Table 16. Correlation of three-point and five-point rut depths versus the wire line rut depths for profiles with less than 4.5 mm of rutting.

	3-Point, Worst Case			5-Point, Worst Case			3-Point, Best Case			5-Point, Best Case			Wire Line		
	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.
Number of Observations	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781	34,781
Mean	1.9	1.9	1.9	-0.3	-0.7	-0.5	1.9	1.9	1.9	-0.3	-0.7	-0.5	2.7	2.7	2.7
Standard Deviation	2.67	3.06	2.26	1.10	1.03	0.78	2.66	3.06	2.26	1.10	1.03	0.78	1.29	1.26	0.95
Minimum	-9.0	-14.0	-5.0	-7.0	-12.0	-6.5	-9.0	-14.0	-5.0	-7.0	-11.0	-6.0	0.0	0.0	0.0
Maximum	14.0	17.0	13.0	4.0	3.0	2.0	14.0	17.0	13.0	4.0	3.0	2.0	8.0	7.0	4.0
Correlation to Wire Line Rut Depths	0.4110	0.1484	0.0829	0.4886	0.3106	0.3481	0.4090	0.1481	0.0817	0.4872	0.3114	0.3466	---	---	---
R^2	0.169	0.022	0.007	0.239	0.096	0.121	0.167	0.022	0.007	0.237	0.097	0.120	---	---	---
RMSE	1.17	1.25	0.95	1.12	1.20	0.89	1.18	1.25	0.95	1.12	1.20	0.89	---	---	---
Se/Sy	0.91	0.99	1.00	0.87	0.95	0.94	0.91	0.99	1.00	0.87	0.95	0.94	---	---	---
p-value from paired t-test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	---	---	---

LWP = Left Wheelpath, RWP = Right Wheelpath, RMSE = Root Mean Square Error, Se/Sy = Standard error of the regression divided by the standard deviation of the *y*-value

Moderate Rutting

The results from the comparisons of the profiles in the moderate rutting category are provided in table 17. The correlation coefficients were lower than those for the combined data set. These values were larger than those for the low rutting data set.

Results from the paired t-test indicate that the measurement techniques do not provide the same value of rut depth. The differences ranged from 2.6 mm to 5.7 mm. These values are large enough to consider the observed differences to be significant from an engineering perspective, as well as a statistical perspective.

The linear regressions were also statistically significant. Although these results were not as good as those for the combined data set, they were better than those for the low rutting data set. The data showed considerable scatter and the value of these regressions have little meaning from the engineering point of view.

High Rutting

The results of the comparisons of the high rutting data set are provided in table 18. The correlation coefficients were smaller than those observed for either the combined data set or the moderate rutting data set.

Results from the paired t-tests indicate that the measurements obtained from the different measurement techniques were not the same. The mean differences were all greater than 5 mm. These differences were greater than those observed for the profiles with moderate rutting.

The linear regressions were statistically significant. However, the R^2 and error terms associated with these regressions indicate that the fit of the lines to the data are very poor.

SUMMARY

In summary, the following conclusions were drawn from these analyses:

- The transverse location of the rut bar dramatically affects the measurement and, hence, the rut depth computation. Thus, consistent lateral placement of the survey vehicle is essential to repeatable rut depth measurements using the three- or five-point rut bars.

- The paired t-tests illustrate that the three rut depth measurement systems (three-point, five-point, and wire line) do not provide the same values (i.e., there are statistically significant differences among them).

- The three-point rut depths underestimate the wire line rut depths for transverse profiles where the middle of the profile is lower than the outside edges of the lane (categories 2 and 3).

Table 17. Correlation of three-point and five-point rut depths versus the wire line rut depths for profiles with from 4.5 mm to 7 mm of rutting.

	3-Point, Worst Case			5-Point, Worst Case			3-Point, Best Case			5-Point, Best Case			Wire Line		
	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.
Number of Observations	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565	23,565
Mean	3.0	2.7	2.9	0.9	-0.2	0.4	3.0	2.7	2.9	0.9	-0.2	0.4	5.6	5.5	5.6
Standard Deviation	3.60	4.11	3.22	1.42	1.47	1.01	3.56	4.12	3.22	1.42	1.46	1.01	1.67	1.70	0.84
Minimum	-14.0	-13.0	-8.0	-9.0	-11.0	-6.5	-15.0	-13.0	-7.0	-9.0	-10.0	-6.0	0.0	0.0	4.5
Maximum	19.0	20.0	17.5	6.0	7.0	3.5	18.0	20.0	17.5	6.0	6.0	3.5	13.0	12.0	7.0
Correlation to Wire Line Rut Depths	0.5013	0.2762	0.1270	0.4900	0.2961	0.2203	0.4997	0.2768	0.1260	0.4901	0.2949	0.2205	---	---	---
R^2	0.251	0.076	0.016	0.24	0.088	0.049	0.250	0.077	0.016	0.24	0.087	0.049	---	---	---
RMSE	1.44	1.63	0.84	1.45	1.62	0.82	1.44	1.63	0.84	1.45	1.62	0.82	---	---	---
Se/Sy	0.86	0.96	1.00	0.87	0.95	0.98	0.86	0.96	1.00	0.87	0.95	0.98	---	---	---
p-value from paired t-test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	---	---	---

LWP = Left Wheelpath, RWP = Right Wheelpath, RMSE = Root Mean Square Error, Se/Sy = Standard error of the regression divided by the standard deviation of the *y*-value

Table 18. Correlation of three-point and five-point rut depths versus the wire line rut depths for profiles with more than 7 mm of rutting.

	3-Point, Worst Case			5-Point, Worst Case			3-Point, Best Case			5-Point, Best Case			Wire Line		
	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.	LWP	RWP	Avg.
Number of Observations	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270	21,270
Mean	5.5	5.6	5.6	3.2	1.1	2.1	5.5	5.6	5.5	3.2	1.1	2.1	11.2	11.6	11.4
Standard Deviation	5.86	6.25	5.43	2.69	2.73	2.00	5.86	6.25	5.43	2.70	2.73	2.00	4.64	4.94	4.18
Minimum	-37.0	-25.0	-21.5	-14.0	-13.0	-10.0	-36.0	-25.0	-21.0	-14.0	-13.0	-10.0	1.0	1.0	7.5
Maximum	73.0	64.0	65.5	36.0	22.0	19.0	74.0	65.0	66.0	36.0	22.0	17.5	77.0	63.0	70.0
Correlation to Wire Line Rut Depths	0.4711	0.3282	0.2941	0.6427	0.4532	0.6066	0.4724	0.3294	0.2955	0.6407	0.4537	0.6074	---	---	---
R^2	0.222	0.108	0.086	0.413	0.205	0.368	0.223	0.109	0.087	0.411	0.206	0.369	---	---	---
RMSE	4.10	4.66	3.99	3.56	4.40	3.32	4.09	4.66	3.99	3.56	4.40	3.32	---	---	---
Se/Sy	0.88	0.94	0.95	0.77	0.89	0.79	0.88	0.94	0.95	0.77	0.89	0.79	---	---	---
p-value from paired t-test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	---	---	---

LWP = Left Wheelpath, RWP = Right Wheelpath, RMSE = Root Mean Square Error, Se/Sy = Standard error of the regression divided by the standard deviation of the *y*-value

- Although a better correlation (but still considered poor) existed between the five-point rut depths and the wire line rut depths than between the three-point rut depths and the wire line rut depths, they consistently underestimated the wire line rut depths.

