Guidelines on Quality Management of Pavement Condition Data

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1. Introduction

1.1 Purpose

The purpose of this guideline is to provide Quality Management (QM) procedures for pavement condition data collection at network-level. This guideline presents the content and tasks of QM procedures as well as the acceptance criteria of collected pavement condition data based on which the Pavement Management Engineer will accept or reject the data deliverables from the service provider.

1.2 Scope

This guideline specifies the types of pavement condition data that need to be collected, the required activities that will ensure the data quality during production, the tasks that data inspection will cover, and the requirements that the data delivery will fulfill. It also specifies the content and scope of a Quality Management Report.

1.3 Referenced Documents

The standards, specifications and protocols used in this guideline are listed as below.

AASHTO PP69-14, Standard Practice for Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles
AASHTO PP70-10, Standard Practice for Collecting the Transverse Pavement Profile
AASHTO R36-13, Standard Practice for Evaluating Faulting of Concrete Pavement
AASHTO R43-13 Standard Practice for Quantifying Roughness of Pavements
AASHTO R48-10, Standard Practice for Determining Rut Depth in Pavements
AASHTO R55-10, Standard Practice for Quantifying Cracks in Asphalt Pavement Surface
AASHTO R56-14 "Standard Practice for Certification of Inertial Profiling Systems
AASHTO R57-10 Standard Practice for Operating Inertial Profilers and Evaluating Pavement Profiles
AASHTO M328-14 "Standard Specification for Inertial Profiler
FHWA. Distress Identification Manual for the Long-Term Pavement Performance Program, FHWA Report RD-03-031.
ASTM E950-98, Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with and Accelerometer Established Inertial Profiling Reference

2. Quality Management Plan

2.1. Scope of Data Collection

The pavement condition data collected for network-level pavement management includes roughness data and distress data. The roughness data consists of International Roughness Index (IRI), rut depth (asphalt pavement only), and faulting (concrete pavement only). These Guidelines on Quality Management of Pavement Condition Data cover pavement condition data collected for Pavement Management System in Tennessee as well as for National Performance Measures on pavement infrastructure in the Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Fixing Americas Surface Transportation (FAST) Act. The descriptions of pavement condition data for asphalt pavements and concrete pavements are listed as below.

(1) Asphalt Pavement

Table 2-1 lists the types of pavement condition data, severity levels, and units for asphalt pavements. For asphalt pavements, IRI is collected in both wheel paths and determined in accordance with “Standard Practice for Quantifying Roughness of Pavements (AASHTO R 43)”. Depending on the methods used for data collection, rut depth is determined in accordance with “Standard Practice for Determining Rut Depth in Pavements (AASHTO R48)” or “Standard Practice for Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles (AASHTO PP69)”. Surface defects, such as fatigue cracks, longitudinal wheel path cracks, patching/potholes, block cracks, transverse cracks, longitudinal non-wheel path cracks, and longitudinal lane joints are identified in accordance with “FHWA Report RD-03-031, Distress Identification Manual for the Long-Term Pavement Performance Program”. The extents of identified surface defects are then converted into percentages in accordance with “Appendix A Asphalt Distress Definitions” in “Work Plan for the State of Tennessee Department of Transportation” (See attachment). The work plan is determined in accordance with the data collection contract between TDOT and service provide. It specifies the scope of work, data collection and processing methods, work schedule, data submittal requirements. It will be updated annually to meet TDOT’s data collection needs. The description and calculation of cracking percentage are in accordance with “Item 52” in “Highway Performance Monitoring System (HPMS) Field Manual”.

Table 2-1 Pavement Condition Data for Asphalt Pavement

Items	Severity levels	Unit	Related Documents
IRI	Not applicable	in./mile	AASHTO R 43
Rut Depth	Not applicable	inches	AASHTO PP69 /AASHTO R55
Fatigue Crack	High, Medium, Low	% Area	AASHTO R55; Distress Identification Manual for the Long-Term Pavement Performance Program; Work Plan for the State of Tennessee Department of Transportation
Longitudinal Wheel Path Crack	High, Medium, Low	% Length	
Patching/ Potholes	High, Medium, Low	% Area	
Block Crack	High, Medium, Low	% Area	
Transverse Crack	High, Medium, Low	Number of cracks	
Longitudinal Non-Wheel Path Crack	High, Medium, Low	% Length	
Longitudinal Lane Joints	Not applicable	% Length	
Cracking_Percent	Not applicable	% Area	HPMS field manual item 52

