8-2012

Improved Protocols for Automated Wheelpath Crack Detection in Pavements

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Recommended Citation

Byram, Daniel Patrick, "Improved Protocols for Automated Wheelpath Crack Detection in Pavements" (2012). *Theses and Dissertations*. 490.
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IMPROVED PROTOCOLS FOR AUTOMATED WHEELPATH CRACK DETECTION IN PAVEMENTS

IMPROVED PROTOCOLS FOR AUTOMATED WHEELPATH CRACK DETECTION IN PAVEMENTS

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering

By

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University of Arkansas
Bachelor of Science in Civil Engineering, 2010

August 2012
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ABSTRACT

Roadway pavement distress evaluations are vital to understanding the mechanics of pavement stability, determining the distribution of rehabilitation costs, and knowing the appropriate rehabilitation strategies. Advancements in technology over the past two decades have changed the way these surveys have been performed by means of automated data collection and interpretation. More and more state agencies have invested in automated road analyzing vehicles that are able to collect high resolution images of the pavement. Fewer have adopted automated data processing software with the ability to interpret road distresses due to the common discrepancies in distress classification algorithms.

In addition to automated data acquisition and interpretation, efforts to implementing automated pavement design software have also progressed in recent years. The Mechanistic-Empirical Pavement Design Guide (MEPDG) is a recent pavement design tool that is in the process of replacing the 1993 American Association of State Highway Transportation Officials Guide as the primary design agent. MEPDG incorporates numerous pavement design traits and conditional factors to predict pavement structural performance. This document investigates the methods behind the calibration for automated pavement distress evaluation and design technologies in order to facilitate the transition into the technology-based MEPDG for the state of Arkansas.

This research describes the implementation of a post-processing tool that refines the Automated Distress Analyzer (ADA) software cracking results in order to better replicate a desired outcome. The tool was first developed to help ADA match pavement cracking distress tabulations derived by human interpreters, which was considered to be the ground truth. The

purpose of this research was to determine whether MEPDG distress predictions better match the tool-equipped automated tabulations as opposed to the ADA software on its own and the distress results provided by human surveyors. An ideal match between MEPDG and the ADA software results, depending on their relation to human interpretations, may lead to quicker and less error-prone methods in pavement evaluation and calibration in order to help Arkansas keep up with the MEPDG system. The results showed that MEPDG predictions match automated interpretations after the implementation of the post-processing tool better than human interpretations.

This thesis is approved for recommendation
to the Graduate Council.

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ACKNOWLEDGEMENTS

I would like to start by thanking the University of Arkansas civil engineering department. Their assistance throughout my graduate career greatly facilitated my work, especially during the completion of this thesis. I would also like to thank my committee: Dr. Kevin D. Hall, Dr. Kelvin C. P. Wang, and Dr. Andrew Braham as well as the workers at Waylink Systems Co. I would like to acknowledge the Arkansas Highway and Transportation Department which supplied me with much of the required data for this research.

A special thanks goes to Danny X. Xiao whose arduous efforts in data collection and research guidance was critical throughout my graduate career. Without his efforts, this thesis would not have been possible. A special thanks also goes to my mother Susan Byram whose continued support helped me to pursue my degree.

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CHAPTER 1

LITERATURE REVIEW

MEPDG and the AASHTO 1993 Guide

The Mechanistic-Empirical Pavement Design Guide (MEPDG) is a design tool that incorporates many aspects and factors into the pavement design procedure. There is existing MEPDG software that predicts the performance (amount of distress) that will be expected for a pavement structure based on the input values for climate, traffic, and layer structure. This research used the MEPDG software available online (Version 1.1) to obtain MEPDG distress predictions for analysis purposes.

Up until this past decade, pavement designers typically followed the guidelines set by the 1993 AASHTO Guide for roadway pavement design. The design equations used in this guide are primarily empirical. Empirical equations are derived from the results of field tests or common observations. In this case, the formulas in the 1993 AASHTO Guide are based on the pavement characteristics witnessed during the AASHO Road Test, which was performed from 1958 to 1961 (1). The test consisted of six separate loops that were subjected to different levels of traffic loads. The guide's empirical equations emphasize the use of various statistical parameters along with the pavement's structural number (SN) to obtain the number of load repetitions required for pavement failure (1).

Given its name, MEPDG considers both mechanistic and empirical approaches to pavement performance prediction and design. Mechanistic equations are based on the mechanistic properties, such as stress and strain, of the materials of interest. By incorporating both mechanistic and empirical principles, MEPDG provides a more realistic approach to pavement design. The projected traffic, climate, and the structural characteristics of the pavement collaborate as the design inputs. Just some of these inputs include traffic growth rates, vehicle class distributions, average monthly rainfall, water table depths, average temperatures (pavement and air), layer thicknesses, aggregate gradations, and void ratios. Given the complexity of the performance prediction models, MEPDG relies heavily on quick, accurate, and efficient data acquisition and storage.

MEPDG Calibration

Calibration, in terms of MEPDG, is the process of iterating distress model coefficients until predicted distress results match a desired outcome. MEPDG has been calibrated on a national level to produce reliable results for roadway distress predictions. However, calibration on a regional or statewide level has been an ongoing effort in order to legitimize MEPDG predictions on a local basis.

Many states have implemented local calibration efforts for MEPDG. A study in Texas suggested that not only were the nationally calibrated coefficients insufficient for design in Texas, but the state itself could not conform to a single set of coefficients. Instead, the study indicated that Texas could be divided into multiple regions of varying calibration coefficients (2). Although generally a straightforward process, calibration can be very time-consuming. The reason for this not only comes from the mathematical iteration, but also the fact that the data required is not easily accessible.

There are three data levels for MEPDG: Level 1, Level 2, and Level 3. Level 1 data refers to data with the highest level of accuracy and therefore the lowest level of uncertainty (3). Level 2 and 3 data are data with an intermediate and low level of accuracy respectively. Level 3 data would consist of national averages or default values (3). Several calibration efforts used Level 2 inputs, which are standard input values specific to a region or state. These values can be for anything including truck classification distributions and material properties. A lack of available data prevents calibration efforts with the use of site-specific Level 1 inputs in many cases. It is recommended that future calibration efforts should conform to Level 1 inputs and more robust sample sizes whenever possible to reduce error between predicted and monitored results (4).

Even if site specific data is available, the data can come from two separate sources: the state’s pavement management system (PMS) or the Long Term Pavement Performance (LTPP) program. A study in Arizona discovered that significant differences for monitored results exist between PMS and LTPP due to the different equipment and methods used for collecting data. This can make the calibration process an even more costly and difficult process (5).

One study concluded that conventional calibration methods alone, meaning the altering of model coefficients, are not suitable for all cases. For instance, the Minnesota DOT stated that the nationally calibrated rutting model is insufficient for design in the region and that MEPDG rutting predictions should be post-processed in a secondary equation (6).

It is clear that local calibration of MEPDG is necessary for accurate distress predictions. However, many obstacles like the lack in data availability and the variation in data acquisition and interpretation methodology exist. It is prudent that more uniform and efficient methods leading to calibration should be produced.

Pavement Distress Surveys

Accurate pavement distress surveys are vital to not only the prioritization of maintenance, but for research purposes as well. By understanding the long-term effects of climate and traffic loads on pavement, engineers can significantly improve methods of design, construction, and rehabilitation. The methods of pavement condition data acquisition have also evolved over the years.

Traditionally, distress surveys were conducted entirely by human surveyors who inspected the sites and documented the distresses by means of illustrating and quantifying them. These types of surveys are called manual surveys. In attempts to improve safety and efficiency, automated data acquisition was introduced. This consists of the implementation of vehicle-mounted cameras that collect images of the road. The images are then transferred to an office environment where trained technicians survey and interpret the distresses.

This method of evaluation is perhaps the most common among state agencies. Although technologies are introduced in this method, this is still considered to be a manual method of pavement evaluation. There are two other types of pavement distress evaluations: automated and semi-automated.

Automated methods of pavement evaluation incorporate the use of distress interpretation software which analyzes the roadway images with the help of built-in algorithms. These algorithms are designed in accordance to a unified system for cracking definition which is also known as a protocol. The automated interpreting software used in this research is the Automated Distress Analyzer (ADA). Semi-automated methods are essentially the same as automated methods except that they contain human interaction. Human raters edit pavement images that have already been analyzed by the built-in algorithms, deleting false positive crack detections and adding crack detections that the software had missed.

Cracking Definitions and Protocols

The cracking definitions associated with MEPDG are based in the Long Term Pavement Performance program (LTPP) distress manual (7). For asphalt concrete surfaces (AC), the major cracking distresses are longitudinal cracking, transverse (thermal) cracking, and fatigue (alligator) cracking. The cracks are documented for three levels of severity (low, medium, high) separately. The severity is based on the average width of the cracks or the connectivity in the case for alligator cracking. Longitudinal cracking, cracking that is mostly parallel to the centerline and measured in feet per mile, is divided into two categories: in the wheelpath and outside of the wheelpath (7). The wheelpath consists of two longitudinal areas designating the boundaries that carry the bulk of the traffic loads.

Alligator (fatigue) cracking is a type of cracking that consists of interconnecting cracks in the wheelpath that resemble alligator skin. Recognizing this kind of pattern is simple for human interpreters, however, coming up with software algorithms to define this sort of thing is no easy task. The use of automated distress interpreting software provides quicker results, however, discrepancies exist. For instance, the Automated Distress Analyzer (ADA) tends to classify alligator cracking as an assortment of longitudinal and transverse cracks.

This shortcoming suggests that automated distress interpreting software typically have issues identifying cracking patterns. This is crucial considering that the LTPP program defines various types of cracking, such as alligator and block cracking, on a scaled pattern basis. This is an obstacle that is easily overcome by human interpreters. Even untrained persons can recognize linear patterns better than the most sophisticated software. For this reason, researchers have proposed next-generation cracking definition protocols for automated analyzing software in order to reduce the need for pattern recognition and ultimately, human intervention. The result would be a uniform standard for rating pavements with respect to crack amount, orientation, and location.

One commonly used protocol is the World Bank’s Universal Cracking Indicator (CI), which takes into consideration the extent, intensity, and width of the crack (8, 9). The extent is the defined area containing cracking, expressed as a percentage of the total pavement segment area. The intensity represents the total length of cracking within the extent area. The crack width is simply the average width for the series of cracks. A separate CI is calculated for longitudinal, transverse, and alligator cracking which is determined by taking the dot product of the three cracking traits (extent x intensity x width). The final CI is determined by taking the sum of the intensity/width products for the three cracking types and dividing by the total pavement segment area (8).

The AASHTO Method distinguishes cracking as either in the wheelpath or nonwheelpath areas which is the same as differentiating between load-associated and nonload-associated cracks. These cracking types consist of longitudinal, transverse, and alligator cracking as was used by the CI protocol. There are three levels of severity for each of the cracking types: Level 1, 2, and 3, which are defined the same way as LTPP. Each severity is tabulated as a total length per unit area (8). The wheelpath boundaries used to distinguish cracking types are defined by LTPP as well. When it comes to LTPP, distinguishing between low severity alligator cracking and longitudinal cracking located in the wheelpath is highly disputable.

Another type of cracking definition protocol is the UK SCANNER. This protocol establishes 200 x 200 mm grids on pavement images. The percentage of cracking is referred to as the UK SCANNER index and is determined by taking the number of grids containing cracks and dividing by the total number of grids on a single image. This is a common protocol for several European countries. The advantage of this protocol is that it does not require a complicated algorithm to determine the total cracking because there is no debate among whether or not a grid contains cracks (10).

Much like the AASHTO Method, the cracking definition protocol designed for this research uses the concept of establishing wheelpath boundaries within the ADA pavement images. This is done with a post-processing Excel spreadsheet that alters the ADA observed distress results to reflect the desired protocol. The distresses defined for this protocol, referred to as the "wheelpath protocol", are longitudinal and alligator cracking. Because MEPDG rarely predicts transverse (thermal) cracking for typical Arkansas conditions, it was not included in this study. Cracks occurring outside the wheelpath boundaries that are primarily parallel to the centerline are longitudinal cracks. Longitudinal cracking occurring inside the wheelpaths is assumed to be alligator cracking. The reason for this is that fatigue cracking almost always occurs in the wheelpath and it is indistinguishable from longitudinal cracking in its early (low severity) stages. There are five different wheelpath sizes/arrangements that were tested (see Figures 10 and 11).

Chapter 2 of this thesis describes the calibration process for MEPDG while chapters 3 and 4 describe the efforts in establishing and implementing the wheelpath protocol. Chapter 4 documents the correlation between distress predictions provided by MEPDG against fully and semi-automated distress interpretation techniques, one of them being ADA results after the application of the wheelpath protocol.

CHAPTER 2

LOCAL CALIBRATION FOR MEPDG

Introduction

The Mechanistic-Empirical Pavement Design Guide (MEPDG) software was designed on a nationally calibrated basis, thus calibrating the existing parameters to suit local conditions is necessary for accurate distress predictions. This chapter discusses the required MEPDG data, the basic procedure of the calibration process, and the challenges facing calibration. The process of calibration involves iterating distress model coefficients until the predicted results match a desired outcome. This desired outcome is typically associated with monitored pavement distress results, documented through manual methods and stored in pavement management systems. Therefore, proper documentation of pavement condition is vital to local calibration. Without accurate distress documentation, there is no sufficient standard with which to calibrate MEPDG.