- A better correlation was found between the rut depths for those transverse profile shapes with a "hump" in the middle (categories 3 and 4).

- Generally, the larger the wire line rut depths, the bigger the difference that will be observed between the wire line rut depths and the three-point and five-point rut bars.

As a result of these analyses and comparisons, the analysts concluded that neither the three-point nor the five-point rut depth measurement systems provide reliable and accurate estimates of rut depths as measured with a wire line.

CHAPTER 7. FIELD STUDY

To determine the bias and precision of the PASCO and Dipstick® data collection methods, it was necessary to conduct a field study. The data set housed in NIMS contains several sets of surveys in which the PASCO method and a Dipstick® method were used to collect data for a 1-year time frame. While these data allowed for comparisons between these two methods, they did not allow for a direct computation of the bias and precision of these two measurement methods.

The field study presented here utilized data from only one roadway. The mechanism causing the rutting could potentially affect the bias and precision of the transverse profile and, subsequently, the bias and precision for the indices. This field study provides a good initial estimate of the bias and precision; however, as additional data become available, the data should be used to verify the bias and precision values presented here.

DATA COLLECTION

A site with varying rut depths was selected outside of Thompsontown, Pennsylvania, on the frontage road of U.S. 322. Two 152.5-m test sections were selected along this roadway for use with the field study. The site had minimal traffic because the frontage road was a dead-end road. Profile measurements were made along each section every 15 m. All data were collected within a 2-week time frame.

Four methods were used to collect the data. The first was a straightedge survey. A 3.9-m straightedge was placed on blocks. The distance between the straightedge and the surface of the pavement was measured every 152 mm. Three operators used this method to collect profile data on each profile with eleven profiles measured on each section. Each operator made three replicate measurements, for a total of nine sets of profiles collected. The data collected by this method were considered the benchmark for the bias computation.

The second method used to collect data was the FACE Dipstick®. The Dipstick® collects data every 305 mm across the profile. As with the straightedge method, each operator made three replicate measurements of each profile.

The RoadRecon unit was then used to collect data along each section. These measurements were made using the standard method of taking a picture approximately every 15 m. The images collected of each profile were digitized five times by five different operators. Due to the speed at which the RoadRecon unit is normally operated, the spacing between the images is rarely exactly 15 m. Therefore, a second set of measurements was taken using the RoadRecon unit in a static mode. The unit was driven to the appropriate station and the image was collected. These measurements were taken every 15 m and at the same stations where the dynamic images were obtained. Therefore, twice as many profiles were collected using this method than for any other method. These images were also digitized five times by each of the five operators. All the data were processed to ensure uniformity. The *y*-values were expressed in terms of elevation relative to a horizontal datum drawn through the end points of the profiles. The x-values were expressed in terms of distance from the outside lane edge.

ANALYSIS

The first step of the analysis was to compute each index using the data collected. All the analyses were conducted by examining differences between the indices. The indices were calculated using the RUTCHAR program. An analysis of variance (ANOVA) was completed to examine the differences by operator, section, and station.(8) Differences were expected to occur between each of the profiles; however, differences between operators may prove to be important in later data collection.

For the straightedge data collection method, the ANOVA results did not show a statistically significant difference between operators for any of the indices. A t-test showed a significant difference of 79 mm for the location of the LWP 1.8-m rut depth. This difference is considered to be fairly small. No differences were observed for the data collected using the Dipstick®.

The dynamic RoadRecon measurements reflect statistically significant differences between operators for the negative area, fill area, LWP 1.8-m rut depth, RWP 1.8-m rut width, and the LWP wire line rut depth. The largest difference observed between operators for the fill area was 3200 mm^2. The largest difference for the LWP 1.8-m rut depth was 2 mm. The difference observed for the LWP 1.8-m rut depth is within the precision limits. The differences observed for both the fill area and the RWP 1.8-m rut width are quite large. Most of the indices obtained from the static RoadRecon unit were significantly different, with the exception of the positive area. The differences observed in the data collected by the RoadRecon unit indicate the importance of trained operators to process the data.

Even though these differences were noted, the remainder of the analyses were conducted using the pooled data set. The precision values noted may be a little larger than are actually seen in practice. Only experienced personnel should process the data. This study incorporated at least one set of data processed by inexperienced personnel. On the other hand, at least one set of data used was processed by very experienced personnel. The data were pooled by operator to provide a between- and within-operator variance, a total variance, and an average for each measurement type. The distributions of each of these values were examined by measurement type.

The first set examined was the measurements collected using the straightedge method. In particular, the within-operator variance for the negative area showed one value to be much larger than the others. A single profile was found to cause the much larger within-operator variance for that one station. Figure 34 shows each of the profiles collected by the straightedge method for all of the operators. One profile in particular does not follow the trend of the other profiles. Tables 19 and 20 provide the precision for each of the indices by measurement method. These are presented by COVs in conjunction with ASTM C670.(9)

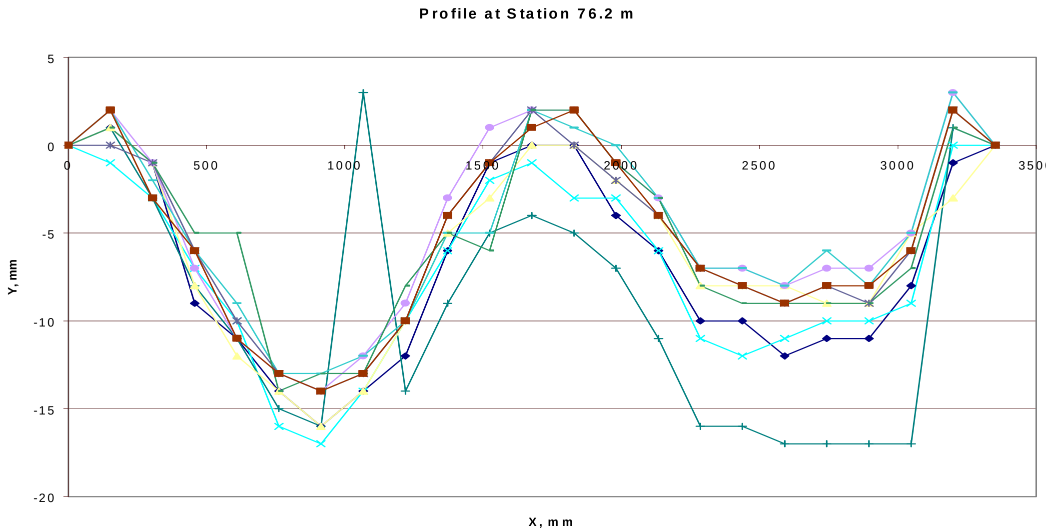


Figure 34. Profiles obtained using the straightedge method at station 76.2 m.

