Pavement Management System Review

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AISCE

Aging Infrastructure Systems Center of Excellence
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and

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

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Final Report

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16. Abstract.

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 3 mm to 1mm. Likewise the size and resolution of display monitors increased. At the same time, 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. 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 pavement baseline measures, 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.

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 1/25th inch to 1/8th inch pavement cracks desired for high order modeling of pavement deterioration.

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Table of Contents

List of Tables

List of Figures

Executive Summary

This study was conducted to assess the existing pavement condition collection procedures and to recommend changes for collection, analysis and quality control of pavement data, and to enhance the 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 3 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 pavement baseline measures, 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.

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[1]

The Alabama Department of Transportation (ALDOT) is faced with a critical challenge of managing the State's transportation assets as it 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, 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 distress measurements and other indicators of distresses (i.e., images) as the vehicle is driven on state-owned roads. The collected images are transformed and processed together with distress measurements 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.

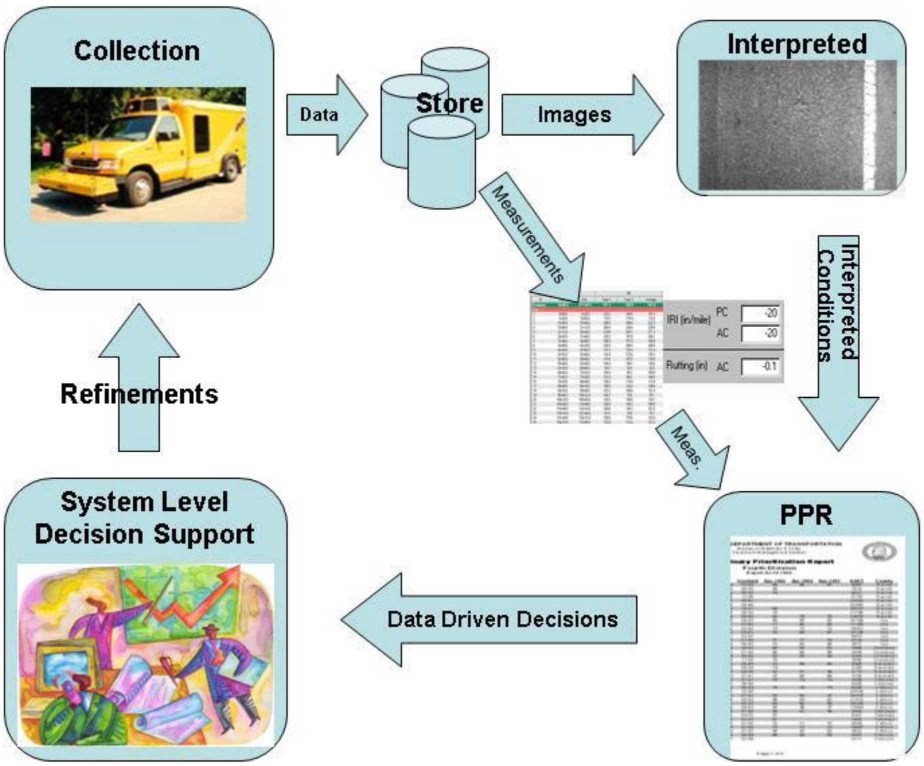

Figure 1: Pavement Assessment Process

[1] Portions of the Background and Initial Study sections have previously appeared in Lindly, Bell, 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-1990's Alabama transitioned from manual surveys of its state highways to an automated collection process due to:

- 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 subjectivity introduced by different sets of raters).
- Timeliness: A manual survey can be a slow process if more than a windshield assessment is obtained.

Alabama's transition is consistent with those of more than half of the other State Departments of Transportation (DOT) 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 collection of distress rose from 7 to 30. Table 1 provides more detail concerning agencies' switch to automated systems (Timm and McQueen 2004, p. 77, and NCHRP 2004, p. 9). Consistent with the data above, ALDOT collects roughness and rut data automatically.

Table 1: Automated Collection Survey Results

(Lindly, Bell, Ullah, 2005 see Appendix C)

	Agencies Using Automated Collection	
Measurement	**NCHRP Study**	**Auburn Study**
Roughness	96%	81%
Rutting	91%	81%
Distress Data	54%	56%

Sources: NCHRP (2004); "The Auburn Study" Timm and McQueen (2004)

As this research project began, the American Association of State Highway and Transportation Officials (AASHTO) released provisional standards for automated pavement condition collection (AASHTO 2004a and AASHTO 2004b) that relate direct to this 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 foot 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 was conducted to assist ALDOT in defining how pavement distresses and conditions can be enhanced for network-level pavement condition data collection.

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 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

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 55 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.

- 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.

The survey and the survey results may be found in the appendix to this report.

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 how the information gathered through benchmarking guided the researchers in assembling a new document to guide collection of 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, 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.

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, p. 9). 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:

- Alligator 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(2003). *(It should be noted at this point that the AASHTO provisional standard adopted by ALDOT was later changed by AASHTO during the course of this project.)* AASHTO PP 44-01 simplifies crack quantification for asphalt pavements by limiting cracks to only those found in the wheelpaths (load-associated cracks) and all others found outside the wheelpaths (non-load-associated cracks). Figure 2 shows ALDOT's adaptation of the AASHTO PP 44-01 diagram defining wheelpath and non-wheelpath areas.

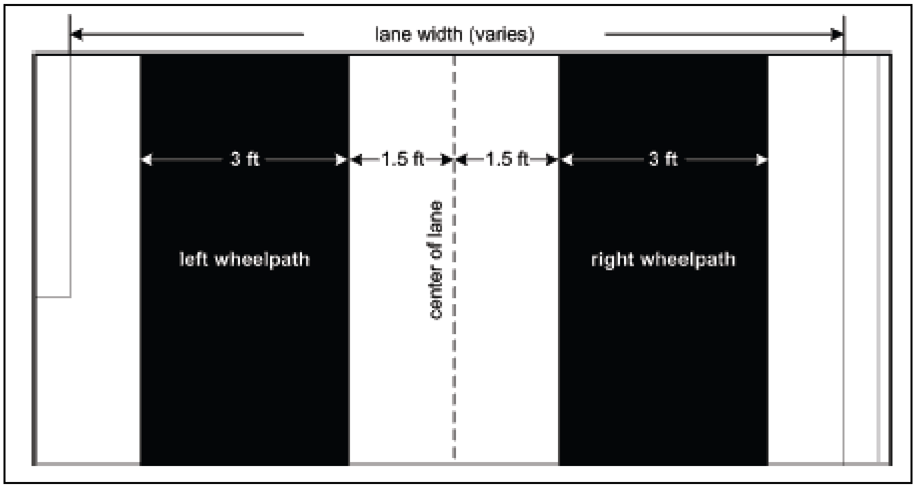

Figure 2: ALDOT Wheelpath Definitions

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's 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 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: Accuracy and Precision Requirements for ALDOT Data Elements

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

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 longer than 1 inch (the minimum crack length as defined in PP 44-01) 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 in the areas within the lane not identified as wheelpaths 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-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.

- 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.

- 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. This was summarized on page 90 of the Trimm/McQueen study.

- 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.

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, which includes a sample of the activities that UA researchers provided to ALDOT to support the network-level pavement condition data collection procedure.

Table 3: Summary of Activities January 2006 through March 2009

Date	Description of Activity
Jan-06	No-cost extension approved and contractor work status updated. ALDOT-UA completed new guidelines for data collection, evaluation, and vendor activities. A new algorithm was discussed and implications of GASB 34 were reviewed.
Mar-06	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
May-06	Selected vendor delivered workstation and conducted training of 3 ALDOT raters on distress identification and rating.
Jul-06	Scope change to investigate new opportunities
Aug-06	ALDOT-UA develops process diagram defining key project questions and work steps. ALDOT decides that selected vendor can begin collecting production data
Sep-06	UA-ALDOT review and discuss IRI definitions and IRI data
Oct-06	Selected Vendor visits to answer ALDOT-UA questions, conduct training, and deliver data
Dec-06	Selected Vendor is asked to re-rate its first data, and agrees to do so
Mar-07	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.
Oct-07	UA asked to modify scope/budget to add evaluation of additional software and vendors
Jun-08	UA requests no-cost time extension until September 30, 2008
May-08	ALDOT summarizes all correlation studies performed so far in the project. This information is used to guide the next research steps.
Jul-08	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
Aug-08	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.
Sep-08	The project is closed financially, with some additional statistical analysis to be performed and a final report to be developed
Nov-08	UA discussed requirements for an IRR instructional guide with ALDOT.
Dec-08	UA reviewed draft user instructions for inter-rater reliability analysis and interpretation, and obtained feedback and revision requests from ALDOT.
Jan-09	UA presented and reviewed revised instructions for inter-rater reliability analysis and interpretation based on Minitab
Mar-09	UA reviewed IRR analysis conducted by ALDOT for accuracy and meaning
Apr-09	UA reviewed a corrected IRR analysis prepared by ALDOT for accuracy and meaning

Statistical Validation of Data Collection Process

The research team monitored and performed statistical analyses throughout the data collection process. Table 4 summarizes typical activities that were performed.