Required Data

For flexible pavements, MEPDG provides distress predictions for cracking, rutting, and the international roughness index (IRI). The amount of each distress is based on the traffic, climate, and pavement structure specifications. MEPDG predicts the traffic levels based on a specified load spectra in the design inputs. Climatic files can be imported to MEPDG in order to provide pavement performance predictions that are more appropriate for the environmental conditions of the area.

One aspect that distinctly separates MEPDG from the 1993 AASHTO design guide is that MEPDG requires substantially more data for pavement analysis. For traffic, this includes but is not limited to the average annual daily truck traffic (AADTT), lane distribution, truck percentage, traffic growth, wheel size and location specifications, along with numerous adjustment factors for the vehicle class distribution. Temperature, rainfall, relative humidity, wind speed, and groundwater table depth are just some of the climatic factors that are used within the MEPDG analysis. The pavement structure parameters include layer thicknesses, Poisson's ratio, elastic modulus, and gradation specifications.

Local Calibration Process

The general procedure for the calibration process starts with collecting the necessary distress data from monitored sites. The distress data is then evaluated for quality assurance. The data must follow a legitimate trend when comparing the amount of a given distress against time. In other words, there should be a steady increase in distress amount with respect to time, after the consideration of pavement rehabilitation and/or healing. Once the quality of the measured data is approved, a large portion of the sites (ie. 80%) are set aside for initial verification with MEPDG distress predictions while a smaller portion of the sites (ie. 20%) are set aside for secondary validation after the calibration process is complete. Using the nationally calibrated coefficients, the sites containing the monitored data are replicated in design and processed through MEPDG to obtain predicted distress results. These results are then compared with the larger portion (80%) of the monitored sites. If the monitored data reflect the predicted results relatively well, then there is no need for local calibration. If there is no correlation between the two sets of results, then calibration is necessary. However, whether or not calibration is necessary is based first and foremost on the person performing the calibration. Therefore, the terms "relatively well" may vary from person to person.

Calibration is the process of minimizing the error between two data sets. For this research, it is an iterative process that involves the altering of distress model coefficients in order to reduce the difference between monitored and predicted results. Once calibrated coefficients are obtained, the MEPDG analysis is performed again using the new coefficients. The predicted results are then compared to the smaller portion (20%) of the monitored results that have been set aside in order to avoid any bias. If the variances between the monitored and predicted results are still too large, then different recalibration methods should be performed. If the variances are plausible, then the calibration coefficients are acceptable for local design. Figure 1 illustrates the calibration process.

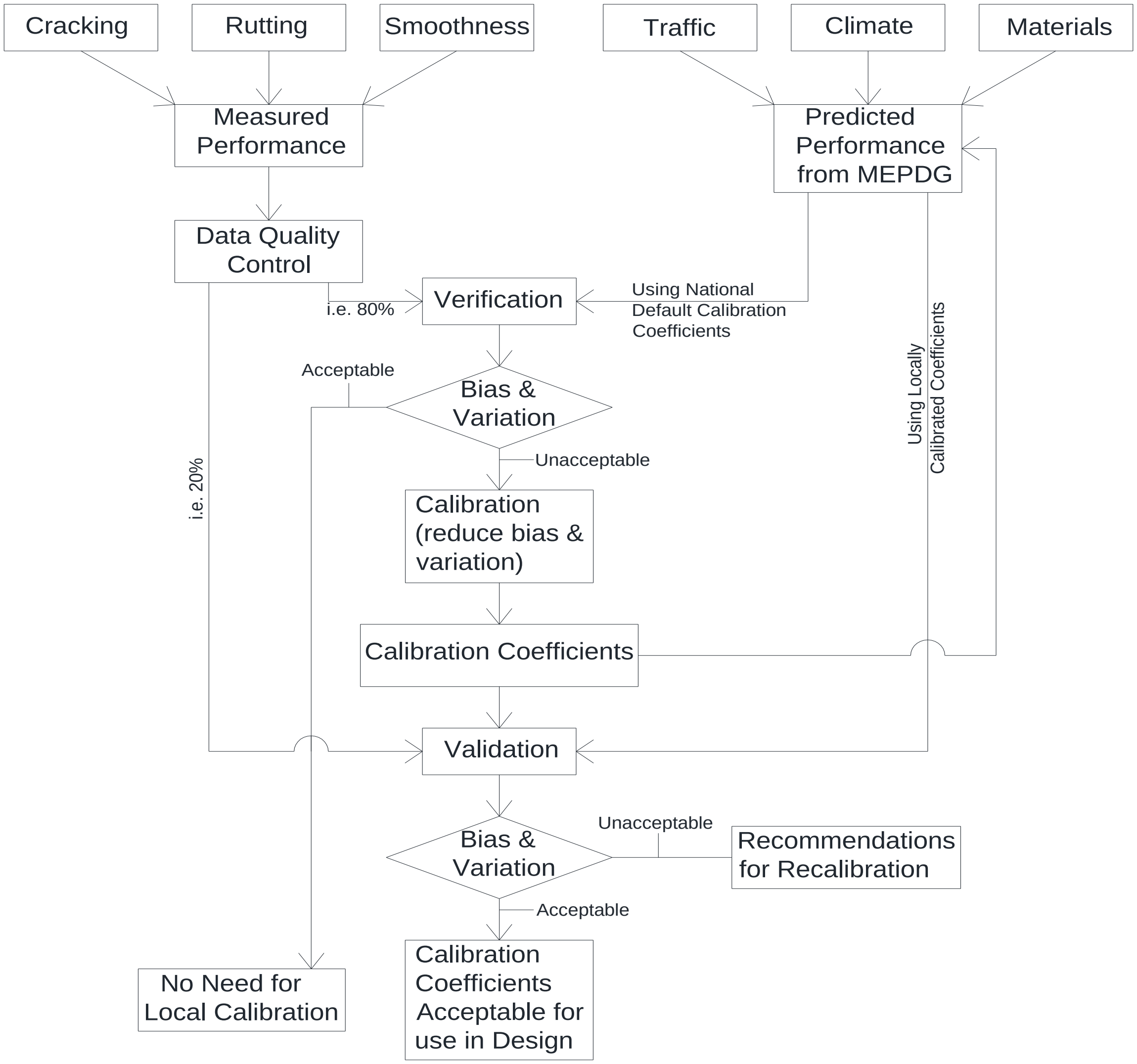


FIGURE 1 Flowchart for basic calibration procedure

Equation 1 is used to predict bottom-up (fatigue) cracking in MEPDG. Equations 2 and 3 represent the calibration coefficients.

$$FC_{bottom}=\left(\frac{6000}{1+e^{\left(C_1*C_1'+C_2*C_2'*\log_{10}(D*100)\right)}}\right)*\frac{1}{60} \qquad (1)$$

$$C_2'=-2.40874-39.748*(1+h_{ac})^{-2.856} \qquad (2)$$

$$C_1'=-2*C_2' \qquad (3)$$

Where,

FCbottom = total amount of fatigue cracking (bottom-up), %

hac = thickness of asphalt layer, in

D = bottom-up fatigue damage

C1 and C2 = calibration factors

Damage is a parameter used to measure the pavement's accumulated response to traffic loading. It is a function of the deflection and the stress and strain behaviors (3). Calibration would consist of trial and error tests where the calibration factors (C_1 and C_2) would be altered until the total amount of fatigue cracking predicted by MEPDG replicated real-world values. Many states have attempted to calibrate MEPDG to suit local conditions. One such study was performed for Arkansas (11). It was found that alligator and longitudinal cracking predictions could be improved through calibration. However, the study concluded that the calibration coefficients should not be used for routine design. Additionally, transverse cracking could not be calibrated due to a lack in sufficient field data (11). These findings shed light on the numerous problems confronting those that perform the calibration procedure.

Challenges in Calibration

There are primarily three problems confronted in the calibration process, the first of which pertain to the accessibility of the monitored data necessary for calibration. MEPDG incorporates a vast quantity of inputs in order to provide pavement distress predictions. The data for these inputs typically come from different sources and can be difficult to find. As a result, there have been efforts in constructing databases that can store all the necessary data in a single source (12). Similarly, the second problem is that there is not a set standard protocol that all state agencies must follow in terms of distress data acquisition and interpretation. Every agency has a different method with which they use to monitor pavement condition. Because of this, certain types of data needed for calibration may not always be a recorded parameter or may need to be derived from whatever data is available. The third problem is the lack of good quality measured data.

The two sources of data (LTPP and PMS) practice many different methods of collecting the necessary MEPDG data. The distresses can be monitored by means of an automated distress monitoring vehicle/equipment or by manual inspection and interpretation. Even if the measured data derived from different sites used the same method of retrieval, there is still a problem with distress interpretation, especially for manual evaluations. For instance, the distinction between low severity alligator cracking and longitudinal cracking is trivial in most cases since the first signs of alligator cracking are typically an assortment of closely spaced longitudinal cracks. Due to distress interpretation, overlays, and environmental effects, the measured data is not always reliable. In other words, the distress amounts do not always show a steady growth with respect to time.

Data quality is not only a challenge for monitored distresses, but also for traffic and climatic parameters. It is difficult to accurately monitor the number of vehicles passing a reference point, classify them, and document the positions of their wheels within the lane at the same time. Because of this, parameters such as these are typically based on national or regional standards. As for climate, a study has shown that poorly monitored climatic data might be the reason for inconsistent MEPDG predictions. When MEPDG prediction results were compared between sites on a national level with dramatic climatic differences, the results were plausible. However, results compared between sites with similar climates showed inconsistencies (13). The concept of data quality control is essential for MEPDG analysis. Only the predicted and monitored results coming from sites with the most well-documented traffic and climatic parameters are suitable for drawing adequate conclusions.

Summary

It is clear that the pavement design process is shifting toward mechanistic and empirical approaches. Calibrating MEPDG to local situations is a vital step if the software is ever to become a sufficient aide in pavement design. The question comes down to whether the monitored, ground truth distress values that the MEDPG against which the distress predictions are calibrated are adequate. In other words, the trivial and sometimes questionable distress interpretations made by human surveyors may not always be suitable for calibration. Calibration is not necessarily a one-time procedure, it is an ongoing process. The following two chapters describe the establishment and implementation of a data post-processing tool that modifies automated distress interpretations to fit a desired outcome. The objective is to supply a more automated method of distress evaluation to obtain values that are more suited to MEPDG, which can greatly facilitate the calibration process.

CHAPTER 3

DEVELOPMENT OF THE WHEELPATH PROTOCOL

Introduction

This aspect of the research portrays a method of refining automated cracking tabulation results in attempt to minimize error between automated and semi-automated techniques. Fully automated cracking analysis involves processing pavement images through the Automated Distress Analyzer (ADA) software and accepting the results as they are. Semi-automated cracking analysis requires a secondary step in which the data tabulated in ADA are uploaded into the Multi-Media Highway Information System (MMHIS) software where human raters work through the individual images and delete false positive crack detections and add crack detections that ADA might have missed.

Semi-automated results are taken to be the ground truth values for the purposes of this research. The Arkansas Highway and Transportation Department provided the research team with roadway images of 15 segments varying in length and condition, 12 of which were processed in ADA and rated by three human raters in MMHIS. The semi-automated results for longitudinal and alligator cracking of these 12 sites were then compared to the fully-automated results. Figure 2 shows the locations of the 12 sites.

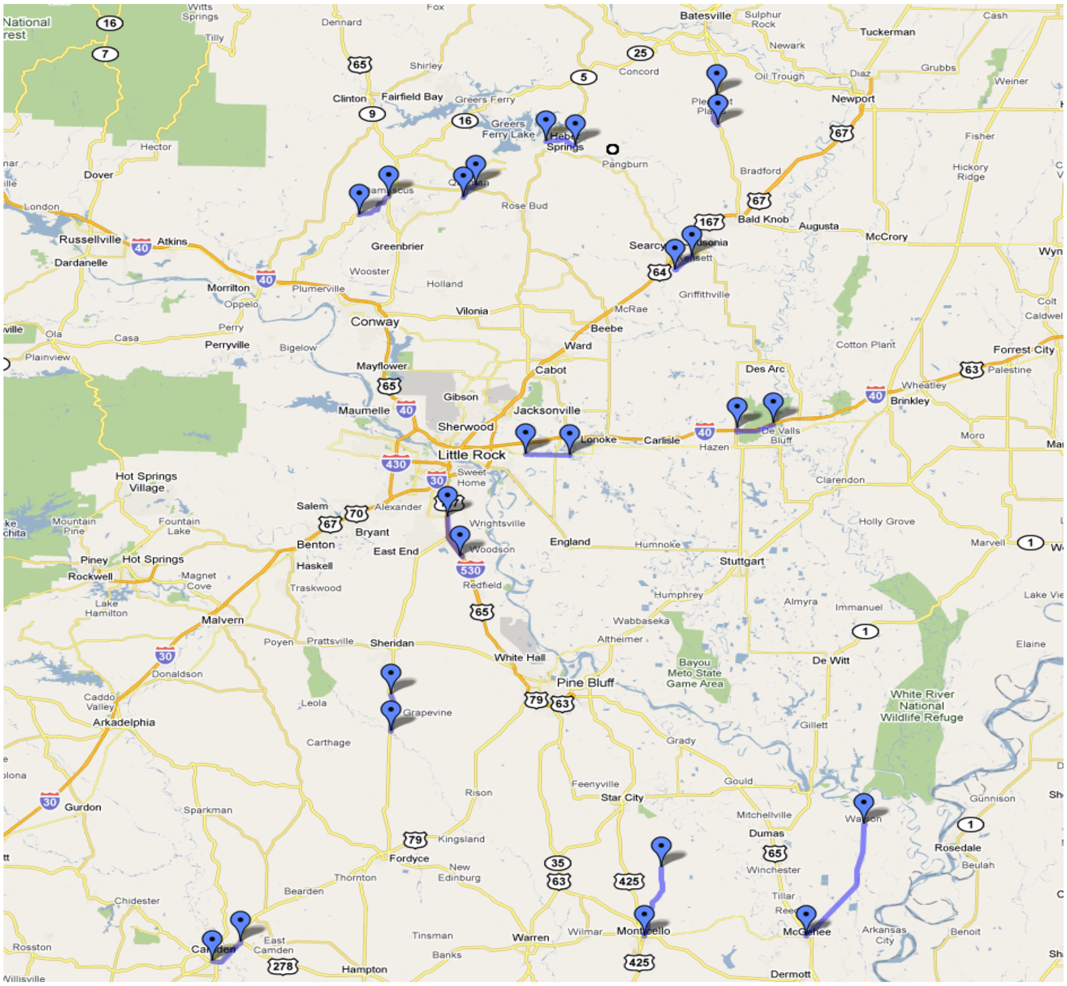


FIGURE 2 Locations of the 12 AHTD road segments (Google Maps)

Due to the ADA software's tendency to overestimate longitudinal cracking and misinterpret alligator cracking, a post-processing Excel spreadsheet was created to refine the automated results. The spreadsheet incorporates the use of wheelpath boundaries (two longitudinal areas carrying the bulk of traffic loads) in order to establish a cracking protocol. This protocol defines alligator cracking as any longitudinal cracking occurring within the wheelpaths. All other longitudinal crack identifications are kept as longitudinal cracks. This is necessary considering that alligator cracking is typically misinterpreted by ADA as an assortment of longitudinal and transverse cracks.