A further investigation was undertaken to determine whether the influential profile was errant or discrepant. The original data were examined and the profile was processed correctly. This profile affects 6 of the 15 indices being examined. No record was made of problems encountered while collecting the profile. Even though the profile may be influential, it was deemed inappropriate to remove it from the analysis simply because it was different from the other observations.

The other measurement methods were examined for similar influential observations. No profiles were found that were significantly different from the other measurements of the same profile.

The within- and between-operator variances were examined to determine whether they were correlated to the average of the index. The within- and between-operator precisions are given in tables 19 and 20, respectively. These are given in terms of COV (as directed by ASTM C670-96) and provide an indication of the repeatability of the data processing by an individual operator and the reproducibility of the data processing between two operators. Only a limited number of the variances for the indices for any of the measurement types were correlated to the average of the index.

The data were reviewed to determine the effect of longitudinal variation on the profile collected. The dynamic measurements were not taken at exactly the same locations as the straightedge and Dipstick® measurements. (It is not possible for the driver to trigger the system to take a measurement at an exact location while the van is moving.) The static RoadRecon measurements were taken at twice as many stations as the other systems. In this case, the unit was driven to the location of interest, stopped, and triggered to take a measurement. This method was used to obtain the data at the stations where the Dipstick® and straightedge methods were used and the stations where the dynamic measurements were taken.

Table 19. Within-operator precision for each index.

Measurement Type	Negative Area	Positive Area	Fill Area	1.8-m LWP Depth	1.8-m LWP Loc.	1.8-m LWP Width	1.8-m RWP Depth	1.8-m RWP Loc.	1.8-m RWP Width	Wire Line LWP Depth	Wire Line LWP Loc.	Wire Line LWP Width	Wire Line RWP Depth	Wire Line RWP Loc.	Wire Line RWP Width
Straightedge	-14	30	6	8	4	5	7	9	4	8	4	11	7	9	10
Dipstick®	-6	12	3	6	1	2	2	2	1	7	1	7	2	2	4
Static PASCO	-17	64	9	11	6	7	11	14	6	11	19	16	11	14	16
Dynamic PASCO	-18	71	9	10	5	7	9	12	6	10	5	14	9	12	13

Table 20. Between-operator precision for each index.

Measurement Type	Negative Area	Positive Area	Fill Area	1.8-m LWP Depth	1.8-m LWP Loc.	1.8-m LWP Width	1.8-m RWP Depth	1.8-m RWP Loc.	1.8-m RWP Width	Wire Line LWP Depth	Wire Line LWP Loc.	Wire Line LWP Width	Wire Line RWP Depth	Wire Line RWP Loc.	Wire Line RWP Width
Straightedge	-13	18	3	5	3	3	4	4	2	5	2	5	4	4	5
Dipstick®	-5	12	2	4	1	1	1	1	1	4	1	4	2	1	2
Static PASCO	-16	41	9	10	3	4	9	9	3	10	3	9	9	9	9
Dynamic PASCO	-12	45	6	9	3	3	6	1	4	9	3	7	6	5	6

The offset stations were compared to the stations that were exactly 15.2 m apart. First, a set of paired t-tests were conducted. The only index for which a significant difference was found was the LWP wire line rut depth, indicating that profiles within a limited distance were very similar.

The data were examined to determine whether the difference in the values of an index increased with increasing distance between the stations where those profiles were observed. The absolute value of the differences at the stations and the indices were checked for a correlation, but none was noted. A correlation between the difference in the index and the difference at the station would provide a means for establishing a limit on the distance from the station the measurement can be taken and still be representative of that location.

A t-test was performed to compare the dynamic PASCO readings to the static PASCO data. In all cases, there were no statistically significant differences. The mean differences shown as part of the results of the test were well within the COV ranges shown in tables 19 and 20. Therefore, the static data were used to assess the bias of the PASCO method of data collection.

A series of paired t-tests were used to determine the bias of the various measurement methods. The straightedge method was used as the benchmark for this analysis. Table 21 presents the minimum and maximum levels of bias found for each index where a statistically significant difference was found by the t-tests. These values are based on the ASTM procedure of providing a 95 percent confidence interval for bias.[9]

The indices calculated from the Dipstick® data versus those from the straightedge show considerable scatter. This scatter presents itself in the bias values determined for the indices that were found to be significantly different from the straightedge indices because the straightedge measurements were taken every 152 mm and the Dipstick® measurements were taken every 305 mm. Therefore, the actual measurements for the Dipstick® could be compared to those taken at the same location. A graph of these data also showed considerable scatter. The bias for these relative elevation measurements lies between –4 and –2.

A direct comparison was made between the indices calculated from the static PASCO data and the indices calculated from the Dipstick® data. The only indices that were significantly different between the two methods were the 1.8-m rut depths, 1.8-m rut widths, wire line rut depths, and wire line rut widths. All of the plots showed a large amount of scatter. For analysis purposes, the data collected by the RoadRecon unit and the Dipstick® may be used interchangeably when the area indices are being considered. However, if the researcher is examining either rut depths or rut widths, only the data from one of the collection methods should be used.

SUMMARY

The precision and bias values for both the Dipstick® and the RoadRecon unit were determined from five repeat runs. These values are presented in tables 19, 20, and 21. Based on these data, the Dipstick® data were more precise, but less accurate than the RoadRecon unit. The Dipstick® and RoadRecon unit provide the same results for the area indices, but the results are different for the rut depths and rut widths.

Table 21. Minimum and maximum levels of bias.

Index	Minimum	Maximum
RoadRecon		
Negative Area	-2135	-5043
Positive Area	-941	-2711
Fill Area	1135	2629
LWP 1.8-m Rut Width	20	85
RWP 1.8-m Rut Depth	0.3	1.3
RWP 1.8-m Rut Location	-20	-75
RWP 1.8-m Rut Width	49	103
RWP Wire Line Rut Depth	0.3	1.3
RWP Wire Line Rut Location	-18	-71
Dipstick®		
Negative Area	2592	-10852
Positive Area	1283	-4775
LWP 1.8-m Rut Depth	-6	-2
LWP 1.8-m Rut Location	-284	132
LWP 1.8-m Rut Width	-222	-40
LWP Wire Line Rut Depth	-6	-2
LWP Wire Line Rut Location	-272	140
RWP Wire Line Rut Depth	0.1	6
RWP Wire Line Rut Width	-37	820

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from these analyses.

