

Adaptability of AASHTO Provisional Standards for Condition Surveys for Roughness and Faulting in Kansas

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ABSTRACT

The Kansas Department of Transportation (KDOT) currently uses a comprehensive, network-level pavement management system known as Network Optimization System (NOS). Annual condition surveys for roughness and faulting generate important inputs for NOS. Recently, AASHTO has published provisional standards for condition surveys in order to harmonize data collection efforts among the states. To study the effects of these provisional standards on KDOT NOS, profile data was collected on about 346 km (215 miles) of Kansas highways following these standards. The comparison data came from KDOT's annual condition survey using KDOT standards. The roughness values, in terms of International Roughness Index, IRI, were computed and aggregated for 20 test sections and the faulting values were computed and compared for four test sections. Various statistical analyses compared the results from the algorithms following KDOT NOS and the AASHTO provisional standards. The roughness measurements and subsequent analysis using AASHTO provisional standard PP-37-00 and current KDOT methodology tend to produce statistically similar results. This may indicate this standard (PP 37-00) can be adopted for NOS without any major changes in current practice. However, significant differences were found in calculated fault values computed from the two methods even after some modification to PP 38-00 following current practices in Kansas.

Key words: condition surveys—faulting—pavement management system—roughness

INTRODUCTION

The Kansas Department of Transportation (KDOT) uses a comprehensive, successful pavement management system (PMS). The network level PMS of KDOT is popularly known as the Network Optimization System (NOS). In support of NOS, annual condition surveys are conducted based on the methodologies proposed by Woodward Clyde consultants (now URS Corp.) and subsequently, refined by the KDOT Pavement Management Section. Current annual condition surveys include roughness, rutting, fatigue cracking, transverse cracking and block cracking for flexible and composite pavements, and roughness, faulting and joint distresses for rigid pavements. Different severity levels and extent are measured in the survey. While the roughness, rutting and faulting data are collected using automated methods, cracking and joint distress surveys are done manually. These survey results constitute basic inputs into the NOS system. The performance prediction methodology in the NOS system is based on the Markov process. The technique uses transition matrices to predict future condition based on current condition for multi-year programming. Thus, the surveys are essential to define the current condition (1). Similarly historic data is used to generate and update the transition matrices, so historic data consistency is also essential.

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 Pavement Management Systems (PMS). The objective was 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 roughness is PP 37-00 and PP 39 -00 is for faulting (2). Each of these standards differs some from the KDOT method. For instance, these standards ask for the metric (0.1km) aggregation for data collection and analysis.

As mentioned earlier, in support of NOS, KDOT conducts annual condition surveys, and the results of these surveys constitute basic inputs into the NOS systems. Preliminary investigations of these standards on KDOT practices presume the impact to be severe. However, no data had been collected using these standards from which the impacts can be evaluated. KDOT reports roughness to FHWA in terms of International Roughness Index (IRI) from actual profile measurements, which is required in AASHTO PP-37. But, KDOT uses a 0.062-km (0.1-mile) aggregation for data collection, processing and analysis. KDOT's automated fault detection algorithms are based on first identifying potential fault locations and then quantifying the extent of the fault. AASHTO PP39-00 contains a similar approach to the extent determination, but has no means of identifying a potential fault location.

ROUGHNESS

Road roughness is an important attribute in evaluating pavement condition because of its effects on ride quality and vehicle operating costs. In its broadest sense, road roughness has been defined as “the deviations of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamics loads, and drainage” (3). The current practice is to measure roughness in terms of the longitudinal profile of the road surface since it is known to cause vertical acceleration of vehicles, and in turn, user discomfort.

Recent surveys by the National Partnership for Highway Quality (NPHQ) and the Federal Highway Administration (FHWA) have shown that the primary concern for the motoring public is road condition, or pavement smoothness. Currently, most state highway agencies (SHAs), as well as many county and municipal agencies measure pavement smoothness on pavement rehabilitation and construction projects. Because some types of roughness are damped by vehicle dynamics and others are amplified, a statistic to quantify roughness transferred to vehicle occupants, International Roughness Index (IRI), was developed. The statistic allows road profile data to be compared as road users experience it. Unfortunately, questions remain about the effects of pavement surface temperature, texture, moisture, signal processing (noise and filter impacts) and other extraneous variables on both profile and IRI.

