Interstate Highway Pavement Sampling Quality Management Plan

PUBLICATION NO. FHWA-HIF-18-032   March 2018

U.S. Department of Transportation
Federal Highway Administration

TECHNICAL DOCUMENTATION PAGE

<table>
<tr><td>1. Report No.
N/A</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Interstate Highway Pavement Sampling
Data Quality Management Plan</td><td colspan="2">5. Report Date
March 2018</td></tr>
<tr><td colspan="2">6. Performing Organization Code
NONE</td></tr>
<tr><td colspan="2">7. Author(s)
Amy Simpson, Gonzalo Rada, James Bryce, Pedro Serigos, Beth Visintine and Jonathan Groeger</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Amec Foster Wheeler Environment & Infrastructure, Inc.
12000 Indian Creek Court, Suite F
Beltsville, MD 20705</td><td colspan="2">10. Work Unit No. (TRAIS)</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
DTFH61-13-A-00001</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Highway Administration
Office of Asset Management
1200 New Jersey Avenue, SE
Washington, D.C. 20590</td><td colspan="2">13. Type of Report and Period Covered
Final Data Quality Management Plan; September 2017 – March 2018</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="4">15. Supplementary Notes
The Task Order Contracting Office Representative (TOCOR) was Mr. Thomas Van, P.E., FHWA</td></tr>
<tr><td colspan="4">16. Abstract
The regulations implementing the MAP-21 and FAST ACT surface transportation authorization bills have required that a Pavement Data Quality Management Plan be developed and followed for the collection and processing of all data collection used for evaluating pavement performance. Because the measures rely on pavement condition data stored in the Highway Performance Monitoring System (HPMS), FHWA undertook a study in 2015 to: (1) collect an unbiased baseline condition of a statistically significant sample of the entire IHS and produce a report indicating the pavement condition on the IHS nationally and in each State where data were collected, (2) determine if HPMS is an unbiased representation of the pavement condition of the IHS, and (3) recommend improvements to HPMS data collection and reporting necessary to make HPMS unbiased or improve its precision. The results provided the outcomes needed at the time. At the present time, FHWA has contracted a follow-up study addressing the similar objectives involving collection of 7500 miles of data describing the condition of pavements on the Interstate System and certain analyses that will be conducted using that data. As a critical part of this study, this quality management plan for data collection and analysis has been completed in advance of the data collection effort.</td></tr>
<tr><td colspan="2">17. Key Words
Highway Performance Monitoring System, MAP-21, data collection, Interstate Highway System, performance measures</td><td colspan="2">18. Distribution Statement
No restrictions.</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
29</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ALPS	Automated Laser Profiling System
CRCP	continuously reinforced concrete pavement
DCC	data collection contractor
DMI	distance measurement instrument
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	global positioning system
HPMS	Highway Performance Monitoring System
IHS	Interstate Highway System
IMU	inertial measurement unit
IRI	International Roughness Index
JCP	jointed concrete pavement
LCMS	Laser Cracking Measurement System
LRS	Linear Reference System
LTPP	Long-Term Pavement Performance
MnROAD	Minnesota Road Research Facility
PCC	Portland cement concrete
QA	quality assurance
QC	quality control
QMP	quality management plan
ROW	right-of-way

INTRODUCTION

This document describes the data Quality Management Plan (QMP) for the project. This QMP was developed to meet the requirements stipulated by item §490.319(c) of the final rule for national performance management measure regulations published by the Federal Highway Administration (FHWA). [1] The final rule requires that the pavement data QMP include, as a minimum, methods and processes for the following five components:

- Data collection equipment calibration and certification.
- Certification process for persons performing manual data collection.
- Data quality control measures to be conducted before data collection begins and periodically during the data collection program.
- Data sampling, review and checking processes.
- Error resolution procedures and data acceptance criteria.

The pavement data to be collected for the project include four condition metrics: (1) International Roughness Index (IRI) and (2) cracking percent for all pavements, (3) rutting for asphalt concrete (AC) pavements, and (4) faulting for jointed concrete pavements (JCP). These data elements are to be collected and computed in accordance with the 2016 HPMS Field Manual. [2] The information to be collected for the project also includes different inventory data elements — e.g., location coordinates (latitude and longitude), linear distance measurements, windshield and pavement surface images to support quality control (QC) and quality assurance (QA) procedures, and auxiliary measurements (e.g., air and pavement surface temperature) to support the project data analyses.

Each data element will be measured at highway speeds using a single automated measurement system to avoid the potential systematic differences in measurements among multiple equipment, i.e., the same equipped van is expected to be used for all data collection without swapping of vans or equipment on the van. The automated measurement system will be provided and operated by a Data Collection Contractor (DCC) that will also be responsible for the equipment calibration, internal quality control, and data processing. Some data elements measured and processed by the DCC's equipment will be subject to manual intervention by trained DCC personnel with the objective of reducing the measurement error. Other QMP processes involving personnel include the manual measurement of reference data in the field for the validation of the DCC's equipment, and the collection of reference data for validating the assessment of surface distresses from pavement images.

This QMP was developed to control the quality of project data at different stages of the data collection effort and provide a systematic approach for resolving potential issues, such that the resulting dataset is of acceptable accuracy and precision. The following sections of this document provide information on the various processes and methodologies of the QMP, as required by the FHWA regulations. [1] The order in which the QMP information is presented follows approximately the order in which the processes occur:

- *Standards and Protocols of Data Deliverables* - information regarding the standards and protocols adopted to collect and characterize the project data deliverables.

- *Certification or Validation of Manual Raters* - information regarding the certification (or validation testing) of manual raters involved in the collection of data for the study.

- *Equipment Calibration* - information regarding the calibration of equipment.

- *Equipment Certification or Validation* - information regarding certification (or validation testing) of equipment.

- *Equipment Verification* – information regarding the verification testing conducted throughout the data collection effort to verify that the quality of measurements is maintained over time.

- *Daily Data Collection Quality Checks* – information regarding the in-field quality checks and processes conducted on a daily basis before, during and after data collection.

- *Review of Data Deliverables* – information regarding quality checks performed on the data reported by the DCC to control the deliverable data completeness and validity. This section includes the acceptance criteria and error resolution of the data deliverables.

Within this document, several terms are used to differentiate between different methods to check data and equipment. Specifically for this study, the following definitions are offered to clarify these terms:

- Calibration – review performed by the DCC to compare data collected by the equipment against a known standard that is used to adjust the equipment or a factor applied to the collected data to reach an expected level of accuracy. Calibration of equipment is conducted prior to the start of the data collection effort and periodically during the data collection effort.

- Certification – review performed by the project team or an independent third party to evaluate the data collected by the DCC equipment or personnel in accordance with a nationally recognized standard or test procedure to check the accuracy and precision of the collected data with respect to reference measurements. Certification of the equipment or personnel is conducted prior to the start of the data collection program.

