IRI

2024 updates

- Updated The first Three chapters.
  - Profiling basics has been split into 3 sections
    1. Introduction to IRI
    2. AASHTO M328, R56, and R57
    3. Profiler Sensitivity
      - Section 1 = Profiling basics is now rewritten and titled; “Introduction to IRI”
      - Section 2 = This is NEW: Added AASHTO Methods 328, R56, and R57.
      - Section 3 = Profiler Sensitivity
- Updated the location and the list for the IRI Proficiency test.
IRI
Table of Contents

• Introduction to Profiling

• AASHTO M328 Inertial Profiler,
  ASHTO R56 Certification of Inertial Profiling Systems,
  AASHTO R57 Operating Inertial Profiling Systems

• Profiler Sensitivity

• Specification Section 610

• MoDOT – TM59 Test Method

• Glossary
Introduction to IRI
INTRODUCTION TO IRI

Pavement surface roughness is generally defined as an expression of irregularities in the pavement surface that adversely affects the ride quality of a vehicle (and thus, the user).

Ride Comfort Depends on...

• Road Roughness
• Vehicle Response to the road
• Human Response to vibration
SMOOTH ROADS

- **Roughness** is the result of surface deviations from a true planer surface with characteristic dimensions that affect ride quality.

- Conversely, **Smoothness** is the lack of roughness.

- As an important indicator of pavement performance, smoothness is used interchangeably with roughness.

Smooth Road - Benefits

- Improved pavement performance
- Longer Service life
- Improved safety
- Reduced fuel consumption
- Reduced vehicle maintenance cost

Smooth Roads – Index System

- The first component of any smoothness specification is the smoothness index system that will be used.
REFERENCES

- **ASTM E950**: Defines classifications of surface profiling devices
- **AASHTO M328**: Standard Specification for Inertial Profiler
- **AASHTO R54**: Pavement Ride Quality when measured using inertial profiling systems
- **AASHTO R56**: Certification of Inertial Profiling Systems
- **AASHTO R57**: Operating Inertial Profiling Systems

TERMINOLOGY

- **Reference Device**: A device used to obtain the true profile of a pavement. Devices such as rod and level, Dipstick™ and walking profiler are considered reference devices.
- **True Profile**: The undistorted shape of a pavement surface.
- **International Roughness Index (IRI)**: A static that summarizes the roughness qualities impacting vehicle response based on the Golden-Car vehicle model at a standard simulation speed of 49.7 mph.

More terms are in the glossary.

TRUE PROFILE

- 'True' profile is the actual cross-section of a pavement surface.
- The sum of a unique set of surface waves along the cross-section creates a profile.
Smooth Roads – Measurement

- Measure of pavement roughness produced by filtering a ‘true profile’ through a mathematical model called a ‘quarter car’.

- Calculates the suspension deflection of a simulated mechanical system with a response like a passenger vehicle.

QUARTER CAR MODEL

- Quarter-car modeled as:
  - One tire
  - Mass of axle supported by tire
  - Suspension spring and damper
  - Mass of the body supported by tire

- Simulation speed is 50 mi/hr.

- Suspension motion is accumulated by vertical displacement and divided by distance traveled to give IRI in inches/mile.
Smooth Roads – Index System

• IRI is reported in units of inches/mile or meters/kilometer.

• Profile traces are collected in either one or both wheelpaths within a pavement lane.

• The most common smoothness index is the International Roughness Index (IRI). IRI can be determined using measurements from any valid profiler (Inertial profiler) which generates a profile trace showing the “true” shape of the pavement surface. This pavement profile is fed into an algorithm that determines the IRI value for the pavement.
**Smooth Roads - IRI**

- *International Roughness Index (IRI)* In using the IRI Index for smoothness, the lower the calculated IRI, the smoother the pavement will ride. The higher the IRI, the rougher the pavement will ride.

