Pavement Management System Review

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Prepared by

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Aging Infrastructure Systems Center of Excellence
The University of Alabama

and

UTCA
University Transportation Center for Alabama
The University of Alabama, The University of Alabama at Birmingham,
and The University of Alabama in Huntsville

UTCA Report Number 03416
ALDOT Report Number 930-598
June 2009

UTCA Theme: Management and Safety of Transportation Systems
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The University of Alabama (UA) researchers worked with Alabama Department of Transportation (ALDOT) managers to investigate various mechanisms to provide quality control of data collection and interpretation for pavements, and to target the data results at system decisions. Toward this end, protocols and statistical methods were created and implemented.

A review of the work steps to develop an automated pavement condition collection process is described along with the collection criteria based on AASHTO PP 44-01, Quantifying Cracks in Asphalt Pavement Surface, used by the ALDOT. During the course of this project multiple vendors, rating approaches and technologies were used. Specifically the resolution of the automated pavement image capture systems (i.e., cameras) improved from 5mm to 1mm. Likewise the size and resolution of display monitors increased. At the same time the underlying algorithms for automated interpretation ranged from rule-based to statistical pattern recognition; and added intensity to strobe lighting and the introduction of laser lighting. Overall the trend is improved technology.

However, the statistical analysis performed on field data found that interpretation reliability among the state quality control staff, the automated interpretation systems and human interpreted images vary considerably. Variability was introduced throughout the collection process beginning with establishing ground truth, to image collection, to rater interpretation of the images. The field work also identified the need for repeated quality control in calibrating sensors and an overall assurance program.

continued on next page →
In summary the ALDOT-UA team recognizes the improvements in image acquisition and interpretation technologies over the course of the four year project, and concludes that automated collection of pavement distress is becoming better, especially where guided by expert human review and enhancement. However, field tests were not conclusive that the current state of practice allows consistent capture and interpretation of 1/25\textsuperscript{th} inch to 1/8\textsuperscript{th} inch pavement cracks desired for high order modeling of pavement deterioration.

17. Key Word(s) PMS, pavement distress, automated data collection, interpretation, inter-rater reliability, quality control, quality assurance

18. Distribution Statement

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Executive Summary

This study was conducted to assess the existing pavement manage condition collection procedures and recommend changes for collection, analysis and quality control of pavement data, to enhance comprehensive pavement management system of the Alabama Department of Transportation ALDOT. ALDOT collects, transforms, and disseminates pavement condition attributes for state-owned roadways. This information provides the basis for pavement condition rating (PCR) values that in turn provide the basis for the Preliminary Prioritization Report (PPR). The PPR is generated from the data and ranks highways by their PCR values from top to bottom. The PPR is intended for use at the ALDOT Division level to help set maintenance and resurfacing priorities.

The existing pavement rating methodology and pavement forecasting algorithm were developed in the early 1980s based on manually collected and evaluated data. Today, the data collection and evaluation processes have migrated far past that and currently utilize video capture and automated evaluation of pavement images. Prior to this study only a small sampling had occurred to analyze whether the changes in collection and evaluation processes systemically bias the results from the rating and forecasting processes. Concerns regarding the use of automated data collection and transformation algorithms meant for manual collection motivated this study.

During the course of this project technology improved and the state of practice evolved, so multiple vendors, rating approaches and technologies were investigated. Specifically the resolution of the automated pavement image capture systems (i.e., cameras) improved from 5 mm to 1 mm. Likewise, the size and resolution of display monitors increased. The underlying algorithms for automated interpretation of video data ranged from rule-based to statistical pattern recognition, intensity was added to strobe lighting, and laser lighting was introduced.

The statistical analyses performed on field data during the project indicated that interpretation reliability among the ALDOT staff, the automated interpretation systems and human interpreted images varied considerably. Variability was introduced throughout the collection process beginning with selecting control segments, to establishing ground truth, to image collection, to rater interpretation of the images. Field investigation identified a need for repeated quality control in calibrating sensors and for development of an overall assurance program. A process for the handling of pavement condition data collection was developed and is discussed later in this report.

This study concentrated on planning for data collection, monitoring the execution of data collection and providing statistical procedures to evaluate the collection and interpretation process for network-level pavement condition data. The creation of a new PCR algorithm was initially a component of the project scope; however, as discussed in the body of the report, the
reliability of the point estimation values of the interpreted data precluded the development of a new pavement condition index. A future project to define and validate a new PCR algorithm is recommended.

The primary deliverables for this project are:

- The ALDOT 414-04 Network-Level Pavement Condition Data Collection Procedure
- Assistance in developing the Request for Proposal Statewide Vendor Data Collection
- Quality Control Algorithms/Work Steps evaluating Raters Interpretation of Automated Captured Pavement Images
- Baseline Quality Assurance Program Work Steps for future Pavement Condition Collection Projects
1.0 Overview

Project Objective

This project was conducted to review the practices of the Alabama Department of Transportation (ALDOT) in collecting and using pavement condition data to estimate future pavement conditions, and in allocating funding for maintenance, rehabilitation and replacement. Portions of the existing system had been in place since the 1980s, data collection methods had changed, and analysis procedures had migrated far past the original methodology for pavement condition analysis.

This project assessed the existing system and recommend changes for collection, analysis and quality control of pavement data, to enhance comprehensive pavement management system of ALDOT.

Overview

The Alabama Department of Transportation (ALDOT) is faced with a critical challenge of managing the State’s transportation assets as it continues to moves forward on initiatives that provide the basis for quantitative data asset management decision making. In the area of pavement preservation, the United States Department of Transportation’s (USDOT) Federal Highway Administration (FHWA) and the Governmental Accounting Standards Board require a standard repeatable process for reliable pavement inspection.

As depicted in Figure 1-1, ALDOT’s network-level pavement condition data collection process consists of a series of steps that begins with on-road data collection using specialized vehicles equipped with multiple sensors that collect multiple categories of distresses and indicators of distresses (i.e., images) as the vehicle is driven on state-owned roads. The collected images are transformed and processed together with distresses to produce the pavement condition rating (PCR). The PCR values provide the basis for the Preliminary Prioritization Report (PPR). The PPR provides a network-level perception using consistent methods and measurements across the state to represent the status of ALDOT managed pavement.

1 Portions of the Background and Initial Study sections have previously appeared in Lindly, Bell, and Ullah (2005). See Appendix C.
The PPR and PCR are used by planners, maintenance engineers, district engineers and researchers to provide quantitative support for budget request and fund allocation decisions based on past performance of pavement and future forecasts of pavement condition. At the division level, PPRs are intended as a starting point for project-level pavement assessment.

Transition to Automated Collection

In the mid-1990s Alabama transitioned from manual surveys of its state highways to automated collections process due to the following:

- Safety: To reduce the risk of personal injury while collecting data (that is, being on the pavement surface).
- Consistency: Improved uniformity in point estimation of distress across the network (that is, reducing regional subjective introduced by different sets of raters).
- Timeliness: Manual survey can be a slow process if more than a windshield assessment is to be obtained.
Alabama’s transition is consistent with those of more than half of the other state departments of transportation (DOTs) that have transitioned to automated collection processes (Timm and McQueen, 2004). This is supported by a National Cooperative Highway Research Program (NCHRP, 2004) report that found that between 1994 and 2004, the number of North American state/province DOTs that switched to automated collections of distress rose from seven to 30.

Table 1-1 provides more detail concerning agencies' switch to automated systems (Timm and McQueen, 2004 and NCHRP, 2004). Consistent with the data above, ALDOT collects roughness and rut data automatically.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>NCHRP Study</th>
<th>Auburn Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>96%</td>
<td>81%</td>
</tr>
<tr>
<td>Rutting</td>
<td>91%</td>
<td>81%</td>
</tr>
<tr>
<td>Distress Data</td>
<td>54%</td>
<td>5%</td>
</tr>
</tbody>
</table>


As this study began, The American Association of State Highway and Transportation Officials (AASHTO) had just released provisional standards automated pavement condition collection (AASHTO 2004a and AASHTO 2004b) that relate direct to our study. These include:

- PP 37-04, Standard Practice for Determination of International Roughness Index (IRI) to Quantify Roughness of Pavements
- PP 38-00 (2003), Standard Practice for Determining Maximum Rut Depth in Asphalt Pavements
- PP 44-01 (2003), Standard Practice for Quantifying Cracks in Asphalt Pavement Surface

In dialogs with other state DOTs the investigators found that there was no dominant method or process for measuring cracks and that most of the agencies had crafted their own standards.

**Drivers for this Study**

ALDOT’s Bureau of Materials and Tests began a quality assurance program in 2002 that manually collected distresses for 200 feet segments every 10 miles. Comparing the manual and automated collected data revealed inconsistency in representing pavement cracking in terms of
categorization, assessed severity and calculated area. This study defines how pavement distresses and conditions can be enhanced for network-level pavement condition data collection.
2.0 Methodology

Initial Study Step: Benchmarking

One of the primary reasons that ALDOT sponsored this project was to help transition from its existing unique practices for quantifying cracks to what appeared to be the emerging national document for such practices (AASHTO PP44-01). As a first step, the University of Alabama (UA) investigators along with ALDOT Materials and Tests personnel developed questionnaires to gather information from representatives of the FHWA, field and central office maintenance personnel, and other state DOTs.

Project personnel met with a pavement management specialist from the FHWA Atlanta Resource Center and subsequently assembled the following list of high-priority topics for investigation:

- Test frequency and lanes to be tested
- Conditions and distresses to be measured
- Standards to follow
- Crack severity level widths
- Area cracking (load associated and block) reporting parameter
- Reporting increments
- Standard wheel path and lane dimensions
- QC/QA Program

A short survey was distributed to the maintenance personnel in the ALDOT central office and field offices, who are the primary end-users of ALDOT's pavement condition data. Thirty-seven of 56 individuals responded. Responses to three questions were particularly specific and provided information relevant to changing the pavement condition survey method:

- Maintenance personnel most desired two pieces of information from a pavement condition survey: (1) PCR tabulated every mile (almost all responses) and (2) average rut depth (three-quarters of responses). Other needs cited included IRI, amount of cracking, cross-slopes, date last resurfaced, and pavement buildup.
The questionnaire asked respondents to list the crack width at the point it becomes significant to them. (They usually ignore cracks less than this width when making maintenance decisions.) Responses of 0.25 inches and 0.125 inches predominated. Network-survey-level digital cameras could detect cracks as small as 0.08 to 0.12 inch wide at the time of the questionnaire, which confirmed that automated condition surveys could detect cracks of importance to maintenance personnel.

Respondents also chose from a list of 12 distresses that they suspect create a need for maintenance or resurfacing. Load-associated cracking garnered the most responses, followed by rutting (nearly all respondents). Patching and potholes led the second tier of distresses.

FHWA personnel provided sample condition survey requests for proposals and specification documents from eight states. Project team members read the documents and tabulated answers to its list of high-priority topics for investigation. Team members also conducted extensive telephone interviews with representatives from the DOTs of three states: Colorado, Louisiana, and Oklahoma. Pertinent results of these activities will be described in following sections.

The next section of this report discusses the information gathered through benchmarking guided the researchers in assembling a new document to guide pavement distress data.

**Development of ALDOT 414-04**

In consultation with the ALDOT project sponsors, the University of Alabama investigators undertook the development of Alabama’s interpretation of AASHTO PP 44-01. To aid in this development, key factors such as test frequency, lane treatment, accuracy and precision requirements, conditions and distresses to be measured were detailed.

**Test Frequency and Lanes to be Tested**

*The Auburn Study* reports that 52% of respondents collect condition data annually; 30% collect data biennially; 15% collect Interstate highway data annually and other road data biennially (Timm and McQueen, 2004). The project team recommended retention of the current ALDOT system of surveying National Highway System (NHS) roads annually and the remainder of its road system biennially. One of the uses of pavement condition data is to predict future PCR of roads to anticipate when they may be candidates for maintenance and resurfacing. In Alabama, resurfaced roads, particularly those off the NHS, typically last 10+ years before requiring significant maintenance activities, which will allow at least five data points over the life of the overlay if data is collected biennially.

Prior to this study, pavement condition data was collected for all highway types in both directions, up to two lanes in each direction. The rationale was to collect data that would support differing resurfacing cycles for the truck lanes on certain routes. Reviewing documents from other state DOTs indicated that they collect condition data on far fewer lanes. The project
investigators and ALDOT personnel concluded that a change to collecting data for one lane in both directions on multi-lane highways and only one lane in the "primary" direction (north or east) for smaller facilities should be adopted as the standard to significantly reduce data collection costs.

A data reporting increment of 0.01 mile or 52.8 feet was chosen by ALDOT. NCHRP Synthesis 334 reports that most agencies report data in increments ranging from 50 to 1,000 feet, and that many U.S. agencies use 0.1 mile (NCHRP, 2004.). The 0.01 mile is within the typical range reported, and values can be aggregated easily if longer reporting increments are desired.