- Validation – review performed by the project team or an independent third party to evaluate the data collected by the DCC equipment or personnel in comparison with reference measurements under representative conditions. Validation of the equipment or personnel is conducted prior to the start of the data collection program.

- Verification – review of the equipment performed by the DCC at regular intervals throughout the data collection schedule to check that the equipment is functioning as expected. Data collection and verification is conducted by the DCC and independent verification analysis is conducted by the project team.

- Quality Assurance (QA) – actions taken to assure that the data collection processes are being followed, as required, such that the resulting data will meet the specified quality standard. QA, as used in this project, refers to the testing performed on the production processes and can be part of the calibration, validation, or verification review.

- Quality Control (QC) – actions taken to measure the quality of the data to identify its compliance with the required quality standard. QC, as used in this project, refers to the product and can be part of the calibration, validation or verification review.

STANDARDS AND PROTOCOLS OF DATA DELIVERABLES

The standards and protocols adopted for the different project data elements are presented in table 1. These standards and protocols were selected to meet the FHWA rule, which requires compliance with the guidelines and definitions contained in the 2016 Highway Performance Monitoring System (HPMS) Field Manual, with the exception of the standard for the collection of faulting data. The 2016 HPMS Field Manual requires faulting data be collected in accordance with American Association of State Highway and Transportation Officials (AASHTO) Standard R36-13, “Standard Practice for Evaluating Faulting of Concrete Pavements,” which is based on data collected using an inertial profiler (whereas faulting data for the project will be collected by the DCC using the equipment’s Laser Cracking Measurement System [LCMS] sensors).

CERTIFICATION OR VALIDATION OF MANUAL RATERS

Two sets of manual raters will be involved in the collection of data for this project: (1) manual raters provided by the project team for the production of consensus surveys of cracking, and (2) manual raters provided by the DCC for the assessment of surface cracking on rigid pavements. This section contains information regarding the certification (or validation testing) of both sets of manual raters to verify that the quality of their measurements is acceptable for the purpose of this study.

Certification of Project Team’s Manual Raters

The manual raters from the project team have a long history of collecting distress survey data. One of the raters, Mr. John Miller, is co-author of the Long-Term Pavement Performance (LTPP) Distress Identification Manual [3] and has led numerous sessions of the LTPP rater accreditation course, starting with the first course in 1991. Mr. Miller has also been responsible for training raters for the collection of distress data at US Air Force facilities as well as facilities for other agencies, each using methods specific to the respective agency.

The other manual rater for our team, Dr. Amy Simpson, has been certified for distress data collection through the LTPP process. She was responsible for the QC reviews of distress data collected from images of the pavement for the LTPP program. Dr. Simpson has led the LTPP distress rater accreditation course on several occasions and she has participated in the development of the procedures used for translating distress data collected in accordance with the LTPP Distress Identification Manual to data in accordance with the definitions specified in the HPMS Field Manual. She has also been responsible for training raters responsible for the collection of distress data at US Postal Service facilities as well as facilities for other agencies, using methods specific to the respective agency. In addition, Dr. Simpson was responsible for the quality assurance review of the distress data collected for the initial FHWA Interstate Pavement Condition Sampling project. [4]

Table 1. Standards and protocols for the data deliverables of the project.

Data Metric	Protocol
IRI for all pavement types	• IRI collection device in accordance with AASHTO Standard M328-14 • Collection of IRI data in accordance with AASHTO Standard R57-14 • Quantification of IRI data in accordance with AASHTO Standard R43-13 • Certification of IRI data in accordance with AASHTO Standard R56-14
Cracking percent for all pavement types	• Collection of pavement surface images in accordance with AASHTO Standard PP 68-14 • Quantification of cracking from pavement surface images in accordance with AASHTO Standard PP 67-16 • Computation of Cracking Percent for each pavement type in accordance with the HPMS Field Manual
Rutting for asphalt pavements	• Collection of transverse pavement profiles in accordance with AASHTO Standard PP 70-14 • Quantification of Rut Depth values in accordance with AASHTO Standard PP 69-14, with the modifications specified in the HPMS Field Manual
Faulting for jointed concrete pavements	• Faulting computed based on AASHTO Standard R36-13 with the parameters specified in the HPMS Field Manual, using data measured with LCMS sensors.

Validation of DCC's Manual Raters

The DCC employs manual raters for the assessment of surface cracking on rigid pavements using the pavement surface images collected by the survey van; the collection of all other distresses is fully automated. Given the absence of a national standard for certifying manual raters for the collection of HPMS distresses, an independent validation testing will be designed and conducted by the project team to certify the DCC's manual raters. The following parts of this section: (1) provide information on the training provided by the DCC to their manual distress raters, and (2) describe the testing that the project team will conduct to validate the DCC's manual raters.

Training of DCC's Manual Raters

The DCC provides training to their manual raters for the assessment of distresses from pavement surface images. The training program is divided into two phases – the first phase focuses on the use of the distress rating software, while the second one focuses on the identification and quantification of pavement surface distresses. For this project, the manual raters will be trained using the definitions of distress identified in the 2016 HPMS Field Manual. [2] The following paragraphs describe the two-phase training program used by the DCC.

Phase I of the training program is part of the DCC's initial onboarding process for new employees. During this phase, trainees are introduced to the DCC's proprietary software and trained on its basic functionality and use. Once trainees demonstrate competency in the software, they are introduced to the basics of distress identification on both flexible and rigid pavement types. These basics include how to identify and mark distresses using the DCC's distress rating software. At the conclusion of Phase I, trainees are given a quiz that they are required to pass prior to them moving on to Phase II. The trainer and trainee review the quiz results and expand on areas with which the trainer finds issue(s).

The Phase I introduction is a general overview of distress processing and identification, while Phase II introduces them to the specific rating rules and procedures for the project team they are to join. Phase II of the training builds on what the raters learned in Phase I and expands to include project specific details. This phase consists of an initial documentation review and production shadowing. Trainees initially spend a few hours with an experienced member of the DCC team (Data Specialist or Data Technician) reviewing the project-specific documentation, asking questions and shadowing that mentor as they do production work. Once the trainee feels comfortable, roles are reversed and the mentor spends up to a few hours sitting with the trainee as they rate sections of pavement. The mentor provides instruction, answers questions and provides feedback as they go.

The final step of the training process involves providing the trainee with a small section of pavement for the trainee to rate on their own, without the direct supervision of their mentor. The mentor remains directly accessible to the trainee for questions. The specifics of this section vary based on the project, but it typically entails multiple testing routes that have been duplicated from a prior project cycle with known distresses and severities, which can be quickly checked for accuracy. This practice session allows for assessing the trainee's knowledge of the project specific distress standards – for this project the cracking standards will be based on the definitions in the 2016 HPMS Field Manual.