This study considered five different wheelpath sizes or alignments (see Figures 10 and 11), one being similar to the Long Term Pavement Performance program (LTPP) standard size, in order to consider the concept of vehicle wander. The differences between automated and semi-automated results were compared before and after the implementation of the wheelpath boundary protocol for longitudinal cracking. The comparison between the automated and semi-automated alligator cracking tabulations are presented after the implementation of the protocol only, seeing as ADA was incapable of detecting alligator cracking without the protocol.

Data Processing Software

Accurate monitoring of roadway pavement distresses is an essential part to not only understanding pavement performance and where rehabilitations are needed, but also for the implications of better design for future projects. Manual pavement distress evaluations can be exceedingly time consuming and costly. Furthermore, there are issues with obtaining legitimate distress tabulations due to the arbitrary nature of human interpretation (14). It is reasonable to suggest that an issue of safety exists for those performing manual surveys on the highways (14). Recent developments in automated surveying technologies served as a basis for eliminating these recurring problems. Technologies have improved for both data collecting and processing methods. Many states have adopted means of automated data collection however few of them have taken steps in implementing data processing software (15).

ADA and MMHIS are the two data processing software used in this research. The ADA software is capable of processing collected pavement images through an analysis sequence where distresses are located and identified. This information is then summarized in a Microsoft Access file where the distress type, location, and severity are all stored. The sensitivity of the distress detection can be adjusted with the noise control level option. 3D imaging technology is still in the developmental stage; therefore the ADA software is currently used for cracking surveys as opposed to rutting or IRI interpretations.

The MMHIS interactive software is used to carry out manual and semi-automated pavement cracking surveys. This software imports and displays the distress data interpreted by ADA. With MMHIS, human evaluators can scroll through the pavement images and add crack detections that ADA missed or delete false positive detections. The toolbar allows the evaluators to identify the type of distress and indicate its level of severity. Figures 3 through 5 consist of visuals of the software and their capabilities.

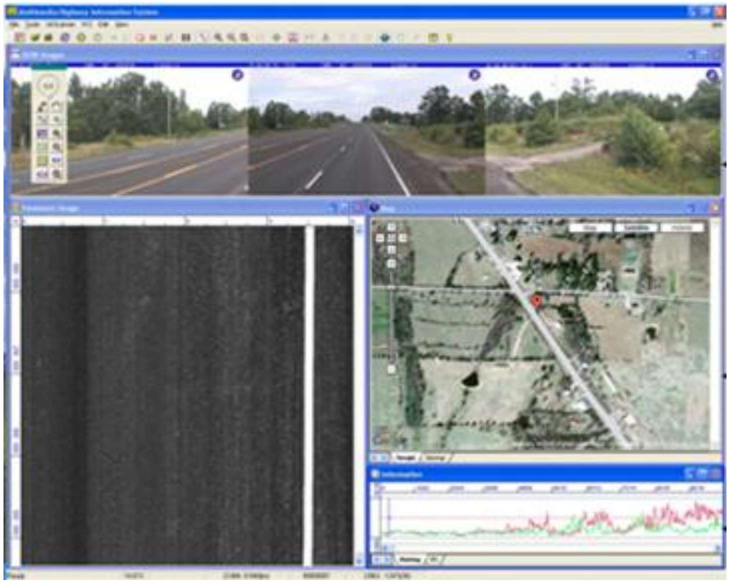
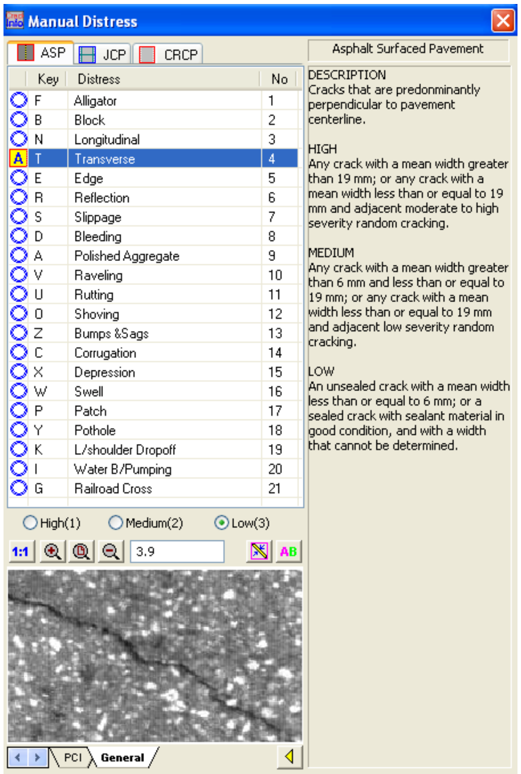


FIGURE 3 Full-screen view of MMHIS



Asphalt Surfaced Pavement

Key	Distress	No
F	Alligator	1
B	Block	2
N	Longitudinal	3
T	Transverse	4
E	Edge	5
R	Reflection	6
S	Slippage	7
D	Bleeding	8
A	Polished Aggregate	9
V	Raveling	10
U	Rutting	11
O	Shoving	12
Z	Bumps &Sags	13
C	Corrugation	14
X	Depression	15
W	Swell	16
P	Patch	17
Y	Pothole	18
K	L/shoulder Dropoff	19
I	Water B/Pumping	20
G	Railroad Cross	21

○ High(1) ○ Medium(2) ● Low(3)

3.9

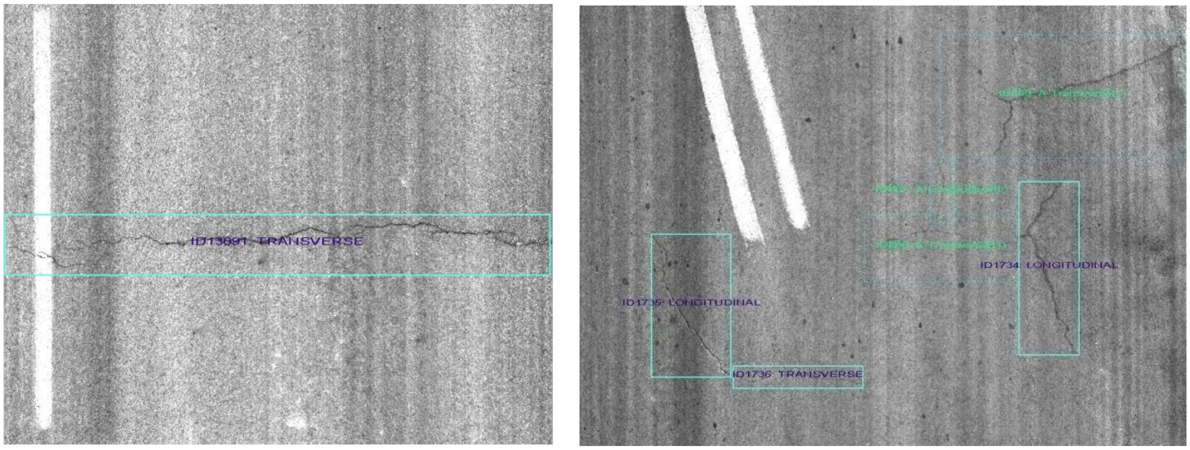
DESCRIPTION
Cracks that are predonminantly perpendicular to pavement centerline.

HIGH
Any crack with a mean width greater than 19 mm; or any crack with a mean width less than or equal to 19 mm and adjacent moderate to high severity random cracking.

MEDIUM
Any crack with a mean width greater than 6 mm and less than or equal to 19 mm; or any crack with a mean width less than or equal to 19 mm and adjacent low severity random cracking.

LOW
An unsealed crack with a mean width less than or equal to 6 mm; or a sealed crack with sealant material in good condition, and with a width that cannot be determined.

FIGURE 4 Manual distress survey screen shot in MMHIS



(a) (b)

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

LTPP Cracking Definitions

The cracking definitions associated with MEPDG are based in the LTPP distress manual. LTPP provides the means of a detailed inventory that not only looks into the quantity of a given distress, but also its level of severity (low, medium, high). The distress quantity for each severity is documented separately (7). To simplify matters, this research combines low, medium, and high severities into a total longitudinal and alligator cracking tabulation.

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, initiates at the surface and propagates downward (top-down). Longitudinal cracking is reported as the average length of cracking per mile (ft/mi) (7). Under the wheelpath protocol established for this research, longitudinal cracking inside the wheelpaths is assumed to be fatigue (alligator) cracking. The reason for this is that fatigue cracking almost always occurs in the wheelpath and is indistinguishable from longitudinal cracking in its early (low severity) stages. This is why ADA typically misinterprets alligator cracking. This is illustrated in Figure 6.

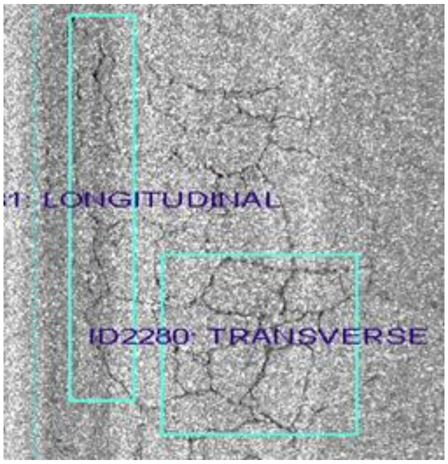


FIGURE 6 ADA falsely classifying alligator cracking

Alligator cracking typically starts out as an assortment of interconnecting longitudinal cracks that eventually develop into a quantified area that resembles alligator skin (7). Because alligator cracking is measured as a percent area, it is determined by taking sum of the areas of the enclosed crack detection boxes and dividing by the total area of the road segment. Figures 7 and 8 illustrate longitudinal and alligator cracking according to LTPP, which is the protocol followed by MEPDG.

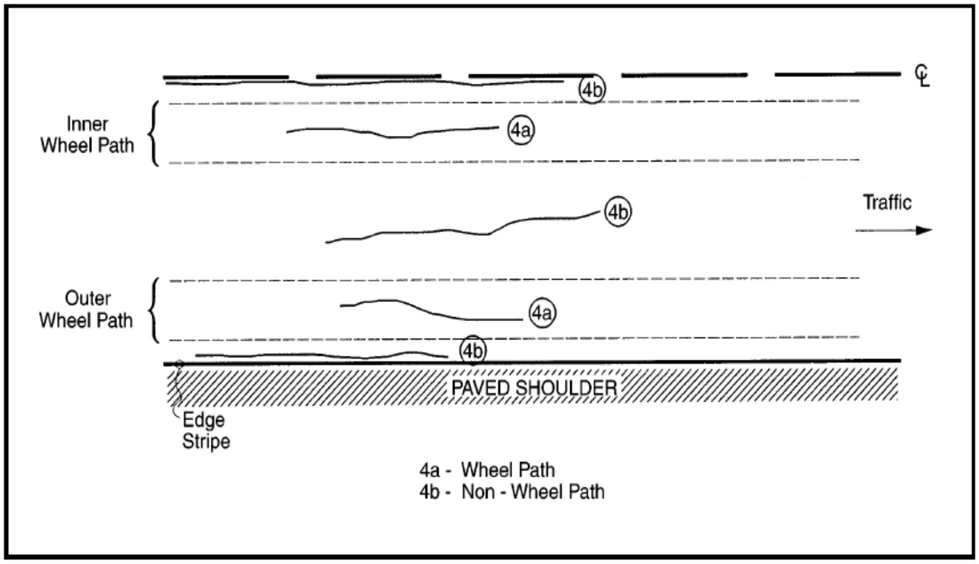


FIGURE 7 LTPP longitudinal cracking

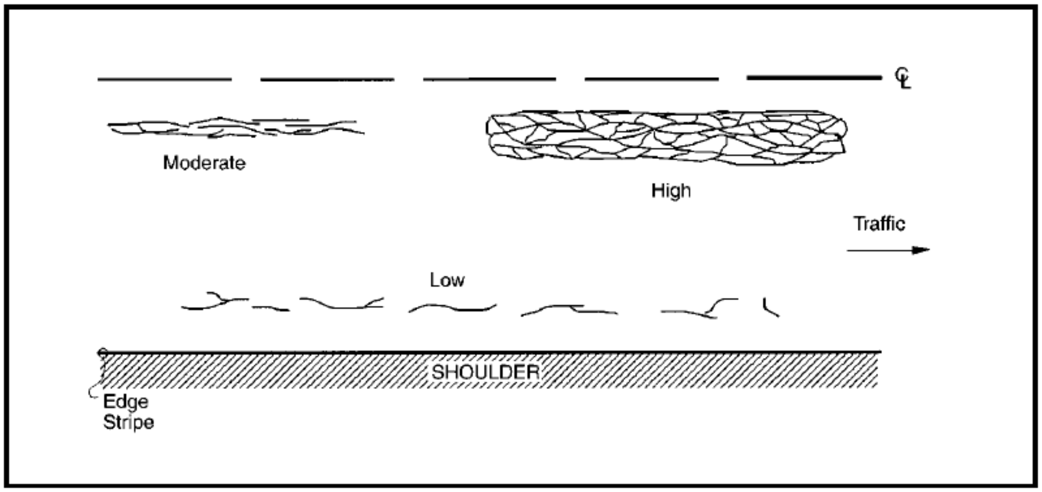


FIGURE 8 LTPP alligator cracking

Rating Preparation and Analysis

The ASTM precision and bias procedure implemented by Wang et al (16) for manual cracking surveys was used to select raters for between-rater consistency and within rater consistency for this project. Tables 1 and 2 show the results of this pilot study, which consist of semi-automated results for the Highway Performance Monitoring System (HPMS) cracking length and cracking percent among three raters for three of the twelve pavement sections. Each rater surveyed the three segments twice. HPMS is simply another protocol for pavement distress classification. Cracking percent is essentially the same as alligator cracking while cracking length is the total length of transverse cracks that are at least six feet in length (17).