FAULTING

Faulting is the difference of elevation across joint or crack (4). Faulting is considered an important distress of jointed plain concrete pavements (JPCP) because it affects ride quality. If significant joint faulting occurs, there will be a major impact on the life-cycle costs of the pavement in terms of rehabilitation and vehicle operating costs. Faulting is caused in part by a buildup of loose materials under the trailing slab near joint or crack as well as the depression of the leading slab. Lack of load transfer contributes greatly to faulting (4).

TEST TRACK SELECTION

In order to assess the effects of the AASHTO provisional standards on the profile data analysis, data was collected on a test track located in northeast Kansas. The track consists of 20 sections of asphalt, portland cement concrete, and composite pavements with an approximate total length of 346 km (215 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, except one, are on two-lane roads with varying shoulder width.

TABLE 1. Test Sections Selected for Study

Section	Route	County	Begin County MP	End County MP	Type
1	177	31	13.413	0.013	BIT
2	56	56	0	14.069	BIT
3	56	70	0	12.936	BIT
4	56	70	13.447	32.971	COMP
5	24	44	6.516	0.154	COMP
6	24	89	17.739	0	BIT
7	16	43	0	14.825	BIT
8	4	44	19.465	10.317	BIT
9	192	52	0	8.51	BIT
11	73	52	17.171	8.815	PCC
12	73	7	9.461	20.906	BIT
13	36	66	23.987	9.732	BIT
14	36	58	25.145	9.207	BIT
15	15	101	18.91	12.094	COMP
16	9	101	26.247	14.253	BIT
17	24	81	0	2.478	BIT
18	82	81	11.859	7.924	BIT
19	70	31	7.124	11.282	PCC
20	18	31	15.341	18.044	PCC
21	18	81	0.234	2.349	PCC

PROFILE DATA COLLECTION

Pavement profile data consists of elevation measurements at discrete intervals along a pavement surface. The data collection program on the road profilers store its data in the binary format to save both space and time while creating the files in the vehicle. While these binary files are efficient, they cannot be reviewed or edited with standard text editors. A software program, such as the ICC report program, is necessary to process the data into reports and to convert the data to text files that may then be read and processed by standard software programs. RP090L is one such report program used to report data from these road profilers. The profile data for this project was analyzed with RP090L v 3.34 for computing pavement roughness statistic (IRI) and faulting. The inputs to this software are event files, speed files, and profile files.

Profile data on the test track was collected on both wheel paths by KDOT using an International Cybernetics Corporation (ICC) South Dakota-type profiler. Data collection was done at highway speeds (usually 50 mph or 80 km/h). The 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. KDOT profiler aggregates profile elevation at every 75 mm (3 in.).

Longitudinal profile data was also collected by CGH Pavement Engineering, Inc. of Mechanicsburg, Penn. using an ICC profiler. That data was collected and reported at 145 mm (approx. 6.07 in.) intervals.

ROUGHNESS MEASUREMENT

The pavement engineer cannot readily use raw profile data. The profile, by itself, does not represent how rough a road is. It must be processed in some manner to produce a meaningful representation of the pavement roughness. A number of summary statistics are available to represent road roughness using road profile data. International Roughness Index (IRI) is most commonly used by many agencies since IRI is required by FHWA for HPMS reporting. The IRI was developed mathematically to represent the reaction of a single tire on a vehicle suspension (quarter-car) to the roughness of the pavement surface, traveling at 80 km/h (50 mph). IRI is expressed in mm/km (inches/mile).

The RP090L software uses the following steps to produce IRI from collected data (5):

1. Combine height sensor and accelerometer data together for each wheel path.
2. Filter data and produce profile points for each wheel path.
3. Put profile into a quarter car simulation at 80 kmph (50 mph) to create a vehicle response set of data points.
4. Put response points into a formula that calculates the IRI using sum of rectified slopes.
5. Produce an IRI report broken up in intervals, sections, or the combination of the two.

The software gives the IRI values for both left and right wheel paths. Average IRI value was used in this analysis.

AASHTO Procedure

AASHTO provisional standard for roughness, PP 37-00 specifies 0.1 km (0.0625 mile) aggregation steps in IRI computation. The standard also calls for a quality assurance plan encompassing certification and training, equipment calibration, verification sections, and data quality checks.

KDOT Procedure

The current KDOT procedure is to get IRI values using 0.16 km (0.1 mile) aggregation steps. KDOT uses the RP090L software, supplied by ICC, to compute the IRI values.