The markers placed by the trainee during the practice session are compared to the established markers placed by the production rater for the section(s). The distresses marked on the route by the trainee can be compared to the acceptance criteria and a percentage score can be computed that relates directly to the amount of distress the trainee has marked correctly. If specific testing routes are not available, the sample is performed on production data. Under this scenario, QC is performed immediately upon completion, and the mentor provides thorough feedback, often completing the QC process with the trainee present to observe and ask questions. This "test route" cycle is repeated until the quality of the trainees output is acceptable, at which point they work exclusively on production data. After this initial training, individuals continue to receive weekly feedback from their QC team member on the quality of their work, specifically pointing out any systematic errors that they need to correct. The DCC will be required to maintain documentation of the training of each rater to be provided to the project team upon request.

Independent Validation of DCC's Raters

A set of consensus surveys will be conducted by the certified project team distress raters named earlier for use in evaluating the DCC raters for the assessment of surface cracking on rigid pavements. The consensus surveys will be on four JCP sections and four continuously-reinforced concrete pavement (CRCP) sections[1] selected by the project team to represent the expected range of conditions to be encountered along the data collection route based on the FHWA Interstate Pavement Condition Sampling project [(4)], and they will include roadway features (e.g., presence of transverse cracks or sealed cracks) expected to affect the rater's accuracy and precision. Each section will consist of approximately 0.1-mile of pavement.

The consensus survey will be conducted by the project team simultaneously viewing the sections and identifying the distresses. This process is in accordance with the procedure used by the LTPP program.[(5)] The consensus survey will be performed to identify cracking in accordance with the requirements of the 2016 HPMS Field Manual.

These same sections will be rated by each of the manual raters to be used by the DCC in evaluating the Portland cement concrete (PCC) pavements encountered on the data collection route. In order to participate in the validation, the DCC will be required to demonstrate that the rater has completed the DCC training program. A rater will be certified for use in performing data collection on JCP for this project if they are able to identify at least 85 percent of the cracking identified by the consensus survey on each of the four JCP sections. Similarly, a rater will be certified for use in performing data collection on CRCP for this project if they are able to identify at least 85 percent of the cracking identified by the consensus survey on each of the four CRCP sections.

For JCP pavements, the assessment of the DCC raters will include an evaluation of their ability to accurately identify joints, which not only affects the percent cracking, but also impacts the faulting measurements. The reference data for the location of joints on JCP pavements will consist of the number of joints per 0.1-mile long JCP section used in the cracking validation. The reference number of joints per each of the four 0.1-mile long JCP sections will be produced by the project team through the visual assessment of the surface images collected by the DCC.

EQUIPMENT CALIBRATION

The DCC will be responsible for (1) calibrating the different data collection equipment components (i.e., inertial profiler's accelerometer and height sensors, distance measuring instrument [DMI], LCMS, global positioning system [GPS], inertial measurement unit [IMU],

[1] No CRCP sections are included in the MnROAD facility. Therefore, a series of sections will be selected from the images collected for the FHWA Interstate Pavement Condition Sampling project [(4)] for validation of raters on this pavement type.

and right-of-way [ROW] cameras in accordance with manufacturer recommendations and their own procedures), and (2) providing the project team with documentation of the proposed calibration processes and proof of the successfully calibrated equipment prior to certification testing. The calibration documentation provided by the DCC will be reviewed by the project team.

In addition, the DCC will also be responsible for conducting additional calibration on their measurement system equipment at a given frequency, or as requested by the project team when the result from the certification, validation and verification testing suggest the need for re-calibration. The DCC will be required to provide the project team with proof of any equipment calibration conducted during the data collection schedule through documentation and results of the testing conducted.

It should be noted that some of the equipment sensors, such as the inertial profiler height sensors, are typically calibrated when they are manufactured and not by the DCC. However, the functioning of these sensors will be reviewed as part of the equipment certification, validation and verification processes.

EQUIPMENT CERTIFICATION OR VALIDATION

The different components of the DCC equipment that will be used in the collection of project data will be subject to testing to check that the resulting data meet the project quality requirements. For this project, certification procedures are procedures that are commonly applied nation-wide, such is the case of inertial profiler equipment; however, there are no nationally recognized certification procedures currently available for the LCMS or for the other equipment components. In order to validate these equipment components lacking certification procedures, the project team developed and will conduct validation testing to evaluate the accuracy and precision of the data reported in the field under conditions representative to the ones anticipated during actual data collection.

Certification of Roughness Data

Both the inertial profiler and the operator of the inertial profiler will be certified in conformance with AASHTO R56-14, "Certification of Profiling Systems," by an independent certification agency. While operator certification is not required by FHWA regulations, it is considered a good practice. The agency selected by the project team to conduct the independent certification will possess a nationally recognized inertial profiler certification program with years of experience, such as the Minnesota Road Research Facility (MnROAD), which is where the project team plans on carrying out the certification. As specified in AASHTO R56-14, the accuracy of the certified inertial profiler will be such that its IRI values are within 5 percent of the reference IRI values with a 95 percent confidence level and its precision will be such that the IRI values from 10 repeated profiles are within 5 percent with 95 percent confidence level.

The project team will require that the test sections selected for the certification of the inertial profiler represent a range of roughness representative of the expected IRI values to be encountered along the data collection route and that the sites include samples for both flexible and rigid pavements of varying surface types, as available. The expected range of IRI values will be defined using approximately 10,000 miles of IRI data collected for the FHWA Interstate Pavement Condition Sampling project. (4)

In addition, the DCC will be requested to provide a comparison of the IRI computed using the software associated with their routine data collection and the IRI for the same profiles computed using the ProVAL software. These data will be reviewed to identify that the computed IRI is within 2 percent of the accepted standard provided by the ProVAL software.

Validation of Distress Data

The objective of the validation testing addressed in this section is to evaluate the accuracy and precision of the DCC equipment in the measurement of cracking, rutting, and faulting, under representative conditions to the ones anticipated during actual data collection, to confirm that the measurements meet the quality specification required for the purposes of this project. The validation testing will be conducted prior to starting data collection and it will be led by the project team. If the equipment does not meet the required quality specification, the DCC will be required to address the issues and the computed metrics will then be re-evaluated. The DCC will not be allowed to collect data for the project until the project team considers that the accuracy and precision presented by the DCC are acceptable.

The next parts of this section describe the various aspects of the validation testing, including the main characteristics of the validation facility, methodologies for collecting reference data, procedure to be followed by the DCC to collect data at the testing facility, approach to assess the bias and precision of the measurement system, and acceptance criteria and error resolution procedure.

