Evaluation of Rut-Depth Accuracy and Precision Using Different Automated Systems for Texas Conditions

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Word count = 7,654 (5,404 words + 3 tables + 6 figures)
ABSTRACT
Collecting accurate rutting data is important in order to assess network-level pavement conditions and to determine maintenance and rehabilitation needs and funding levels in order to optimize the use of available economic resources. The technical objective of this study was the assessment of the rut-depth (RD) accuracy and precision of different continuous automated systems (CAS), which represent the state-of-the-art for the automated data collection of rutting, and discrete automated systems (DAS), which are still used by several Department of Transportation (DOTs) in the United States.

The RD values analyzed in this study were obtained by 1) field measurements at highway speeds using five different optical CAS, and 2) calculation simulating the use of DAS with different configurations. The analysis of the first type of values assessed the closeness of the RD produced by the different CAS to the RD manually measured for this study. The analysis of the second type of values assessed the effects of the number of sensors and the width of measurement on the DAS’s accuracy and precision. In addition, the impact of the RD accuracy and precision on the assessed pavement condition at network-level was analyzed for both the CAS that participated in the experiment and the simulated DAS.
INTRODUCTION

A key factor for the success of a pavement management system (PMS) is that it should be populated with accurate and reliable pavement distress data. Rutting is a major distress in flexible pavements, which constitute greater than 90% of the more than 196,000 lane-miles maintained by the Texas Department of Transportation (TxDOT) (1) and a similar percentage of the total U.S. highways and roads (2). Therefore, collecting accurate rutting data is essential to assess network-level pavement conditions, to determine maintenance and rehabilitation needs, and to estimate funding levels in order to optimize the use of available economic resources.

Rut-depth (RD) is one of the most commonly used index variables for quantifying pavement surface rutting. This index has been traditionally measured manually, using a gage with either a straight-edge or a wire. These methods are considered a reliable and low budget option, but they are not efficient for network level data collection. Automated rut measurement systems offer advantages including faster and denser data surveys using non-contact sensors, lower staffing requirements, and no need for traffic control. These factors make automated systems more efficient and safer at network-level. These systems measure coordinates of the pavement transverse profile, which are then used for the calculation of the RD for each wheel-path.

The first automated systems, referred to in this paper as discrete automated systems (DAS), collected a small number of coordinates, originally three or five per transverse profile. The lower the number of points collected, the higher the likelihood of not detecting the actual maximum depression of the rut and, therefore, the greater the chances of underestimating the RD. Because of this, the automated system developers increased the number of sensors and, thereby, the number of points per profile. Some of the main findings from studies found in the literature (3,4,5,6,7) indicate that the RD measured by three-point or five-point systems are significantly different than the ones manually measured using a straight-edge and the lateral placement of the survey vehicle drastically affects the results of this type of systems, which makes them not reliable for monitoring the evolution of the rutting level throughout time. In addition, the minimum recommended number of sensors has been reported by Simpson (3) as nine.

The newest available systems generally collect more than 1,000 coordinates per transverse profile at highway speeds, which in essence represents a continuous profile. The complete representation of the pavement transverse profile by the continuous automated systems (CAS) ensures, in theory, the detection of the actual shape of the rut, the determination of the maximum RD, and avoids the effect of the lateral wandering of the survey vehicle on the RD accuracy and precision. In practice, the accuracy of the CAS is affected by different sources of error, such as the accuracy of the sensors or the inappropriate processing and calculation of the measured data.

The CAS currently available may be divided into two major categories according to the technology used by their sensors: optical systems and scanning lasers. Optical systems digitalize the transverse profile of the pavement by using a laser and a 3D camera. The camera captures the laser line at an angle; the image is digitalized and then processed to get a continuous transverse profile of the road. Scanning lasers use Phase Measurement Laser Radar technology to measure the profile of a pavement (8).