Table 4: Summary of Quality Control and Vendor Monitoring Tasks

Date	Description
May-06	ALDOT documented results for five control sites, first 3/10 mile, selected Vendor vs ALDOT raters. ALDOT visited control sites to try to account for variability
Jul-06	ALDOT tabulated pilot sites of selected Vendor v ALDOT, color code and % difference
Aug-06	May control site data reveals - no reliability for wheelpath sums
Sep-06	Selected Vendor took data collection van to 12 sensor correlation sites; 8th Division site distress survey (provided by ALDOT)
Nov-06	Evaluation of ALDOT raters speed and consistency
Jun-07	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
Jul-07	UA reports on inter rater reliability, 3 ALDOT raters v selected Vendor data
Aug-07	ALDOT/UA meet to review rating results, demo Selected Vendor computer system, but no level 3 was found, no common definition of level 1/2, ALDOT raters > 10% variance. Strategies - find pavement baseline measures, more training, see about using other software, and see if the another distress collection/interpretation contractor will do a sample of Selected Vendor data for us.
Dec-07	UA overviews Selected Vendor inter-rater reliability analysis
Mar-08	ALDOT rater comparison of Oct 07 and Mar08 field ratings
Apr-08	ALDOT sends UA a DVD, 2nd generation Selected Vendor distress images
May-08	ALDOT summarizes various correlation studies of various ratings; Phase 1 – completed; Inter-rater reliability between ALDOT office raters; comparison of ALDOT office raters/ ALDOT field rater—Oct 2007 rating ;Comparison of ALDOT office raters & Selected Vendor office—“collection” phase; Comparison of ALDOT field rater—Oct 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
Jun-08	ALDOT initial analysis, Selected Vendor v alternative vendor v ALDOT rater evaluation
Jun-08	ALDOT reliability analysis - Selected Vendor visit2 vs Alternative Vendor 1mm vs ALDOT field
Jul-08	ALDOT manual vs digital data (Selected Vendor) comparison - 414, distress, rutting, etc
Jul-08	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
Aug-08	UA researchers conduct interpretation of vendor reliability analysis and determine vendor contract recommendations. Document is prepared containing summary of both.
Dec-08	UA prepared detailed advice on how to conduct vendor reliability analysis and how to interpret the results.
Jan-09	UA revised vendor reliability user instructions to accommodate ALDOT statistical software and preferences of engineers conducting the analysis.
Mar-09	UA reviewed the IRR analysis conducted by ALDOT for accuracy and meaning
Apr-09	UA reviewed the corrected IRR analysis conducted by ALDOT for accuracy and meaning

As part of the validation of the collection of data, ALDOT and UA researchers devoted time to defining (from ALDOT's pavement management standpoint) the meaning and use of each data item, including the various severity levels and measurement protocols. This led to identification of the most important pavement data items and the most important location on the road from which to collect them.

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, comparing each of the two evaluated vendors to the ALDOT field rating. The findings are displayed in Table 5.

Table 5: Wheel Path Cracking Example Correlation Analysis Pairwise Comparison of Each Vendor to ALDOT Field Rating

1[2]	2	3	4	5	6	7
Vendor	Sum (levels 1-3)	Sum (levels 1-2)	Sum (levels (2-3)	Level 1	Level 2	Level 3
Alternative Vendor 2nd visit, 1 mm camera	0.753	0.760	0.633	N/A	0.641	-0.011*
Selected Vendor 2008 pilot visit	0.870	0.463	0.716	N/A	0.371	0.152*

*Designates statistical insignificance

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).

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

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 vendors 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 - 3 are summed, 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.

Both ALDOT and UA researchers recognized during the project that it is becoming increasingly possible for competing vendors to produce similar data collection results. To reach a high level of interpretation requires a degree of subjectivity on the part of a vendor's rating supervisor, who adjusts sensitivity and other internal controls to produce a deterioration rating from video images that matches ALDOT's manual rating taken on the ground. Under-adjustment of sensitivity can cause software to ignore certain distress cracks, but over-adjustment might cause the software to interpret pavement features as cracks when in fact they are not.

It is important to recognize that the correlation analyses conducted in this project evaluated the composite results (distress ratings) of vendor cameras, lighting, other hardware, software, and human intervention in comparison to composite results of other vendors, and to distresses produced by ALDOT pavement raters.

Future Data Collection

As part of the validation of the collection of distress data, UA researchers and ALDOT devoted time to recommend a 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 site inspection to establish pavement image baseline measures. The baseline measures will be used throughout the pavement data collection process to assure quality. The next phase collects pavement data that will be interpreted in the last process phase. The process phases are shown in Figure 3.

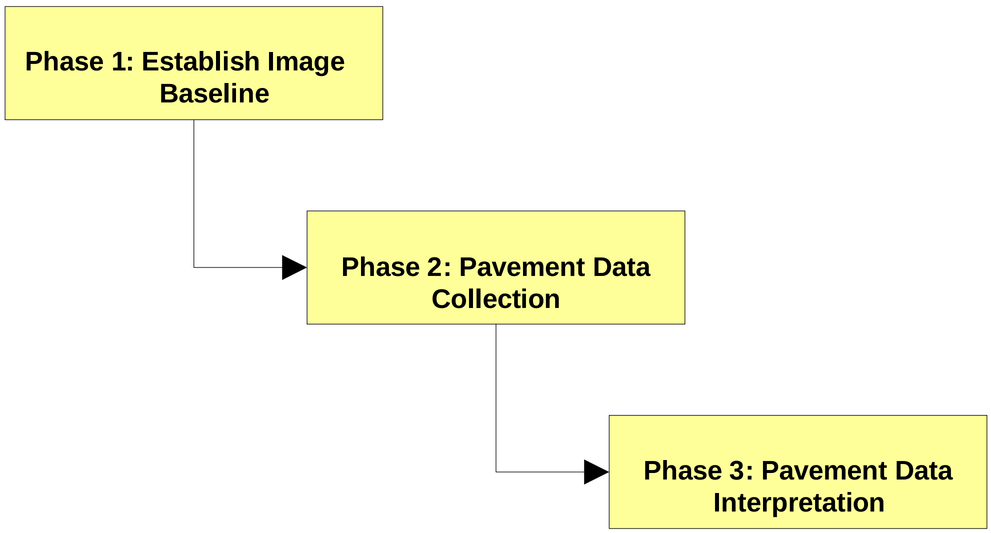

Figure 3: Process Phases

Phase 1: Establish Image Baseline (ALDOT)

The purpose of the phase is to establish image baselines, which will be used to measure vendor rater reliability. A baseline will be first established using a set of pavement images rated by an experienced ALDOT pavement rater. Periodically, vendor raters will be asked to rate the baseline image sets, and their ratings compared to those of the experienced ALDOT pavement rater. Figure 4 details the process view for evaluating vendor reliability.

The selection of control sites is an important step in the process of establishing image baseline measures. 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, ages, and prevalent distress types, and topologies. These sites should be representative of the variations in the general population of the pavement across the state.

Each site should be manually collected to produce control data (image baseline measures).