Validation Facility

Except for percent cracking on CRCP, validation testing will be conducted at MnROAD, as this facility provides for a number of experimental factors in a single location and has appropriate reference data collection systems available. The use of MnROAD will allow for evaluation of the accuracy and precision of the DCC's measurement equipment under a number of experimental conditions without additional traffic control. The selected validation test sections will address the following experimental factors:

- Type and extent of distress – MnROAD provides pavement sections with different levels (i.e., rated poor, fair, and good as defined in HPMS for the individual distress types) of each of the three distress types (i.e., cracking, rutting, and faulting) to be evaluated in order to validate the equipment's accuracy and precision for a representative range of surface distresses. The validation test sections will be selected by the project team to represent the distress levels expected to be encountered on the IHS. The range of distress values will be based on the data collected as part of the Interstate Pavement Condition Sampling study. (4)

- Surface type – MnROAD includes a variety of surface types for both AC (e.g., hot-mix asphalts, open-graded asphalts, and chip seals) and JCP pavements (e.g., diamond-ground pavement). The surface types to be included in the validation test will be selected to cover typical surfaces encountered in the Interstate Highway System (IHS). As noted previously, MnROAD does not incorporate CRCP sections; therefore, images collected as part of the FHWA Interstate Pavement Condition Sampling project [(4)] will be used for validation of percent cracking on this pavement type.

Reference Distress Measurements

The reference distress data for the validation testing will be collected by experienced manual raters trained to follow the distress definitions in the 2016 HPMS Field Manual. [(2)] The following list provides information regarding the collection of reference measurements for each distress type:

- Cracking Percent – reference cracking percent data will be collected manually by a team of raters provided by the project team. This team will produce a consensus survey of surface cracking from the visual assessment of pavement images reported by the DCC. The manual raters will be Mr. John Miller and Dr. Amy Simpson, and their experience was provided earlier, under the "Certification of Project Team's Manual Raters" section. Reference cracking percentage values will be collected for each section selected by the project team for direct comparison with the values reported by the DCC. The cracking percent data will be collected at a total of ten 0.1-mile long sections, distributed as follows: two AC sections, four CRCP sections, and four JCP sections. Sections will be selected to represent the range of cracking percent expected to be encountered on the IHS, as determined from the FHWA Interstate Pavement Condition Sampling project. [(4)] For example, the two AC sections will be selected such that one will have "low" cracking percent and the other "high" cracking percent based on the distribution of cracking percent expected to be encountered on the IHS.

- Rutting – reference rut depth values will be computed from reference transverse profiles. The reference transverse profiles will be measured using MnROAD's Automated Laser Profiling System (ALPS). The ALPS will be operated by MnROAD's staff with experience in the operation of the device. The ALPS is checked at least once per year by MnROAD staff to confirm that it is collecting accurate data at regular intervals across the profile.[2] The computational algorithm to compute the rut depth values corresponding to each wheelpath of the reference transverse profiles complies with the procedure specified in the AASHTO PP 69-14 standard. The reference data will be collected at transverse profiles selected by the project team to cover a range of "low" and "high" rutting, based on the anticipated rutting values to be encountered on the IHS, as determined from the FHWA Interstate Pavement Condition Sampling project. [(4)] A total of ten transverse profiles will be measured using the ALPS – five profiles with low rutting and five profiles with high rutting.

---

[2] MnROAD will be requested to provide documentation and results from the latest calibration procedure conducted on the ALPS. If the latest procedure was conducted more than one year ago, MnROAD will be requested to complete the calibration procedure prior and submit the results of the calibration prior to collecting reference data for the validation testing.

- Faulting – reference faulting values also will be collected using the ALPS. The ALPS will be used to collect transverse profiles 150 mm before the joint and 150 mm after the joint. The elevation data in the right wheelpath will be used to estimate the faulting at each joint. This approach effectively estimates faulting in accordance with the AASHTO R36 approach. A total of ten joints will be selected for the validation of the DCC equipment – five joints with low faulting and five joints with high faulting. The levels of "low" and "high" faulting will be based on the anticipated levels of faulting to be encountered on the IHS data collection route, as determined from the FHWA Interstate Pavement Condition Sampling project. (4)

Validation Test Procedure

The specifications for the validation test procedure is divided into two main components:

1. Collection of DCC data.
2. Collection of reference data.

Information regarding the procedural stages, in sequential order as they occur for each component of the validation test is provided next:

1)Collection of DCC data

- Planning – the DCC will be provided with location coordinates and inventory information for the MnROAD test facility sections two weeks prior to testing to allow the DCC proper planning. In addition, the project team will provide the DCC with documentation detailing information on the data collection procedure. The project team will also host a web-based meeting to discuss possible questions the DCC may have before starting the validation test data collection. For the CRCP sections, the DCC will be provided with the reference locations for the sections to be used in validating their manual raters.

- Marking of test sections – specific locations at the MnROAD facility will be marked using temporary markings (e.g., aluminum masking tape), to guide the DCC in the identification of the testing locations.

- Number of data collection runs – the DCC will be required to collect data on the complete set of MnROAD facility test sections three times consecutively – this will minimize the risk of missing data on specific sections and provide a sample dataset of repeated measurements to assess the measurement systems' repeatability. In addition, the DCC will be required to perform additional runs on specific test sections to obtain a more robust estimate of the measurement systems' precision.

- Data collection speed – the DCC will be required to perform repeat runs at the MnROAD facility at 55 mph ± 5 mph. This speed is expected to be representative of the average speed at which the DCC will collect data for the project.

- Data delivery timeframe – DCC will be required to deliver all data collected at the MnROAD facility within two weeks of the data collection date. This time-frame provides sufficient time for the DCC to process the data to estimate each of the distresses to be validated.

2) Collection of reference data

- Planning – project team will select test sections within the MnROAD test facility for the collection of reference data; i.e., the location of sections for reference data collection. These sections will be selected to obtain a representative sample for the different combinations of the experimental design matrix.

- Marking of sections – selected test sections within the MnROAD facility will be marked using temporary marking to identify where the reference data are to be collected.

- Collection of reference data – collection of reference data is planned to occur within two weeks of the DCC completing its data collection.

Analysis of Validation Test Data

Data from the validation tests will be used to estimate the accuracy and precision of the system components. The statistics to be estimated from the data collected on the test facility include:

- Measurement bias (system's accuracy) – measurement bias refers to the systematic difference between the value produced by the measurement system and the true value being measured, and it will be used to characterize the accuracy of the measurement systems. Bias is expressed as the expected value of the population of measurement errors and can be estimated as the sample mean of the set of measurement errors observed in the validation test. The reference data to be collected for the project may not represent true values rigorously speaking; however, they are considered acceptable for practical purposes.

- Measurement repeatability (system's precision) – measurement repeatability refers to the degree of agreement between repeat measurements taken under the same conditions and it will be used to characterize the precision of the measurement system. Measurement repeatability can be quantified using either standard deviation or range. These values may be estimated as the sample standard deviation and sample range, respectively, of the set of measurement errors from the validation test.

