

Comparison of 3-point and 5-point Rut Depth Data Analysis

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ABSTRACT

The Kansas Department of Transportation (KDOT) currently utilizes a comprehensive, network-level pavement management system (PMS) known as Network Optimization System (NOS). For input into NOS, KDOT collects three-sensor rut depth data on its network annually, using two South Dakota-type road profilers. Recently, AASHTO has published provisional standards by modifying FHWA protocols for pavement condition data collection. The primary purpose of these data collection standards is to standardize Highway Performance Monitoring System (HPMS) reporting with the eventual goal of using them in all states' PMS. AASHTO provisional standard PP 38-00 is a protocol for quantifying maximum rut depth. Under AASHTO PP38-00, maximum rut depth is quantified using a five-sensor calculation.

In order to study the effect of AASHTO PP 38-00 on KDOT NOS, profile data was collected on about 241.4 kilometers (150 miles) of bituminous and composite pavements in Kansas, using an ICC profiler equipped with a five-sensor rut bar and a KDOT South Dakota-type profiler with a three-sensor rut bar. The rut depth values were computed and aggregated for the KDOT PMS segments within 11 bituminous and two composite pavement sections. Various statistical analyses were then conducted to compare the results from the KDOT NOS and PP 38-00 algorithms for rut depth computation. The results obtained thus far show that the four-level stratification for rut depth severity suggested by AASHTO PP 38-00 compares reasonably well with the current NOS practice. Both algorithms compared well for the composite pavement test sections. On six out of 11 bituminous sections, the KDOT and the ASSHTO algorithms produced statistically similar mean rut depths. On these sections, the effects of 0.16-km (0.1-mile) and 0.1-km aggregations are insignificant. The dissimilarities on other sections may result from lateral wander of the survey vehicle as well as due to the outer sensors. The outer sensors may not have measured the profile elevations in the cross slope plane (off the edge of the road or over the centerline crown).

Key words: Profiler, Transverse Profile, Condition Survey, Rut Depth, Pavement Evaluation

INTRODUCTION

Rutting, loosely defined as the longitudinal depressions on the wheel paths in asphalt concrete pavements, stems from the permanent deformation in any or all of the pavement layers or the subgrade, and is usually caused by the relative movement of materials due to traffic loading (1). While significant rutting may be interpreted as a major structural failure, it also is a serious safety issue for road users because there is a potential for hydroplaning when water accumulates in the ruts. The hydroplaning phenomenon consists of buildup of a thin layer of water between the pavement and the tire, and results in tire losing contact with the surface, causing a loss of steering control (2). In winter, the accumulated water may freeze in the wheel paths and thus seriously affect a driver's ability to steer a vehicle. Because of increasing magnitudes and repetitions of truckloads as well as increasing tire pressures, rutting has become a widespread problem on many highway asphalt and composite pavements.

Measurement of rut depth has become an integral component of the condition survey of the asphalt concrete and composite pavement network for most state highway agencies. Different agencies have used different techniques for measuring rut depths along a roadway. In the past, rut depth was measured manually with a 1.2 m or 1.8 m straight edge. The process is covered by a specification (E1703-95) developed by the American Society for Testing and Materials (ASTM). This approach was very slow and also required traffic control. ASTM E1656-94 covers the collection of automated transverse profile data. Automated transverse profile data allow for numerous methods to calculate rut depths. The Long Term Pavement Performance (LTPP) program has used transverse profiles to compute wheel path rut depths. Currently, most State Highway Agencies use automated rut depth measurements, either three- point or five- point systems for the project and network evaluations (3). A rut bar mounted on a vehicle with three or five sensors is commonly used to collect profile measurements. The sensors measure the distance, or height, from the sensor to the pavement surface for the three point and five point system and the location of the sensors for both systems is described below (3):

- The three point systems have two sensors located in the wheel paths and one sensor in the middle.
- The five point systems have two extra sensors, usually located approximately 0.30 m from the outside of the two wheel path sensors.