FAULTING MEASUREMENT

KDOT Procedure

The fault values are calculated from the profile data using an algorithm developed by KDOT internally. In this process, anytime the absolute relative elevation difference between two points at 150 mm (6 in) intervals for the right sensor from the output of RP090L exceeds 2.3 mm (0.09 inch), then the relative elevation difference (fault) values are algebraically summed until either three consecutive fault values are less than 2.3 mm (0.09 in) or 0.9 m (3 ft) has been traversed. The calculated fault value would be the algebraic sum of the points divided by two. Once a fault has been detected, the next fault must be located at least 3.05 m (10 ft) away. A 0.16-km (0.1-mile) aggregation was used for the data analysis.

AASHTO Procedure

The AASHTO protocol for faulting PP 39-00 specifies a 0.1-km aggregation. For automated surveys, relative elevation measurements must be taken at points 75 to 225 mm (3 to 8 in.) from the joint or crack and separated by 300 mm (11.8 inch) as shown in Figure 1. The faulting value should be recorded only when it exceeds 5 mm (0.2 in). It also states that care must be taken not to measure spalling and report it as faulting. However, the proposed standard does not specify any particular way to do that.

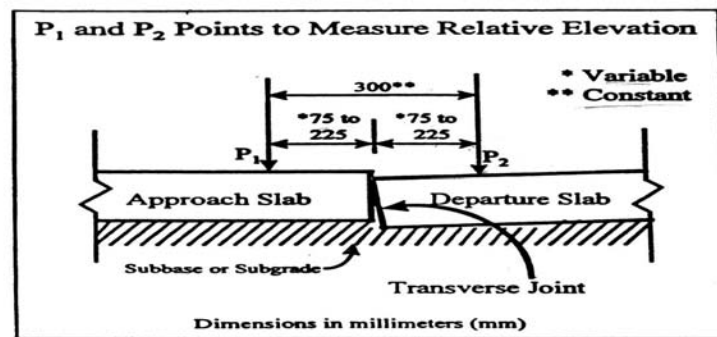


FIGURE 1. Faulting Measurements According to AASHTO PP 39-00 (after 2)

DATA AGGREGATION AND ANALYSIS

Roughness

KDOT Methodology

The aggregation interval used was 0.1 mile. 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. Roughness is calculated as the average of the two IRI values in left wheel and the right wheel path (historically KDOT has used the right

wheel path only following HPMS guidelines). Then the average roughness for every 1.6 km (one-mile) segment was computed as a length-weighted average.

AASHTO Methodology

The aggregation interval used was 0.1km. Data on less than 0.1–km (0.0625-mile) segments was omitted from the analysis, following the practice of truncating data for NOS input. Roughness is calculated as the average of the two IRI values in the left and right wheel paths. Then the average roughness for every 1.6 km (one-mile) segment was computed as a length-weighted average.

Comparison of Roughness Data

Statistical analysis techniques were used to compare the roughness values from both algorithms. The roughness values were initially tested for normality and equality of variances using the Shapiro-Wilk and Levene’s tests at 10% level of significance (6). If the data were normal 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 the normality and variance tests failed, Kruskal-Wallis nonparametric test was done (6). 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%) (12). All statistical analyses were performed using the MINITAB software (7). The results are shown in Table 2. The roughness values from both methodologies were statistically similar for all sections.

TABLE 2. Comparison of Roughness Measurements (m/km) from KDOT and AASHTO Methodologies

Sec	Route	Begin MP	End MP	Type	KDOT Roughness	AASHTO Roughness	p-Value	Similar
1	177	13.413	0.013	BIT	0.848	0.851	0.887	Yes
2	56	0.029	14.069	BIT	1.014	1.058	0.646	Yes
3	56	0.061	12.936	BIT	1.552	1.548	0.96	Yes
4	56	12.936	32.971	BIT	1.716	1.712	0.932	Yes
5	24	6.516	0.154	COMP	1.500	1.510	0.95	Yes
6	24	17.739	0	COMP	1.069	1.091	0.68	Yes
7	16	0.032	14.825	BIT	0.953	0.948	0.834	Yes
8	4	19.465	10.317	BIT	1.075	1.074	0.991	Yes
9	192	0.092	8.51	BIT	1.059	1.295	0.064	Yes
11	73	17.171	8.815	PC	1.8	1.8	0.878	Yes
12	73	9.461	20.906	BIT	1.071	1.062	0.603	Yes
13	36	23.987	9.732	BIT	0.882	0.890	0.963	Yes
14	36	25.145	9.207	COMP	0.942	0.942	0.992	Yes
15	15	18.91	12.094	BIT	1.238	1.246	0.89	Yes
16	9	26.247	14.253	BIT	1.153	1.150	0.963	Yes
17	24	0	2.478	BIT	1.529	1.506	0.951	Yes
18	82	11.859	7.924	BIT	1.036	1.043	0.913	Yes
19	70	7.124	11.282	PC	1.5	1.4	0.352	Yes
20	18	15.341	18.044	PC	2.0	2.0	0.818	Yes
21	18	0.234	2.349	PC	2.289	2.594	0.65	Yes

