AHTD Cracking Protocol Application with Automated Distress Survey for Design and Management

Final Report

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ABSTRACT

Manual surveys of pavement cracking have problems associated with variability, repeatability, processing speed, and cost. If conducted in the field, safety and related liability of manual survey present challenges to highway agencies. Therefore automated processes for cracking analysis have been sought after in the past decades. Processed cracking results need to be compiled based on a standard or a protocol so pavement engineers can apply the results in design and management. Pavement cracking protocols vary in details. Cracking definitions in the Highway Performance Monitoring System (HPMS) and the Mechanistic-Empirical Design Guide (MEPDG) represent two efforts in defining cracking applications for pavement condition monitoring and prediction modelling of pavement condition in design respectively. This paper presents the findings of using a fully automated process with the Automated Distress Analyzer (ADA) to establish a viable method for analyzing cracks based on 2D laser images for HPMS and MEPDG. It is determined that automated survey is possible for both protocols as long as careful design and implementation are made and errors are controlled in the process as much as possible. In addition, an analysis of wheelpath wandering and its effect on cracking analysis is conducted by varying positions of wheelpaths and their sizes.

INTRODUCTION

A pavement distress survey is essential to nearly all aspects of pavement engineering. It is a critical process for roadway agencies to accomplish the tasks of pavement evaluation and performance measurement, maintenance, rehabilitation, and reconstruction of the pavement structure. Network-level pavement management systems require accurate distress data to support sound conclusions as to where and when to invest highway maintenance, rehabilitation, and construction dollars. At the project level, distress data are critical to correctly diagnosing the causes of pavement deterioration, and therefore used to select the most appropriate remedial measures. Distress data are important independent variables in the development of structural design methods and performance prediction models for both new and rehabilitated pavements. This is particularly true for the next-generation pavement design guide, the

Mechanistic-Empirical Pavement Design Guide (MEPDG) (1). In addition, the recently released Field Manual of Highway Performance Monitoring System (HPMS) (2) has distinctive definitions of cracking reporting.

Many DOTs in the US have adopted automated technologies for data collection (2). A recent report on an automated cracking questionnaire survey (3) concluded that for the state DOTs in 2003; most of the 30 agencies surveyed were using an automated method to acquire pavement surface images, but few adopted automated processing software. In the survey, some believed that data quality was compromised and they were hesitant to invest in the new technologies until they have been more thoroughly proven, while other agencies mentioned an improved data quality through automation. With the new laser imaging technology released in 2006 for 2D image acquisition, the quality concern is more relevant to data processing and interpretation than data acquisition.

The data quality issue of distress surveying exists in both automated and manual processes. For example, the manual survey result shows wide variability (4). The variability in manual survey comes from six sources: 1) complex pavement condition, 2) varying data collection method, 3) rater inconsistency, 4) inter-rater uniformity, 5) time, and 6) transcription, referencing and data entry. The variability or error in automated interpretation of cracking survey mainly comes from the automated cracking interpretation algorithms which rely on image processing and pattern recognition of two dimensional pavement images. Despite the fact that the automated cracking result is not perfect with today's computer vision technology, it shows promising capabilities in network level cracking survey. For example, the Maryland DOT has successfully implemented automated network level crack surveying with proper quality assurance through a quality control process (5). It demonstrates that the automated cracking data can provide effective inputs to pavement management systems. At a minimum, if properly calibrated, fully automated interpretation systems for cracking survey are consistent and repeatable in their results.

This report describes the conversion of pavement data from the Arkansas highway department data vehicle into the format for the Automated Distress Analyzer (ADA) and relevant software for fully automated processing and semi-automated processing. Cracking definitions in MEPDG and HPMS were used for comparing results based on the two processing methods. Wheelpath wandering and wheelpath sizes were tested for variability analysis.

RAW DATA, CONVERSION, AND PROCESSING

The Arkansas State Highway and Transportation Department (AHTD) provided the research team 1mm resolution laser images for a total of 15 pavement segments, which were collected from January 2009 to September 2009. Each road segment ranges anywhere from 3 to 49 miles. Only 12 of these segments were selected and analyzed under both automated and semi-automated processes.

While ADA and the user software Multimedia Highway Information System (MHIS) were not specifically made to tailor the data from AHTD, custom software was made in the project to convert the AHTD data into formats that ADA and MHIS can read. Figure 1 illustrates ADA reading a raw image from the AHTD data vehicle and displaying the processed crack map. ADA results are contained in a database which stores the cracking geometrics shown in the crack map and the locations of the cracks with data from the Distance Measurement Instrument (DMI) and GPS receiver.

MHIS Deluxe, shown in Figure 2, is a software suite that provides the user with a graphical representation of all the data sets collected using the DHDV. These data sets shown in MHIS include pavement images, Right-of-Way images, rutting and roughness profiles, DMI and GPS readings etc. MHIS Deluxe is customized to meet the AHTD usage requirement such as loading data files from the AHTD data vehicle. MHIS Deluxe also provides a set of tools to assist the user in identifying the distresses based on the digital pavement images. The tools are especially useful for editing ADA's processed images, by either deleting or changing the detected distresses. In addition, non-cracking distresses can be processed as well using MHIS Deluxe, such as those defined in the LTPP distress manual (6) and the PCI procedure. With MHIS Deluxe, all distress information collected by ADA and the manual raters are shown on the image, saved in the database, and summarized in cracking indices based on commonly used cracking protocols.

The software is able to display pavement distresses located in wheelpaths as defined by the LTPP distress manual (6) in Figure 3. The software also allows the cracking information of both asphalt concrete and plain concrete pavements to be calculated based on the HPMS and MEPDG definitions. Figure 4 shows the screen shot of the manual distress survey options in MHIS Deluxe. Figure 5 shows ADA results and manual results in MHIS Deluxe.

The report also presents the correlation between both the fully automated data and the semi-automated data (provided by three raters/evaluators). Fully automated data processing for cracking is based on ADA without any human intervention. Semi-automated processing is based on manual editing of ADA results by using the MHIS Deluxe software in a post-processing workstation. There were 12 sites provided by AHTD that had undergone the analysis procedure. The report illustrates the results for three of these sites: A_025020, A_001010, and A_040410 shown in Figure 6. These particular sites were chosen because they vary in length, quality, and pavement material. Results of the data analysis were compiled and compared based on cracking definitions in MEPDG and HPMS. The post-processing software is currently applicable to flexible pavement surfaces only.

CRACKING DEFINITIONS IN HPMS AND MEPDG

The cracking definitions in both MEPDG and HPMS have their roots in the LTPP distress manual (6). The main difference between the definitions is the level of specificity for cracking length and cracking percent documentation. The MEPDG requires a more detailed inventory that not only looks into the quantity of a given distress, but also its level of severity (low, medium, high). The MEPDG definitions also require that the quantity of each severity level for that distress be documented separately.