- The 1.8-m and wire line rut depths are fairly highly correlated ($R^2 \approx 0.95$) and provide the same type of information, namely the severity of the rutting.

- It was anticipated that the 1.8-m and wire line rut widths would be related. The data do not substantiate this.

- The fill area provides a two-dimensional rut depth. This index exhibited a fairly high correlation with the rut depths ($R^2 \approx 0.85$) and the negative area ($R^2 \approx 0.91$).

- The positive area did not behave in the same manner as any of the other indices; therefore, it may provide additional information about the profile.

- The mean rut depth for a section can be accurately obtained with only six profiles. However, the other indices considered in this study require the 11 measurements that were originally included in the data collection plan.

- Results of the paired t-tests indicate that there are statistically significant differences between three rut depth measurement systems – three-point, five-point, and wire line.

- The transverse location of the rut bar dramatically affects the measurement and, hence, the rut depth computation. Thus, consistent lateral placement of the survey vehicle is essential to repeatable rut depth measurements using the three or five-point procedures.

- Although a better correlation ($R^2 \approx 0.5$), but still considered poor, existed between the five-point rut depths and the wire line rut depths than between the three-point rut depths and the wire line rut depths ($R^2 \approx 0.2$), the five-point rut depths consistently underestimated the wire line rut depths.

- The three-point rut depths underestimate the rut depths for transverse profiles where the middle of the profile is lower than the outside edges of the lane (categories 2 and 3).

- A better correlation was found between the three-point, five-point, and wire line rut depths for those transverse profile shapes with a "hump" in the middle ($R^2 \approx 0.35$ for the three-point and $R^2 \approx 0.6$ for the five-point) (categories 3 and 4).

- These data indicate that the five-point rut depth never exceeds the wire line rut depth. However, the three-point rut depth may be larger or smaller than the wire line rut depth.

- The average three-point and five-point rut depths did not show a stronger relationship with the wire line rut depths calculated for the individual wheelpaths.

- Generally, the size of the difference observed between the wire line rut depths and the rut depths from the three-point and five-point rut bars increases with an increase in the wire line rut depth.

- Neither the three-point nor the five-point rut depth measurement system provides reliable and accurate estimates of rut depths as measured with a wire line.

- The Dipstick® relative elevation measurements are very precise, but not very accurate. The RoadRecon unit relative elevation measurements are not very precise, but are relatively accurate. For example, the coefficient of variation of the rut depth for the RoadRecon unit was approximately three times that of the Dipstick® (11 percent versus 4 percent, respectively). Also, the bias for the LWP rut depth is much larger for the Dipstick® than for the RoadRecon unit (4 mm versus 0 mm, respectively). These trends, as shown in tables 19, 20, and 21, are consistent for all the indices.

- Analysis performed using rut widths or rut depths should be performed using only one method of data collection. Analysis involving any of the other indices could be performed using the combined data set.

The recommendations from this study are as follows:

- Two tables should be added to NIMS. The first table should contain the values of the indices studied for each individual profile. These indices include the positive area, negative area, fill area, LWP and RWP 1.8-m rut depths, LWP and RWP 1.8-m rut locations, LWP and RWP wire line rut depths, LWP and RWP wire line rut widths, and LWP and RWP wire line rut locations. The second table should contain the mean, standard deviation, and minimum and maximum values for each index for each survey. The rut depths are the most commonly used and most widely understood measure of rutting. The rut widths and positive area indices appear to provide additional information about the profile. Until it is proven that this additional information is not useful, these indices should be kept in NIMS. The fill area and negative area are both highly correlated to the rut depths. However, the fill area is a very easily understood index and provides the user an opportunity to segue into viewing the transverse profile from different perspectives.

- Further review needs to be undertaken to determine the cause of the negative trends for the sections provided in table 11.

- The three-sensor rut bar does not provide repeatable and accurate rut depth measurements and, therefore, would not provide adequate network-level rut depths for pavement management systems. Inconsistent rut depths obtained over time from the highway network would be problematic for determining rehabilitation needs.

- If a five-sensor rut bar is used for network-level data collection, care should be taken to ensure that the transverse location of the rut bar is consistent from year to year and that the mean values are adjusted to reflect more realistic rut depth values.

- A second field study should be undertaken. This field study should examine the relationship between the indices studied and the mechanism causing the rutting. This study should also provide additional information to verify the bias and precision values presented here.

- Indices not recommended for inclusion in the database are: PASCO typecasting, radius of curvature, and maximum water depth in each wheelpath.

- To limit the variability of the area and rut width indices, a transverse profile measurement should be made every 15.2 m on each test section.

APPENDIX A.
RUTCHAR PROGRAM USER'S GUIDE

INTRODUCTION

The purpose of the User's Guide for the RUTCHAR program, developed under the Transverse Profile Data Study by Fugro-BRE, Inc. in Austin, Texas, is: (1) to describe the system so that potential users can determine its applicability, and (2) to provide users with all the information necessary to operate and use the system efficiently and effectively.

One of the objectives of the Transverse Profile Data Study was to provide a method for characterizing the transverse profiles collected on the test sections included in the LTPP project. The characterizations were then to be determined for all of the data that had passed through the Quality Control (QC) process in the NIMS. At that time, 45,370 transverse profiles resided in NIMS for which the rutting characterizations needed to be determined. The RUTCHAR program was written to perform these calculations and to provide a method by which these calculations could be easily performed for all of the transverse profile data to be collected.

This program was intended for the sole purpose of calculating the rutting indices of data collected for LTPP. The output of the program should then be filtered into a table in NIMS.

The program was written in VisualBasic and requires an IBM 486-compatible system or later with Windows 95 or later.

APPLICATION DESCRIPTION

As previously stated, the program was written to calculate the indices used to characterize the transverse profile data for NIMS.

The first step in the program is a check of the input data. This data should be a series of *x*-*y* coordinates that define the transverse profile. Each of the *x*-*y* coordinates is reviewed to determine whether there are any duplicates. If a duplicate set of *x*-*y* coordinates is encountered, one of the duplicates is removed from the data set for all further calculations. A message is written to a file named DATCHK.OUT, which provides the section ID, construction event number, survey data, the *x*-coordinate, and the statement "IS A DUPLICATE POINT."

Next, a check is performed to find duplicate *x*-values. It was found that not all of the problems encountered were due to duplicate *x*-*y* coordinates in the data being used to perform these calculations. In some cases, the *x*-values were the same, but the *y*-values were different. In this case, the first of the duplicate *x*-values is reduced by 1. Furthermore, the section ID, construction event number, survey data, the *x*-coordinate, and the statement "IS A DUPLICATE X" are written to the DATCHK.OUT file.