TABLE 1 HPMS cracking length (ft/mi) consistency

Segment	Rater	Test Results, x		$\overline{X}$ ⍰
		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 HPMS cracking percent (%) consistency

Segment	Rater	Test Results, x		$\overline{X}$ ⍰
		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

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 (typically 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 is possible that the repeatability, the ability for a single rater to get the same number for any parameter for multiple tests, was 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 may have had the tendency to analyze each segment in accordance to their own judgement, despite demonstrated experience and training. However, because of the lack in available data for this particular test, this theory is not fully validated.

Before Wheelpath Protocol Application

Figure 9 illustrates the data comparison between the automated and semi-automated interpretations without the application of the wheelpath protocol for longitudinal cracking. The diagonal line is the line of equality (y = x). A perfect comparison would require all the data points to fall on this line. Each data point represents the longitudinal cracking amount for a single road segment. The semi-automated tabulations are the average values between the same three human raters used in the precision and bias procedure. Occasionally, a single rater value would be considered an outlier and would not be used in the average value.

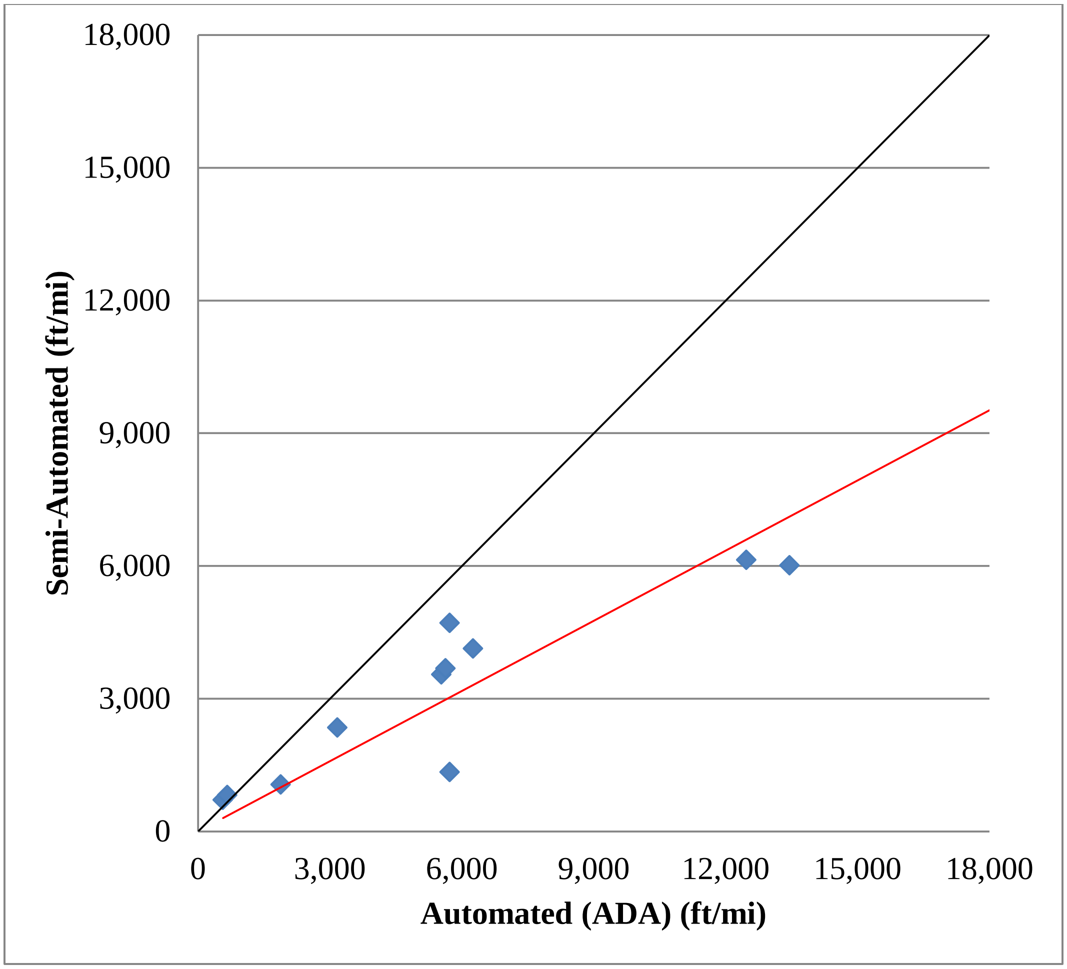


FIGURE 9 Automated to semi-automated comparison for longitudinal cracking without the application of the wheelpath protocol

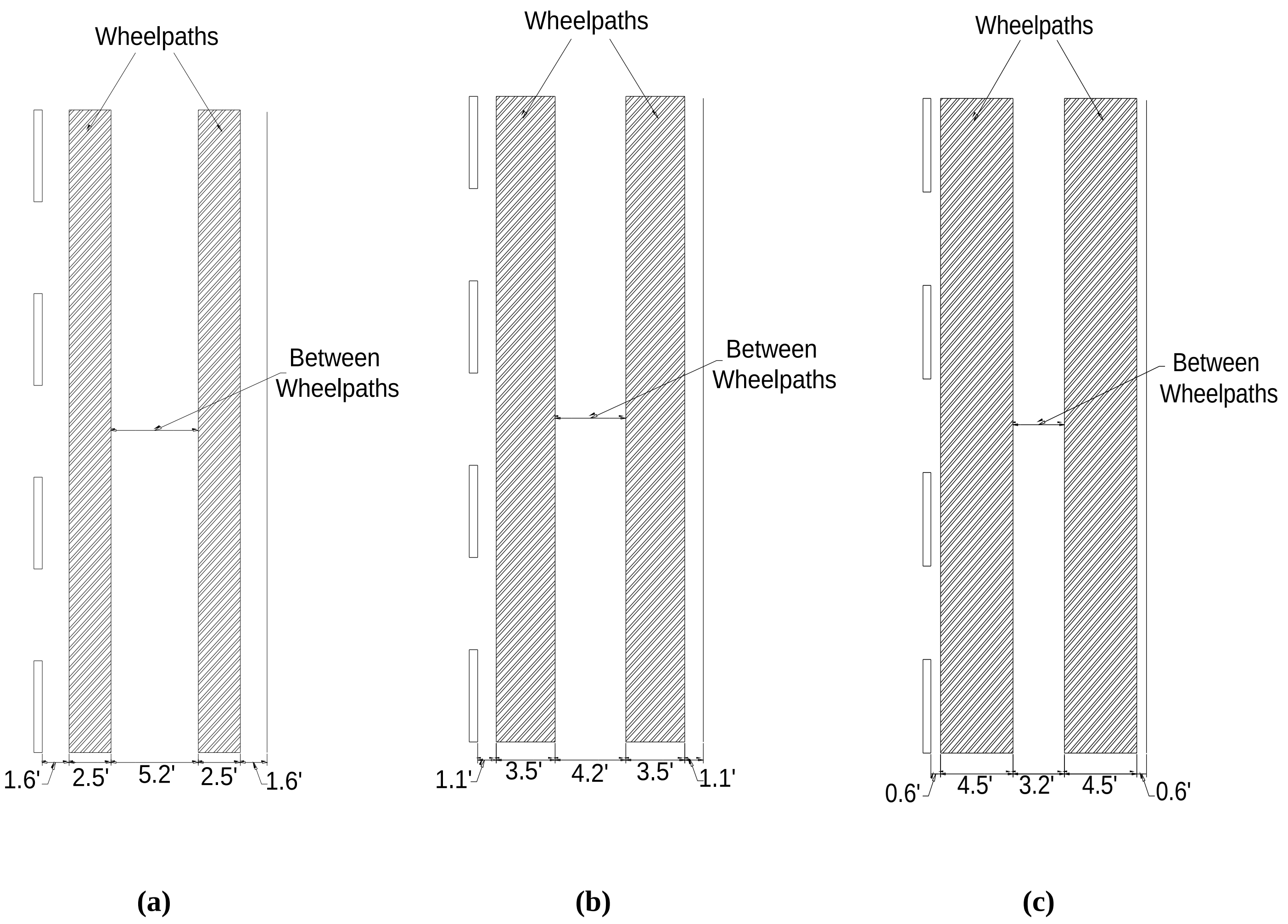
By not defining a wheelpath boundary for the data collection, every crack detection and classification ADA makes is included in the data processing regardless of the crack's location. Clearly, the claim stating that ADA typically overestimates longitudinal cracking is supported since virtually all of the data points fall well to the right of the equality line. This figure implies that ADA would typically obtain a value double the average of the three raters.

These significantly high differences are due to ADA's tendency to detect and include certain pavement noises as cracks (such as tire marks and oil drip stains), 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 reason is that the ADA software's 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 MEPDG requires an inventory of the percentage of cracking, primarily for alligator cracks, in addition to longitudinal and transverse cracking. Because ADA cannot detect alligator cracking without the use of the wheelpath protocols, no documentation for this distress is reported.

After Wheelpath Protocol Application

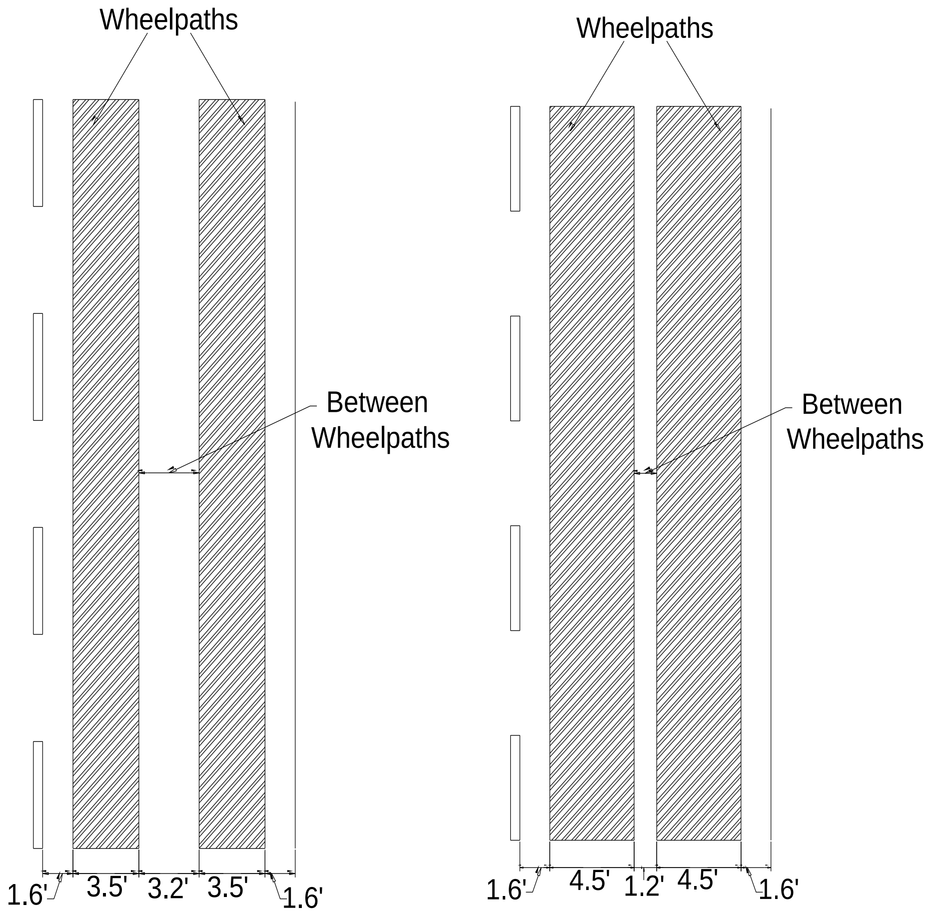
In an effort to improve the effectiveness of the ADA software in detecting alligator cracking and to minimize the error between automated and semi-automated longitudinal cracking length tabulation, a post-processing method was created in Microsoft Excel to include longitudinal cracks within wheelpaths as alligator cracking. In addition, as wheelpath positions would impact cracking statistics, particularly those sensitive to crack positioning, various wheelpath alignments were used for the road segments.