Tsai, et al. (9) assessed the rut depth measurements of an optical CAS conducting both laboratory and field tests and concluded that this type of system dramatically improves the measurement accuracy when compared with the three- and five-point DAS. The CAS tended to
underestimate the manual measurements. The absolute difference between the manual and the automated measurements reported on the referenced study ranged between 0.003 in to 0.03 in for the laboratory tests and 0.03 in to 0.09 in for the field tests.

A survey conducted in 2003 (10), reported that 46 of the 56 U.S. and Canadian transportation agencies that responded to the survey collected automated RD measurements. Out of these 46, 16 used a 3-point system, 16 used a 5-point system, and 14 used a DAS with more than 5 sensors (usually 31).

A more recent survey conducted by TxDOT in 2011 (11), to which 30 U.S. state departments of transportation (DOT) and one Canadian province responded, reported that 15 of 30 respondents (50%) use CAS. Of the other 15, twelve respondents reported that they use DAS and three reported that they do not collect rutting automatically. Comparing both surveys, note that several transportation agencies have upgraded their automated rut measurement system from a DAS to a CAS during the last eight years; however, DAS are still widely used. Another interesting finding of the referenced survey (11) was that the majority of the respondents used 0.5 in as a threshold, or “critical” RD value. That is, a section with an RD ≥ 0.5 in is considered in need of maintenance or rehabilitation.

The technical objective of this study is the assessment of the RD accuracy and precision of different CAS, which represent the state-of-the-art for automated data collection of rutting, and DAS with different configurations, which are still used by several U.S. transportation agencies. The purpose of this study is to gather information that can be used to decide whether to change the current automated rut measurement system used and to estimate the change in RD accuracy when changing from one system to another.

RUT DEPTH DATA
There are two types of RD values analyzed in this study: 1) manually measured in the field and 2) calculated from continuous transverse profiles measured by five different CAS in the field at highway speeds. This second type is further divided into three sets. One set containing the RD values reported by the five CAS that participated in the experiment calculated using their own proprietary algorithms. The other two sets of RD values were calculated by the authors using the transverse profiles reported by one of the CAS, one set using the continuous profiles and the other using different discrete profiles. This allowed the authors to simulate the measurement of different DAS, in order to study the effect of the number of sensors and the width of measurement on the RD accuracy and precision.

The source of each set of rutting data is presented in Figure 1. The boxes with bold type indicate the four sets of values compared in the analyses.

![Diagram of types of rutting data used in the study.](image-url)
The field measurements were obtained during Phase One of TxDOT Research Project 0-6663, “Evaluation of Pavement Rutting and Distress Measurements” (12). The first three parts of this section describe the sites where rutting data were collected as well as both the manual and automated methods used in the experiment. For a more detailed description of these three parts refer to Serigos et al, (12). The last part of this section describes the calculations of the RD values performed by the authors.

Survey Sections

Twenty-six 550-ft long sections on different highways in the TxDOT Austin District were selected based on the experiment design. The criteria for section selection included highways representative of conditions in Texas, including different lane widths and surface textures. In addition, the surveyed sections included potentially challenging features for automated equipment such as lack of pavement edge stripes, variable center line stripe configurations, unusual rut shapes, variable roadside conditions (e.g., vegetation, curbs, paved shoulder, etc.), presence of other distresses, and different highway geometric conditions. Of the original twenty-six sections, the first two were lost because they were subjected to maintenance by TxDOT.

Each section was divided into stations evenly spaced every 5 ft and marked with paint so that both the manual and the automated measurements were taken at the same locations. Therefore, each test section comprised 111 (550/5+1) stations, resulting in a total of 2,664 (24*111) stations in the experiment. Special marking was applied to the stations located every 25 ft to indicate the location of the stations at which the CAS were requested to report the transverse profile coordinates.

