A Study of Manual vs. Automated Pavement Condition Surveys

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ABSTRACT

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Pavement condition surveys play a vital role in the management of a pavement network. The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding. The first objective of this study was to survey States' Department of Transportation (DOT) to assess current automated data collection practices and gather information from states that have made the transition from manual to automated pavement condition surveys. The second objective was to evaluate the accuracy of automated pavement condition data compared to manual pavement condition data.

A pavement condition survey questionnaire was constructed and sent to 46 state DOT pavement management engineers. A total of 27 questionnaires were returned with each completed at least partially. The questionnaires were used to summarize pavement condition survey methods other state agencies are currently using, and to make recommendations for the use of automated pavement condition surveys.

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Data from the first cycle of Alabama Department of Transportation's automated pavement condition quality assurance program was used to complete statistical analyses of manual versus automated data. The analyses included a regression study on manual versus automated data and a sensitivity analysis of the Alabama DOT Pavement Condition Rating (PCR). An investigation into the methodology used for the quality assurance program was also completed. It was determined that the quality assurance program may be improved by using a global positioning system (GPS) for locating manual as well as automated sample sections. The regression study showed that the error between manual and automated data was random; and some general trends were observed. Finally, the PCR sensitivity analysis showed that cracking data (i.e., severe transverse cracking) have the greatest influence on the final PCR value.

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CHAPTER 1

INTRODUCTION

Pavement condition surveys play a vital role in the management of a pavement network. The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding. Therefore, it is critical to collect accurate pavement condition data in an efficient and safe manner. In the past the only method of completing a pavement condition survey was to walk or drive down the road and collect the data manually. This method is time consuming, hazardous, and subjective. Therefore, over the past two decades an effort has been made to fully automate the data collection process.

An automated pavement condition survey consists of driving down the road at or near highway speeds while collecting data. The vehicles used to collect the data are outfitted with numerous technologically complex systems. Each system is designed to collect a specific type of data and some of the systems work in conjunction with each other. Some of the data that are commonly collected by automated data collection vehicles include, but are not limited to: rut depth, ride quality, texture, global positioning, position orientation, and numerous types of surface distress. Surface distresses such as cracking are commonly the most difficult type of data to detect and classify

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automatically. Hence, the most widely used method of detecting and classifying surface distresses is still with the human eye. However, in recent years, technological advancements in computer hardware and imaging recognition techniques have provided the means to successfully detect and classify surface distresses automatically in a cost-effective manner. These technological advancements include pavement imaging systems such as digital line-scan cameras that have the capability of capturing pavement images that can exceed a resolution of 6,000 pixels per line, as well as surface distress classification software that has the capability to classify surface distresses in real time.

Pavement condition surveys can produce an enormous amount of data regarding the condition of a pavement network. Basing pavement management decisions on the raw data would be a cumbersome task. Therefore, composite pavement condition indices are often used. The composite pavement condition indices use the raw data from a pavement condition survey for a roadway to compute a single value that is then used to describe the pavement's condition. The composite indices provide for a concise tool for making management decisions, and have allowed for standardization of pavement rating on a statewide basis.

The ideal automated survey would provide less subjective and more accurate data, the ability to survey the entire network in a time efficient manner, and a safer means of collection. Through extensive research and technological advancements, the concept of a fully automated pavement condition survey is nearly realized. However, there are some issues that have hindered the acceptance of the automated data collection technology.

One issue that has stalled the advancement of the automated pavement condition survey is the lack of information about successful transitions from manual to automated

data collection. Making the transition is a major task that few have fully accomplished. There are few states that have adopted a fully automated pavement condition survey and those that have faced many obstacles along the way. These states possess information that could make the transition much smoother for others.

A second issue that has slowed the acceptance of automated pavement condition surveys is the accuracy of the data compared to manual survey data. Most pavement management systems have been developed around manual data and no agency wants to redesign their management system. If the automated surveys do not collect data that are similar to the manual data then the transition will cause discontinuity in the pavement management system. In other words, the pavement management system would require recalibration for the new means of data collection.

The Alabama Department of Transportation (ALDOT) has been in the process of transitioning to an automated pavement condition survey system for close to a decade. ALDOT began conducting pavement condition surveys in 1984. The first survey was performed manually on a 200-ft sample for every mile. The surveys were completed on a two year cycle up to the year 1990. In 1990 ALDOT began evaluating automated pavement condition survey vendors due to safety issues and the length of time it took to complete a manual survey for the state's pavement network. ALDOT conducted evaluations of several companies' automated data collection systems only to find them unacceptable. In 1996, ALDOT contracted with an external vendor and the first cycle of surveys was completed in 1997. ALDOT set up a quality assurance (QA) program for the first half of the third cycle, completed in 2002. This program consisted of conducting 200-ft manual surveys every 10 miles by ALDOT raters with over eight years of

experience in pavement condition surveys. These data were then compared to the data obtained by the vendor for the corresponding 200-ft section. Some significant discrepancies between the vendor data and the ALDOT rater data were discovered during the QA procedure. ALDOT has since begun a reevaluation of their QA practices and an investigation into discrepancies between the vendor data and ALDOT data.

OBJECTIVES

The first objective of this research was to survey state DOT's to assess current automated data collection practices and gather information from states that have made the transition from manual to automated pavement condition surveys. The second objective was to evaluate the accuracy of automated pavement condition data compared to manual pavement condition data. This comparison will also be used to determine if the automated data and manual data are statistically similar and if not, what parameters have a discrepancy that is not within a tolerable level.

SCOPE

To accomplish the first objective, a review of literature on automated pavement condition surveys was completed. Also, a pavement condition survey questionnaire was constructed and sent to 46 state DOT pavement management engineers. The second objective was accomplished by completing statistical analysis on automated and manual pavement condition data collected for ALDOT's first automated data quality assurance cycle.

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ORGANIZATION OF REPORT

This report is organized into five chapters. These five chapters include: Introduction, Literature Review, Pavement Condition Survey Questionnaire, Automated Data vs. Manual Data, and Conclusions and Recommendations. These chapters are followed by References and Appendices.

Chapter two includes the summarization of a literature review of automated pavement condition surveys. This chapter reviews methods for completing, technology, protocol, and other issues surrounding pavement condition surveys. Chapter three contains the results of the pavement condition survey questionnaire completed by 27 states. Chapter four is composed of the automated data vs. manual data analysis. This chapter describes and investigates ALDOT's quality assurance program, presents the results of a statistical analysis on automated and manual data, and determines the sensitivity of ALDOT's Pavement Condition Rating (PCR) due to error in each variable. The conclusion and recommendations for the report are presented in chapter five followed by References and Appendices.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Pavement condition surveys play a vital role in the management of a pavement network. In this chapter, literature is reviewed in order to better understand technology and procedures that are associated with pavement condition surveys. Methods for completing a manual pavement condition survey are discussed. Also, automated pavement condition surveys along with technology used for completing them are examined. Pavement distress indices and how they are calculated are described. And lastly, crack classification protocols are discussed.

PAVEMENT CONDITION SURVEY

Pavement management is a key part of any state's transportation system. One of the duties of the pavement management department in each state is to evaluate the pavement performance for the state's pavement network. As defined by the Highway Research Board (1962), pavement performance is a function of the pavements relative ability to serve traffic over a period of time. The ability of a pavement to serve traffic is dependent on various factors, one of which is the amount of deterioration the pavement has undergone, or the pavement condition. Typically, the amount of deterioration of a given pavement is determined by the pavement management department by means of a

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pavement condition survey. Pavement condition surveys are completed at both network and project levels periodically. The condition surveys along with records of traffic history and time provide the pavement management department with a history of deterioration of the ride quality, or serviceability (Haas, 1994). It is this history of serviceability that defines pavement performance as shown in Figure 2.1. The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding.
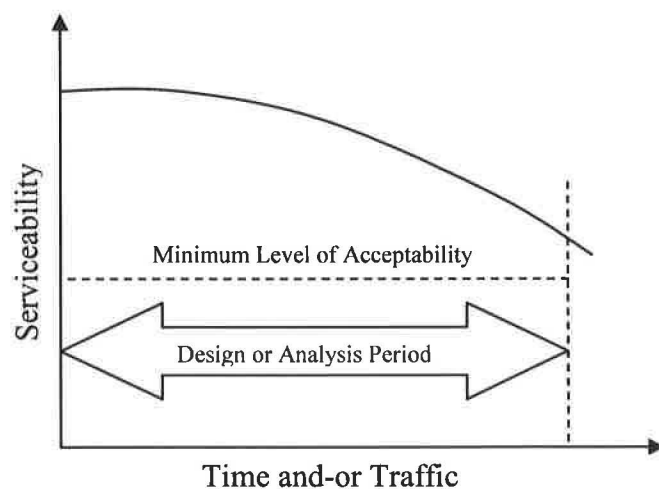
Figure 2.1 Deterioration of Serviceability Over Time (after Haas, 1994).

Pavement Distress Indices

Pavement condition surveys can produce an enormous amount of data regarding the condition of a pavement network. The type of data collected varies from state to state and by pavement type; however, the most common data collected for flexible and rigid

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pavements include International Roughness Index (IRI), rutting, faulting, and other surface distresses. Surface distresses include cracking, patching, raveling, etc. The severity and extent of each surface distress are also typically collected in the condition survey. Using all of the raw data collected by the pavement condition survey in a pavement management system would prove to be difficult; therefore, composite pavement condition indices are often used.

The first pavement condition index was developed in the 1960's for the American Association of State Highway Officials (AASHO) Road Test (1962). It was determined that there was a need for an objective measurement of serviceability-performance in order to develop the pavement design equations (Roberts, 1996). Carey and Irick (1960) developed the following concepts to address the need for an objective measurement of serviceability-performance:

1. Highways are designed and built for the comfort and convenience of the traveling public. Therefore, a good highway is one that is smooth and safe.

2. One user's opinion about how well a highway is serving its function is subjective.

3. There are objective characteristics of the road which, when measured and properly combined, can be correlated to the average subjective evaluation of the highway.

4. The serviceability of a road can be adequately represented by the arithmetic average of opinions of a group of highway users. Single rating values should not be used since honest differences in opinion are too divergent to produce a reliable rating.

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5. Performance is defined as the area under a serviceability-time curve from the time of construction to the time performance is being evaluated.

Present Serviceability Index

Present Serviceability Index (PSI) was developed and used as the composite pavement condition index at the AASHO Road Test (1962). PSI was developed using relationships between a panel of raters and roughness measurements made by the AASHO profilometer and the Bureau of Public Roads (BPR) roughometer. The original equation developed by Carey and Irick (1960) for flexible pavements was:

$$PSI = 5.03 - 1.91\log\left(1 + \overline{SV}\right) - 1.38\overline{RD^2} - 0.01\sqrt{C + P} \qquad (2.1)$$

where,

PSI = present serviceability index;

$\overline{SV}$ = mean slope variance, the variance of slopes measured over a 6-inch wheel base using the CHLOE profilometer;

$\overline{RD}$ = mean rut depth, inches;

C = pavement cracking in $ft/1000\ ft^2$ of pavement surface; and

P = patching in $ft^2/1000\ ft^2$ of pavement surface

A new pavement will generally score a PSI between 4 and 5, and repair is usually needed at a PSI between 1.5 and 2.5 (Roberts, 1996). Carey and Irick (1960) defined the general condition of the pavement in relation to PSI as shown in Figure 2.2.
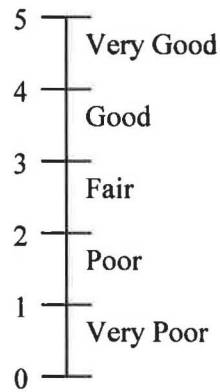
Figure 2.2 Relationship Between Pavement Condition and PSI.

The PSI equation developed by the AASHO Road Test has the following shortcomings (Huang, 1993):

1. It was based on the evaluations of the Road Test rating panel. Whether the public's perception of serviceability is the same today as 40 years ago is questionable because vehicles, highway characteristics, and travel speeds have changed significantly.

2. It includes not only the rideability but also the surface defects. For the management of pavement inventory, it would be better to have separate measures of ride quality and surface defects.

3. The prolifometer used in the Road Test is no longer in use today.

Deduct Value Approach

   PSI was effectively used as a composite pavement condition index; however, in part, due to the shortcomings listed previously and advancements in the ability to identify pavement deterioration the majority of states have developed a deduct value approach to

composite pavement condition indices. The deduct value approach assigns an index of 100 to a perfect pavement. The index is decreased by deduct values based on specific types of deterioration. While each state that uses this approach has developed their own criteria for deduct values the overall approach is the same. Following are several states' approaches to a pavement condition index.

Alabama

ALDOT uses a composite pavement condition index called Pavement Condition Rating (PCR). For the development of this index, experienced maintenance engineers evaluated a series of sites across Alabama to determine the required level of maintenance. Thirty one inspectors made 1,086 site visits, preparing ratings in terms of minor maintenance, overlays or structural rehabilitation (Glover et al., 1985). The ratings were based upon a linear scale calibrated to maintenance needs through a Delphi study. After all inspections were complete, the engineers' opinions were correlated to distress measurements at each site. An extensive regression study produced the PCR equation used today. The PCR equation used by ALDOT is (Glover et al., 1985):

$$
\begin{aligned}
\mathbf{PCR} = {}& 95.5727 - 5.5085\,(5.0\text{-}ROUGH) - 1.5964\,LNALL1 \\
& - 1.9629\,LNALL2 - 2.9795\,LNALL3 - .01630\,PAT2RD \\
& - .07262\,BLK2RD - .2220\,AVGOUT - 3.4948\,RAVL31 \\
& - 7.5269\,RAVL32 - 11.2297\,RAVL33 - .03032\,LONG12 \\
& - .05484\,LONG34 - .53050\,TRAN12 - .69736\,TRAN34
\end{aligned}
\tag{2.2}
$$

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where,

ROUGH = roughness or present serviceability index

LNALL1 = ln (level 1 alligator cracking + 1.0)

LNALL2 = ln (level 2 alligator cracking + 1.0)

LNALL3 = ln (level 3 alligator cracking + 1.0)

PAT2RD = patching (level 2 + level 3), $\leq 400\ \text{ft}^2$

BLK2RD = block cracking (all levels summed), $\leq 400\ \text{ft}^2$

AVGOUT = outer wheel path rutting (all locations averaged), 10^{-2} inches

RAVL31 = severe localized raveling (Code: 0 = none, 1 = present)

RAVL32 = severe wheel path raveling (Code: 0 = none, 1 = present)

RAVL33 = severe entire lane raveling (Code: 0 = none, 1 = present)

LONG12 = longitudinal cracking (level 1 + level 2), ft

LONG34 = longitudinal cracking level 3, ft

TRAN12 = transverse cracking (level 1 + level 2), number of cracks

TRAN34 = transverse cracking level 3, number of cracks

The various levels represent the severity of the specific distress. The ALDOT PCR equation is discussed in further detail in following chapters.

Washington State

The Washington State Department of Transportation (WSDOT) uses a Pavement Structural Condition (PSC) index to quantify all forms and severity levels of pavement cracking. This includes alligator cracking, longitudinal cracking, transverse cracking,

and patching for flexible pavements; and slab cracking, joint and crack spalling, pumping, faulting, scaling, and patching for rigid pavements (WSDOT, 1999). Each type of type of distress is converted to an "equivalent cracking" number (EC) based on its extent and severity. The PSC is then calculated using the following equations:

Flexible Pavements:

$$PSC = 100 - 15.8(EC)^{0.50} \qquad (2.3)$$

Rigid Pavements:

$$PSC = 100 - 18.6(EC)^{0.43} \qquad (2.4)$$

PSC, Pavement Rutting Condition (PRC), and IRI are used by WSDOT to decide which roads are in need of maintenance. WSDOT has established trigger values for PSC, PRC, and IRI for which rehabilitation should be performed.

Georgia

The Georgia Department of Transportation (GDOT) uses a Surface Condition Rating (SCR) that ranges from 0 to 100. Points are deducted from the possible 100 based on average extent and severity of each surface distress (GDOT, 1996). Some of the surface distresses are grouped for rating and calculation of the SCR and they include: rutting, load cracking, block/transverse cracking, reflection cracking, raveling, edge distress, bleeding/flushing, corrugations/pushing, loss of section, and patches/potholes/local base failure. Once the average value for severity and extent have been established for a section, deduct values are looked up in tables or charts established by GDOT. The SCR is calculated as follows:

$$SCR = 100 - \text{Total Deduct Points} \qquad (2.5)$$

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Summary

It can be seen, from the three methods of calculating a pavement distress index mentioned above, that the process varies widely from state to state. While GDOT and WSDOT use a maximum rating of 100, it can be seen in Equation 2.2 that ALDOT has a maximum rating of 95.5727. Also, ALDOT's PCR is truly a composite pavement condition index while WSDOT's PSC does not include ride or rutting, and GDOT' SCR does not include ride. This variation in different agency's indexes is common.

Manual Pavement Condition Surveys

While the use of automated pavement condition surveys are becoming more and more common, many agencies still rely on manual pavement condition surveys to provide their pavement condition data. There are two basic methods for conducting manual pavement condition surveys, walking and windshield surveys. Walking and windshield surveys are also commonly combined to provide a more complete pavement network survey.

Walking Survey

Walking surveys are completed by a rater who is trained to rate distresses according to the agency's distress identification specifications. The rater walks down the side of the pavement and fills out a pavement condition form that describes the amount, extent, and severity of each distress present on the roadway. Walking surveys provide the most precise data about the condition of the rated pavement (Haas, 1994), provided the raters are well trained an experienced. However, only a sample of the pavement

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network can be surveyed because of the amount of time a walking survey consumes. For example, the pavement network could be represented by only surveying the first 100 ft of each mile. Some of the methods used by agencies to select a site for the sample include: sample at fixed distance intervals, make a predetermined random selection, and have the rater pick a "representative" sample. Random selection can sometimes be difficult to accept because the pavement under review may have a considerable amount of distress, but the random sample has, for example, recently been patched. However, selecting a more "representative" sample will distort or bias the data about the condition of the pavement network (Haas, 1994). Under the theory of random selection some of the samples will have more distress than the pavement actually has and some of the samples will have less distress than the pavement actually has. Therefore, the overall condition of the network will average out, provided the sample size is large enough.

Windshield Survey

A windshield survey is completed by driving along the road or on the shoulder of the road. The pavement is rated by a rater through the windshield of the vehicle. This method allows for a greater amount of coverage in less time; however, the quality of the pavement distress data is compromised. The entire network could possibly be surveyed using this method or samples may still be used.

Walking + Windshield Survey

Combining a walking survey with a windshield survey is a good method to achieve detailed pavement distress data and complete pavement surveys on a greater

percentage of the network. Haas (1994) states that this method is acceptable only if the same procedure is used on every section in the network, and a random method is used for selecting the sample where the walking survey will be performed.

AUTOMATED PAVEMENT CONDITION SURVEYS

Over the past two decades the concept of a fully automated pavement condition survey has grown closer to a reality through research and major technological advancements. The automated pavement condition survey vehicle and some types of data it is capable of collecting are described in this section. Also, surface distress surveys and technology used in completing them are discussed. Lastly, pavement condition survey protocols are examined.

Automated Pavement Condition Survey Vehicle

One of the most important parts of an automated pavement condition survey is the data collection process. This process is completed by technologically complex vehicles traveling down the road at highway speeds collecting and storing data. There are numerous types of automated pavement condition survey vehicles available and some utilize different kinds of data collection technology; however, generally they are similar in the fact that they are all trying to achieve the same final result, accurate pavement condition data. The type of data collected by automated pavement condition survey vehicles and the technology used to collect it are discussed below.

Surface Distress

Surface distress data are collected automatically using downward facing cameras aimed at the pavement surface. Either analog-based area-scan cameras, digital area-scan cameras, or digital line-scan cameras are used to capture a continuous image of the pavement surface as the data collection vehicle travels down the road. The images are then analyzed to determine the type, extent, and severity of any surface distress that is present. Each type of camera previously listed is discussed in greater detail later.

Rutting

Rutting data are collected automatically by the pavement condition survey vehicle in real time. There are a few different types of technologies that are employed to collect rutting data. The use of a rutbar and a laser transverse profiler are discussed in detail below.

A rutbar is a vehicle mounted subsystem that uses ultrasonic transducers or lasers to measure the transverse cross section of a roadway. The rutbar has as few as 3 or many sensors that are closely spaced and cover a full lane width. Some rutbar system software can produce graphic displays, plots, water ponding depths, reports, and calculations as to what quantity of asphalt would need to be milled to level the ruts. An example of a rutbar is shown in Figure 2.3.
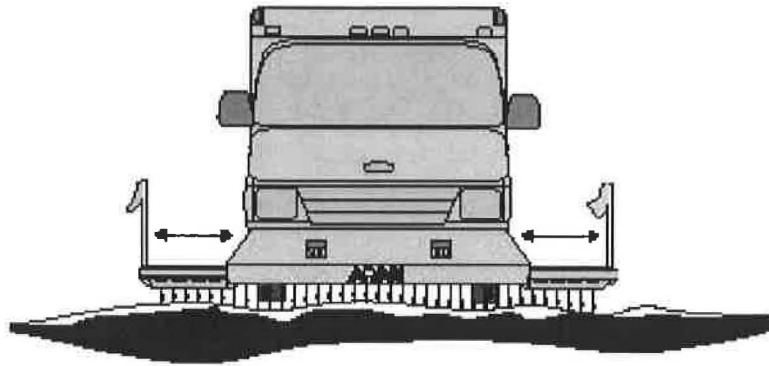
Figure 2.3 Example of a Rutbar (Roadware, 2004).

Lasers can also be used to measure the transverse section of a roadway. A laser transverse profiler is a vehicle mounted subsystem that uses dual scanning lasers to measure the transverse profile of the road (Roadware, 2004). From the transverse profile the rutdepth is then automatically calculated. Since the complete profile for the lane is measured, the effect of driver wandering is eliminated.

Ride

How rough a road feels to the passenger when riding down the road is commonly referred to as "ride". There are several indices used to describe ride; however, the index used presently by nearly every state is International Roughness Index (IRI). IRI is a statistic used to estimate the amount of roughness in a measured longitudinal profile (AASHTO, 1999). IRI is computed from a single longitudinal profile using differential equations and algorithms (Sayers, 1995). The longitudinal profile is measured using a laser or other device to measure the vehicle's height above the roadway. An accelerometer is also used to measure the vertical forces caused by surface deformities

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(Roadware, 2004). The longitudinal profile and the vertical force data are used to calculate IRI for the roadway. The IRI calculation is completed in real time.

Texture

Texture data are an important measure of drainage and skid resistance for a pavement surface (Roadware, 2004). Texture data can be collected using a vehicle mounted module that uses high frequency lasers to measure the mean profile depth of the road surface macrotexture. Texture data are gathered in real time. Correlation studies conducted by Roadware Group Inc. have produced an R^2 of 96% with the American Society for Testing and Materials (ASTM) standard sand patch method for texture measurements (Roadware, 2004).

Position Orientation

Many pavement condition survey vehicles have a position orientation system. A position orientation system collects curve radius, grade, and elevation data automatically (Roadware, 2004). These systems can also be used to provide roll, pitch, heading, velocity, and position data. The position information can be used to compensate for motion, which may have an effect on other sensors on the vehicle.

Global Positioning

Global Positioning Systems (GPS) are often used to provide location coordinates of roadway features and to create maps using a Geographic Information System (GIS)

(Roadware, 2004). Such maps could include distress information, bridge locations, rail crossings, etc. for a state's pavement network.

Other Data

An automated pavement condition survey vehicle can be equipped to collect other types of data along with the data types previously discussed. A survey vehicle can be equipped with a system that will measure the retroreflectivity of pavement markings. Also, cameras that collect right of way images are common on survey vehicles. Figure 2.4 shows an automated pavement condition survey vehicle.

Figure 2.4 Automated Pavement Condition Survey Vehicle (ICC, 2003).

Surface Distress Survey

The most difficult part of an automated pavement condition survey is detecting and classifying surface distresses. The most widely used method of detecting and

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classifying surface distresses is still with the human eye; however, this method is labor-intensive, subjective, and potentially dangerous. Ideally, an automated distress detection and classification system could be used, instead of the human eye, which could find all types of cracking, spalling, and any other surface distress of any size, at any collection speed, and under any weather conditions (Wang, 1999). In recent years, technological advancements in computer hardware and imaging recognition techniques have provided the means to successfully detect and classify surface distresses automatically in a cost-effective manner. These technological advancements include pavement imaging systems and surface distress classification software. In this section, pavement imaging systems and surface distress classification software used for automated distress surveys are evaluated.

Pavement Imaging Systems

Traditionally, analog-based area scan cameras have been used in automated pavement surface distress surveys. However, Wang (1999) describes the following three problems with analog-based cameras:

1. A digitization step is required to convert the wave signal data to digital data that can be understood by computers.

2. The highest possible digital resolution from data with analog cameras is about 400 pixels per line.

3. Area scan cameras have an inherent problem in the inspection of a moving surface when the complete and exact coverage of the surface is required.

Furthermore, additional computation is needed to have exact and complete coverage of the pavement surface due to surface overlapping or discontinuity of adjacent images. For instance, Figure 2.5 shows an example of two consecutive images taken by an analog-based area scan camera. The pavement in the example images has been marked in feet. The section of pavement that appears on both images creates a problem in the fact that if there is a crack on that section it will be counted as two cracks in an automated system and result in overrating of cracking for this pavement. Figure 2.5 shows the overlapping problem that commonly occurs. A similar problem exists when a section of pavement is absent from two consecutive images. In this case an underrating of cracking would be reported for the pavement.
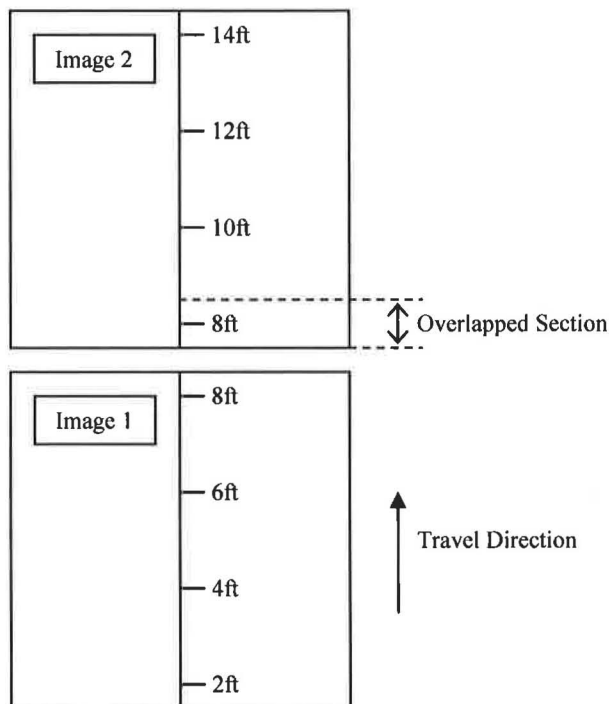
Figure 2.5 Example of Overlapped Images.