Texas uses a five-point system in which x-y coordinates are collected adjacent to the lane edge, in each wheel path, and midlane. The rut depth is then defined as the vertical distance between a line connecting the points at the edges of the lane and the point in each wheel path (3). Many states including Kansas use a three-point system in which data are collected in each wheel path and mid-lane. In that case, the rut depth is calculated as the difference in elevation between the mid-lane measurement and the wheel path measurements (3).

PROBLEM STATEMENT

FHWA published protocols developed in 1996 by Texas Research and Development Foundation (TRDF) for condition survey data collection. These protocols were developed primarily for the Highway Performance Monitoring System (HPMS) reporting with the eventual goal of using it in the Pavement Management System (PMS). The objective is to harmonize condition data collection among the states. The American Association of State Highway Transportation Officials (AASHTO) has modified and adopted these protocols as Provisional Standards. The AASHTO provisional standard for quantifying maximum rut depth is PP 38-00 (4). Under this standard, the maximum rut depth is computed using five sensors. Also, these standards ask for the metric (0.1-km) aggregation for data collection and analysis.

The Kansas Department of Transportation (KDOT) has a comprehensive, successful PMS for developing a pavement preservation program. The network level PMS of KDOT is known as Network Optimization System (NOS). In support of NOS, KDOT conducts annual condition surveys, and the results of these surveys constitute basic inputs into the NOS systems. For rut depth, current KDOT practice is to compute the rut depth from the output of three laser sensors on the South Dakota-type road profiler. Also, KDOT uses a 0.16-km (0.1-mile) aggregation for data collection, processing and analysis. With the release of AASHTO PP38-00, several questions arise. For example, does a 5-sensor configuration produce more precise results than a 3-sensor configuration? Furthermore, is this level of accuracy really needed for network-level survey? Finally, what stratification of rut depth by this method is compatible with the current NOS practice? A study of transverse profile data collected on the Long Term Pavement Performance (LTPP) sections has shown that the three-point rut depths are significantly different from the five-point rut depths. The study also showed that neither the three-point nor the five-point rut depth measurement systems provide reliable and accurate estimates as measured with a wire line extended across the entire lane width (3). Rut depth computation from the transverse profile data also has been studied by other researchers (5, 6).

OBJECTIVE

The primary objective of this research is to evaluate the effects of using a five-sensor rut bar configuration on the KDOT PMS practices. The study would also see if the AASHTO provisional standard for rutting can be incorporated into the KDOT PMS systems either directly or by making necessary minor changes without affecting the historical consistency in the rut depth data on the KDOT system. The other objective of this study is to suggest the level of stratification of rut depth from the AASHTO standard that will be compatible with the KDOT practice.

TEST TRACK SELECTION AND DATA COLLECTION

Profile data was collected on the test track located in northeast Kansas consisting of 13 sections of asphalt and composite pavements with an approximate total length of 241.1 kilometers (150 miles) as shown in Table 1. The track was selected to be representative of all bituminous and composite pavements mileage in Kansas in terms of both total mileage and pavement condition. All test sections are on two-lane roads with varying shoulder widths.

KDOT Data Collection Methodology

As mentioned earlier, data was collected on the test sections using an International Cybernetics Corporation (ICC) South Dakota-type profiler (Figure 1) with 3-sensor configuration operating at highway speeds (usually 80 km/h). These sensors measure the vertical distance from the vehicle body to the pavement surface, and the profiler is equipped with accelerometers at each of the wheel path sensors to compensate for the vertical motion of the vehicle body. The KDOT ICC profiler is equipped with three Selcom 220 laser sensors. The outer two sensors are spaced at about 1.67 m (65.8 in.) apart. The third sensor is located in the middle.