**Conditions and Distresses to be Measured**

Prior to 2005, ALDOT collected the following highway condition (distress) data types:

- Load associated cracking
- Longitudinal cracking
- Transverse cracking
- Block cracking
- Patching
- Raveling
- Bleeding
- Rut depth
- Shoulder type and condition
- Coded remarks about various other parameters

Considering the surveyed priorities of maintenance personnel, benchmarking results and network-level decisions of the front-office, the research team focused on adapting ALDOT pavement condition and distress collection processes to be aligned with AASHTO PP 44-01. AASHTO PP44-01 simplifies crack quantification for asphalt pavements by limiting cracks to only those found in the wheel paths (load-associated cracks) and all others found outside the wheel paths (non-load-associated cracks). Figure 2-1 shows ALDOT's adaptation of the AASHTO P 44-01 diagram defining wheel path and non-wheel path areas.
In general, ALDOT adopted the AASHTO PP 44-01 designation for width of cracks as shown below:

- Severity level 1: Cracks having widths > 1/25 inch and ≤ 1/8 inch
- Severity level 2: Cracks having widths > 1/8 inch and ≤ 1/4 inch
- Severity level 3: Cracks having widths > 1/4 inch

After reviewing other DOT practices and considering the preferences expressed by ALDOT maintenance personnel, the research team recommended and ALDOT accepted selecting the following condition data for evaluation in both flexible and rigid pavements. (Table 2-1 lists accuracy and precision requirements for the data.)

- IRI reported separately for the two wheel paths of the survey lane in inches/mile
- Transverse cracking reported in linear feet of cracking per 0.01 mile segment. To qualify, a single crack must be greater than six feet long and project within 30° of perpendicular to the pavement centerline.
Table 2-1. Accuracy and Precision Requirements for ALDOT Data Elements

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Required Accuracy</th>
<th>Required Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Roughness (IRI)</td>
<td>± 5%</td>
<td>1 inch/mile</td>
</tr>
<tr>
<td>2. Cross slope, superelevation, and grade data</td>
<td>± 0.20</td>
<td>% 0.1%</td>
</tr>
<tr>
<td>3. Load-associated cracking</td>
<td>± 10%</td>
<td>0.1 linear foot per 0.01-mile segment</td>
</tr>
<tr>
<td>4. Non-load associated cracking</td>
<td>± 10%</td>
<td>0.1 linear foot per 0.01-mile segment</td>
</tr>
<tr>
<td>5. Transverse cracking</td>
<td>± 10%</td>
<td>0.1 linear foot per 0.01-mile segment</td>
</tr>
<tr>
<td>6. Rut depth</td>
<td>± 0.1 inch</td>
<td>0.1 inch</td>
</tr>
<tr>
<td>7. Raveling</td>
<td>Identical</td>
<td>present/not present</td>
</tr>
<tr>
<td>8. Patching</td>
<td>Identical</td>
<td>present/not present</td>
</tr>
<tr>
<td>9. Macrotexture</td>
<td>N/A</td>
<td>0.01 inch</td>
</tr>
<tr>
<td>10. Joint faulting</td>
<td>± 0.1 inch</td>
<td>0.1 inch</td>
</tr>
</tbody>
</table>

*Accuracy is the required conformity to measured value representing the "true" value. Precision is the exactness of the measured value, e.g., measured to the nearest 0.1 inch.*

The following condition data was specified for flexible pavements:

- Load-associated cracking reports cracks in the wheel paths that were not previously identified as transverse cracks. Load-associated cracking is reported as the number of linear feet of road segment containing such cracking and cannot exceed 52.8 feet per 0.01 mile segment. When cracking occurs in both wheel paths, the higher severity level of the two wheel paths is reported.

- Non-load-associated cracking reports cracks longer than 1 inch (the minimum crack length as defined in PP 44-01) in the areas within the lane not identified as wheel paths and not previously identified as transverse cracks. Non-load-associated cracks are reported as the number of linear feet of the 0.01 mile segment containing such cracking. The highest severity level present in the non-wheel path areas is reported.

- Rutting reports mean and maximum values for both outside and inside wheel paths for each 0.01 mile segment.

- Raveling reports instances where the aggregate and/or binder have worn away, coded as present or not present in each segment.

- Patching reports instances where patching exists and ride quality is affected, coded as present or not present in each segment.

- Macrotexture reports the mean and maximum values for wavelengths from 0.50 mm to 50 mm each 0.01 mile segment.
Though only about 2% of the state’s pavements have concrete surfaces, the following information was specified for rigid pavements:

- Transverse joint faulting reports mean and maximum values for each segment according to AASHTO R-36(04)

Prior to this study the distress collection procedure measured fatigue cracking by area and summarized most non-load-associated cracking by adding lengths of individual cracks. The new procedure measured the proportion of the longitudinal extent of the road that contains fatigue or non-load associated cracking. The decision to align with the requirements in PP 44-01 as much as possible motivated this change. The data collection procedures also referenced PP 38-00 (2003) and R-36(04), and FHWA's *Highway Performance Monitoring System Field Manual* (FHWA, 2002).

**Other Data**

During the study, ALDOT and the UA researchers added pavement surface geometry, GPS, and travel events to the collected data. Specifically included in the collection are the following:

- Slope data including cross-slope of the pavement lane (percentage) and longitudinal grade (percentage). This is another example of sensor data, and accuracy and precision requirements are shown in Table 2-1.

- Global Positioning System (GPS) coordinates including longitude, latitude, elevation, and dilution of precision measurements. Positional accuracy for latitude and longitude must not exceed ± 10 feet. Prior to this study, it was noted that ALDOT’s linear referencing system (LRS) mileposts and the physical location of mileposts were found to be identifying different locations.

- Travel events such as pavement surface changes, railroad crossings, changes in number of lanes, and transitions from the lane specified for data collection. Event information is keyed in by personnel in the survey van.

The investigators also recommended that measurements be taken at the beginning of each 0.01 mile segment. In addition to the extra data, digital right of way (ROW) images photographed with forward-facing cameras are specified for the beginning and midpoint of each segment, such that 10-inch lettering is visible at a distance of 15 feet from the travel lane. These images are archived and can be used by central personnel to conduct preliminary inspections of sites without leaving the office.

With the above information detailed, the ALDOT and University of Alabama project team collaboratively developed, revised, and gained approval for ALDOT 414-04, Network-Level Pavement Collection Data Collection Procedure. (See Appendix A.). Project participants
believed that this document contained a collection of definitions, methodologies and criteria that reflected the best of current practices in the U.S.
3.0 Project Execution and Statistical Analysis

Project Execution

Once ALDOT 414-04 was adopted, it was used as part of the vendor selection for state-wide automated pavement condition data collection. The University of Alabama assisted ALDOT personnel in creating:

- the Request for Proposal for Statewide Automated Collection conducted by an Independent Contractor,
- the Vendor Evaluation Process, and
- the Contract Language.

These documents are solely the property of ALDOT and may be requested from their offices.

After receiving and evaluating proposals, ALDOT selected a vendor for collection of statewide data. Prior to initiating full scale production of data, the vendor was required to demonstrate calibration of its equipment to replicate human gathered distress data at test sites, provide test data for evaluation by ALDOT (with UA researcher guidance), and provide a workstation and its unique distress interpretation software for use by ALDOT.

As the project evolved, the state of practice in pavement data collection migrated to higher levels of technology for both equipment and software. This led to investigations of multiple ways to interpret video data (human subjective interpretation and machine automated interpretation), the practices of multiple vendors, the effectiveness of multiple software interpreters, and other situations. Throughout this process, the ALDOT-UA team attempted to identify appropriate procedures and criteria to provide quality assurance. As a result the project lasted over four years, with multiple extensions and variations of scope. The extent of activity may be gleaned from Table 3-1, which included a sample of the activities that UA researchers provided to ALDOT to support the network-level pavement condition data collection procedure.
Table 3-1. Summary of Activities from January 2006 through March 2008

<table>
<thead>
<tr>
<th>Date</th>
<th>Description of Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan-06</td>
<td>No-cost extension approved and contractor work status updated. ALDOT-UA completed new guidelines for data collection, evaluation, and vendor activities. The project scope was modified for friction testing, a new algorithm was discussed and implications of GASB 34 were reviewed.</td>
</tr>
<tr>
<td>Mar-06</td>
<td>Strategy meeting – The selected Vendor is getting ready to gather data, ALDOT-UA decide to train three ALDOT pavement personnel in using the vendor’s hardware and software as a way to investigate the vendor’s QA. A discussion was conducted on how to train ALDOT raters, maybe by developing a rating manual with photos of various distresses. ALDOT-UA will identify needed changes to 414, identify QA procedures, and extend the project through September 2007.</td>
</tr>
<tr>
<td>May-06</td>
<td>Selected vendor delivered workstation and conducted training of 3 ALDOT raters on distress identification and rating.</td>
</tr>
<tr>
<td>Jul-06</td>
<td>Scope change to investigate new opportunities</td>
</tr>
<tr>
<td>Aug-06</td>
<td>ALDOT-UA develops process diagram defining key project questions and work steps. ALDOT decides that selected vendor can begin collecting production data</td>
</tr>
<tr>
<td>Sep-06</td>
<td>UA-ALDOT review and discuss IRI definitions and IRI data</td>
</tr>
<tr>
<td>Oct-06</td>
<td>Selected Vendor visits to answer ALDOT-UA questions, conduct training, and deliver data</td>
</tr>
<tr>
<td>Dec-06</td>
<td>Selected Vendor is asked to re-rate its first data, and agrees to do so</td>
</tr>
<tr>
<td>Mar-07</td>
<td>Strategy session at UA – discussion of data types, final use of data, when to QA, how long it will take for ALDOT to manually evaluate field data, how to determine inter-rater results of ALDOT raters, how to compare their ratings to vendor ratings, etc. The ALDOT-UA team also discussed “what if” scenarios and options for the project to proceed.</td>
</tr>
<tr>
<td>Oct-07</td>
<td>UA asked to modify scope/budget to add evaluation of additional software and vendors</td>
</tr>
<tr>
<td>Jun-08</td>
<td>UA requests no-cost time extension until September 30, 2008</td>
</tr>
<tr>
<td>May-08</td>
<td>ALDOT summarizes all correlation studies performed so far in the project. This information is used to guide the next research steps.</td>
</tr>
<tr>
<td>Jul-08</td>
<td>UA presented new vendor reliability analysis to ALDOT, obtained feedback regarding additional analysis desired. ALDOT-UA agree that sufficient analysis has been completed, and that it is time to make key decisions and close the project. ALDOT asked for QA advice during next data collection cycle</td>
</tr>
<tr>
<td>Aug-08</td>
<td>UA and ALDOT discussed interpretation of vendor reliability analysis and resulting contract decision recommendations. UA presented its interpretation of vendor reliability analysis and the resulting contract decision process for ALDOT.</td>
</tr>
<tr>
<td>Sep-08</td>
<td>The project is closed financially, with some additional statistical analysis to be performed and a final report to be developed</td>
</tr>
<tr>
<td>Nov-08</td>
<td>UA discussed requirements for an IRR instructional guide with ALDOT.</td>
</tr>
<tr>
<td>Dec-08</td>
<td>UA reviewed draft user instructions for inter-rater reliability analysis and interpretation, and obtained feedback and revision requests from ALDOT.</td>
</tr>
<tr>
<td>Jan-09</td>
<td>UA presented and reviewed revised instructions for inter-rater reliability analysis and interpretation based on Minitab</td>
</tr>
<tr>
<td>Mar-09</td>
<td>UA reviewed IRR analysis conducted by ALDOT for accuracy and meaning</td>
</tr>
<tr>
<td>Apr-09</td>
<td>UA reviewed a corrected IRR analysis prepared by ALDOT for accuracy and meaning</td>
</tr>
</tbody>
</table>
Statistical Analysis Used to Validate Data Collection Process

The research team monitored and performed statistical analyses throughout the data collection process. Table 3-2 summarizes typical activities that were performed.