<table>
<thead>
<tr>
<th>IRI scale (in/mi)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=60</td>
<td>Very Smooth</td>
</tr>
<tr>
<td>61 – 120</td>
<td>Smooth</td>
</tr>
<tr>
<td>121 – 170</td>
<td>Fair</td>
</tr>
<tr>
<td>171 – 220</td>
<td>Rough</td>
</tr>
<tr>
<td>&gt;=220</td>
<td>Very Rough</td>
</tr>
</tbody>
</table>

**IRI** is used to define a characteristic of the longitudinal profile of a traveled wheel track and constitutes a standardized roughness measurement.

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**Smooth Roads – Longitudinal Profiles**

- *Longitudinal Profile* Is a longitudinal two-dimensional slice of a road surface taken along an imaginary line that consists of elevation value and a distance reference for each elevation.

**IRI** is calculated from a measured longitudinal road profile by accumulating the output from a quarter-car model and dividing by the profile length to yield a summary roughness index with units of slope.

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**Smooth Roads - Longitudinal Profile and Waves**

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1. **Straightedge**
   - 15' Rolling Straightedge
   - Useful to study localized roughness issues.
   - Does not record true profiles.

   Smoothness = Straightedge Deviation

2. **California Profilograph**
   - Truss-type California profilograph.
   - Ability to collect continuous profile data.
   - Does not record true profiles of the road.

   Smoothness = Profile Index (PI)
3. & 4. Inertial Profilers
- Generate TRUE PROFILES.
- Record wheel path elevation profiles.
- Inertial profiling systems include:
  - Laser Height Sensor
  - Accelerometer
  - Distance Measurement Instrument
  - Data Collection system to a software or ProVal to calculate IRI values.

Inertial Profilers
- Profilers are typically mounted to the front or back of a pickup truck, van, or on light weight profilers.
- Contains equipment software that can convert true profile data to multiple smoothness indices.

Profilograph VS Profiler profiles
Inertial Profiler - Setup

1. Inertial Reference
2. Height Relative to Reference (laser, infrared, or optical transducer)
3. Speed/Distance Measuring System

GPS Option

Computer

Accelerometer: A

Collection and storage

Data collection window

1.989  0.0
Lasers measuring Left and right wheel paths for the same lane measuring a true profile.

Mean Roughness Index (MRI)

• The average of the IRIs from the left and right wheel paths for the same lane is the Mean Roughness Index (MRI).

• Pavement smoothness is quantified as averaging the results of the IRI for the left and the right wheel paths in an individual lane.

• Every 0.1-mile (528 ft) section of the lane is analyzed.

True Profile - Graph
5. Reference Profiler (SurPRO)

- MoDOT's primary reference profiler
- Reference profilers obtain true profiles of pavement.
- Used for verification of profilers.
- Dispute resolution
- Repeatability cross correlation above 98%.

Computed Roughness Indices:
IRI, RN (PRI, RI)

Profile Accuracy:
0.01 in/25 ft
Plus, level error for non-closed loop surveys.

Dispute Resolution

- Any dispute between the engineer and contractor regarding IRI QC/QA comparisons that cannot be settled at the project level is arbitrated with the MoDOT reference profiler.
- The results of the reference profiler are binding for the engineer and the contractor.
AASHTO

AASHTO M328 Inertial Profiler
ASHTO R56 Certification of Inertial Profiling Systems
AASHTO R57 Operating Inertial Profiling Systems
INTRODUCTION

All inertial profilers used for construction acceptance must be VERIFIED annually, call Jason Blomberg for the location.

Operators of inertial profilers shall hold current certification issued by the Technician Certification Program (TCP).

The certification test section is measured with a reference profiler.
INTRODUCTION

- MoDOT will not calibrate or ‘fix’ inertial profilers at the certification site.
- Inertial profilers will not be able to adjust filters to match desired results.
- No filters are allowed.
  - Except for built-in 10-inch low pass filter that can’t be turned off.
- Un-calibrated equipment can generate erroneous data!!