The five different wheelpath widths/alignments that were used for each of the 12 segments were the LTPP standard 2.5 ft size, 3.5 ft, 4.5 ft, 3.5 ft inward, and the 4.5 ft inward alignment shown in Figures 10 and 11. The term "inward" indicates that the outer boundaries of the left and right wheelpaths remain stationary while the inner boundaries are moved inward toward the center of the lane accordingly. Figures 12 through 16 illustrate the comparison between automated and semi-automated results for longitudinal cracking after the application of the wheelpath protocol.



(a) (b) (c)

FIGURE 10 Wheelpath alignments (LTPP standard 2.5 ft (*a*), 3.5 ft (*b*), 4.5 ft (*c*))



(a) **(b)**

FIGURE 11 Wheelpath alignments (3.5 ft inward (a), and 4.5 ft inward (b))

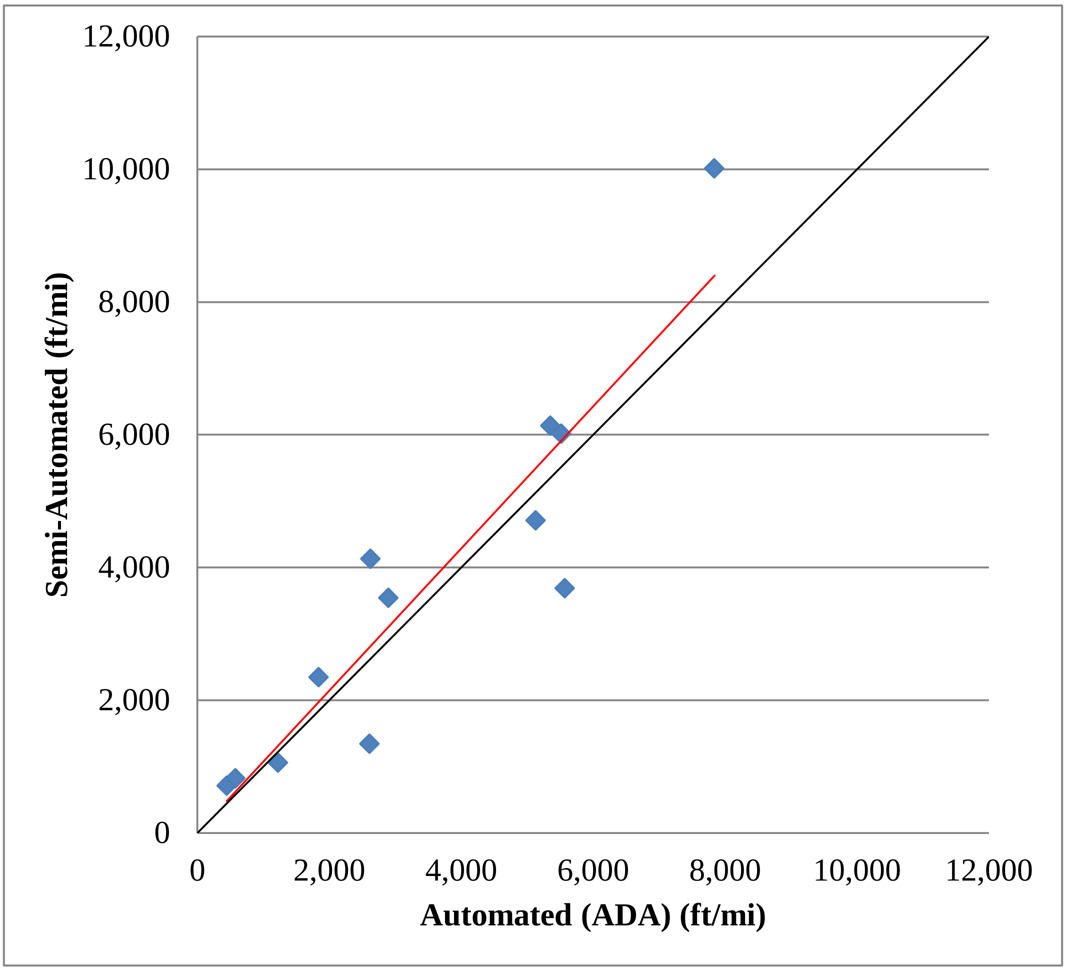


FIGURE 12 Automated to semi-automated comparison for longitudinal cracking using the wheelpath protocol (LTPP standard size-2.5 ft alignment)

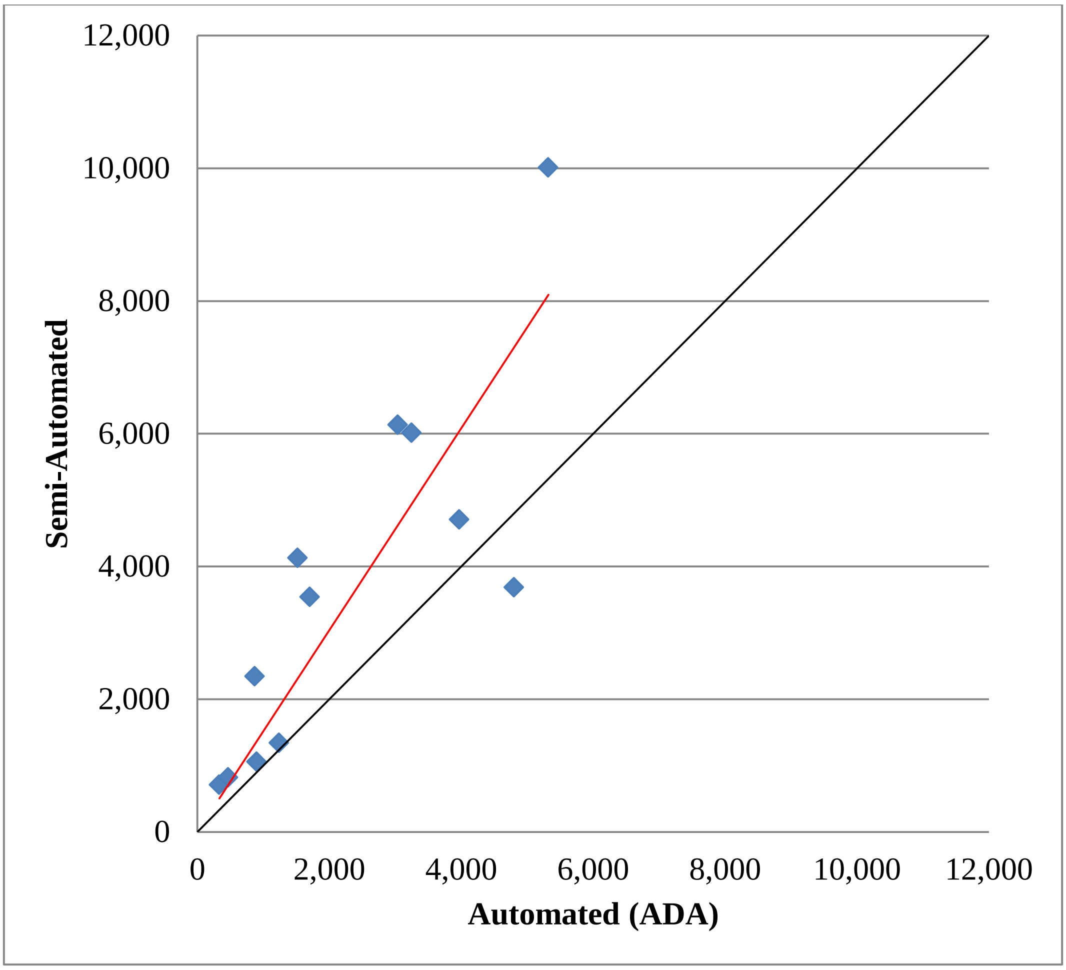


FIGURE 13 Automated to semi-automated comparison for longitudinal cracking using the wheelpath protocol (3.5 ft alignment)

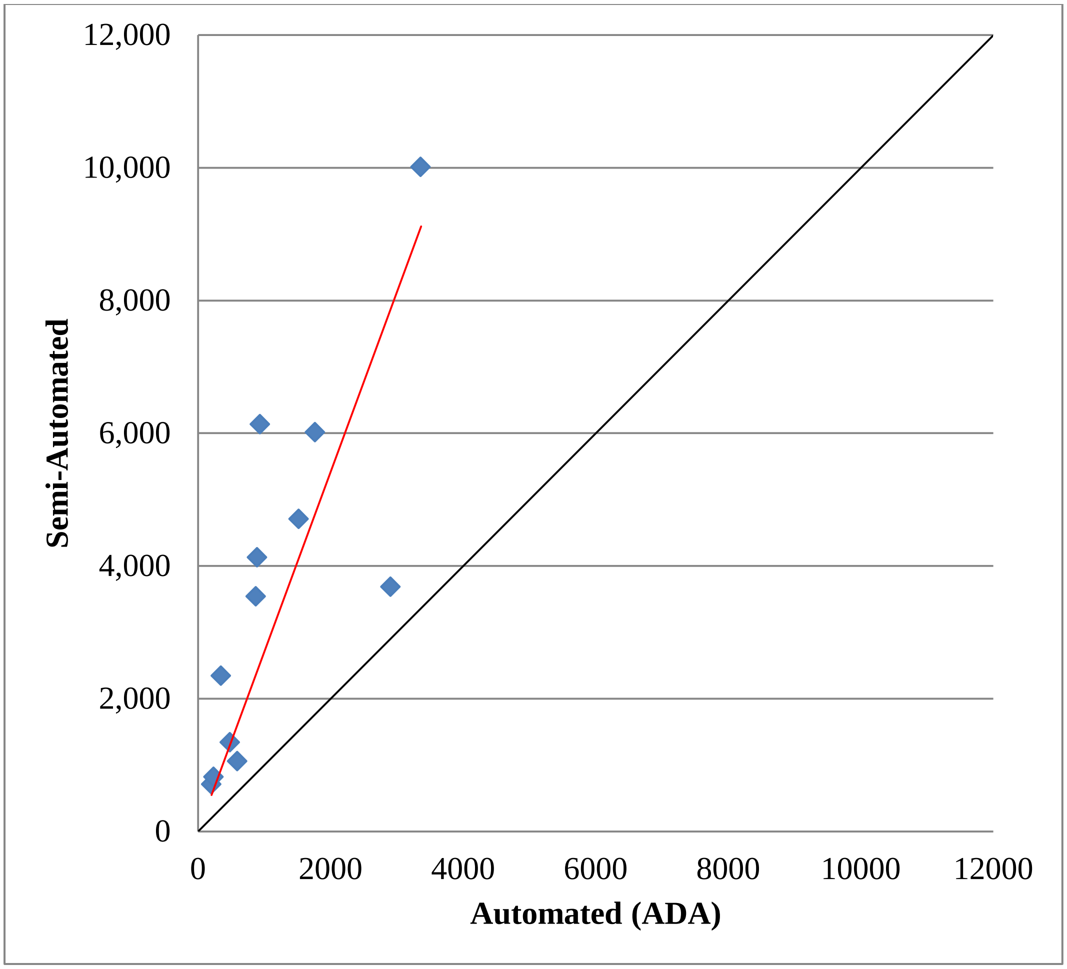


FIGURE 14 Automated to semi-automated comparison for longitudinal cracking using the wheelpath protocol (4.5 ft alignment)

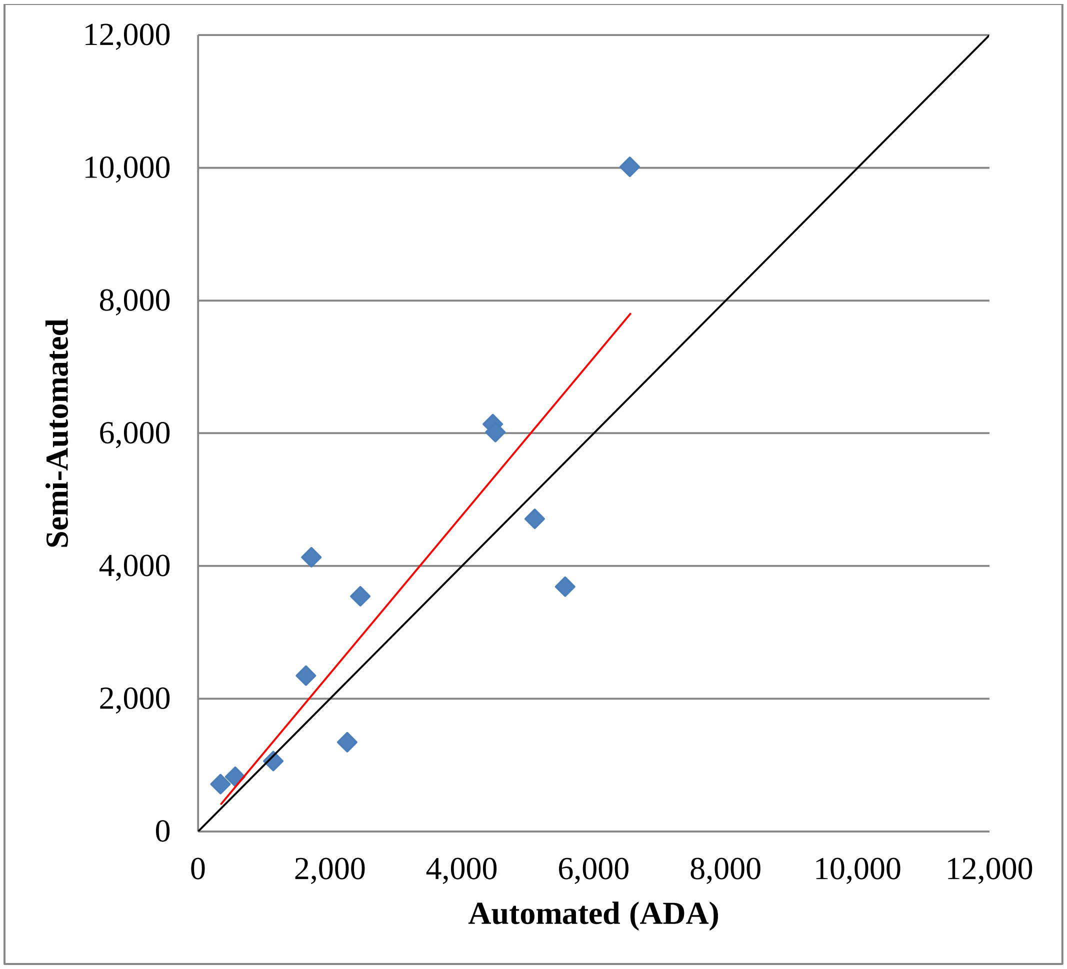


FIGURE 15 Automated to semi-automated comparison for longitudinal cracking using the wheelpath protocol (3.5 ft inward alignment)