### Table 3-2. Summary of Quality Control and Vendor Monitoring Tasks

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-06</td>
<td>ALDOT documented results for five control sites, first 1/10 mile, selected Vendor vs. ALDOT raters. ALDOT visited control sites to try to account for variability</td>
</tr>
<tr>
<td>Jul-06</td>
<td>ALDOT tabulated pilot sites of selected Vendor v ALDOT, color code and % difference</td>
</tr>
<tr>
<td>Aug-06</td>
<td>May control site data reveals - no reliability for wheel path sums</td>
</tr>
<tr>
<td>Sep-06</td>
<td>Selected Vendor took data collection van to 12 sensor correlation sites; 8th Division site distress survey (provided by ALDOT)</td>
</tr>
<tr>
<td>Nov-06</td>
<td>Evaluation of ALDOT raters speed and consistency</td>
</tr>
<tr>
<td>Jun-07</td>
<td>Selected Vendor provided first production data which was forwarded to UA. Selected Vendor data on pilot sites forwarded to UA. ALDOT tried a “quick” manual review for general ratings (0, 1, 2, 3), but the results do not give insight into the Selected Vendor ratings</td>
</tr>
<tr>
<td>Jul-07</td>
<td>UA reports on inter rater reliability, 3 ALDOT raters v selected Vendor data</td>
</tr>
<tr>
<td>Aug-07</td>
<td>ALDOT/UA meet to review rating results, demo Selected Vendor computer system, but no level was 3 found, no common definition of level 1/2, ALDOT raters &gt; 10% variance. Strategies - find ground truth, more training, see about using other software, and see if the VA contractor will do a sample of Selected Vendor data for us.</td>
</tr>
<tr>
<td>Dec-07</td>
<td>UA overviews Selected Vendor inter-rater reliability analysis</td>
</tr>
<tr>
<td>Mar-08</td>
<td>ALDOT rater comparison of Oct 07 and Mar08 field ratings</td>
</tr>
<tr>
<td>Apr-08</td>
<td>F Bell sends UA a DVD, 2nd generation Selected Vendor distress images</td>
</tr>
<tr>
<td>May-08</td>
<td>ALDOT summarizes various correlation studies of various ratings; Phase 1 – completed; Inter-rater reliability between ALDOT office raters discussed; Comparison of ALDOT office raters and ALDOT field rater—October 2007 rating ;Comparison of ALDOT office raters &amp; Selected Vendor office—“collection” phase; Comparison of ALDOT field rater—October 2007 and Selected Vendor “collection” phase with eye toward suitability for algorithm development; Phase 2 – completed; Comparison of ALDOT field rater—Mar 2008 and Alternative Vendor’s second visit—1 mm camera. Comparison of ALDOT field rater—Mar 08 and Selected Vendor 6k linescan—second visit, for algorithm suitability; Phase 3 attempted - July 2008; Comparison of ALDOT field rater—Mar 08 and Alternative Vendor their Software; Comparison of Selected Vendor 6k linescan, second visit Alternative Vendor their Software ALDOT provides Pilot site data, Selected Vendor visit2/alternative vendor 1mm/field rater</td>
</tr>
<tr>
<td>Jun-08</td>
<td>ALDOT initial analysis, Selected Vendor v alternative vendor v ALDOT rater evaluation</td>
</tr>
<tr>
<td>Jun-08</td>
<td>ALDOT reliability analysis - Selected Vendor visit2 vs. Alternative Vendor 1mm vs. ALDOT field</td>
</tr>
<tr>
<td>Jul-08</td>
<td>ALDOT manual vs. digital data (Selected Vendor) comparison - 414, distress, rutting, etc</td>
</tr>
<tr>
<td>Jul-08</td>
<td>ALDOT and UA agree that it is time to move on, make decisions, close project and prepare final report; ALDOT asks for QA advice for use in next data collection cycle</td>
</tr>
<tr>
<td>Aug-08</td>
<td>UA researchers conduct interpretation of vendor reliability analysis and determine vendor contract recommendations. Document is prepared containing summary of both.</td>
</tr>
<tr>
<td>Dec-08</td>
<td>UA prepared detailed instructions regarding how to conduct vendor reliability analysis and how to interpret the results.</td>
</tr>
<tr>
<td>Jan-09</td>
<td>UA revised vendor reliability user instructions to accommodate ALDOT statistical software and preferences of engineers conducting the analysis.</td>
</tr>
<tr>
<td>Mar-09</td>
<td>UA reviewed the IRR analysis conducted by ALDOT for accuracy and meaning</td>
</tr>
<tr>
<td>Apr-09</td>
<td>UA reviewed the corrected IRR analysis conducted by ALDOT for accuracy and meaning</td>
</tr>
</tbody>
</table>
Statistical analyses were conducted for many comparisons of rating results. For example, ALDOT rating of video deterioration was compared with ALDOT field rating of deterioration for each of the three cracking categories. One of the analyses is featured here as an example. The first correlation analysis results indicated low reliability, so the analysis was repeated using the following prioritization:

- Wheel Path Cracking is certainly the most important distress for determining pavement deterioration.
- Transverse Cracking is second in importance.
- Non-Wheel Path is of little importance.

While conducting the analysis, ALDOT and UA established the following for pavement cracks:

- Level 3 indicates large and serious deterioration, but there is little of this level remaining on state highways thanks to ALDOT’s aggressive maintenance activities.
- Level 2 indicates cracks that are growing in severity. This appears to currently be the dominant type on Alabama highways.
- Level 1 indicates minor cracks; they are somewhat difficult to identify in the field but are necessary for deterioration modeling.

Using this guidance, UA prepared a correlation analysis for Wheel Path Cracking. The findings are tabulated in Table 3-3.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Sum (levels 1-3)</th>
<th>Sum (levels 1-2)</th>
<th>Sum (levels 2-3)</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Vendor 2nd visit, 1 mm camera</td>
<td>0.753</td>
<td>0.760</td>
<td>0.633</td>
<td>N/A</td>
<td>0.641</td>
<td>-0.011*</td>
</tr>
<tr>
<td>Selected Vendor 2008 pilot visit</td>
<td>0.870</td>
<td>0.463</td>
<td>0.716</td>
<td>N/A</td>
<td>0.371</td>
<td>0.152*</td>
</tr>
</tbody>
</table>

Each column has a numerical value inserted for purposes of referencing.

The following pertinent comments emerged during a review of the analysis:

**Level 1 Cracking (column 5):** One of the initial analysis finding was that the ALDOT field rater identified little to no Level 1 cracking. Because the ALDOT rater did not record any Level 1, no correlation was possible by either of the vendors. (See column 5
of the table above.) The UA research team points out that the absence of Level 1 cracking will limit the ability to model and predict crack growth (deterioration modeling).

**Level 2 Cracking (column 6):** Both vendors recorded Level 2 cracking, and the Alternative Vendor provided the best correlation with the ALDOT rater by a substantial amount. Level 2 cracking in the Wheel Path is the most important cracking location and the most prevalent level of cracking on Alabama highways.

**Level 3 Cracking (column 7):** The prevalence of zero ratings in the Level 3 observations clouds the analysis and interpretation. However, using the column 7 correlation scores and data in columns 1 through 3, it is clear that the Alternative Vendor detected Level 1 cracking that neither the ALDOT rater nor the Selected Vendor saw, and that the Selected Vendor detected some minor amount of Level 3 cracking that neither the ALDOT rater nor the Alternative Vendor saw. That is, the 1 mm camera of the Alternative Vendor appeared to distinguish more clearly between Level 1 and Level 2, and drove the overall Alternative Vendor rating toward smaller cracks. The opposite appeared to occur with the Selected Vendor, which identified more Level 3 cracks than either ALDOT or the Alternative Vendor and drove its average rating toward larger cracks.

**Sum of Levels 1-3 (column 1):** The Selected Vendor had the better correlation with the ALDOT rater, which is expected since the Alternative Vendor detected Level 1 cracking that was not observed by ALDOT.

**Sum Levels 1-2 (column 2):** The Alternative Vendor had a substantially better correlation in this category. This indicates that the Level 1 + Level 2 cracking observed by the Alternative Vendor correlated well with the Level 2 observed by the ALDOT rater (i.e., the ALDOT rater did not see Level 1). In other words, the two raters seemed to see the same cracking pattern, but Alternative Vendor’s 1 mm camera was able to better distinguish the difference between Level 1 and Level 2.

The Selected Vendor had a much weaker correlation for Levels 1+2. But when Level 3 was added to the mix (i.e., column 1), the correlation was much stronger. In other words, Selected Vendor appears to have identified less Level 2 but more Level 3 than ALDOT, so that the sum of 1-3 gave a good correlation, while the correlation of the individual levels did not.

**Sum Levels 2-3 (column 3):** When Levels 2 and 3 are summed, the Selected Vendor had the highest correlation. Since neither the Selected Vendor nor the ALDOT rater observed Level 1 cracking, it is expected that the Selected Vendor would have the highest correlation for Levels 2-3.

A summary of the statistical processes used in the study are presented in Appendix C.
4.0 Recommendations Future Data Collection Process

The pavement condition data collection process recommended in this project consists of three phases. The process begins with sensor correlation and condition data site inspection to establish ground truth. The ground truth data will be used throughout the pavement data process to assure quality. The next process phase collects pavement data that will be interpreted in the last process phase. The process phases are shown in Figure 4-1.

![Figure 4-1. Process phases.](image)

**Phase 1: Establish Ground Truth**

Two types of ground truth will be established in this phase: (1) distresses measured directly by sensors and (2) conditions represented in images that must be interpreted. Figure 4-2 details the process view for establishing ground truth.

The selection of control sites is an important step in this process. Based on the variety of surface textures, five to ten condition sites should be selected for distress types expected to be identified during data collection. Control sites should reflect different pavement types, age, and prevalent distress types, and topology. These sites should be representative of the variations in the general population of the pavement across the state.
Ground Truth is Established

Begin

Select Condition Data Sites

For Each Selected Condition Site

Performs Manual Assessment

Performs Automated Data Collection

Perform Image Interpretation

Change procedures as required and repeat portions of process as required to achieve correlation

Root Cause Analysis

Uncorrelated

Correlate Manual and Automated Results

Correlation Achieved

Reassess when no intra-rater reliability

Reliability Achieved

Reassess when no inter-rater reliability

Reassess when no intra-rater reliability

Reassess when no inter-rater reliability

Consensus Achieved

End

Select Sensor Correlation Sites

For Each Selected Sensor Site

Performs Manual Assessment

Performs Automated Data Collection

Recollect when Unreliable collection

Re-collect when Unreliable Interpretation

Reliability Achieved

Reliability Achieved

Reassess when no intra-rater reliability

Correlate Manual and Automated Results

Correlation Achieved

Correlation Achieved

Uncorrelated

Root Cause Analysis

Figure 4-2. Establish ground truth baseline.
Each site should be manually collected to produce control data.

- Multiple pavement engineers should identify the pavement condition at intervals that will allow statistical comparisons with the automated “vendor” collection process.
- The same engineer should repeat data collection on a sampling basis, providing data to assess the reliability of that individual engineer.
- Cross-rater condition data should be used to determine inter-rater reliability.

Data from each site should be collected using automated means.

- Sensor-based readings are collected and stored automatically.
- Images are taken.
- Images are interpreted in the same manner as that done for the full state-wide collection process.

Correlate values among the manual and automated collection procedures.

- The values do not have to match, rather they must statistically correlate.
- If the results do not correlate, a root cause analysis can be used to determine if either of the approaches is in error and whether one or both need to be repeated. If the analysis indicates that there is no method to achieve the correlation, then modifications must be made in the procedures.

Once the ground truth results are correlated, statewide collection can be initiated.

**Phase 2: Pavement Data Collection**

The statewide collection provides sensor data is collected by the vendor’s vehicular sensor equipment and condition data (images) is collected by cameras, producing video images that must be interpreted.

The data collection process must be implemented while maintaining appropriate levels of quality. The implementation process is shown in Figure 4-3. First, pre-collection procedures include pre-collection checklists and calibration of equipment. Second, data is collected from assigned roads and quality guidelines are followed. Finally, post-collection procedures are followed including quality sign-offs, delivery of data to ALDOT, and post-collection verification.
Quality Indicators

This process implements the quality indicators established for the pre-data collection process. The following pre-collection quality indicators ensure that environmental and equipment conditions do not corrupt data collection:

- Atmospheric Indicators
  - Pavement must be free of ice
  - Correct lighting (depends on strobe or laser)
  - Within Limits for precipitation and fog
Camera Indicators

- Road images must be taken at sufficient resolution to ensure 10-inch sign lettering is legible at a distance of 15 feet from the edge of the travel lane while traveling at highway speeds.

- All exterior cameras must be capable of collecting images during normally encountered fair weather conditions in Alabama.

- Camera lenses must be checked prior to every pavement segment.

- Camera lenses must be cleaned if necessary.


- Sensor Calibration
  - Vendor data collection vehicles must be tested on all sensor correlation sites a minimum of five times prior to data collection. The average of these tests must meet the data quality requirements specified in ALDOT 414-04: Network-Level Pavement Condition Data Collection Procedure – Section 4: Data Quality Requirements.

- Condition Calibration
  - Vendor data collection vehicles must be tested on all condition data sites prior to data collection. These tests must achieve the same result as ALDOT results. Any differences will be investigated and resolved prior to data collection.

Multiple Vehicle Indicator

- If multiple data collection vehicles are used, all must be calibrated.

- If multiple data collection vehicles are used, the variance reported in sensor calibration between trucks must be less than or equal to 5%.