SCOPE

- Inertial Profilers are used to measure longitudinal surface elevation based on an inertial reference system that is mounted on a host vehicle.
- This presentation is to provide standards and procedure for obtaining certification for longitudinal surface elevation profile measurements and network-level data collection.

SCOPE

- System and operator certification include the following:
  1. Verification of calibration
  2. Field Certification of equipment
  3. Certification of operators
**MODOT NOTE:**

**Calibration** of the inertial profiler re-establishes target values in which it operates by correcting the scale of a transducer. This calibration is usually conducted by the manufacturer.

**Verification/Certification** of the inertial profiler checks the calibration values annually to determine if it is still valid/accurate.

**Certification** of the driver/operator will be renewed every 5 years. (Completed at STC College classroom)

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**TERMINOLOGY**

- **Distance Measuring Instrument (DMI):** A transducer used to determine the longitudinal distance that the measurement vehicle has traveled.

- **Inertial Profiler (IP):** A profile measurement device that measures the pavement profile using an accelerometer to form an inertial reference and a height sensor to measure the pavement surface height relative to that reference.

- **ProVAL:** Computer application used for pavement ride quality analysis.

**NOTE:** More definitions can be found in the glossary.

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**REFERENCES**

- **AASHTO R 56**
  Certification of Inertial profiling system

- **AASHTO R 57**
  Operating Inertial Profiling Systems

- **AASHTO M 328**
  Inertial Profiler
## THREE STANDARDS

### 1. Longitudinal (528 ft = 0.1 mile)
- Longitudinal verification standard will be a straight and level roadway test section of at least 528 ft in length with sufficient lead-in distance for the vehicle to attain a constant speed before the start of the test section and a safe stopping distance.
- Measure this length accurately to within 0.05% using a measurement tape.

### 2. Vertical (Block Test)
- The vertical measurement standard will be flat plates or gauge blocks 0.25, 0.50, 1.0 and 2.0 inch in thickness.
- Using a calibrated digital caliper, verify the block thickness of the smooth base plate, the 0.25, 0.50, 1.0 and 2.0 inch gauge blocks, accurate to within 0.001 inch. Mark each block with its known thickness and record it in the log.
  **NOTE:** Each inertial profiler must have their own blocks.

### 3. Vertical (Bounce Test)
- The vertical displacement will be measured from flat plates centered on the ground beneath the height sensors.
- Performed over a simulated distance of 528 ft. A vertical displacement (bounce) of the vehicle of 1 – 2 inches will be performed.
**EQUIPMENT**

**Minimum Requirements:**
The inertial profiling system must meet all requirements and specification found in AASHTO M328 and must be currently certified in accordance with AASHTO R 56.

- **Host Vehicle** – Capable of traveling at a constant speed while traveling at least 20mph for high-speed profilers and at least 15mph for low-speed profilers while collecting pavement profile data.

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**Three Transducers OR Sub-Systems**
for measuring longitudinal pavement profiles:

1. Height sensor – (Vertical measure)
2. Accelerometer – (Vertical measure)
3. Distance Sensor – (Horizontal measure)

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1. **Height Sensor:**
   (Lasers)
   - Measures the vertical distance (height) between the vehicle and the pavement surface.
   - Vertical measurements are usually acquired by one or multiple non-contact laser sensors.
   - Lasers are a 4” beam, or a single point laser.
2. Accelerometers:

- Measures vertical acceleration.
- Vehicle must be traveling a minimum speed of 7 miles/hr. to measure acceleration.
- An inertial profiler uses the signal from the on-board accelerometer(s) to compute the inertial reference value such as relative height that can be combined with the height sensor data to produce a complete profile.
- An accelerometer is paired with each wheel path height sensor to cancel out the vertical motion of the host vehicle.
Distance Measuring Instrument (DMI):
- A horizontal measure, the DMI is a transducer, that measures the longitudinal distance traveled by the profiler.
- Rotation of a wheel measured by detection of pulses as the wheel rotates and notches pass.
- Affected by rolling radius of tire.
- GPS beginning to replace tire-mounted DMIs.
- The DMI, must be accurate to within 0.15% per mile when traveling at the vehicles maximum specified test speed.