The observed distress for rigid surfaces in MEPDG is transverse cracking. For asphalt concrete surfaces (AC), the cracking distresses in MEPDG are longitudinal cracking, transverse (thermal) cracking, and fatigue (alligator) cracking. Longitudinal cracking, cracking that is mostly parallel to the centerline, is subdivided into two categories: in the wheelpath and outside of the wheelpath. The wheelpath consists of two longitudinal areas designating the boundaries that carry the bulk of the traffic loads. Longitudinal cracking inside the wheelpaths is assumed to be fatigue (alligator) cracking (6). The reason for this is that fatigue cracking in early stages is typically difficult to distinguish from longitudinal cracking. Longitudinal cracking outside of the wheelpath and transverse cracking, cracking that is mostly perpendicular to the centerline, is reported as the average length of cracking per mile (ft/mi), while alligator cracking is estimated as a percent of the total road segment area. Alligator cracking typically starts out as an assortment of interconnecting longitudinal cracks that eventually develop into a quantified area (6). For JPCP (rigid) surfaces, an MEPDG analysis tends to include documentation for the percentage of slabs that contain fatigue cracks. Figures 7 through 9 illustrate the LTPP definitions for each of the distresses.

The two cracking distresses for HPMS are cracking length and cracking percent (7). Cracking length is an estimate of the total length of transverse and/or reflection cracking for every mile (measured to the nearest ft/mi, only counts cracks of at least 6 feet in length). For rigid pavements, cracking percent is the percent of slabs along a given segment that contain fatigue cracking; which does not concern the area (rounded to the nearest 5%). Cracking percent for flexible pavements is the percent area containing alligator or longitudinal cracking (typically in the wheelpath) of the total segment area, rounded to the nearest 5%. Cracking percent for flexible pavements in HPMS is the same as alligator cracking percent for MEPDG. Thus, the data tables only present HPMS cracking percent to avoid redundancy.

One aspect that separates HPMS protocol from the MEPDG protocol is that HPMS is more flexible in terms of how certain data is reported. For instance, if there is no data available for the precise area of the road containing fatigue cracking, a percentage representing the number of cracks per mile that is multiplied by the width of the road and then divided by the total area of the segment can be used as a legitimate documentation (7). The statistical comparison between the automated and semi-automated data use the percent area containing alligator/fatigue cracking to represent the cracking percent for HPMS.

RATING PREPARATION AND ANALYSIS

The ASTM precision and bias procedure (8) implemented by Wang et al for manual cracking survey (9) was used to select raters for between-rater consistency and within rater consistency for this project. The rating results from the semi-automated processing in this study are considered usable and no outliers were thrown out. Tables 1 and 2 show a sample of semi-automated results for cracking length and percent among three raters for the three pavement sections. Generally, each of the three raters repeated their individual values relatively well between the two tests. The standard deviation of the raters' averages from the total average (denoted as $S_{\overline{X}}$) ranged from 20 to 60 ft/mi for the cracking length and anywhere from 0.3 to 10% for cracking percent. It should be emphasized that cracking survey results based on manual processing, or the semi-automated processing in this study, are subject to variablity and precision issues as fully automated results do. Therefore, ground-truth values of cracking data are hard to come by, or impossible. For analytical purposes, however, the raters' average "$\overline{X}$" was still taken to be the value for which the comparisons between the automated and semi-automated data were to be made.

From the tables, it can be concluded that the repeatability, the ability for a single rater to get the same number for any parameter for multiple tests, proved to be better in precision as opposed to the reproducibility, which is the ability for a rater to get the same number obtained by other independent raters. This goes to show that each of the three raters had the tendency to analyze each segment in accordance to their own judgement, despite demonstrated experience and training.

WITHOUT CONSIDERING WHEELPATH

Tables 3 and 4 show the data comparison between the automated and semi-automated interpretations without considering a wheelpath as defined for both MEPDG and HPMS. By not defining a wheelpath boundary for the data collection, every crack detection ADA makes on the 1mm laser based pavement image is included in the data processing regardless of the crack's location. The variable denoted as "$\overline{X}$", represents the average value obtained for any given parameter between the three raters. "$\overline{X}$" was taken to be the "true" value for each parameter and was compared to the values obtained by the ADA software. For HPMS, the total difference in cracking percent extends as much as 8% while the deviance of the cracking length surpasses 1000 ft/mi for a single road segment. For MEPDG, the total deviance of the automated data from the semi-automated data expands as far as over 1,400 ft/mi for total transverse length and over 7,000 ft/mi for total longitudinal length. These significantly high differences (always overestimations by ADA for longitudinal length) are due to ADA's tendency to detect and include certain pavement noises as cracks, despite tremendous efforts in de-noising the pavement images in ADA algorithms. These false-positive detections quickly accumulate and instigate the overestimations for the amount of longitudinal cracks. Another shortcoming in the ADA software is that its ability to detect alligator cracking is not strong. Instead, it frequently detects alligator cracking as an assortment of longitudinal and transverse cracks spaced closely together. The outcome of this shortcoming clearly contributes to the overestimation of longitudinal cracks. This misjudgment is important considering that both MEPDG and HPMS require an inventory of the percentage of cracking, primarily for alligator cracks, in addition to longitudinal (MEPDG only) and transverse cracking.

CONSIDERING WHEELPATH

In an effort to improve the effectiveness of the ADA software in detecting alligator cracks, a post-processing method was created in Microsoft Excel to include linear cracks within wheelpaths as alligator cracking. In addition, as wheelpath positions would impact cracking statistics, particularly these statistics sensitive to positions of cracks, various wheelpath alignments were used for the road segments (Figure 10a-10e). With a defined wheelpath, all of the detected cracks falling outside of the wheelpath boundaries were thrown out and not used in the statistical comparison, thus ultimately improving the correlation between the automated and semi-automated data. The wheelpaths also regulate the semi-automated process, removing false positive crack detections that the raters forgot to delete.

The definition of alligator (fatigue) cracking in the LTPP distress manual states that fatigue cracks are developed after repetitive load applications in the wheelpaths. Cracking occurring between the wheelpaths has to be considered as well, as vehicles do not always stay in the wheelpath, therefore for the portions labeled “Between Wheelpaths”. Distresses occurring in this region can only exist as longitudinal or transverse cracking. The tables indicating data on longitudinal cracking are referring to the longitudinal cracking between the wheelpaths for MEPDG.