(2) Concrete Pavement

Table 2-2 lists the types of pavement condition data, severity levels, and units for concrete pavements. Similar to asphalt pavements, IRI for concrete pavements is collected in both wheel paths and determined in accordance with “Standard Practice for Quantifying Roughness of Pavements (AASHTO R 43)”. The description and calculation of average faulting and crack percentage for concrete pavements in Table 2-2 are in accordance with “Item 51” and “Item 52” in “Highway Performance Monitoring System (HPMS) Field Manual”. Surface defects for concrete pavements, such as faulting, transverse cracking, longitudinal cracking, transverse joint spalling, and patching, are presented in table 2-2 and identified in accordance with “FHWA Report RD-03-031, Distress Identification Manual for the Long-Term Pavement Performance Program”. The extents of identified surface defects are then converted into percentages in accordance with “Appendix B Concrete Distress Definitions” in “Work Plan for the State of Tennessee Department of Transportation” (See attachment).

Table 2-2 Content and Severity of Distress for Concrete Pavement from Video Images

Items	Severity Levels	Unit	Related Documents
IRI	Not applicable	in./mile	AASHTO R 43
Average Faulting*	Not applicable	inches	AASHTO R36; HPMS field manual item 51
Crack Percent	Not applicable	%	HPMS field manual item 52
Faulting	High, Medium, Low	% slabs at each severity	Distress Identification Manual for the Long-Term Pavement Performance Program; Work Plan for the State of Tennessee Department of Transportation
Transverse Crack	High, Medium, Low	% slabs at each severity	
Longitudinal Crack	High, Medium, Low	% slabs at each severity	
Transverse Joint Spalling	High, Medium, Low	% slabs at each severity	
Patching (Both rigid and flexible patching)	High, Medium, Low	% slabs at each severity	

* Note: As no Continuously Reinforced Concrete Pavements (CRCP) were constructed in Tennessee, average faulting will be collected on all concrete pavements.

2.2 Procedure for Quality Management of Pavement Condition Data

The procedure for quality management of pavement condition data is illustrated in Figure 2-1.