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

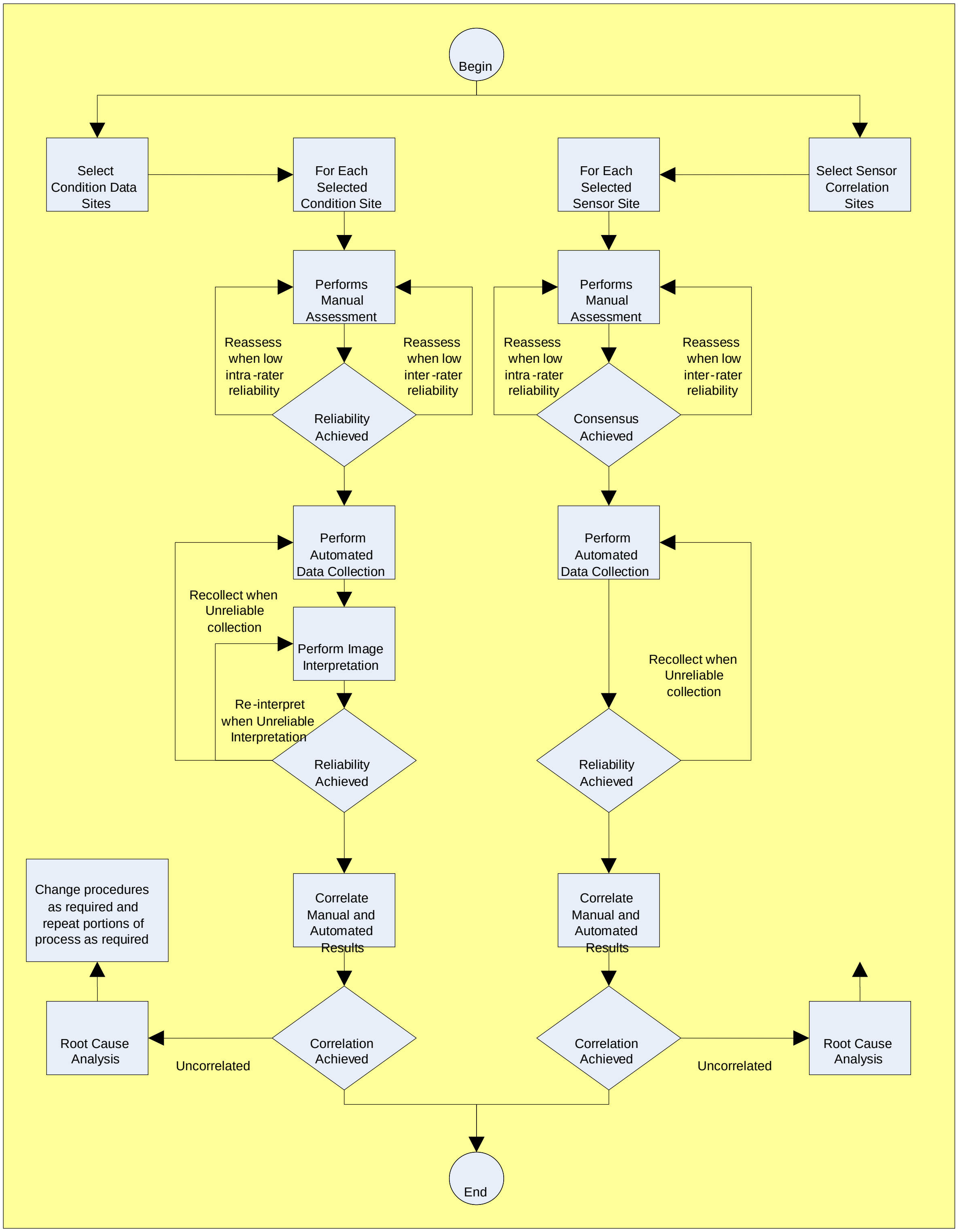

Figure 4: Establish Pavement and Image Baseline Measures

Phase 2: Pavement Data Collection (Vendor)

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 is implemented while maintaining appropriate levels of quality. The implementation process is shown in Figure 5. 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.

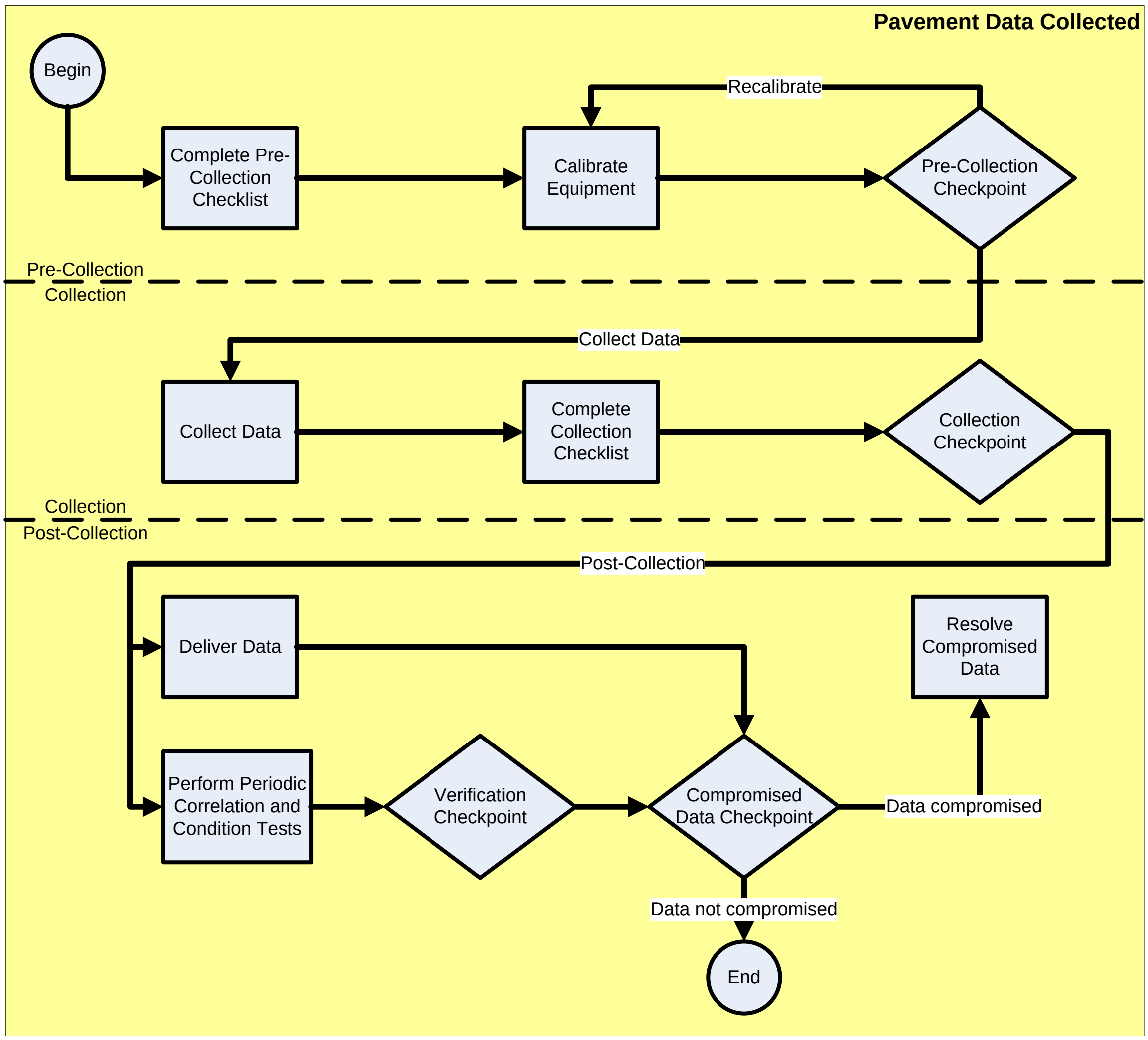

Figure 5: Pavement Condition Data Collection

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 (per ALDOT 414, with the proviso that both ALDOT and UA researchers realize that the AASHTO provisional standards for sensor calibration migrated to another form and might continue to migrate in the future; thus it is anticipated that ALDOT 414 might migrate to another form in the future).

- 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.
- Calibration Indicators as specified in ALDOT 414-04: Network-Level Pavement Condition Data Collection Procedure – Section 4: Quality Control / Quality Assurance Requirements
    - 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 accuracy and precision requirements (see table 2, page 9 of this report), then data collected since last successful verification will be considered compromised. Compromised data may be refused by ALDOT.

Checkpoint:

1. 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.
2. 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 (ALDOT and Vendor)

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, vendor raters will be asked periodically to rate the baseline image sets (established in Phase 1), and their ratings compared to those of the experienced ALDOT pavement rater through inter-rater and intra-rater reliability techniques. The vendor-interpreted baseline images and associated vendor rating will be sent to ALDOT where random samples will be interpreted and the ALDOT baseline results will be correlated to the vendor interpretation for a second level of quality control. The process is shown in Figure 6.