The input file containing the original data set is not overwritten, but the data being used for the calculation are slightly altered. Once the check has been completed, the computation of the indices is initiated. The following discusses the computation of each index.

SYSTEM OPERATION

In order to run the software, double-click on the RUTCHAR icon. The system will prompt the user for four file names. The first file should be a data extraction of the MON_T_PROF_PROFILE table. The last file should be a data extraction of the MON_T_PROF_MASTER table. Both files should be in a fixed-width format.

The other two file names are the output file names. The first file being created will contain the calculated indices for each profile contained in the MON_T_PROF_PROFILE extraction. This file name should be formatted UR##YYYY.RIP. In this case "##" refers to the number of times these calculations have been performed in the year. "YYYY" is the year. The second file being created will contain the mean, standard deviation, and minimum and maximum values for each index for each survey. This filename should be formatted UR##YYYY.RIS. The format of these files is provided in tables 22 and 23.

While the data is being processed, a message will appear on the screen, "Please wait, your data is being processed."

The second output file is the DATCHK.OUT file, which has been previously discussed. This file will automatically be written in the directory from which the program was run. This file will be written if neither of the two discontinuities discussed are encountered; however, it will be 0-bytes long. If this file already exists in the directory from which the program is run, it will not be overwritten. The program will append information to the DATCHK.OUT file, but will never overwrite it. The user should rename or delete the previously written DATCHK.OUT file if he/she wants to work with a new file.

Table 22. File format output for the UR##YYYY.RIP file.

Item	Format	Units	IMS Field Name	Comments
1	Character(4)		SHRP_ID	1 - 6
2	Numeric		STATE_CODE	8 - 10
3	DD-MMM-YYYY		SURVEY_DATE	12 - 22
4	Numeric	m	POINT_LOC	24 - 29
5	Numeric	mm^2	NEGATIVE_AREA	31 - 39
6	Character(1)		NEGATIVE_AREA_FLAG	41 - 43
7	Numeric	mm^2	POSITIVE AREA	45 - 51
8	Character(1)		POSITIVE_AREA_FLAG	53 - 55
9	Numeric	mm^2	FILL_AREA	57 - 63
10	Character(1)		FILL_AREA_FLAG	65 - 67
11	Numeric	mm	LLH_DEPTH_1_8	69 - 73
12	Character(1)		LLH_DEPTH_1_8_FLAG	75 - 77
13	Numeric	mm	LLH_WIDTH_1_8	79 - 83
14	Character(1)		LLH_WIDTH_1_8_FLAG	85 - 87
15	Numeric	mm	LLH_OFFSET_1_8	89 - 93
16	Character(1)		LLH_OFFSET_1_8_FLAG	95 - 97
17	Numeric	mm	RLH_DEPTH_1_8	99 - 103
18	Character(1)		RLH_DEPTH_1_8_FLAG	105 - 107
19	Numeric	mm	RLH_WIDTH_1_8	109 - 113
20	Character(1)		RLH_WIDTH_1_8_FLAG	115 - 117
21	Numeric	mm	RLH_OFFSET_1_8	119 - 123
22	Character(1)		RLH_OFFSET_1_8_FLAG	125 - 127
23	Numeric	mm	LLH_DEPTH_WIRE_REF	129 - 133
24	Character(1)		LLH_DEPTH_WIRE_REF_FLAG	135 - 137
25	Numeric	mm	LLH_WIDTH_WIRE_REF	139 - 143
26	Character(1)		LLH_WIDTH_WIRE_REF_FLAG	145 - 147
27	Numeric	mm	LLH_OFFSET_WIRE_REF	149 - 153
28	Character(1)		LLH_OFFSET_WIRE_REF_FLAG	155 - 157
29	Numeric	mm	RLH_DEPTH_WIRE_REF	159 - 163
30	Character(1)		RLH_DEPTH_WIRE_REF_FLAG	165 - 167
31	Numeric	mm	RLH_WIDTH_WIRE_REF	169 - 173
32	Character(1)		RLH_WIDTH_WIRE_REF_FLAG	175 - 177
33	Numeric	mm	RLH_OFFSET_WIRE_REF	179 - 183
34	Character(1)		RLH_OFFSET_WIRE_REF_FLAG	185 - 187
35	Numeric	mm	TRANS_PROFILE_MEASURE_LENGTH	189 - 193
36	Character(1)		SECTION_STAT_INCLUDE_FLAG	195 - 197
37	DD-MMM-YYYY		DATA_PROCESS_EXTRACT_DATE	199 - 209

Table 23. File format for the UR##YYYY.RIS file.

Item	Format	Units	IMS Field Name	Comments
1	Character(4)		SHRP_ID	1 - 6
2	Numeric		STATE_CODE	8 - 10
3	DD-MMM-YYYY		SURVEY_DATE	12 - 24
4	Numeric		NO_PROFILES	26 - 27
5	Numeric	mm^2	POSITIVE_AREA_MEAN	29 - 35
6	Numeric	mm^2	POSITIVE_AREA_STD	37 - 43
7	Numeric	mm^2	POSITIVE_AREA_MIN	45 - 51
8	Numeric	mm^2	POSITIVE_AREA_MAX	53 - 59
9	Numeric	mm^2	NEGATIVE_AREA_MEAN	61 - 69
10	Numeric	mm^2	NEGATIVE_AREA_STD	71 - 79
11	Numeric	mm^2	NEGATIVE_AREA_MIN	81 - 89
12	Numeric	mm^2	NEGATIVE_AREA_MAX	91 - 99
13	Numeric	mm^2	FILL_AREA_MEAN	101 - 107
14	Numeric	mm^2	FILL_AREA_STD	109 - 115
15	Numeric	mm^2	FILL_AREA_MIN	117 - 123
16	Numeric	mm^2	FILL_AREA_MAX	125 - 131
17	Numeric	mm	LLH_DEPTH_1_8_MEAN	133 - 137
18	Numeric	mm	LLH_DEPTH_1_8_STD	139 - 143
19	Numeric	mm	LLH_DEPTH_1_8_MIN	145 - 149
20	Numeric	mm	LLH_DEPTH_1_8_MAX	151 - 155
21	Numeric	mm	RLH_DEPTH_1_8_MEAN	157 - 161
22	Numeric	mm	RLH_DEPTH_1_8_STD	163 - 167
23	Numeric	mm	RLH_DEPTH_1_8_MIN	169 - 173
24	Numeric	mm	RLH_DEPTH_1_8_MAX	175 - 179
25	Numeric	mm	MAX_MEAN_DEPTH_1_8	181 - 185
26	Numeric	mm	LLH_WIDTH_1_8_MEAN	187 - 191
27	Numeric	mm	LLH_WIDTH_1_8_STD	193 - 197
28	Numeric	mm	LLH_WIDTH_1_8_MIN	199 - 203
29	Numeric	mm	LLH_WIDTH_1_8_MAX	205 - 209
30	Numeric	mm	LLH_OFFSET_1_8_MEAN	211 - 215
31	Numeric	mm	LLH_OFFSET_1_8_STD	217 - 221
32	Numeric	mm	LLH_OFFSET_1_8_MIN	223 - 227
33	Numeric	mm	LLH_OFFSET_1_8_MAX	229 - 233
34	Numeric	mm	RLH_WIDTH_1_8_MEAN	235 - 239
35	Numeric	mm	RLH_WIDTH_1_8_STD	241 - 245
36	Numeric	mm	RLH_WIDTH_1_8_MIN	247 - 251
37	Numeric	mm	RLH_WIDTH_1_8_MAX	253 - 257
38	Numeric		RLH_OFFSET_1_8_MEAN	259 - 263
39	Numeric		RLH_OFFSET_1_8_STD	265 - 269
40	Numeric		RLH_OFFSET_1_8_MIN	271 - 275
41	Numeric		RLH_OFFSET_1_8_MAX	277 - 281
42	Numeric	mm	LLH_DEPTH_WIRE_REF_MEAN	283 - 287
43	Numeric	mm	LLH_DEPTH_WIRE_REF_STD	289 - 293
44	Numeric	mm	LLH_DEPTH_WIRE_REF_MIN	295 - 299
45	Numeric	mm	LLH_DEPTH_WIRE_REF_MAX	301 - 305