Manual Measurement of RD

The RD values for both the inner wheel-path (IWP) and the outer wheel-path (OWP) were manually measured using a 6-ft straight-edge and a gage at every station. Therefore, a total of 5,328 (2,664 stations*2 wheel-paths) RD values were manually measured. The manual data collection started at the end of February 2011 and was completed at the end of July 2011.

The procedure adopted for the measurement of the RD is the one described in ASTM Standard “E1703/E1703M-10: Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge”, (13). The two gages used for manual measurements consisted of 6.0 in long, 0.25 in wide and 3.0 in high aluminum wedges, graduated to 16ths of an inch. Although the gages used are narrower than the minimum width specified by ASTM E1703 (13), their length made them long enough to span the aggregate particles and therefore are considered acceptable by the research team. The measurements were always rounded up to the nearest gradation in order to ensure consistency among the different raters.

Figure 2 presents the distribution of the 5,328 RD values manually measured in the experiment categorized into the TxDOT Pavement Management Information System (PMIS) rutting severity levels: No Rut: RD < 0.25 in; Shallow: 0.25 in ≤ RD < 0.50 in; Deep: 0.50 in ≤ RD < 1.00 in; Severe: 1.00 in ≤ RD < 2.00 in; and Failure ≥ 2.00 in.
Measurement of Transverse Profiles and calculation of RD by CAS

Five different CAS, referred to in this study as CAS 1 through CAS 5, participated in the experiment. Each CAS was requested to measure every section at around 50 mph (except for sections 14, 25, and 26, with lower posted speed limits) and report their best estimate of the RD values for both wheel-paths at the stations located every 5 ft and their best estimate of the transverse profile coordinates at the stations located every 25 ft. Therefore, every participant was requested to report a total of 5,328 RD values and 552 transverse profiles. The automated data collection started at the end of May 2011 and was completed at the end of June 2011.

All of the automated systems that participated in the experiment are optical systems capable of measuring more than 1,000 points per profile at highway speeds. One of the participating CAS was developed in-house by TxDOT. The other four are commercially available systems. Each participant used proprietary algorithms (not provided to the researchers) to calculate the RD values from their measured transverse profiles. While the sensors used by each of the participants consisted of a laser and a camera, the configuration of the system (e.g. the angle at which the laser plane is projected) as well as the number of sensors varied.

Figure 3 shows the CAS developed by TxDOT that participated in the experiment. The red triangle represents the projected laser plane, while the yellow triangle represents the camera plane. The dashed line indicates the location of the transverse profile being measured.
FIGURE 3 TxDOT's 3D system for the automated measurement of rutting.

Calculation of RD by the Authors

The coordinates of the 552 transverse profiles reported by one of the CAS were used for the calculation of the RD values using an algorithm developed and calibrated by the authors that simulates the use of a 6-ft straight-edge. The RD values at each wheel-path were calculated using different discrete profiles to simulate the measurements of DAS with different number of sensors and width of measurements. The RD values obtained for each proposed DAS were compared against the ones obtained using the continuous profiles.

The DAS simulations were calculated using the combination of three different coverages (i.e., width of measurements) and five different sensor separations (sensors were assumed to be equally spaced). Therefore, 15 different DAS configurations were simulated. Table 1 shows the number of sensors used by each DAS simulation, calculated as: number of sensors = coverage/separation + 1. Thus, the number of sensors, or number of transverse profile coordinates used for the calculation of the RD values, varied from 9 to 73.

<table>
<thead>
<tr>
<th>Coverage [in]</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td>49</td>
<td>33</td>
<td>25</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>120</td>
<td>61</td>
<td>41</td>
<td>31</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>144</td>
<td>73</td>
<td>49</td>
<td>37</td>
<td>25</td>
<td>13</td>
</tr>
</tbody>
</table>

The algorithm developed by the authors is based on the “Straight-Edge Algorithm” described in Bennett et al, 2002 (6). Since DAS measurements are affected by the lateral wandering of the survey vehicle, 300 runs were simulated at each station varying the lateral placement of the sensors at each time. A total of 1,104 RD values were calculated for each
proposed DAS at each run, resulting in a total of 331,200 (1,104 values*300 runs) calculated RD values for each of the 15 simulated DAS.