In recent years, digital cameras have become the preferred method for capturing images of pavements for automated surface distress surveys. Digitization is conducted inside the digital cameras. This eliminates the separate digitization step needed for analog-based cameras allowing for the output images to be processed directly by computers in real time (Wang, 1999). Digital cameras also provide higher resolution capabilities than analog-based cameras. Analog cameras can achieve 400 pixels per line while some of the digital cameras can exceed 6,000 pixels per line. The two types of digital cameras used for automated surface distress surveys are area-scan and line-scan.

A digital image is made up of thousands of square pixels. These pixels line up to make the image. Area-scan cameras capture a square image (two-dimensional); hence, it has as many vertical pixels as horizontal pixels. This situation is shown in Figure 2.6. Digital area-scan cameras can experience overlapping and discontinuity problems similar to those encountered by analog area-scan cameras. Therefore, digital area-scan cameras are most often used for right of way data collection while line-scan cameras are most commonly used for the pavement surface distress data collection. Line-scan cameras only capture one strip of pixels at a time and are therefore considered one-dimensional. This situation is shown in Figure 2.7. Gunaratne et al. (2004) state that digital line-scan cameras are better suited for capturing moving objects. Furthermore, digital line-scan cameras can achieve high resolution which can exceed 6000 pixels per line. This high resolution is better suited for the detection of small cracks. Gunaratne et al. (2004) found that the Florida Department of Transportation (FDOT) digital line-scan camera was able to identify a crack up to a minimum width of 3.45 mm. Others have been successful in detecting even smaller cracks.
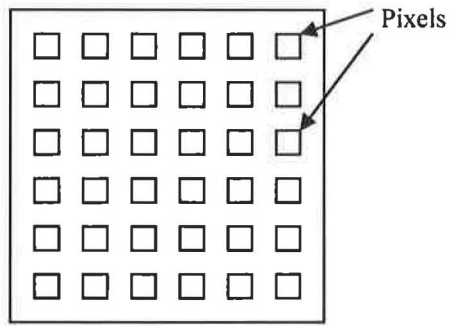
Figure 2.6 Example of an Area-Scan Image.
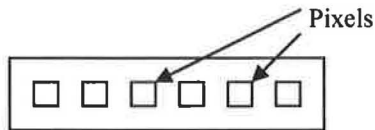
Figure 2.7 Example of a Line-Scan Image.

Wang (1999), states that many problems associated with analog area-scan cameras do not exists with digital line-scan cameras; however, line-scan cameras require higher light intensity. The greater light intensity is commonly achieved by the installation of lights on the back of the survey vehicle. FDOT has ten 150 watt lights each with polished reflectors mounted on the back of their data collection vehicle (Gunaratne et al., 2004). These lights are used in order to achieve the required light intensity for the digital line-scan camera.

Surface Distress Classification Software

Detection and classification of pavement surface distress is relatively easy for humans. However, it is not so simple for a computer to perform the same task. Computer vision systems distinguish cracks through identifying disturbances in the brightness range of the surrounding texture and must be designed to seek connected regions through mathematical algorithms (Wang, 2000). Ideally surface distress classification software would have real-time processing capability with acceptable consistency, repeatability, and accuracy. Wang (2000) states the following obstacles in achieving this goal:

1. Real-time surface distress classification at any practical speed requires very high performance computing equipment.

2. Despite advancements in recent years, image processing as a field of study is still evolving.

3. Pavement surface texture and foreign objects on a pavement make surface distress detection and classification difficult.

4. Currently there are no standard indices to quantitatively define the types, severity, and extent of pavement surface distress.

5. Incompatibility of hardware and software between different vendors results in non-comparable survey data.

Despite these difficulties, there are numerous surface distress classification software systems available today. Not all of this software provides real-time surface distress analysis; however, they do all analyses automatically. Roadware's WiseCrax, the

Swedish PAVUE, and Samsung's uniANALYZE surface distress classification software systems are discussed below; however, these are not the only systems available.

WiseCrax

WiseCrax (Roadware, 2004) is a crack classification system developed by Roadware that can detect and classify cracks as small as 3 mm in width automatically. Pavement images are processed off-line overnight at the office workstation. WiseCrax operates in either an automated mode or interactive mode. In the automated mode, all processing is done automatically without human intervention, once the initialization parameters on pavement type, camera and light settings, etc. are set (Wang, 1999). In the interactive mode, the user can interact with the analysis process by reviewing, validating, and editing the WiseCrax results. The interactive mode works well for quality control purposes.

The WiseCrax software works by referencing the beginning and end of each crack using an x-y coordinate system (Wang, 1999). The crack length, width, and orientation are also computed and saved. Once the cracks have been identified and measured, the software creates a crack map of the pavement surface. A statistical report is created during the crack identification phase. Each crack is represented in a table that shows the location, start and end points, length, width, and orientation of individual cracks. WiseCrax compares the location, length, and width of cracks against criteria for various crack distress categories in the crack classification phase. The criteria can be changed to meet an agency's distress category specifications. Roadware states that WiseCrax is compliant with relevant AASHTO and SHRP protocols.

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PAVUE

PAVUE (IMS, 1996) uses an imaging processing technique that is referred to as pipeline processing. In this process, image data is piped through a series of on-board computer chips that contain algorithms (Wang, 2000). The images are filtered to remove noise (oil drips, shadows from trees, power lines, surface texture, discolored stones, etc.) so only distress patterns are shown. Next, the image is converted to a vector format consisting only of the outline of cracks with coordinates of the crack boundaries. The PAVUE system classifies distress information into crack types, severity, and extent through the performance of feature extractions. A pattern classifier calculates a number of statistics for each individual crack based on perimeter of the crack, average width, orientation, and convexity. Each crack is then assigned a type and extent and accumulated for a given pavement segment. Crack indices are computed as the final output. The PAVUE system can complete surface distress analysis on pavement images up to 55 mph and it can detect cracks as small as 2.5 mm in width (Wang, 1999).

uniANALYZE

Samsung (Samsung, 2004) created an automated crack detection and analysis system called uniANALYZE. This system detects and classifies pavement surface distress automatically from digital images. The system uses a digital crack measurement algorithm to identify crack type, extent, and severity. Crack maps are also generated with the system. Pavement surface distresses are detected and recorded based on AASHTO, SHRP, and LTPP cracking protocols. Raman et al. (2004) found that uniANALYZE tends to overestimate distresses.

Crack Classification Protocol

As with any type of sampling or testing, there is a need for protocol to standardize the classification of cracks detected through automated pavement condition surveys. Since automated pavement condition surveys are a relatively new technology, there is not an official protocol as of yet. However, there is an interim protocol and other protocols developed and adopted by individual states. AASHTO PP44-01 and the Universal Cracking Indicator are discussed below.

AASHTO Designation: PP44-01

AASHTO Designation PP44-01, *Standard Practice for Quantifying Cracks in Asphalt Pavement Surface*, is an interim protocol that covers the procedures for quantifying cracking in asphalt pavement surfaces both in wheel path and non-wheel path areas (AASHTO, 2001). PP44-01 primarily focuses on automated data collection for which it calls for 100% coverage of the roadway. The protocol does not include detailed specifications for equipment used for automated surveys. Instead, the protocol states that "any equipment that can quantify, with the accuracy stipulated herein, and which can be adequately validated, is considered acceptable". Therefore, it is unclear what is considered acceptable equipment to use for crack detection and what accuracy this equipment must have. However, a crack is defined by PP44-01 as a "discontinuity in the pavement surface with minimum dimensions of 1 mm (1/25 in) width and 25 mm (1 in) length". Cracks are also defined by three severity levels and intensity. The three severity levels are as follows:

Severity Level 1: Cracks ≤ 3 mm (1/8 in) width

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Severity Level 2: Cracks with dimensions > 3 mm (1/8 in) and ≤ 6 mm (1/4 in) width

Severity Level 3: Cracks with dimensions > 6 mm (1/4 in) width

Intensity is quantified at each level as the total length of cracking per unit area (m/m^2) for each defined survey strip as shown in Figure 2.8. Therefore, it is assumed that the equipment should be able to detect cracks at each severity level and intensity.

Figure 2.8 Cross Section of Survey Lane Showing Survey Area (AASHTO, 2001).

AASHTO PP44-01 states, "Each agency shall designate the lane(s) and direction(s) of travel to be surveyed or rated based on sound engineering principles and management needs within the agency." This statement is vague and leaves individual

states with the option of additional data collection, such as, edge cracking, centerline cracks, and transverse cracks. However, the following is recommended as minimums:

- Survey a 2.500 m (8ft) strip in the outside lane as shown in Figure 2.8. As another option, survey the 3.6 m (12ft) full lane width.

- For undivided highways survey one direction.

- For divided highways survey the outside lane in both directions.

- For each survey cycle it is desirable to use the same direction(s) of travel and survey lane(s).

PP44-01 is designed in a manner which allows for cracks to be distinguished as load associated cracks and non-load associated cracks. Increased cracking intensity in the wheel path, as defined in Figure 2.8, compared to non-wheel path areas is assumed to quantify load associated cracking (AASHTO, 2001). Non-load associated cracks are quantified by the cracking detected in the non-wheel path areas. Wheel path cracking is determined both inside and outside wheel paths, and non-wheel path cracking is determined in the area between wheel paths, as shown in Figure 2.8.

PP44-01 also states that each agency shall develop an adequate quality assurance plan. This plan should include survey personnel certification training, accuracy of equipment, daily quality control procedures, and periodic and on-going control activities (AASHTO, 2001). PP44-01 recommends the following for a quality assurance plan.

- Each agency is responsible for the proficiency of their survey personnel.

- A regular maintenance and testing program must be established for the equipment in accordance with the manufacturer's recommendations.

- Test sections with established cracking types and levels should be used as a comparison to check accuracy of results. Alternatively, up to 5% of the data may be audited and compared for quality control.

- Additional checks can be made through comparison of the previous year's survey with the current survey.

Evaluation of AASHTO Designation: PP44-01

As part of a contract with the Federal Highway Administration (FHWA), the Maryland Department of Transportation, State Highway Administration (MD SHA) evaluated AASHTO PP44-01. The results of this evaluation are documented by Groeger et al. (2003). The objective of the research was to determine the effectiveness of PP44-01 as a procedure to collect, process, and report performance data for network level pavement management needs. It was also evaluated to determine if it could accurately identify cracks to create a cracking condition category.

Groeger et al. (2003) found that PP44 -01 could effectively be used to determine the network level crack condition of the Maryland pavement network. They also state that the AASHTO protocol needs to be extended to provide a cracking condition rating methodology for the network. Maryland currently uses the ARAN vehicle with WiseCrax software to detect and classify cracks. Groeger et al. (2003) found that the WiseCrax software had a problem in compliance with PP44-01 because it had difficulty detecting cracks less than 4 mm in width. Therefore, little low severity cracking will be detected using PP44-01 criteria.

Universal Cracking Indicator

The Universal Cracking Indicator (CI) is an index used to define cracking for a pavement that includes longitudinal, transverse, and alligator cracking (Paterson, 1994). CI is the product of the three primary physical dimensions observed for cracks:

$$CI = \text{extent} \times \text{intensity} \times \text{crack width} \tag{2.6}$$

Extent is measured as the area of cracked pavement within a sample area expressed as a percent of the total pavement area. Intensity is measured as the total length of cracks within the area defining the extent and is expressed in m/m^2 (Wang, 2003). Crack width is the mean width of crack opening at the surface of a set of cracks and is expressed in mm. In the calculation for longitudinal cracking CI_L can be computed by dividing the section into a sub area (a) in the vicinity of the crack and the remaining area of the section (b) as in equation 2.7 or it can be calculated just considering the entire section area ($a + b$) as in equation 2.8. An example of a road section used for calculating CI is shown in Figure 2.9. In Figure 2.9, C is the bounded extent of area for alligator cracking expressed as a percent of the total pavement area. The method for calculating CI is as follows.

Longitudinal Cracking:

$$CI_L = 100\left[\frac{a}{A} \cdot \frac{l_L}{a} \cdot w_b + \frac{b}{A} \cdot \frac{0}{b} \cdot 0\right] = \frac{100 l_L w_L}{A} \tag{2.7}$$

or,

$$CI_L = 100\left[\frac{(a+b)}{A} \cdot \frac{l_L}{(a+b)} \cdot w_l\right] = \frac{100 l_L w_L}{A} \tag{2.8}$$

Alligator Cracking:

$$CI_A = 100 \left[\frac{C}{A} \cdot \frac{l_A}{C} \cdot w_A \right] = \frac{100 l_A w_A}{A} \qquad (2.9)$$

Transverse Cracking:

$$CI_T = 100 \left[\frac{A}{A} \cdot \frac{l_T}{A} \cdot w_T \right] = 100 \frac{l_T w_T}{A} \qquad (2.10)$$

Final CI:

$$CI = \frac{100 \left(l_L w_L + l_A w_A + l_T w_T \right)}{A} \qquad (2.11)$$
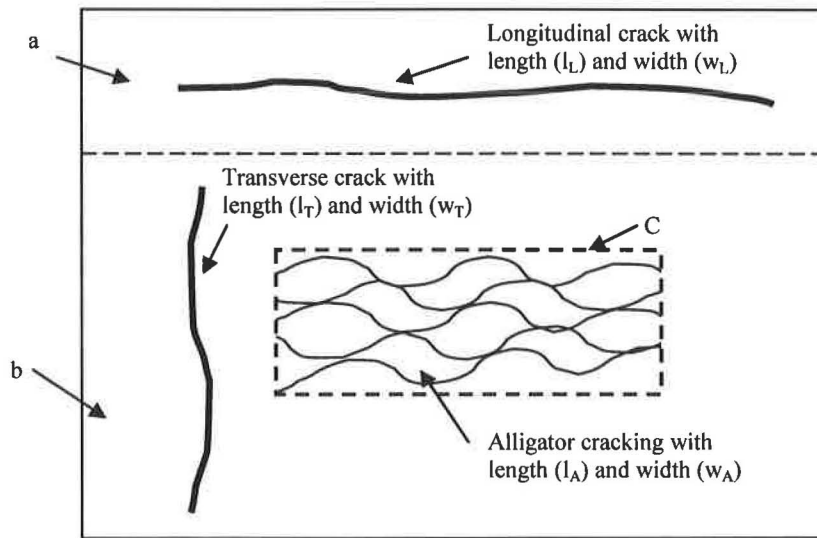
Figure 2.9 Example of a Road Section Used for Computing CI (Paterson, 1994).

MANUAL VS AUTOMATED PAVEMENT CONDITION SURVEYS

There is no question that automated pavement condition surveys are more efficient and safer than manual pavement condition surveys; however, the quality of automated survey data has been under heavy skepticism since its conception. This

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skepticism has prompted numerous studies comparing manual and automated pavement condition survey data.

Gregory et al. (2003) conducted a study in response to the request by the Naval Pavement Center of Expertise to compare manual vs. automated pavement condition surveys. The Navy uses a Pavement Condition Index (PCI) to quantify the condition of the roads and parking lots on their bases. The PCI is a numerical indicator based on a scale from 0 to 100 and is a measure of the pavement's integrity and surface operational condition (Gregory et al., 2003). The automated data were collected using a data collection vehicle equipped with a digital line-scan camera, profiling devices, and laser sensors. The pavement images were reviewed by qualified personnel using a computer monitor to visually determine distress type, severity, and quantity. Results of the study indicated that in general, distress type and quantity were consistent between techniques and the severity was somewhat inconsistent. The automated system typically reported lower severity. The difference in PCI calculated by the manual and automated surveys on nine test sections that were not disclosed to the contractor was an average of 3.2 with a maximum discrepancy of 5. The study also found that the cost to perform an automated and manual survey on 405,000 yd^2 was similar.

Wang et al. (2003) conducted a network crack survey on a large portion of Arkansas' non-interstate National Highway System (NHS). A Digital Highway Data Vehicle (DHDV), developed at the University of Arkansas, was used to acquire high-resolution digital images and analyze cracks with an automated real-time Distress Analyzer on a network of about 100 miles of pavement. A manual survey was also conducted on the same network of pavements. The data analysis with the Distress

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Analyzer covers the entire network, and the manual survey covers 5% of the same area on a mile-by-mile basis. The Universal Cracking Indicator (CI) was used to quantify cracking for the comparison between the manual and automated surveys. Wang et al. (2003) found that when cracking presence on a pavement section is limited or does not exist, results from manual and automated surveys are very close. However, for a large number of sections where cracking presence was substantial, differences between results from manual and automated surveys did exist (Wang et al., 2003). But, it was found that in most cases the results of the two surveys were statistically similar, particularly when cracking presence was small to moderate. Overall, the automated survey produced higher CI values than the manual survey. Wang et al. (2003) states two possible reasons for this discrepancy:

1. The automated procedure may have found more cracks because it grades 100% of each mile.

2. The automated survey picked up some noises for cracks, such as stains, tire tracks, or train rails.

Groeger et al. (2003) completed a study to evaluate AASHTO PP44-01 using Roadware's Automatic Road Analyzer (ARAN) vehicle and WiseCrax. A comparison of manual and automated data was also completed with this study. The data were analyzed using manual field data as "truth." Each result was compared to the field and its deviation was calculated. In their analysis, if the manual data showed that the pavement was in "Good" condition and the automated data determined that the pavement was in "Poor" condition, a deviation of three was recorded. If both methods indicated "Very Good", a deviation of zero was recorded, and so on (Groeger et al., 2003). Also, only

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longitudinal and transverse cracking, without regard for whether the cracking could be classified as fatigue cracking, were considered. The results showed that 94% of the data was within one deviation from "truth." However, when fatigue cracking was considered, only 88% of the data was within one deviation.

SUMMARY

Pavement condition surveys play a vital role in the pavement management process. The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance priorities, and allocate funding.

The most common data collected by a pavement condition survey for flexible and rigid pavements include International Roughness Index (IRI), rutting, faulting, and surface distresses. In an effort to make pavement management decisions easier and to standardize pavement rating on a statewide basis, nearly every state has developed a different composite pavement condition index for their individual use. The majority of these indexes follow the deduct value approach.

Over the past two decades the concept of a fully automated pavement condition survey has grown closer to a reality through research and major technological advancements. Some of the data collection capabilities of automated pavement condition survey vehicles include, but are not limited to: surface distresses, rutting, ride, texture, position orientation, and global positioning. The most difficult part of an automated pavement condition survey is detecting and classifying surface distresses. The first part

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in successfully classifying surface distresses automatically is collecting quality pavement images. Digital line-scan and area-scan cameras provide high resolution images for distress classification. The second part in successfully classifying surface distresses automatically is surface distress classification software. Software such as Roadware's WiseCrax, the Swedish PAVUE, and Samsung's uniANALYZE are commonly used.

As with any type of sampling or testing, there is a need for protocol to standardize the classification of cracks detected through automated pavement condition surveys. AASHTO Designation PP44-01, *Standard Practice for Quantifying Cracks in Asphalt Pavement Surface*, is an interim protocol that covers the procedures for quantifying cracking in asphalt pavement surfaces both in wheel path and non wheel path areas (AASHTO, 2001). PP44-01 is the primary protocol used for pavement condition surveys and it has been found by researchers to be effective in determining the network level crack condition (Groeger et al., 2003). The Universal Cracking Indicator is another protocol that describes cracking. Longitudinal cracking, alligator cracking, and transverse cracking are considered in the calculation for CI.

Several studies have been conducted to compare manual and automated pavement condition surveys. Overall, these studies showed a relatively good comparison of data obtained manually and automatically. However, there is room for improvement.

Overall, from the review of literature, it has been found that automated pavement condition surveys are a valuable tool that have the capability of accurately and efficiently collecting vital pavement condition data. While this technology has not been widely employed, further technological advancements and overhauls of agency's pavement

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management systems will allow for automated pavement condition surveys to be used by everyone.

CHAPTER 3

PAVEMENT CONDITION SURVEY QUESTIONNAIRE

INTRODUCTION

Many states are currently transitioning or have already made the transition from predominantly manual pavement condition surveys to automated pavement condition surveys. This transition has taken place in part due to safety and efficiency issues that exist with manual condition surveys. The use of automated pavement condition surveys is a relatively new procedure for collecting valuable data used for a state's Pavement Management System (PMS). It has been shown by previous researchers that automated surveys are a viable and efficient tool for collecting such data (Groeger, 2003). However, a number of issues have been raised by the Alabama Department of Transportation (ALDOT), and other states, that need to be addressed to realize the full advantage of the new technology.

One issue that has inhibited the use of automated pavement condition surveys from becoming more widespread is the lack of standardization. Currently there is not an official standard for automated surveys. However, AASHTO Designation PP44-01 is an interim protocol that is available and some states have developed their own protocol. Despite the availability of interim protocol PP44-01, there is limited research on the results of its use.

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A second issue is the lack of information about states that have made a successful transition to automated surveys. These pioneering states possibly have the answers to other states' biggest obstacles to making the transition.

The lack of an official standard for automated pavement condition surveys and limited information on states that have successfully transitioned to automated surveys has left many unanswered questions for those who would consider implementing an automated system. A survey of state department of transportation pavement management engineers was conducted in an effort to answer some of these questions and to evaluate the state of the practice. The pavement condition survey questionnaire was constructed and sent to 46 state DOT pavement management engineers via e-mail. A total of 27 questionnaires were returned with each completed at least partially. The findings of this questionnaire are presented in this chapter.

Background

ALDOT began conducting pavement condition surveys in 1984. The first survey was performed manually on a 200-ft sample for every mile. The surveys were completed on a two year cycle up to the year 1990. In 1990 ALDOT began evaluating automated pavement condition survey vendors due to safety issues and the length of time it took to complete a manual survey for the state's pavement network. Four vendors showed interest in conducting a 500 mile test section for evaluation by ALDOT: IMS, PAVEDEX, PAVETECH, and Roadman-PCES. PAVEDEX and PAVETECH were the only vendors to submit their results. PAVETECH was the vendor selected, based on their results from the 500 mile test section, to be evaluated on a survey that covered half of the

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pavement network. The results of this survey were deemed unacceptable by ALDOT and the other half of the survey was completed manually in 1992. In 1996, ALDOT contracted Roadware and the first cycle of surveys was completed in 1997. Roadware uses an Automated Road Analyzer (ARAN) vehicle to collect pavement condition data and an automated crack detection system called Wisecrax to detect and classify cracking. Visual crack mapping (V-rating) is also used to identify cracking on difficult sections. ALDOT set up a quality assurance program for the first half of the third cycle, completed in 2002. This program consisted of conducting 200-ft manual surveys every 10 miles by ALDOT raters with over eight years of experience. These data were then compared to the data obtained by Roadware for the corresponding 200-ft section. Some significant discrepancies between the Roadware data and the ALDOT rater data were discovered during the QA procedure. The majority of the discrepancies were with fatigue cracking. ALDOT has since begun a reevaluation of their QA practices and an investigation into discrepancies between ALDOT and Roadware data. Also, Roadware has since upgraded their cameras to increase the resolution of the pavement images. This upgrade should increase Roadware's crack detection capabilities and will be tested on the second half of ALDOT's third survey cycle.

ALDOT uses a composite pavement condition index called Pavement Condition Rating (PCR) to summarize data obtained from the pavement condition surveys. The PCR is calculated using an equation developed by Turner et al. (1985). This composite index was developed in response to a need to standardize pavement rating on a statewide basis. PCR is a composite score combining many aspects of pavement performance/distress used to compare different pavements. PCR is calculated as follows:

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$$\mathbf{PCR} = 95.5727 - 5.5085 \ (5.0\text{-ROUGH}) - 1.5964 \ \text{LNALL1}$$

$$- \ 1.9629 \ \text{LNALL2} - 2.9795 \ \text{LNALL3} - .01630 \ \text{PAT2RD}$$

$$- \ .07262 \ \text{BLK2RD} - .2220 \ \text{AVGOUT} - 3.4948 \ \text{RAVL31} \qquad (3.1)$$

$$- \ 7.5269 \ \text{RAVL32} - 11.2297 \ \text{RAVL33} - .03032 \ \text{LONG12}$$

$$- \ .05484 \ \text{LONG34} - .53050 \ \text{TRAN12} - .69736 \ \text{TRAN34}$$

where,

ROUGH = roughness or present serviceability index

LNALL1 = ln (level 1 alligator cracking + 1.0)

LNALL2 = ln (level 2 alligator cracking + 1.0)

LNALL3 = ln (level 3 alligator cracking + 1.0)

PAT2RD = patching (level 2 + level 3), ≤ 400 square feet

BLK2RD = block cracking (all levels summed), ≤ 400 square feet

AVGOUT = outer wheel path rutting (all locations averaged), 10^{-2} inches

RAVL31 = severe localized raveling (Code: 0 = none, 1 = present)

RAVL32 = severe wheel path raveling (Code: 0 = none, 1 = present)

RAVL33 = severe entire lane raveling (Code: 0 = none, 1 = present)

LONG12 = longitudinal cracking (level 1 + level 2), ft

LONG34 = longitudinal cracking level 3, ft

TRAN12 = transverse cracking (level 1 + level 2), number of cracks

TRAN34 = transverse cracking level 3, number of cracks

The various levels represent the severity of the specific distress.

METHODOLOGY

The questionnaire was constructed based on the review of literature and the consultation of ALDOT. Questions were chosen that were believed would answer some of ALDOT's questions as well as other DOT's. Furthermore, questions were chosen to help get an idea of what procedure each state was currently using for their pavement condition surveys. This includes specifics on running the pavement condition survey, quality control and quality assurance (QC/QA) procedures, means of reporting data, and any issues they were facing or have faced in the past. A sample of the questionnaire used is provided in Appendix A and two of the questionnaires that were returned are included as an example in Appendix B.

RESULTS

Information obtained on individual states is reported separately in an effort to provide an overview of the procedure each state uses for their pavement condition surveys. Some states provided more information than others; therefore, some states' practices are reported in more detail than others. Following this detailed report of each state's pavement condition survey practices is a more general summary of the information obtained through the questionnaire.

Arizona

The Arizona Department of Transportation (ADOT) collects IRI, rut, cracking, patching, friction, and flushing data on 100% of their road network. ADOT does not outsource its data collection. All data are collected annually except for friction which is

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collected on about a three year cycle. ADOT surveys one lane for undivided roads and only the outside lane in each direction for multilane divided roads. Due to safety issues, ADOT only runs surveys when the weather permits. ADOT collects cracking, flushing, and patching data using manual walking surveys on the first 1000 ft^2 of each mile beginning at each milepost. ADOT collects IRI, rut, and friction data using Dynatest profilers and friction testers. IRI and rut data are collected on 100% of the network (on lanes as specified above) and friction data are collected on the first 300 ft of each mile beginning at each milepost. ADOT uses average condition overall to report results of pavement condition surveys to management. The only problem ADOT is currently experiencing is that manual methods are slow.