Comparison of Roughness Data from the CGH ICC Profiler

Similar statistical approach was followed to analyze roughness data from the CGH ICC profiler according to the KDOT and AASHTO methodologies discussed earlier. The results from the statistical analysis show that the roughness values from both methodologies were statistically similar for all but two sections (Sections 1 and 14).

Faulting

KDOT Methodology

The aggregation used for the analysis was 0.16 km (0.1 mile). The fault detection and calculation methodologies described earlier were followed. The absolute fault values were used for the analysis.

AASHTO Methodology

The aggregation used was 0.1 km (0.0625 mile) and the KDOT profiler data was used for analysis. As per PP39-00, the relative elevation difference (fault) measurements must be taken at 75 to 223 mm (3 to 8.8 in) from the crack or joint and separated by 1300 mm (approximately 12 inch). Since this is difficult to quantify from the output of RP090L, when the fault value from the right sensor exceeded 2.3 mm (0.09 in), only then the fault values were computed. This was done to be consistent with the KDOT method. The fault value was taken as the sum of that value and the consecutive identifiable fault values after that, and then divided by two. The fault value was reported only if it exceeded 5 mm (0.2 inch) per PP 39-00 requirements. A minimum distance of 3.05 mm (10 ft) was maintained between two successive fault values. Although this was not specified in the AASHTO PP 39-00, it also was done in this study to be consistent with the KDOT methodology and to eliminate the possibility of reporting spalling as faulting.

Revised Method (a)

In this method, the aggregation interval used was 0.1 km (0.0625 mile) and all fault values obtained from the AASHTO methodology were used for the analysis (unlike PP 39-00 where the faulting values greater than 0.2 inch must be used for analysis).

Revised Method (b)

In this method, 0.1 km (0.0625 mile) aggregation interval was used and the KDOT methodology was followed in the analysis.

Statistical analysis, for comparing the results from two methodologies, was done in the same way as roughness results. The results for the PCC sections of the test track (Sections 11, 19, 20 and 21) are summarized below:

Section 11:

- The fault values obtained from the KDOT and AASHTO methods were significantly different for all one-mile segments.
- The fault values obtained from the KDOT and AASHTO (revised methods (a) & (b)) methods were statistically similar for all one-mile segments.

Section 19:

- The fault values obtained from the KDOT and AASHTO methods were significantly different for all one-mile segments.

- The fault values obtained from the KDOT and AASHTO (revised methods (a) & (b)) were statistically similar for all one-mile segments except one for the revised method (a).

Section 20:

- The fault values obtained from the KDOT and AASHTO methods were significantly different for all one-mile segments.
- The fault values obtained from the KDOT and AASHTO (revised methods (a) & (b)) were statistically similar for all one-mile segment.

CONCLUSIONS

The following conclusions can be drawn from this study:

- The KDOT and the AASHTO algorithms compared well for the roughness statistics determination. All test sections had statistically similar IRI values. On these sections, the effects of 0.16 km (0.1 mile) and 0.1km data aggregation are insignificant.
- The KDOT and the AASHTO algorithms for faulting produce significantly different fault values.
- The KDOT and the AASHTO (revised method (a) & (b) following somewhat KDOT algorithm for fault detection and threshold fault values) algorithms had statistically similar fault values.

RECOMMENDATIONS

The following recommendations can be made from the above study:

- The AASHTO provisional standard PP 37-00 is compatible with the current KDOT practices and can be implemented easily.
- Although modified AASHTO method PP 39-00 produced fault values similar to the KDOT NOS algorithm, further research is needed to investigate ways to recognize the joint or crack in the concrete pavement as specified in the standard. The standard also does not specify ways to recognize faulting at the beginning. More study is needed in this area.

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