<td>25,400</td>
</tr>
</tbody>
</table>

TABLE F1
### TEXAS-AUSTIN NO. 2
### WHEEL TRANSDUCER CALIBRATION
### LEFT WHEEL TRACTION

#### Run No. 1

<table>
<thead>
<tr>
<th>HORIZONTAL FORCE</th>
<th>SKID NUMBER</th>
<th>VERTICAL FORCE</th>
<th>HORIZONTAL FORCE</th>
<th>SKID NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1085</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>9.3</td>
<td>1072</td>
<td>97</td>
<td>9</td>
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<tr>
<td>200</td>
<td>18.9</td>
<td>1060</td>
<td>196</td>
<td>19</td>
</tr>
<tr>
<td>300</td>
<td>28.6</td>
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<td>297</td>
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</tr>
<tr>
<td>400</td>
<td>38.6</td>
<td>1037</td>
<td>397</td>
<td>38</td>
</tr>
<tr>
<td>500</td>
<td>48.8</td>
<td>1025</td>
<td>497</td>
<td>47</td>
</tr>
<tr>
<td>600</td>
<td>59.2</td>
<td>1013</td>
<td>598</td>
<td>58</td>
</tr>
<tr>
<td>700</td>
<td>69.9</td>
<td>1001</td>
<td>697</td>
<td>68</td>
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<tr>
<td>800</td>
<td>80.9</td>
<td>989</td>
<td>797</td>
<td>79</td>
</tr>
</tbody>
</table>

TABLE F2
**TEXAS-AUSTIN NO. 2**  
WHEEL TRANSDUCER CALIBRATION  
LEFT WHEEL TRACTION

**Run No. 2**

<table>
<thead>
<tr>
<th>FORCE PLATE</th>
<th>VEHICLE INSTRUMENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>HORIZONTAL FORCE</td>
<td>SKID NUMBER</td>
</tr>
<tr>
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<td>59.2</td>
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<td>700</td>
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<tr>
<td>800</td>
<td>80.9</td>
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**TABLE F3**
### TEXAS-AUSTIN NO. 2
WHEEL TRANSDUCER CALIBRATION
LEFT WHEEL TRACTION

Run No. 3

<table>
<thead>
<tr>
<th>HORIZONTAL FORCE</th>
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<th>VERTICAL FORCE</th>
<th>HORIZONTAL FORCE</th>
<th>SKID NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>1085</td>
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<td>196</td>
<td>19</td>
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<td>300</td>
<td>28.6</td>
<td>1048</td>
<td>295</td>
<td>28</td>
</tr>
<tr>
<td>400</td>
<td>38.6</td>
<td>1037</td>
<td>397</td>
<td>38</td>
</tr>
<tr>
<td>500</td>
<td>48.8</td>
<td>1025</td>
<td>498</td>
<td>47</td>
</tr>
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<td>600</td>
<td>59.2</td>
<td>1013</td>
<td>598</td>
<td>58</td>
</tr>
<tr>
<td>700</td>
<td>69.9</td>
<td>1001</td>
<td>697</td>
<td>69</td>
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<tr>
<td>800</td>
<td>80.9</td>
<td>989</td>
<td>797</td>
<td>79</td>
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</table>

**TABLE F4**
<table>
<thead>
<tr>
<th>$F_H$ (C/W FTC) (LBS)</th>
<th>TEXAS-AUSTIN NO.2 RUN 1 (LBS)</th>
<th>TEXAS-AUSTIN NO.2 RUN 2 (LBS)</th>
<th>TEXAS-AUSTIN NO.2 RUN 3 (LBS)</th>
<th>AVERAGE (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
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</tr>
<tr>
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<td>793</td>
<td>799</td>
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<td>799</td>
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</table>

*0 = Slightly preloaded (nullled to zero)  
NBS CALIBRATED LOAD CELL  
BLH TSP2B - SN 77198 SIDE A  
STATED CAL = 500  
ACTUAL CAL = 500  
FINAL CAL = 500