This process implements the quality indicators established for the data collection process. The collection quality indicators include all information required, in sufficient accuracy and precision to permit descriptions of distresses and other items as described in ALDOT 414-04: Network-Level Pavement Condition Data Collection Procedure. The accuracy and precision of collected data must be sufficient to meet the data quality requirements specified in ALDOT 414-04: Network-Level Pavement Condition Data Collection Procedure – Section 4: Data Quality
Requirements, any roads that are obscured by debris are flagged during the collection of data using the data collection checklist.

This process implements the quality indicators established for post-collection verification. The post-collection verification includes a weekly verification and a monthly correlation as described in ALDOT 414-04: Network-Level Pavement Condition Data Collection Procedure – Section 5.3: Production. If these verifications exceed the previously described quality requirements, then data collected since last successful verification will be considered compromised. Compromised data may be refused by ALDOT.

**Checkpoints**

- The pre-collection checkpoint includes completion and signoff of checklists for each of the pre-collection quality indicators (i.e., atmospheric, lighting, camera, and calibration). The collection checkpoint assures that all required checklists have been completed and signed off prior to delivery of data to ALDOT. Post-collection verification checklists assure collected data is not compromised. All checklists must be signed and delivered to ALDOT.

- Periodically the vendor is to re-run control test areas (as in phase 1) to ensure the process is still in control.

**Roles**

The operator of the data collection vehicle must perform the data collection.

**Phase 3: Image Interpretation**

In this phase, a vendor interprets the images taken during the data collection process. Using the criteria in ALDOT 414-04 the images are translated to numeric values and severity levels. To verify that the interpretation process has integrity, the results are verified through test of inter-rater and intra-rater reliability. (Appendix B provides the statistical processes.) The interpreted images and numeric values are sent to ALDOT where random samples will be interpreted and the ALDOT results will be correlated to the vendor interpretation for a second level of quality control. The process is shown in Figure 4-4.
Quality Indicators

This process implements the quality indicators established for the pre-interpretation process. The pre-interpretation quality indicators are:

- **Ground Truth** – A sample of ground truth images are randomly placed in the collected data and the ground truth images must be indistinguishable from collected images.

This process implements the quality indicators established for the interpretation process. The interpretation process indicators are:

- **Inter-rater Reliability** – a sample of images will be interpreted by two or more reviewers
- **Intra-rater Reliability** – a sample of images will be interpreted more than once by the same reviewer and placed a random number of images away from each other.
This process implements the quality indicators established to determine interpretation reliability. The quality indicators are:

- Inter-rater Reliability verified
- Intra-rater Reliability verified
- Ground Truth Reliability

In the post-interpretation process, ALDOT will sample images in the data returned to ALDOT and perform interpretations that will be compared to the vendor performed interpretations should the interpretations not correlate then the issues must be resolved.

**Checkpoints**

The pre-interpretation quality indicators are verified using a checklist. The interpretation quality indicators are verified using a checklist and any reliability issues require the images in question to be reinterpreted. Documentation must be provided describing reinterpreted images and resolution of interpretation issue. All reinterpretation of images must be reported on the reliability checklist. The post-interpretation quality indicators are verified using a checklist and any reliability issues must be resolved prior to acceptance of interpretation data.

**Roles**

Vendor performs the pre-interpretation process and the interpretation process, including determination quality indicators and signoff of checklists. Vendor will deliver checklists and interpretation data to ALDOT. ALDOT QA employees perform the post-interpretation process.
5.0 General Observations and Recommendations

This study concentrated on planning for data collection, monitoring the execution of data collection and providing statistical procedures to evaluate the collection and interpretation process for network-level pavement condition data. The primary deliverables for this project are:

- The ALDOT 414-04 Network-Level Pavement Condition Data Collection Procedure
- Assistance in developing the Request for Proposal Statewide Vendor Data Collection
- Quality Control Algorithms/Work Steps evaluating Raters Interpretation of Automated Captured Pavement Images
- Baseline Quality Assurance Program Work Steps for future Pavement Condition Collection Projects.

This study was conducted to assess the existing pavement condition collection procedures and recommend changes for collection, analysis and quality control of pavement data, to enhance the comprehensive pavement management system of ALDOT. The project has enabled UA researchers to make several observations and recommendations as a result of the investigation of vendor capabilities.

Observations

- A complete understanding of the planned use of the data should drive requirements for the precision and accuracy of the data collection. For example
  - Using the data to estimate system wide conditions is the basic use of the data and requires consistency;
  - Whereas using the data to determine budgetary allocation among divisions requires a base level of data accuracy and precision;
  - Whereas using the data to determine which pavement sections need maintenance, rehabilitation or replacement requires a higher level (or levels) of accuracy and precision; and
Whereas using the data to determine the rate of deterioration of a section of pavement to predict the occurrence of future distresses requires a fourth level of accuracy and precision.

Rating of deterioration is a subjective process.

- Human beings can be trained to distinguish various types and levels of distress. Some of ALDOT's best pavement raters did a good job of manual rating, but even they could not consistently make fine distinctions between crack sizes and levels of deterioration.
- Fatigue and other factors impact the consistency of these distinctions at lower levels of detail and finer levels of distinction.
- Processes for quality assurance and quality control offer hope for moving automated ratings toward higher accuracy and precision, but are often limited by the procedures used for the human interpretation of data.

Technology has significantly improved over the course of the project.

- The project investigated technology of multiple vendors and found camera, lighting, and other key components to vary; however, all vendors appeared to be continuously looking to further enhance their technology.
- Camera and interpretation software technology has improved considerably. Camera and software technology is not yet sufficient to accurately distinguish various types of distress without human intervention.
- For example, it is difficult to rate a crack that has been sealed with liquid asphalt without human intervention.
- Continuing improvement in technology may allow hope of fully automated distress ratings in the future.

Currently, it does not appear possible to accurately identify and provide deterioration ratings for individual narrow pavement cracks (ALDOT Level 1).

ALDOT 414-04 provided a standard procedure to collect and interpret pavement condition; without such a standard it was not possible to know whether the data collection was or was not in control.

Consistent capture and integration of level 1 crack severity (i.e., 1/25” to 1/8”) as defined in ALDOT 414-04 is beyond the current state-of-practice.
Recommendations

- Define the explicit uses pavement condition and distress data in terms of system-wide ratings, budget allocation, segment maintenance selection, and forecasting.

- Refine ALDOT 414-04 to define collection so that the processes used to ensure accuracy and precision of the data can be aligned with the purpose.

- Invest as necessary to achieve high levels of quality with regard to ground truth.
  - All data collection and interpretation quality determinations are dependent upon the ability to compare results to ground truth.
  - Use ground truth to test abilities of vendors prior to contracting and periodically to maintain quality.
  - Use ground truth and vendor testing to establish the boundaries of data accuracy and precision achievable given human and technological limitations and then adjust procedures, algorithms, and decision approaches accordingly.

- Require data collection and interpretation vendors to utilize the process described in Error! Reference source not found. section of this document and periodically audit vendor compliance with the process.

- Collection of data for one lane in both directions on multi-lane highways and only one lane in the "primary" direction (north or east) for smaller facilities should be adopted as the standard to significantly reduce data collection costs.

- Prior to the next full pavement condition data collection cycle, advances in image collection and interpretation technologies should be benchmarked to determine state-of-the-practice for data accuracy and precision. These practices should be incorporated as revisions to ALDOT 414-04. This benchmarking includes:
  - AASHTO and FHWA research and standards
  - Processes used by other state department of transportations
  - Practices offered by potential collection and interpretation vendors

- As part of the quality control process for image interpretation, inter-rater reliability (also referred to as inter-rater agreement or concordance) should be determined. This statistic provides a score of how much consensus there is in the ratings given by multiple raters. It is useful in refining the tools given to raters, for example by determining if a particular measurement method is appropriate for measuring a particular variable. If raters do not agree, either:
the measurement method is defective or

- the raters need to be re-trained.

Several statistics can be used to determine inter-rater reliability. Different statistics are appropriate for different types of measurement. Here, we recommend the use of:

- Pearson’s correlation coefficient (r), the most straightforward measure, useful when only two raters are to be compared (for example, a vendor compared to an ALDOT rater considered to provide ground truth)

- Intra-class correlation (ICC – absolute agreements), to be used when more than two raters are to be compared or when it is important to detect consistent differences between raters.

We recommend ALDOT procure a statistical package that will calculate inter-rater reliability such as the package used in Appendix B, Statistical Procedures Using Minitab.

In conclusion, this project has established baseline processes for automated asphalt pavement condition and distress data collection. In addition to creating a collection procedure aligned with AASHTO pp-44, this project created quality assurance and statistical procedures to evaluate the collection of pavement condition and distresses. The major obstacle inhibiting data collection at the 1/25th inch to 1/8th inch level of severity is technological. That is, statistical tests of data from field data did not support the ability to consistently capture and interpret images at this level of resolution. Measurement errors were found to be introduced throughout the process and including obtaining ground truth, image maximum resolution and image interpretation by the raters.

This project initially included the creation of a new PCR algorithm; however, the current reliability of the point estimation values of the interpreted data precluded the development of a new pavement condition index. A future project to define and validate a new PCR algorithm is recommended.
6.0 Acknowledgements

THIS REPORT WAS PREPARED WITH COOPERATION AND ASSISTANCE OF REPRESENTATIVES OF THE FOLLOWING AGENCIES AND ORGANIZATIONS:

Alabama Department of Transportation; Federal Highway Administration-Alabama Division;
American Association of State Highway and Transportation Officials; and
The University of Alabama’s Information Technology Innovation Center,
Department of Civil, Construction, and Environmental Engineering, and
Area of Management Information Systems

The project associated with this report was funded wholly or in part by the Aging Infrastructure Systems Center of Excellence (AISCE), and the University Transportation Center for Alabama (UTCA). The contents of this project report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government, AISCE, UTCA, and the three universities comprising UTCA assume no liability for the contents or use thereof.
7.0 References


Appendix A: ALDOT 414-04 Network-Level Pavement Condition Data Collection Procedure

ALDOT-414-04
NETWORK-LEVEL PAVEMENT CONDITION DATA COLLECTION PROCEDURE

1. Scope

1.1. This method describes the collected data and the quality assurance process for network-level pavement condition data collection.

1.2. The values stated in English units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced documents


2.2. AASHTO PP 38-00 (2003), Standard Practice for Determining Maximum Rut Depth in Asphalt Pavements

2.3. AASHTO R-36(04), Standard Practice for Evaluating Faulting of Concrete Pavements

3. Description of distresses and other data items

3.1. Each distress or data item shall be collected for the entire length of each 0.01-mile (16.1 m) road segment, unless otherwise noted, and reported at 0.01-mile (16.1 m) increments. The CONSULTANT may suggest more cost-efficient data collection procedures for the DEPARTMENT’s consideration.

3.2. Information to be collected for all pavements:

3.2.1. Location information—route type, route, milepost, and direction.

3.2.2. Surface type—flexible or rigid.

3.2.3. Other segment information—Is the 0.01-mile (16.1 m) segment on a bridge (yes/no)? Is the 0.01-mile (16.1 m) segment in a construction zone (yes/no)?

3.2.4. Slope data—The following shall be recorded for a single point at the beginning of each 0.01-mile (16.1 m) segment:

• Cross slope of the pavement lane as a percentage.
• Longitudinal grade of the pavement shown as a percentage.

3.2.5. Global Positioning System (GPS) coordinates—Longitude and latitude shall be recorded for a single point at the beginning of each 0.01-mile (16.1 m) segment.
Elevation data shall be recorded at the same point. For each record, the vertical and horizontal dilution of precision (DOP) and date/time shall be included.

3.2.6. ROW/shoulder images—Color digital images shall be collected at the beginning and midpoint of each 0.01-mile (16.1 m) segment from one or more cameras that show left and right shoulder and ROW. The CONSULTANT will attach distinguishing information to each image specifically identifying highway number, direction, milepost, and date.

3.2.7. Events—The following events on the DEPARTMENT’s highway network shall be marked on the corresponding 0.01-mile (16.1 m) record:

- Every surface change—this event refers to noticeable changes in the age or type of the surface course
- Every railroad crossing
- Every transition from a multilane facility (at least two lanes in each direction) to a single lane facility, or vice versa
- Any time the test vehicle moves out of the specified lane

3.2.8. International Roughness Index (IRI)—Mean ride quality for each 0.01-mile (16.1 m) segment shall be reported separately for the two wheel paths in the survey lane in units of in/mile (m/km). The data shall be Highway Performance Monitoring System (HPMS) compliant as described in the Highway Performance Monitoring System Field Manual.