The profile data was analyzed for computing rut depths with the ICC software RP090L version 3.34. The event files, velocity files and profile files constituted the basic inputs to the software. The software analyzed the profile data from the sensors and reports the rut depths and IRI values for left and right wheel paths as outputs for specified aggregation and appropriate rut depth algorithm (3 point). The rut depth is computed as:

$$\text{Rut Depth} = (D_2 + D_3) / 2 - D_1$$

Where D_1 , D_2 and D_3 are the distances/heights measured as shown in Figure 2.

The rut depths were calculated for 0.16- km (0.1-mile) aggregation in a one-mile segment of the multi-mile test sections. KDOT assigns a rut code for input into the NOS based on the rut depths shown below:

<u>Rut Depth (mm)</u>	<u>Rut Code</u>
0.0 - 6.35	0
6.35 - 12.7	1
12.7 - 25.4	2
> 25.4	3

AASHTO Methodology

Profile data on the test track was collected by CGH Pavement Engineering, Inc. of Mechanicsburg, Pennsylvania using an ICC Profiler (Figure 3) equipped with a five-sensor rut bar. The spacing between the sensors in the wheel paths is 1.75 m (69 in.). The

outer two sensors are located at 0.546 m (21.5 in.) from the wheel path sensors. The fifth sensor is located at the mid-location of two wheel path sensors.

The rut depths are estimated in both wheel paths of the survey lane. Five-point rut depth is computed as follows

$$R_o = D_2 - (D_1 + D_3)/2 \text{ and } R_i = D_4 - (D_3 + D_5)/2$$

Where R_o and R_i are rut depths for the outer and inner wheel paths respectively and D_1 , D_2 , D_3 , D_4 and D_5 are distances/heights measured as shown in the Figure 4. The same RP090L version 3.34 software was used for profile analysis and rut depth calculation. The aggregation used for the calculation of rut depths is 0.1-km (0.062-mile). The following level of stratification of rut depth suggested in PP-38 that closely matches the current NOS practice was used.

<u>Stratification of Rut Depth</u>	<u>Range of Observed Rut Depth (mm)</u>
Level 1	< 5 (0.20 in.)
Level 2	≥ 5 (0.20 in.) to < 10 (0.39 in.)
Level 3	≥ 10 (0.39 in.) to < 25 (0.98 in.)
Level 4	≥ 25 mm (0.98 in.)

The average rut depth from both the wheel paths was used for performing the analysis.

DATA AGGREGATION AND ANALYSIS

Statistical analysis techniques were used to compare the calculated rut depths. Data on less than 0.16–km (0.1-mile) segments was omitted from the analysis, following the practice of truncating data for NOS input. The average rut depth for every 1.6 km (one-mile) segment was computed by summing up the absolute values of the rut depths for each 0.16-km (0.1-mile) segment and then dividing by the segment length. Similar approach was used for the AASHTO procedure in which data on less than 0.1-km long segments was not considered in the analysis.

Figures 6,7 and 8 compare the rut depths obtained from the KDOT (3-point) and AASHTO (5-point) algorithms for different segments on Sections 5, 7 and 1, respectively. Section 5 is a composite pavement section while the other two are bituminous sections. Results in Table 2 show that the average rut depths on Section 5 respectively are 2.5 mm (0.098 in.) and 2.46 mm (0.097 in.) for the KDOT (3-point) and AASHTO (5-point) algorithm. These algorithms resulted in the same average rut depth of 2.9 mm (0.114 in.) for Section 7. However, the average rut depths from the two methods are completely different for Section 1 as shown in Table 8. The average rut depth on this section from the KDOT algorithm is almost five times higher than that from the AASHTO algorithm using five sensors.

Statistical Analysis

The three-point and five-point rut depths obtained were initially tested for normality and equality of variances using the Shapiro-Wilk and Levene's tests at 10% level of significance. If the data was normally distributed with equal variances then the equality of means was tested using the Analysis of Variance (ANOVA) F-test at 95 % confidence interval (5% level of significance). If there were only a few data points then the Welch t-test was performed to test for the equality of means at 95% confidence interval (level of significance = 5%). All statistical analyses were performed using the MINITAB software (7).