Optical Trigger Device:
- Automatically initiates data collection at a specified location.
- Triggered when it detects a change in reflectivity.
- Mounted either vertically or horizontally in the profiler.
- Vertical is triggered by a reflective tape on pavement.
- Horizontal is triggered by a cone with a reflective mark placed on the shoulder.
- Essential for defining section profile limits and for repeated testing.
Starting the Measurement – MODOT

- The optical trigger should be used to automatically start the profiler when the machine crosses the testing start point.
  - If conditions preclude using the optical trigger, then the start and end point may be manually triggered, but the profile data must be adjusted to precisely superimpose over the profile length.

Advantages of Automated Triggering – MoDOT

- Data collection can be initiated at exact start of the section.
- Roughness features can be identified at correct location in the field based on profile data.
- Repeatability of profile data and roughness indices can be evaluated.
Integrated System

- Must include hardware and software capable of storing inertial profiles by combining the data from the inertial referencing system, the distance measuring instrument, and the height sensor.
- Must be capable of measuring and storing profile elevations at 3 in. intervals or less.

![Integrated System](image)

Must have the capability of computing the profile elevation data into a summary roughness statistics (IRI) over a section length equal to 0.1 mile (528 ft.) for each longitudinal path profiled.

![Integrated System](image)

- Must have a design to allow field calibration and verification of calibration for the distance measurement (horizontal) subsystem and the height measurement (vertical) subsystem described in "Procedures".
- Must be approved by MODOT verification and certification process.
- Maintain a Calibration Verification Log in accordance with AASHTO R56 to maintain records of calibration history.
PROCEDURE

1. **Daily calibration verification** is required for QA testing on all MODOT contracts.

2. **Verifying Calibration – Completed Annually**
   - the following daily verification procedure is required for QA testing and is recommended when an inertial profiler is to be used as a QC instrument.
     - Check the tire air pressure on the wheels of the host vehicle daily and maintain according to the vehicle manufacturer’s recommendations.

Vertical Verification of calibration consists of two tests:

1. **Block Test**
2. **Bounce Test**

1. **BLOCK TEST:**
   - The block test verifies the sensors for accurate elevation readings. This check is performed after the operating system has reached operation stability per manufacturer. During the test, do not lean on the profiler or cause it to move in any way.
BLOCK TEST:

1. Place a smooth base plate under the height sensors. Allow the system to measure this height. Zero out the sensors.
2. Center a 0.25-inch block under the height sensors on top of the base plate and record height measurement.
3. Replace the 0.25-inch block with the 0.50-inch block. Record the height measurement.
4. Replace the 0.50-inch block with the 1.00-inch block. Record the height measurement.

PROCEDURE

Verifying Calibration

BLOCK TEST:

5. Replace the 1.00-inch block with the 2.00-inch block. Record the height measurement.
6. For each gauge block, the absolute difference between the height measurement and the actual gauge block thickness should be less than or equal to 0.01 inch.

Side Note: As a minimum perform the 1 and 2 inch measurement blocks, if fails the minimum test, then perform the full range of block measurements.

Height Sensor Verification

PROCEDURE

Verifying Calibration

Reading on base plate + calibration plate (H1)  
Reading on base plate + 1 inch block + calibration plate (H2)  

\[ H2 - H1 = \text{Block Height} \]

NOTE: 1-inch block must be within ± 0.001 inch to pass

NOTE: Calibrated blocks should be marked with accurate measure as well as recorded in the log from earlier work.
2. **BOUNCE TEST**

**PROCEDURE**

**Verifying Calibration**

**BOUNCE TEST:**
This test is performed while the host vehicle is on a flat level surface. It is performed after the operating system has reached operational stability according to the manufacturer. Follow the manufacturer’s recommendation for performance procedure of the bounce test. The static portion of the test should result in an IRI of less than 3 inch per mile and the bounce portion shall result in an IRI of less than 8 inch per mile. This test is performed over a simulated 528-foot section.