There are five different wheelpath widths/alignments that were used for each of the three segments: 2.5 ft (LTPP standard size), 3.5 ft, 4.5 ft, 3.5 ft inward, and 4.5 ft inward shown in Figure 10 (a) to 10 (e). The term “inward” suggests that the outer boundaries of the left and right wheelpaths remain stationary while the inner boundaries are moved inward toward the centerline accordingly. Tables 5 through 8 summarize all of the data comparisons alligator percent, transverse, and longitudinal cracking for both MEPDG and HPMS cracking after considering the wheelpath. The column labeled “ADA Difference” represents the value difference between ADA and the average value of the three raters (negative meaning that ADA has underestimated). The “Original ADA Abs. Diff.” column represents the absolute value of the difference between ADA and the raters’ average before the wheelpath was considered for the automated process. The column indicated as “Better/Worse?” represents the absolute value of the “ADA Difference”. The cells that are shaded green represent an improvement due to the wheelpath alignment while the red shaded columns indicate values that have worsened.

Before the wheelpaths were considered, ADA’s tabulation of the cracking length (HPMS) exceeded the raters’ average by a total of over 1100 ft/mi while the cracking percent deviated at a sum of 15% between all three segments. When the wheelpath boundaries were established, these deviances subsided, especially for the 4.5 ft inward wheelpath alignment. The total ADA deviance for cracking length for all three segments was just over 500 ft/mi, with the highest single segment deviance being 377 ft/mi. ADA’s deviance for cracking percent showed a total of 9%. For MEPDG, the effects of the wheelpath alignments showed improvements for longitudinal cracking while transverse cracking deviances were worsened (with the exception of A_040410). Because of the larger wheelpath size (4.5 ft inward), the boundary includes cracks induced by traffic veering out of the standard LTPP size, thus there is a bigger tabulation for alligator cracking, which the smaller wheelpath alignments underestimate. With the larger wheelpath alignment, the boundary between the wheelpaths is thinner, thus the tabulation of the longitudinal cracking is reduced. Because longitudinal cracking is a parameter that ADA always overestimates, this improved the results immensely. The results were improved by as much as a factor of 17 (8,114ft/mi deviance to 459 ft/mi deviance for A_001010). There is a simple explanation for the worsening of the transverse cracking deviances. Before considering the wheelpaths, ADA's deviances already exist as underestimations. Because the wheelpath acts as a type of "filter" that reduces ADA's crack tabulation, an underestimation can only be worsened. Fortunately, the underestimations are very small and already close to the raters' average as is. Unlike segments A_025020 and A_001010, segment A_040410 contains concrete portions with transverse joints running across the road every 12 feet or so. These joints are sometimes distinguished as transverse cracks which quickly accumulate to an overestimation for transverse cracking. The wheelpath alignments regulate what are counted as cracks, thus ADA's deviance is reduced and improved for segment A_040410.

Tables 9 and 10 show the sensitivity of the ADA values between the different wheelpath alignments. Cracking percent for HPMS and MEPDG only have a range of about 4%. Transverse cracking (MEPDG) and cracking length (HPMS) can range to as much as a 400 ft/mi difference. Longitudinal cracking, on the other hand, has a large range of values between the different wheelpath alignments (over 1000 ft/mi). Because longitudinal cracking in the datasets exists only between the inner wheelpath boundaries, it has the highest sensitivity to the alignment compared to the other parameters. The large range of transverse cracking values for A_040410 was due to the same issue as transverse cracking which is typically overestimated by ADA.

CONCLUSION AND RECOMMENDATIONS

We are clearly getting closer to relying on automated methods for cracking analysis, but there is still work to be done. Although the rater consistency can be still a problem, and the automated to semi-automated deviations can be high for some of the cases, further improvements are recommended as follows:

- Develop a standard procedure to select qualified manual raters, whose rating results will be used as a benchmark for control sections of pavements in the quality control and quality assurance process.
- Enhance ADA software algorithms to properly detect joints, oil spills, and linear patterns
- Develop an algorithm in MHIS for determining the percent of slabs cracked for JPCP surfaces

It is apparent that it is not cost effective to use manual processing for crack detection and classification. In addition, acceptable levels of variability and repeatability are not proven yet with manual surveys. The research in the project demonstrates that fully automated processing of 2D laser images faces challenges as well. However, as long as factors influencing automated processing are fully understood and errors are controlled, automated results are usable. The recent advances in using 3D laser images at 1mm resolution for automated distress survey have opened new possibilities in improving precision and bias levels for automated cracking survey. The research team hopes to release results on 3D based automated processing in 2011. Furthermore, additional studies based on the soon-to-be released AASHTO provisional guide will be conducted with both 2D and 3D pavement surface data in the near future.

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FIGURE 1 Customized ADA for AHTD.