The statistical results are shown in Table 2. On both composite pavement sections the three-point and the five-point rut depths were statistically similar. On six out of 11 bituminous pavement sections, these rut depths were statistically similar. For the sections that had statistically different mean run depths from these two approaches, the rut depths were further investigated. The three-point rut depths calculated from five sensors (i.e. CGH data) were compared with five-point rut depths for 0.16- km (0.1-mile) aggregation. The results are shown in Table 3. Only Section 13 was found to have statistically similar average rut depths. . So, the same inputs to the two methods lead to statistically different results. Therefore, the two measures are different and cannot be correlated. It appears that the sensor configuration is responsible for the dissimilarities between the average rut depths on the other sections.

Then the three-point rut depths from three-sensor configuration data collected by KDOT were also compared with the three-point rut depths obtained from the five-sensor configuration data obtained by the CGH profiler. In both cases, 0.16-km (0.1-mile) aggregation was used. The results are also presented in Table 3. Only Sections 2 and 8 were found to have statistically similar average rut depths. For section 13, it was found that the three-point rut depth from KDOT data and three-point rut depth from CHG were significantly different. The possible reason for this could be that the KDOT profilometer and CGH profilometer may not have traversed the same path. Sections 1 and 6 always had dissimilar rut depths. The possible reasons could be: (i) outer sensors may not have measured the profile elevations in the wheel paths; and (ii) two profilometers may not have traversed in the same path during data collection. An LTPP study has shown that a lateral "wander" of the same profile survey vehicle for five repeated measurements is about 127 mm (3).

CONCLUSIONS

The following conclusions can be drawn from this study:

- 1) The four-level stratification for rut depth severity suggested by AASHTO PP 38-00 compares reasonably well with the current NOS practice.
- 2) The KDOT and the ASSHTO algorithms compared well for the composite pavement test sections.

- 3) On six out of 11 bituminous sections, the KDOT and the ASSHTO algorithms produced statistically similar mean rut depths. On these sections, the effects of 0.16-km (0.1-mile) and 0.1-km aggregations are insignificant. The dissimilarities may result from lateral wander of the survey vehicle as well as due to the outer sensors.
- 4) Algorithms to determine rut depths from three and five sensor systems do not represent the same statistic and cannot be correlated.

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TABLE 1 Test Sections Selected for Study

Section	Route	County	Begin County MP	End County MP	Type	Width (m) may include paved shoulders	AADT	EAL
1	177	Geary	13.413	0	BIT	7.31	1065	65
2	56	Osage	0	6.163	BIT	7.31	420	36
3	56	Osage	13.447	32.813	BIT	7.31	1320	28
4	24	Jefferson	2.000	0	COMP	7.31	3520	229
5	24	Shawnee	17.739	0	COMP	7.31	2775	209
6	16	Jackson	0	14.825	BIT	7.31	870	35
7	4	Jefferson	19.465	10.305	BIT	7.31	1505	92
8	73	Brown	9.461	20.943	BIT	7.31	1640	34
9	36	Nemaha	23.987	9.732	BIT	7.31	1870	240
10	15	Washington	18.91	12.094	BIT	7.31	910	101
11	9	Washington	26.247	14.153	BIT	7.31	740	98
12	24	Riley	0	2.503	BIT	7.31	608	47
13	82	Riley	11.859	7.878	BIT	7.31	538	44

EAL: Equivalent Axle Load (daily one direction)