The project team may compute additional statistics, such as the coefficient of variation or cross-correlation, if deemed necessary for the purposes of evaluating the quality of the distress measurements produced by the DCC.

Acceptance Criteria and Error Resolution

The statistics computed from the data collected during the validation testing to estimate the accuracy and precision of the DCC system will be used to decide whether the system is apt to collect data for the project or not. Table 2 summarizes the acceptance criteria with the details provided next for each distress data type along with the errors resolution procedure to adopt if the acceptance criteria is not met:

Table 2. Acceptance criteria for the validation of DCC distress data.

Data Metric	Accuracy	Precision
Cracking Percent	• ±15%, or ±3, whichever is higher, for rigid pavement • ±30%, or ±3, whichever is higher, for flexible pavements • ± 2 joints for any of the 500-ft long JCP sections	• values within ±15% of mean with a 90% confidence level for rigid pavements • values within ±30% of mean with a 90% confidence level for flexible pavements
Rutting	• ±0.08 inches	• values within ±0.08 inches of mean with a 90% confidence level
Faulting	• ±0.05 inches	• standard deviation of values not to exceed 15% of mean value

- Cracking percent accuracy and precision – bias for DCC's cracking percent data should not exceed the higher of either ±15 percent, or ±3 for rigid pavement surfaces. Bias on flexible pavement surfaces should not exceed the higher of either ±30 percent, or ±3. The variability for DCC's cracking percent should be such that the measured values are within ±15 percent of their mean value with a 90 percent confidence level for rigid pavement surfaces, and ±30 percent of their mean value with a 90 percent confidence level for flexible pavement surfaces. These levels of accuracy and precision are based on studies of distress data variability performed by the LTPP program. (6) The number of joints identified by the DCC should not differ from the reference number of joints by more than ±2 joints for any of the 500-ft long JCP sections selected for the analysis.

- Rutting accuracy and precision – bias for the DCC's rut depth data should not exceed ±0.08 inches. The variability for DCC's rut depth should be such that the measured values are within ±0.08 inches of their mean value with a 90 percent confidence level. The bias and variability will be estimated as the sample mean and range of the set of 20 pair-wise differences in rut depth values from the comparison of DCC and reference rutting data for the 10 transverse profiles, each consisting of right and left wheel path rut depth values – i.e., two rut depth values per transverse profile. These criteria are based on a review of the current standard of practice adopted by various State agencies, as consulted from the literature (7,8,9) and from phone interviews conducted by the project team with Texas Department of Transportation (DOT), Florida DOT, and Virginia DOT.

- Faulting accuracy and precision – bias for DCC's faulting data should not exceed ±0.05 inches. The variability for DCC's faulting should be such that the standard deviation of the measured values does not exceed 15 percent of the mean value. The bias and variability will be estimated as the sample mean and coefficient of variation of the set of 10 pair-wise differences in faulting value from the comparison of DCC and reference faulting data with one value per joint from the right wheelpath for each of the 10 joints. These acceptance criteria, similar to the rutting criteria, are based on a review of the current standard of practice adopted by various State agencies, as consulted from the literature (7,8,9) and from the phone interviews conducted by the project team as noted above.

The DCC's measuring system will pass the validation test if it meets all the acceptance criteria set for each distress type. If one or more of the acceptance criteria are not met, the DCC will asked to re-process their measurements within a specified period of time agreed upon by the DCC and the project team. Once the DCC's measurements have been re-processed, the analysis of the validation data will be repeated. If the re-processed measurements do not meet the acceptance criteria, the project team will review the data and discuss appropriate actions with FHWA staff.

EQUIPMENT VERIFICATION

The DCC's measurement system will be subject to periodic verification testing throughout the data collection phase of the study to verify that the quality of the measurements is maintained over time. There will be two types of verification testing: one performed by the DCC for internal quality control purposes and the second one performed by the project team for independent quality assurance purposes. The following parts of this section provide information regarding the different verification testing to be conducted for the study.

Weekly Verification Testing Performed by the DCC

This section reviews the standard approaches adopted by the DCC for performing verification of their equipment throughout a data collection cycle. This testing typically occurs weekly using 0.2-mile verification sites located along or near the data collection route. The DCC's weekly verification testing includes test procedures for the DMI, the LCMS components, and the repeatability of roughness, rutting, faulting, and cracking measurements. The following list provides information regarding the verification test procedures to be performed by the DCC along with the corresponding acceptance criteria.

- Linear reference system (LRS) – length of a straight pavement section is measured five times with the DMI and the resulting measurements are compared to the one obtained manually using a steel tape. The DMI will pass the weekly verification test if it meets the following acceptance criteria:
    - Bias of DMI readings is lower than 0.15 percent of 1 mile.
    - Difference between runs is within 0.1 percent.
    - Difference in unit pulse count with respect to previous week count should be lower than 0.15 percent.
- LCMS Static Testing – this test is conducted following the manufacturer's specification, which involves 18 vertical height measurements and 30 horizontal measurements. The test evaluates the laser's noise level and focus quality using the validation board shown in Figure 1—the dimensions of the validation board are shown in Figure 2. The DCC will be required to perform the check using the calibration board at a minimum of three locations along the LCMS footprint.

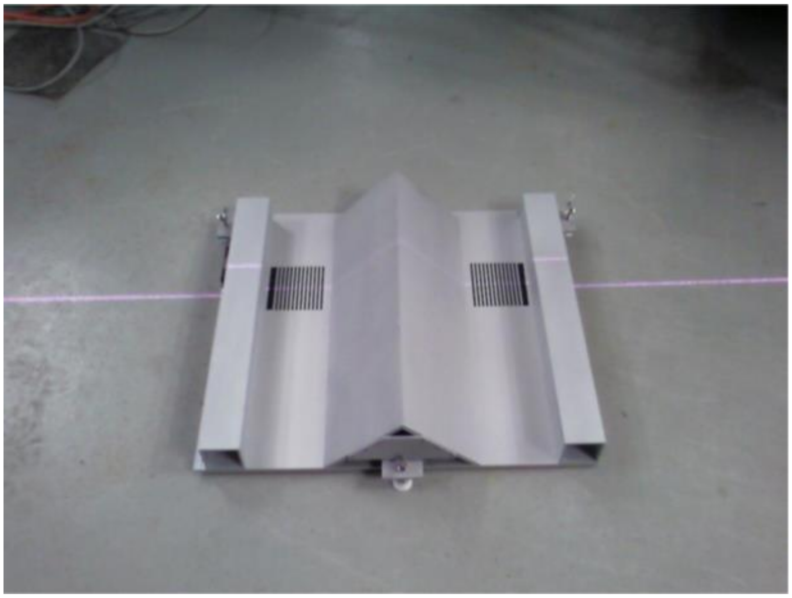

Photo courtesy Mandli Communications

Figure 1. Photograph. LCMS scanning DCC's Calibration Board.