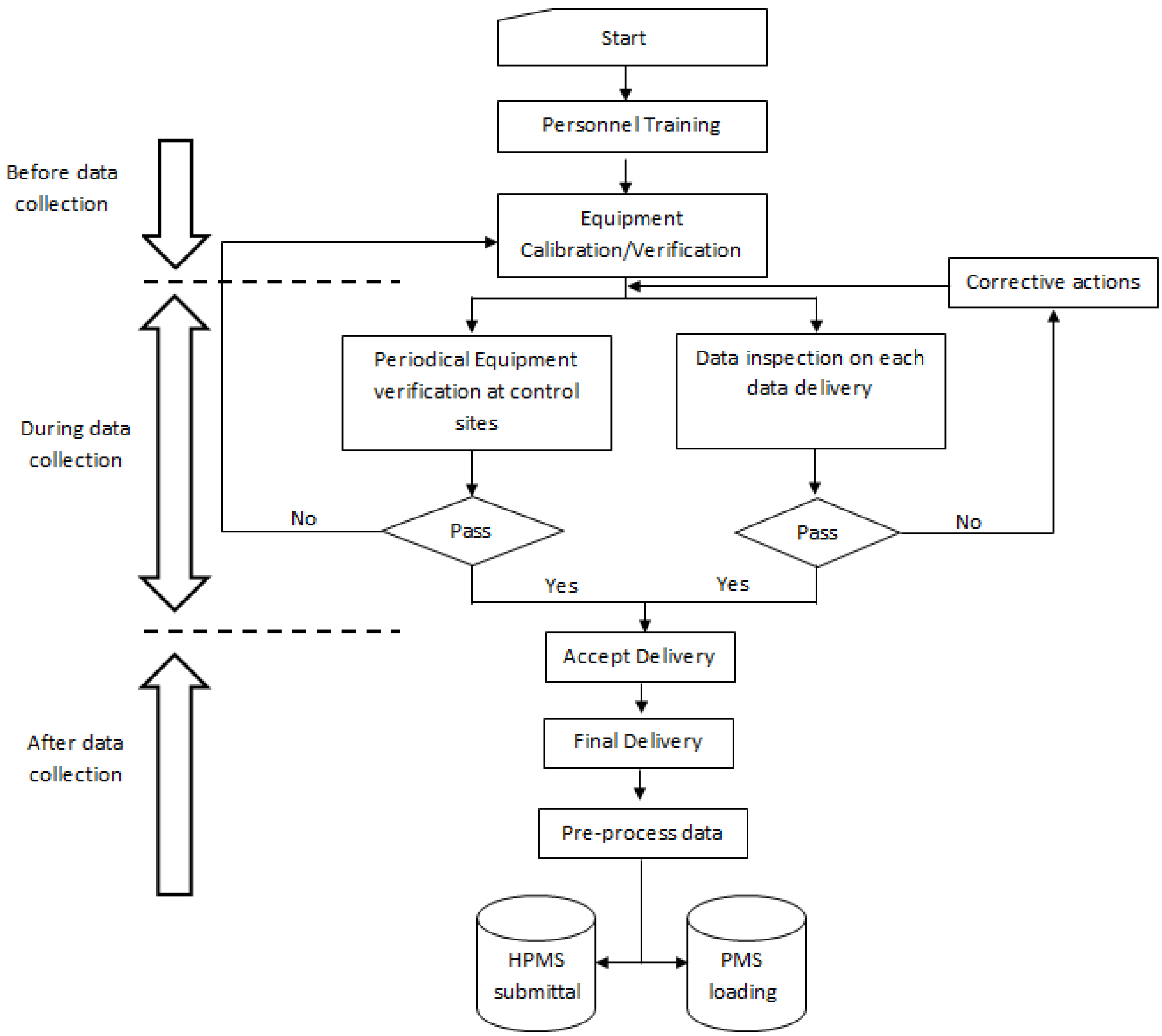

Figure 2-1 TDOT Procedure for Quality Management of Pavement Condition Data

3. Before Data Collection

3.1 Personnel Training

Training is a critical step in the quality management process. Well-trained data collection team is indispensable for ensuring high-quality pavement condition data. The purposes of personnel training are 1) to ensure that the technicians possess good understanding of how to operate the equipment correctly; 2) to ensure that the test equipment and the technicians, as a whole, is able to meet the requirements for data repeatability and accuracy. The completion of personnel training may be in the form of certification test. The test results will be documented and submitted to TDOT prior to data collection.

Personnel training may include, but not limited to: 1) equipment operation training, 2) safety operation guideline (SOG) training, 3) troubleshooting and diagnostics training; 4) equipment maintenance training, etc.

The Tennessee Department of Transportation (TDOT) contracts with a service provider to collect pavement condition data on an annual basis. Therefore, personnel training will be conducted by the service provider and shall be completed before data collection.

It is required that the related documentation for personnel training be submitted prior to data collection and be included in the quality management report.

3.2 Equipment Calibration/Validation Process

Testing equipment shall be calibrated before data collection according to the manufacturer's manual. The equipment shall be periodically verified during data production to ensure that the equipment is functioning as expected. Two months prior to data collection, the calibration program will be performed on the service provider's equipment in accordance with the procedures established by the service provider. It is required that the relevant calibration documentation be submitted prior to data collection. Meanwhile, parallel validation tests on control sites will also be conducted after the calibration program is complete. During normal data collection processes, parallel validation tests shall be conducted on control sites once a month. During data collection, the service provider is required to conduct repeatability test on control site once a week and submit test results within a week.

Depending on the collection method used by the service provider, TDOT will use the same data collection method for validation tests to eliminate the influence of systematic errors. If the equipment used by the service provider is not available, TDOT may contract a third-party using the same data collection method used by the service provider to conduct the validation tests.

The RSP used for collecting surface profiles conforms to AASHTO R-56 "Certification of Profiling Systems", AASHTO R43 "Quantifying Roughness of Pavements," and ASTM E950-98 "Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with and Accelerometer Established Inertial Profiling Reference".

The documentations of equipment calibration and parallel validation tests on control sites will be included in the Quality Management Report.

4. During Data Collection

Data inspection is conducted on each data delivery during data production. The purpose of data inspection is to find potential data quality issues that may compromise the precision and accuracy of the data and implement immediate corrective actions if issues are recognized. The data inspection plays an important role toward ensuring good data quality and will be performed at each delivery.

4.1 Data Format and Completeness Check

Data format and completeness check are conducted first because the remaining checks may not be valid if the data is not initially in the right format. To perform the format check, the standard database containing definitions for all segments to be collected will be established from the ArcMap shape file based on which service provider conducted the data production. The goal of a completeness check is to determine the percentage of missing roadway sections and ensure that the missing/invalid sections are within the allowable tolerance.

Table 4-1 lists the contents of the standard database. The feature column marks the event within this sub-segment during data production. “B” represents bridge; “C” represents construction actions; “R” represents railways. The items required for a completeness check are listed in Table 4-2. All issues on data format and completeness need to be resolved by the service provider before other QMP activities are performed.