The effect of the lateral wandering was included in the algorithm by defining the following two variables: section_placement_{sec}, which represents the lateral placement of the simulated DAS at the first station of each section (sec), and station_placement_{st}, which indicates the lateral placement at each of the consecutive stations (st) of the same section. The first variable was randomly generated for each of the 24 sections and 300 runs using a normal distribution with mean and standard deviation equal to -2.36 in and 4.92 in, respectively. To determine these two values, the distribution of the lateral placement of the CAS at the profiles of the 552 reported stations were analyzed. The lateral placement value was defined as the distance between the center of the survey vehicle and the center of the lane. A negative value indicates the vehicle is closer to the inner side of the lane (i.e. the left side, when facing the direction of traffic). The value adopted for the standard deviation of section_placement_{sec} was similar to the ones used in other analyses found in the literature (3,6). The second variable, station_placement_{st}, was randomly generated using also a normal distribution for each of the 23 stations per section for each of the 300 runs. The mean was equal to the value of section_placement_{sec} corresponding to the section and run being analyzed, and a standard deviation equal to 4.92 in.

Figure 4 illustrates the continuous transverse profiles coordinates (continuous black line) and the coordinates used for the calculation of the RD values at a particular station for every combination of coverage and separation (in color dots). The coordinates shown in Figure 4 correspond to a particular lateral placement and, therefore, the coordinates for the same stations varied at each of the 300 runs. However, for a particular station and run, the same lateral placement was used for all the different DAS in order to control that factor of variability in the comparison of the calculated RD accuracy and precision.
FIGURE 4 DAS sensors location obtained from the combination of the three values of coverage and the five separations.

ANALYSIS OF RUT-DEPTH VALUES ACCURACY AND PRECISION

The accuracy and precision of both the RD values reported by the different CAS and the ones calculated simulating the use of different types of DAS, were evaluated by comparing them against the reference RD values. For each case, the RD error at a particular station (st), $RD_{\text{error}}_{\text{st}}$, was defined as the difference between the reference value and the calculated one for the same station. The reference values for the evaluation of the RD reported by the CAS consisted of the manual measurements, whereas the reference values for the sets of calculated RD using different discrete profiles were the ones calculated using the continuous profile.

Rut-Depth Values Reported by the CAS

The RD values reported by the five CAS that participated in the study were compared against the values manually measured, which served as reference. The RD errors were computed for the
2,664 stations for both wheel-paths. The accuracy and precision, defined as the mean and standard deviation of the 5,328 RD errors respectively, were calculated for each CAS, and their values are presented in Table 2.

In addition, a linear regression model was developed to analyze the effect of the RD value on each CAS error. The coefficient of the manually measured RD, $\beta_{RD}$, for each CAS RD error is presented in the last column of Table 2. The $p$-value of the estimated coefficient $\beta_{RD}$ was less than 0.001 for every CAS and, therefore, the RD value significantly affected the accuracy of all CAS; the larger the RD value, the larger the measurement error. The value of $\beta_{RD}$ represents the increment in error caused by a unitary increment of the RD value. For example, the CAS 5 error increased, in average, by 0.46 in for every 1.0 in increment in the RD value.

The negative accuracy values observed in Table 2 indicate that all of the CAS tended to underestimate the manual measurements and three of the five CAS had an average accuracy less than 1/16th in. The results obtained for the different CAS were sorted from the smallest to the largest RD accuracy. Also, all of the systems presented a standard deviation of the measurements greater than 2.5 16th in, which indicates a significant dispersion of their errors. Also, from the last column in Table 2, it can be observed that the error increased as the RD value increased for all the CAS, as indicated above.