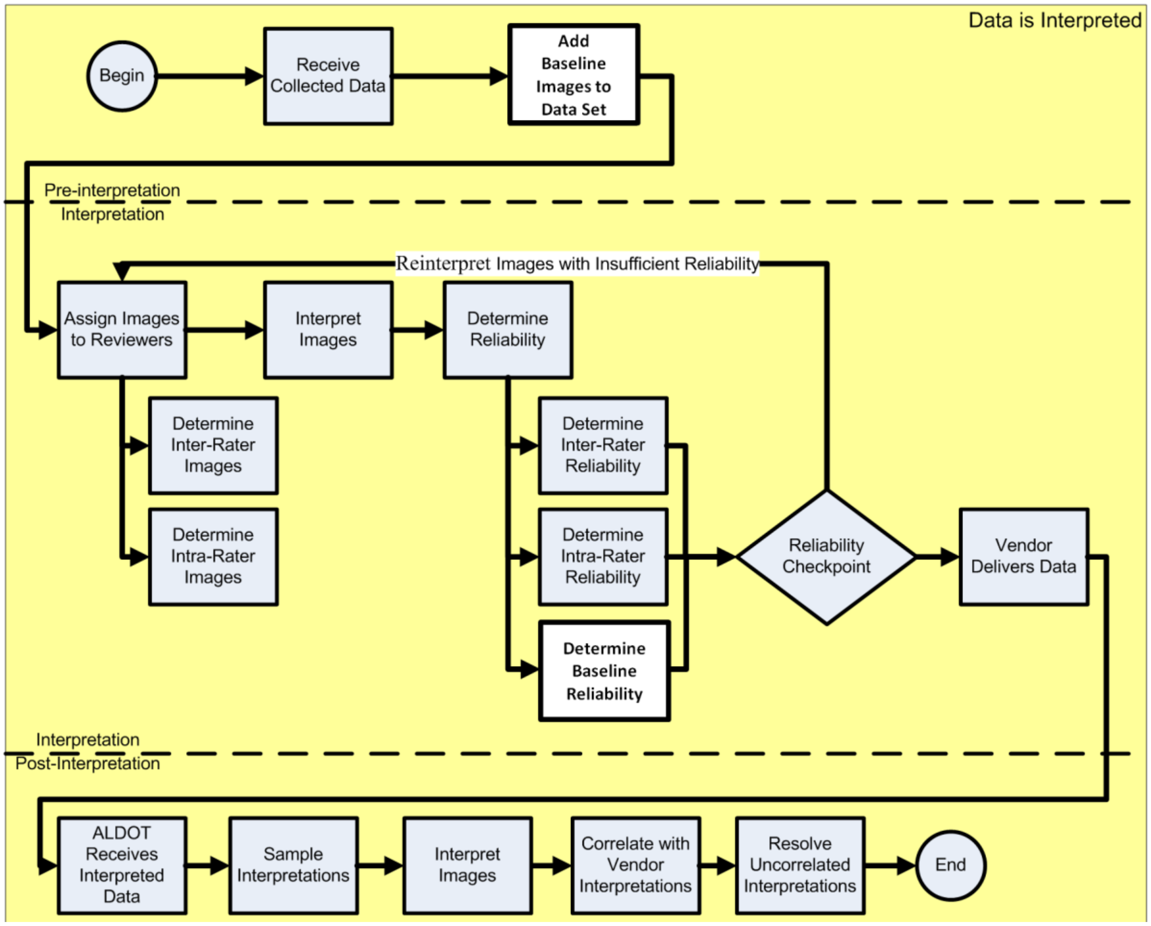

Figure 6: Images are interpreted

Quality Indicators

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

- Baseline Images - A sample of baseline images, (e.g., from the initial pilot sites, collected periodically as outlined in Phase 1) are periodically placed in the collected image sets for assessing vendor reliability.

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

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.

Checkpoint

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.

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 the following 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
        - 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 of 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. In preparing the refinements, anticipate that AASHTO criteria might continue to migrate.
    - Invest as necessary to achieve high levels of quality with regard to pavement image baseline measures
        - All data collection and interpretation quality determinations are dependent upon the ability to compare results to the baseline measures
        - Use pavement baseline measures to test abilities of vendors prior to contracting and periodically to maintain quality
        - Use pavement baseline measures 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 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 departments of transportation
    - 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 pavement baseline measures)
    - Intraclass 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. Minitab, SPSS and SAS are three widely used packages, and there are others with similar capabilities.

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 pavement baseline measures, 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.

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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

2.1. "Highway Performance Monitoring System Field Manual," OMB No. 21250028, Federal Highway Administration, December 2000

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 > $^1/_{25}$ in. and ≤ $^1/_8$ in. (> 1 mm and ≤ 3 mm).
- Severity level 2: Cracks having widths > $^1/_8$ in. and ≤ $^1/_4$ in. (> 3 mm and ≤ 6 mm).
- Severity level 3: Cracks having widths > $^1/_4$ 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 > $^1/_{25}$ in. and ≤ $^1/_8$ in. (> 1 mm and ≤ 3 mm).
- Severity level 2: Cracks having widths > $^1/_8$ in. and ≤ $^1/_4$ in. (> 3 mm and ≤ 6 mm).
- Severity level 3: Cracks having widths > $^1/_4$ 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.

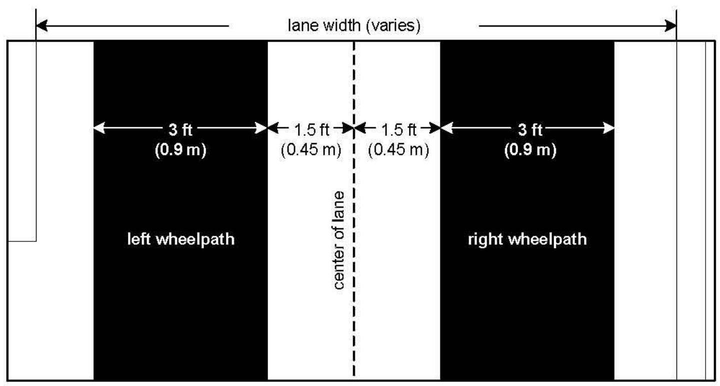

FIGURE 1. TYPICAL WHEELPATH DIMENSIONS

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 > $^1/_{25}$ in. and ≤ $^1/_8$ in. (> 1 mm and ≤ 3 mm).
- Severity level 2: Cracks having widths > $^1/_8$ in. and ≤ $^1/_4$ in. (> 3 mm and ≤ 6 mm).
- Severity level 3: Cracks having widths > $^1/_4$ 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.

DATA ELEMENT	REQUIRED ACCURACY	REQUIRED PRECISION
1. Ride quality (IRI)	± 5% compared to Rod & Level, Dipstick, or Class I profiler	1 in./mile (.016 m/km)
2. Cross slope, superelevation, and grade data	± 0.20 %	0.1%
3. Load associated cracking	± 10%	0.1 linear ft (30 mm) per 0.01-mile (16.1 m) segment
4. Non-load associated cracking	± 10%	0.1 linear ft (30 mm) per 0.01-mile (16.1 m) segment
5. Transverse cracking	± 10%	0.1 linear ft (30 mm) per 0.01-mile (16.1 m) segment

DATA ELEMENT	REQUIRED ACCURACY	REQUIRED PRECISION
6. Rut depth	± 0.1 in. (±2.5 mm)	0.1 in. (2.5 mm)
7. Raveling	Identical	present/not present
8. Patching	Identical	present/not present
9. Macrotexture	N/A	0.01 in. (0.25 mm)
10. Transverse joint faulting	± 0.1 in. (±2.5 mm)	0.1 in. (2.5 mm)

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: Summary of Responses to the "Questionnaire Regarding Statewide Pavement Management Distress System"

1. Introduction: A Pavement Management Distress System questionnaire (attached) was sent to all Division Engineers, Division Maintenance Engineers, and District Engineers of the Alabama Department of Transportation (ALDOT) in May 2004. A total of 37 out of 55 questionnaires were returned.

2. Objective: ALDOT's Pavement Management System (PMS) is currently being reviewed. The five-question survey was intended to provide field input to that review and to help the new PMS provide information that is useful to field personnel.

3. Summary of the Responses: Table B-1 shows the number of responses by Division.

Divisions	Total number of responses from each division	Is response from the Division Engineer available?	Is response from the Division Maintenance Engineer available?
Division 1	4	Yes	Yes
Division 2	3	Yes	Yes
Division 3	3	No	No
Division 4	5	No	Yes
Division 5	6	No	Yes
Division 6	5	No	Yes
Division 7	3	No	No
Division 8	3	No	Yes
Division 9	5	Yes	Yes
Total	37	03	07

Table B-1: Responses from ALDOT Divisions and Districts

3.1. Responses to Question 1: This question asked the respondent to choose from a list of four types of PMS reports that could be sent to Division personnel. The respondent could also specify additional reports that would be useful.

All responses to Question 1 are summarized in Figure B -1. Results show that field personnel would prefer to be supplied pavement condition ratings (PCR) and rut depths for their roadways. Data on International Roughness Index (IRI) was also selected by one third of respondents. Please note that most respondents checked more than one box in the response column.

Three respondents desired additional information, including two Division Maintenance Engineers (DME) and one Division Engineer (DE). The DME for Division 2 added *Skid Numbers, Amount of Cracking, and Cross-slopes*. The DME for Division 9 specified *Date Last Paved* and *Build Up.* The DE for Division 9 added *Cross Slope information on specified length*.