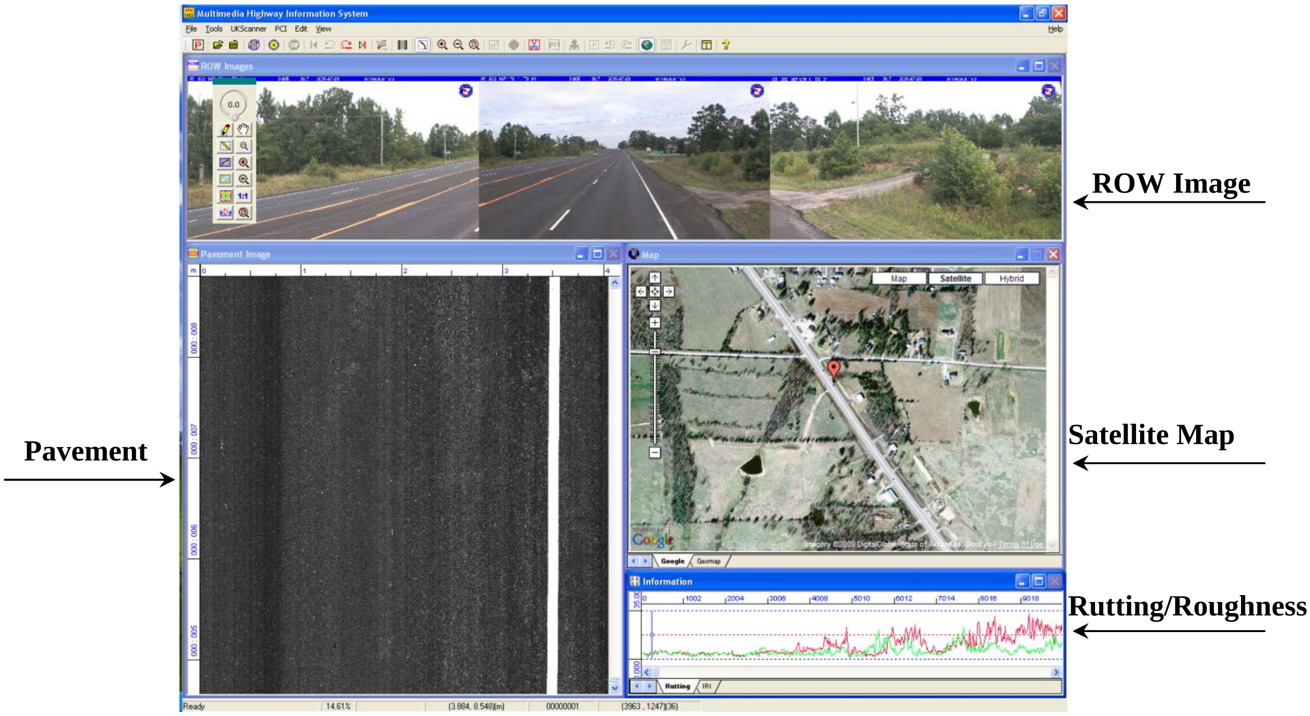


FIGURE 2 Customized MHIS Deluxe for AHTD.

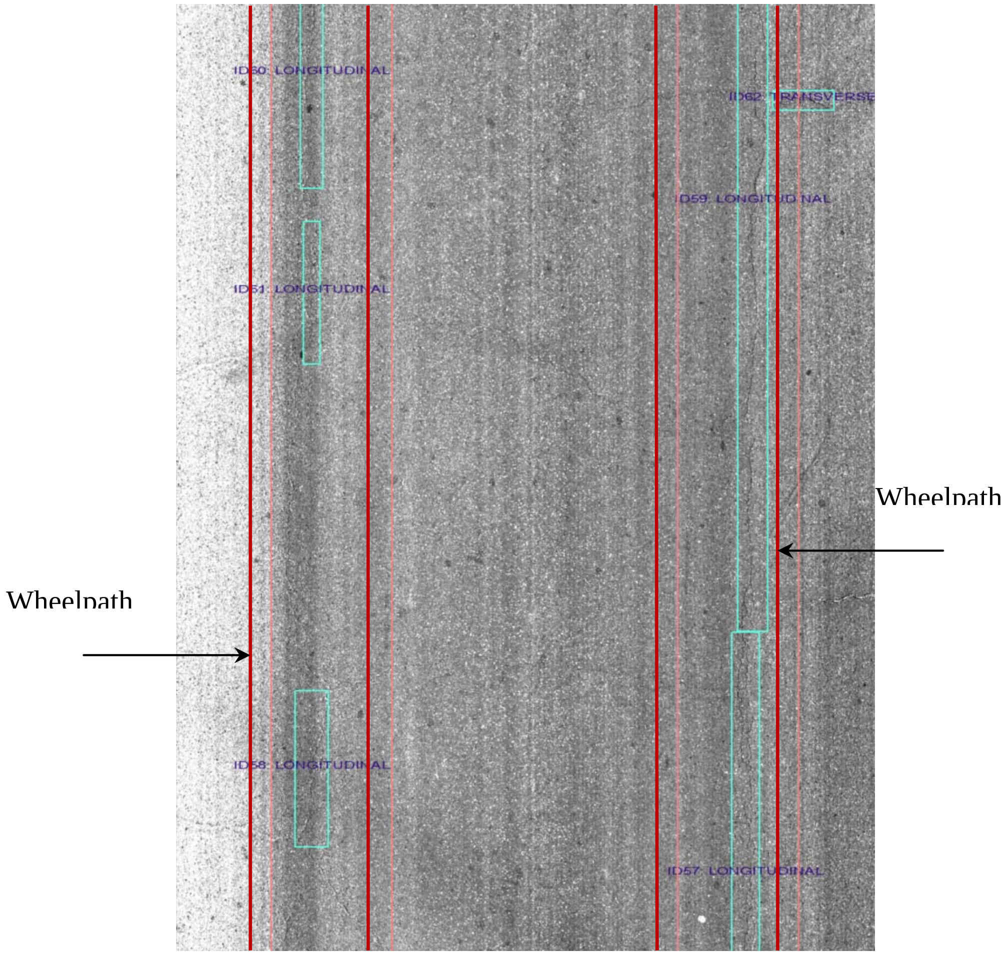


FIGURE 3   Pavement image with wheelpaths.