3.2.9. Transverse cracking—This type of cracking consists of cracks that occur at approximately right angles to the centerline. Transverse cracks shall be categorized as one of the following:

- Severity level 1: Cracks having widths > $\frac{1}{16}$ in. and $\leq \frac{1}{8}$ in. (> 1 mm and ≤ 3 mm).
- Severity level 2: Cracks having widths > $\frac{1}{8}$ in. and $\leq \frac{1}{4}$ in. (> 3 mm and ≤ 6 mm).
- Severity level 3: Cracks having widths > $\frac{1}{4}$ in. (> 6 mm).

Transverse cracks shall be rated prior to other cracking, and shall be reported as feet of cracking per 0.01-mile (16.1 m) segment. In order for a crack to be categorized as transverse, a single crack shall be greater than 6 ft (1.8 m) long and project within 30° of perpendicular to the pavement centerline.

3.3. Information to be collected for flexible pavements:

3.3.1. Load associated cracking—This type of cracking consists of any cracks longer than 1 in. found in the wheelpaths as defined in Figure 1 that were not previously identified as transverse cracks. Load associated cracking is categorized as follows:
• Severity level 1: Cracks having widths > \( \frac{1}{25} \) in. and \( \leq \frac{1}{8} \) in. (> 1 mm and \( \leq 3 \) mm).
• Severity level 2: Cracks having widths > \( \frac{1}{8} \) in. and \( \leq \frac{1}{4} \) in. (> 3 mm and \( \leq 6 \) mm).
• Severity level 3: Cracks having widths > \( \frac{1}{4} \) in. (> 6 mm).

Load associated cracking shall be reported as the number of linear feet (linear meters) of road segment containing such cracking. In each 0.01-mile (16.1 m) segment, the maximum length of load associated cracking that shall be reported is 52.8 ft (16.1 m). If load associated cracking is present in both wheelpaths for the same length of road, the higher severity shall be reported.

![Diagram of wheelpath dimensions](image)

**Figure 1. Typical Wheelpath Dimensions**

3.3.2. Non-load associated cracking—Non-load associated cracks are those cracks longer than 1 in. in the areas within the lane width not identified as wheelpaths, as described in Figure 1, that were not previously identified as transverse cracks. These may include longitudinal cracks or and interconnected longitudinal and transverse cracks forming a series of polygons. Non-load associated cracking shall be categorized as one of the following:

• Severity level 1: Cracks having widths > \( \frac{1}{25} \) in. and \( \leq \frac{1}{8} \) in. (> 1 mm and \( \leq 3 \) mm).
• Severity level 2: Cracks having widths > \( \frac{1}{8} \) in. and \( \leq \frac{1}{4} \) in. (> 3 mm and \( \leq 6 \) mm).
• Severity level 3: Cracks having widths > \( \frac{1}{4} \) in. (> 6 mm).

Non-load associated cracking shall be reported as the number of linear feet (linear meters) of road segment containing such cracking. In each 0.01-mile (16.1 m) segment, the maximum length of non-load associated cracking that shall be
reported is 52.8 ft (16.1 m). If non-load associated cracking is present in multiple locations for the same length of road, the highest severity shall be reported.

3.3.3. Rutting—Report mean and maximum values for outside wheel path and report mean and maximum values for inside wheel path for each 0.01-mile (16.1 m) segment. Rut depths shall be determined according to AASHTO PP 38-00 (2003). The maximum distance between measurements shall be 0.001 miles (1.61 m).

3.3.4. Raveling—Report instances in which the aggregate and/or binder has worn away and the surface texture is extremely rough and pitted, coded as follows:
- 0 – not present
- 1 – present

3.3.5. Patching—Report instances in which patching exists and is of a condition such that ride quality is affected, coded as follows:
- 0 – not present
- 1 – present

3.3.6. Macrotexture—The mean right wheelpath RMS amplitude of texture for wavelengths from 0.50 mm to 50 mm shall be collected for each 0.01-mile (16.1 m) segment.

3.4. Information to be collected for rigid pavements:

3.4.1. Transverse joint faulting—Report mean and maximum values for each 0.01-mile (16.1 m) segment according to AASHTO R-36(04).

4. Data Quality Requirements

4.1. Pavement condition data—The following table describes the required accuracy and resolution of the collected pavement condition data.

<table>
<thead>
<tr>
<th>DATA ELEMENT</th>
<th>REQUIRED ACCURACY</th>
<th>REQUIRED PRECISION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ride quality (IRI)</td>
<td>± 5% compared to Rod &amp; Level, Dipstick, or Class I profiler</td>
<td>1 in./mile (0.016 m/km)</td>
</tr>
<tr>
<td>2. Cross slope, super-elevation, and grade data</td>
<td>± 0.20 %</td>
<td>0.1%</td>
</tr>
<tr>
<td>3. Load associated cracking</td>
<td>± 10%</td>
<td>0.1 linear ft (30 mm) per 0.01-mile (16.1 m) segment</td>
</tr>
<tr>
<td>4. Non-load associated cracking</td>
<td>± 10%</td>
<td>0.1 linear ft (30 mm) per 0.01-mile (16.1 m) segment</td>
</tr>
<tr>
<td>5. Transverse cracking</td>
<td>± 10%</td>
<td>0.1 linear ft (30 mm) per 0.01-mile (16.1 m) segment</td>
</tr>
<tr>
<td>DATA ELEMENT</td>
<td>REQUIRED ACCURACY</td>
<td>REQUIRED PRECISION</td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>6. Rut depth</td>
<td>± 0.1 in. (±2.5 mm)</td>
<td>0.1 in. (2.5 mm)</td>
</tr>
<tr>
<td>7. Raveling</td>
<td>Identical</td>
<td>present/not present</td>
</tr>
<tr>
<td>8. Patching</td>
<td>Identical</td>
<td>present/not present</td>
</tr>
<tr>
<td>9. Macrotexture</td>
<td>N/A</td>
<td>0.01 in. (0.25 mm)</td>
</tr>
<tr>
<td>10. Transverse joint faulting</td>
<td>± 0.1 in. (±2.5 mm)</td>
<td>0.1 in. (2.5 mm)</td>
</tr>
</tbody>
</table>

All data elements should be repeatable within 5% run-to-run for three repeat runs.

4.2. GPS and elevation data—Latitude and longitude shall be reported in degrees, minutes, and seconds, with seconds recorded to four units after the decimal; elevation data shall be reported in feet. Positional accuracy for latitude and longitude shall not exceed ±10 feet (+3 m).

4.3. ROW/Shoulder images—ROW images shall be taken at sufficient resolution to ensure 10 in. (250 mm) sign lettering is legible at a distance of 15 ft (4.5 m) from the edge of the travel lane while traveling at highway speeds. All exterior cameras shall be capable of collecting images during normally encountered fair weather conditions in Alabama. In addition, camera lens or enclosures shall be cleaned regularly to prevent build up of road debris and insects.

5. Quality Control/Quality Assurance Requirements

5.1. For the purposes of this section, sensor data refers to IRI, rutting, faulting, texture, and grade and cross-slope data. Condition data refers to cracking, raveling and patching.

5.2. Equipment correlation

5.2.1. Sensor correlation sites—The CONSULTANT shall run its test equipment over the DEPARTMENT’s sensor correlation sites prior to data collection. Five to ten sites will be chosen representing various surface textures with specific sites requiring test runs for speed. All sites shall be run a minimum of five times prior to data collection. The average of the results of these data collections shall meet the requirements outlined in Section 4 when compared with DEPARTMENT-collected data.

5.2.2. Condition data sites—The CONSULTANT shall run its test equipment over DEPARTMENT’s condition data test sites prior to data collection. Five to ten sites will be chosen to reflect different pavement variables such as pavement type, age, prevalent distress types, etc. DEPARTMENT personnel will have recently rated these sites for pavement distress. Any sites that do not correlate will be investigated. If differences exist, the DEPARTMENT and the CONSULTANT
will jointly investigate the causes of the differences and agree upon a solution before production testing begins.

5.3. Production

5.3.1. Weekly verification sites—Once per week after production-level data collection has begun, the CONSULTANT shall return to a pavement section that it surveyed the previous week and will re-survey that overlay section for sensor data. The DEPARTMENT and the CONSULTANT will then review the results of the re-survey; the results shall satisfy the accuracy requirements outlined in Section 4. At that time, the CONSULTANT shall supply to the DEPARTMENT the ROW/shoulder images taken in the previous week. The DEPARTMENT will review those images for such parameters as clarity and brightness within one week and inform the CONSULTANT whether the images are acceptable. If the images are not acceptable, the CONSULTANT shall re-acquire the images for the unacceptable pavement sections.

5.3.2. Monthly correlation sites—Once per month, the CONSULTANT shall return to one or more of the sensor correlation sites to confirm that its sensor equipment remains in calibration. The CONSULTANT shall provide the DEPARTMENT with a report of IRI and rutting in the left and right wheel paths in 0.01-mile (16.1 m) increments for each of three runs on each sensor correlation site required.

5.3.3. If the verification or correlation sites’ results are erratic and exceed DEPARTMENT’s quality assurance thresholds, all prior reported data from the previous week will be considered compromised. The DEPARTMENT may refuse to purchase compromised data; however, the DEPARTMENT will purchase re-collected data so as long as subsequent correlation site reports indicate the new data is within the DEPARTMENT’s thresholds.

5.4. Survey vans—If the CONSULTANT wishes to use multiple vans, each van shall be approved after collecting data on the sensor correlation and condition data sites. In addition, the vehicles shall be calibrated to produce sensor measurement differences of 5% or less between vehicles. This demonstration shall be reported in writing to the DEPARTMENT whenever the vehicle first enters the state or returns to the project after leaving the state.
Appendix B: Statistical Procedures Using Minitab

Importing Data into Minitab

1. The data should be in an Excel spreadsheet, with:
   a. Headings in the first row
   b. Data starting in row two
   c. Each row should contain the data for a road segment
   d. Each column should contain the ratings for each rater (other columns may be present and can be ignored in the analysis detailed here).
2. Open Minitab, Select “File,” then “Open Worksheet.”
3. Select Files of Type: Excel.
4. Navigate to the data file folder, then select the data file.
5. The rating data should display automatically, and can then be saved as a Minitab file.

Measurement of Inter-Rater Reliability

Inter-rater reliability, inter-rater agreement, or concordance is the degree of agreement among raters. It gives a score of how much consensus there is in the ratings given by multiple raters. It is useful in refining the tools given to raters, for example by determining if a particular measurement method is appropriate for measuring a particular variable. If various raters do not agree, either:

- the measurement method is defective or
- the raters need to be re-trained.

There are a number of statistics which can be used to determine inter-rater reliability. Different statistics are appropriate for different types of measurement. Here, we recommend the use of:
Pearson’s correlation coefficient (r), the most straightforward measure, useful when only two raters are to be compared (for example, a vendor compared to an ALDOT rater considered to provide ground truth).

Intraclass correlation (ICC – absolute agreements), to be used when more than two raters are to be compared or when consistent differences between raters is important to detect.

Because Pearson’s r will be used most frequently in evaluating the performance of a vendor, we start with it.

**Pearson’s Correlation Coefficient**

In probability theory and statistics, correlation (often measured as a correlation coefficient) indicates the strength and direction of a linear relationship between two random variables. In general statistical usage, correlation or co-relation refers to the departure of two random variables from independence.

Pearson's r can be used to measure pairwise correlation among raters using a scale that is continuous. It is obtained by dividing the covariance of the two variables by the product of their standard deviations.

The correlation is 1 in the case of an increasing linear relationship, −1 in the case of a decreasing linear relationship, and some value in between in all other cases, indicating the degree of linear dependence between the variables. The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables.

**Continuous Ratings, Two Raters: Pearson’s r**

For example, suppose that we have two raters rating the number of cracks found in 10 road segments. If the raters agree with one another, then there should be a high correlation between the ratings given by the one rater and those given by the other. Accordingly, one thing we can do to assess inter-rater agreement is to correlate the two raters' ratings. Consider the following ratings of ten road segments:

<table>
<thead>
<tr>
<th>Segment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater 1</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Rater 2</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

In Minitab: Here is the dialog window in Minitab. Click on Stat, Basic Statistics, Correlation. Doubleclick on “Rater 1” and “Rater 2.”
The Pearson correlation is impressive, $r = .976$. 
**Limitations of Pearson’s r**

As shown in Figure B-1, Pearson's r does not take into account the magnitude of the differences between raters. For example, in rating on a scale of 1...5, Rater A might assign the following scores to four items: 1,2,1,3 and Rater B might assign 2,3,2,4. Using Pearson's method, the correlation coefficient would be 1, indicating perfect correlation; however the raters do not agree on any of the items!