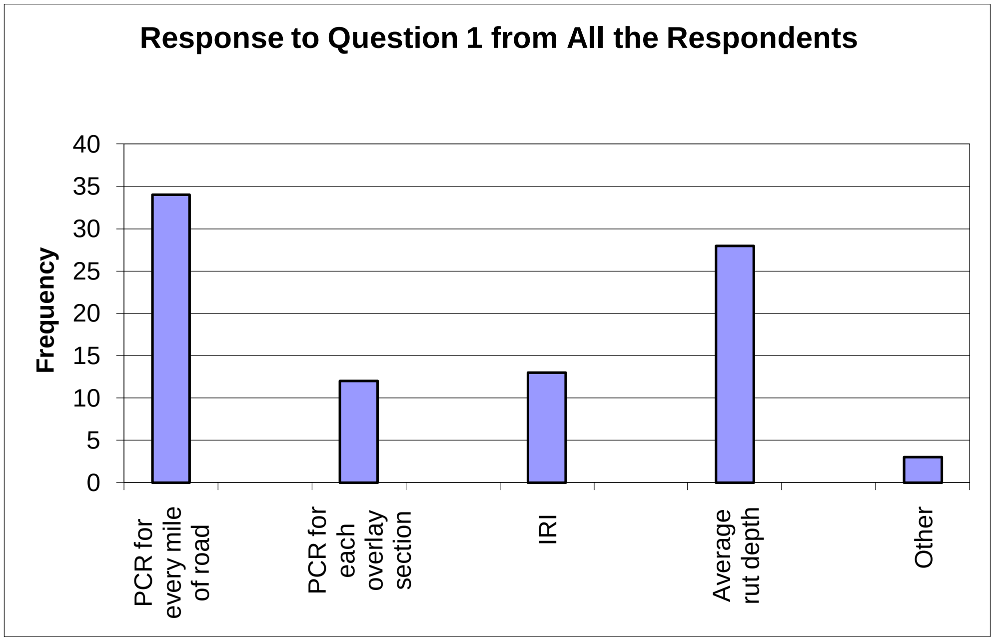

Figure B-1: Response to Question 1

Figure B-2 summarizes the responses on Question 1 from the DMEs. Their responses mirror the general responses, with PCR and IRI information being most desirable.

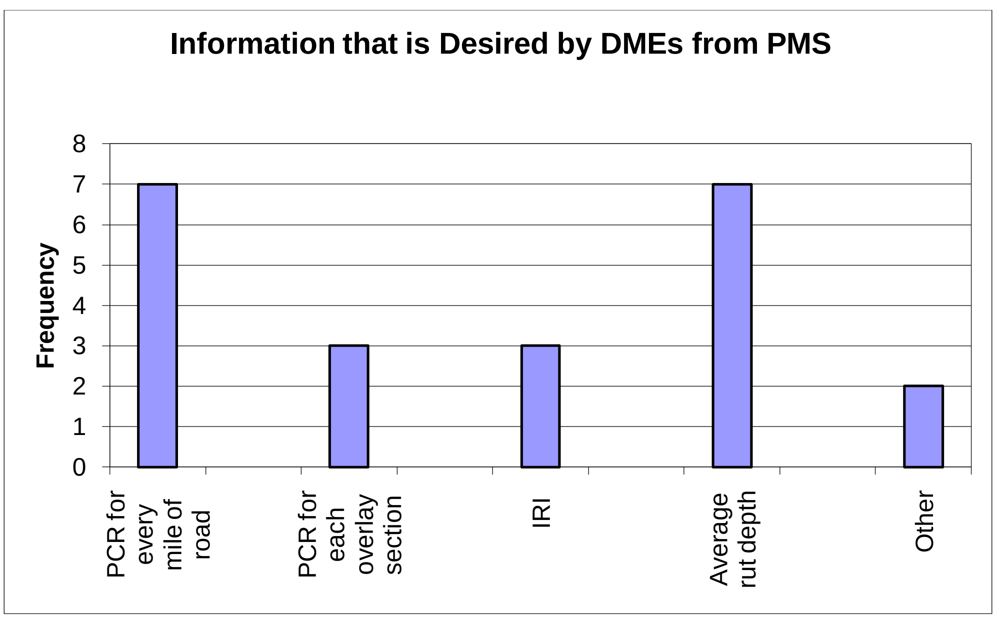

Figure B-2: The Response to Question 1 from DMEs

3.2 Response to Question 2: Question 2 asked respondents to identify maintenance activities they perform at significant levels other than resurfacing. The questionnaire provided 8 answer options and allowed the respondent to list additional answers. Figure B-3 shows the summary of responses to Question 2 from all respondents. The majority of the respondents checked more than one box in the response column. Spot premix patching was the only item checked by more than 50% of the respondents (33 of 37 respondents). Major premix patching, strip patching, and crack sealing were also selected 17 to 20 times each.

The respondent from Division 6, District 3 selected the 'other' option in the list of choices for Question 2. He added *minor planning of pavement upheavals outside of wheel paths* as a maintenance operation.

Figure B-4 shows responses from Division Maintenance Engineers to Question 2. Their responses are similar to those from all respondents, though more than half of DMEs indicate that their Divisions perform significant amounts of spot premix patching, major premix patching, strip patching, and crack sealing.

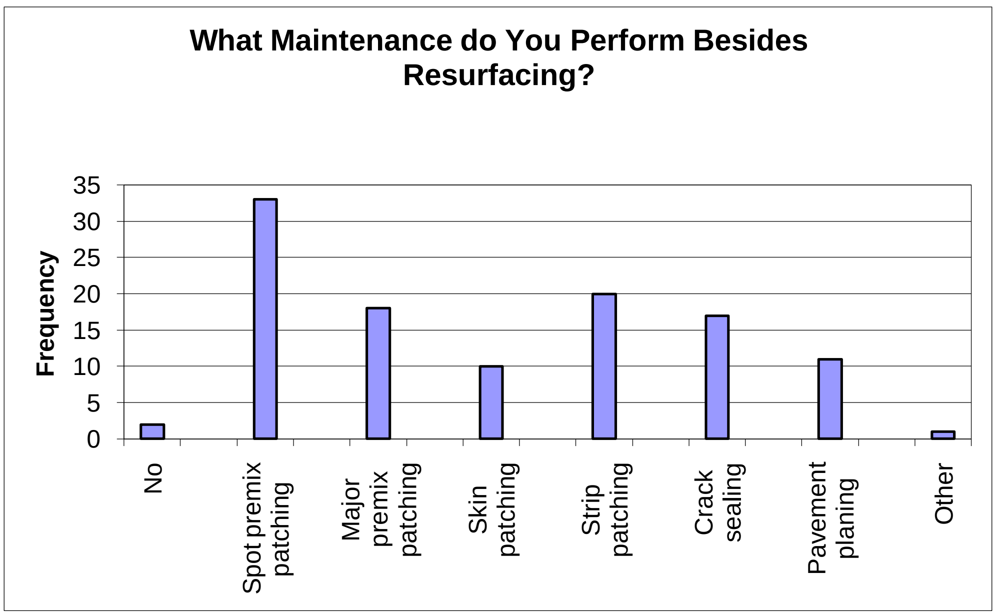

Figure B-3: The Response to Question 2 from All Respondents

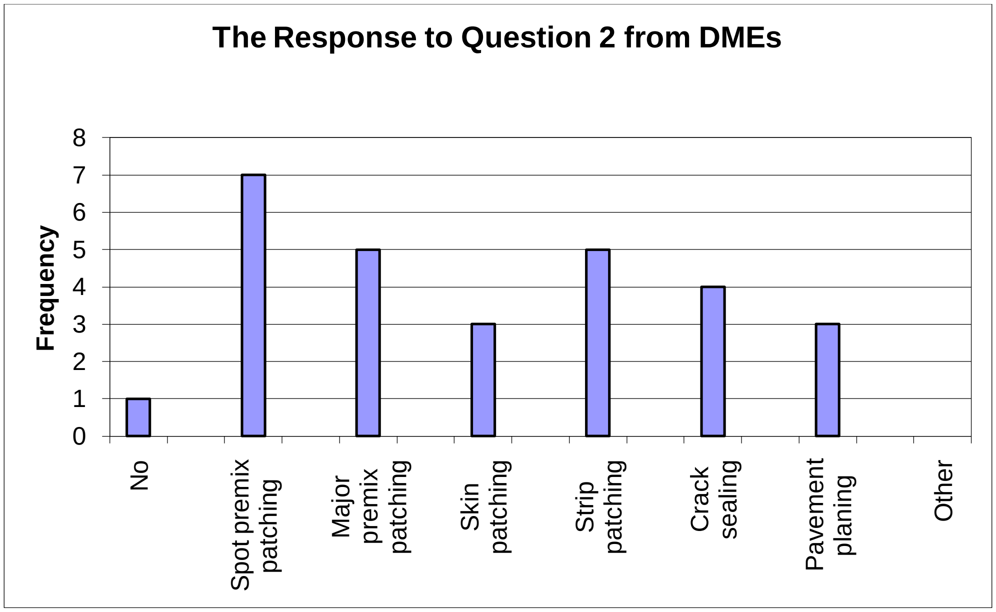

Figure B-4: The Response to Question 2 from DMEs

3.3 Response to Question 3: Question 3 asked the respondents to list the crack width at the point that it becomes significant to them (they usually ignore cracks less than this wide when making maintenance decisions). The questionnaire listed five answer options, one of which was "other". Figure B-5 shows the summary of responses to this question from all respondents. One-quarter inch and one-eighth inch were the most frequent responses.