Table 4-1 Format for Standard Database

Name	Description	Type	Format
HR_COUNTY	County Number	Number	Integer
HR_CNTYSQ	Route County Sequence	Number	Integer
HR_ROUTTY	Route type	Text	Short Length
HR_ROUTNUM	Route Number	Number	Integer
HR_ROUTAUX	Route Special Case	Number	Integer
HR_DIRECTM	Route Direction Identifier	Text	Short Length
HR_DATYEAR	Collection Year	Number	Integer
HR_DATE	Collection Date	Date	mm/dd/yyyy
HR_BEGMILE	Segment Begin Log Mile	Number	Float
HR_ENDMILE	Segment End Log Mile	Number	Float
FEATURE	Event Identifier	Text	Short Length

Table 4-2 Completeness Check (by Route type: Interstate, NHS State Routes, NHS-Local, non-NHS State Routes)

Items	Description	Corrective actions
Route Mileage Check	Sum of mileage by route (group by ID number)	1) Re-collect or re-process by request 2) Verify
Construction Mileages	Sum of mileage under construction	
Total Mileages	Sum of mileage by interstate, NHS-state routes; NHS-local and non-NHS state routes	

4.2 Sensor Data Check

Both IRI and rutting depth are collected on both wheel paths. When analyzed, the average values are utilized to estimate the pavement performance. Therefore, the difference between the left and right wheel paths can be a potential indicator to estimate the variability of pavement condition data for a given segment. Ideally, the deterioration rates of IRI and rutting depth on both wheel paths may be close, as both wheel paths are subjected to the same traffic and environmental factors. Therefore, larger difference of IRI and rut depth between two wheel paths may be the indication of data quality issues. Therefore, the requirement of distinguishing IRI and rutting depth between two wheel paths seems necessary to eliminate possible data quality issues.

Note that large differences in IRI and rutting depth between two wheel paths may be also be caused by the presence of distress only on one wheel path including 1) wheel-path cracks; 2) joint cracks on the wheel path; 3) presence of potholes and patches. The above scenarios can be verified by checking photolog or downward images. If so, this data can also be accepted.

Table 4-3 Resolution of Sensor Data

Items	Resolution	Expected Values	Percent within limits	Corrective actions
IRI	1.0 in/mi	20-500 in/mi	100	1) Re-collect or re-process by request 2) Verify
Rutting Depth (Asphalt pavement only)	0.01 in	0-1.25 in	100	
Faulting (Concrete pavement only)	0.01 in	0-1.00 in	100	

4.3 Distress Data Check

Distress data is determined by identifying the extent of individual distresses from images and calculated by the amount of individual distress at each severity level. The definition and calculation of distress is conducted in accordance with the LTPP distress identification manual. Table 4-4 lists the expected valuesof distress data for asphalt pavement. Table 4-5 lists the expected value of distress data for concrete pavement.

Table 4-4 Expected Value of Pavement Condition Data (Asphalt Pavement)

Items	Expected Values,% (Sum of extent at all severity levels)	Percent within limits,%	Corrective actions
Fatigue Crack	0-100	100	1) Re-collect or re-process by request 2) Verify
Pothole/Patching	0-100	100	
Block Crack	0-100	100	
Longitudinal Cracks (NWP and WP)	0-100	100	
Crack percent	0-54.20	100	

Table 4-5 Expected Value of Pavement Condition Data (Concrete Pavement)

Items	Expected Values, % (Sum of extent at all severity levels)	Percent within limits,%	Corrective actions
Faulting	0-100	100	1) Re-collect or re-process by request 2) Verify
Transverse Crack	0-100	100	
Transverse Joint Spalling	0-100	100	
Patching (Both rigid and flexible patching)	0-100	100	

4.4 Image Check

Downward images collected by Laser Crack Measurement System (LCMS) are used for distresses classification and measurement. The downward images shall be delivered along with a graphic overlay of the identified distresses at different severity levels. The camera used to capture 2D surface profiles shall have sufficient resolution so that cracks of 0.1 inch can be easily identified and included in automated processing. The overall requirements for downward images are clear (signs readable): minimal or no debris can be in the camera’s viewing path, and highway signs can be easily read. The image deliverables may be rejected if poor quality of images is found due to the above issues. The image samples will be checked by the Pavement Management Staff when data anomalies are found during distress data check. Corrective actions will include re-collection or re-processing of the downward image and re-calculation of surface distresses.