![Pairwise data patterns resulting in various Pearson’s r.](image-url)

Figure B-1. Pairwise data patterns resulting in various Pearson’s r.
Pearson’s r Example Using ALDOT Data

Data:
- First 20 segments from the file: AllRaters Parallel 052708
- Analyze Sum of all transverse cracking (levels 1-3), comparing ALDOT Rater 3(A3T) and Selected Vendors (PWT)

<table>
<thead>
<tr>
<th>Site</th>
<th>Route</th>
<th>ActMP</th>
<th>NomBMP</th>
<th>NomEMP</th>
<th>Sort MP</th>
<th>PWT</th>
<th>A3T</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AL0002</td>
<td>55.006</td>
<td>55</td>
<td>54.99</td>
<td>445.000</td>
<td>11</td>
<td>52</td>
</tr>
<tr>
<td>A</td>
<td>AL0002</td>
<td>54.996</td>
<td>54.99</td>
<td>54.98</td>
<td>445.010</td>
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</tr>
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<td>54.98</td>
<td>54.97</td>
<td>445.020</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>A</td>
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<td>54.97</td>
<td>54.96</td>
<td>445.030</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td>A</td>
<td>AL0002</td>
<td>54.966</td>
<td>54.96</td>
<td>54.95</td>
<td>445.040</td>
<td>21</td>
<td>55</td>
</tr>
<tr>
<td>A</td>
<td>AL0002</td>
<td>54.956</td>
<td>54.95</td>
<td>54.94</td>
<td>445.050</td>
<td>37</td>
<td>75</td>
</tr>
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<td>A</td>
<td>AL0002</td>
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<td>54.94</td>
<td>54.93</td>
<td>445.060</td>
<td>7</td>
<td>42</td>
</tr>
<tr>
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<td>54.92</td>
<td>445.070</td>
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<td>41</td>
</tr>
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<td>A</td>
<td>AL0002</td>
<td>54.926</td>
<td>54.92</td>
<td>54.91</td>
<td>445.080</td>
<td>26</td>
<td>62</td>
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<td>A</td>
<td>AL0002</td>
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<td>54.91</td>
<td>54.9</td>
<td>445.090</td>
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<td>41</td>
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<td>42</td>
</tr>
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<td>54.88</td>
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<td>30</td>
</tr>
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<td>54.876</td>
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<td>AL0002</td>
<td>54.866</td>
<td>54.86</td>
<td>54.85</td>
<td>445.140</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>A</td>
<td>AL0002</td>
<td>54.856</td>
<td>54.85</td>
<td>54.84</td>
<td>445.150</td>
<td>20</td>
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</tr>
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<td>445.170</td>
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<td>54.82</td>
<td>54.81</td>
<td>445.180</td>
<td>18</td>
<td>34</td>
</tr>
</tbody>
</table>
Select Stat, Basic Statistics, Correlation, then doubleclick on PWT and A3T.

Results for: Base Data

Correlations: PWT, A3T

Pearson correlation of PWT and A3T = 0.498
P-Value = 0.030
Intra-class Correlation Coefficient

Another way of performing reliability testing is to use the intra-class correlation coefficient (ICC). The ICC will be high when there is little variation between the scores given to each item by the raters, e.g. if all raters give the same, or similar scores to each of the items. The ICC is an improvement over Pearson's r as it:

- Allows for the measurement of inter-rater reliability when there are more than two raters (Pearson’s r is only a pairwise measure of consistency.)
- Takes into account of the differences in ratings for individual segments (that is, consistent differences between raters), along with the correlation between raters

ICC is, however, more complex and difficult to compute. Thus, we recommend its use when more than two raters must be compared.

What if we have more than two raters, as below? We could compute Pearson r and then average those coefficients, but we still would have the problem of high coefficients when the raters agree on ordering but not on magnitude. We can, however, compute the intraclass correlation coefficient when there are more than two raters. For the data from three raters below, the intraclass correlation coefficient is .8821.

<table>
<thead>
<tr>
<th>Segment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rater 1</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Rater 2</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Rater 3</td>
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<td>10</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

The intra-class correlation coefficient is an index of the reliability of the ratings for a typical, single rater. We employ it when we are going to collect most of our data using only one rater at a time (for example, a hired external vendor), but we have used two or (preferably) more raters on a subset of the data for purposes of estimating inter-rater reliability (for example, expert ALDOT raters).
Macro Needed to Calculate the ICC in Minitab

Note:
- \( K30 \) = point estimate of the ICC
- \( K36 \) and \( k37 \) represent the lower and upper limits of a 95% confidence interval for the ICC
- \( PWT \) and \( A3T \) represent the rater scores to be compared. This can be generalized to include 3 or more rater scores (information to be added)

MACRO BEGINS:

```plaintext
LET K1 = N(PWT)
LET K2 = SUM(PWT)
LET K3 = SUM(A3T)
LET K4 = SUM(PWT*PWT)
LET K5 = SUM(A3T*A3T)
LET C3 = PWT + A3T
LET C4 = C3/2
LET C5 = PWT - A3T
LET K6 = SUM(C3*C3)
LET K7 = MEAN(PWT)
LET K8 = MEAN(A3T)
LET K9 = MEAN(C3)
LET K10 = MEAN(C4)
LET K11 = MEAN(C5)
LET K12 = STAN(PWT)
LET K13 = STAN(A3T)
LET K14 = STAN(C3)
LET K15 = STAN(C4)
LET K16 = STAN(C5)
LET k17 = 100*(K12/K7)
LET k18 = 100*(K13/K8)
LET k19 = ((K2+K3)**2)/(2*K1)
LET k20 = (K2**2)/K1
LET k21 = (K3**2)/K1
LET k22 = K2*K3/K1
LET k23 = K1-1
LET k24 = (K20 + K21)-k19
LET k25 = (k6/2)-K19
LET k26 = (K4+K5)-K19
LET k27 = K26-K24-K25
LET k28 = K25/K23
LET k29 = K27/K23
LET k30 = K1*(K28-K29)/((K1*K28) + (2*K24) + ((K1-2)*K29))
PRINT k30
LET K31 = K28/K29
LET K32 = K24/K29
LET k33 = k23*(2*K30*K32 + K1*(1+K30)-2*K30)**2
LET K34 = (K23*4*(K30**2)*(K32**2))+ (K1*(1+K30)-2*K30)**2
LET K33 = K33/K34
INVCDF 0.95 K34;
F K23 K33.
INVCDF 0.95 K35;
F K33 K23.
LET K36 = K1*(K28-K34*K29)
LET K37 = K1*(K35*K28-K29)/(2*K24 + (K1-2)*K29+K1*K35*K28)
PRINT K36 K37
```

Specifying Automated Pavement Condition Surveys

Between 1994 and 2004, the number of U.S. and Canadian Departments of Transportation (DOTs) using automated techniques to record pavement surface distresses increased fourfold to approximately 30. Twenty more U.S. state agencies can be expected to automate techniques in the near future. The typical agency will use vans traveling at highway speeds to automatically measure roadway roughness, rutting, joint faulting, and cracking. This paper describes the upgrade of the Alabama Department of Transportation’s automated pavement condition data survey specifications. The objective of the paper is to provide information concerning costs, standards, and survey methodology that will be valuable to other DOTs as they add automation to their systems.

by Jay K. Lindly, Frank Bell, and Sharif Ullah

INTRODUCTION

State Departments of Transportation (DOTs) face difficult highway maintenance and resurfacing decisions as funding becomes increasingly limited. A pavement management system (PMS) is a necessary tool to help decision-makers best preserve the condition of the road system.

The basis of any pavement management system is the condition survey. Many of these surveys have been conducted on foot or while driving slowly on the shoulder (windshield surveys). Inspectors write down or key in the types, amounts, and severities of surface distresses. That data is later combined with roughness data and translated into what is often called a pavement condition rating (PCR), usually on a 0-100 scale, where 100 represents a perfect pavement. Pavements with low PCRs are candidates for preventive maintenance, resurfacing, or reconstruction. These manual surveys and manual evaluation of data are becoming impractical for many larger agencies for at least three reasons:

- **Safety**: Manual raters are at risk simply by being on the pavement.
- **Consistency**: Manual rating is subjective, and there may be significant differences in the PCR ratings generated by different raters.
- **Personnel time**: With downsizing, agencies may not wish to employ the staff to manually rate thousands of miles of roads. Unless a large staff is utilized, the relatively slower manual collection methods cannot be completed in a timely way.

Recent trends indicate that 20 or more DOTs will automate part or all of their pavement condition data collection/processing activities in the next few years. The objective of this paper is to describe recent Alabama Department of Transportation (ALDOT) work to incorporate automated pavement condition specifications of innovative highway agencies into its pavement management system. It reviews applicable standards, provides cost figures, and describes data collection and evaluation procedures that policy makers in other DOTs will find useful as they plan their conversion to automated procedures for PMS data collection.

BACKGROUND

Automated data collection surveys involve a van equipped with sensors and cameras traveling at highway speeds to detect the same types of pavement data that manual raters collect (Figure 1). Typically, laser sensors collect data on roughness as measured by the International Roughness Index (IRI), rutting, and joint faulting (see the Glossary for definitions of pavement condition data terminology). Downward-facing cameras provide images of surface distresses such as cracks. Data processing typically involves human interaction with surface...
Pavement condition survey methods are constantly improving. Pavement experts and software developers describe new systems where the computer analyzes the distress images without human aid, potentially saving labor costs and producing results almost in real time (Lee and Lee 2004, and Cheng and Clatzer 2002). Camera technology is evolving, with line scan digital cameras beginning to replace the area scan digital cameras typically used to produce downward-facing images (Scolnic et al. 2004).

Traditionally, states have recorded different pavement distress types and even defined distresses differently. The American Association of State Highway and Transportation Officials (AASHTO) recently issued a series of provisional standards to help standardize data collection. Researchers are evaluating the provisional standards to determine if they can be adopted without losing the usefulness of historical databases (Raman et al. 2004).

State DOTs are engaged in a variety of efforts to improve data acquisition and processing. The Pennsylvania and Florida DOTs have investigated areas such as quality assurance (QA) of the condition survey program and distress image quality and accuracy (Stoffels et al. 2003, and Gunaratne, Mraz, and Scolnic 2003).

Recent Surveys

Two recent studies reported results of questionnaires sent to pavement maintenance or pavement management engineers in U.S. and Canadian transportation agencies. Auburn University recently published results of a questionnaire returned by 27 of 46 DOT pavement maintenance engineers contacted (Thimm and McQueen 2004). The study's objective was to gather information from states that have switched from manual to automated surveys and to provide information on current automated data collection practices. The study provides thumbnail sketches of the pavement distress collection practices of the 27 DOTs and summarizes those practices in a series of tables and graphs.

The National Cooperative Highway Research Program (NCHRP) published Synthesis 384, Automated Pavement Distress Collection Techniques (NCHRP 2004) that reported the results of 56 surveys returned by DOTs, the Federal Highway Administration (FHWA), and Canadian agencies. The NCHRP synthesis indicates that in 1994, only seven of 59 agencies surveyed used automated techniques to record pavement distresses. In 2004, the new survey indicated that 30 of 56 agencies...
collect data on at least some surface distresses automatically. The trend toward automation is clear.

Table 1 provides more detail concerning agencies’ switch to automated systems (Timm and McQueen 2004, p. 77, and NCHRP 2004, p. 9). Almost all agencies collect roughness and rut data automatically, while a lower percentage of agencies collect joint faulting automatically.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Agencies Using Automated Collection (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NCHRP Study</td>
</tr>
<tr>
<td>Roughness</td>
<td>96</td>
</tr>
<tr>
<td>Rutting</td>
<td>91</td>
</tr>
<tr>
<td>Joint Faulting</td>
<td>59</td>
</tr>
<tr>
<td>Distress Data</td>
<td>54</td>
</tr>
</tbody>
</table>

Sources: National Cooperative Highway Research Program (2004); Timm and McQueen (2004)

All three types of “sensor” data are processed automatically. A little more than half of the agencies collect distress images automatically. Of those agencies, only about half of them process the data automatically. Thus, though many agencies have switched to automation in the last decade, many others have yet to make the change.

Transportation Agency Collection or Contract Collection

Some agencies such as the Missouri DOT collect and process their own pavement condition data (DOT 2003, p. 1). Other agencies such as the Oklahoma DOT pay a vendor to collect and process data (ODOT 2004, p. 2). Agencies such as the Indiana DOT collect data from only a few hundred feet of every road mile (Timm and McQueen 2004, p. 50), but most agencies collect automated data continuously in the outside lane of traffic (NCHRP 2004, p. 8). Agencies that collect distress data typically contract with a vendor to collect it. In the Auburn study, 56% of responding agencies use vendors (Timm and McQueen 2004, p. 79); in NCHRP Synthesis 334, 67% of responding agencies report doing so (NCHRP 2004, p. 9).

There are both staffing and technological reasons for the trends toward automation and the use of vendors. First, many agencies are not staffed sufficiently to provide one or more field crews to collect the data. Additionally, sensor and camera technologies are advancing rapidly, and many agencies wish to avoid the need to continuously research and update this technology and instead rely on vendors to keep pace with advances. Finally, vendors with multiple clients can get economies of scale and lower costs than DOTs which only survey their networks periodically.