Arkansas

The Arkansas State Highway and Transportation Department (AHDT) collects IRI, rut, faulting, alligator cracking, transverse cracking, longitudinal cracking, joint distress, raveling, block cracking, punchouts, corner breaks, patch condition, and reflective cracking data. AHDT does not outsource their data collection. IRI, rut, and faulting data are collected on the Interstate System annually. Other National Highway System (NHS) and secondary system roadways are collected every two years. Crack data are collected annually for the Interstate System and every second year for other NHS routes. Cracking data are not collected on the secondary system. AHDT surveys both directions of the roadway and only the outside lane for multilane roadways. Data collection is restricted to permitting weather and to a limited degree, time of day. AHDT

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uses an ARAN van traveling at about 50 mph to collect IRI, rut, and faulting data as well as video which is post processed.

Results of the pavement condition surveys are reported to management typically upon request. IRI data are included in an annual road inventory system and cracking data are being compiled to begin establishing a pavement condition index.

AHDT is not currently experiencing any problems collecting pavement condition data. Like ALDOT, AHDT found it difficult to compare manual data collection to automated data collection when they were in the transition process from manual to automated. For example, comparing crack data collected manually on 0.1-mile sample sections and data collected automatically at 100%. Currently, AHDT is evaluating data collected by automatic crack detection verses manually rating a video of the pavement at a work station.

Colorado

The Colorado Department of Transportation (CDOT) collects IRI, rut, fatigue cracking, block cracking, transverse cracking, longitudinal cracking, and corner break data on all roads, every year. CDOT outsources its data collection through a competitive bid system which is re-contracted every 5 years. One lane in both directions is surveyed for multilane segments. On undivided roadways one lane is surveyed each year with the survey lane direction alternating from year to year. Restrictions for data collection are performance based; generally, no precipitation and ability to see cracks. CDOT's vendor collects IRI, rut, and video images of the roadway automatically while traveling at

highway speeds. The vendor manually reduces crack data. Currently the only problem CDOT is experiencing is that IRI data on concrete tends to be somewhat erratic.

CDOT uses statewide condition maps to report information to management. These condition maps identify highways as good, fair, or poor. Also reported to management is a list of suggested projects for the next three years and long-term condition projections that forecast the condition of the state's highways at various funding levels. The condition of the roadway is expressed using Remaining Service Life (RSL). The basic components of RSL are year of last work, pavement type, pavement thickness, traffic volume, and climate zone.

While making the transition from manual to automated data collection CDOT did not encounter any problems with IRI and rut data. For the last seven years CDOT's vendor has analyzed cracks in accordance with the *Distress Identification Manual for the Long-Term Pavement Performance Project* (SHRP-P-338). CDOT has considered using a crack analyzing software system; however, this would include approximately a 5-year transition period in order to obtain enough consistent cracking data to accurately regress their performance curves. Furthermore, CDOT is unaware of any crack analyzing software that can duplicate the SHRP method.

CDOT has employed a QC/QA program to accompany their pavement condition surveys. They run computer diagnostics on 100% of the data, visually verify 25% of the video images, and field check less than 1% of the data. Field sections are chosen to maximize the diversity of distress types, traffic levels, climate zones, and pavement thickness. CDOT has no set tolerances for discrepancies in the data due to the subjective nature of pavement distress identification; best engineering judgment is used instead.

Delaware

The Delaware Department of Transportation (DelDOT) collects the following data for their pavement condition surveys: surface defects, fatigue, joint reflection, block cracking, patching, transverse cracking, slab cracking, alkali silica reactivity (ASR), joint deterioration, joint seals, bleeding, edge cracking, and rough crown based on the surface type. Data are collected using manual windshield surveys on the entire road segment. DelDOT uses an Overall Pavement Condition (OPC) rating as their summary method. Each distress previously listed has a deduct value associated with it to calculate the final OPC. IRI is collected by another section of DelDOT and may later be incorporated into their rating system. Information is reported to management using a prioritization paving list annually. Any other information or statistics are available upon request.

DelDOT runs surveys annually on 100% of their road network. All lanes are surveyed to establish a composite score for the roadway. If it is a divided highway all lanes in both directions are surveyed but each direction is given a separate composite score. Data collection is restricted to times when an individual has the ability to effectively see the distresses. DelDOT outsources its data collection by request for consultant services.

DelDOT has established a QA program based on field surveys. Samples are chosen specifically for QA and are reevaluated for the purpose of QA. The sample sections are chosen based on the presence of a specific type of distress.

Georgia

The Georgia Department of Transportation (GDOT) collects data for the following distress types: rut depth, load cracking, block cracking, reflection cracking, patches, potholes, raveling, edge distress, bleeding/flushing, corrugations/pushing, and loss of section. Both presence of the above distresses and severity levels are taken into account. Other distresses such as transverse cracking are included in one of the above distress types. Transverse cracking is considered to be an initial stage of block cracking and is therefore rated in that category. HRI and friction data are also collected.

GDOT pavement condition surveys are completed annually on the entire state route network. The surveys are completed manually. The outside lane is surveyed in each direction for divided roadways and only the worst lane is surveyed for undivided roadways. The surveys are conducted during November and December of each year.

GDOT's data collection is completed manually using walking surveys on a 100-ft/mile representative sample. All data are collected by GDOT personnel (do not outsource). The road network is divided into logical projects and each project is given an individual rating. Projects may be divided by: a major change in pavement condition for more than two consecutive miles, a change in pavement type (not including spot overlays), or common sections containing more than on county route. The rating is a score from 0 to 100 with 100 representing a pavement with no visual surface defects. Points are deducted from the possible 100 based on the extent and severity of each surface defect. A wide variety of information is reported to management through the Georgia Pavement Management (GPAM) system. These reports are used at various levels for prioritization, optimization, budgeting, forecasting, etc. Projects with ratings

below the threshold value of 70 are confirmed by senior maintenance engineers at both the district and general office level.

Illinois

The Illinois Department of Transportation (IDOT) pavement condition surveys include the collection of the following data: IRI, rut, and digital images of the pavement for distress information. IRI, rut, and images of the pavement are collected through automated means. IDOT does not outsource their data collection. Interstates are surveyed every year and non-interstate pavements are surveyed over two years. During the two year cycle, 100% of the state network is recorded. The data collection is restricted by time of year and weather. IDOT only collects data in good weather conditions, and all data must be collected by the end of July in order to allow for sufficient time to create data summaries. IDOT uses a Condition Rating Survey (CRS) value to summarize pavement condition. The CRS is based on a 1 to 9 scale. The CRS values are stored in a database where they are used to help prioritize projects.

Indiana

The Indiana Department of Transportation (INDOT) collects IRI, rut, cracking, and faulting data for their pavement condition surveys. INDOT outsources its data collection by request for proposal. Interstates are surveyed annually and the rest of the network is surveyed biannually. IRI, rut, and faulting data are collected automatically at typical highway speeds. Video tape of the pavement is used by the consultant to measure the severity and extent of cracking as described by an INDOT manual supplied to the

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consultant. The first 500 ft of each mile post is rated from the video by the consultant. Data collection is suspended when raining. One lane is surveyed for multilane segments.

A Pavement Condition Rating (PCR) is used to summarize the data. The PCR is a composite index based on the severity and extent of various distresses. Surface condition reports, summary reports, and graphs are prepared for management as needed. INDOT is currently working on the establishment of a QC/QA program.

Kansas

The Kansas Department of Transportation (KDOT) collects IRI, rut, transverse cracking, fatigue cracking, joint distress, and faulting data for their pavement condition surveys. Cracking and joint distress data are collected manually by windshield surveys on three 100-ft randomly selected samples per pavement management section. A pavement management section is typically one mile long. These sections are not repeated from year to year. IRI, rut, and faulting data are collected using a profilometer.

Data are collected annually in the spring by KDOT, they do not outsource. For multilane segments only the driving lane is surveyed while both directions are surveyed for divided roadways. Data collection is primarily restricted to safe and efficient conditions.

KDOT combines a few ideas to summarize their pavement condition data. First, a "distress state" is computed from IRI, rut, and transverse cracking data (for flexible pavements). For rigid pavements different distresses are used to compute distress state. Next, an "index of first distress" is assigned. This index is a number from 1 to 4 that represents the extent of the last action performed on that particular segment. An index of

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1 implies the last action was fairly light and the distress is likely to come back sooner. An index of 4 implies the last action was heavy and the return of distress should take some time. Finally, the "distress state" is used with pavement type to obtain a single indicator called performance level. Performance level can be loosely interpreted as 1=good, 2=okay, and 3=poor condition.

An annual condition survey report is used to report information to management and it is also broadly distributed by KDOT (via their web site). In addition, the PMS group runs an optimization procedure to determine which locations would produce the greatest benefits for the available funds while achieving system wide performance goals.

KDOT has a redundant sampling program for both automated and manual surveys. The automated over-sampling allows them to evaluate variability in multiple runs. This over-sampling is achieved by collecting data on roadways that have already been surveyed as they travel to new locations that still need surveying. This results in some locations being sampled as many as six or seven times in a survey season. The manual QC sends two different groups over the same segment. This is achieved simply when survey crews assigned to adjacent areas overlap. KDOT also has a QA program to review a very small sample of each of their rater's work. This process involves running queries against the database to find locations that contain some variable of interest and this section is reviewed. The data collected from the QC/QA processes is mostly used so that KDOT knows how much variability they have and to help them with training exercises to help reduce variability.

Louisiana

The Louisiana Department of Transportation and Development (LaDOTD) collects the following data for their pavement condition surveys: IRI, rut, faulting, alligator cracking, random cracking, transverse cracking, longitudinal cracking, and patching. All of the data are collected automatically at about 50 mph on 100% of their network on a two year cycle. LaDOTD currently outsources their data collection. They invite interested vendors to demonstrate their capabilities and each is rated on certain criteria. LaDOTD surveys one lane for undivided highways and one lane in each direction for divided highways. Data are not collected if the pavement is wet or in any condition where the quality of the digital images will be affected.

Data are summarized using indexes for overall rating. IRI and a composite index that uses an average of all distress indexes are used for the overall rating. LaDOTD uses their Pavement Management analysis software to report information to management.

LaDOTD uses field surveys for calibration. The rest of their QC/QA program uses digital images for checks. Sections are chosen at random for QC/QA. 100% of the right of way images and 10-20% of the distress data are reviewed for QC/QA. A set tolerance for discrepancies was established as follows: 5% for IRI, 20% for rutting, and 10% for cracking.

Maine

The Maine Department of Transportation (MaineDOT) collects IRI, rut, longitudinal cracking, transverse cracking, and alligator cracking for their pavement condition surveys. MaineDOT does not outsource their data collection. Data are

collected on a two year cycle on all roads except for local roads or town ways. Data are

collected on the same sections, in the same direction, each time. All data are gathered by

automated means traveling in a van at a maximum speed of 45 mph. The data are

summarized at a frequency of 1/100 mile. Data are only collected on the most heavily

traveled lane for multilane segments. Data acquisition is restricted to the following:

daytime hours from approximately April thru December, above freezing weather with no

frost, and no rain.

MaineDOT uses a Pavement Condition Rating (PCR) composed of ride, rut, and

cracking type and severity to summarize their data. MaineDOT has a department wide

database through which data can be accessed. This database is used to create pavement

preservation program recommendations for project development. Data are also reported

in annual State of the System Reports.

Currently one of the biggest challenges MaineDOT is facing with automated

pavement condition surveys is finding space to store the digital images of the roadway

that have been collected on the network.

Maryland

The Maryland Department of Transportation (MDOT) collects IRI, rut, cracking,

and friction data for their pavement condition surveys. MDOT uses an automated data

collection vehicle to collect data at posted speeds annually on all roads over 1 mile in

length. Data are collected only on the slow lane for multilane segments. Data acquisition

is limited to daytime hours and dry weather. Data are summarized at 1/10 mile intervals.

MDOT does not use a composite rating. Instead, the summarized data are used to create

condition reports and preservation need reports based on results from optimization routines.

MDOT has been collecting data with the automated data collection vehicle since 1995 and are not experiencing any problems. The main challenge MDOT faced when making the transition from manual surveys to automated surveys was normalizing the data.

Michigan

The Michigan Department of Transportation (MDOT) collects the following data for their pavement condition surveys: IRI, rut, transverse cracking, longitudinal cracking, alligator cracking, delaminated areas, shattered areas, block cracking, Popouts, high steel, raveling, flushing, etc. The surface distresses are also assigned a severity and extent which are assigned using video taken of the roadway. Longitudinal and alligator cracking are also described with lane location. MDOT outsources their data collection to a vendor that collects data through automated means. Vendor selection is performed utilizing a formal qualifications-based proposal evaluation process overseen by their Contracts Division. Data are collected on the entire state network over a two year cycle. Data are collected on one lane per roadbed (outside lane). MDOT has various restrictions on data collection including seasonal, daily time, weather conditions, lane location, etc.

MDOT uses a Distress Index (DI) for surface distress indication. DI includes the accumulation of individual distress points normalized to a 0.1-mile pavement section length. DI increases as surface distress increases. Rutting is reported as average, minimum, and maximum depth per 0.1-mile section. IRI is reported as average over 0.1-

mile section. The DI values are analyzed over time to track pavement section performance, which is then reported in terms of Remaining Service Life (RSL). RSL is the estimated time remaining until major rehabilitation or reconstruction is required from a cost effectiveness standpoint. RSL is reported per homogenous pavement section for the entire statewide network. This can then be subdivided into regions, etc. as needed for department management purposes.

For surface distress QA purposes, MDOT reviews the same videotape of the pavement surface that the vendor reviews. A predetermined length percentage of each successive mile is randomly chosen for review by MDOT technicians for the comparison. MDOT allows a maximum percentage of wrong distress "calls" on the vendor's part per each submitted data file (per pavement management section) for acceptance.

Minnesota

The Minnesota Department of Transportation (Mn/DOT) collects the following data for their pavement condition surveys: IRI, rut, transverse cracking, longitudinal cracking, longitudinal joint deterioration, block cracking, alligator cracking, patching, raveling, transverse joint spalling, longitudinal joint spalling, faulting at joints and cracks, cracked and broken panels, and patched panels. Transverse cracking, longitudinal cracking, and longitudinal joint deterioration are further classified in severity levels of low, medium, or high. Longitudinal joint spalling and transverse joint spalling are further classified as slight or severe. Mn/DOT summarizes the collected data using three separate indices: Present Serviceability Rating (PSR), Surface Rating (SR), and Pavement Quality Index (PQI). PSR is Mn/DOT's ride or smoothness index and it uses a 0.0 – 5.0

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rating scale with the higher number representing a smoother road. SR is Mn/DOT's crack and surface distress index and it uses a 0.0 – 4.0 rating scale with the higher number representing less cracking. PQI is Mn/DOT's overall pavement condition index. PQI combines PSR and SR to give an overall performance indicator. PQI is calculated as follows:

$$PQI = \sqrt{PSR} \times SR \qquad (3.2)$$

PQI ranges from 0.0 to about 4.5. Information is reported to management through a published annual report that shows the average SR and PSR for each district as well as the whole state. They also have performance targets such as a maximum percentage of the system that can be in poor condition, the average years of remaining life, etc.

All Mn/DOT data collection is completed with state equipment and personnel. Mn/DOT collects rut, faulting, and ride automatically and determines the type and amount of distress by manually viewing video of the pavement surface taken from a van traveling at highway speeds. The first 500 ft of each mile is rated for distress information and the same sample is rated each cycle. Mn/DOT films the network annually but only rates half of the system each year for distress. IRI and PSR are measured annually on all roads. Only the outside lane in one direction is surveyed for distress. For IRI Mn/DOT surveys the outside lane in each direction for multilane divided roads and both lanes on 2-lane undivided roads. Data collection is restricted to: frost must be out of the ground, no water on the roadway, and light enough to see the film.

Mn/DOT does not have a formal QC/QA procedure. However, they have the same 2 people rate the entire system each time. Any problems/questions are worked out

between the two. Also, the indexes are evaluated from year to year to insure the change seems consistent and if it is not further investigation follows.

Mississippi

The Mississippi Department of Transportation (MDOT) collects IRI, rut, faulting, and other distresses according to the SHRP manual for their pavement condition surveys. Data are summarized with a Pavement Condition Rating (PCR) that takes into account IRI, rut, and all distresses with density and severity level of each distress. MDOT outsources their data collection. The vendor is selected based on qualifications, available staff, and past experience. Data are collected automatically for IRI, rut, and faulting on the entire state-maintained system. Distress analysis is completed by manually viewing video of the roadway on two 500-ft samples per mile, or the entire section if less than ½ mile. IRI, rut, and faulting data are collected in both directions for all roads while distress data are only collected in the north and east directions on undivided roads and both directions for divided roads. For multilane segments only the outside lane is surveyed. Data are not collected in the dark or when it is raining. MDOT uses a two year data collection cycle.

MDOT uses a Transportation Management Information System (TMIS) to help relay information to management. Usually PCR, IRI, rut, and faulting are reported when requested.

MDOT has an established QC/QA program based on field surveys. This program randomly selects and reviews 5% of the data for each pavement type. All problems are reported to the contractor.

Problems that MDOT has encountered include: occasionally video is not clear enough to see distresses and raters sometimes confuse certain crack types (e.g. transverse with reflective). Laser sensors are calibrated every day during the survey to avoid any problems with these data.

Missouri

The Missouri Department of Transportation (MoDOT) collects IRI, rut, alligator cracking, longitudinal cracking, block cracking, transverse cracking, patching, raveling, etc. MoDOT does not outsource its data collection. They collect IRI, ride, and rut data through automated means. Data are collected in both directions for divided roadways, one direction for undivided roadways, and only on the outside lane for multilane roadways. National Highway System (NHS) and routes over 1700 AADT are collected annually by automated method and routes under 1700 AADT are collected manually. Data are not collected when raining, snowing, or in the dark. Data are not validated in the field. Data are summarized as PSR for cracking and ride, and condition for just cracking. Information is reported to management through percent fair or better, condition maps, etc.

Nebraska

The Nebraska Department of Roads (NDOR) collects the following data for their pavement condition surveys: IRI, rut, faulting, alligator cracking, transverse cracking, grid/block cracking, edge cracking, wheel path cracking, centerline cracking, between wheel path cracking, failures, patches, excess asphalt, ravel/weathering, repairs, surface

cracking, spalling, joint and crack seals, and structural cracks. NDOR does not outsource its data collection. Data are collected on the complete system annually from about March or April to August 15. Data are not collected when raining. NDOR uses a profiler with rear mounted downward facing digital cameras to collect data at max speeds between 60-65 mph. IRI, rut, and faulting are collected automatically with the profiler and the digital images are rated to classify distress. A detailed rating is conducted on a 200 ft/mile section and then a windshield survey is conducted for the rest of the section to verify the results. For multilane roadways two lanes are surveyed in each direction.

Pavement distress data are converted to a number and the numerical ratings are fed into a formula that produces a rating called the Nebraska Serviceability Index (NSI). The NSI is a rating from 0 to 100 with 100 representing the best pavement. The NSI formula also contains a weighting factor concerning the rutting value of the road. Information is reported to management through prioritization reports, optimization reports and programs, needs assessment reports, and inventory reports. Also, maps showing the ranges of NSI, PSI, IRI and rutting are used.

NDOR's QC/QA program is partially based on field surveys with 10-15% of the data being randomly reviewed. The tolerance for discrepancies in the data is generally one severity level and one extent level.

Some of the problems NDOR has faced during the transition from manual to automated pavement condition surveys and still face include: the resolution and clarity of the digital images disabled the raters from seeing all distresses clearly, and ratings obtained from the images do not reflect some of the finer detail that can be observed by a rater standing on the shoulder of the road.

New Jersey

The New Jersey Department of Transportation (NJDOT) collects the following data for their pavement condition surveys: IRI, rut, multiple cracking, longitudinal cracking, transverse cracking, patching, shoulder condition, shoulder drop, cracks, faulting, longitudinal joint, and transverse joint. The distresses are also classified as slight, moderate, or severe. Load related distresses (in the wheel path) are also collected but are currently kept separate from other distresses. NJDOT summarizes the data using a Surface Distress Index (SDI) which is from 0-5. The SDI is calculated by subtracting the sum of the distress weights for all the distress types from 500 and then dividing by 100. Trigger values for SDI are established which are used for the selection of possible projects.

NJDOT collects all data on the State Highway System data and uses a consultant for data collection on the County Road System and Municipal Federal-Aid Roads. Data are collected on a two year cycle on 100% of the network. Data are only collected on the outside line for multilane roadways and both directions are surveyed on all roads. NJDOT data collection season is March 15 through December 15 of each year. Data are not collected in the rain, when there is water on the roads, or on extremely windy days.

NJDOT uses manual windshield surveys to collect surface distress for the State Highway surveys. The County Road System and Municipal Federal-Aid Roads are surveyed by the vendor automatically. The vendor collects IRI, rut, visible surface distresses, and load related distresses in the wheel path. The data collected automatically is summarized at 0.01-mile increments in the field and then is later summarized into 0.1-mile increments in the office.

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NJDOT has a QC/QA program based on field surveys. Sections are chosen for this program that range from good to poor in distress. NJDOT does not have a set tolerance for discrepancies in the data; however, they accept data that is within around 5%.

NJDOT has found that their manual surveys give good results on repeatability and that when moving to an automated system productivity increased but the quality of the data was compromised. They also feel that the subjectivity of raters rating surface distresses is still a weak link in the Pavement Management data collection process.

New York

The New York State Department of Transportation (NYSDOT) collects IRI, rut, and faulting using an automated road analyzer and collects distress data manually using windshield surveys. The distress data are summarized using a Pavement Condition Rating (PCR) and Dominant Distress. The data are reported to management through annual Pavement Condition Reports which summarizes condition data and trends in a variety of ways. The windshield survey covers 100% of the state-owned highways and some locally owned roads and the automated survey covers about 50% of this mileage. The windshield survey is conducted annually and the automated survey is conducted annually on Interstates and principal arterials, and biannually on the lower functional class highways. The windshield survey includes only the primary direction on divided highways and all lanes in both directions for others. Automated surveys are run on one lane in the primary direction. The windshield survey is conducted in May and June and

the automated survey is from April to December. Both surveys are limited to stable and dry pavement conditions.

NYSDOT has an established QA program that is based on field surveys. Shadow scoring is used on up to 10% of the mileage covered by the windshield survey. Five percent of the weekly mileage covered by the automated survey is resurveyed. The windshield QA sections are chosen semi-randomly (convenient locations). The automated QA sites are pre-established with additional random resurveys. Discrepancies between windshield survey data are considered acceptable within one percentage point. Fifteen percent variation is acceptable for the automated surveys.

Currently NYSDOT's manual windshield survey does not distinguish load-related from non-load related distresses. As a result some regions with cold temperature cracking receive a lower score, but the pavement structure is not necessarily in bad condition. NYSDOT has also recognized, while making the transition from manual to automated (although not fully) condition surveys, that maintaining continuity with historical pavement condition information has been a significant issue.

North Carolina

The North Carolina Department of Transportation (NCDOT) collects the following data for their pavement condition surveys: IRI, rut, alligator cracking, transverse cracking, raveling, oxidation, bleeding, patching, surface wear, longitudinal cracking, punchouts, narrow cracks, Y cracks, corner breaks, spalling, joint seal, faulting, and skid resistance. NCDOT collects interstate data only on odd years and the entire system on even years. Data are collected using manual windshield surveys on the entire

road segment for flexible pavements and manual walking surveys on 0.2 mile per 1 mile segment for concrete. NCDOT generally does not outsource their data collection, but have done it in the past for the interstate and primary systems. Data are collected in Spring/Summer for the interstates and Winter/Spring on the primary and secondary system. Data are only collected in the daytime and in dry weather.

NCDOT uses an overall condition rating to summarize their data. The overall condition rating is calculated by the deduction of points based on severity and amount of each distress. The rating is from 0 to 100 with 100 as the best pavement. Information is reported to management with the overall condition rating as well as individual distresses. Reports also give condition by county, district, and division as well as statewide condition.

Oklahoma

The Oklahoma Department of Transportation (ODOT) collects the following data for their pavement condition surveys: IRI, rut, transverse cracking, fatigue cracking, miscellaneous (non-wheel path) cracking, raveling, patching, faulting, multi cracked slabs, shattered slabs, corner breaks, joint spalling, D cracking, patching, and punchouts. IRI, rut, and faulting are collected automatically using sensors by a contractor for which ODOT outsources their data collection to. All other distresses are analyzed by the contractor by viewing images of the pavement. All distress analysis is done in accordance with ODOT protocols.

ODOT surveys 100% of their network on a two year cycle (half of the network each year). For a multilane, undivided segment only the outside lane in the primary

direction is surveyed. Both directions are surveyed for divided segments. Data are not collected when the pavement is wet, when there is ice on the road, or in the dark.

ODOT uses condition indices to summarize data along with some averages and percentages of individual distress. For asphalt concrete and composite pavements a ride index, rut index, functional index (non-load related distresses), and structural index (load related distresses) are used to summarize the condition. For jointed concrete pavements a ride index, fault index, joint index, and slab index are used to summarize the condition. For continuously reinforced concrete pavements a ride index and structural index are used to summarize the condition. The information is reported to management through Pavement Management Project Reports, which describe the route in question and give the condition indices for the route with some individual distress averages and percentages. ODOT also uses an Interstate Highway Rehabilitation Analysis Report, which gives a detailed analysis of the Oklahoma Interstate System.

ODOT has an established QC/QA program. This program uses four 0.5 mile control sites in the field to verify accuracy of automated data collection (IRI, rut, and fault). Their QC program is primarily based on examination of the pavement video with about 4 checks per mile. If problem areas are found, then those areas are further isolated and re-worked.

ODOT is currently experiencing a problem with consistency between raters and difficulty in interpreting AC cracking.

Oregon

The Oregon Department of Transportation (ODOT) collects IRI, rut, fatigue cracking, patching, longitudinal cracking, transverse cracking, raveling, potholes, bleeding, punchout, corner breaks, and joint condition. Data are collected on 100% of the network every other year by ODOT in the summer. They do not outsource data collection. The surveys are conducted manually using windshield surveys. One lane is surveyed for multilane segments. Data are not collected on excessively wet pavements.

Data are summarized with an overall index, rut index, fatigue index, patch index, no-load index, and raveling index. Information is reported to management using Pavement Condition Report for each section and summarized by region. National Highway System, state, and district highways are also given a functional classification.