4.5 Control/Verification Sites

Control sites are road segments with known pavement condition data which is measured by TDOT (or third party). The data collected from the control site by TDOT Materials and Tests Division is used as a "reference value/ground truth" to verify test equipment or evaluate the reliability of data obtained from service providers. The control sites are important for quality control process for data production.

The establishment of a reference value can be both automatically and manually measured. In order to increase the repeatability, a "reference track" is determined before the calibrations are performed. A "reference track" is generally the wheel path on which the testing vehicle will be conducting data collection at each run. Due to measurement uncertainty, the reference value is determined by multiple runs. Both TDOT and service provider conduct data collection on control sites for at least five runs to obtain the data set to make the statistical comparison. Statistical analysis of paired t-test is then performed to determine difference of collected data between TDOT and service provider. The paired t-test is performed by defining the null (H_0) and alternative (H_1) hypothesis:

Null hypothesis: $H_0: \overline{X_1} - \overline{X_2} = 0$

Alternate hypothesis: $H_1: \overline{X_1} - \overline{X_2} \neq 0$

$\overline{X_1}$ and $\overline{X_2}$ are the two mean values from two individual group (TDOT or third-party collected and service provider collected).
The paired t-test statistic t_0 is calculated by

$$t_0 = \frac{\bar{d}\sqrt{n}}{s_d}$$

Where,
$\bar{d}$=average of the n difference
s_d= standard deviation of the differences
n=number of matched pairs, number of runs, n=5

Do not reject the null hypothesis if $t_0 < t_{critical}$, signifying the two data set are likely the same. At the significance level of 95% (two-tailed, α=0.05), $t_{critical} = 2.57$
The service provider shall use the control site to conduct verification tests during data production. There are more than 15 control sites in the state of Tennessee. The service provider shall conduct verification tests once every week during normal data collection cycles. The purpose of verification testing is to check the repeatability of collected data and evaluate the time series of collected data. Verification testing is also performed to evaluate the consistency of data based on the history of the reference values at the site if no treatment has been applied. Verification sites are run at the specified times, and the average values of multiple runs are statistically compared. Verification test will be conducted once potential issues related to data collection quality are identified. During data collection, the field collection crew shall run verification tests periodically to ensure the repeatability of sensor data including roughness and rutting depth.

4.6 Time-Series Comparisons

Time-series comparisons are conducted between data collected in previous cycles and current cycles. The time-series check is helpful to identify the potential data quality issues that may cause uncertainty in maintenance and rehabilitation (M&R) analyses. Table 4-6 lists the expectation on changes of pavement condition data between two data collection cycles. Time series check will be conducted on interstate and other NHS routes, where pavement condition data are collected annually. Table 4-6 lists the proposed values which serve as reference for pavement engineers to identify suspicious time-series trend. There is no "percent within limits" applied on this type of comparison. Further actions on re-collection and/or re-processing of raw surface profile data may be needed upon request from TDOT pavement office. Note that comparisons on time series for faulting and cracking percent may be added into Table 4-6 when more time-history data on faulting and cracking percent are available.

Table 4-6 Time Series Checks for Pavement Condition Data

Items	Expected Values	Corrective actions
ΔIRI*	-10 to 30 in/mi	Verify, re-collect or re-process upon request
ΔRut*	<0.2 in	

* ΔIRI and ΔRut are the difference of IRI and rut depth between two adjacent collection cycles, respectively. $\Delta IRI = IRI_{current} - IRI_{previous}$; $\Delta Rut = Rut_{current} - Rut_{previous}$.

5. Final Deliverables

Before the deliverables are accepted by TDOT, the quality assurance procedures will be used to evaluate the total data quality. These acceptance activities are performed by the TDOT Pavement Management section to determine if deliverables have met the established quality standards. The Pavement Management Engineer will also review the results of corrective actions, estimate whether the abnormal data has been corrected, and ensure that the issues found during data inspection had been properly resolved.

5.1 Estimation of Corrective Activities

Before the final deliverables are accepted, all quality issues that are identified during data inspection shall be properly addressed or resolved. The data that need to be re-processed and re-collected shall be properly addressed to fulfill the quality requirements.

5.2 Quality Management Report

The Guidelines on Quality Management of Pavement Condition Data will be summarized in report and documented for future reference. The Quality Management Report contains the following content:

- Documentation of equipment certification
- Documentation of collection procedures and protocols used
- Documentation of records regarding personnel training information
- Documentation of records regarding equipment calibration/checks/maintenance, equipment problems and corrective actions taken
- Report on verification tests

- Report on data format check, sensor data check, distress data check, image check (if applicable), time-series check
- Recommendations for improvements (if applicable)