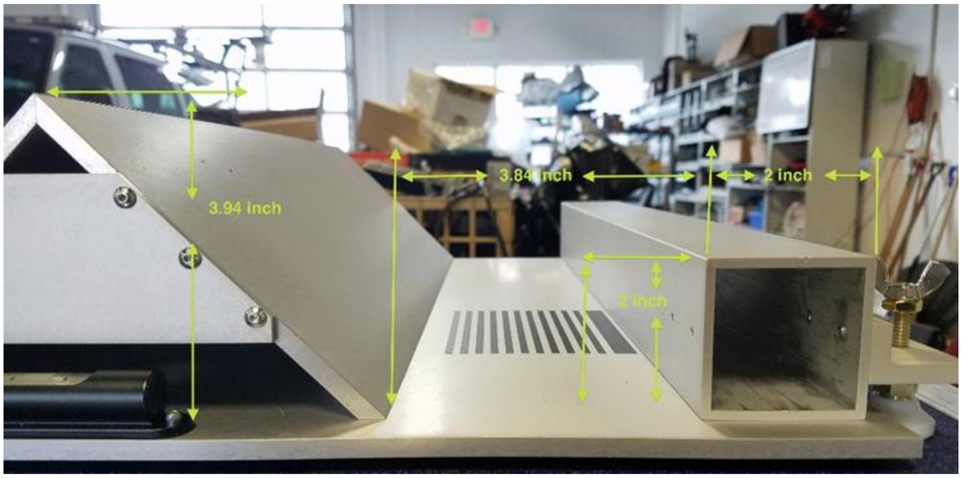

Photo courtesy Mandli Communications

Figure 2. Photograph. Dimensions of DCC's Calibration Board.

The error levels identified below are for a single component of the measurement. As the noise associated with each measurement is expected to be random, the calculated rut depth or faulting value is expected to have less error associated with it as the noise from each data point will be additive with some positive and some negative levels of error. Additional improvement may be expected with averaging of these values across multiple locations. The LCMS sensors will pass the weekly verification test if they meet the following acceptance criteria[3]:

  - Average error for set of vertical measurements should be less than 0.05 in.
  - Average error for set of horizontal measurements should be less than 0.15 in.

- <u>Distress measurement repeatability</u> – the repeatability of IRI, rutting and faulting data should be evaluated by the DCC from measurements taken from five consecutive runs of their verification sites. The distress measurement repeatability will pass the weekly verification test if it meets the following acceptance criteria:
  - Coefficient of variation for the set of repeat IRI measurements should be less than five percent.
  - Repeatability of rut depth from run to run should be within ±0.04 inch.
  - Repeatability of faulting from run to run should be within ±0.04 inch.
  - Coefficient of variation for the set of cracking measurements should be less than 15 percent.

Independent Verification Testing Performed by the Project Team

The independent verification testing to be conducted by the project team will include two different procedures[4]: (1) a repeatability verification testing and (2) a LCMS static verification testing.

Independent Repeatability Verification Testing

The independent repeatability verification testing will be similar to the periodic quality checks conducted for the FHWA Interstate Pavement Condition Sampling project. [(4)] For this, the DCC will be requested to collect all data elements ten consecutive times on 0.1-mile-long sections selected along the data collection route by the project team. These verification sites will be selected such that the repeatability verification testing is conducted weekly, and they may include some of the LTPP sections selected as part of the data collection plan. The DCC will be required to deliver the data collected from the verification testing within three days of the test date.

---

[3] The accuracy requirement corresponds to the measurement of an individual point on the surface. The accuracy of the metrics computed from the measured surface points is a function of this accuracy as well as of the processing of data and the computational algorithm.

[4] The procedures planned for conducting independent verification testing for this study focus on the repeatability of the measurements produced by the DCC, not on their accuracy. These verification procedures were designed specifically for the purposes of this study, and do not necessarily reflect current practices adopted by State DOT for the verification of their data.

The set of repeated measurements at each verification site will be analyzed to quantify the equipment's repeatability. If the repeatability conditions defined for the validation testing are not met, the DCC will be required to stop data collection and investigate the potential cause(s) of the difference. The DCC will only be allowed to resume data collection after re-evaluating its measurement system following the same procedure on a different set of verification sites and successfully passing the acceptance criteria. In addition, all data collected after the latest successful verification test will be rejected and the DCC will be required to recollect these data.

Independent LCMS Static Verification Testing

The purpose of this step is to document the LCMS static verification testing performed by the DCC, as previously defined. This documentation will allow the project team to independently verify that the testing procedure is being conducted as described in the documentation submitted by the DCC before the beginning of data collection. To accomplish this, verification testing of the LCMS sensor based on the calibration board shown in Figure 1 will be performed in the presence of the project team twice within the data collection schedule at two separate locations. The first location will be selected such that the equipment is tested within the first two weeks of the data collection program, while the second location will be such that the equipment is evaluated at some point between 50 percent and 75 percent of completion of the data collection effort. If the system does not pass the acceptance criteria set by the DCC and approved by the project team before the beginning of data collection, the DCC will be requested to stop data collection and to address the issue(s) before resuming. Similar to the routine verification testing, the data collected since the last successful verification testing will be rejected and the DCC will be required to recollect these data.

DAILY DATA COLLECTION QUALITY CHECKS

The DCC will be responsible for conducting a series of field quality checks on a daily basis during the data collection period. These checks will allow for detection of potential data quality issues in a timely manner. The following list provides information regarding the quality procedures and checks to be performed by the DCC on a daily basis before starting data collection, during data collection, and once data collection has been completed. The DCC will be required to report selected quality checks results to the project team for purposes of verifying successful execution of the checks and for documenting the results for future reference.

1) Before data collection

- <u>Check environmental conditions</u> – the operator will confirm that environmental conditions are appropriate for data collection. For example, data should not be collected on a wet surface as it increases the risk of measurement error. Operator should not start, or should stop, data collection until pavement surface is dry. Another environmental condition that would cause an interruption of data collection is air temperatures outside the operational range of the individual measurement system components. For example, the operational temperature range of an inertial profiler is defined between 32ºF and 105ºF.

- Inspect and clean all laser apertures – the operator of the survey vehicle will inspect laser apertures to confirm they are in good condition (e.g., no visible cracks) and clean each of them using a soft rag to ensure they are free of obstructions.

- Clean data collection vehicle or camera enclosures – the operator of the survey vehicle will clean the windshield to ensure that ROW cameras have a clear front view to reduce risk of data recollection due to poor quality images.

- Review of ROW images – the operator will visually inspect ROW images to verify that they are in focus, of appropriate color, acceptable luminance, and clear and free of obstructions. If ROW images are not clear or are low quality, the operator will clean the windshield and reconnect camera connections until the issue is resolved. If problems persist, the operator will interrupt data collection and contact the DCC's technical support team for assistance.