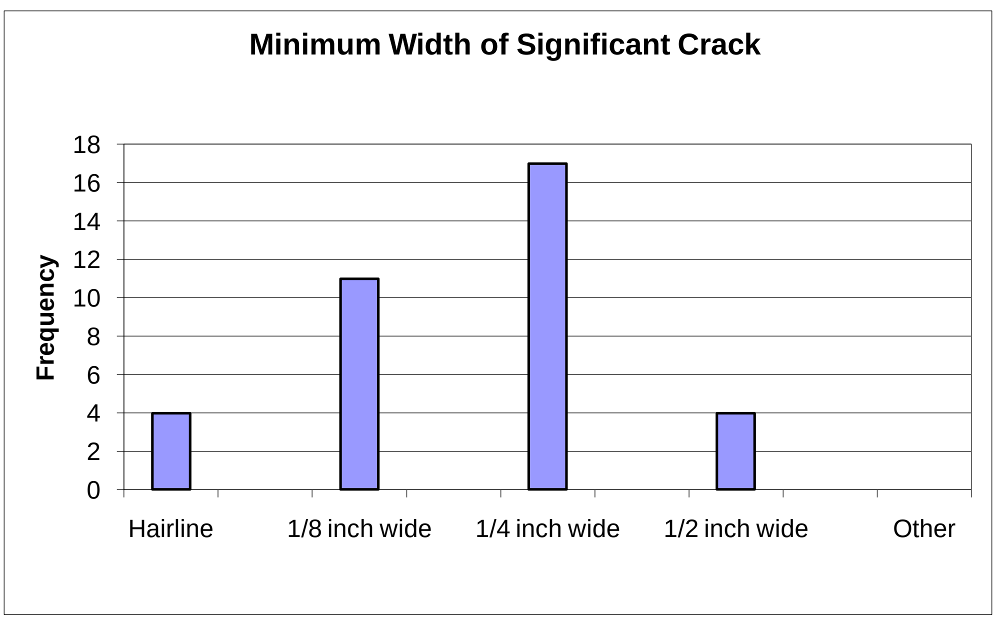

Figure B-5: The Response to Question 3 from All Respondents

The responses from the Division Maintenance Engineers to Question 3 are summarized separately in Figure B-6. Again, 0.125 and 0.25 inches are listed most frequently, though in reverse order from Figure B-5.

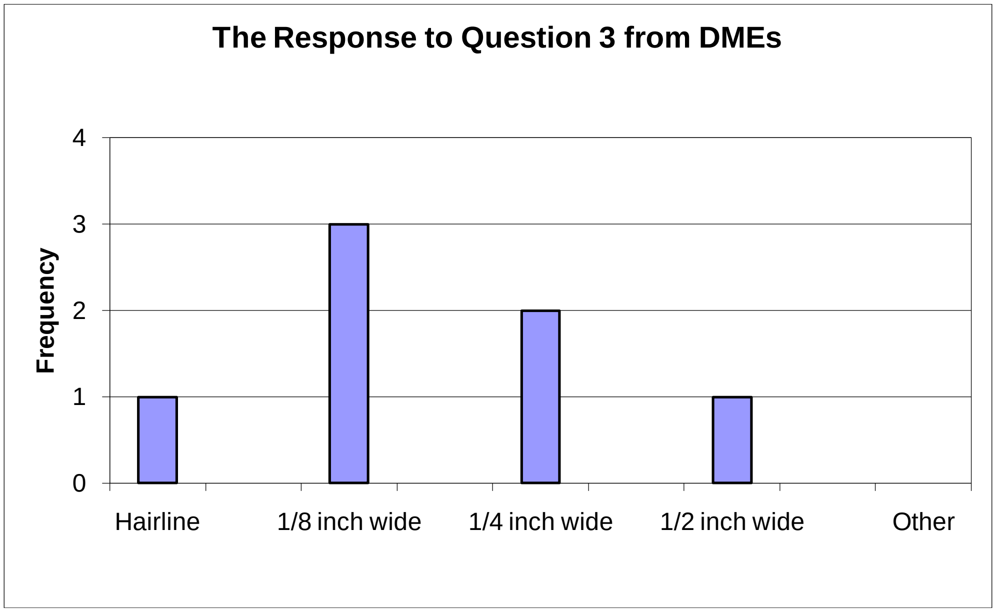

Figure B-6: The Response from DMEs to Question 3

3.4 Response to Question 4: Question 4 asks respondents to list the types of distresses that trigger in their minds a need for maintenance or resurfacing. The question listed 11 answer options, including “other”. The respondents were allowed to select one or more answer options. If they listed rutting, they were also requested to provide rut decision point in inches. The responses to this question from all respondents are summarized in Figure B-7. Alligator (load associated) cracking, patching, potholes, raveling, and rutting were responses selected by more than half the respondents.

Two respondents selected the ‘other’ option for Question 4. The respondent from Division 5, District 3 listed *Polishing* as an indicator for maintenance. The DE from Division 9 listed *Accident Information*.

Figure B-8 summarizes the responses from DMEs to Question 4. Seven distresses were listed by more than 50% of the DMEs: alligator, block, longitudinal, patching, potholes, raveling, and rutting.