Applicable Standards

AASHTO has published provisional and full standards for use in automated pavement condition surveys (AASHTO 2004a and AASHTO 2004b):

- R 36-04, Standard Practice for Evaluating Faulting of Concrete Pavements
- PP 37-04, Standard Practice for Determination of International Roughness Index (IRI) to Quantify Roughness of Pavements
- PP 38-00 (2003), Standard Practice for Determining Maximum Rut Depth in Asphalt Pavements
- PP 44-01 (2003), Standard Practice for Quantifying Cracks in Asphalt Pavement Surface

AASHTO provisional standards do not become full standards until approved by two-thirds
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of the AASHTO member agencies, and the standards may well be changed significantly before approval.

Only PP 37-04 is currently used by a majority of agencies. PP 44-01 is used by several agencies for quantifying cracks, but so is the Distress Identification Manual for the Long-Term Pavement Performance Program (Federal Highway Administration 2003), a research-level tool that nonetheless has agency users. Many DOTs use their own agency-specific crack measurement standards. Likewise, a variety of standards (including the AASHTO provisional standards) are used by agencies that automatically collect rutting and joint faulting data (NCHRP 2004, p. 9).

Suitability of Automated Results

The results of statewide pavement condition surveys are typically used in pavement management systems that provide an overview of the agency’s entire road network. These network-level surveys may provide data for several activities:

- Identifying pavement condition trends,
- Identifying candidate maintenance and resurfacing projects,
- Forecasting pavement performance, and
- Allocating funding.

After candidate road sections for maintenance and resurfacing projects are identified, agency personnel visit those sections and perform a more detailed project-level survey, usually performed on foot. That survey first establishes or rejects the need for work and then identifies the controlling conditions present, which determines the maintenance or resurfacing method to be used, if any.

The manual surveys currently performed at the network level can approach or reach project level quality, including data on bleeding, patching, and identification of small cracks that automated surveys may miss. Some DOTs are reluctant to substitute automated surveys for manual surveys because they do not want to lose the manually collected data. If the manual data is not collected, the agencies must change their method for calculating PCR. However, a recent study confirms that automated surveys are appropriate for network-level coverage when quality levels are strictly monitored (Groeger et al. 2003, p. 116).

ALDOT Background

ALDOT administers approximately 11,000 centerline miles of highways, consisting of approximately 98% asphalt-surfaced roads and 2% concrete-surfaced roads. ALDOT began using manual pavement distress surveys in 1984, sampling 200 feet every mile and surveying its system once every two years. In 1996, it transitioned to automatic condition surveys performed by a vendor and discontinued manual condition surveys. In 2002, ALDOT started a QA program, manually rating 200 feet every 10 miles and comparing the manual results to the automatically-generated results. Significant discrepancies between ALDOT and vendor data occurred in areas such as distress types and extent of the pavement surface covered by those distresses. ALDOT also discovered significant differences between its linear referencing system (LRS) mileposts and the physical mileposts in the field, which made it more difficult to compare the same 200 foot sections.

Because of the results of the QA study and the outputs from its standard pavement management report, ALDOT began to mistrust the system’s results. The method of determining PCR had not been updated when manual surveys were replaced by automated surveys, even though human eyes and cameras “see” cracks differently (humans usually detect more cracks, which can lead to the automated systems’ underreporting of low-severity cracking). During the metric system’s brief reign, the system had been metricized and de-metricized, which introduced changes into the LRS that were not always captured by the vendor. Ultimately, ALDOT decided that it needed to overhaul its pavement management system to cope with these changes.

As described previously, most states follow practices for quantifying pavement cracks that are unique to that state. As a result of the investigations described in this paper, ALDOT decided to discontinue its unique practices for quantifying cracks and to begin following the new AASHTO PP 44-01. Under PP 44-01,
some entirely different categories of cracks will be measured, and the amount of the cracking may be recorded in different units. Thus, while much of ALDOT's historic pavement condition data (particularly that taken by manual survey teams) is accurate, it is not directly comparable to the data that will be collected in the future, and its usefulness to the PMS will be reduced. However, the adoption of PP 44-01 by several states may eventually allow them to "pool" data for joint analysis.

ALDOT INVESTIGATIONS

ALDOT concluded that it must obtain more information about the needs of the users of its pavement condition data as well as determine the state-of-the-art of pavement condition data collection and processing before overhauling its PMS system. It sought input from the FHWA, sent a questionnaire to its own maintenance personnel, and consulted with other agencies.

FHWA

ALDOT and University of Alabama personnel met with a pavement management specialist from the FHWA Atlanta Resource Center and subsequently assembled a list of high-priority topics for investigation:

- Test frequency and lanes to be tested
- Conditions and distresses to be measured
- Standards to follow
- Crack severity level widths
- Area cracking (load associated and block) reporting parameter
- Reporting increments
- Standard wheelpath and lane dimensions
- QC/QA Program

ALDOT Survey

A short survey was distributed to the maintenance personnel in both the ALDOT central office and field offices, who are the primary end-users of ALDOT's pavement condition data. Thirty-seven of 56 individuals responded. Responses to three questions were particularly specific and provided information relevant to changing the pavement condition survey method:

- Maintenance personnel most desired two pieces of information from a pavement condition survey: PCR tabulated every mile (almost all responses) and average rut depth (three-quarters of responses). Other needs cited included IRI, amount of cracking, cross-slopes, date last resurfaced, and pavement buildup.
- The questionnaire asked respondents to list the crack width at the point it becomes significant to them (they usually ignore cracks less than this width when making maintenance decisions). Responses of 0.25 inches and 0.125 inches predominated. Network-survey-level digital cameras could detect cracks as small as 0.08 to 0.12 inch wide at the time of the questionnaire, which confirmed that automated condition surveys could detect cracks of importance to maintenance personnel.1
- Respondents also chose from a list of 12 distresses that they believe create a need for maintenance or resurfacing. Load-associated cracking garnered the most responses, followed by rutting (nearly all respondents). Patching and potholes led the second tier of distresses.

State Agency Contacts

FHWA personnel provided sample condition survey requests for proposals and specification documents from eight states. Project team members read the documents and tabulated answers to its list of high-priority topics for investigation. Team members also conducted extensive telephone interviews with representatives from the DOTs of three states: Colorado, Louisiana, and Oklahoma. Pertinent results of these activities will be described in following sections.

INVESTIGATION RESULTS

The results of ALDOT's investigations allowed the project group to make decisions concerning the list of high-priority investigation topics it had compiled in consultation with the FHWA. Those decisions are described in the following paragraphs.
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Test Frequency and Lanes to be Tested

The Auburn study reports that 52% of respondents collect condition data annually; 30% collect data biennially; 15% collect interstate data annually and other road data biennially (Timm and McQueen 2004, p. 78). The project team recommended retention of the current ALDOT system of surveying National Highway System (NHS) roads annually and the remainder of its road system biennially.

One of the uses of pavement condition data is to predict future PCR of roads to anticipate when they may be candidates for maintenance and resurfacing. In Alabama, resurfaced roads, particularly those off the NHS, typically last 10+ years before requiring significant maintenance activities, which will allow at least five data points over the life of the overlay if data is collected biennially.

Historically, ALDOT surveyed all highway types in both directions up to two lanes in each direction because ALDOT had considered doing differing resurfacing cycles for the truck lanes on certain routes. This practice continued with ALDOT’s transition to automated data collection. The review of other transportation agencies’ documents indicated that those agencies survey far fewer lanes. A simple change to surveying one lane in both directions on multi-lane highways and surveying one lane in the “primary” direction (north or east) for smaller facilities was selected and will significantly reduce ALDOT data collection costs.

ALDOT chose a data reporting increment of 0.01 mile or 52.8 feet. NCHRP Synthesis 334 reports that most agencies report data in increments ranging from 50 to 1,000 feet, and that many U.S. agencies use 0.1 mile (NCHRP 2004, p. 9). ALDOT’s value is within the typical range reported, and values can be aggregated easily if longer reporting increments are desired.

Conditions and Distresses to be Measured

Prior to 2005, ALDOT collected the following highway condition data types:
- Load associated cracking
- Longitudinal cracking
- Transverse cracking
- Block cracking
- Patching
- Raveling
- Bleeding
- Rut depth
- Shoulder type and condition
- Coded remarks about various other parameters

The project team evaluated the arguments that limited distress types are all that are required for a network survey and found them compelling. In particular, AASHTO PP 44-01 simplifies crack quantification for asphalt pavements by limiting cracks to only those found in the

![Figure 2: ALDOT Wheelpath Definitions](image_url)
wheelpaths (load-associated cracks) and all others found outside the wheelpaths (non-load-associated cracks). Figure 2 shows ALDOT’s adaptation of the AASHTO P 44-01 diagram defining wheelpath and non-wheelpath areas.

In general, ALDOT adopted the AASHTO PP 44-01 designation for width of cracks as shown below:

- **Severity level 1**: Cracks having widths greater than 1/25 inch and ≤ 1/8 inch
- **Severity level 2**: Cracks having widths greater than 1/8 inch and ≤ 1/4 inch
- **Severity level 3**: Cracks having widths > 1/4 inch

After reviewing other states’ practices and considering the preferences expressed by ALDOT maintenance personnel, ALDOT selected the following condition data for evaluation in both flexible and rigid pavements (Table 2 lists accuracy and precision requirements for the data):

- **IRI** reported separately for the two wheel paths of the survey lane in inches/mile
- **Transverse cracking** reported in linear feet of cracking per 0.01 mile segment.

To qualify, a single crack must be greater than six feet long and project within 30° of perpendicular to the pavement centerline. The following condition data was specified for flexible pavements:

- **Load-associated cracking** reports cracks in the wheelpaths that were not previously identified as transverse cracks. Load-associated cracking is reported as the number of linear feet of road segment containing such cracking and cannot exceed 52.8 feet per 0.01 mile segment. When cracking occurs in both wheelpaths, the higher severity level of the two wheelpaths is reported.

- Non-load-associated cracking reports cracks longer than 1 inch (the minimum crack length as defined in PP 44-01) in the areas within the lane not identified as wheelpaths and were not previously identified as transverse cracks. Non-

### Table 2: Accuracy and Precision Requirements for ALDOT Data Elements

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Required Accuracy</th>
<th>Required Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Roughness (IRI)</td>
<td>± 5%</td>
<td>1 inch/mile</td>
</tr>
<tr>
<td>2. Cross slope, superelevation, and grade data</td>
<td>± 0.20%</td>
<td>0.1%</td>
</tr>
<tr>
<td>3. Load-associated cracking</td>
<td>± 10%</td>
<td>0.1 linear foot per 0.01-mile segment</td>
</tr>
<tr>
<td>4. Non-load associated cracking</td>
<td>± 10%</td>
<td>0.1 linear foot per 0.01-mile segment</td>
</tr>
<tr>
<td>5. Transverse cracking</td>
<td>± 10%</td>
<td>0.1 linear foot per 0.01-mile segment</td>
</tr>
<tr>
<td>6. Rut depth</td>
<td>± 0.1 inch</td>
<td>0.1 inch</td>
</tr>
<tr>
<td>7. Raveling</td>
<td>Identical</td>
<td>present/not present</td>
</tr>
<tr>
<td>8. Patching</td>
<td>Identical</td>
<td>present/not present</td>
</tr>
<tr>
<td>9. Macrotexture</td>
<td>N/A</td>
<td>0.01 inch</td>
</tr>
<tr>
<td>10. Joint faulting</td>
<td>± 0.1 inch</td>
<td>0.1 inch</td>
</tr>
</tbody>
</table>

Accuracy is the required conformity to an ALDOT-measured value representing the “true” value. Precision is the exactness of the measured value, e.g., measured to the nearest 0.1 inch.
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Load-associated cracks are reported as the number of linear feet of the 0.01 mile segment containing such cracking. The highest severity level present in the non-wheelpath areas is reported.

- Rutting reports mean and maximum values for both outside and inside wheelpaths for each 0.01 mile segment.
- Raveling reports instances where the aggregate and/or binder have worn away, coded as present or not present in each segment.
- Patching reports instances where patching exists and ride quality is affected, coded as present or not present in each segment.
- Macrotexure reports the mean and maximum values for wavelengths from 0.50 mm to 50 mm each 0.01 mile segment.

Though only about 2% of ALDOT pavements have concrete surfaces, the following information was specified for rigid pavements:

- Transverse joint faulting reports mean and maximum values for each segment according to AASHTO R-36(04).

ALDOT's old distress collection procedure measured fatigue cracking by area and summarized most non-load-associated cracking by adding lengths of individual cracks. The new procedure measures the proportion of the longitudinal extent of the road that contains fatigue or non-load associated cracking. ALDOT's decision to parallel the requirements in PP 44-01 as much as possible motivated this change. In its data collection procedures, ALDOT also references PP 38-00 (2003) and R-36(04), and FHWA's Highway Performance Monitoring System Field Manual (FHWA 2002).