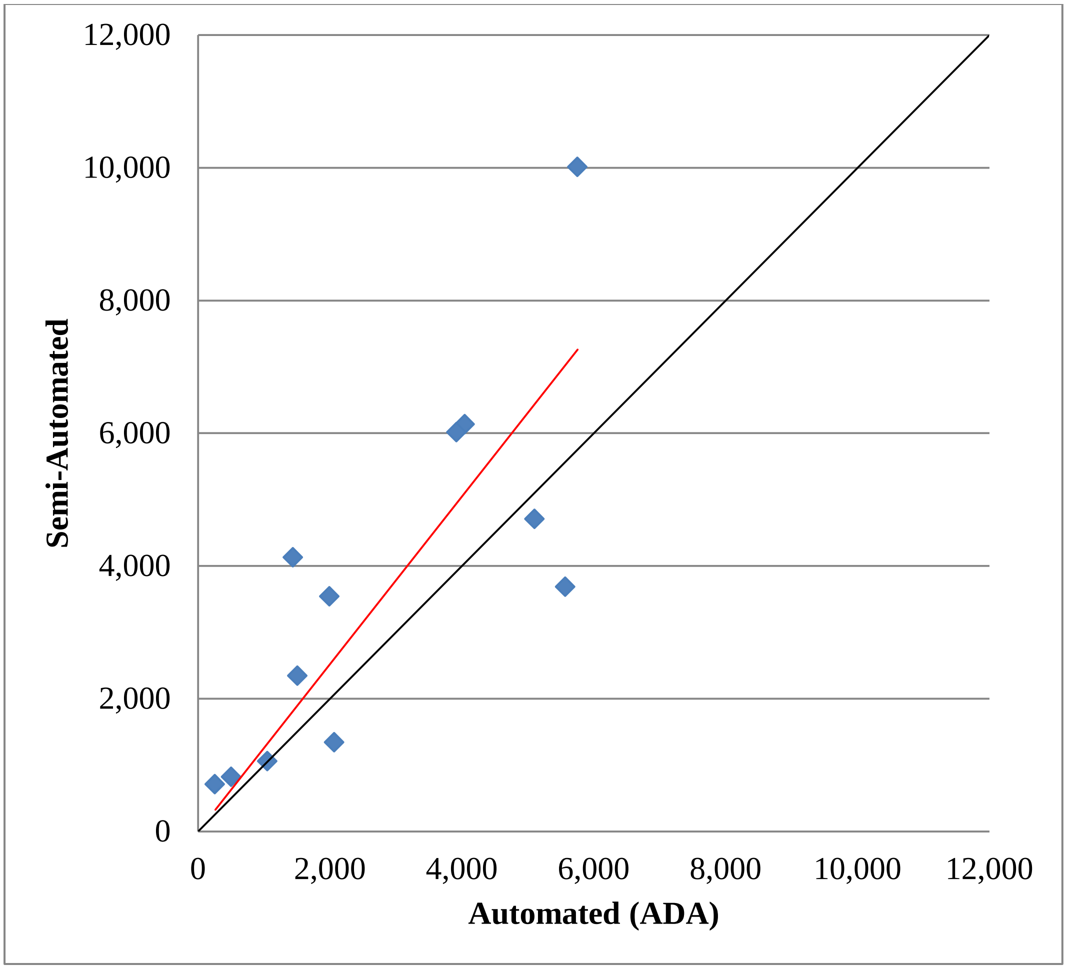


FIGURE 16 Automated to semi-automated comparison for longitudinal cracking using the wheelpath protocol (4.5 ft inward alignment)

The results indicate that the correlation between automated and semi-automated tabulations is improved, particularly for the LTPP standard 2.5 ft wheelpath alignment. It would appear that the 3.5 ft and 4.5 ft alignments had a tendency to reduce the ADA tabulations to a point where there was a constant underestimation in relation to the semi-automated values. The 3.5 ft inward and 4.5 ft inward alignments provide a good correlation. However, it is apparent that the 2.5 ft wheelpath alignment produced the best correlation between automated and semi-automated results for longitudinal cracking. This is derived from the fact that the data points for this alignment trend very closely to the equality line. Figures 17 through 21 show the results for the automated to semi-automated comparison for alligator cracking after the application of the wheelpath protocol.

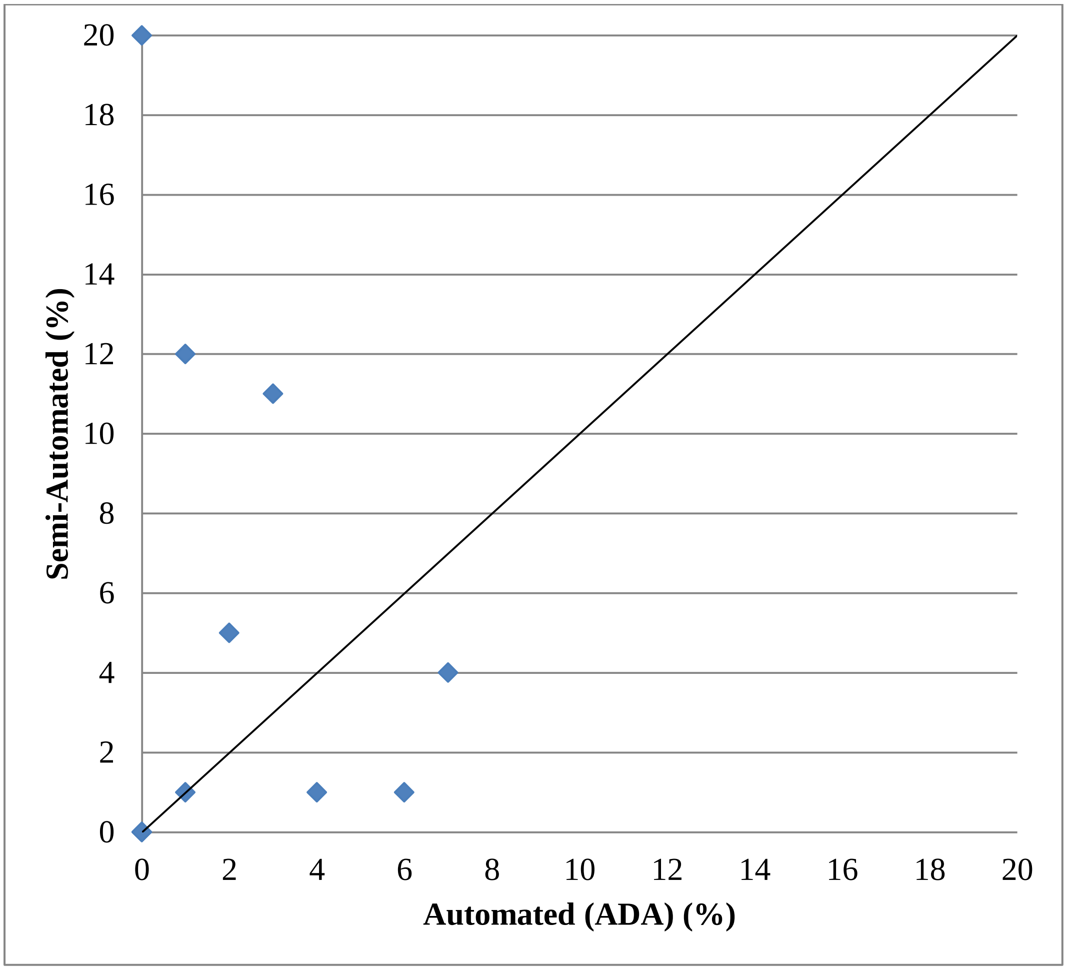


FIGURE 17 Automated to semi-automated comparison for alligator cracking using the wheelpath protocol (LTPP standard size-2.5 ft alignment)

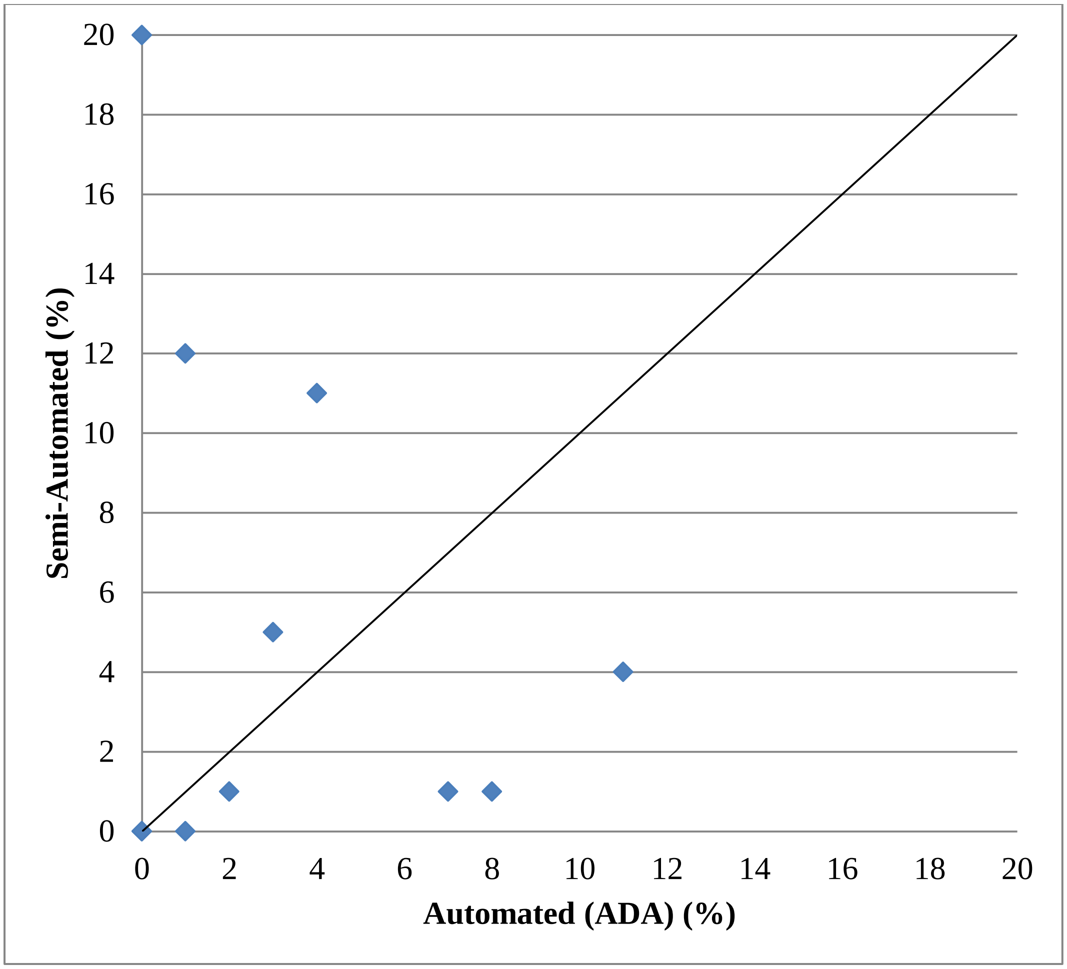


FIGURE 18 Automated to semi-automated comparison for alligator cracking using the wheelpath protocol (3.5 ft alignment)