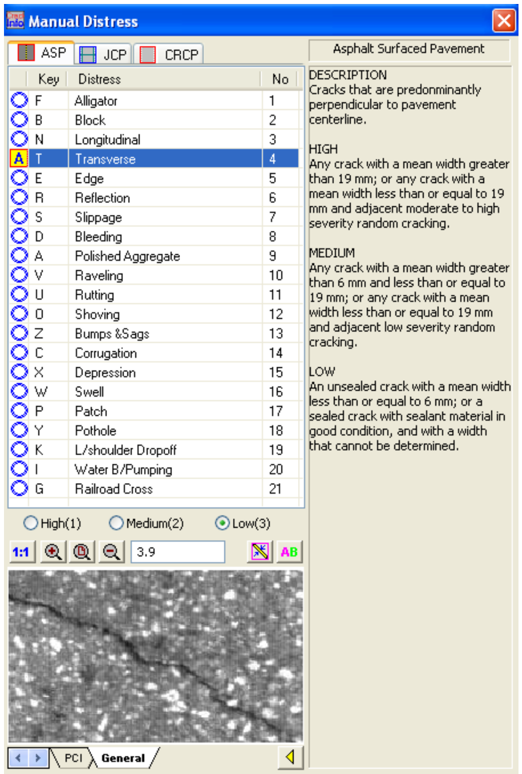
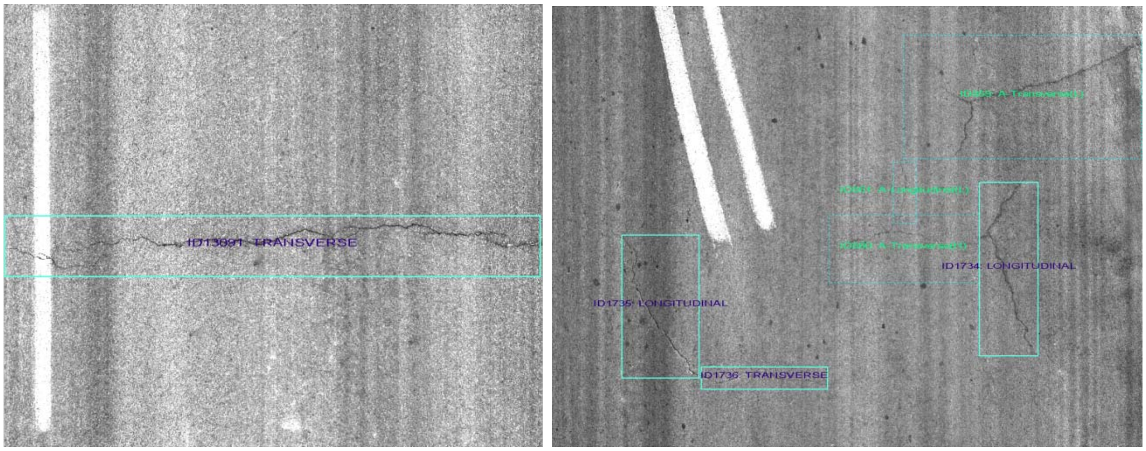
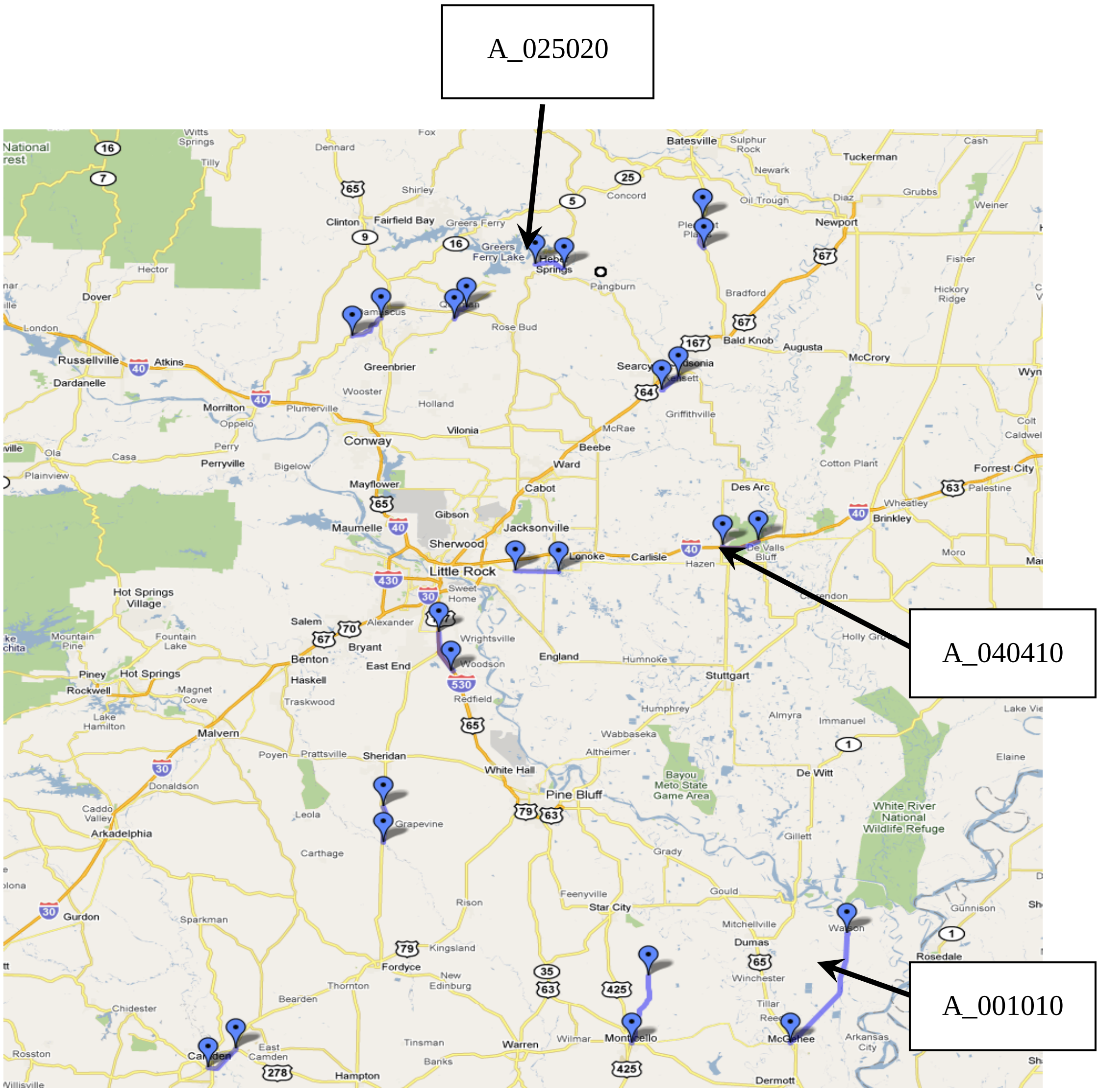


FIGURE 4 Manual distress survey screen shot in MHIS deluxe.



(a) **(b)**

FIGURE 5 ADA Results (*a*) in solid lines and (*b*) manual results in dotted lines.



(A_001010)

(A_025020)

(A_040410)

FIGURE 6 Three AHTD pavement sections.

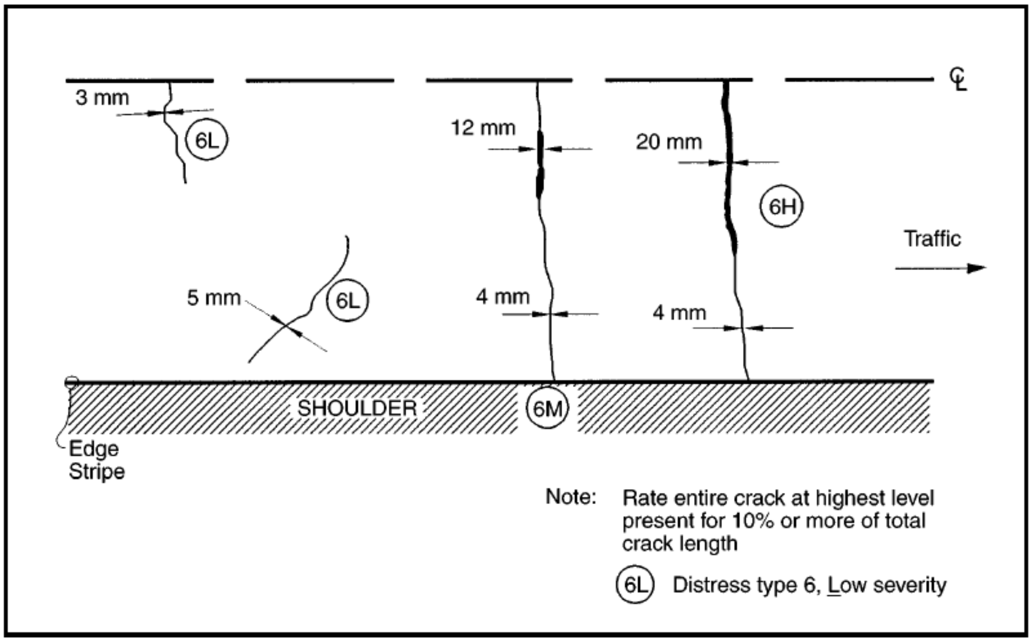


FIGURE 7 Transverse cracking (6).