Pennsylvania

The Pennsylvania Department of Transportation (PENNDOT) collects the following data for their pavement condition surveys: IRI, rut, fatigue cracking, transverse cracking, miscellaneous (block) cracking, edge deterioration, raveling/weathering, bituminous patching, transverse joint spalling, longitudinal joint spalling, transverse joint faulting, broken slab, and concrete patching. PENNDOT outsources its data collection. They use an Automated Road Analyzer Vehicle to collect 100% of the National Highway System (NHS) and 50% of the non-NHS annually. The vehicle collects data at speeds up to 50 mph. Data are collected on one lane of a multilane segment. Both directions are surveyed for divided highways and only one direction is surveyed on undivided highways. The same direction is surveyed each year for undivided highways. Data are

collected from April 1 to November 30 each year. Data are not collected in the rain or snow, and the sun must be high enough not to affect the pavement images.

Data are summarized and reported using an Overall Pavement Index (OPI). Individual distresses are also reported. Information is reported to management through a calculated maintenance dollar need per segment of highway.

PENNDOT has established a QA program that is currently in its first year. PENNDOT uses its own video log van to collect QA data. They are starting the QA program with 5% of the network coming under review. QA segments are chosen through stratified random sampling. The condition database is used to project anticipated condition for sample selection. The majority of samples selected are chosen near critical condition values as determined through a sensitivity analysis. Table 3.1 lists some data types, the criteria, percent of data within the limits, and recommended action if criteria not met.

Table 3.1 PENNDOT's Tolerances for Discrepancies in Data.

Reported Value	Initial Criteria	Percent within Limits	Recommended Action if Criteria Not Met
IRI	±25%	95	Reject deliverable
Individual Distress Severity Combination	±30%	90	Feedback on potential bias or drift in ratings, retrain on definitions.
Total fatigue	±20%	90	Reject deliverable
Total Non-Fatigue Cracking	±20%	90	Reject deliverable
Total Joint Spalling	±20%	90	Reject deliverable
Transverse Cracking, JCP	±20%	90	Reject deliverable

PENNDOT is not currently experiencing any problems measuring distresses. When making the transition from manual to automated data collection PENNDOT had to redefine the conditions they would survey. This meant eliminating some and changing the definition and measurement method of others. They also had to change their treatment matrices to allow for the detail now provided through automated data collection.

South Dakota

The South Dakota Department of Transportation (SDDOT) collects the following data for their pavement condition surveys: IRI, rut, transverse cracking, block cracking, fatigue cracking, patch deterioration, faulting, joint spalling, d-cracking/ASR, corner cracking, joint seal damage, and punchouts. Each distress is also assigned a severity and extent. SDDOT collects data on 100% of their network annually (do not outsource). IRI, rut, and faulting are collected through automated means and all other distresses are collected through manual windshield surveys. All lanes are surveyed on multilane segments in both directions. Data are not collected in rain or in conditions that are considered unsafe by the survey crew.

SDDOT summarizes the data using an overall condition rating called Surface Condition Index (SCI). The SDDOT Pavement Management Unit produces Highway Needs and Project Analysis Reports, Highway Needs Maps, and Surface Type Maps from the pavement condition surveys.

Texas

The Texas Department of Transportation (TxDOT) collects the following data for their pavement condition surveys: IRI, ride quality, texture, deflection, rut, patching, failures, alligator cracking, block cracking, longitudinal cracking, transverse cracking, raveling, flushing, spalled cracks, punchouts, asphalt patches, concrete patches, average crack spacing, failed joints and cracks, shattered slabs, slabs with longitudinal cracks, and apparent joint spacing. TxDOT collects data on 100% of their network annually. Data are collected on the worst lane for multilane roadways and are collected in both directions for divided roadways. IRI, rut, and ride quality are collected automatically with a TxDOT built van at speeds up to 70 mph. Data collected with the van are summarized at 0.1-mile intervals. All other data are collected primarily using manual windshield surveys with some walking on the side of the road when needed. TxDOT outsources their manual data collection only.

Data are only collected in dry conditions in daylight hours. Pavement distress ratings are completed from September through December, ride quality and rut measurements are made September through February, skid resistance and texture measurements are made April through August, and deflection measurements are made at any time in the year.

Data are summarized using a rating that includes distress ratings, ride quality, average daily traffic, and speed limit. Information is reported to management in various ways. Network Needs Estimate Reports and Prioritization Reports are generated. Maps of specific routes or regions as well as detailed lists of sections are also used to report information.

TxDOT has established a QC/QA program that is based on field surveys. All sections with distress ratings are eligible for audit. They use a 6 to 12% random sample, by county, for approximately half of the counties in each district for the program. District personnel choose the counties to be audited, but have authority to reject data for any county that they contest. TxDOT rejects a county's data if the calculated "Distress Score" (based on distress types, except for rutting) on audit sections differs from the rated sections by more than 15 points on more than 10% of the audit sections.

Currently TxDOT is experiencing a few problems measuring distresses. Rutting is currently measured using five acoustic sensors and these sensors over-report rutting on coarse-aggregate surfaces such as seal coats. They also have trouble measuring rutting in high wind (this includes driving into the wind) and during periods of high humidity. TxDOT hopes to replace the ultrasonic rut sensors with a scanning laser system by September 2004. Also, the ride quality (profile) lasers have had occasional problems over-reporting roughness on concrete pavements, especially on CRCP section with spalled cracks and JCP sections with wide/spalled joints.

TxDOT is in the process of changing there distress ratings from manual to automated. It is their hope that by September 2004 they will have completed this task.

Vermont

The Vermont Agency of Transportation (VTran) collects IRI, rut, wheelpath cracking, non-wheelpath cracking, and transverse cracking data for their pavement condition surveys. VTran uses a contractor that collects data on 100% of the network on a two year cycle using an automated data collection vehicle. Data are collected on one

lane for multilane roadways and in only the primary direction for non-divided highways. Data are collected continuously and summarized in 1/10 mile sections. VTran uses a summary index to summarize data. Information is reported to management using an average statewide condition index and percent "very poor".

VTran checks the consultant's results on small field sections. The sections are chosen for their proximity to the office, representative conditions, and safe sites.

VTran has been using automated pavement condition surveys for about 10 years. They are currently not experiencing any problems measuring distresses.

Virginia

The Virginia Department of Transportation (VDOT) collects smoothness, surface distress, and structural analysis data for their pavement condition surveys. VDOT currently collects their data through manual windshield surveys on 100% of their Interstate and Primary System. Data are collected on 5% of their Secondary System, which is chosen by random stratification. However, VDOT will soon be changing over to automated data collection.

Data are collected from only one lane for multilane roadways and in both directions for divided roadways. Data are collected annually through the winter months to avoid construction season. VDOT summarizes data using a Load Distress Rating and a Non-Load Distress Rating. The components of these indices are all the surface collected quantified distresses. Information is reported to management with a State of the Pavement Report.

VDOT has a QC/QA program based on field surveys that is performed separately and independently from the survey production team. Data are chosen based upon the central limit theorem and results in collecting 30 random samples from each district. VDOT has established approximately a 2 standard deviation maximum acceptable variance for data.

VDOT has been experiencing problems finding a system that can perform automatic crack detection for their future system. Also, VDOT has had to create a distress rating manual that addresses the problem of making the transition from manual to automated data collection.

West Virginia

The West Virginia Department of Transportation (WVDOT) collects IRI and rut for their pavement condition surveys. WVDOT outsources their data collection. IRI and rut are collected automatically and summarized at 0.1-mile intervals. In the past WVDOT has collected data on a biannual cycle; however, in 2003 they will start to collect data annually. WVDOT collects data on 25% of their network and use approximately the same routes from year to year with slight adjustments as needed. Data are collected in one direction for two-lane roads and both directions for four-lane roads and above. One lane in each direction is surveyed for four-lane roads and the number increases as the total number on lanes increases (e.g. four lanes for a six-lane road). Data are only collected in clear and dry weather. Average IRI and rutting are reported to management as needed.

WVDOT has a QC/QA program based on field surveys. One percent of the data are chosen for audit. WVDOT has established a 3 to 5% tolerance for discrepancies in the data.

SUMMARY

Information obtained through the questionnaire was broken into three basic groups in order to summarize. These groups include the actual procedure used to perform pavement condition surveys, quality control and quality assurance, and problems/challenges that states have faced in their experiences with pavement condition surveys.

Pavement Condition Surveys

Of the 27 states that responded to the survey only 5 states did not report the use of any automated data collection. The remaining 22 states all collect International Roughness Index (IRI) and rutting data automatically. Fifteen of the states collect surface distress data through automated means. The data that each state reported they collect using automated collection practices are shown in Table 3.2.

The majority of the states surveyed reported the collection of pavement condition data was completed annually. A biannual data collection cycle was the second most common response. A summary of the findings on each state's data collection cycle is shown in Figure 3.1.

Almost all of the states surveyed reported they collect data in both directions on divided roadways and only collect data in one direction for multilane, undivided

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roadways. The outside lane is chosen by most states to survey for multilane roadways. Figure 3.2 and Figure 3.3 summarize the results of which lanes the states collect data on.

The overall consensus from the 27 states is that dry non-freezing weather is needed to collect data. Furthermore, most states reported that data are only collected in the daylight hours. Also, any condition that may compromise safety is not surveyed in.

Just over half of the states reported that they do not outsource their data collection (see Figure 3.4).

Quality Control and Quality Assurance

The responses to the questions on quality control and quality assurance (QC/QA) varied and most were left blank. However, some states reported QC/QA systems that they have incorporated into their data collection process.

The Colorado Department of Transportation (CDOT) runs computer diagnostics on 100% of the data, visually verifies 25% of the video images, and field checks less than 1% of the data. Field sections are chosen to maximize the diversity of distress types, traffic levels, climate zones and pavement thickness.

The Louisiana Department of Transportation (LaDOTD) uses field surveys for calibration. The rest of their QC/QA program uses digital images for checks. Sections are chosen at random for QC/QA with 100% of the right-of-way images and 10-20% of the distress data being reviewed. LaDOTD has established a set tolerance for discrepancies as follows: 5% for IRI, 20% for rutting, and 10% for cracking.

The New York State Department of Transportation (NYSDOT) has an established QA program that is based on field surveys. Shadow scoring is used on up to 10% of the

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mileage covered by the windshield survey. Five percent of the weekly mileage covered by the automated survey is resurveyed. The windshield QA sections are chosen semi-randomly (convenient locations). The automated QA sites are pre-established with additional random resurveys. Discrepancies between windshield survey data are considered acceptable within one percentage point. Fifteen percent variation is acceptable for the automated surveys.

The Kansas Department of Transportation (KDOT) has a redundant sampling program for both automated and manual surveys. The automated over sampling allows them to evaluate variability in multiple runs. This over sampling is achieved by collecting data on roadways that have already been surveyed as they travel to new locations that still need surveying. This results in some locations being sampled as many as 6 or 7 times in a survey season. The manual QC sends two different groups over the same segment. This is achieved simply when survey crews assigned to adjacent areas overlap. KDOT also has a QA program to review a very small sample of each of their rater's work. This process involves running queries against the database to find locations that contain some variable of interest and this section is reviewed. The data collected from the QC/QA processes is mostly used so that KDOT knows how much variability they have and to help them with training exercises to help reduce variability.

Other QC/QA practices used by DOT's include:

- Check the vendor by reviewing the same video.
- Use control sites in the field to verify the accuracy of automated data collection devices.

- Use of a condition database to project anticipated condition for a sample section.

Problems/Challenges

Along with all of the other questions, each state was asked if they were experiencing any specific problems in measuring distresses; and, what kind of problems/challenges they faced when transitioning from manual to automated distress collection.

A problem faced by those states conducting manual surveys is the amount of time that it takes to complete them. Also, the subjectivity and lack of consistency in raters has proved to be a problem. One state also reported that their manual windshield survey did not distinguish load related from non-load related distresses causing unfair penalization for some roadways. Other states that rate images of the pavement have found that occasionally the images are not clear enough for their raters to properly rate. Some have found that while production has gone up with automated data collection, the quality of the data has suffered. Also, the amount of storage required to save data for automated surveys has proved to be a problem for some.

A common problem that states have faced is trying to find a system that can perform automated crack detection and classification. Some states feel there is not a current crack analysis program available that can duplicate the SHRP-P-338 method. Furthermore, if and when there is a crack analysis program that is found to be satisfactory, different states already see a problem with trying to maintain continuity with their historical pavement condition data.

When making the transition from manual to automated distress collection the Pennsylvania Department of Transportation (PENNDOT) had to redefine the conditions they would survey. This meant eliminating some and changing the definition and measurement method of others. They also had to change their treatment matrices to allow for the detail now provided through automated data collection. South Dakota reported that they had to write and change programs to deal with the additional data. Virginia DOT created a distress manual that addressed the problem specifically.

CONCLUSIONS

From the results of the questionnaire, it is concluded that a fully automated pavement condition data collection system has been successfully incorporated into few state DOT's Pavement Management System. While IRI, rut, and faulting data are collected automatically by most states, the automatic collection and analysis of crack data has proved to be much more of a challenge. There are current programs that can collect and analyze crack data; however, there are state organizations such as ALDOT who have encountered problems incorporating such programs into their system and other organizations that would rather wait for more advanced technology to become available. There are also organizations like Maryland Department of Transportation (MDOT) that have had success running a fully automated system. Organizations such as MDOT did not complete this transaction successfully without some difficulty and some system changes and any organization planning to make the transaction should intend on facing similar obstacles.

Table 3.2 Data Collected Automatically by Each State.

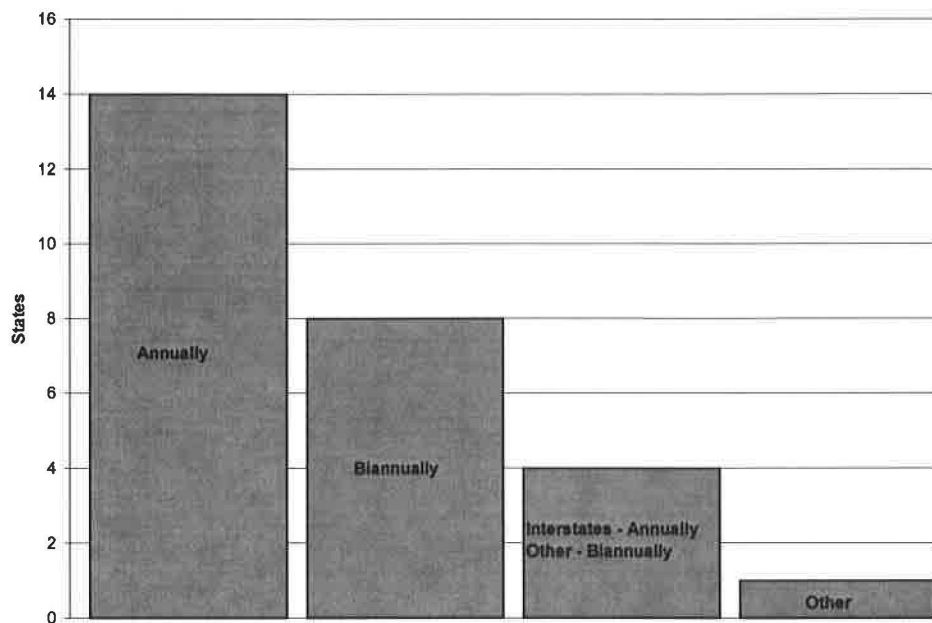|	IRI	Rutting	Cracking	Faulting	Friction	Other
Arizona	×	×			×	
Arkansas	×	×	×	×		
Colorado	×	×	×			
Delaware						
Georgia						
Illinois	×	×	×			
Indiana	×	×	×	×		
Kansas	×	×		×		
Louisiana	×	×	×	×		
Maine	×	×	×			
Maryland	×	×	×		×	
Michigan	×	×	×			
Minnesota	×	×	×	×		
Mississippi	×	×	×	×		
Missouri	×	×				
Nebraska	×	×	×	×		
New Jersey	×	×	×			
New York	×	×		×		
North Carolina						
Oklahoma	×	×	×	×		×
Oregon						
Pennsylvania	×	×	×	×		×
South Dakota	×	×		×		
Texas	×	×				
Vermont	×	×	×			
Virginia						
West Virginia	×	×				
Total	**22**	**22**	**15**	**11**	**2**	**2**

Figure 3.1 Results for the Length of Each State's Data Collection Cycle.
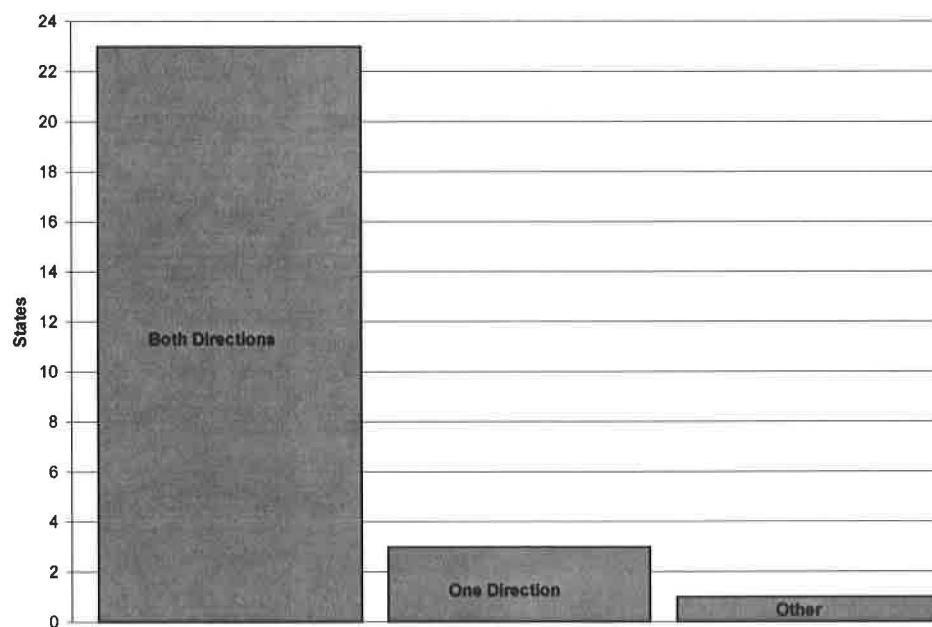

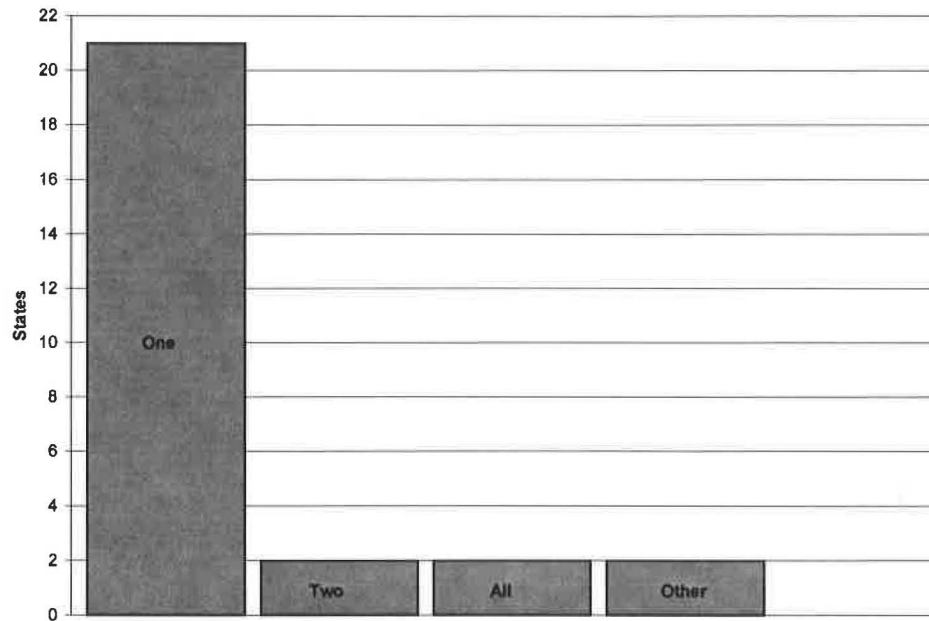**Figure 3.2 Results for How Many Directions are Surveyed on Divided Roadways.**

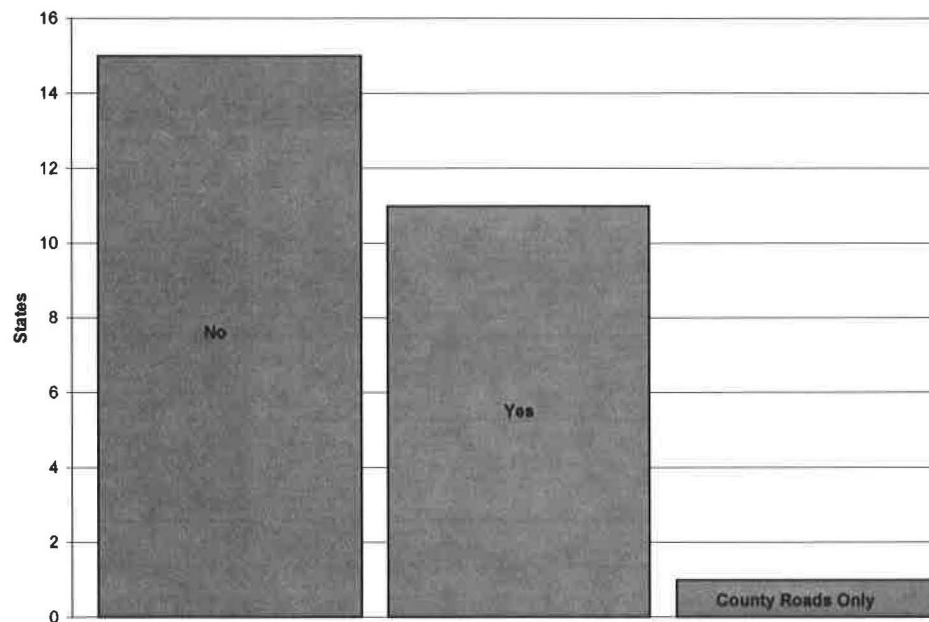**Figure 3.3 Results for the Number of Lanes Surveyed on a Multilane Roadway.**

Figure 3.4 Results of Whether or Not Each State Outsources Their Data Collection.

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CHAPTER 4

AUTOMATED DATA VS MANUAL DATA

INTRODUCTION

The Alabama Department of Transportation (ALDOT) has a quality assurance (QA) program that compares automated pavement condition survey data, collected by an external vendor, to pavement condition data obtained manually by an ALDOT rater. The automated data are collected continuously, with data tabulated every 52.8 ft (100 data points per mile) and every 264 ft (20 data points per mile). For the comparison, ALDOT raters surveyed 200-ft sections using the same method that was used before ALDOT adopted an automated system, except the QA program uses a collection frequency of once every ten miles instead of once every mile. The first cycle of the QA program was completed in 2003.

The data from the first cycle of the QA program was used to complete research on the QA program and to examine the manual and automated data. The results of an investigation on the methodology used for matching up pavement sections for the QA program are discussed in this chapter. This investigation was completed in order to determine if the automated and manual pavement sections used for comparison in the QA program are in fact the same section of pavement. Also, statistical analysis that was completed on the data obtained from the first cycle of the QA program is presented in this chapter. The statistical analysis was completed to check for systematic error and to

observe any general trends in the data. Lastly, the results of a sensitivity analysis on the ALDOT Pavement Condition Rating (PCR) equations are presented in this chapter. The sensitivity analysis was completed in order to determine the effect that the error in each input has on the final PCR value.

DATA COLLECTION

Automated pavement condition data, used for the QA program, are tabulated every 52.8 ft and saved in a Microsoft Access file. The manual data are collected by an ALDOT rater on 200-ft sections at a frequency of once every ten miles. Once all data are collected the automated and manual sections are matched for comparison. The manual data collection process and the method for comparing it to automated data are discussed in this section.

Manual Data Collection

For the manual pavement condition survey of a two-lane section of pavement, the raters begin at the milepost and rate for 200 ft in the primary direction and then turn and rate the secondary direction (Bell, 2002). An example of this scenario is pictured in Figure 4.1.
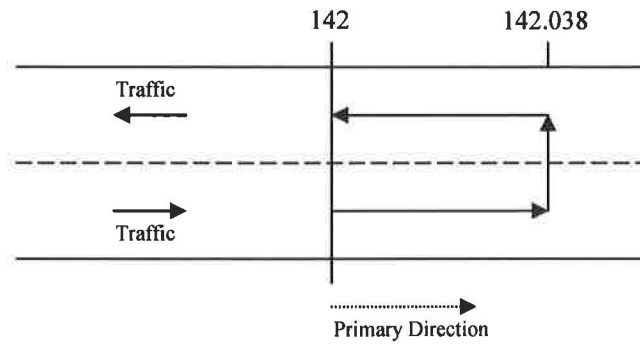
142   142.038

Traffic

Traffic

Primary Direction

Figure 4.1 Schematic of ALDOT's Manual Survey for a 2-Lane Section.

The procedure for a multilane route is similar to the procedure used for a 2-lane route.
The raters rate the section the same as they did for a 2-lane route in the primary direction.
However, the raters survey in the direction of travel for lane 1 and then return to the
milepost in lane 2 for the secondary direction. An example of this scenario is pictured in
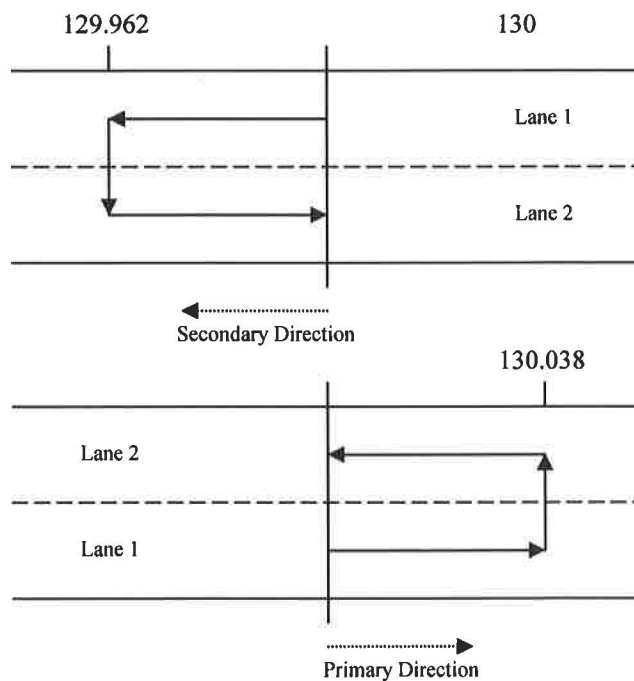Figure 4.2.

129.962   130

Lane 1

Lane 2

Secondary Direction

130.038

Lane 2

Lane 1

Primary Direction

Figure 4.2 Schematic of ALDOT's Manual Survey for a Multilane Section.