Table 23. File format for the UR##YYYY.RIS file (continued).

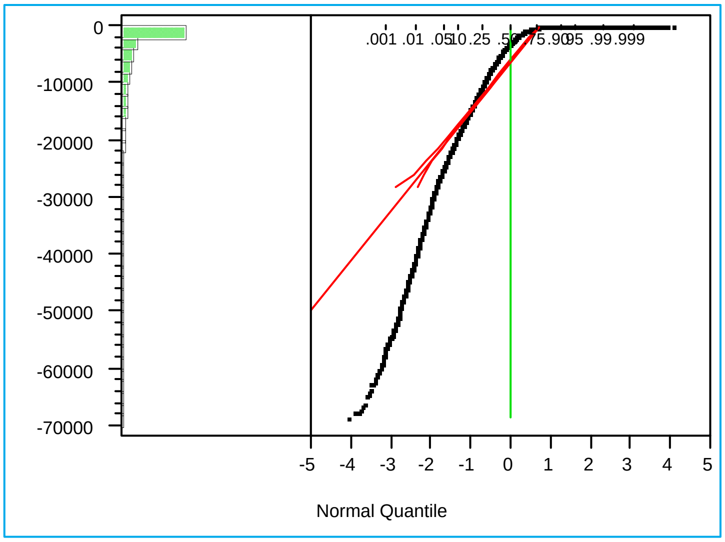
Item	Format	Units	IMS Field Name	Comments
46	Numeric	mm	RLH_DEPTH_WIRE_REF_MEAN	307 - 311
47	Numeric	mm	RLH_DEPTH_WIRE_REF_STD	313 - 317
48	Numeric	mm	RLH_DEPTH_WIRE_REF_MIN	319 - 323
49	Numeric	mm	RLH_DEPTH_WIRE_REF_MAX	325 - 329
50	Numeric	mm	MAX_MEAN_DEPTH_WIRE_REF	331 - 335
51	Numeric	mm	LLH_WIDTH_WIRE_REF_MEAN	337 - 341
52	Numeric	mm	LLH_WIDTH_WIRE_REF_STD	343 - 347
53	Numeric	mm	LLH_WIDTH_WIRE_REF_MIN	349 - 353
54	Numeric	mm	LLH_WIDTH_WIRE_REF_MAX	355 - 359
55	Numeric	mm	LLH_OFFSET_WIRE_REF_MEAN	361 - 365
56	Numeric	mm	LLH_OFFSET_WIRE_REF_STD	367 - 371
57	Numeric	mm	LLH_OFFSET_WIRE_REF_MIN	373 - 377
58	Numeric	mm	LLH_OFFSET_WIRE_REF_MAX	379 - 383
59	Numeric	mm	RLH_WIDTH_WIRE_REF_MEAN	385 - 389
60	Numeric	mm	RLH_WIDTH_WIRE_REF_STD	391 - 395
61	Numeric	mm	RLH_WIDTH_WIRE_REF_MIN	397 - 401
62	Numeric	mm	RLH_WIDTH_WIRE_REF_MAX	403 - 407
63	Numeric	mm	RLH_OFFSET_WIRE_REF_MEAN	409 - 413
64	Numeric	mm	RLH_OFFSET_WIRE_REF_STD	415 - 419
65	Numeric	mm	RLH_OFFSET_WIRE_REF_MIN	421 - 425
66	Numeric	mm	RLH_OFFSET_WIRE_REF_MAX	427 - 431
67	Character(1)		T_PROF_DEVICE_CODE	433 - 435
68	DD-MMM-YYYY		DATA_PROCESS_EXTRACT_DATE	447 - 457

APPENDIX B.
DISTRIBUTION OF THE INDICES

This appendix contains distributions of each of the indices by various categories. Each distribution includes a histogram, a normal probability plot, a list of quantiles, the mean, the standard deviation, the confidence interval, the skewness of the distribution, and the kurtosis of the distribution. The histogram provides a distribution of the data collected. The histogram in figure 35 illustrates that the majority of the data for the negative area index lies between 0 and -10,000. The normal probability plot, located to the right of the histogram, is another method for viewing the distribution of the data. This type of plot is often used to determine if the data are normally distributed. The closer the line presented in the plot is to a straight line, the more the data are considered to follow a normal distribution. The quantities are determined by sorting the data in ascending order. The value for the 25^{th} percentile is the value found one-quarter of the way through the data. The skewness and kurtosis are both values that pertain to the normality of the data. Skewness is a measure of the tendency of the deviations to be larger in one direction than in the other. Skewness values that have a large absolute value are likely to be from a non-normal distribution. Kurtosis measures the "heaviness" of the tails of a distribution. A large value of kurtosis indicates a heavy-tailed distribution. Kurtosis and skewness values are usually less than $\pm$1.0.

Figures 35 through 49 contain the distribution of all of the individual values for each index. Figures 50 through 63 provide the distribution of the section means. All of the sections are included in these distributions. Figures 64 through 79 provide the distribution of the GPS-1 (HMAC over granular base) section means. Figures 80 through 94 provide the distribution of the GPS-2 (HMAC over stabilized base) section means. The GPS-6 (HMAC overlay of HMAC) section mean distributions are provided in figures 95 through 109. The GPS-7 (HMAC overlay of PCC) section mean distributions are provided in figures 110 through 124.