TABLE 2 Comparison of 3-point and 5-point Rut Depth Measurements

Section	Type	3-point Avg. Rut Depth (mm)	5-point Avg. Rut Depth (mm)	p -Value	Statistically Similar*
1	BIT	4.928	1.422	0.000	No
2	BIT	5.156	3.429	0.008	No
3	BIT	2.743	2.235	0.111	Yes
4	COMP	1.880	2.540	0.295	Yes
5	COMP	2.489	2.464	0.936	Yes
6	BIT	1.143	2.007	0.000	No
7	BIT	2.896	2.896	0.953	Yes
8	BIT	1.803	0.457	0.000	No
9	BIT	0.432	1.118	0.058	Yes
10	BIT	1.194	1.372	0.602	Yes
11	BIT	1.803	1.626	0.522	Yes
12	BIT	3.937	2.718	0.104	Yes
13	BIT	0.559	1.245	0.006	No

* at 5% level of significance

TABLE 3 Comparison of the Rut Depth Results from 3-Point Rut Depths from Three and Five Sensors and 5-Point Rut Depths

Section	Type	P value from 3-point rut depth (5 sensors) and 5-point rut depth	Stat. Similar	P value from 3-point rut depth (3-sensor and 5-sensor)	Stat. Similar
1	BIT	0.000	No	0.018	No
2	BIT	0.000	No	0.874	Yes
6	BIT	0.008	No	0.000	No
8	BIT	0.000	No	0.54	Yes
13	BIT	0.936	Yes	0.009	No

FIGURE 1 KDOT South Dakota Profilometer



FIGURE 2 Rut Depth Measurement according to Current KDOT Practice

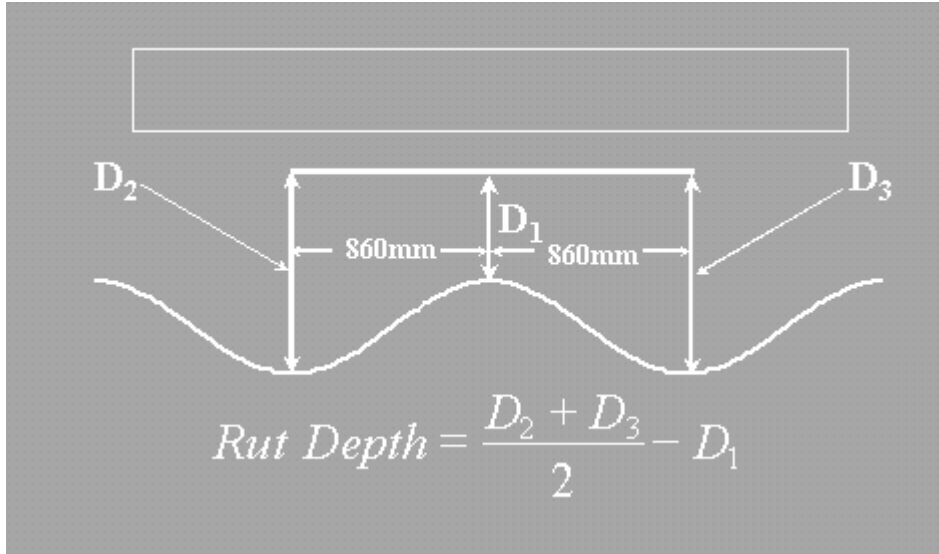


FIGURE 3 CGH Profiler and Rut Bar



FIGURE 4 Rut Depth Measurements as per AASHTO PP 38-00

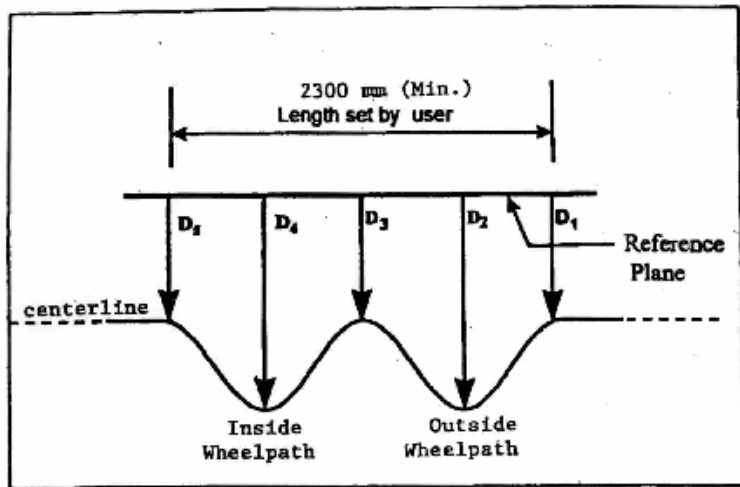


FIGURE 5 Comparison of 3-point and 5-point Rut Depths for Test Section 5 (Composite Pavement)