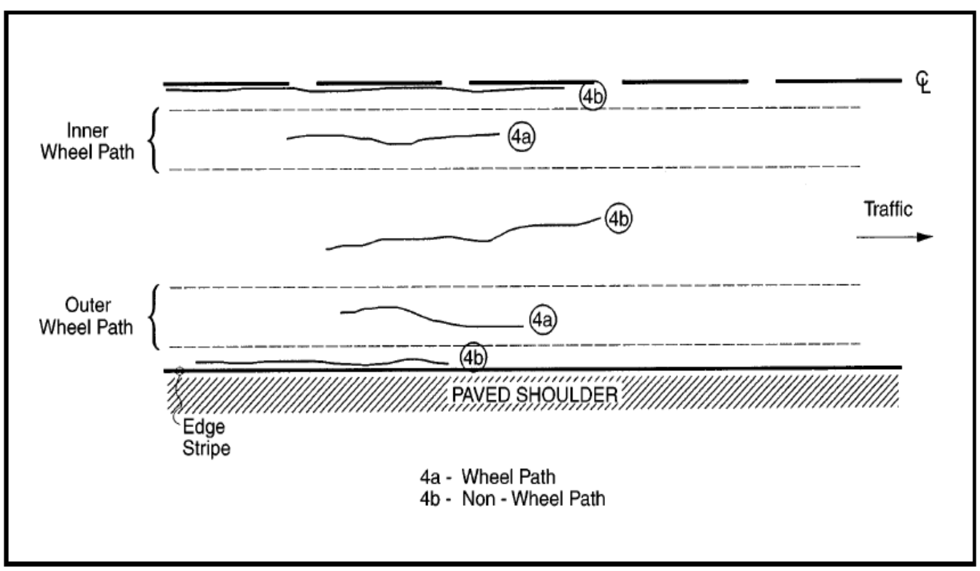


FIGURE 8 Longitudinal cracking (6).

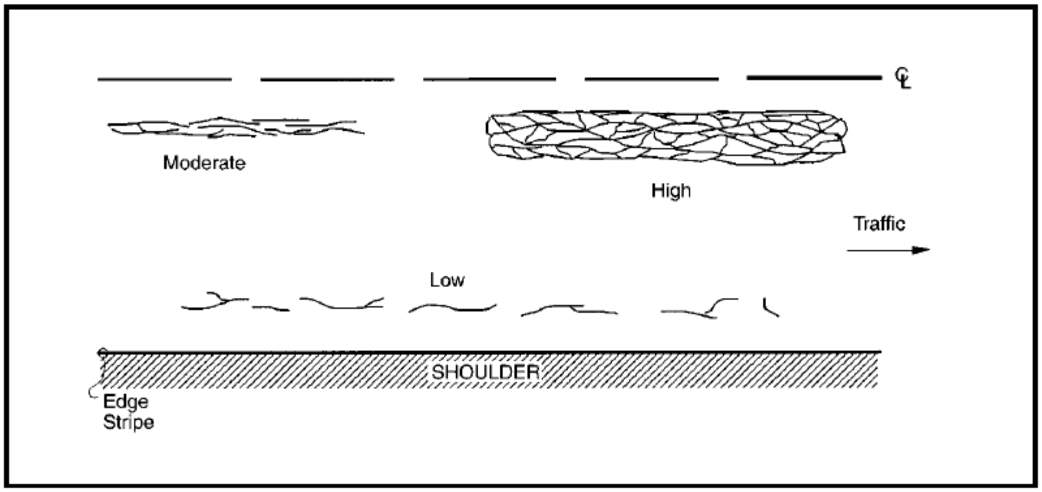
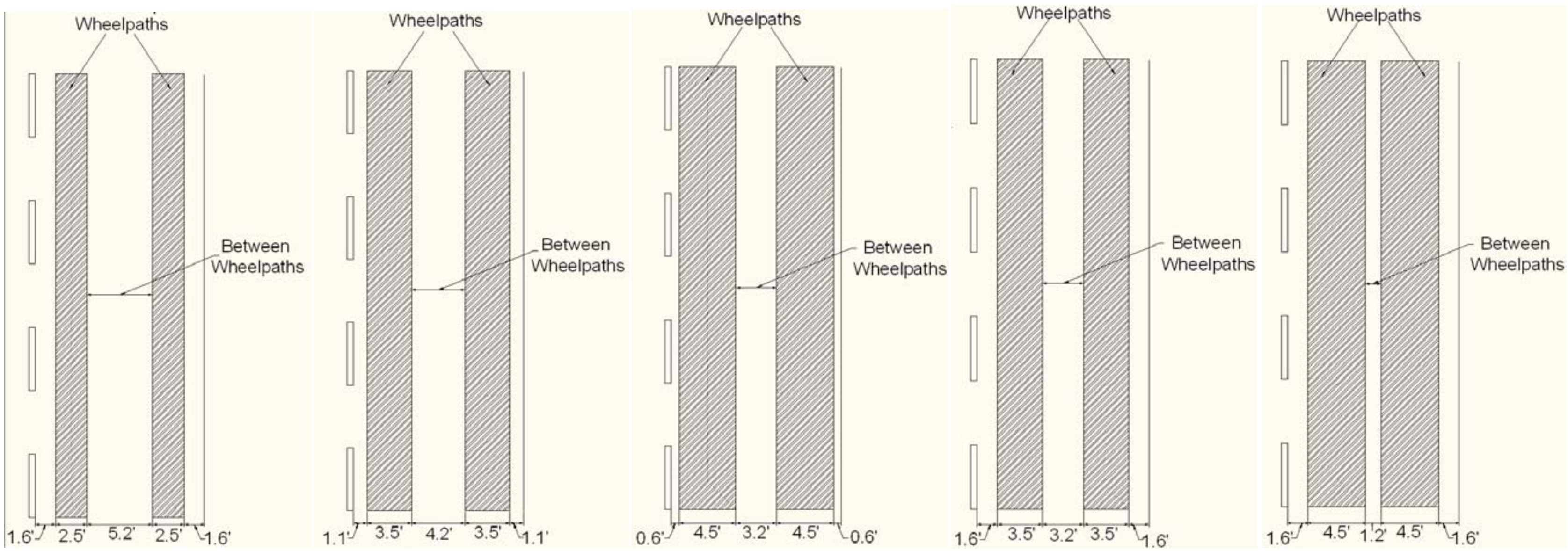