Neg Area



Quantiles

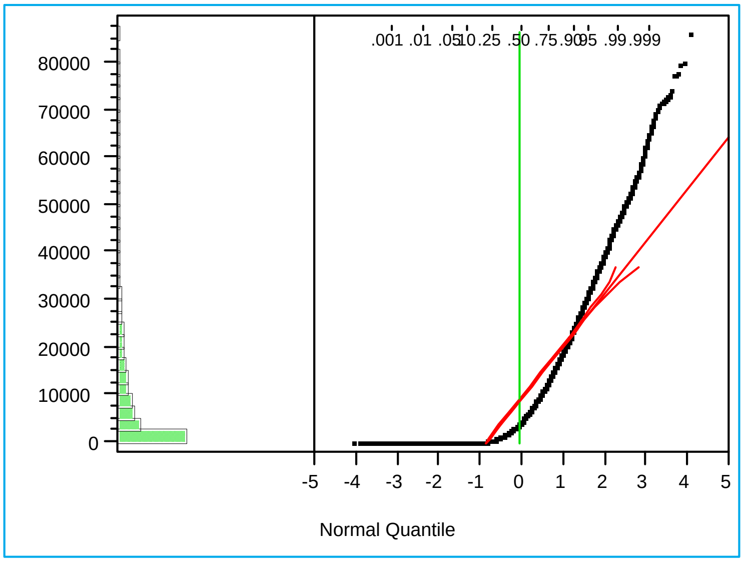
maximum	100.0%	0
	99.5%	0
	97.5%	0
	90.0%	0
quartile	75.0%	-82
median	50.0%	-2539
quartile	25.0%	-9579
	10.0%	-18282
	2.5%	-29687
	0.5%	-44499
minimum	0.0%	-68429

Moments

Mean	-6316.62
Std Dev	8667.60
Std Error Mean	40.69
Upper 95% Mean	-6236.86
Lower 95% Mean	-6396.38
N	45370.00
Sum Weights	45370.00
Sum	-2.8658e8
Variance	75127285
Skewness	-2.05
Kurtosis	5.25
CV	-137.22

Figure 35. Distribution of the negative area index.

Pos Area



Quantiles

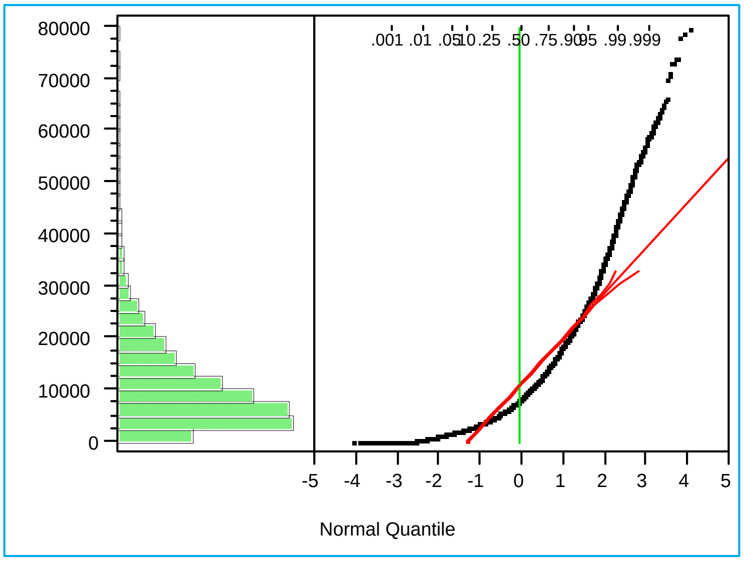
maximum	100.0%	86338
	99.5%	51961
	97.5%	39314
	90.0%	24873
quartile	75.0%	13739
median	50.0%	4868
quartile	25.0%	777
	10.0%	0
	2.5%	0
	0.5%	0
minimum	0.0%	0

Moments

Mean	9138.77
Std Dev	11060.67
Std Error Mean	51.93
Upper 95% Mean	9240.55
Lower 95% Mean	9036.99
N	45370.00
Sum Weights	45370.00
Sum	414625843
Variance	122338458
Skewness	1.72
Kurtosis	3.24
CV	121.03

Figure 36. Distribution of the positive area index.

Fill Area



Quantiles

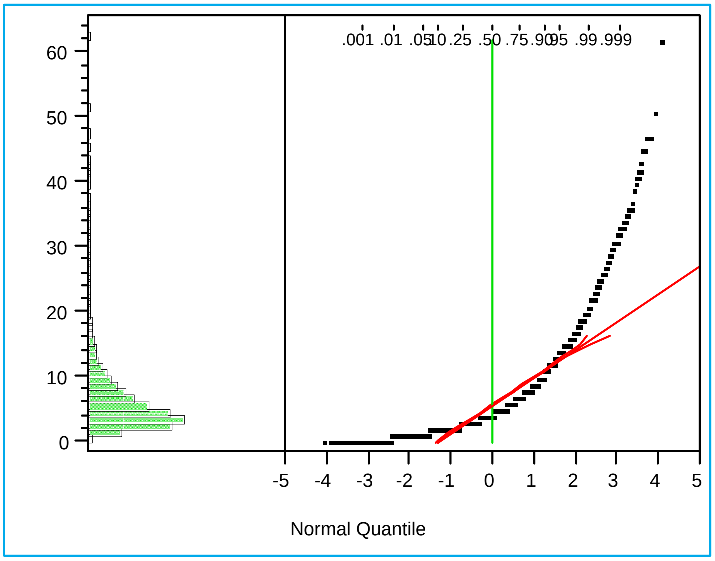
maximum	100.0%	79877
	99.5%	48746
	97.5%	34059
	90.0%	22250
quartile	75.0%	14768
median	50.0%	8600
quartile	25.0%	4900
	10.0%	2882
	2.5%	1443
	0.5%	310
minimum	0.0%	0

Moments

Mean	11054.19
Std Dev	8710.74
Std Error Mean	40.90
Upper 95% Mean	11134.35
Lower 95% Mean	10974.03
N	45370.00
Sum Weights	45370.00
Sum	501528624
Variance	75877044
Skewness	1.81
Kurtosis	4.80
CV	78.80

Figure 37. Distribution of the fill area index.