TABLE F5. FORCE PLATE CALIBRATION - HORIZONTAL
<table>
<thead>
<tr>
<th>$F_v$ (C/W FT&amp;EC)</th>
<th>TEXAS-AUSTIN NO.2</th>
<th>FORCE PLATE: Law 1275M210-018 Indicator: Texas-Austin (LBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RUN 1</td>
<td>RUN 2</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
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<td>1600</td>
<td>1599</td>
<td>1599</td>
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</tbody>
</table>

*0 = Slightly preloaded (null to zero)
NBS CALIBRATED LOAD CELL
BLH TSP28 - SN 85420 SIDE B

TABLE F6. FORCE PLATE CALIBRATION - VERTICAL
### SPEED CALIBRATION DATA

<table>
<thead>
<tr>
<th>TEXAS-AUSTIN NO.2 SPEED INDICATOR (MPH)</th>
<th>C/W FT&amp;EC READING (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.5</td>
<td>20.0</td>
</tr>
<tr>
<td>38.7</td>
<td>40.0</td>
</tr>
<tr>
<td>48.4</td>
<td>50.0</td>
</tr>
<tr>
<td>Average of five runs</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE F7**

### TIRE PRESSURE GAGE CALIBRATION

<table>
<thead>
<tr>
<th>REFERENCE GAGE READING (PSI)</th>
<th>TEXAS-AUSTIN NO.2 GAGE READING (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>10</td>
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<tr>
<td>20.0</td>
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</tr>
<tr>
<td>28.0</td>
<td>28</td>
</tr>
<tr>
<td>30.0</td>
<td>30</td>
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</tbody>
</table>

Average of 3 runs, gage type- Dill

**TABLE F8**
PARAMETERS MEASURED ON
TEXAS-AUSTIN NO. 2 INVENTORY SYSTEM

<table>
<thead>
<tr>
<th>Water</th>
<th>'81 exit</th>
<th>'82 arrival</th>
<th>'82 exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total flow, 40 mph, gal/min</td>
<td>28.5</td>
<td>28.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Trace width, 40 mph, inches</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Flow rate, 40 mph, gal/wetted inch</td>
<td>4.1</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Nozzle angle, degrees</td>
<td>22</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Nozzle lateral position relative to tire center lines, inches</td>
<td>19 3/4</td>
<td>20 1/2</td>
<td>20 1/2</td>
</tr>
<tr>
<td>Nozzle orifice height above ground, inches</td>
<td>2 1/2</td>
<td>2 1/2</td>
<td>2 1/2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/W FT&amp;EC speed 40 mph - Texas-Austin No. 2 indicates, mph</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test wheel load, pounds</td>
</tr>
<tr>
<td>Left wheel</td>
</tr>
<tr>
<td>Right wheel</td>
</tr>
<tr>
<td>Tongue</td>
</tr>
</tbody>
</table>

TABLE F9
FIGURE F1. TEXAS-AUSTIN NO.2 SKID TRAILER AND NOZZLE DIMENSIONS
Figure F2. Texas-Austin No. 2 Skid Timing Sequence
1980 Chevrolet
Vehicle I.D.# 29-5656
Crew cab style, dual tires
Automatic transmission

One ton
454 cu. in. displacement
Two bucket seats, front
Air conditioning

Trailer I.D.# 29-9945-B
Texas State Department of
Highways and Public
Transportation

Hydraulic disc brakes
Skid cycle automatically timed
Left brakes locks only
Manual override

Franklin centrifugal pump
Fiberglass with baffles
Water tank capacity: 300 gallons

Printer: Texas Instruments ASR 733
Micro-processor based
system-Pro-Log 2-80
Amplifier: Micro-processor based

Texas State Department of
Highways and Public Transportation

Douglas Chalman
Billy Braddock

Mr. Curtis Goss
Field Test Coordinator
P.O. Box 5051
Austin, Texas 78763
512/465-7545
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C/W FT&EC RECORD OF EVENTS
TEXAS-AUSTIN NO. 2

Tuesday, October 12, 1982

As arrive correlation (20 & 40 mph test)
Force plate calibration

Wednesday, October 13, 1982

Completed as arrive correlation
Measurements of system
TP gage calibration
Speed calibration
Water calibration
Photography

Thursday, October 14, 1982

Wheel transducer calibration
Check automatic skid sequence

Friday, October 15, 1982

Final correlation