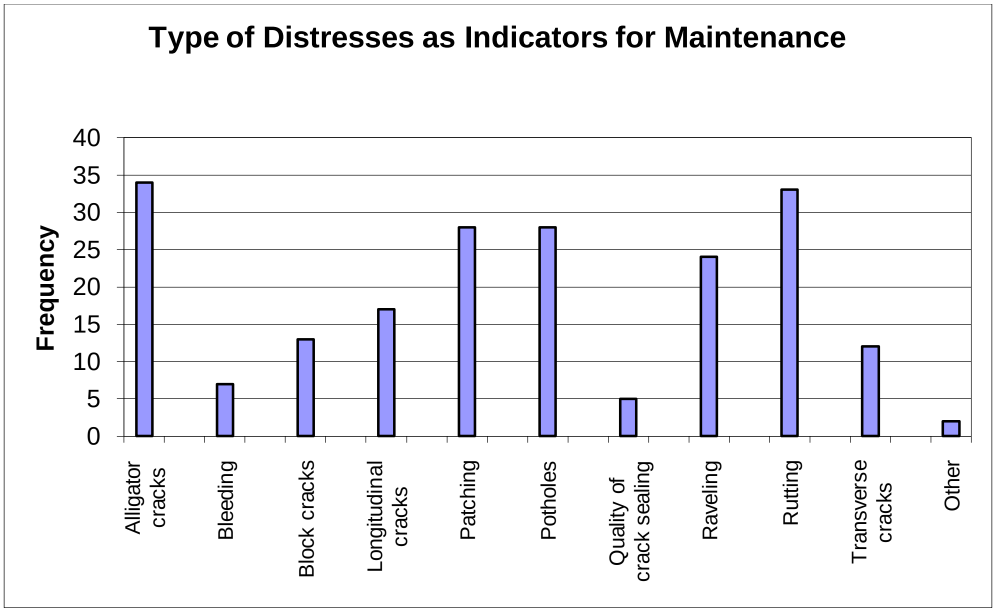

Figure B-7: Type of Distresses as Indicators for Maintenance

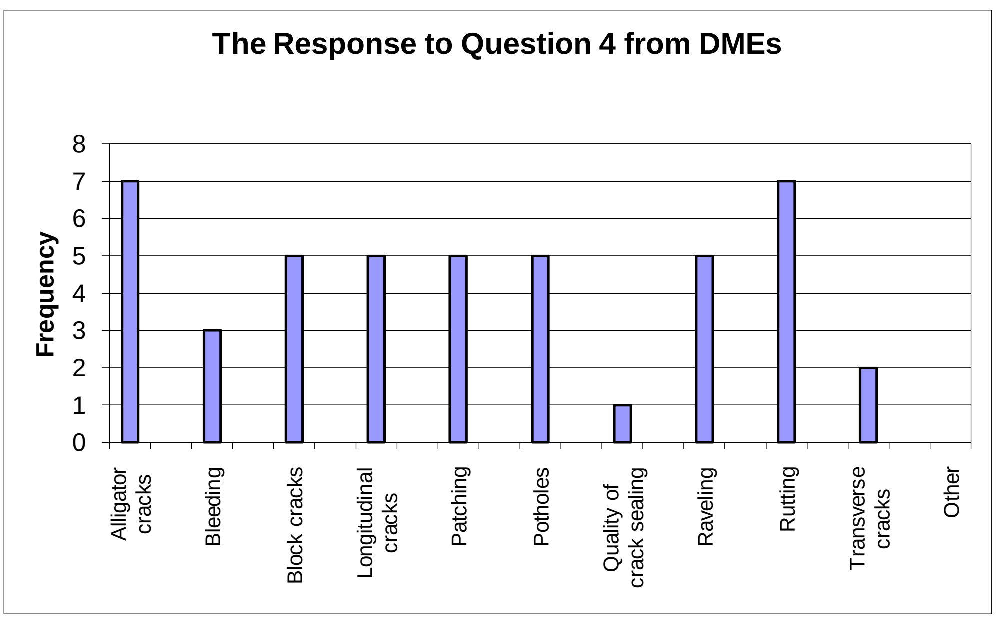

Figure B-8: The Response to Question 4 from DMEs

Figure B-9 shows the rut decision points listed by all respondents. The figure is significant in that most respondents either list a rut depth much larger than is usually considered significant or did not provide an answer.

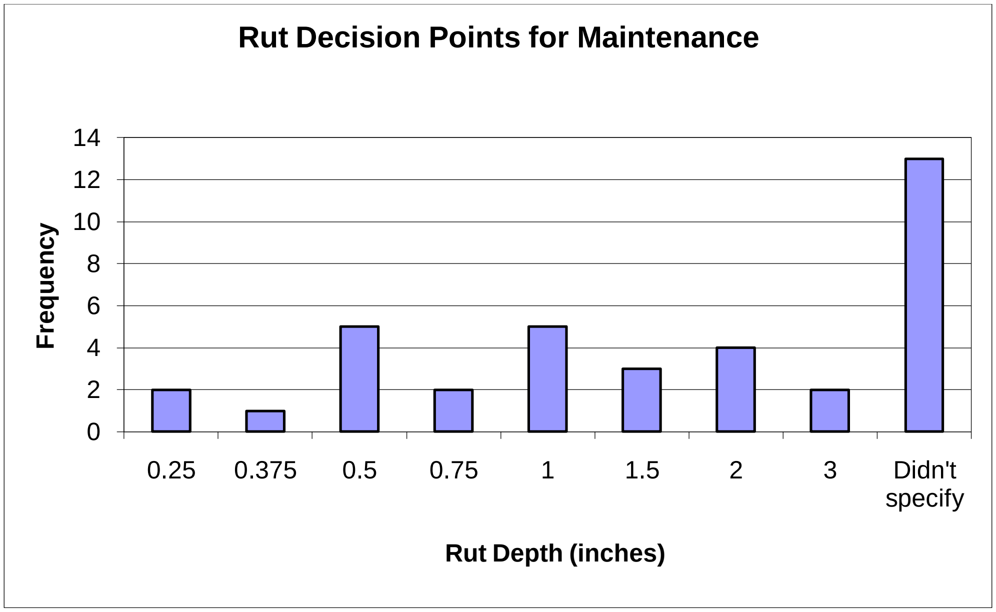

Figure B-9: Rut Decision Points for Maintenance from All Respondents

Figure B-10 shows the rut decision points listed by Division Maintenance Engineers. All the decision points 1-inch and deeper are higher than the threshold values generally associated with rutting.

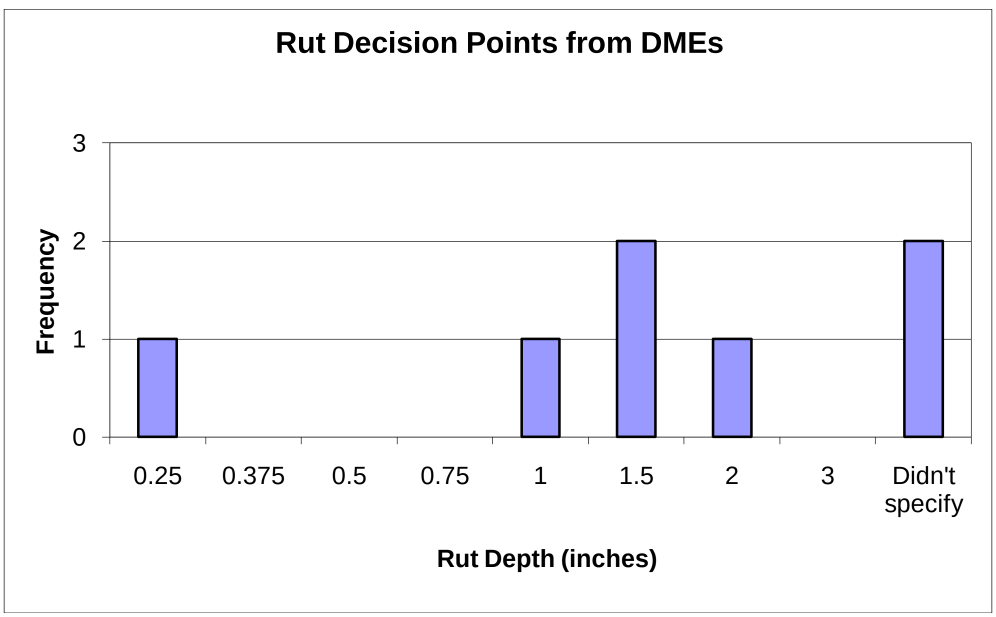

Figure B-10: Rut Decision Points from DMEs

3.5 Response to Question 5: Question 5 concerns open graded friction courses (OGFC) and stone matrix asphalt (SMA), which are considered to have open pavement surfaces on which it may be hard to see cracks. The question asked the respondents which pavement distresses they use to determine when such a pavement requires maintenance or resurfacing. Question 5 provided four options, including “not applicable” if the Division had few OGFC and SMA surfaces.

The response summary from all the respondents is presented in Figure B-11, which indicates that ALDOT field personnel would use raveling and typical crack distresses as the basis for maintenance decisions on open pavement surfaces. Raveling is listed most frequently, though this distress is difficult to observe in the high-speed, network-level PMS survey currently used by ALDOT. Four respondents selected the ‘other’ option. They mentioned criteria as follows:

- *Closure of the mix, have some that are no longer open*
- *Skid data*
- *Rutting*

Figure B-12 lists responses to Question 5 from DMEs. Their responses indicate that most DMEs believe that raveling is the appropriate indicator of when maintenance/resurfacing is necessary in open-surfaced pavements. Please note that some DMEs listed more than one response.