Data Comparison

All data for the automated and manual surveys are saved in a Microsoft Access file. Data is tabulated every 52.8 ft for the automated survey; therefore, four segments of 52.8 ft are used for comparison to the 200-ft manual survey data. Four segments of 52.8 ft equates to approximately 211 ft, which is roughly the same as the 200-ft sections (Bell, 2002). ALDOT's goal is to select the four automated data points that most closely match the 200-ft sections. An example of how the data is matched is pictured in Figure 4.3 for milepost 142. For a four lane section both the primary direction data and secondary direction data are matched for comparison.

After the data has been matched for comparison, automated cracking and patching distress data are multiplied by .947 in order to account for the longer automated section (211.2 ft).
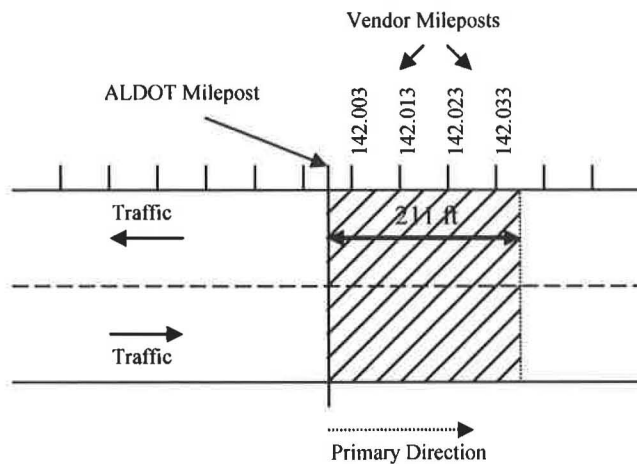

Figure 4.3 Schematic of the ALDOT Data Comparison Methodology.

International Roughness Index (IRI) data are compared for an entire mile. ALDOT uses the South Dakota Profiler (SDP) to determine IRI for the entire mile. The SDP measures the pavement profile using a vehicle mounted accelerometer used to record the vertical position of a reference point and a device that measures the vehicle height (Huft, 1984). The pavement profile is then used to calculate IRI. The vendor data are matched to the ALDOT data in the same way as mentioned above, except 100 records are used instead of four. The frequency for IRI comparison is the same, once every 10 miles.

DATA COMPARISON METHODOLOGY INVESTIGATION

In order for ALDOT's QA program to be valid, it is important to establish that the section being surveyed manually by ALDOT is the same section that was surveyed automatically by the vendor. In other words, the QA comparison should be made from data that represents the same section of roadway. The vendor collects data continuously and tabulates the data every 52.8 ft. The tabulated data are assigned a milepost and a set of directional coordinates. In theory, the vendor coordinates should be a close match to coordinates of ALDOT mileposts. This section describes an investigation conducted in order to determine the location of ALDOT mileposts in comparison to the vendor mileposts.

Investigation

The automated data interstate database was queried for exact mileposts on Interstate 85. In theory, this should be located exactly even with the ALDOT milepost

standing on the side of the road. From the database, the latitude and longitude of the vendor mileposts were known. Two hand held GPS systems were used to establish the latitude and longitude of the ALDOT mileposts. This allows for a comparison to be made between the location of the vendor milepost and the ALDOT milepost. The distance between the vendor and ALDOT milepost can be determined with the coordinates; however, the direction in which the two mileposts are off is not known. Since the vendor was surveying down the roadway when the coordinates were recorded it is assumed that all differences in milepost location are linear down the roadway.

Two GPS systems were used in an effort to eliminate some error. Hand held GPS systems vary in accuracy and can not be relied on to give the exact location; however, they can be considerably accurate. Different GPS systems can give results that vary. Therefore, two systems were used in order to obtain an average distance. The two GPS systems used in this investigation will be referred to as blue and yellow.

With the coordinates of the vendor and ALDOT mileposts known, the distance between the two was calculated using the Great Circle Calculator program created by Ed Williams (2003). This program uses a WGS84/NAD83/GRS80 earth model to calculate the distance between two sets of coordinates. The program also allows for other earth models to be used for the calculations. Several other earth models were tested, but all resulted in approximately the same answer.

The distance between consecutive miles was also checked for both the vendor and ALDOT mileposts. For instance, the distance between the vendor coordinates for milepost 1 and milepost 2 was calculated. This was also completed for the measured

coordinates at the ALDOT mileposts. This was completed as a check to see if the mileposts were in fact a mile apart and to see how accurate the coordinates are.

Results

Four stretches of Interstate 85 were found to have exact mileposts in the automated database. Two stretches were in the primary direction (North East), and two stretches were in the secondary direction (South West). The primary direction will be referred to as direction 5 and the secondary direction as direction 6. Table 4.1 defines the direction and location of each of the four stretches under investigation.

Table 4.1 Location of the Four Stretches Under Investigation.

Direction	Milepost	Stretch
5	1 - 6	1
5	33 - 38	2
6	40 - 47	3
6	27 - 32	4

The distance between the vendor and ALDOT milepost for stretch one, milepost 1 is an average of 30 ft. This is not an exact match; however, it is close, with all things considered. Milepost 6, for the same stretch, is an average of 68 ft off. This difference in milepost location would result in 132 ft out of the two 200-ft sections that would be valid for comparison. The described scenario is pictured in Figure 4.4. The shaded area is the only section that would be valid for comparison in lane 1. All of the results for stretch one are presented in Table 4.2.
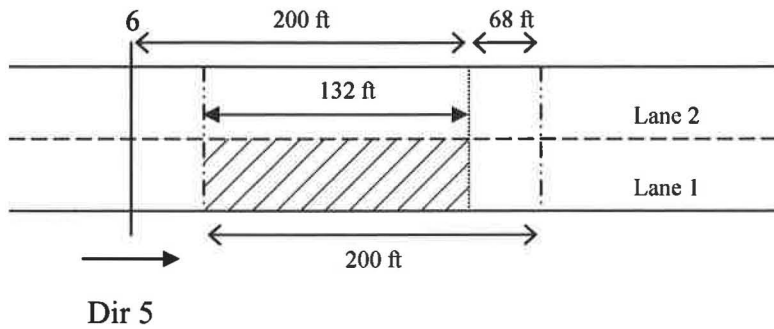
86

6   200 ft   68 ft

132 ft

Lane 2

Lane 1

200 ft

Dir 5

Figure 4.4 Difference in Location of Milepost Scenario for Milepost 1.

Table 4.2 Results of the GPS Investigation for Stretch One.

Stretch	Milepost	Direction	Difference, ft		
			blue	yellow	average
1	1	5	28.1	31.9	30.0
	2	5	24.4	37.6	31.0
	3	5	28.9	26.9	27.9
	4	5	45.3	57.9	51.6
	5	5	44.0	63.6	53.8
	6	5	62.3	73.3	67.8

The vendor and ALDOT mileposts for stretch 2 all had a considerable amount of distance between them. At milepost 33 the average distance between the milepost locations was calculated to be 84 ft and the distance increased every mile up to an average of 128 ft for milepost 38. This trend of increasing distance between milepost locations as milepost number increases was observed for all the data examined for direction 5. At milepost 1 the average difference is 30 ft and at milepost 38 the average difference is up to 128 ft. A difference in milepost location of 128 ft only allows for about 70 ft of valid comparison. The general trend for direction 5 is pictured in Figure 4.5. This trend could be the result of compounding error. For example, the second

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milepost is off by the error in the first milepost plus the error in the second milepost. The third milepost is then off by the error in the first milepost plus the error in the second milepost plus the error of the third milepost, and so on. The set of results for stretch 2 is presented in Table 4.3.
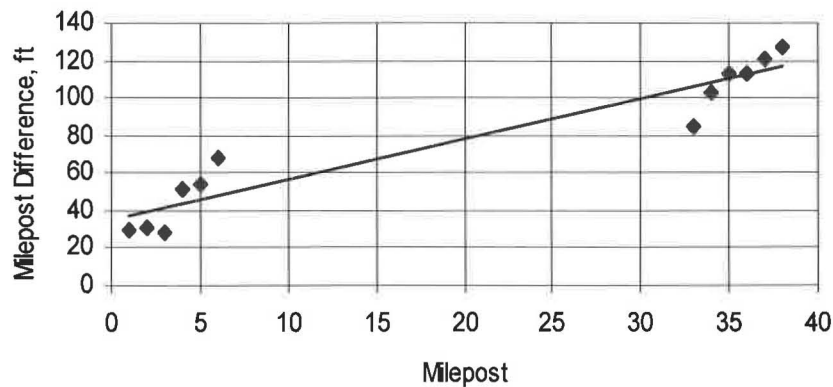

Figure 4.5 The General Trend for Difference in Milepost Location for Direction 5.

Table 4.3 Results of the GPS Investigation for Stretch Two.

Stretch	Milepost	Direction	Difference, ft		
			blue	yellow	average
2	33	5	84.9	84.9	84.9
	34	5	102.3	103.6	102.9
	35	5	108.5	118.0	113.3
	36	5	113.6	113.6	113.6
	37	5	120.2	120.2	120.2
	38	5	129.4	125.8	127.6

The average difference in milepost location for all of the data of stretch 3 is 3265 ft or 0.62 miles. This was thought to be an error in the investigation until these

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differences were confirmed by a previous GPS investigation conducted a few weeks prior. In this case, it is clear that the two sections in comparison are not the same. However, stretch 4, which is only 8 miles from stretch 3, had an average difference in milepost location of 47.4 ft. The high value was 82.1 ft and the low value was 19.3 ft. This shows that there was a major error that occurred somewhere between milepost 32 and 40. The results for stretch 3 and stretch 4 are presented in Table 4.4.

Table 4.4 Results of the GPS Investigation for Stretch Three and Four.

Stretch	Milepost	Direction	Difference, ft		
			blue	yellow	average
3	47	6	3250.4	3294.2	3272.3
	46	6	3288.5	3288.5	3288.5
	44	6	3330.4	3323.9	3327.1
	43	6	3276.1	3263.6	3269.8
	42	6	3274.8	3262.4	3268.6
	41	6	3236.2	3285.0	3260.6
	40	6	3121.2	3210.1	3165.6
4	32	6	63.9	51.0	57.5
	31	6	22.3	16.3	19.3
	30	6	16.2	25.6	20.9
	29	6	38.6	22.6	30.6
	28	6	72.7	74.8	73.7
	27	6	79.1	85.1	82.1

The calculated distances between the vendor mileposts based on coordinates had small amounts of error. The maximum calculated error was 2.35%. This error is the result of the calculated distance between milepost 3 and 4 coming up 124 ft short of a mile. The average error in the distance between the vendor mileposts is 0.65%. The small amount of error shows that the vendor is accurate measuring from milepost to milepost.

The calculated distances between ALDOT mileposts based on measured coordinates also had small amounts of error. The maximum calculated error was 5.73% and the average error was 1.26%. The small amount of error shows that the placement of ALDOT mileposts is fairly accurate.

It is concluded that the ALDOT and the automated 200-ft sections in comparison for the quality assurance program are not always the same pavement section. Out of the four stretches of Interstate 85 investigated, the average distance between the ALDOT and the automated mileposts are shown in Table 4.5. The difference in location of the ALDOT mileposts and the automated mileposts could be the result of a number of things. It is first important to note that the ALDOT mileposts are not placed at survey level accuracy. Second, the automated survey vehicle starts data collection at a "zero marker". The "zero marker" is a known physical location. An example of a "zero marker" could be a milepost, a bridge, a railroad crossing, or an intersection. If the data collection is not started in the same location as the "zero marker", there could be a difference in the location of ALDOT and the vendor mileposts. The vendor does have a navigational system that is used to help verify the location of the vehicle. However, this is not used to verify that the vehicle is in an exact location compared to an ALDOT location.

Table 4.5 Average Distances Between ALDOT and the Vendor Mileposts.

	Stretch 1	Stretch 2	Stretch 3	Stretch 4
Average Difference, ft	44	110	3265	47

STATISTICAL ANALYSIS

Regression was used in an effort to determine if there was some sort of systematic error between the manual ALDOT data and the automated data, and to observe any general trends in the data. If a systematic error was found, a correction factor could likely be used to correct the error in the data. An example of a systematic error that would be evident from running regression is shown in Figure 4.6. For the example, the trend line that was computed from the data would need only a correction factor to compensate for the offset.
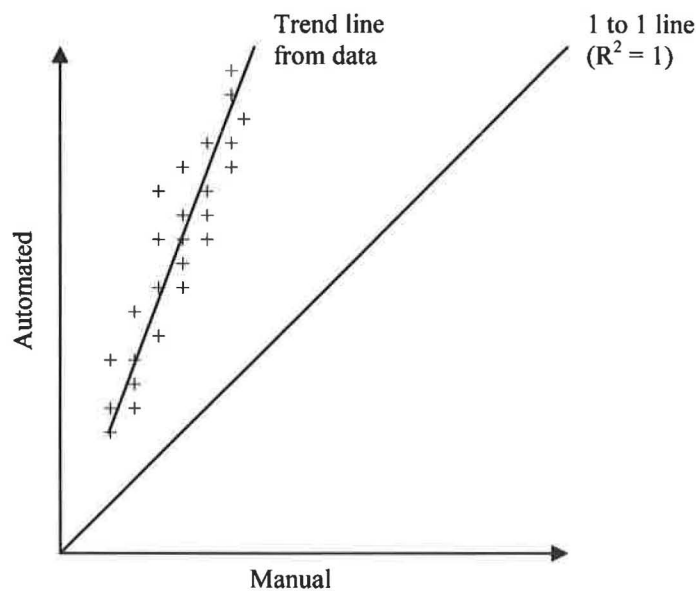

Figure 4.6 Example of a Trend that Could be Corrected Using a Correction Factor.

Methodology

The regression was run using Microsoft Excel by plotting automated verses manual data. A trend line, complete with a computed R^2 value, was then constructed for

each input. Each plot was examined to determine if there was any systematic error evident or if there were any general trends in the data. Raveling was not included in this analysis because it is classified by severity level only and not extent. Also, there was not enough patching data in order to achieve any practical analysis.

Results

The regression plots showed that most of the distress types did not have a good correlation. IRI was found to have the best fit with a R^2 value of approximately 0.65. The linear regression plot for IRI is shown in Figure 4.7. The complete set of regression plots is located in Appendix C.
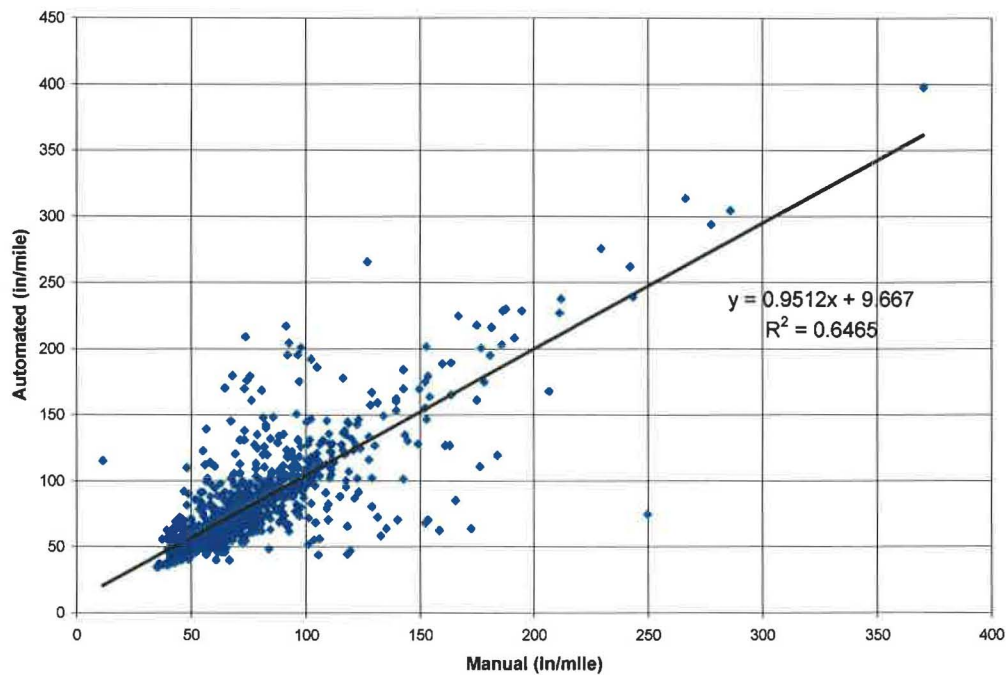

The plot shows Automated (in/mile) on the y-axis versus Manual (in/mile) on the x-axis with the regression equation $y = 0.9512x + 9.667$ and $R^2 = 0.6465$.

Figure 4.7 Regression Plot for IRI.

From the examination of the regression plots, it was determined that there is not a systematic error that occurs between any type of manual and automated data. The majority of the error looks to be randomly distributed. However, there were a few trends in the data that were discovered. In Figure 4.8, it was observed that the automated data over-reports average outside wheel path rutting. One cause for this trend in rutting could possibly be an error in the manual collection process. A 4-ft long level with a dial gage is used to collect rut depth. The ends of the level may be in the rut, which would result in lower rut depth values. Also, a general trend that the automated data underreports alligator 1 cracking was observed from Figure 4.9. This trend in alligator 1 cracking could be caused by the difficulty in detecting low severity cracks, such as cracks less than 3 mm wide. Lastly, it was observed in Figure 4.10 that the automated data over reports alligator 3 cracking.
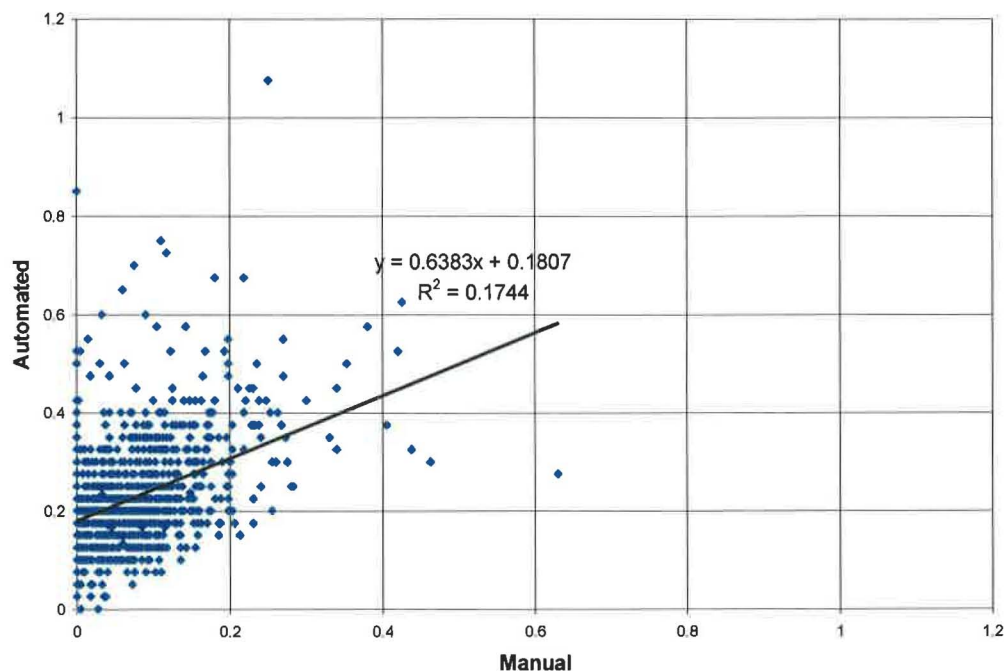

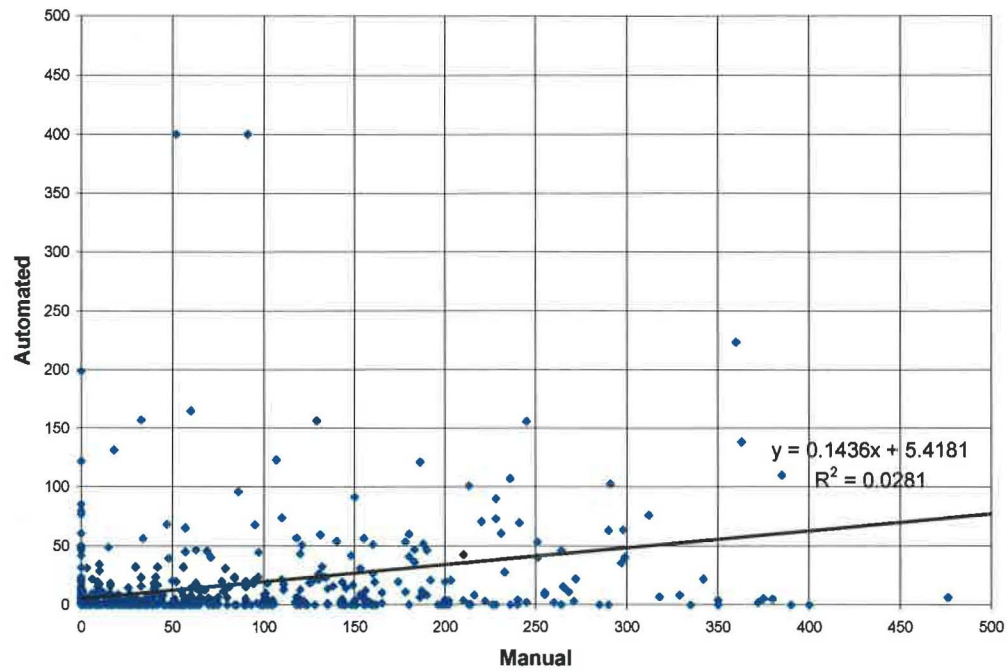**Figure 4.8 Regression Plot for Outside Wheel Path Rutting.**

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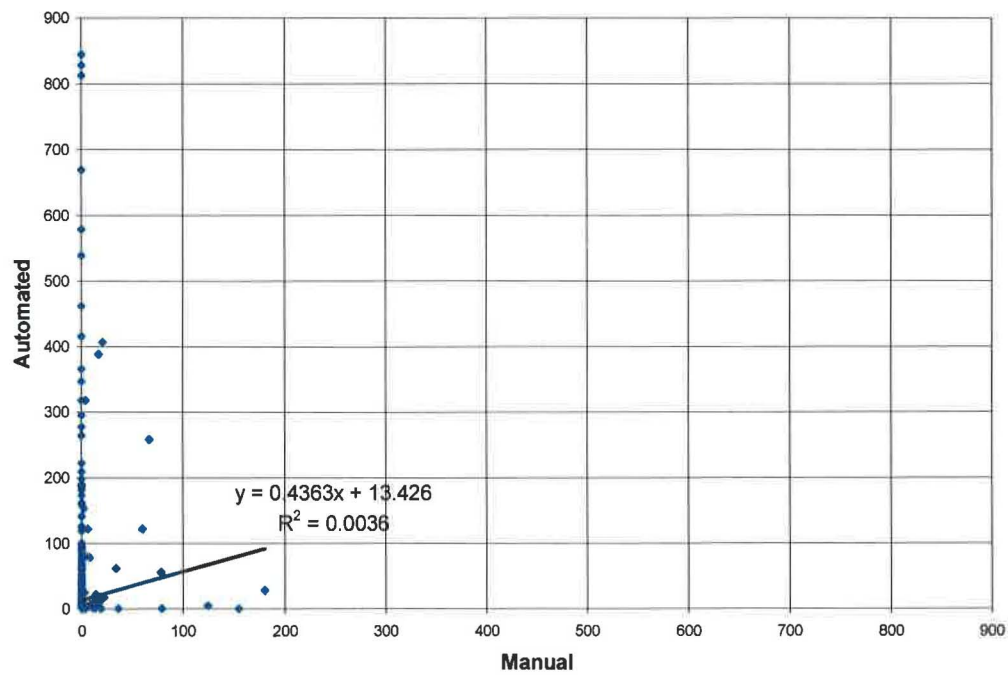**Figure 4.9 Regression Plot for Alligator 1 Cracking.**

$y = 0.1436x + 5.4181$
$R^2 = 0.0281$

Figure 4.10 Regression Plot for Alligator 3 Cracking.

$y = 0.4363x + 13.426$
$R^2 = 0.0036$

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MONTE CARLO ANALYSIS

The ALDOT PCR equations are complex equations with many inputs. A casual observation of the equations does not lead to the effect each input has on the final PCR value. Therefore, a method of determining the effect each input has on the final PCR value, or the sensitivity of the PCR due to each input, is valuable. The sensitivity of the PCR due to each input can then be used to determine which inputs are in need of more accurate data. For example, an input that causes a change in PCR of ten needs to have more accurate data than an input that causes a change in PCR of two. Since the error between the ALDOT and the automated data can be calculated from the QA database, the Monte Carlo simulation method can be used to determine the sensitivity of the PCR due to each input. This information can then be used to determine which inputs are in need of a higher degree of accuracy.

The Monte Carlo simulation method is a numerical method that utilizes sequences of random numbers to perform a simulation. The Monte Carlo simulation method requires that a physical (or mathematical) system be described by a probability density function (pdf) (CSEP, 1995). The cumulative probability density function (cdf) is then computed using the pdf. Once the cdf is known, the Monte Carlo simulation can proceed by random sampling from the cdf. This random sampling is then used to produce the desired result. For instance, let x be a random variable with some known cdf. The cdf is represented by the function shown in Equation 4.1. The function describes the probability of getting a value less than or equal to x for any given x value.

$$F_x = P(X \le x) \tag{4.1}$$

In order to better explain, take a value of x = 0.5 as in Figure 4.11. Next, draw a line that intersects the cdf and a line from there that intersects the y-axis. That y value represents the probability of getting an x value of 0.5 or less.
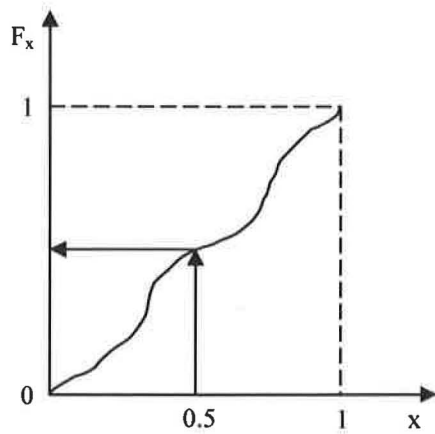

Figure 4.11 Plot of the cdf for the Random Variable x.

The next step is to let u be a standard uniform random variable. This standard uniform random variable (u) is represented by the pdf shown in Figure 4.12.
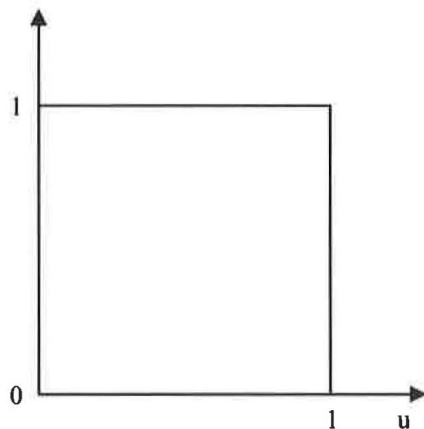

Figure 4.12 Plot of the pdf for the Standard Uniform Random Variable u.