Other Data

Adding additional data to that already described results in relatively minor additional cost. For this reason, ALDOT decided to use the automated survey to collect data for other functions within ALDOT:

- Slope data including cross-slope of the pavement lane (percentage) and longitudinal grade (percentage). This is another example of sensor data, and accuracy and precision requirements are shown in Table 2.

- Global Positioning System (GPS) coordinates including longitude, latitude, elevation, and dilution of precision measurements. Positional accuracy for latitude and longitude must not exceed ± 10 feet.

- Travel events such as pavement surface changes, railroad crossings, changes in number of lanes, and transitions from the lane specified for data collection. Event information is keyed in by personnel in the survey van.

For all cases involving measurements, these measurements are taken at the beginning of each 0.01 mile segment. In addition to extra data, digital right of way (ROW) images photographed with forward-facing cameras are specified for the beginning and midpoint of each segment, such that 10-inch lettering is visible at a distance of 15 feet from the travel lane. These images are archived and can be used by central personnel to conduct preliminary inspections of sites without leaving the office.

Some vendors offer forward-facing cameras with the added capability of locating roadside objects in both the vertical and horizontal planes to within approximately 6 inches. Such images can be used to create accurate sign inventories or to monitor guardrail distance from the traveled way (Roadware 2005). ALDOT did not specify this service.

DATA QUALITY

ALDOT subscribes to the QA plan laid out in Section 5 of PP 44-01. The document describes qualification and training, equipment, validation sections, and additional checks that can be performed by the highway agency.

Pre-Testing

After experimenting with field verification of cracking data, ALDOT has adopted an approach similar to several of the states using automated collection of cracking data. Before statewide testing begins, ALDOT will select five to 10, one-mile correlation sections that the vendor will rate using its equipment; ALDOT will then conduct a manual field rating of at
least three randomly selected one-tenth-mile segments within them. Pavements displaying different distresses and levels of distress will be selected (most will be asphalt, given ALDOT’s network). Vendor vans will then survey those sites. Vendor distress data and sensor data are expected to compare to ALDOT values within the accuracies specified in Table 2. ALDOT and the vendor will investigate differences between the datasets before statewide rating is allowed to proceed.

The QA procedure for sensor-collected data such as IRI rutting, cross-slope, and texture uses a similar approach. ALDOT will select five to 10 2,000-foot sections for the vendor to rate that may or may not correspond to the cracking sections. All of the sites will be rated at least five times, and the vendor results will be averaged and compared to department-collected data. ALDOT and the vendor will investigate differences between the datasets before statewide rating is allowed to proceed.

Statewide Data Collection

After the vendor has satisfied the requirement of the pre-testing, statewide data collection will begin. As a QA check for surface distresses, ALDOT will use the same software as the vendor to rate up to 5% of each set of data the vendor delivers to test for surface distress accuracy. ALDOT contract documents will specify that the vendor supply ALDOT with hardware, software, maintenance, and training to enable ALDOT personnel to perform these checks. Differences between the results obtained by ALDOT and the vendor will result in the vendor being required to re-rate some or all of the pavements rated in that set of data. The vendor should not have to recollect images to do the required re-processing.

ALDOT chose to follow the lead of Louisiana and Oklahoma in using a rolling approach to QA for data measured by sensors. Once per week, the consultant is required to return to a pavement section rated the previous week and resurvey that section. This data is compared with the prior week’s data and must agree within the accuracies specified in Table 2. Also, the consultant is required to return to one of the initial correlation sites monthly to verify its results. If either comparison reveals errors, the data collected between visits is considered compromised and must be rerun.

Additionally, there are times when consultants may temporarily remove a test vehicle from ALDOT testing and times when the consultant may wish to operate multiple test vehicles in the state. ALDOT specified that each time a test vehicle enters the state, it must rate the sensor and condition data correlation sites, and the measurements must be correlated to produce sensor measurement differences of 5% or less between the consultant’s vehicles.

ALDOT’s long-term goal is to incorporate statistically-based QA procedures for surface distress data collection and processing. However, until further basic research is performed regarding variable pavement conditions, the imaging process, and the data reduction process, ALDOT intends to follow general nationwide current QA practice.

Post-Data Collection

After statewide surveys and data are summarized in the desired increments, the data will be checked using a variety of methods, as in the incomplete list below:

- Are one or more types of data missing for a segment?
- Does data exceed limits, e.g., in Alabama, does fatigue cracking exceed 32.8 feet in any segment?
- Is data from this year’s run significantly different from the preceding year’s run?
- Is data from one side of a multi-lane road significantly different from data for the other side?

INTEGRATION INTO THE PMS

When ALDOT began work on its PMS in 1984, there was vast experience in the maintenance areas of the organization. For this reason, a Delphi study was used to match engineers’ qualitative opinions with quantitative data; the original PCR equation was developed from this study. Today, ALDOT employs fewer experienced engineers, and they are less likely to be able to devote time to such an extensive study. ALDOT plans to report separate
indices for load-associated cracking, non-load-associated cracking, roughness, and rutting that are also combined into a single PCR for prioritization. The indices and the PCR will be developed using the first year of new data. For each type of data, maps can be drawn at statewide and division levels to provide ALDOT personnel more tools to make local and network maintenance decisions.

ALDOT has historically used ratings across years for individual pavement sections to predict the future condition of that particular pavement. This was accomplished using a logarithmically-transformed linear regression that simulated the performance of pavements over the overlay life. The significantly different automated data that will be collected, however, makes continued use of the old prediction equation impossible. ALDOT has thus chosen a “family” approach for use with the new data. Routes with similar traffic and loading characteristics will be grouped together and, based on only one or two years of “new” data, will provide the necessary background to predict the future condition of that family of pavements. Critics may argue that this procedure is unsound because it forgoes years of historical data. However, Oklahoma DOT has recently followed this course successfully, and, as described earlier, ALDOT’s distrust of its recent historical pavement condition data makes the decision necessary.

COST

ALDOT compiled cost data for three methods of pavement condition data collection and analysis: (1) manual data collection and manual computer entry using ALDOT personnel, (2) automated collection by vendor and distress image processing by vendor, and (3) automated collection using DOT personnel and distress image processing by DOT personnel. Those costs and the major benefits/drawbacks of each method are discussed below.

ALDOT updated old records to estimate 2004 costs for manual collection and data entry by ALDOT personnel. Because crews capturing data manually do not measure roughness, the estimate contained a provision for a separate van to drive the road system and collect IRI data at highway speed. The combined cost was approximately $38/lane-mile. A major benefit of manual collection is the lower cost compared to the alternatives. Manual data collection also approaches the detail of a project-level survey, though project-level quality is not needed for a network-level study. However, there are major drawbacks to manual data collection:

- Increased safety risk for the field crew, particularly given the increased traffic on today’s highways.
- The ALDOT manual survey crew only surveyed the first 200 feet of every road mile, giving an incomplete picture of the roadways. (Complete surveying would have been cost prohibitive.)
- This method does not provide “extras” such as continuous images from forward facing cameras, GPS data, and continuous cross slope measurements.

Discussions with FHWA personnel and other state DOTs indicated that vendor charges for a basic package of sensor data collection and processing, digital images and digital image processing, plus images from forward facing cameras were approximately $50/lane-mile in 2004. ALDOT’s own vendor costs in 2004 were approximately $53/lane-mile. NCHRP Synthesis 334 reports similar figures but cautions that some states have experienced higher charges on interstate roads or in urban, high-traffic areas (NCHRP 2004, pp. 44-45).

Vendor collection does not allow the DOT to control all aspects of automated data collection because quality control is in the hands of the vendor. However, ALDOT found benefits to vendor collection as compared to automated surveys performed by ALDOT personnel:

- ALDOT would not be required to hire and train six to eight technicians to perform data collection and distress image analysis.
- The vendor – not ALDOT – will have the responsibility to operate and maintain the high-tech survey van and remain on the cutting edge of camera and sensor improvements.

ALDOT contacted five state DOTs to inquire about costs to collect pavement condition data with their own van(s) and process distress images with their own personnel. Three DOTs did not have readily-available data, but two had
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recently completed life-cycle cost analyses of the data collection and analysis process. One contact reported a cost of approximately $55/lane-mile, while the second contact reported $47-$57/lane-mile, depending on the service life of the data collection van. These costs are very close to the costs for employing a vendor to collect and process data, and the principle benefits and drawbacks of the two methods were outlined in the previous paragraph.

**ALDOT’S SELECTED METHOD**

ALDOT selected vendor collection and processing of pavement condition data. The principle reason for not returning to manual data collection was survey crew safety: ALDOT did not want to return manual survey crews to roads with ever-increasing traffic volumes. The principle reasons for choosing not to collect and analyze pavement condition data with ALDOT personnel were concerns about hiring and training staff and the requirements of maintaining and upgrading the computers, sensors, and digital cameras in the van.

**CONCLUSIONS AND RECOMMENDATIONS**

The pavement condition survey is a requirement for a roadway PMS. Recent trends indicate that as many as 20 additional U.S. states will automate part or all of their pavement condition data collection/analysis activities in the next few years. This paper has described applicable standards, pertinent syntheses and studies, typical system components, test frequency, accuracy and precision requirements, costs, and QA/QC procedures frequently used in pavement condition studies. The information was presented in the context of ALDOT’s reorganization of its condition data collection and analysis. ALDOT manual data collection and processing costs approximately $38/lane-mile. Automated data collection and analysis—whether performed by DOT forces or through vendor contract—costs approximately $50-$55/lane-mile in most areas of the country.

**Recommendations**

The authors present the following recommendations for states considering switching to automated pavement condition collection or modifying existing automated procedures:

- Consider collecting and reporting data according to AASHTO PP 44-01. Most states collect their own unique set of distress types using their own measurement scales. As more states use PP 44-01, the resulting standardized data can be compared easily from one region to another or pooled to compare and contrast pavement condition around the nation.
- Consider adding low-cost, extra services that will benefit other areas of the DOT to the standard data collected by the van. For example, extra data resulting in a traffic sign inventory system may benefit maintenance personnel even though signs are not a direct concern of the group that collects the pavement condition data.
- The authors cannot recommend one condition data collection procedure that fits every state. However, DOTs can consider the following information when making their decision:
  - ALDOT manual data collection and processing costs approximately $38/lane-mile. Automated data collection and analysis—whether performed by DOT forces or through vendor contract—costs approximately $50-$55/lane-mile in most areas of the country.
  - Manual data collection is becoming increasingly difficult to continue in some areas because of safety concerns for the field crews and desires by some DOTs to reduce personnel.
  - DOTs may need to consider their agencies’ stance regarding new personnel hiring, the responsibilities of maintaining and upgrading sophisticated test van equipment, and the level of quality control they wish to exert over data measurement when they are choosing between purchasing vendor services and performing automated data collection with their own personnel.
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Glossary

Bleeding—Bituminous material that has arisen to the surface of an asphalt pavement, causing a slick, black surface.

Block cracking—Cracks in asphalt pavements that occur in roughly rectangular shapes, usually one square foot or greater in size.

Cross slope—The slope of the road surface perpendicular to the direction of travel that drains water from the road.

Distress images—Digital photographs of road surface distresses.

Grade—The change in elevation per horizontal distance traveled, expressed in percent.

Joint faulting—Difference in elevation between the sides of a joint in a concrete pavement that causes a bumpy ride.

Load-associated cracking—Cracks in the wheelpaths, generally caused by repeated passages of heavy wheel loads.

Macrotexture—The texture of the road surface having to do with the particle size gradation of stones in asphalt pavements.

Longitudinal cracking—Cracks in the pavement surface in the direction of vehicle travel.

Non-load-associated cracking—Cracks outside the wheelpaths, generally attributed to environmental causes such as age-hardening of asphalt.

Raveling—The wearing away of the pavement surface caused by the dislodging of aggregate particles.

Roughness—Variations in the longitudinal profile of the pavement surface that decrease ride quality.

Rutting—Longitudinal surface depressions in the wheelpaths.

Superelevation—The banking of a road going around a curve.

Surface distresses—Cracks, patches, etc. that indicate decay in the functionality of the pavement surface.

Transverse cracking—Cracks in the pavement surface at right angles to the direction of vehicle travel.

QA, Quality Assurance—Program established by the Department of Transportation to monitor quality of delivered data.

QC, Quality Control—Vendor-established program to ensure data delivery quality.
Endnotes

1. There are differences in the crack detection abilities of the systems sold and used by different vendors and DOTs. For example, one system is operated only at night at speeds under 25 miles per hour (mph) and uses artificial lights to illuminate the pavement to meet crack detection requirements. Another prominent vendor operates at 55 mph in the daytime and uses artificial lights to ensure that cracks are visible and shadows are avoided.

References


Pavement Condition


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