FIGURE 9 Fatigue cracking (6)



(a) **(b)** **(c)** **(d)** **(e)**

FIGURE 10 Five Wheelpath Variations (2.5 ft (*a*), 3.5 ft (*b*), 4.5 ft (*c*), 3.5 ft inward (*d*), and 4.5 ft inward (*e*)

TABLE 1 HPMS Cracking Length (ft/mi) Consistency of the Three Raters

	Raters	Test Results, x		$\bar{x}$
		1	2	
A_025020	1	41.8	32.5	37.2
	2	134.5	131.6	133.0
	3	57.9	57.9	57.9
A_001010	1	77.5	58.9	68.2
	2	29.4	25.9	27.7
	3	50.7	63.3	57.0
A_040410	1	112.6	158.9	135.7
	2	87.5	87.5	87.5
	3	17.1	17.1	17.1

TABLE 2 Cracking Percent (%) Consistency of the Three Raters

	Raters	Test Results, x		$\bar{x}$
		1	2	
A_025020	1	8.4	5.5	7.0
	2	20.9	19.8	20.4
	3	8.9	9.0	9.0
A_001010	1	1.9	1.7	1.8
	2	1.4	1.1	19.8
	3	2.0	3.3	2.7
A_040410	1	0.6	1.1	0.8
	2	0.8	0.7	0.7
	3	0.3	0.3	0.3

TABLE 3 Automated to Semi-Automated Comparison for Cracking Percent and HPMS Cracking Length without Considering Wheelpath

	Segments	Raters	Value	$\overline{x}$	ADA	ADA Difference
Cracking Percent (%)	**A_025020**	1	5	13	9	**-4**
		2	23			
		3	12			
	A_001010	1	2	3	10	**8**
		2	2			
		3	4			
	A_040410	1	0	0	3	**3**
		2	0			
		3	0			
Cracking Length (ft/mi)	**A_025020**	1	188	189	196	**7**
		2	215			
		3	164			
	A_001010	1	291	275	219	**-56**
		2	256			
		3	279			
	A_040410	1	179	102	1156	**1055**
		2	97			
		3	29			

TABLE 4 Automated to Semi-Automated Comparison for MEPDG Longitudinal and Transverse Cracking without Considering Wheelpath

	Segments	Raters	Low Sev.	Med. Sev.	High Sev.	$\bar{x}$ Low	$\bar{x}$ Med.	$\bar{x}$ High	$\bar{x}$ Total	ADA Total	ADA Difference
Long. Crack Length (ft/mi)	**A_025020**	1	580	40	0	485	28	16	529	5862	**5333**
		2	283	2	41						
		3	592	41	6						
	A_001010	1	1239	80	2	1095	81	5	1181	8326	**7145**
		2	989	79	8						
		3	1057	83	5						
	A_040410	1	143	24	3	82	18	22	121	3031	**2910**
		2	81	23	47						
		3	20	7	15						
Trans. Crack Length (ft/mi)	**A_025020**	1	1869	23	0	1381	12	26	1420	1239	**-181**
		2	1110	1	45						
		3	1165	12	34						
	A_001010	1	2624	10	2	1970	17	28	2015	1938	**-77**
		2	1754	16	41						
		3	1532	25	42						
	A_040410	1	397	26	2	167	31	42	240	1652	**1412**
		2	84	45	95						
		3	21	22	27						

TABLE 5 Automated to Semi-Automated Comparison for Cracking Percent Considering Wheelpath

WP Size and Segments		Raters	Cracking %	$\overline{x}$	ADA	ADA Difference	Original ADA Abs. Diff.	Better/Worse?
WP (2.5)	A_025020	1	5	13	3	**-10**	**4**	**10**
		2	23					
		3	12					
	A_001010	1	2	3	3	**0**	**8**	**0**
		2	2					
		3	4					
	A_040410	1	0	0	0	**0**	**3**	**0**
		2	0					
		3	0					
WP (3.5)	A_025020	1	6	14	4	**-10**	**5**	**10**
		2	24					
		3	13					
	A_001010	1	3	4	4	**0**	**6**	**0**
		2	3					
		3	5					
	A_040410	1	0	0	0	**0**	**3**	**0**
		2	0					
		3	0					
WP (4.5)	A_025020	1	7	15	6	**-9**	**6**	**9**
		2	24					
		3	14					
	A_001010	1	4	5	6	**1**	**5**	**1**
		2	5					
		3	7					
	A_040410	1	0	0	1	**1**	**3**	**1**
		2	0					
		3	0					
WP (3.5-Inward)	A_025020	1	6	14	5	**-9**	**5**	**9**
		2	23					
		3	13					
	A_001010	1	3	4	3	**0**	**6**	**0**
		2	3					
		3	5					
	A_040410	1	0	0	0	**0**	**3**	**0**
		2	0					
		3	0					
WP (4.5-Inward)	A_025020	1	7	15	7	**-8**	**6**	**8**
		2	24					
		3	15					
	A_001010	1	5	5	4	**-1**	**5**	**1**
		2	5					
		3	6					
	A_040410	1	0	0	0	**0**	**3**	**0**
		2	0					
		3	0					

TABLE 6 Automated to Semi-Automated Comparison for HPMS Cracking Length Considering Wheelpath

WP Size and Segments		Raters	Length (ft/mi)	$\overline{x}$	ADA	ADA Difference	Original ADA Abs. Diff.	Better/Worse?
WP (2.5)	A_025020	1	188	189	145	-44	7	44
		2	215					
		3	164					
	A_001010	1	291	275	167	-108	56	108
		2	256					
		3	279					
	A_040410	1	179	102	479	377	1055	377
		2	97					
		3	29					
WP (3.5)	A_025020	1	204	206	164	-42	10	42
		2	234					
		3	180					
	A_001010	1	314	298	188	-110	79	110
		2	278					
		3	300					
	A_040410	1	189	108	644	536	1048	536
		2	102					
		3	34					
WP (4.5)	A_025020	1	222	220	178	-42	24	42
		2	246					
		3	192					
	A_001010	1	324	307	197	-111	89	111
		2	288					
		3	310					
	A_040410	1	201	113	869	756	1043	756
		2	103					
		3	35					
WP (3.5-Inward)	A_025020	1	188	189	145	-44	7	44
		2	215					
		3	164					
	A_001010	1	291	275	167	-108	56	108
		2	256					
		3	279					
	A_040410	1	179	102	479	377	1055	377
		2	97					
		3	29					
WP (4.5-Inward)	A_025020	1	188	189	145	-44	7	44
		2	215					
		3	164					
	A_001010	1	291	275	167	-108	56	108
		2	256					
		3	279					
	A_040410	1	179	102	479	377	1055	377
		2	97					
		3	29					