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The pdf can then be integrated to compute the cdf. The cdf for u is shown in Figure 4.13.
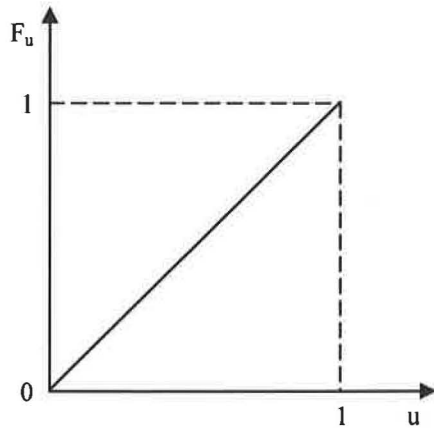

Figure 4.13 Plot of the cdf for the Standard Uniform Random Variable u.

The cdf for u is defined by the function shown in Equation 4.2. This function is similar to the function in equation 4.1.

$$F_u = P(U \leq u) \tag{4.2}$$

To complete the Monte Carlo simulation, the random variable (x) cdf and the standard uniform random variable (u) cdf are combined, as shown in Figure 4.14. Next, a random number u_i is generated which equals F_u and F_x ($F_u = u = F_x$). Then, find the x that corresponds to F_x (x_i). Finally, the x_i value is used to produce the desired result.
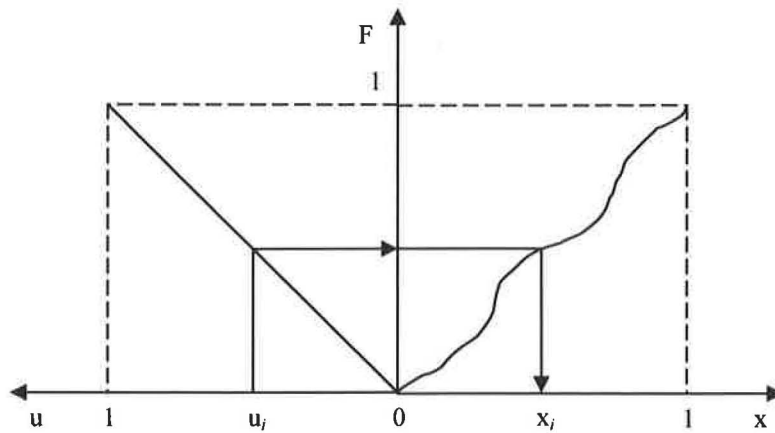
Figure 4.14 Combined Random Variable cdf and Standard Uniform Random Variable cdf.

Governing Equations

The Monte Carlo simulation method was used to analyze the sensitivity of each parameter for the ALDOT Pavement Condition Rating (PCR) equations. Several equations were used to complete the simulation. This section describes the equations used to complete the sensitivity analysis on the PCR equations using the Monte Carlo simulation method.

Two PCR equations (Equation 4.3 and Equation 4.4) were developed for ALDOT in a study conducted by Glover et al. (1985). ALDOT only uses Equation 4.3 in their calculation of PCR; however, it was decided that a sensitivity analysis on both equations could be beneficial to ALDOT. ALDOT PCR Equation 4.3 and Equation 4.4 are (Glover et al., 1985):

$$\textbf{PCR} = 95.5727 - 5.5085\,(5.0\text{-ROUGH}) - 1.5964\;\text{LNALL1}$$

$$- 1.9629\;\text{LNALL2} - 2.9795\;\text{LNALL3} - .01630\;\text{PAT2RD}$$

$$- .07262\;\text{BLK2RD} - .2220\;\text{AVGOUT} - 3.4948\;\text{RAVL31} \qquad (4.3)$$

$$- 7.5269\;\text{RAVL32} - 11.2297\;\text{RAVL33} - .03032\;\text{LONG12}$$

$$- .05484\;\text{LONG34} - .53050\;\text{TRAN12} - .69736\;\text{TRAN34}$$

where,

ROUGH = roughness or present serviceability index

LNALL1 = ln (level 1 alligator cracking + 1.0)

LNALL2 = ln (level 2 alligator cracking + 1.0)

LNALL3 = ln (level 3 alligator cracking + 1.0)

PAT2RD = patching (level 2 + level 3), $\leq 400\;\text{ft}^2$

BLK2RD = block cracking (all levels summed), $\leq 400\;\text{ft}^2$

AVGOUT = outer wheel path rutting (all locations averaged), 10^{-2} inches

RAVL31 = severe localized raveling (Code: 0 = none, 1 = present)

RAVL32 = severe wheel path raveling (Code: 0 = none, 1 = present)

RAVL33 = severe entire lane raveling (Code: 0 = none, 1 = present)

LONG12 = longitudinal cracking (level 1 + level 2), ft

LONG34 = longitudinal cracking level 3, ft

TRAN12 = transverse cracking (level 1 + level 2), number of cracks

TRAN34 = transverse cracking level 3, number of cracks

and,

$$PCR = 93.6497 - 4.8313 (5.0\text{-ROUGH}) - .04970 \text{ ALL2RD}$$

$$- .05518 \text{ ALL3RD} - .02220 \text{ PAT2RD} - .06982 \text{ BLK2RD}$$

$$- .2206 \text{ AVGOUT} - 3.2847 \text{ RAVL31} - 8.0265 \text{ RAVL32} \qquad (4.4)$$

$$- 11.2445 \text{ RAVL33} - .03970 \text{ LNG1} - .05799 \text{ LNG2}$$

$$- .06029 \text{ LNG34} - .63387 \text{ TRAN12} - .76698 \text{ TRAN34}$$

where,

ROUGH = roughness or present serviceability index

ALL2RD = alligator cracking (level 1 + level 2), $\leq 400 \text{ ft}^2$

ALL3RD = alligator cracking (level 3), $\leq 400 \text{ ft}^2$

PAT2RD = patching (level 2 + level 3), $\leq 400 \text{ ft}^2$

BLK2RD = block cracking (all levels summed), $\leq 400 \text{ ft}^2$

AVGOUT = outer wheel path rutting (all locations averaged), 10^{-2} inches

RAVL31 = severe localized raveling (Code: 0 = none, 1 = present)

RAVL32 = severe wheel path raveling (Code: 0 = none, 1 = present)

RAVL33 = severe entire lane raveling (Code: 0 = none, 1 = present)

LNG1 = longitudinal cracking (level 1), ft

LNG2 = longitudinal cracking (level 2), ft

LNG34 = longitudinal cracking level 3, ft

TRAN12 = transverse cracking (level 1 + level 2), number of cracks

TRAN34 = transverse cracking level 3, number of cracks

ALDOT considers the 200- ft manual pavement condition survey sections as the "ground-truth" for their QA program. Therefore, any difference in any one of the types of data collected manually by ALDOT and the data collected automatically by the vendor was considered to be an error due to the vendor. Taking this into consideration, the amount of error due to the automated data for each input was computed by Equation 4.5. A cdf was then constructed for the error in each input.

$$\text{Error}_i = \text{Manual}_i - \text{Automated}_i \qquad\qquad (4.5)$$

where,

i = any one type of input in the PCR equations (e.g. TRAN12)

Equation 4.5 also holds true for the error in the PCR calculated using ALDOT and the automated data. Therefore, the error in PCR can be calculated by subtracting equation 4.7 from equation 4.6 to get equation 4.8. The automated PCR equation is the same as the manual PCR equation, except for the added error (ε) term due to the automated data in each input.

$$\text{PCR}_{\text{Manual}} = C_0 + C_1 X_1 + C_2 X_2 + C_3 X_3 + C_4 X_4 \dots \qquad\qquad (4.6)$$

$$- \text{PCR}_{\text{Automated}} = C_0 + C_1(X_1 + \varepsilon_1) + C_2(X_2 + \varepsilon_2) + C_3(X_3 + \varepsilon_3) + C_4(X_4 + \varepsilon_4) \dots \qquad (4.7)$$

$$\text{PCR}_{\text{Error}} = C_1\varepsilon_1 + C_2\varepsilon_2 + C_3\varepsilon_3 + C_4\varepsilon_4 \dots \qquad\qquad (4.8)$$

where,

C = constant

X = measured amount of distress for a given input

ε = Error

All of the constants were known and the error in each input was described by cdf's; therefore, the error in PCR, or ΔPCR, due to the error of each input (e.g. Error PCR$_{AVGOUT}$) was calculated using the Monte Carlo simulation method in order to determine how much that individual input error effects the PCR value. In other words, the sensitivity of the PCR equation due to each input was calculated. The change in PCR due to the error of each input was calculated using Equation 4.9.

$$\Delta PCR_i = C_i \varepsilon_i \qquad\qquad (4.9)$$

Methodology

In order to calculate the sensitivity of the PCR equation due to the error in each input, the Monte Carlo simulation method was used. The Monte Carlo simulation method allowed for thousands of ΔPCR values to be calculated based on the measured error from the QA data. In theory, this covers the entire range of possible ΔPCR values based on the data from the QA cycle. Once a sufficient amount of the ΔPCR values were computed, statistical analysis of the ΔPCR data due to the error in each input were completed.

The first step in completing the simulation was to compute the error for each data point for every input. The error for each input represents the mathematical system for

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this Monte Carlo simulation and was therefore described by a cdf. An example pdf and cdf plot for the error between manual and automated data for rut depth is shown in Figure 4.15. The error in Figure 4.15 appears to have an approximately normal distribution. This was true for all of the data. This further signifies that the error is random and not systematic.
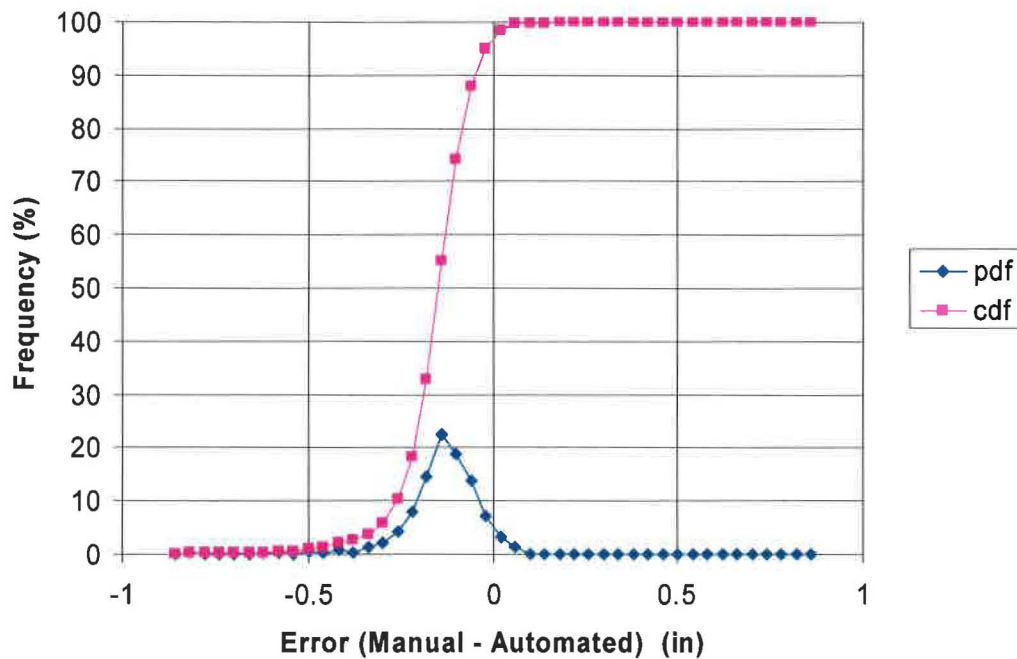

Figure 4.15 The pdf and cdf Plot for Average Outside Wheelpath Rut Depth Error.

Once a cdf for the error was constructed for each input, random numbers (u_i) between 0 and 100 were generated. This allowed for an error value to be determined from the cdf (ε_i). The error value determined from the cdf was then used to calculate ΔPCR using Equation 4.9. The method used to complete the Monte Carlo simulation is shown in Figure 4.16. ΔPCR was computed for numerous cycles until the running average of ΔPCR stabilized. An example of the running average plot for the LONG34 input for

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Equation 4.3 is shown in Figure 4.17. The number of cycles required for ΔPCR to

stabilize varied for each input; however, they all eventually stabilized. The number of

cycles ranged from 9,000 cycles to 1,000 cycles. For both Equations 4.3 and 4.4

PAT2RD required 9,000 cycles to stabilize and AVGOUT required only 1,000. Also, for

Equation 4.3 TRAN34 required 9,000 and LONG12 required 1,000. Once the running

average of ΔPCR stabilized, statistical analysis was completed on the ΔPCR data in order

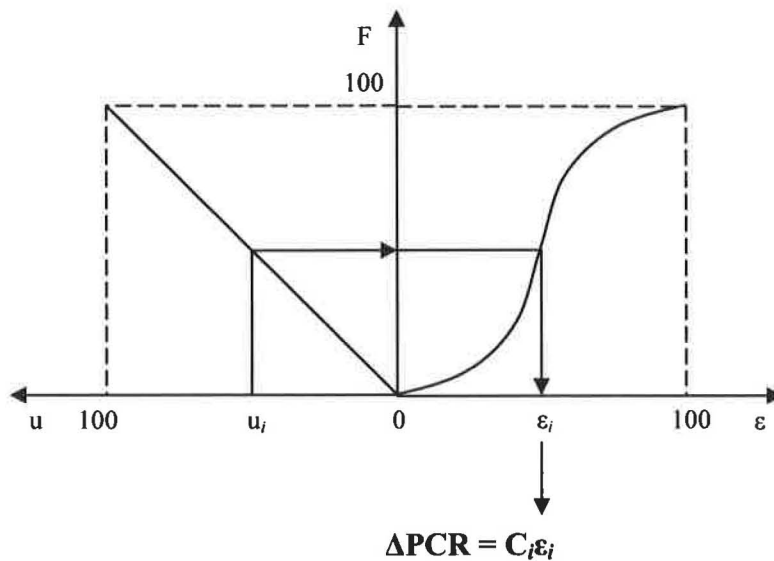to determine the sensitivity of the PCR equation due to error in each input.

$$\Delta PCR = C_i \varepsilon_i$$

Figure 4.16 Method for Completing the Monte Carlo Simulation to Find ΔPCR.
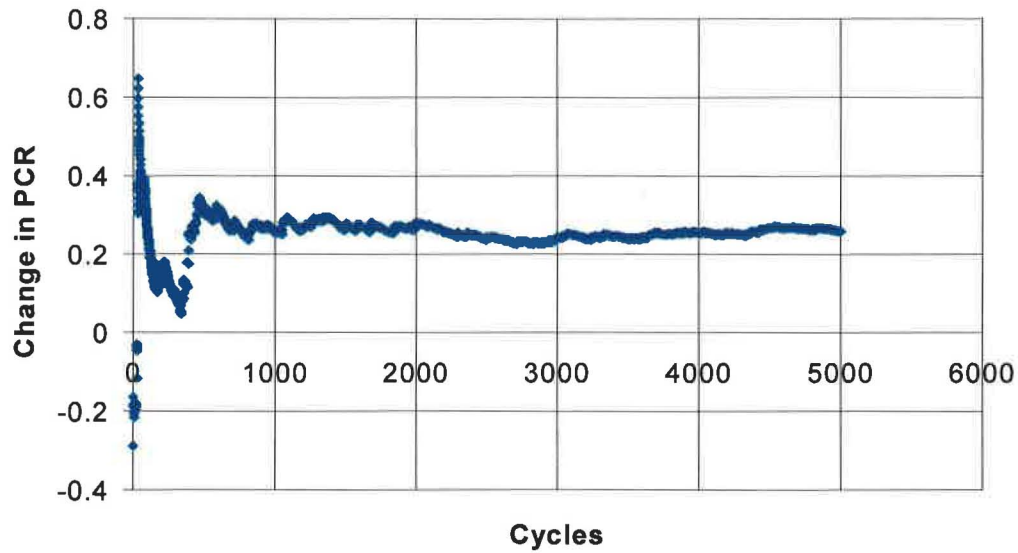
Figure 4.17 ΔPCR Running Average Plot for the LONG34 Input in Equation 4.3.

Two types of distress did not allow for the Monte Carlo simulation to be completed on the inputs for that particular distress. The alligator cracking inputs in Equation 4.3 take the natural log of the amount of alligator cracking plus 1. The natural log would not allow for the amount of alligator cracking to cancel out when computing ΔPCR. Therefore, Equation 4.9 could not be used to compute ΔPCR. As a result, Equation 4.10 was used to compute ΔPCR for alligator 1, alligator 2, and alligator 3 cracking for Equation 4.3.

$$\Delta PCR = C\left[\ln\left(\frac{ALL_{ALDOT}+1}{ALL_{Vendor}+1}\right)\right] \tag{4.10}$$

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This equation did not require the Monte Carlo simulation method to be used in order to get an error term. Instead, the error is computed in the equation directly.

Raveling was the second distress that did not require the Monte Carlo simulation. Raveling is represented by a code (0 = not present, 1 = present) instead of an actual measure of extent in PCR Equations 4.3 and 4.4. Therefore, there are four possible scenarios in the comparison of the ALDOT and vendor data:

1. no error with ALDOT raveling = 0 and vendor raveling = 0

2. no error with ALDOT raveling = 1 and vendor raveling = 1

3. -1 error with ALDOT raveling = 0 and vendor raveling =1

4. +1 error with ALDOT raveling =1 and vendor raveling =0

Also, since the amount of error in Equation 4.9 is either one or zero, ΔPCR is equal to the constant (C) or is equal to zero. As a result, the amount that each of the four possible error scenarios occurred was analyzed in order to determine the effect that each raveling input has on the PCR value.

Results

Upon completion of the Monte Carlo simulation, all of the ΔPCR data for each input were statistically analyzed in order to determine the sensitivity of PCR Equation 4.3 and 4.4 due to each input. The statistical analysis resulted in finding the maximum change in PCR (ΔPCR) (+/-) that can be expected due to error in each of the inputs.

The average and standard deviation was calculated for the ΔPCR values for each input excluding the raveling inputs. Each raveling input was analyzed using the representative distribution functions. From the pdf's for the RAVL31, RAVL32, and

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RAVL33 inputs it was found that 95% of the time ALDOT and the vendor both did not report any severe raveling. Raveling was reported by ALDOT, by the vendor, or both only 4.5% of the time for RAVL31, 4.3% for RAVL32, and 5.5% for RAVL33. The complete distribution of reported severe raveling is shown in Table 4.6. The V in the table stands for the automated data collected by the vendor.

Table 4.6 Results for Severe Raveling Inputs.

Condition	RAVL31		RAVL32		RAVL33	
	Count	pdf (%)	Count	pdf (%)	Count	pdf (%)
No Error (ALDOT=0 and V=0)	1011	95.47	1013	95.66	1001	94.52
+1 Error (ALDOT=1 and V=0)	38	3.59	29	2.74	55	5.19
-1 Error (ALDOT=0 and V=1)	8	0.76	14	1.32	3	0.28
No Error (ALDOT=1 and V=1)	2	0.19	3	0.28	0	0.00

Since each raveling input is represented by a code (0 = not present, 1 = present), the maximum change in PCR (+/-) is equal to the constant. The maximum change in PCR (+/-) is shown in Table 4.7 for each of the raveling inputs for Equation 4.3 and 4.4. However, since an error in raveling only occurs approximately 5% of the time, it is concluded that raveling causes the least amount of error in the PCR value for Equation 4.3 and 4.4.

Table 4.7 The Maximum ΔPCR (+/-) Due to Raveling.

Input	Equation 4.3	Equation 4.4
	Max ΔPCR (+/-)	Max ΔPCR (+/-)
RAVL31	3.4948	3.2847
RAVL32	7.5269	8.0265
RAVL33	11.2297	11.2445

The remainder of the inputs were analyzed by computing the average and standard deviation for ΔPCR. An example of the statistical analysis that was run on ΔPCR is shown in Figure 4.18. Figure 4.18 is the pdf and cdf plot of the ΔPCR caused by the error in outside wheelpath rut depth. The maximum ΔPCR (+/-) due to each input was established using the fact that 95% of the data will fall between +/- two standard deviations from the mean. Therefore, +/- two standard deviations describes the maximum ΔPCR (+/-) for 95% of the data. Once the maximum ΔPCR (+/-) was established for each input, they were ranked from lowest to highest. The maximum ΔPCR (+/-) of each input describes how sensitive the final PCR value is to that particular input. An input with a low maximum ΔPCR (+/-) yields an input that causes a lower amount of sensitivity in the PCR value than an input with a high maximum ΔPCR (+/-). Table 4.8 and 4.9 show the results of the statistical analysis for Equation 4.3 and 4.4. The tables include the statistical analysis of the error in order to provide for a comparison.
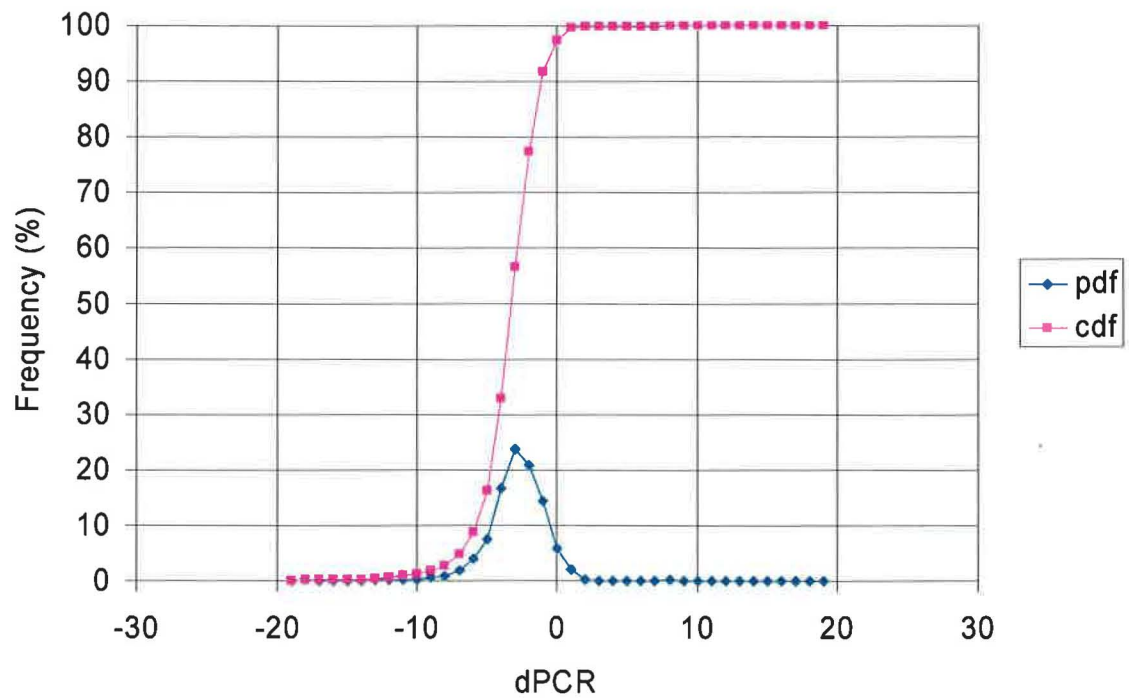
Figure 4.18 Statistical Analysis for ΔPCR Caused by the Error in Outside Wheelpath Rut Depth Data.

Table 4.8 Results of the Statistical Analysis for Equation 4.3.

Distress	Error		ΔPCR		
	Average	St. Dev.	Average	St. Dev.	Max (+/-)
PAT2RD, ft^2	2.436	34.160	-0.008	0.506	1.012
ROUGH	0.088	0.329	0.540	1.814	3.628
LONG34, ft	6.952	38.069	0.272	2.150	4.300
AVGOUT, in	-0.155	0.099	-3.447	2.175	4.351
LONG12, ft	18.411	70.796	0.516	2.204	4.408
TRAN12, count	1.508	5.274	0.705	2.824	5.648
LNALL1, ft^2	30.316	96.931	1.368	3.063	6.126
LNALL2, ft^2	-3.274	140.840	0.277	3.304	6.609
LNALL3, ft^2	-12.885	69.342	-1.282	3.964	7.928
BLK2RD, ft^2	-16.092	70.000	-1.165	4.709	9.418
TRAN34, count	0.396	8.763	-1.373	5.583	11.167

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Table 4.9 Results of the Statistical Analysis for Equation 4.4.

Distress	Error		ΔPCR		
	Average	St. Dev.	Average	St. Dev.	Max (+/-)
PAT2RD, ft^2	2.436	34.160	-0.004	0.739	1.478
ROUGH	0.088	0.329	0.378	1.710	3.420
AVGOUT, in	-0.155	0.099	-3.394	2.194	4.389
LNG1, ft	10.407	55.524	0.335	2.235	4.471
LONG34, ft	6.939	38.034	0.335	2.428	4.857
ALL3RD, ft^2	-11.023	52.193	-0.718	2.778	5.556
LNG2, ft	7.986	51.659	0.365	2.958	5.915
TRAN12, count	1.504	5.267	0.797	3.358	6.717
BLK2RD, ft^2	-16.092	70.000	-1.372	5.020	10.040
ALL2RD, ft^2	26.056	103.289	1.200	5.065	10.130
TRAN34, count	0.396	8.763	-1.408	7.407	14.814

Due to the nature of Equations 4.3 and 4.4, some of the inputs cause a high

maximum ΔPCR (+/-) value as a result of a small amount of error. In contrast, some

inputs with a high amount of error results in a low maximum ΔPCR (+/-) value. Level 3

transverse cracking (TRAN34) has the greatest maximum ΔPCR (+/-) value for

Equations 4.3 and 4.4. This high maximum ΔPCR (+/-) is caused by an average error of

0.396 and a standard deviation of 8.763. Although TRAN34 is measured as the number

of level 3 transverse cracks, the data imply that failure to make an accurate count will

cause a high maximum ΔPCR (+/-) value. Other inputs such as alligator 1 cracking in

Equation 4.3 (LNALL1) have a high amount of error that results in a moderate maximum

ΔPCR (+/-) value. LNALL1 has an average error of 30.316 ft^2 and a standard deviation

of 96.931 ft^2. This error results in a maximum ΔPCR (+/-) value of 6.126. This implies

that significant errors in the data will not affect the final PCR values substantially.