- Confirm data collection vehicle tire pressure – the operator will check that pressure of all tires is the one used during calibration of the DMI, as a different tire pressure may impact the readings. If the tire pressure is found to be different from that used during calibration, the operator will be expected to adjust the tire pressure to the appropriate level prior to starting data collection.

- Perform inertial profiler's block test – the operator and driver of vehicle will perform the block test following the procedure described in Section 5.3.2.3.1 of the AASHTO R57 standard, "Standard Practice for Operating Inertial Profiling Systems." This test is performed for vertical verification of the calibration. The DCC will be required to interrupt data collection if the equipment fails to pass the block test and it is responsible for conducting further checks as indicated in AASHTO R57. If the equipment fails to pass the daily block test, the DCC will be required to notify the project team immediately. Documentation of the block tests performed will be included with the standard data submittal.

- Perform inertial profiler's bounce test – the operator and driver of the vehicle will perform the bounce test following procedure described in Section 5.3.2.3.2. of the AASHTO R57 standard, "Standard Practice for Operating Inertial Profiling Systems." This test is also performed for vertical verification of calibration. The DCC will be required to interrupt data collection if the equipment fails to pass the bounce test and to address the issue. If the equipment fails to pass the daily bounce test, the DCC will be required to notify the project team immediately. Documentation of the bounce tests performed will be included with the standard data submittal.

- LCMS height check – the operator will use a reference object with known dimensions to confirm that the height readings produced by the LCMS is comparable to the height readings obtained after calibration.

2) During data collection

- Check and monitor GPS – GPS data accuracy may be affected by weak signal strength or loss of signal due to proximity to airports or areas with potential obstructions (e.g., large number of tall buildings or trees) that will affect the accuracy of data. Operator will continuously monitor that GPS accuracy is within the acceptable range. The DCC will be required to stop data collection and address issues with the GPS accuracy before resuming data collection.

- Monitor images – the operator will monitor the on-board computer monitor to confirm that displayed ROW images are crisp, clear and void of obstructions, that there is minimal sunlight interference, and that the images are updating as the vehicle moves down the road.

3) After data collection

- Completeness checks – the operator will run on-board verification software to confirm the completeness of data collected each day. This check will allow the DCC to identify pavement sections with missing data, so that those data can be collected in a timely manner.

REVIEW OF DATA DELIVERABLES

The DCC will deliver data to the project team in batches every two weeks (or more frequently) throughout the data collection phase of the project. The project team will review each data batch received for completeness and validity, and flag the observations not passing the acceptable criteria. Flagged data will be subject to further review by members of the project team to identify systemic problems with the collection, if any. Review of data batches throughout data collection will allow for identification of issues on a timely manner, and potentially for reducing the amount of data recollection.

The remainder of this section provides information on the quality checks to be performed during the data review and the associated acceptance criteria and error resolution procedure. The acceptance criteria for these checks are mostly based on the criteria successfully adopted for the FHWA Interstate Pavement Condition Sampling project. (4)

Completeness Checks

The data elements to be reviewed for completeness include:

- Roughness.

- Percent cracking.

- Faulting for all records with a surface type of 3 (i.e., jointed concrete pavements).

- Rutting for all records with a surface type of 2 (i.e., asphalt concrete surfaces).

- Surface type (DCC will identify surface type strictly on a visual review of the surface, therefore only surface types 2, 3, or 5 [AC, JCP, or CRCP, respectively] will be used from the HPMS surface type codes).
- Location information.
- Event data.

Missing data will be flagged and reviewed by the project team to investigate the cause and decide whether data are to be recollected or not. The decision of recollecting missing data will be based on:

- Data type missing – e.g., inventory data, such as surface type, may be recoverable through review of ROW images whereas distress data are less likely to be recoverable.
- Length of pavement missing data – e.g., no more than 10 consecutive 0.1-mile long pavement sections, or no more than 2 percent of the extent of a certain route, should be missing data.
- Reasonable cause for missing data – certain issues, marked as events in the data or detected through review of the ROW images, may make data recollection impractical or not feasible, such as missing data due to construction activity on the collection lane.

As appropriate, the project team will communicate the records with missing values requiring data recollection to the DCC and it will discuss the reasons for the decision to recollect. The DCC may conduct an internal investigation to determine if the data to be recollected can be recovered through reprocessing the original batch of raw measurements.

Validity Checks

The second set of checks to be performed by the project team during the review of delivered data batches consists of validity checks to detect the presence of unacceptable or inconsistent data values. The following acceptance criteria for the range and consistency checks are based on the criteria successfully applied during the FHWA Interstate Pavement Condition Sampling project. [(4)] In addition, temporal analyses will be conducted to detect cases for which the yearly change in condition are outside the expected range. The acceptance criteria that will be used for the temporal analysis checks are based on the findings from the FHWA Infrastructure Health study [(10)] as well as from the experience gained during in the FHWA Interstate Pavement Condition Sampling project. [(4)] More specifically, the acceptance criteria include:

1) Data range checks

- IRI – 40 to 250 in/mile.
- Percent cracking – 0 to 60 percent for surface type 2, and 0 to 100 percent for surface type 3 or 5.
- Rutting – 0 to 1 in.

- Faulting – 0 to 1 in.
- Surface type – no unpaved surfaces. Surface type should be 2, 3, or 5.
- Air temperature – 40 to 100°F.
- Pavement surface temperature – 20°F to 130°F.
- Speed – 40 to 65 mph.

2) Data consistency checks

- Faulting data should not be provided on a surface type of 2 or 5.
- Rutting data should not be provided on a surface type of 3 or 5.
- Difference in rut depth between wheelpath values at the same location should be lower than 0.25 in.
- Difference in IRI between wheelpath values at the same location should be lower than 50 in/mile.
- For every begin event marker, there should be ending event marker.

3) Temporal analysis (applied to data passing both range and consistency checks)

- Expected change in IRI per year: between -5 and +10 in/mile per year.
- Expected change in Rut Depth per year: between -0.05 and +0.1 in per year.
- Expected change in Faulting per year: between -0.04 and +0.08 in per year.
- Expected change in Percent Cracking per year: between -5 and +10 percent per year.

Acceptance of Flagged Data

Data failing the checks listed above will be flagged and further reviewed by the project team. This review will include the comparison of the flagged data values to the pavement images to assess whether the data are reasonable. If the flagged data are deemed reasonable, they will be accepted and added to the project database. The acceptance criteria after review of flagged data will be as follows:

- If data appears to be an outlier, data will be maintained and stored in the project database.
- If data appears to be part of a persistent issue (multiple records flagged for a day for the same reason), the DCC will be notified.

- If more than 10 records flagged for the same issue, a stop work order will be issued to the DCC to sort out the issue and correct any equipment problems. Data discarded from the review checks will be recollected by the DCC once the issues with the measurement systems have been resolved.