1. The typical method for a high-speed host vehicle, is to push the mounting system (bumper) down an inch or so and allow to rebound.

2. For a lightweight slow-speed host vehicle, stand toward the center of the vehicle platform and hop up and down such that all four corners of the vehicle create a bounce.

3. Save the test results on the latest version of ProVAL software.
LONGITUDINAL VERIFICATION
of CALIBRATION

For Verification of the IRI, Jeff will drive the truck on a premeasured track at the Airport.

Driving the Test–Track

- Drive at a constant speed;
- Manufacturer provides operating speed range.
- Usually ranges from 15 to 65 mi/hr. for high-speed profilers.
- Max speed for lightweight profilers is usually 20 mi/hr.
- Accelerometer cannot measure accurately at low speeds.
- Do a ‘dry run’ through testing length for familiarization.

LONGITUDINAL VERIFICATION: (accelerometer)

1. Clean the roadway path to be measured of all debris. Collect data on dry pavement. (Damp pavement is OK, if approved by MODOT).
2. Warm up host vehicle tires and operating system in accordance with manufacturer’s recommendations.
3. Turn off filters, except the built in 10-inch low pass filter.
4. Perform the longitudinal verification by navigating the inertial profiler over a measured test section of 528 ft. ± 0.1 ft.

5. If the profiler’s distance measuring subsystem measures the length of the test section to within 0.2% of its actual length, the system has passed the test. If the system fails to measure the length with in 0.2% the calibration, it shall be adjusted according to the manufacture’s guidelines and longitudinal verification repeated.

6. Measured profiles shall be saved and analyzed in ProVAL.

Note: After the test run at the airport, results shall be saved on a thumb drive and given to Jason Blomberg to analyze.

CERTIFICATION

1. Success in achieving an average of 92% repeatability when correlating with other contractor certification files will result in a PASS for that category.

2. Success in achieving an average of 90% accuracy in each wheel path when compared to the MoDOT accepted calibration test run will result in a PASS for that category.
Operators of inertial profilers must pass a written exam (computerized), a proficiency test, and be certified to operate an inertial profiler.

Must have undergone training on the use of the specific inertial profiler they will be operating in the field.

Must know how to perform profiler checks, collect profile data.

Must bring their profiler with them to the test site for annual certification. The profiler certification may be on a different day from the exam and proficiency tests.

MoDOT Certification card:

- Note: Check mark indicates a restriction.
- MoDOT Technician Certification (735) 522-2742
- This is to verify that John Doe is certified to perform inspection or testing on MoDOT Projects.

TCP-476
Test section is 528 ft ± 0.1 ft long. To pass the MoDOT longitudinal test, the profiler must be within 0.2% of this measure. (The profiler’s DMI records longitudinal profile)

12 DYNAMIC CERTIFICATION TESTS

1. Test Sections -
Must be ≥528 ft. in length. With a proper lead in distance and safe stopping distance.

MODOT Note: The profiler should stay a constant transverse distance from the centerline or shoulder. Both wheel paths should be 3 feet from and parallel to the edge of lane (assuming 12-foot lane width).

Speed Changes – MoDOT
- Operate at a constant speed while collecting data.
  - Manufacturer provides operating speed range.
  - Usually ranges from 15 to 65 mi/hr. for highspeed profilers.
  - Max speed for lightweight profilers is usually 20 mi/hr.
- Accelerating or decelerating while collecting profile data will contaminate the data.
- Newer ‘zero-speed’ Inertial Profilers are exception to this requirement.
Lead-in Distance

- Profiler needs a lead-in distance to bring it up to speed and to initialize filters used for profile computation.
- Manufacturers’ recommendations should be followed regarding lead-in distance.