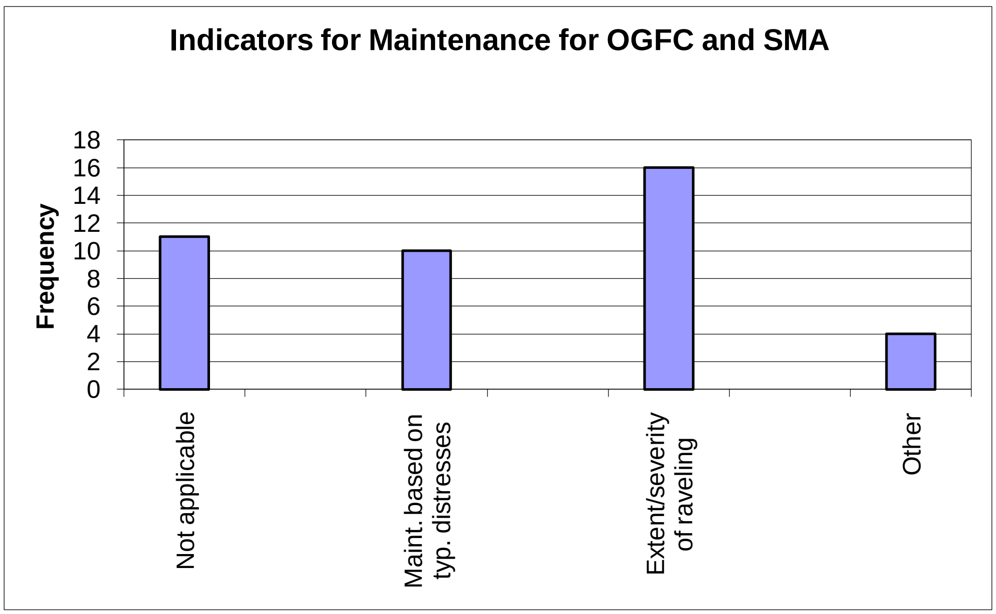

Figure B-11: The Indicators for Maintenance of OGFC and SMA

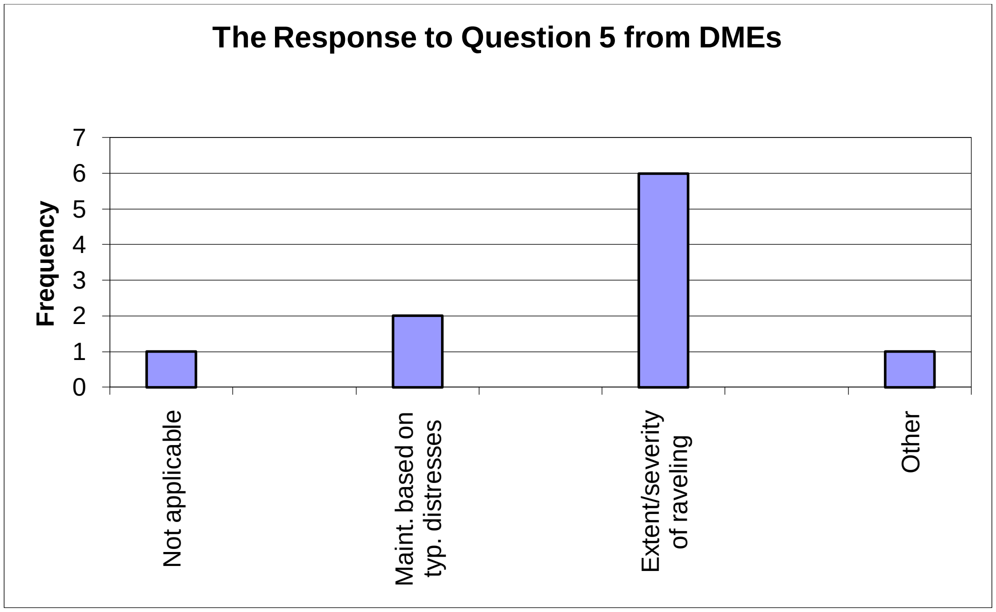

Figure B-12: The Response from DMEs to Question 5

4. Summary: Thirty-seven of 55 ALDOT field personnel involved in maintenance decisions responded to the May 2004 survey titled "Questionnaire Regarding Statewide Pavement Management Distress Systems". The results yielded the following data, which may be observed in more detail in the preceding portions of this report:

- ALDOT personnel desired the PMS to provide them with pavement condition rating (PCR) and with average rut depth. Personnel also wrote in *cross slope data* as desirable information.
- ALDOT personnel report performing significant amounts of spot premix patching, major premix patching, strip patching, and cracking sealing, in addition to resurfacing. Spot premix patching was listed most frequently.
- ALDOT personnel indicate that 0.125-inch and 0.25-inch are the smallest widths of cracks that they normally consider when making maintenance and resurfacing decisions.
- ALDOT personnel most frequently list alligator, block, longitudinal, patching, potholes, raveling, and rutting as distresses that indicate a need for maintenance or resurfacing. For many respondents, rutting must exceed 1 inch before they believe remedial action is necessary.
- ALDOT personnel indicate that for open-surfaced pavements such as OGFC and SMA, raveling may be the best indicator of need for maintenance or re-surfacing. Typical crack distresses were also frequently listed as possible indicators.

Questionnaire Regarding
Statewide Pavement Management Distress System

We want to discover how the ALDOT statewide Pavement Management System (PMS) can be modified to better serve ALDOT. This questionnaire asks background questions about general Division and District maintenance and resurfacing activities so that the PMS can support those activities. It also asks for the data that Divisions and Districts want from the PMS to help them select pavements for maintenance or resurfacing.

The ALDOT Pavement Condition Rating (PCR) is meant to be a network-level tool that describes the relative amounts of distresses on road surfaces. Division personnel are encouraged to use that information to help identify a short list of sections for maintenance or resurfacing. Division/District personnel then perform site visits and may perform project level investigations (cores, FWD, etc.) to make final selections and to obtain project-specific design information.

Please give your Division Number

Please give your District Number (if applicable)

Please give your name

Please give your phone number

Please give your email address

For the questions below, please check the box or boxes that apply, and please type information in the gray squares provided IF you checked the associated box.

1. What would you like to know from the PMS results?
   - ☐ Pavement condition rating (PCR) for every mile of road.
   - ☐ PCR for each overlay section.
   - ☐ International Roughness Index (IRI) for user-specified lengths of road.
   - ☐ Average rutting depth for user-specified lengths of road.
   - ☐ Other (please specify)

2. Do you perform significant amounts of maintenance on the driving lanes (not the shoulder) other than resurfacing? If you seldom do anything other than resurfacing, please indicate ‘no’.

   - ☐ No
   - ☐ Yes, spot premix patching
   - ☐ Yes, major premix patching
   - ☐ Yes, skin patching
   - ☐ Yes, strip patching

☐ Yes, crack sealing
☐ Yes, pavement planning
☐ Yes, other (please specify type)

3. What minimum crack width is significant to you? (That is, do you usually ignore cracks less than this wide because you know they aren't bad enough for you to spend money on maintenance or resurfacing on that road?)

☐ Hairline (say 1 mm or less)
☐ 1/8 inch wide
☐ ¼ inch wide
☐ ½ inch wide
☐ Other (please specify the width and explain your answer)

4. What type of distresses trigger in your mind a need for maintenance or resurfacing? (That is, in a typical situation, is the presence of this type of cracking the thing that makes up your mind that it's time to perform maintenance or to resurface the pavement?)

☐ Alligator cracking
☐ Bleeding
☐ Block cracking
☐ Longitudinal cracking
☐ Patching
☐ Potholes
☐ Quality of crack sealing
☐ Raveling
☐ Rutting (please specify rut decision point in inches)
☐ Transverse Cracking
☐ Other (please specify)

5. Open-graded friction courses (OGFC) and stone matrix asphalt (SMA) have open pavement surfaces on which it may be harder to see cracks. If you have OGFC or SMA surfaces in your division, how do you determine when it is time to perform maintenance or resurfacing on them?

☐ Not applicable
☐ Typical distresses (cracks) are still observable on the surface, so I make a decision to perform maintenance/resurfacing based on typical distresses
☐ I can't see cracks well, so I use extent/severity of raveling as the decision criterion
☐ I use another criterion to make a decision to resurface (please specify the criterion)

This questionnaire was made short purposefully. We hope you don't mind if we contact you later with follow-up questions. Thank you for filling it out.

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Phone: 205-348-1724
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Tuscaloosa, AL 35487-0205

Appendix C: Specifying Automated Pavement Condition Surveys (2005) in *the Journal of the Transportation Research Forum*, 44(3), 19-32

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

Figure 1: Automated Pavement Condition Survey Vehicle

Source: International Cybernetics Corporation (2005)

distress images shown on computer monitors to identify and record the types and amounts of surface distresses.

Current Literature

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 Glazier 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 (Sokolic 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 Sokolic 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 (Timm 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 334, 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 surface 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. 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.

Table 1: Automated Collection Survey Results

Measurement	Agencies Using Automated Collection (percent)	
	NCHRP Study	Auburn Study
Roughness	96	81
Rutting	91	81
Joint Faulting	59	41
Distress Data	54	56

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

Transportation Agency Collection or Contract Collection

Some agencies such as the Minnesota DOT collect and process their own pavement condition data (Mn/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 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 reports, 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.

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.

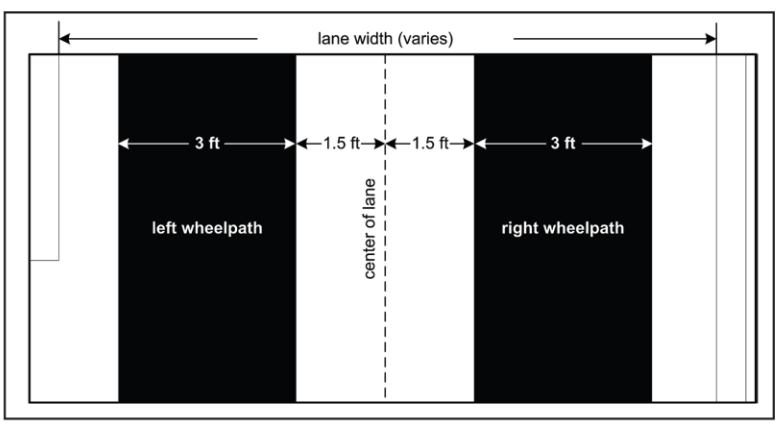
Conditions and Distresses to be Measured

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



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 > 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 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

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

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.

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.
- 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 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 52.8 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 unwise because it forsakes 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 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 survey procedures and will be useful to other governmental units embarking on automated pavement condition data collection and processing.

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.

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.

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