**TABLE 2 Accuracy and Precision of the RD values reported by the CAS.**

<table>
<thead>
<tr>
<th>CAS</th>
<th>Accuracy [16th in]</th>
<th>Precision [16th in]</th>
<th>$\beta_{RD}$ = $\Delta$RDerror / $\Delta$RD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAS 1</td>
<td>-0.83</td>
<td>3.14</td>
<td>0.10</td>
</tr>
<tr>
<td>CAS 2</td>
<td>-0.87</td>
<td>2.52</td>
<td>0.15</td>
</tr>
<tr>
<td>CAS 3</td>
<td>-0.99</td>
<td>2.67</td>
<td>0.09</td>
</tr>
<tr>
<td>CAS 4</td>
<td>-2.45</td>
<td>5.22</td>
<td>0.58</td>
</tr>
<tr>
<td>CAS 5</td>
<td>-3.10</td>
<td>4.37</td>
<td>0.46</td>
</tr>
</tbody>
</table>

The set of RD values calculated and calibrated by the authors using the continuous profile, were also compared against the manual measurements, obtaining an accuracy of -0.51 16th in and a precision of 1.79 16th in. Therefore, the authors’ RD values were closer to the manual measurements than the ones reported by the five CAS that participated in the experiment. This indicates that the participants’ algorithms can be further improved to increase their accuracy.

**Rut-Depth Values Calculated Using Discrete Profiles**

The lower the number of coordinates used in the calculation of RD, the higher the likelihood of underestimating the actual RD value; therefore, the RD calculated using the continuous profiles were used as the reference for the evaluation of the values calculated using the discrete profiles. The RD errors were computed for each simulated DAS at the 552 transverse profiles and included consideration of the 300 runs in order to add the effect of the lateral wandering of the survey vehicle on the variability of the results.

The distributions of the errors for each DAS were analyzed and the results are presented in Figure 5. The red, green and blue solid lines connect the median (50th percentile) of the errors for the DAS with a coverage of 144, 120 and 96 in, respectively, whereas the shaded regions...
indicate the RD errors that fall between the first and third quartiles (25th and 75th percentiles) for each of the three coverages.

For the purpose of this comparison, the median of the errors (solid lines) is used as a measurement of the accuracy, whereas the range of the quartiles of the errors (shaded region) is used as a measurement of the precision.

From Figure 5 it is observed that the RD accuracy improves as the number of sensors increases and as the coverage increases. Furthermore, it is observed that the improved accuracy due to the increase of the number of sensors is greater as the coverage increases. It is also interesting to note that the RD accuracy of the DAS with coverage 120 and 144 in are superior to the accuracy of the DAS with coverage equal to 96 in regardless of the number of sensors.

As for the RD precision of the DAS, it can be observed that the greater the coverage, the smaller the dispersion of the RD errors. The dispersion of the RD errors decreased as the number of sensors increased for the DAS with a coverage of 144 in, but it did not significantly affect the RD dispersion for the other two narrower coverages.

**FIGURE 5 RD Accuracy and Precision as a function of the number of sensors.**

**IMPACT OF RUT-DEPTH ACCURACY AT NETWORK LEVEL**
The RD values collected at network level are used as an input into the highway agency’s Pavement Management System (PMS) for assessing the condition of the highway network and determining the pavement sections needing maintenance and rehabilitation. Highway agencies use different criteria for establishing the threshold values for each type of pavement distress at which a section needs to be treated. According to the National Survey of Automated Rut Distress Measurement Practices (11), a “critical” condition for rutting adopted by several State’s
Department of Transportation (DOT) in the U.S. is RD equal to, or greater than, 0.5 in. Therefore, in order to evaluate the impact that the accuracy of the different automated rut measuring systems have at network level, the percentages of critical RD values reported by the five CAS and the ones calculated simulating the use of different DAS are compared against reference values.