Lead-out Distance

- At the project end point the profiler continues for a lead-out distance.
- The profiler should not start to slow until passing the end point, so the accelerometers and the resulting data points are not affected.

EQUIPMENT CERTIFICATION

2. Reference Profiles
- Shall be made on the designated profile trace of each test section.
  - Five repeat runs of the candidate inertial profiler shall be made at each test speed on the designated profile trace of each test section in the prescribed direction of measurement.
  - Make five runs at the maximum desired certification speed and five runs at the minimum desired certification speed.
• Data collection shall be automatically triggered at the starting location of the section, and reported so that a longitudinal position of zero occurs at the starting location.

• An automatically detected mark at the end of the section may be used to verify the DMI repeatability and accuracy.

3. Test Data

Report data shall be reported in a format specified by MODOT (ProVAL).

• Use the naming convention as indicated in upcoming slide.

• The performance of the profiler is evaluated by analyzing the test data using cross-correlation to establish the repeatability and accuracy for the application of the device. ProVAL software can be used for this.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>YYMMDD-###_</td>
<td>Contract ID (Letting date–Call Number)</td>
</tr>
<tr>
<td>YYMMDD_</td>
<td>Test Date</td>
</tr>
<tr>
<td>Q _</td>
<td>Type of quality test (C for control, a for assurance)</td>
</tr>
<tr>
<td>D</td>
<td>Direction of Lane (N,E,W or S)</td>
</tr>
<tr>
<td>L</td>
<td>Lane number (1 for inside lane, increasing by one for each lane to the right)</td>
</tr>
<tr>
<td>W</td>
<td>Wheel path (L, R, or B)</td>
</tr>
<tr>
<td>S</td>
<td>Beginning Log Mile or Station ( Rounded to nearest thousandth log mile or foot)</td>
</tr>
</tbody>
</table>

*Example: 100528-501_111103_C_N2R105045.pdf

Letting Date, Call #, Test Date, GF, North, lane 2, Right Wheel Path, Station (105045)
<table>
<thead>
<tr>
<th>Example #2</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Station:</td>
<td>945 + 15</td>
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<tr>
<td>Purpose:</td>
<td>Quality Control</td>
</tr>
<tr>
<td>Letting Date:</td>
<td>06/09/2023</td>
</tr>
<tr>
<td>Test Date:</td>
<td>07/16/2023</td>
</tr>
<tr>
<td>Lane Direction:</td>
<td>West</td>
</tr>
<tr>
<td>Lane:</td>
<td>Inside Lane</td>
</tr>
<tr>
<td>Wheel Path:</td>
<td>Left</td>
</tr>
<tr>
<td>Call Number:</td>
<td>390</td>
</tr>
</tbody>
</table>

Answer: 230609 390 230616 C W1L 94515

**EQUIPMENT CERTIFICATION**

4. **Equipment Repeatability**

Evaluate repeatability using the cross-correlation of the filtered output.

- Calculate the repeatability score of each trace.
  - For **single-sensor profilers**, one score for each path will be determined:
  - For **dual-path profilers**, twice as many scores will be determined, two for each test section.
  - When the IRI is applied to the profile, the IRI filter should be used.

**EQUIPMENT CERTIFICATION**

- **Equipment Precision (Repeatability)**
  - Compare ten Inertial Profiler runs over same test section against each other.
  - Calculate repeatability agreement score.
  - Score of **0.92%** or greater is required.
5. **Equipment Accuracy**
   Evaluate accuracy using the cross-correlation of the appropriate filtered output. On each trace, cross-correlate each of the ten profiles to the reference profile.

   **Equipment Accuracy (reproducibility)**
   - Compare several inertial profiler runs over same test section against a reference profiler.
   - Calculate accuracy agreement score
   - Score of **0.90%** or greater is required.