Overall, it can be concluded from the results of the sensitivity analysis that some

of the inputs are in greater need of a higher degree of accuracy than others. Table 4.10

shows inputs that need to have more accurate data for a maximum ΔPCR (+/-) of 5 and 10 for an individual input. For Equation 4.3, all severity levels of transverse cracking, block cracking, and alligator cracking need more accurate data if a maximum allowable ΔPCR (+/-) of 5 is considered. This is also the case for Equation 4.4 with the addition of level 2 longitudinal cracking. At a maximum allowable ΔPCR (+/-) of 10, level 3 transverse cracking is the only distress in need of more accurate data for Equation 4.3; however, the summation of all levels of block cracking input (BLK2RD) is not for from the mark. In Equation 4.4, level 3 transverse cracking, level 1 and 2 alligator cracking, and the summation of all levels of block cracking are in need of more accurate data for a maximum allowable ΔPCR (+/-) of 10. All of the inputs listed in Table 4.10 are composed of cracking distresses. This means that cracking data are not only the most difficult distress types to detect and classify, but also cause the greatest amount of sensitivity in the PCR equations. Therefore, it is essential to have accurate cracking data.

Table 4.10 Inputs in Need of More Accuracy for a Given Max ΔPCR (+/-).

Equation 4.3		Equation 4.4	
Maximum ΔPCR		Maximum ΔPCR	
+/- 5	+/- 10	+/- 5	+/- 10
TRAN34	TRAN34	TRAN34	TRAN34
BLK2RD		ALL2RD	ALL2RD
LNALL1		BLK2RD	BLK2RD
LNALL2		TRAN12	
LNALL3		LNG2	
TRAN12		ALL3RD	

CONCLUSIONS

The Alabama Department of Transportation has a quality assurance program that compares automated pavement condition survey data, collected by an external vendor, to pavement condition data obtained manually by an ALDOT rater. As a result of a milepost location investigation, it was found that the automated and manual sections in comparison for the QA procedure are not always the same section of pavement. In fact, some have an error that is over half of a mile. This suggests that there is a need for a more accurate method of matching QA sections. One possible solution would be to use a GPS system to gather directional coordinates for the location of the manual survey for comparison to the automated section coordinates.

Regression plots were constructed in order to determine if there was a systematic error between the vendor and ALDOT data, and to observe any general trends in the data. Upon inspection of the regression plots, no systematic error was evident; however, the following general trends were observed from the regression plots:

1. The vendor reports greater average outside wheel path rutting

2. The vendor underreports alligator 1 cracking

3. The vendor over reports alligator 3 cracking

The Monte Carlo simulation method was used in order to determine the sensitivity of the ALDOT PCR due to each input. The sensitivity was described by statistical analysis completed on the results of the Monte Carlo simulation. It was determined from the analysis that some of the inputs are in greater need of a higher degree of accuracy than others. For a maximum allowable ΔPCR (+/-) of 5 and 10 all of the inputs in need of a greater degree of accuracy were composed of crack data. This means that cracking

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data are not only the most difficult distress types to detect and classify, but also cause the greatest amount of sensitivity in the PCR equations. Therefore, it is essential to have accurate cracking data.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding. In the past the only method of completing a pavement condition survey was to walk or drive down the road and collect the data manually. This method is time consuming, hazardous, and subjective. Therefore, over the past two decades an effort has been made to fully automate the data collection process; and in recent years, through extensive research and technological advancements, the concept of a fully automated pavement condition survey has nearly become a reality. However, there are some issues that have hindered the acceptance of the automated data collection technology. One of these issues is the lack of information about successful transitions from manual to automated data collection. Another issue is the accuracy of automated survey data compared to manual survey data. In an effort to clear up some of these issues for the Alabama Department of Transportation and other agencies, an extensive literature review was completed, a pavement condition survey questionnaire was constructed and sent to 46 state DOT pavement management engineers, and statistical analysis on automated and manual pavement condition data was completed.

The literature revealed overall that automated pavement condition surveys have the capability of accurately and efficiently collecting pavement condition data. The most difficult part of an automated pavement condition survey is detecting and classifying surface distresses such as cracking. However, new digital cameras that have the capability of capturing pavement images that can exceed a resolution of 6,000 pixels per line used with improving surface distress classification software should provide for a better means to detect and classify accurate surface distress data. It was also found through the literature review that AASHTO Designation PP44-01, *Standard Practice for Quantifying Cracks in Asphalt Pavement Surface*, while still an interim protocol, has been found by a few researchers to be effective in determining the network level crack condition.

The pavement condition survey questionnaire was sent to 46 state department of transportation pavement management engineers. A total of 27 questionnaires were returned with each completed at least partially. Of the 27 states that responded to the survey 5 states did not report the use of any automated data collection, 22 states reported the collection of International Roughness Index (IRI) and rutting data automatically, and fifteen of the states reported the collection of surface distress data through automated means. The majority of the states surveyed reported the collection of pavement condition data was completed annually with a biannual data collection cycle coming in second. Almost all of the states surveyed reported they collect data in both directions on divided roadways and only collect data in one direction for multilane, undivided roadways. The outside lane is chosen by most states to survey for multilane roadways. The overall consensus from the 27 states is that dry non-freezing weather is needed to collect data.

Furthermore, most states reported that data are only collected in the daylight hours. Also, any condition that may compromise safety is not surveyed in. Just over half of the states reported that they do not outsource their data collection.

The pavement condition survey questionnaire also provided some information on the quality control and quality assurance practices that other state agencies use. Some of these practices include:

- The use of control sites in the field to verify the accuracy of the automated data collection devices.

- Redundant sampling in order to evaluate variability in multiple runs.

- Reviewing the same images as the vendor.

- Use of a condition database to project anticipated condition for a sample section.

Another important part of the pavement condition survey questionnaire was the responses to the questions about specific problems the states were facing. States that use manual surveys for data collection reported that the amount of time to complete, subjectivity, and consistency between raters were the top problems they were facing. States that are using pavement images for surface distress data reported that image clarity, data quality, and a shortage of storage for data were some of the problems they had encountered. Another common problem states are facing is trying to find a system that can perform automated crack detection and classification. Also, some states already see a problem with trying to maintain continuity with their historical pavement condition data when and if they make the transition to the automated survey. The few states that have already made the transition reported that they had to make changes such as: redefine

conditions, change programs to deal with the additional data, change the definition and measurement method of some data, and even create a new distress identification manual.

ALDOT has a quality assurance program that compares automated pavement condition survey data, collected by the vendor, to pavement condition data obtained manually by an ALDOT rater. The methodology of the QA program and the data collected from the first cycle were investigated. As a result of a milepost location investigation used to check the methodology of the QA program, it was found that the automated and manual sections in comparison for the QA procedure are not always the same section of pavement. In fact, some have an error that is over half of a mile. This suggests that there is a need for a more accurate method of matching QA sections. Statistical analysis was also run on the QA data from the first cycle. It was determined from the analysis that there was not any systematic error between the vendor and ALDOT data. However, the following general trends were observed:

4. The vendor reports greater average outside wheel path rutting

5. The vendor underreports alligator 1 cracking

6. The vendor over reports alligator 3 cracking

The Monte Carlo simulation method was used in order to determine the sensitivity of the ALDOT Pavement Condition Rating (PCR) due to each input. The sensitivity was described by statistical analysis completed on the results of the Monte Carlo simulation. It was determined from the analysis that some of the inputs are in greater need of a higher degree of accuracy than others. For a maximum allowable ΔPCR (+/-) of 5 and 10 all of the inputs in need of a greater degree of accuracy were composed of crack data. This means that cracking data are not only the most difficult distress types to detect and

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classify, but also cause the greatest amount of sensitivity in the PCR equations. Therefore, it is essential to have accurate cracking data.

RECOMMENDATIONS

Based on the results of the pavement condition survey questionnaire, the following are recommended:

- Use an annual or biannual data collection cycle.
- Survey both directions for divided roadways.
- Survey one lane for multilane roadways.
- Consider using the pavement images as well as field surveys for QC/QA.
- Consider using redundant sampling to evaluate variability in multiple runs.

In order to better match the automated and manual pavement sections used in ALDOT's QA program, it is recommended that a GPS system be used to gather directional coordinates for the location of the manual survey for comparison to the automated pavement section coordinates. This should provide for a check on the location of the two sections in comparison.

For the ALDOT PCR equation (Equation 4.3) the following types of data are in need of greater accuracy for a maximum ΔPCR (+/-) value of 5: all severity levels of transverse cracking, block cracking, and alligator cracking. However, if a maximum ΔPCR (+/-) value of 10 is considered tolerable, then level 3 transverse cracking is the only data type in need of greater accuracy.

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APPENDIX A

SAMPLE PAVEMENT CONDITION SURVEY QUESTIONNAIRE

Pavement Condition Survey Questionnaire

General Questions

1. What is your position?

2. What state do you work for?

3. What kinds of pavement distress data do you collect (IRI, rutting, alligator cracking, etc.)?

4. Are summary methods (overall condition rating, etc.) used to report pavement condition rather than individual distresses? If so, what are the basic components of the indices?

5. How is the information reported to management (resurfacing prioritization reports, average condition by geographic district, etc.)?

6. How long is your data collection cycle (every other year, annually, etc.)?

7. What percent of your state's road network do you survey in this period? Are the surveys replicated from year to year if a sample is used?

8. How many lanes are surveyed on a multilane segment?

9. Are both directions surveyed?

10. What restrictions are placed on data collection (i.e., time of day, seasonal, weather)?

11. Does your agency outsource its data collection? If so, how was the vendor selected?

Please return to: Jason McQueen, 277 Technology Parkway, Auburn, AL 36830; or mcquejm@eng.auburn.edu; or (334)-844-6248 (fax)

Pavement Condition Survey Questionnaire

Quality Control/Quality Assurance:

Please complete this section if your agency outsources its distress data collection or has an in-house QC program for data collection.

12. Is your QC/QA program based on field surveys?

13. What frequency of your collected data is chosen for QC/QA?

14. How are sections chosen for QC/QA?

15. What kind of tolerance is there for discrepancies (i.e., allowable percentage out, statistical testing, etc.)?

Manual Surveys:

Please complete this section if a) your agency does its primary data collection by manual survey or b) if your agency uses manual surveys for QC/QA.

16. Is manual collection your primary data source?

17. Are your manual surveys windshield or walking?

18. Do you rate a representative sample (i.e. 200 ft/mile) or the entire road segment?

Automated Surveys:

Please complete this section if your agency does all or part of its collection by automated survey.

19. Is automated distress collection your primary data source?

20. What distresses do you collect using automated equipment?

Please return to: Jason McQueen, 277 Technology Parkway, Auburn, AL 36830; or mcquejm@eng.auburn.edu; or (334)-844-6248 (fax)

Pavement Condition Survey Questionnaire

21. What manufacturer/type of vehicle is used for data collection?

22. At what frequency is data collected (mile, 1/10 mi., 1/100 mi., etc.)?

23. At what speed is data collected?

24. Are you experiencing any specific problems in measuring distresses?

25. What kinds of challenges/problems did you face when making the transition from manual to automated distress collection?

Thank you for your time in completing this survey.

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APPENDIX B

EXAMPLES OF COMPLETED PAVEMENT CONDITION

SURVEY QUESTIONNAIRES

Pavement Condition Survey Questionnaire

General Questions

26. What is your position? Pavement Management Engineer

27. What state do you work for?   Arizona

28. What kinds of pavement distress data do you collect (IRI, rutting, alligator cracking, etc.)? IRI, Rut, cracking, patching, friction, flushing

29. Are summary methods (overall condition rating, etc.) used to report pavement condition rather than individual distresses? If so, what are the basic components of the indices? No

30. How is the information reported to management (resurfacing prioritization reports, average condition by geographic district, etc.)? Average condition overall for Interstates and for non-Interstates

31. How long is your data collection cycle (every other year, annually, etc.)? Yearly except for friction with is about 3 year cycle

32. What percent of your state's road network do you survey in this period? Are the surveys replicated from year to year if a sample is used? 100%

33. How many lanes are surveyed on a multilane segment? Outside lane is the survey lane.

34. Are both directions surveyed? Only for divided sections

35. What restrictions are placed on data collection (i.e., time of day, seasonal, weather)?None other then weather as it affects safety.

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Pavement Condition Survey Questionnaire

36. Does your agency outsource its data collection? If so, how was the vendor selected?
No.

Quality Control/Quality Assurance:

Please complete this section if your agency outsources its distress data collection or has an in-house QC program for data collection.

37. Is your QC/QA program based on field surveys?

38. What frequency of your collected data is chosen for QC/QA?

39. How are sections chosen for QC/QA?

40. What kind of tolerance is there for discrepancies (i.e., allowable percentage out, statistical testing, etc.)?

Manual Surveys:

Please complete this section if a) your agency does its primary data collection by manual survey or b) if your agency uses manual surveys for QC/QA.

41. Is manual collection your primary data source?

42. Are your manual surveys windshield or walking? Walking

43. Do you rate a representative sample (i.e. 200 ft/mile) or the entire road segment? Roughness and rutting is 100% of the outside lane, friction is first 300 feet at each milepost, cracking, flushing, patching is the 1000 sq feet at each milepost.

Pavement Condition Survey Questionnaire

Automated Surveys:

Please complete this section if your agency does all or part of its collection by automated survey.

44. Is automated distress collection your primary data source? Roughness, rutting, friction are automated, cracking, flushing, patching are manual.

45. What distresses do you collect using automated equipment? See above

46. What manufacturer/type of vehicle is used for data collection? KJ Law (now Dynatest) profilers (roughness and rutting) and friction tester.

47. At what frequency is data collected (mile, 1/10 mi., 1/100 mi., etc.)? See answers to prior question that already covered this.

48. At what speed is data collected? Approximately 60 mph

49. Are you experiencing any specific problems in measuring distresses? Manual methods are slow.

50. What kinds of challenges/problems did you face when making the transition from manual to automated distress collection? None for those tests such as roughness and rutting. We have not transitioned the other tests yet.

Thank you for your time in completing this survey.

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Pavement Condition Survey Questionnaire

General Questions

51. What is your position?

Asst. Geotechnical Engineer

52. What state do you work for?

Kansas

53. What kinds of pavement distress data do you collect (IRI, rutting, alligator cracking, etc.)?

Roughness (IRI) is collected for all pavement types. Transverse cracking, fatigue cracking, and rutting are collected for all black-surface pavements. Joint distress and faulting are collected for white-surface pavements.

54. Are summary methods (overall condition rating, etc.) used to report pavement condition rather than individual distresses? If so, what are the basic components of the indices?

We have several tiers of aggregation of our pavement condition data. IRI values are converted into three roughness levels (<105 in/mile, 105-165, and >165). Transverse cracking values are similarly assigned to one of three levels. Levels for rutting are <0.5", 0.5-1", and >1". Distress State is then created by concatenating the roughness, transverse cracking, and rutting levels (eg. 231 would indicate moderate roughness, severe transverse cracking, and minor or no rutting). The next tier is to concatenate an "index to first distress" to the distress state. The index is a number 1-4 representing the extent of the last action performed on that segment. An index of 1 implies the last action was fairly light and the distress is expected to come back sooner. An index of 4 implies the last action was heavy and the return of distress should take some time. The distress state is also used with pavement type to obtain a single indicator called performance level. Performance level can be loosely interpreted as 1=good, 2=okay, and 3=poor condition. This indicator is a good means to be able to show the overall

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Pavement Condition Survey Questionnaire

system performance. Currently 92% of our system is in good condition and about 1% is in poor condition.

White pavements are treated in a similar way. The variables are roughness, joint distress, and faulting. More information is available from the Kansas pavement management web site at http://kdot1.ksdot.org/public/kdot/matreslab/pmis/index.html (particularly the glossary may be helpful).

55. How is the information reported to management (resurfacing prioritization reports, average condition by geographic district, etc.)?

An annual condition survey report (also available at the above site) is broadly distributed. In addition, the PMS group runs an optimization procedure to determine which locations for projects would produce the greatest benefit for the available funds while achieving system wide performance goals.

56. How long is your data collection cycle (every other year, annually, etc.)?

Data is collected annually in the spring on about 11,000 miles of highways.

57. What percent of your state's road network do you survey in this period? Are the surveys replicated from year to year if a sample is used?

The roughness, rutting, and faulting data are generated automatically from profilometers, so they are (nearly) 100% coverage. The cracking and joint distress data come from 3-100' sample sections in each mile (~5% sample). The sample locations within each mile are random and do change every year.

58. How many lanes are surveyed on a multilane segment?

Only the driving lane is sampled.

59. Are both directions surveyed?

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Pavement Condition Survey Questionnaire

Divided facilities are sampled in each direction.

60. What restrictions are placed on data collection (i.e., time of day, seasonal, weather)?

We mostly leave this to our trained raters' discretion. We occasionally experience snow or rain problems. The primary restriction is to collect the data as safely and efficiently as possible. If the randomly selected sample location is not representative of the surrounding conditions, they have the option to move to a more representative location. Also, if the sample location is unsafe to conduct the survey (blindly over the top of a hill, in a busy gore area, or a location with no shoulders) again the raters have the option to move.

61. Does your agency outsource its data collection? If so, how was the vendor selected?

No.

Quality Control/Quality Assurance:

Please complete this section if your agency outsources its distress data collection or has an in-house QC program for data collection.

62. Is your QC/QA program based on field surveys?

We have a redundant sampling program for both automated and manual surveys. The automated oversampling simply allows us to evaluate variability in multiple runs. The manual QC simply sends two different groups over the same segments. We also have a QA program where our trainers independently select and review a very small sample of each of our rater's work.

63. What frequency of your collected data is chosen for QC/QA?

Our profilers simply collect multiple passes as the travel to locations the still need to sample. This results in some locations being sampled many (6 or 7) times in a survey season. The manual oversampling simply occurs where survey crews assigned to adjacent areas overlap. Therefore, these locations only have two samples. The QA

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Pavement Condition Survey Questionnaire

program has a very small sample that allows our trainers to assess the quality of the ratings from each of our raters.

64. How are sections chosen for QC/QA?

The QC process is described above. The QA process involves running queries against the database to find locations that contain some variable of interest. The trainers also rely on the data collection logs for notes indicating a condition worthy of another look.

65. What kind of tolerance is there for discrepancies (i.e., allowable percentage out, statistical testing, etc.)?

No rigid statistics are used to determine acceptability of the data. Instead, the data is mostly used so that we know how much variability we have and to help us with training exercises to help reduce variability.

Manual Surveys:

Please complete this section if a) your agency does its primary data collection by manual survey or b) if your agency uses manual surveys for QC/QA.

66. Is manual collection your primary data source?

Yes for cracking and joint distress.

67. Are your manual surveys windshield or walking? Windshield.

68. Do you rate a representative sample (i.e. 200 ft/mile) or the entire road segment?

3- 100 foot randomly selected samples per pavement management section (usually 1 mile).

Pavement Condition Survey Questionnaire

Automated Surveys:

Please complete this section if your agency does all or part of its collection by automated survey.

69. Is automated distress collection your primary data source?

Yes for roughness, rutting, and faulting.

70. What distresses do you collect using automated equipment? See 19

71. What manufacturer/type of vehicle is used for data collection?

ICC laser profilometer.

72. At what frequency is data collected (mile, 1/10 mi., 1/100 mi., etc.)?

The profilometer fires 32,000 times per second. This data along with the accelerometer readings are combined on-board to generate 3 inch profiles for left and right wheelpaths plus one between the wheelpaths. This data is transferred through several steps in to our PMS sections. These sections are typically 1 mile long.

73. At what speed is data collected?

74. Are you experiencing any specific problems in measuring distresses?

75. What kinds of challenges/problems did you face when making the transition from manual to automated distress collection?

Thank you for your time in completing this survey.

APPENDIX C

AUTOMATED VS MANUAL DISTRESS REGRESSION PLOTS
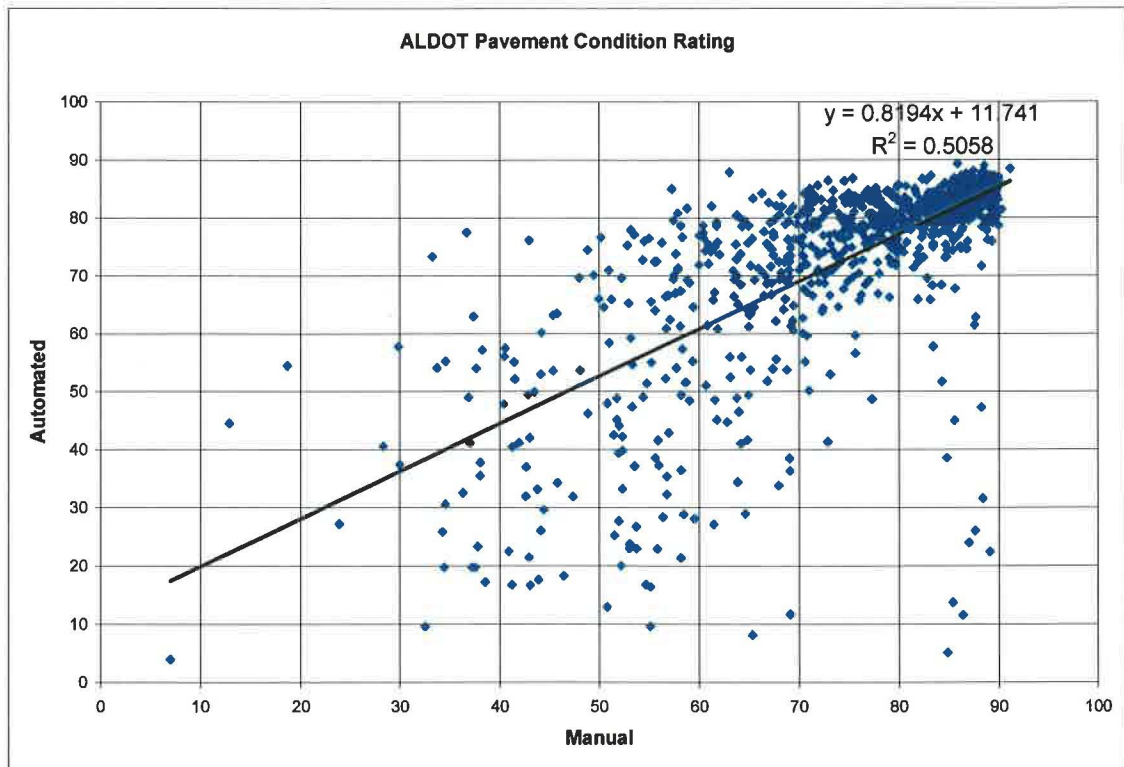
Figure C.1 ALDOT Pavement Condition Rating (Eq. 3.3) Regression Plot
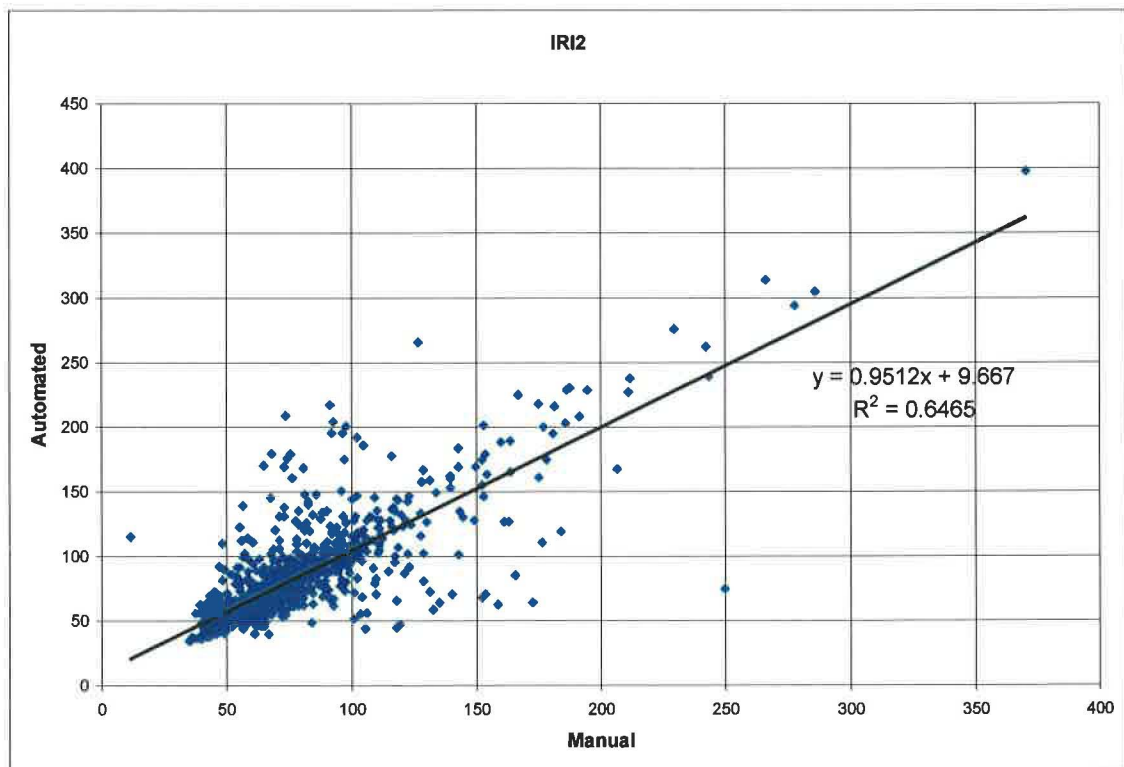
Figure C.2 International Roughness Index 2 Regression Plot