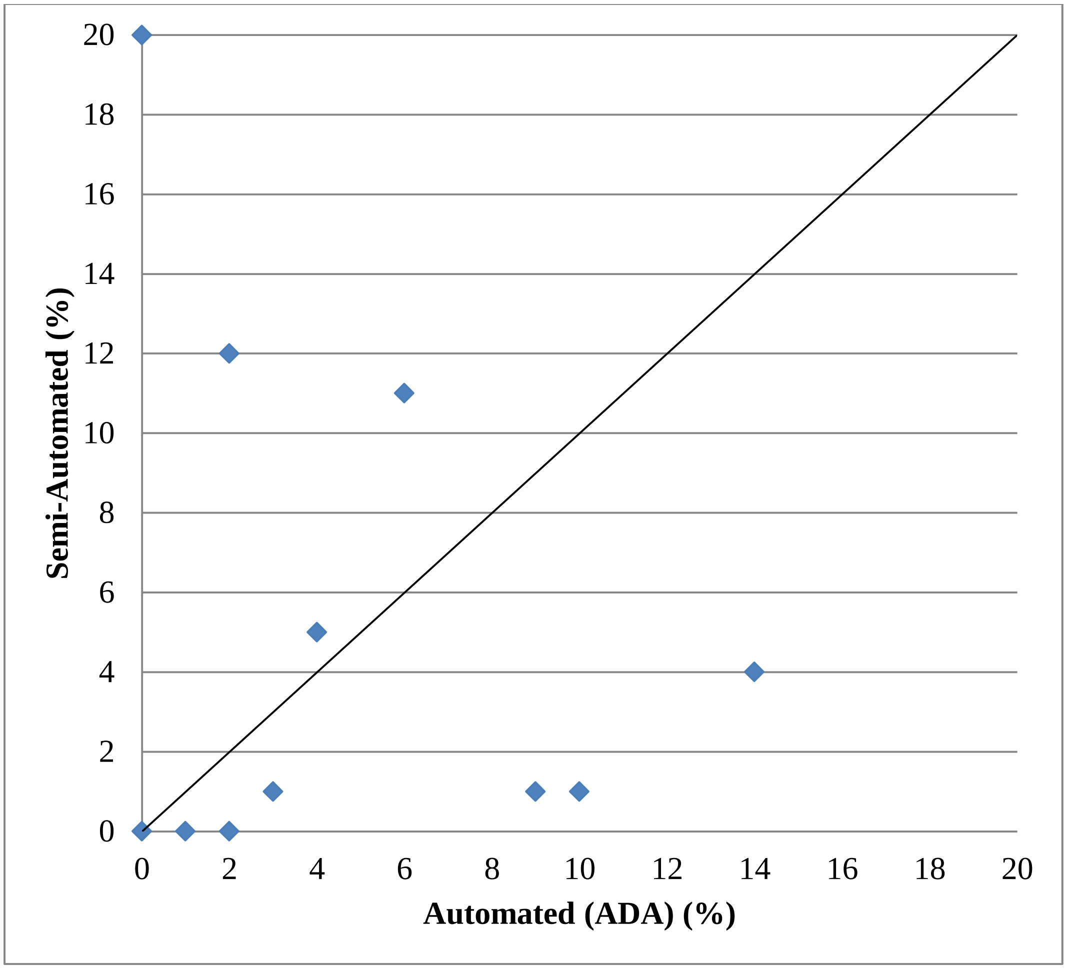


FIGURE 19 Automated to semi-automated comparison for alligator cracking using the wheelpath protocol (4.5 ft alignment)

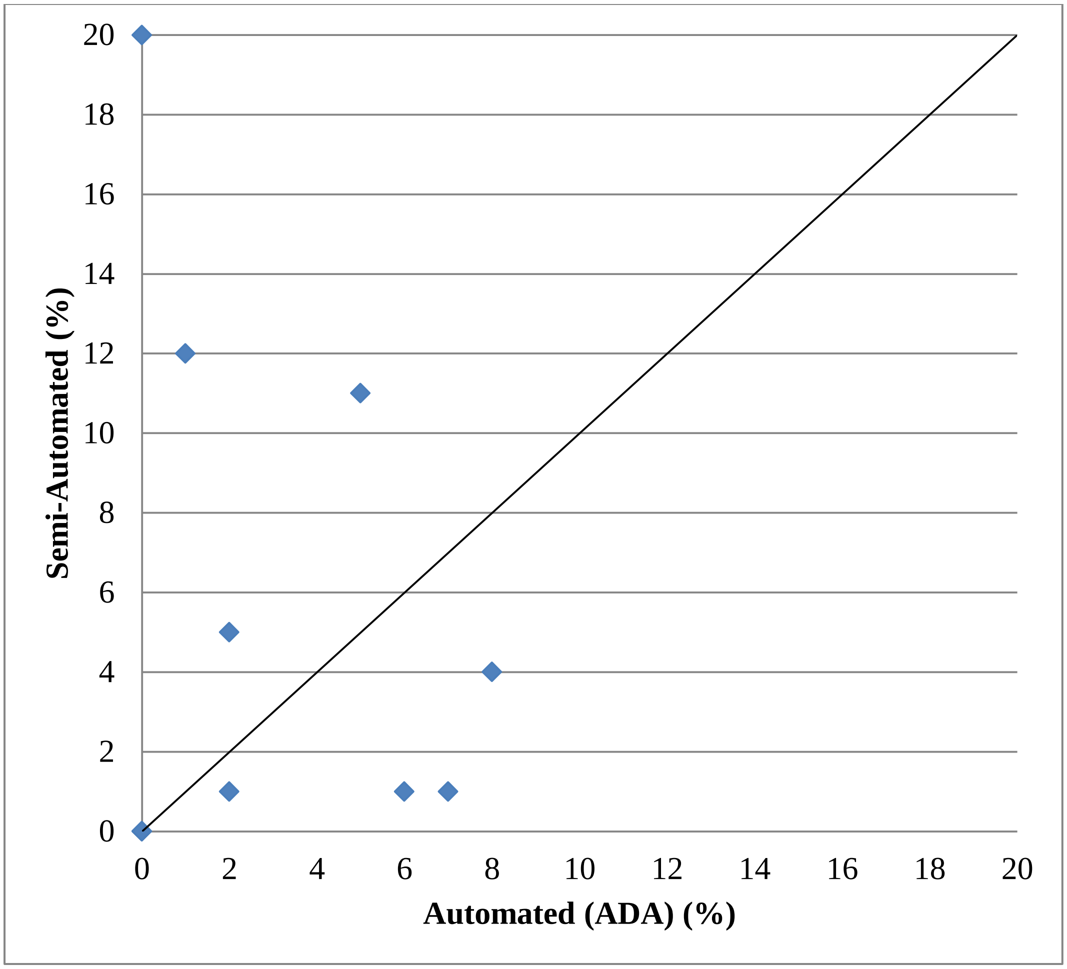


FIGURE 20 Automated to semi-automated comparison for alligator cracking using the wheelpath protocol (3.5 ft inward alignment)

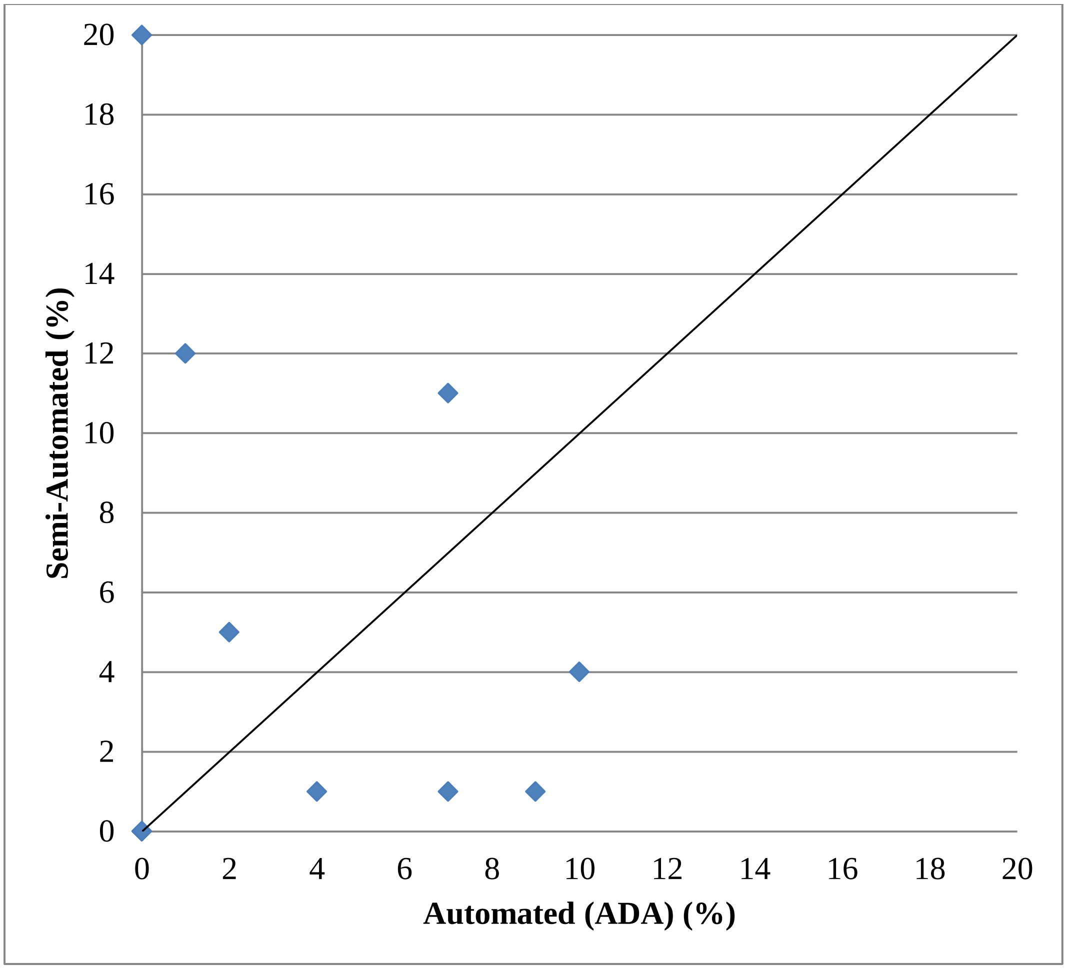


FIGURE 21 Automated to semi-automated comparison for alligator cracking using the wheelpath protocol (4.5 ft inward alignment)

It is clear that none of the wheelpath alignments improved the correlation between automated and semi-automated results to the extent achieved by the longitudinal cracking results. The data points are significantly scattered and there appears to be no visible trend for any of the wheelpath alignments. This is due primarily to the highly trivial and disputable way in which alligator cracking is defined. What one human rater might consider an area of low severity alligator cracking, another rater might see it as a series of longitudinal cracks. This shortcoming led to some very high differences among the human raters. As it was previously mentioned, the human raters were more efficient in replicating their own values as opposed to correlating with other rater values. These issues are in addition to the ADA software itself. Problems with the noise control level, which is the sensitivity of the crack detection, can lead to significant error. A low sensitivity can cause ADA to overlook cracks.

Nevertheless, it should be noted that several of the data points overlap at 0% for the 2.5 ft alignment. This is to say that seven of the twelve segments were either on or within 3% of the line of equality. Additionally, the ADA software failed to detect alligator cracking at all by itself. Therefore, the wheelpath protocol still provides an improvement for the software.

Summary

This chapter introduced a post-processing tool known as the wheelpath protocol in order to calibrate fully automated distress tabulations to match semi-automated (partially manual) interpretations which were taken to be the ground truth. The need for this protocol comes from the fact that ADA typically fails to properly classify alligator cracking which simultaneously overestimates longitudinal cracking. There were five different wheelpath alignments tested to account for vehicle wander. The results indicated that the wheelpath protocol, particularly the LTPP 2.5 ft alignment, can help ADA replicate human interpretations with less variance for longitudinal cracking. The wheelpath protocol does not show a solid correlation between ADA and semi-automated results for alligator cracking due to trivial interpretation; however it was still an improvement from the ADA software’s tendency to overlook the distress.

The following chapter investigates which of the pavement distress evaluation methods the MEPDG software replicates best: fully automated (ADA results), semi-automated (ADA results with human intervention), or automated after the application of the newfound wheelpath protocol (ADA results with post-processing tool). The objective is to determine whether MEPDG distress predictions are better suited in being calibrated to distress tabulations provided by automated methods. A fuller reliance on automated methods can quicken and thus simplify the calibration process.

CHAPTER 4

CORRELATING MEPDG PREDICTIONS WITH RATING METHODS

Introduction

Proper documentation of pavement condition assists with maintenance prioritization as well as the understanding of pavement performance. After the implementation of mechanistic-empirical pavement design, pavement distress data will also be used for model calibration and pavement designing. Therefore, it is necessary to investigate the comparison between automated and semi-automated distress interpretations with distress predictions provided by the Mechanistic-Empirical Pavement Design Guide (MEPDG) developed under NCHRP 1-37A. Local calibration of MEPDG is highly recommended for state highway agencies before full implementation of the design guide. The concept of local calibration is to tune the software so that predicted distresses match measured distresses from the field. In other words, it is assumed that manually interpreted distresses serve as the ground truth. However, a well-accepted standard of automated distress analysis is still under development.

It is worth investigating local calibration from a new perspective: identifying which evaluation methods, whether automated or semi-automated, the MEPDG predictions replicate best. This study looks at four segments in Arkansas that have been monitored by human raters and the Automated Distress Analyzer (ADA) software for longitudinal and alligator cracking. The four segments are a subset of the original 12 AHTD segments from the previous chapter. The results were compared to the MEPDG distress predictions for the pavement structures that reflect the traffic and structure characteristics of these four segments.

Problem Statement and Research Goals

The accuracy of automated distress prediction and interpretation technologies is typically estimated in relation to manual interpretations, which are considered to be the ground truth. Due to variations in data collection, interpretation methods, and bias assumptions, human evaluation can be erroneous and inconsistent. Additionally, manual surveys are time consuming which only makes the MEPDG calibration process more cumbersome. To gain perspective on the accuracy of automated technologies, it is necessary to compare them amongst each other in addition to human interpretations.