1.8 m LWP



Quantiles

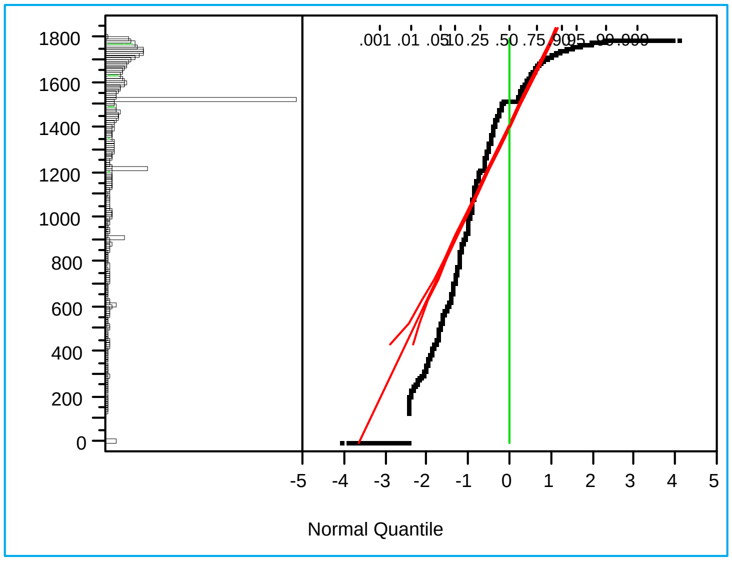
maximum	100.0%	62.000
	99.5%	24.145
	97.5%	17.000
	90.0%	11.000
quartile	75.0%	7.000
median	50.0%	4.000
quartile	25.0%	3.000
	10.0%	2.000
	2.5%	1.000
	0.5%	0.000
minimum	0.0%	0.000

Moments

Mean	5.59
Std Dev	4.27
Std Error Mean	0.02
Upper 95% Mean	5.62
Lower 95% Mean	5.55
N	45370.00
Sum Weights	45370.00
Sum	253404.00
Variance	18.20
Skewness	2.18
Kurtosis	8.26
CV	76.39

Figure 38. Distribution of the LWP 1.8-m rut depth.

W 1.8 m LWP



Quantiles

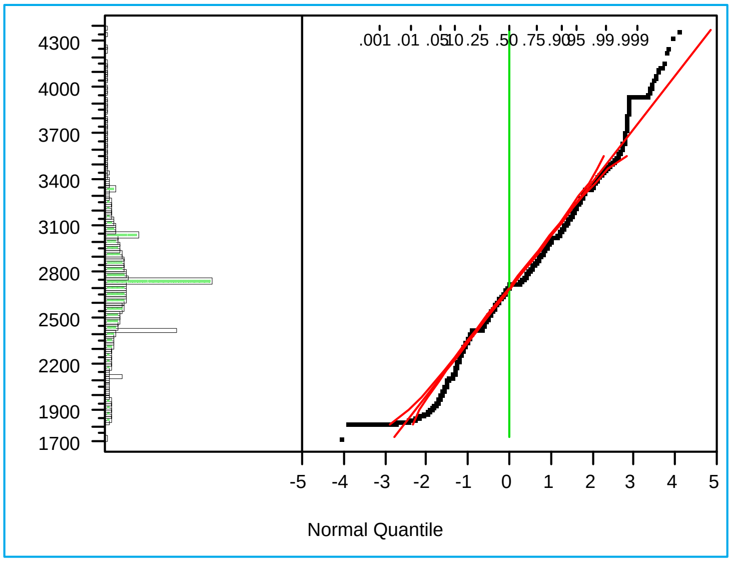
maximum	100.0%	1800.0
	99.5%	1797.0
	97.5%	1786.0
	90.0%	1752.0
quartile	75.0%	1688.0
median	50.0%	1524.0
quartile	25.0%	1219.0
	10.0%	771.0
	2.5%	384.0
	0.5%	0.0
minimum	0.0%	0.0

Moments

Mean	1399.10
Std Dev	385.49
Std Error Mean	1.81
Upper 95% Mean	1402.65
Lower 95% Mean	1395.56
N	45370.00
Sum Weights	45370.00
Sum	63477346
Variance	148600.10
Skewness	-1.41
Kurtosis	1.39
CV	27.55

Figure 39. Distribution of the LWP 1.8-m rut width.

LWP 1.8 Loc



Quantiles

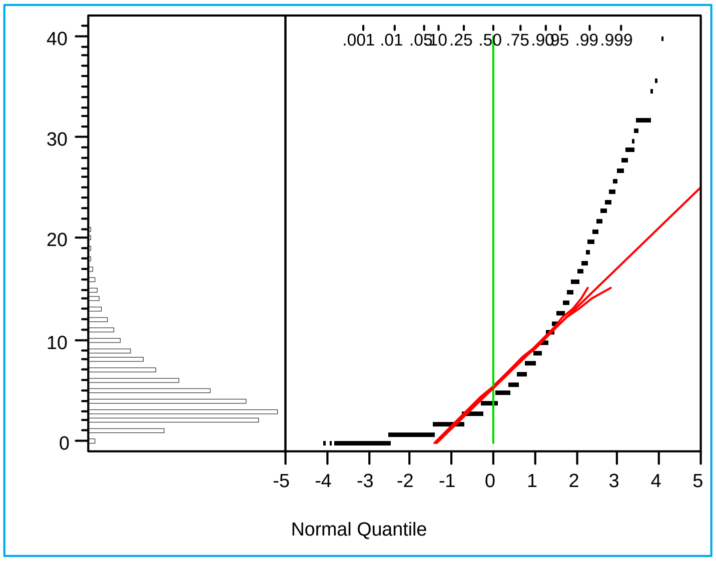
maximum	100.0%	4383.0
	99.5%	3566.0
	97.5%	3372.0
	90.0%	3107.0
quartile	75.0%	2904.0
median	50.0%	2740.0
quartile	25.0%	2456.0
	10.0%	2221.0
	2.5%	1918.0
	0.5%	1843.9
minimum	0.0%	1732.0

Moments

Mean	2692.99
Std Dev	348.40
Std Error Mean	1.64
Upper 95% Mean	2696.20
Lower 95% Mean	2689.79
N	45370.00
Sum Weights	45370.00
Sum	122181165
Variance	121381.24
Skewness	-0.09
Kurtosis	0.39
CV	12.94

Figure 40. Distribution of the LWP 1.8-m rut location.

1.8 m RWP



Quantiles

maximum	100.0%	40.000
	99.5%	22.000
	97.5%	16.000
	90.0%	10.000
quartile	75.0%	7.000
median	50.0%	4.000
quartile	25.0%	3.000
	10.0%	2.000
	2.5%	1.000
	0.5%	0.000
minimum	0.0%	0.000

Moments

Mean	5.34
Std Dev	3.95
Std Error Mean	0.02
Upper 95% Mean	5.38
Lower 95% Mean	5.31
N	45370.00
Sum Weights	45370.00
Sum	242353.00
Variance	15.61
Skewness	1.83
Kurtosis	4.83
CV	73.96

Figure 41. Distribution of the RWP 1.8-m rut depth.