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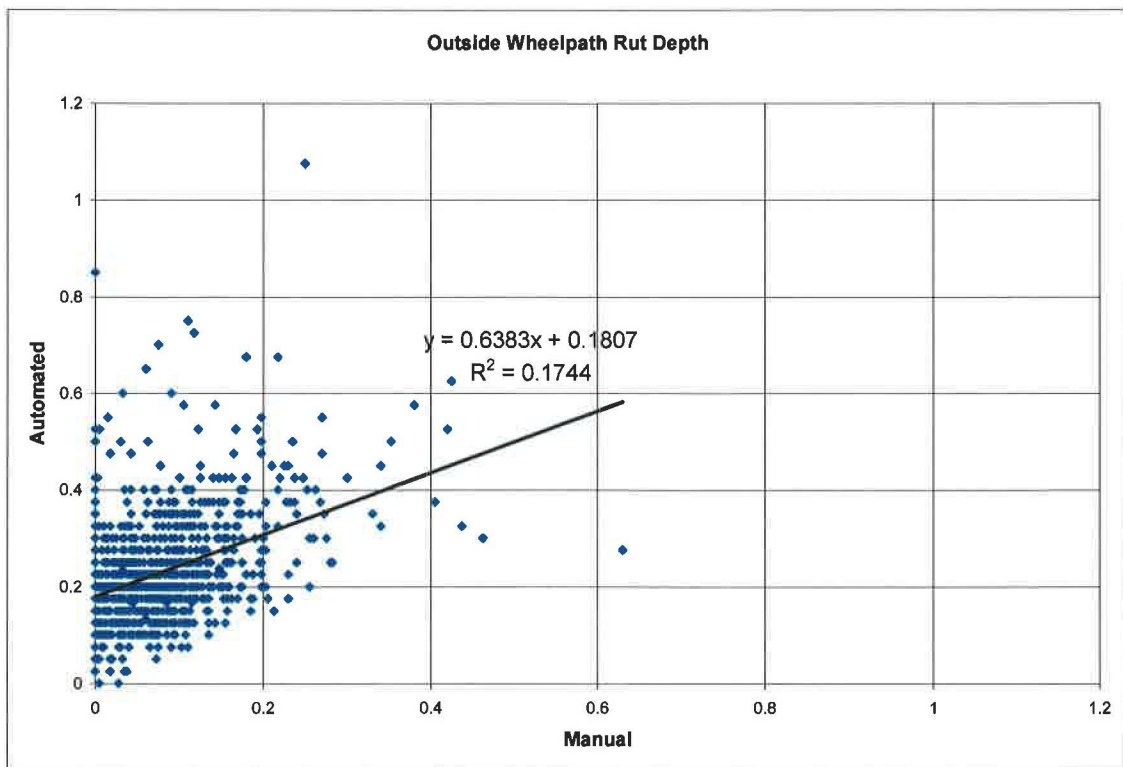
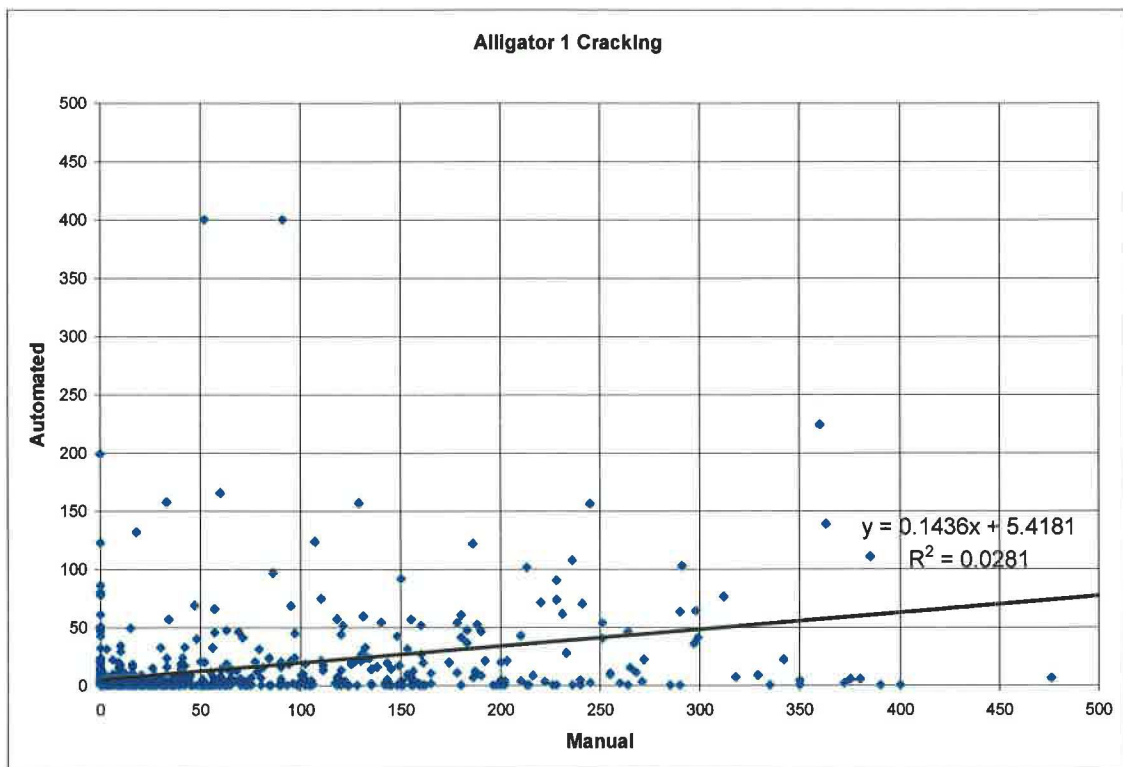**Figure C.3 Outside Wheelpath Rut Depth Regression Plot**

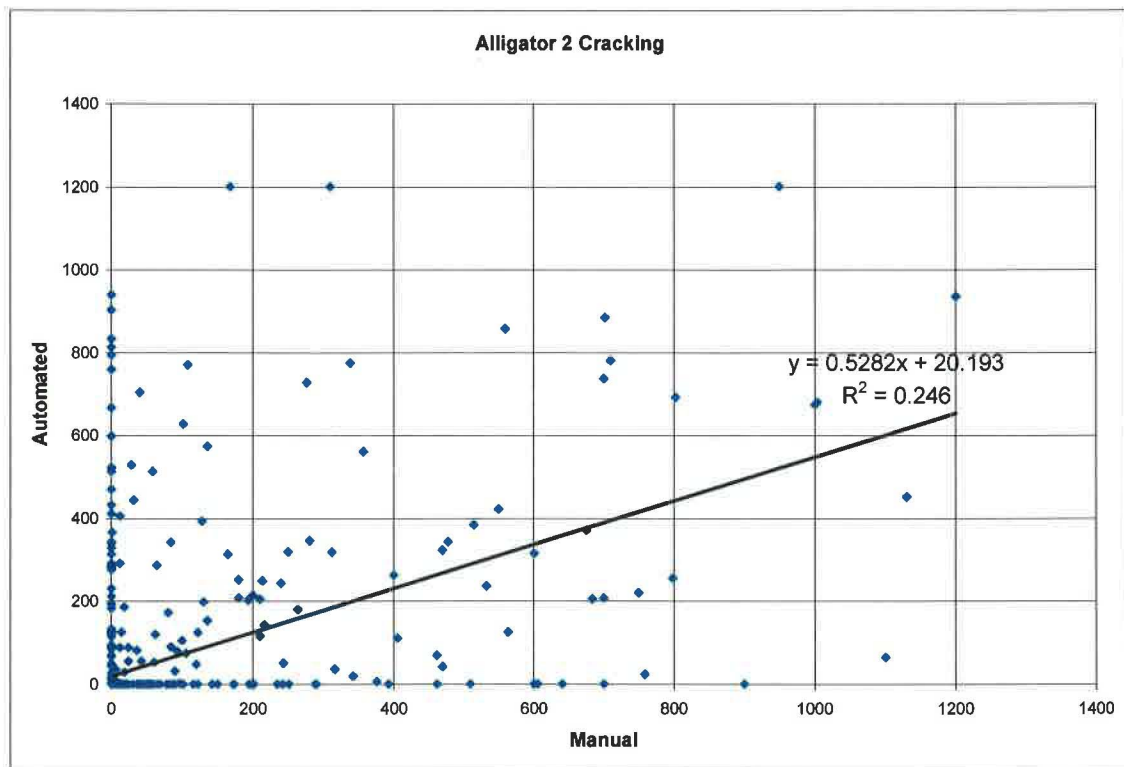**Figure C.4 Alligator 1 Cracking Regression Plot**
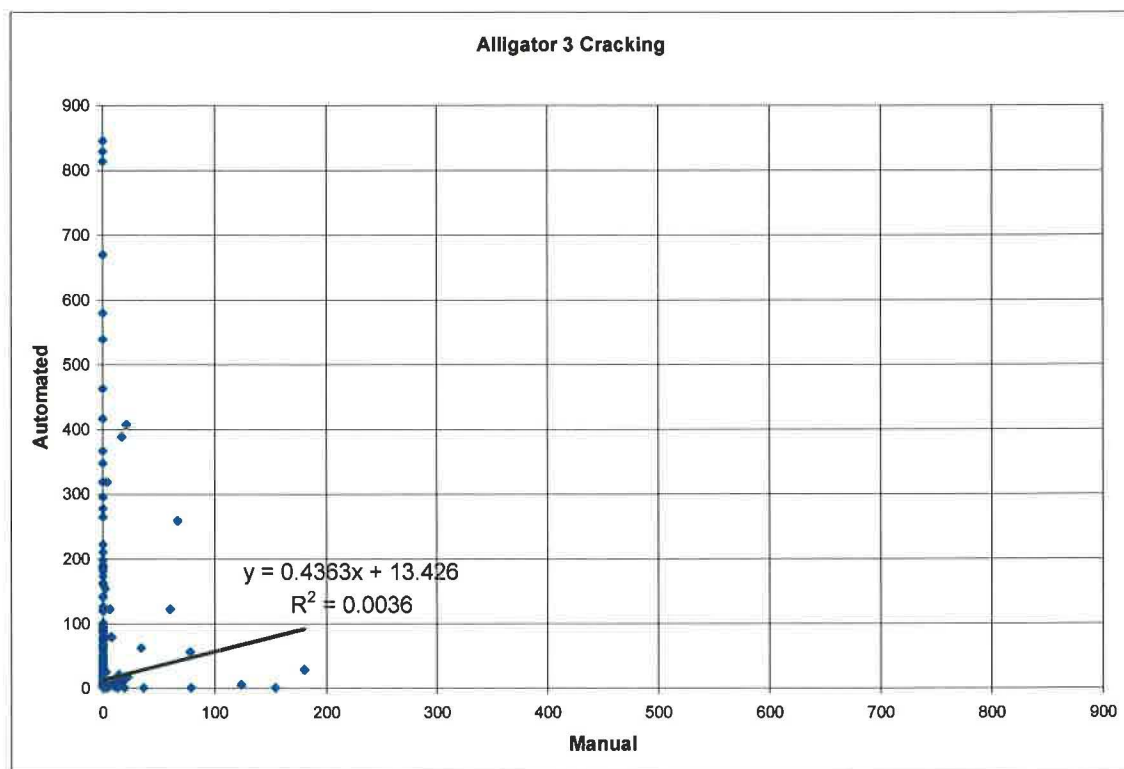
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Figure C.5 Alligator 2 Cracking Regression Plot

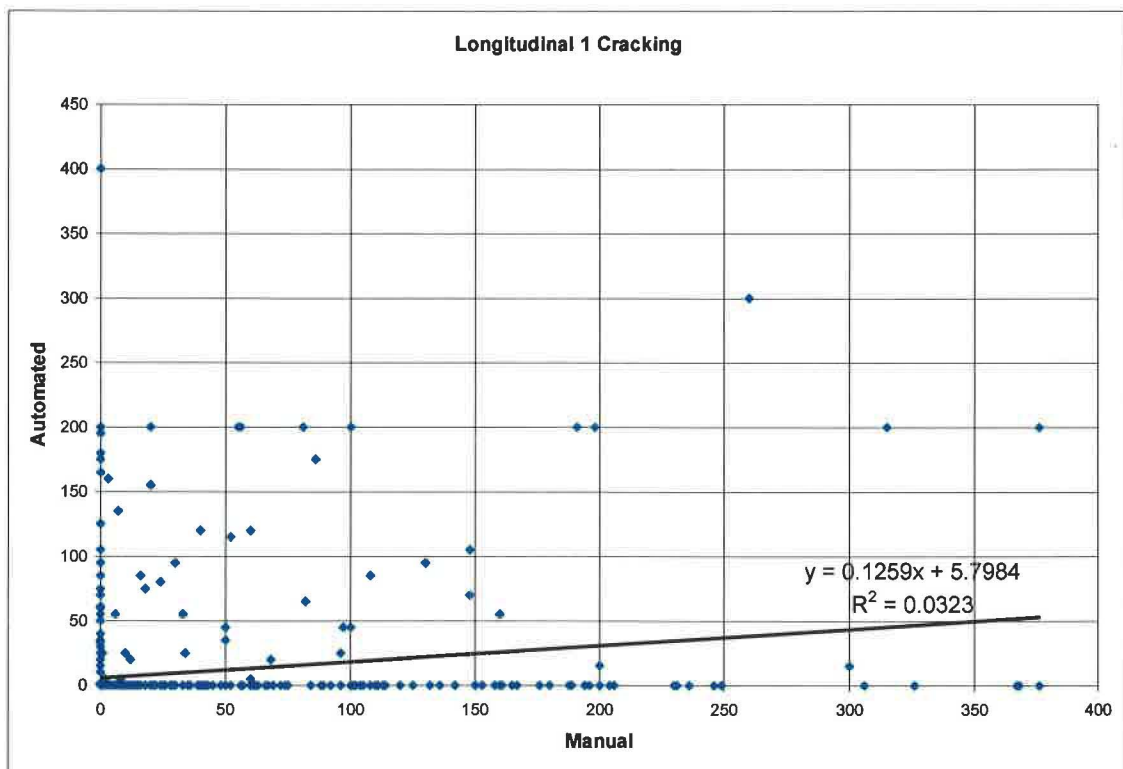**Figure C.6 Alligator 3 Cracking Regression Plot**
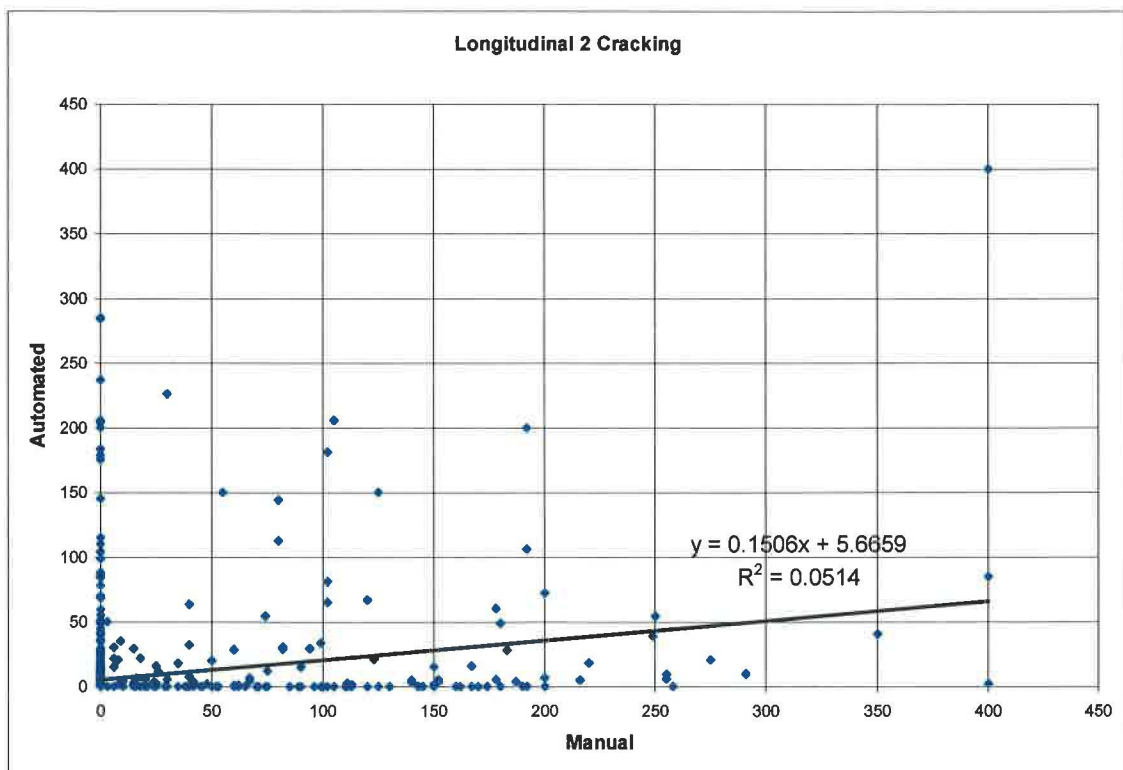
Figure C.7 Longitudinal 1 Cracking Regression Plot

Figure C.8 Longitudinal 2 Cracking Regression Plot

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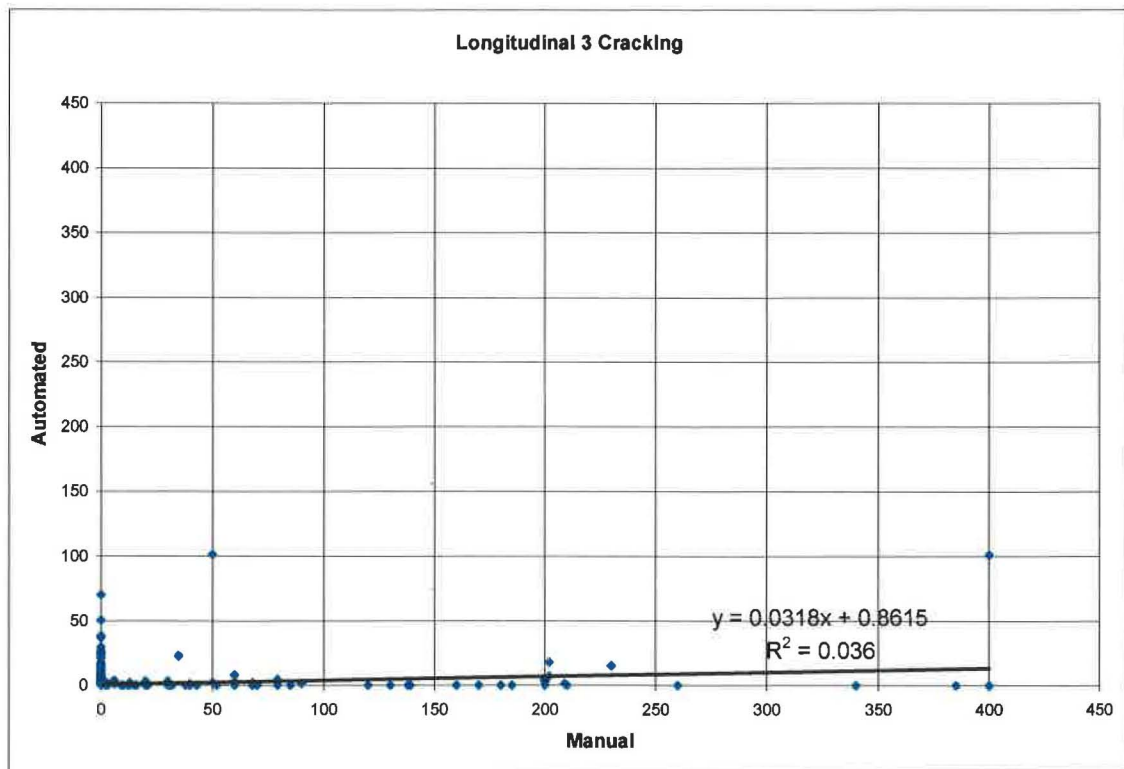
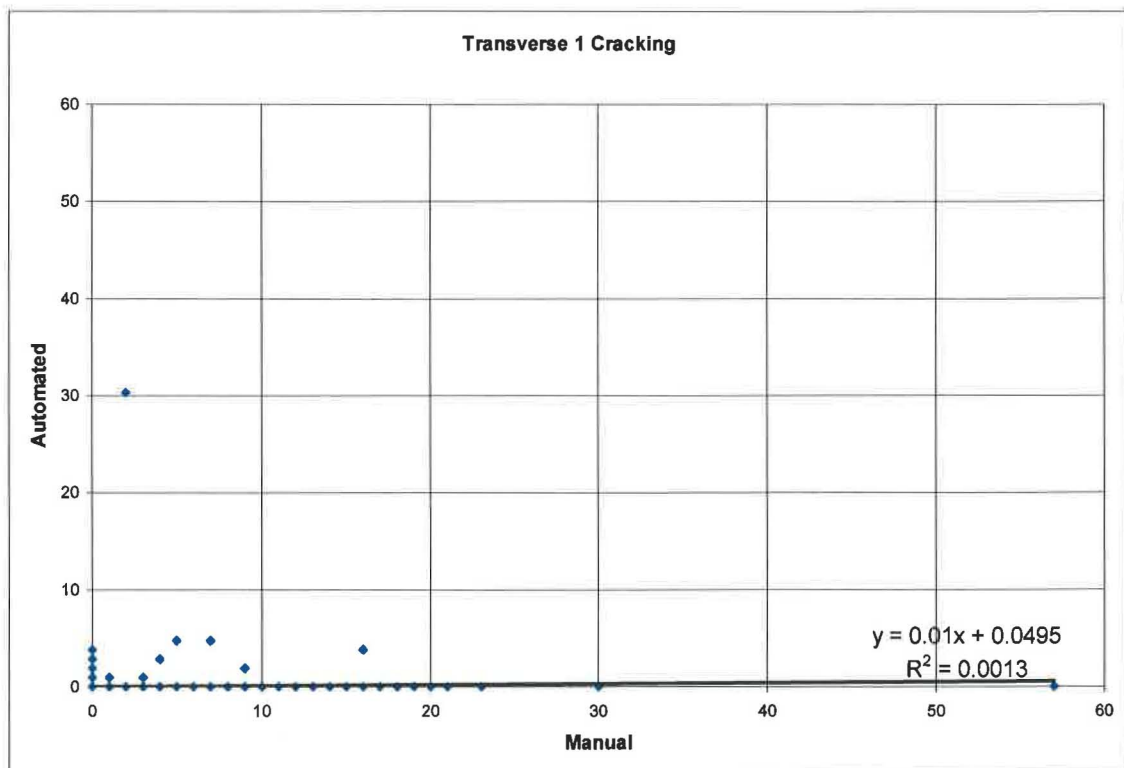**Figure C.9 Longitudinal 3 Cracking Regression Plot**

Figure C.10 Transverse 1 Cracking Regression Plot
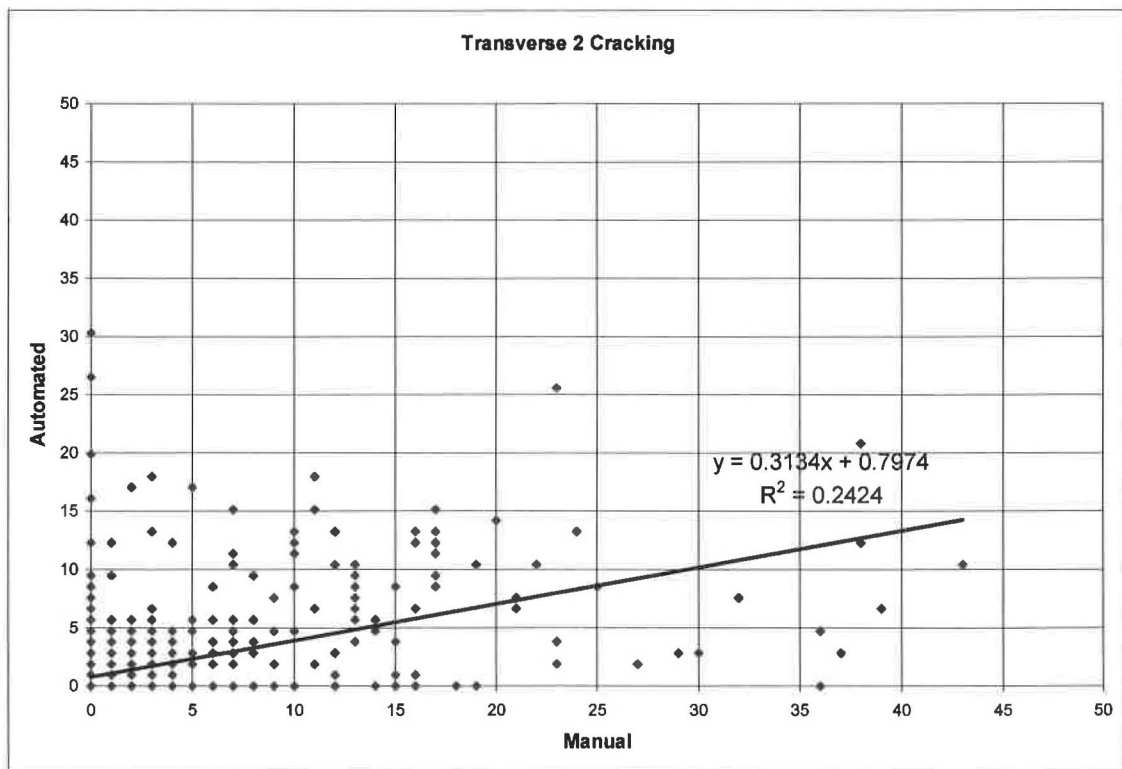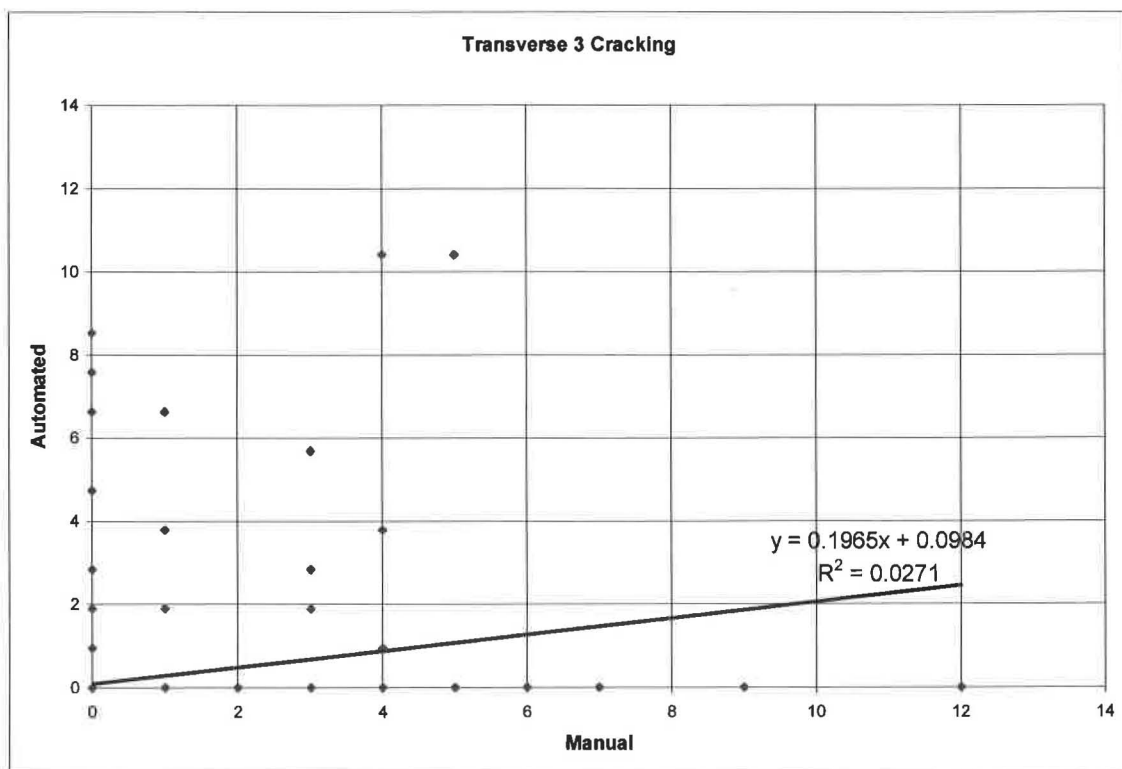
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Figure C.11 Transverse 2 Cracking Regression Plot

Figure C.12 Transverse 3 Cracking Regression Plot

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