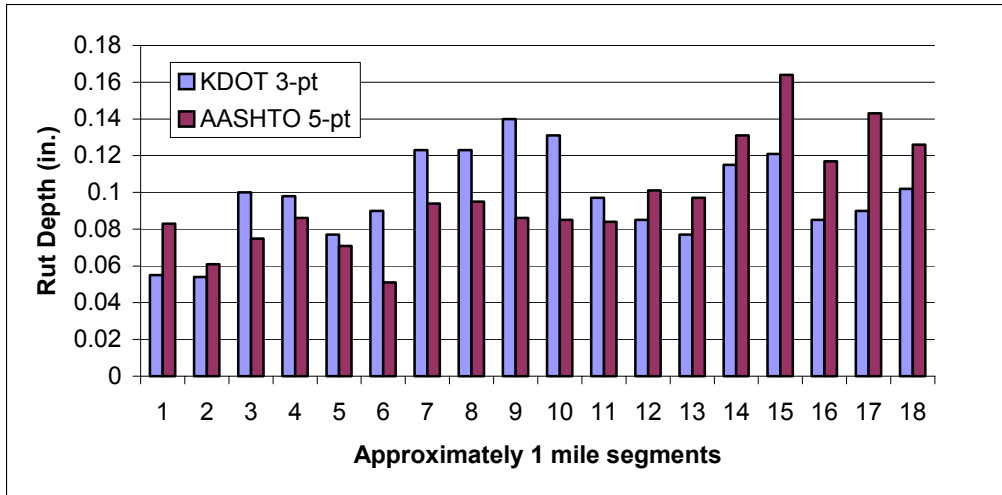


FIGURE 6 Comparison of 3-point and 5-point Rut Depths for Test Section 7 (Bituminous Pavement)

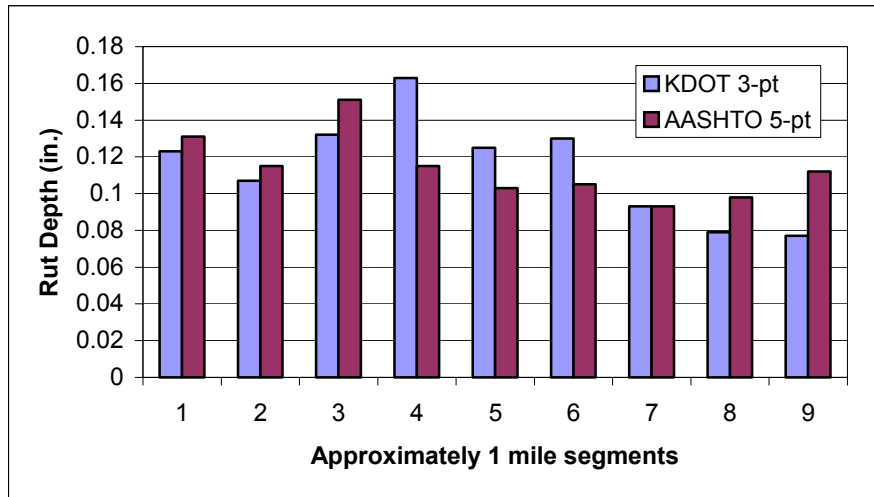


FIGURE 7 Comparison of 3-point and 5-point Rut Depths for Test Section 1 (Bituminous Pavement)