The error resolution procedure defined to address issues with data not passing the acceptance criteria is illustrated in Figure 3. The first step consists of identifying the cause of the error through detailed investigation of the data. Based on the identified cause(s), the next step will consist of sorting the errors into one of the four categories shown in Figure 3. The error resolution approach will be decided based on the error category. The following list identifies the error categories along with their corresponding error resolution approach:

- Procedural error – an error such as an incorrect method of calculating percent cracking requires an adjustment to the method or procedure. With procedural errors, there is not an issue with the raw data, but with the post-processing procedures used to report the data; e.g., faulting measurements taken outside of the right wheelpath area. The DCC will be required to re-process the raw data when procedural errors are identified.

- Processing error – an example of these errors includes not selecting the proper filters during processing, such as including sealed cracks in the calculation. The DCC will be required to re-process the raw data if these errors are identified.

- Data quality and omission error – these errors include poor image quality, poor accuracy due to equipment malfunction or out of calibration. The DCC will be required to re-collect data where these errors are identified.

- Data correctness error – these errors include collecting the wrong route, data elements or using an incorrect standard for data collection. The DCC will be required to re-collect data where these errors are identified.

Lastly, the feedback mechanism in Figure 3 loops back to both the data issue sorting and the recommended procedures to address the errors. This enables the approach to be improved and updated throughout the project.

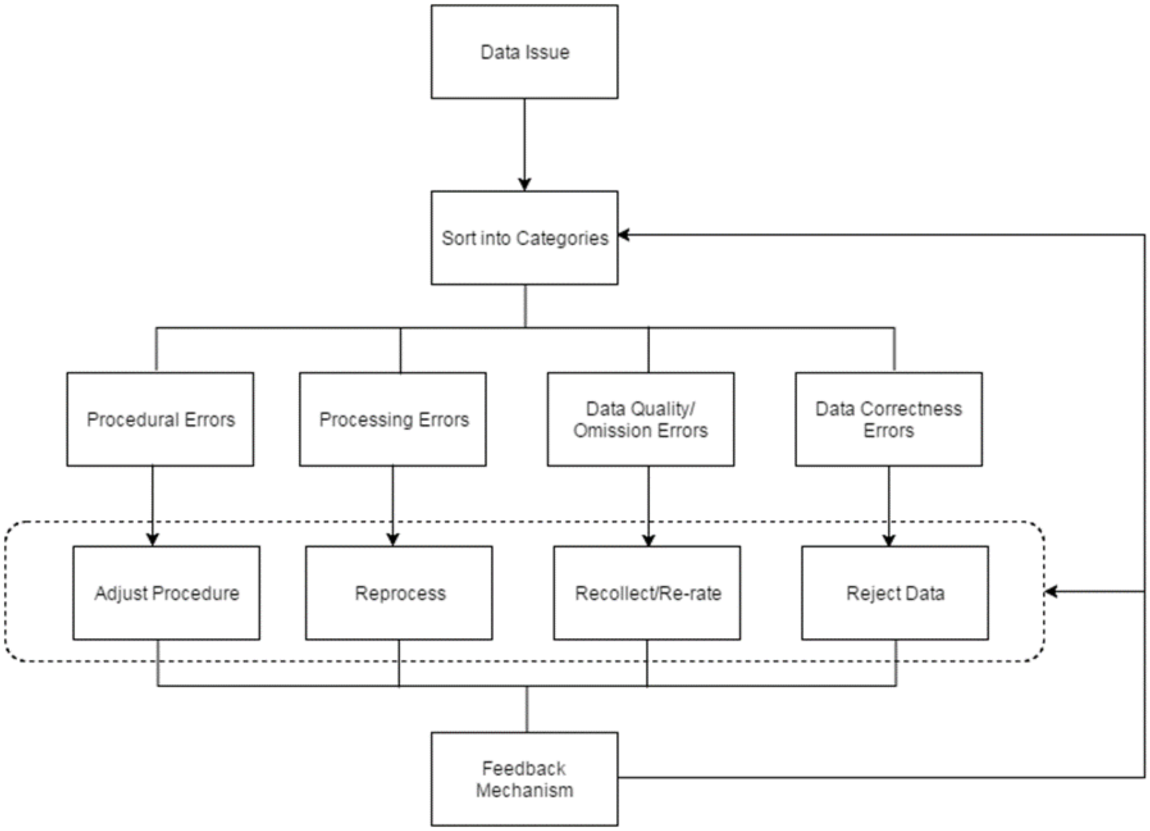

Figure 3. Flowchart. Error resolution methodology.

REFERENCES

1. Federal Register. (2017). National Performance Management Measures; Assessing Pavement Condition for the National Highway Performance Program and Bridge Condition for the National Highway Performance Program, 82(11), 23 CFR, Part 490, Washington, D.C., Department of Transportation, Federal Highway Administration.

2. Federal Highway Administration. 2016. Highway Performance Monitoring System - Field Manual. http://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/. Federal Highway Administration, Washington, DC.

3. Miller, J.S. and W.Y. Bellinger. 2003. Distress Identification Manual for the Long-Term Pavement Performance Program (Fourth Revised Edition). Report No. FHWA-RD-03-031. Federal Highway Administration, Washington, DC.

4. Simpson, A. L., G.R. Rada, B.A. Visintine, and J. L. Groeger. Interstate Pavement Condition Sampling, Report No. FHWA-HIF-17-022, Federal Highway Administration. Washington, D.C. August 2017.

5. Rada, G.R., J.S. Miller, W.Y. Bellinger, and R.B. Rogers, "Accreditation of Strategic Highway Research Program Long-Term Pavement Performance Pavement Distress Raters," Transportation Research Record 1410. Transportation Research Board, Washington, D.C., 1993.

6. Rada, G.R., C.L. Wu, R.K. Bhandari, A.R. Shekharan, G.E. Elkins, and J.S. Miller, 1999. Study of LTPP Distress Data Variability, Volume I. Report No. FHWA-RD-99-074. Federal Highway Administration, Washington, D.C.

7. Virginia Department of Transportation, 2015. Pavement Data Collection & Evaluation Services. Request for Proposal No. 152675-FH. Administrative Services, Procurement Section. Richmond, Virginia.

8. Texas Department of Transportation, 2017. Pavement Condition Data Collection Services. Specification No. 968-62-65. Austin, Texas.

9. Flintsch, G.W., and K. McGhee, 2009. Quality management of pavement condition data collection. Appendix 1. NCHRP Synthesis 401. Transportation Research Board, Washington, D.C.

10. Guerre, J., J. Groeger, S. Van Hecke, A. Simpson, G. Rada, and B. Visintine. 2012. Improving FHWA's Ability to Assess Highway Infrastructure Health - Pilot Study Report. FHWA-HIF-12-049. Federal Highway Administration, Washington, DC.