Since a critical RD value indicates the need for maintenance or rehabilitation, and assuming for this analysis that each RD value of the experiment is representative of the condition of a pavement section, the percentage of critical RD values indicates the portion of the sections needing rehabilitation in a hypothetical network. This hypothetical pavement network, consisting of 5,328 sections, would have the distribution of rutting shown in Figure 2.

**Evaluation of the CAS’s Accuracy at Network Level**

The impact of the CAS’s accuracy at network level was evaluated by comparing the reported percentage of sections needing rehabilitation against the percentage obtained using the RD manually measured. For this, the percentages of critical RD values (RD ≥ 0.5 in) for each CAS and for the manual measurements were computed and they are presented in the second column of Table 3.

TxDOT has used a five-point sensor rut measurement system for collecting rutting data at network level for the last 15 years. The percentage of critical RD values measured by the TxDOT five-sensor rut system is presented in the second column of the last row of Table 3. This value was obtained by adding the percentages of “deep”, “severe” and “failure” RD categories reported on the TxDOT PMIS (Fiscal Year 2011) for the 24 sections of the experiment.

The third column of Table 3 presents the difference between the values corresponding to each evaluated system and the manual measurements. As can be observed from Table 3, all of the evaluated systems underestimated the percentage of sections needing rehabilitation, as expected since all of the CAS tended to underestimate the RD values. The 5-points DAS missed the greatest number of sections needing rehabilitation as compared to the continuous systems.

**TABLE 3 Percentage of measurements indicating rehabilitation missed by each CAS.**

<table>
<thead>
<tr>
<th></th>
<th>% Sections needing rehabilitation</th>
<th>% Sections needing rehabilitation missed</th>
</tr>
</thead>
<tbody>
<tr>
<td>REFERENCE (manual)</td>
<td>30%</td>
<td>-</td>
</tr>
<tr>
<td>CAS 1</td>
<td>22%</td>
<td>8%</td>
</tr>
<tr>
<td>CAS 2</td>
<td>23%</td>
<td>7%</td>
</tr>
<tr>
<td>CAS 3</td>
<td>22%</td>
<td>8%</td>
</tr>
<tr>
<td>CAS 4</td>
<td>19%</td>
<td>11%</td>
</tr>
<tr>
<td>CAS 5</td>
<td>13%</td>
<td>17%</td>
</tr>
<tr>
<td>5-sensor rut system</td>
<td>2%</td>
<td>28%</td>
</tr>
</tbody>
</table>

**Evaluation of the simulated DAS’s Accuracy at Network Level**

The impact of the number of sensors and width of measurement on the DAS’s accuracy at network level was also evaluated by comparing the reported percentage of sections needing rehabilitation against the one corresponding to the set of RD calculated using the continuous profile. Once the percentages of critical RD values (RD ≥ 0.5 in) for each DAS were computed...
for each of the 300 runs, they were compared against the reference value to obtain the percentage of sections needing rehabilitation missed at each run.

The statistics of the distribution of the percentage of sections needing rehabilitation missed (also referred to as “error” for this section) by each simulated DAS for the 300 runs is presented in Figure 6 as a function of the number of points. As in Figure 5, the red, green, and blue solid lines connect the median of the errors for the DAS with a coverage of 144, 120 and 96 in, respectively, whereas the shaded regions indicate the errors that fall between the first and third quartiles for each coverage.

FIGURE 6 Percentage of sections needing rehabilitation missed by the simulated DAS.

The effects that the number of sensors and the coverage have on the simulated DAS’s accuracy at network level are similar to the ones observed for the RD values analysis, since the evaluated index is a threshold of the calculated RD. In this case, unlike the analysis performed for the RD precision, the dispersion of each system error is explained by the effect of the lateral wandering of the simulated survey vehicle since there is only one error value determined for every run. It is interesting to note that the effect of the lateral wandering on the errors is practically independent of the DAS number of sensors and width of measurement.