Table 7 Automated to Semi-Automated Comparison for MEPDG Longitudinal Cracking Considering Wheelpath

WP Size	Segments	Raters	Low Sev.	Med. Sev.	High Sev.	$\bar{x}$ Low	$\bar{x}$ Med.	$\bar{x}$ High	$\bar{x}$ Total	ADA Total	ADA Difference	Original ADA Abs. Diff.	Better/Worse?
WP (2.5)	A_025020	1	580	40	0	485	28	16	529	1688	**1160**	**5333**	1160
		2	283	2	41								
		3	592	41	6								
	A_001010	1	1239	80	2	1095	81	5	1181	1846	**665**	**7145**	665
		2	989	79	8								
		3	1057	83	5								
	A_040410	1	143	24	3	82	18	22	121	680	**559**	**2910**	559
		2	81	23	47								
		3	20	7	15								
WP (3.5)	A_025020	1	343	13	0	262	13	16	290	1193	**903**	**5572**	903
		2	209	1	41								
		3	233	25	6								
	A_001010	1	789	41	0	658	43	3	704	1459	**755**	**7622**	755
		2	554	42	7								
		3	631	46	3								
	A_040410	1	143	17	3	82	13	22	116	672	**555**	**2915**	555
		2	81	16	47								
		3	20	6	15								
WP (4.5)	A_025020	1	176	5	0	151	7	16	174	788	**614**	**5688**	614
		2	190	1	41								
		3	88	15	6								
	A_001010	1	534	24	0	432	26	3	461	1155	**693**	**7864**	693
		2	343	25	7								
		3	421	28	3								
	A_040410	1	143	10	2	82	8	21	110	663	**553**	**2921**	553
		2	81	11	46								
		3	20	3	15								
WP (3.5-Inward)	A_025020	1	176	5	0	151	7	16	174	788	**614**	**5688**	614
		2	190	1	41								
		3	88	15	6								
	A_001010	1	534	24	0	432	26	3	461	1155	**693**	**7864**	693
		2	343	25	7								
		3	421	28	3								
	A_040410	1	143	10	2	82	8	21	110	663	**553**	**2921**	553
		2	81	11	46								
		3	20	3	15								
WP (4.5-Inward)	A_025020	1	118	2	0	116	1	16	132	506	**374**	**5730**	374
		2	185	0	41								
		3	43	0	6								
	A_001010	1	287	2	0	206	3	3	212	671	**459**	**8114**	459
		2	132	3	7								
		3	198	4	3								
	A_040410	1	142	4	0	80	4	19	103	652	**550**	**2929**	550
		2	80	6	44								
		3	19	2	13								

Table 8 Automated to Semi-Automated Comparison for MEPDG Transverse Cracking Considering Wheelpath

WP Size and Segments		Raters	Low Sev.	Med. Sev.	High Sev.	$\bar{x}$ Low	$\bar{x}$ Med.	$\bar{x}$ High	$\bar{x}$ Total	ADA Total	ADA Difference	Original ADA Abs. Diff.	Better/Worse?
WP (2.5)	A_025020	1	1869	23	0	1381	12	26	1420	1131	**-289**	**181**	**289**
		2	1110	1	45								
		3	1165	12	34								
	A_001010	1	2624	10	2	1970	17	28	2015	1327	**-689**	**77**	**689**
		2	1754	16	41								
		3	1532	25	42								
	A_040410	1	397	26	2	167	31	42	240	626	**386**	**1412**	**386**
		2	84	45	95								
		3	21	22	27								
WP (3.5)	A_025020	1	1979	24	0	1452	15	26	1493	1191	**-302**	**254**	**302**
		2	1161	5	45								
		3	1215	16	34								
	A_001010	1	2748	14	2	2095	21	29	2145	1472	**-672**	**206**	**672**
		2	1880	19	41								
		3	1658	29	43								
	A_040410	1	406	36	3	172	38	42	253	1033	**780**	**1400**	**780**
		2	85	48	96								
		3	26	30	28								
WP (4.5)	A_025020	1	2067	24	0	1499	15	26	1540	1226	**-314**	**301**	**314**
		2	1188	5	45								
		3	1242	16	34								
	A_001010	1	2818	17	2	2174	25	29	2228	1600	**-628**	**290**	**628**
		2	1953	22	41								
		3	1750	37	43								
	A_040410	1	423	57	4	179	52	44	275	1665	**1390**	**1378**	**1390**
		2	87	57	97								
		3	28	40	30								
WP (3.5-Inward)	A_025020	1	1869	23	0	1381	12	26	1420	1131	**-289**	**181**	**289**
		2	1110	1	45								
		3	1165	12	34								
	A_001010	1	2624	10	2	1970	17	28	2015	1327	**-689**	**77**	**689**
		2	1754	16	41								
		3	1532	25	42								
	A_040410	1	397	26	2	167	31	42	240	626	**386**	**1412**	**386**
		2	84	45	95								
		3	21	22	27								
WP (4.5-Inward)	A_025020	1	1869	23	0	1381	12	26	1420	1131	**-289**	**181**	**289**
		2	1110	1	45								
		3	1165	12	34								
	A_001010	1	2624	10	2	1970	17	28	2015	1327	**-689**	**77**	**689**
		2	1754	16	41								
		3	1532	25	42								
	A_040410	1	397	26	2	167	31	42	240	626	**386**	**1412**	**386**
		2	84	45	95								
		3	21	22	27								

Table 9 Sensitivity of Wheelpath Alignments on ADA values for Cracking Percent and HPMS Cracking Length

	Segments	Wheelpath Alignment				
		2.5 ft	3.5 ft.	4.5 ft.	3.5 ft. Inward	4.5 ft. Inward
Cracking Percent (%)	A_025020	3	4	6	5	7
	A_001010	3	4	6	3	4
	A_040410	0	0	1	0	0
Cracking Length (ft/mi)	A_025020	145	164	178	145	145
	A_001010	167	188	197	167	167
	A_040410	479	644	869	479	479

Table 10 Sensitivity of Wheelpath Alignments on ADA values for MEPDG Longitudinal and Transverse Cracking

	Segments	Wheelpath Alignment				
		2.5 ft	3.5 ft.	4.5 ft.	3.5 ft. Inward	4.5 ft. Inward
Long. Crack Length (ft/mi)	A_025020	1688	1193	788	788	506
	A_001010	1846	1459	1155	1155	671
	A_040410	680	672	663	663	652
Trans. Crack Length (ft/mi)	A_025020	1131	1191	1226	1131	1131
	A_001010	1327	1472	1600	1327	1327
	A_040410	626	1033	1665	626	626