This chapter documents the comparison between ADA distress interpretations before and after the implementation of the wheelpath protocol, human interpretations (semi-automated), and MEPDG distress predictions. The objective is to determine which evaluation method is best represented by MEPDG predictions. Future efforts might involve incorporating these post-processing techniques into the calibration process, which would be greatly facilitated if fully-automated methods could be used as opposed to manual interpretations.

Data Source and Methodology

Wheelpath Protocol

This chapter builds on the efforts made in Chapter 3, which consisted of the establishment of a post-processing Excel spreadsheet used to calibrate ADA distress tabulations to better match human rater interpretations. The spreadsheet established various wheelpath boundaries in order to better distinguish alligator from longitudinal cracking (See Figures 10 and 11). Note that the lane width is approximately 13.5 feet in order for the protocol to be applicable to virtually any lane size. The shaded portions represent the wheelpath areas. As was mentioned previously, alligator cracking is any longitudinal cracking enclosed within these regions while longitudinal cracking that occurs outside the shaded areas is kept as longitudinal cracking. Ordinarily, ADA has difficulty detecting alligator cracking and the total tabulations are negligible. When ADA detects a crack, it encloses the crack in a blue box as shown in Figure 22.

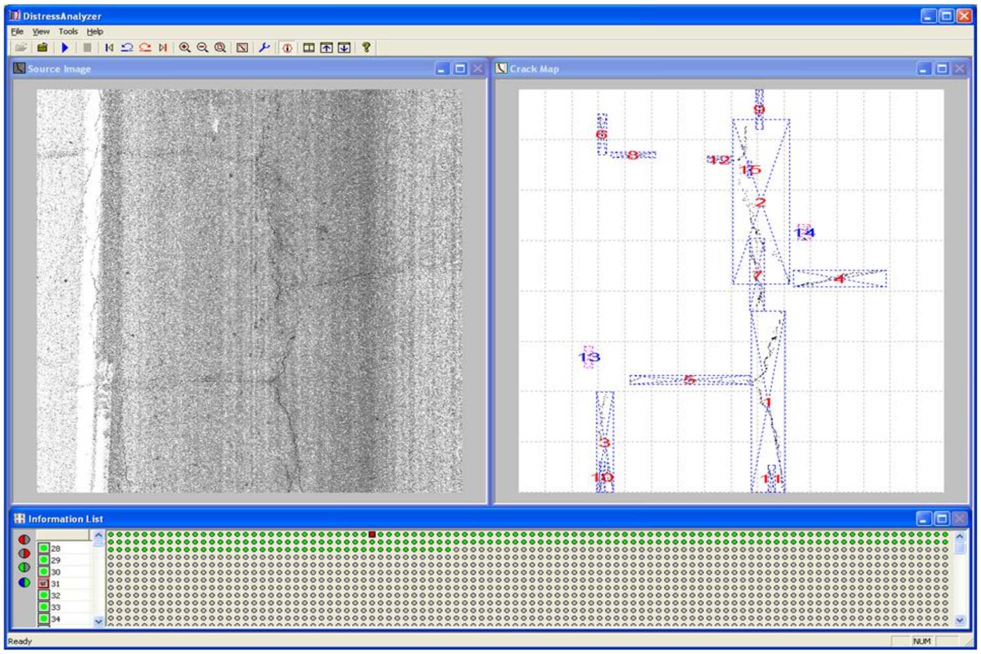


FIGURE 22 ADA software workspace showing image, crack ID, and progress

The post-processing spreadsheet uses a series of “IF” statements to pinpoint precisely where the cracks are located in relation to the wheelpath boundaries using the coordinates of the blue box. This allows for proper classification of the detected cracks. The ADA software by itself does not distinguish between wheelpath and non-wheelpath cracks. If the blue box is longer than it is wide, the crack is classified as longitudinal; it is otherwise classified as a transverse crack.

The five wheelpath alignments used in this research are the standard LTPP size (2.5 ft), the 3.5 ft, the 4.5 ft, the 3.5 ft inward, and the 4.5 ft inward boundaries (See Figures 10 and 11). The term “inward” indicates that the outer boundaries of the inner and outer wheelpaths remain stationary while the inner boundaries have been moved inward toward the center of the lane accordingly. With the application of these wheelpath boundaries, the overflow of false positive crack detections is eliminated and a sufficient recognition of alligator cracking is established.

Data Collection

In order to get an accurate comparison, the MEPDG inputs had to reflect site-specific (Level 1) data whenever possible. If site-specific data was not available, the inputs were designated to resemble typical values for that particular roadway environment. The data acquired for MEPDG were collected from various pavement management systems (PMS) provided by the Arkansas Highway and Transportation Department (AHTD). The primary data inputs of interest are those categorized under pavement structure and traffic. These inputs include the initial average annual daily truck traffic (AADTT), truck traffic growth rate, vehicle class distributions, pavement layer thicknesses, layer material, and subgrade material.

The MEPDG software can calculate the initial AADTT using the average daily traffic (ADT) and the percentage of trucks, which are two parameters that were input to MEPDG. The traffic growth rate was assumed to be compound growth and was obtained through backcalculation using the ADT values. The vehicle class distributions were determined in accordance to the historical data provided by a traffic count station either within or nearby the section that has the same traffic pattern (18). The most common truck class classifications (TTC) in Arkansas are TTC 2, 4, 6, 9, and 12 (19). AHTD provides the percentage of each truck class for various years for an abundant supply of traffic stations; however MEPDG only allows the input for classes 4 through 13. Because of this, a vehicle class distribution must be chosen based on which of the most common TTC's in Arkansas replicate the AHTD table values the best.

Of the 12 segments from Chapter 3, four of them had a sufficient amount of data readily available for MEPDG analysis purposes. These segment portions lie within A_040410 (I-40 L.M. 193.00 to 194.16), A_167100 (Highway 167 south of Sheridan L.M. 4.93 to 9.01), A_079040 (Highway 79 in Camden L.M. 0.60 to 1.54), and A_167170 (Highway 167 in Pleasant Plains L.M. 1.22 to 1.72). Figure 23 indicates the locations of these segments. To simplify matters, A_040410 will be Road 1, A_079040 will be Road 2, A_167100 will be Road 3, and A_167170 will be Road 4.

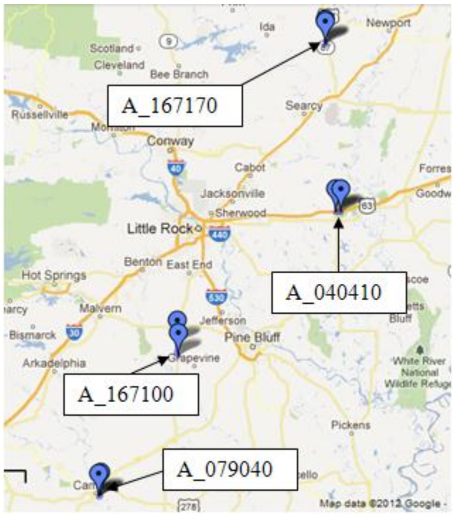


FIGURE 23 The four segments analyzed by human raters, ADA, and MEPDG

The structural data of these segments were obtained from the design specifications of various AHTD jobs at specified locations. The design specifications came from various PMS catalogs. The subgrade material was obtained from the U.S. Department of Agriculture (20).

Once the necessary inputs were collected, the MEPDG analysis was performed for the four segments. The alligator and longitudinal cracking tabulations were extracted from the distress summary in accordance to the pavement age. The age of each segment is the same as the corresponding segment that has been analyzed by ADA. For example, Road 2 had an overlay procedure done in 2003. The pavement images processed in ADA for each segment were collected in 2009, thus segment Road 2 is considered to be a six year old overlay design. The six year distress data for the MEPDG segment that reflects the properties of Road 2 was the data compared to the ADA distress results of that segment.

Comparison Results

Tables 3 and 4 display the comparison between MEPDG, ADA, and human interpretations for longitudinal and alligator cracking respectively.

TABLE 3 Longitudinal cracking comparison (ft/mi) for all methods

Road	MEPDG	ADA With Wheelpath Protocols					ADA Without Wheelpath Protocol	Semi-Automated
		2.5 ft	3.5 ft	4.5 ft	3.5 ft Inward	4.5 ft Inward		
1	0	5,572	4,801	2,907	5,572	5,572	5,639	3,683
2	4	84	36	14	79	79	132	1,621
3	88	447	332	203	347	260	569	708
4	17	631	518	422	572	350	1,584	1,731

TABLE 4 Alligator cracking comparison (%) for all methods

Road	MEPDG	ADA With Wheelpath Protocols					ADA Without Wheelpath Protocol	Semi-Automated
		2.5 ft	3.5 ft	4.5 ft	3.5 ft Inward	4.5 ft Inward		
1	0.09	0.00	0.13	0.81	0.00	0.00	Cannot Tabulate	0.00
2	0.00	0.00	0.00	0.04	0.00	0.00	Cannot Tabulate	0.00
3	0.43	0.11	0.14	0.23	0.15	0.27	Cannot Tabulate	20.00
4	0.27	0.82	1.11	1.21	1.04	1.14	Cannot Tabulate	32.50

It is clear from the results that MEPDG typically tends to over-predict pavement performance in comparison to what is tabulated through automated and semi-automated methods. In other words, MEPDG underestimates the amount of cracking distress. For longitudinal cracking, the 4.5 ft alignment provides the lowest tabulations in general. Therefore, MEPDG reflects this particular alignment better than the other protocol alignments or the other two rating methods (ADA without the protocol and semi-automated human interpretations).

The reason for the particularly high longitudinal cracking tabulations for the automated methods for Road 1 is due to poor pavement image quality. The vehicle that collects the pavement images has a camera on each side of the rear; one for capturing the left side of the segment and the other for capturing the right side. Sometimes, the lighting contrast between the left and right images is very high, creating a definite longitudinal line where the two images meet. This problem is illustrated in Figure 24. This line can be misinterpreted as longitudinal cracking by ADA through the wheelpath protocol, which ultimately overestimates the total amount. As for the semi-automated method, cracks can simply be overlooked by the human surveyors. The overlooked cracks can significantly increase the final tabulation for longitudinal cracking.

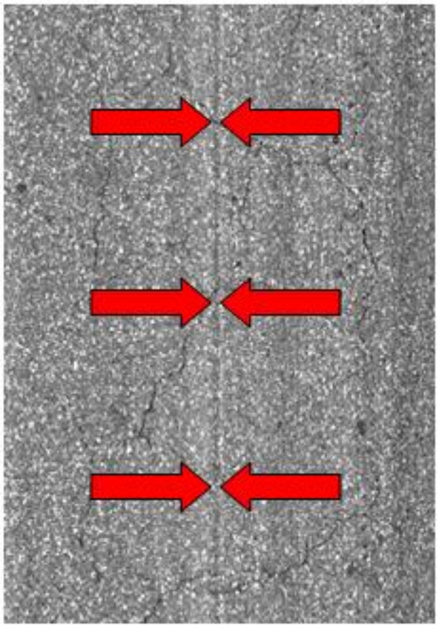


FIGURE 24 Pavement image lighting contrast problem

The alligator cracking results indicate a similar situation to the longitudinal cracking results. MEPDG predicted very little alligator cracking (less than 1%) for all four segments. The wheelpath protocol alignments provide very similar results. There is no alignment that is particularly better than the others. Without the implementation of the wheelpath protocol, ADA did not detect any alligator cracking at all. For Roads 3 and 4, the human interpretations were much larger than that of the automated methods. As trivial as alligator cracking is, however, there are no means of claiming that the values interpreted by the human raters are more correct than the automated methods. The objective of the study was to determine which of the distress evaluation method results the MEPDG predictions matched best.

Summary

When it comes to pavement distress evaluation, it is difficult to collaborate the precision of various methods due to differing cracking protocols, data collection methods, human error, and the variation in what interpreters consider to be the ground truth for distress values. While automated distress interpretations and predictions are typically compared to manual efforts, it is necessary to compare these methods amongst each other as well. This chapter analyzed the correlation between automated and semi-automated interpretations with MEPDG distress predictions. The ADA results were also processed through an Excel spreadsheet (wheelpath protocol) that uses various wheelpath boundary alignments that distinguish alligator cracking from longitudinal cracking.

It is evident from the results that MEPDG distress predictions matched the 4.5 ft wheelpath alignment results for longitudinal cracking better than any of the other alignments or evaluation methods. It is plausible that this wheelpath alignment has potential for being a beneficial tool in MEPDG calibration for the longitudinal cracking model. It is apparent that any of the wheelpath alignments can be used to assist in calibration for the alligator cracking model. It is recommended, however, that further investigations with larger samples should be carried out. The primary shortcoming of this report is that only four segments were analyzed, which was due to the lack in input data availability. In addition, imaging errors (such as lighting contrast) should be eliminated to enhance the reliability of the results.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The implementation of the wheelpath protocol certainly shows promising potential in setting a precedent for more reliance on automated technologies. There are two suggestions for future efforts that would help improve the case for using automated surveying for MEPDG calibration.

- 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 avoid classifying linear patterns, such as tire marks and oil drip stains, as cracks.

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 yet proven with manual surveys. This research demonstrates that fully automated processing faces challenges as well. However, as long as factors influencing automated processing are fully understood and errors are controlled, automated results are usable.

Adequate MEPDG distress predictions demand continuous calibration efforts that require up-to-date conditions and situations. Manual and semi-automated pavement evaluation methods are time-consuming and can be very erroneous. The post-processing wheelpath protocol is not perfect, but it opens a new perspective for automated distress analysis. Plausible improvements were portrayed through the 2.5 ft and 4.5 ft wheelpath alignments for both alligator and longitudinal cracking. It is recommended however that further investigations should be performed with more robust sample sizes.

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