From Figure 6, it can also be observed that the percentage of sections needing rehabilitation missed by the DAS with 144 in coverage is lower than 8% regardless of the number of points. Note that the errors of this analysis were determined with respect to the results obtained for the set of RD calculated by the authors using the continuous profiles and they should not be directly compared with the results obtained from the analysis of the CAS’s accuracy at network level. The percentage of sections needing rehabilitation calculated with the author’s algorithm using the 552 reported continuous profiles is 24%, which is 6% lower than the
percentage obtained for the manual measurements. Therefore, in order to compare the accuracies
of the CAS and the simulated DAS, the errors of the DAS reported in Figure 6 should be
increased by 6%.

CONCLUSIONS
The study reported in this paper analyzed the RD values obtained by 1) field measurements of
dfive optical Continuous Automated Systems (CAS), which represent the state-of-the-art for the
automated data collection of rutting, and 2) calculation simulating the use of Discrete Automated
Systems (DAS), which are still widely used by several U.S. transportation agencies. The analysis
of the first type of values assessed the closeness of the RD values produced by the different CAS
to the manual measurements. The analysis of the second type of values assessed the effects of the
number of sensors and the width of measurement on the DAS’s accuracy and precision. In
addition, the impact of the RD accuracy and precision at network level was analyzed for both the
CAS that participated in the experiment and the simulated DAS.
The observations and conclusions from this study are:

• All of the CAS tended to underestimate the manual measurements. However, three of the five
  CAS underestimated the manual measurements, in average, for less than 1/16th in, which
  indicates that CAS can produce RD values similar to the manually measured ones for all
  practical purposes.
• The standard deviation of the RD errors for all CAS evaluated was greater than 2.5 16th in,
  therefore, all of the systems showed a high dispersion of their measurements errors.
• The RD error increased with the RD value for all CAS, that is, as rutting of the pavement
  increases so does the error of the measurement. The error increased between 0.09 and 0.46
  in. per inch of RD.
• The RD accuracy and precision of the set of RD calculated and calibrated by the authors
  using the continuous profile were -0.51 and 1.79 16th in, respectively, which are higher than
  the ones obtained for the CAS. Therefore, the algorithms and filters applied by the CAS for
  the calculation of RD values can be further improved for Texas conditions.
• The increased accuracy due to the increase of the number of sensors was greater as the
  coverage increased, which indicates that the width of measurement has a most significant
  effect on the accuracy than the density of the sensors.
• The RD accuracy of the DAS with coverage 120 and 144 in outperformed the DAS with 96
  in coverage.
• The median of the underestimation of the RD, with respect to the results of the calculation
  using the continuous profile, can be 1/16th of an inch or less for a number sensors equal to, or
  larger than, 22 sensors for a coverage of 144 in or 30 sensors for a coverage of 120 in.
  Therefore, considering that the RD values calculated using the continuous profile were very
  close to the manually measured ones, it is possible to produce RD values similar to the
  manually measured ones by the use of DAS.
• The dispersion of the DAS RD errors increased as the coverage decreased. The number of
  sensors affected the RD precision only for the DAS with 144 in coverage.
• Three of the five CAS underestimated the percentage of sections needing rehabilitation by
  7% to 8% with respect to the manual measurements.
• The 5-points DAS missed the largest proportion (28%) of sections needing rehabilitation.
  This indicates that the upgrade from the use of a 5-sensor rut system to a CAS can generate a
drastic change in the number of sections that are identified as needing rehabilitation in the assessed pavement condition at network level.

- Considering that the percentage of sections needing rehabilitation missed by the results of the calculation using the continuous profile was 6%, an error at network level of 10% or less, with respect to the manual measurements, was achieved only for the DAS with 144 in of coverage for a number of sensors equal to, or greater than 30 sensors.

REFERENCES


TRB 2013 Annual Meeting