6. **Cross-Correlation**
   When cross-correlating two profiles, the following steps are required:
   - Apply the filter associated to both traces before cross-correlating them. (for IRI, use the IRI filter).
   - When comparing a profile from a candidate device to a reference profile, interpolate the candidate profile to the recording interval of the reference profile.

7. **Verification of Computed Ride Statistics (IRI)**
   The test equipment software must be capable of computing and reporting the IRI of each profile trace tested.
   - The performance of the calculation of known accuracy.
   - Each IRI value should be comparable to the value from the reference program such as **ProVAL**, with an error not greater than **2%**.
8. **Distance Measurement Instrument Test**
MODOT can elect to test the accuracy of the DMI on one section.

- It is recommended this test be performed before the profiler obtains data at the test sections because an error in the DMI can cause the profiler to fail the Equipment Accuracy criteria.

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9. **Distance Measurement Instrument Test Section** - Provide a section for the DMI testing.

- The test section at least 1000 ft in length, with proper lead in distance for constant speed before the start of the section and a safe stopping distance at the end.
- Can use the section that was used for accuracy and repeatability testing.
- Clearly mark the starting and ending points of the test section.

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- Measure the distance between the starting and ending points with a measurement tape.
- At least 3 auto-triggered runs at the lowest and highest test speeds of the candidate inertial profiler shall be made on the designated length of pavement in the prescribed direction of measurement.
At the end of each run, record the reading from the profiler’s DMI.

For high-speed profilers, this results in at least six values.

Collection speed-governed devices should make at least 5 runs.

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10. DMI Accuracy
Compute the absolute difference between the DMI readings and the known distance of the path tested for each run.

The average of the absolute difference for both the high-speed and low-speed runs. If applicable, must be less than 0.2% to pass the test.

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11. Test Results – Reporting
MODOT documents the certification results. Results may include the following:

- Identification of the profiler tested, make, model serial number, software version, owner, etc.
- Date of last certification
- Operator of the profiler
- Name of individual conducting the test.
- Date of the test
- Number of paths the profiler can measure in the same run.
EQUIPMENT CERTIFICATION

- Filter type, name of the filter program, and application program version number used to evaluate the profiler accuracy.
- Overall determination from the test: Pass or Fail.
- Known longitudinal distance of the DMI test section.
- Average absolute difference between the DMI readings and the known distance, expressed in distance unit and as a percentage of the known longitudinal distance.
- Information on each trace: overall repeatability score, overall accuracy score, and average % difference of the IRIs computed from the profiles and those from the reference software.

EQUIPMENT CERTIFICATION

- The report shall also label each test result with a Pass or Fail depending on whether the given test value meets or fails to meet the prescribed criterion.
- The profiler must pass all tests to be certified.
- A MODOT certification label, decal or marking shall be placed on the profiler as evidence of certification. This decal shall show the expiration date (month and year) of the certification.

Post-Operational Checks – MoDOT

- Perform cursory check on raw profile data to see if it is reasonable.
- Look at IRI values and see if they are reasonable.
- Overlay repeat runs and see if they match.
Post-Profiling – MoDOT

- Save ppf file data to flash drive or other electronic media. Raw data must be submitted to the Engineer within 24hr of testing.
- Raw profiles shall be analyzed by MoDOT in ProVAL.
International Roughness Index (IRI) 2024 Proficiency Pack

Name: ________________________________

Employer: ________________________________

MoDOT
# PROFICIENCY CHECKLIST

**Applicant**

**Employer**

<table>
<thead>
<tr>
<th>1. Explain: Is the machine certified by MoDOT?</th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup with values on calibration certificate?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the driver IRI certified?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Explain: Items that should be checked prior to profiling.</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Vehicle fluid levels ...........................................</td>
</tr>
<tr>
<td>• Headlights, signals, safety strobes/beacons, signage ......</td>
</tr>
<tr>
<td>• Profile path project readiness – dry run ......................</td>
</tr>
<tr>
<td>• Warm up: Engine..................................................</td>
</tr>
<tr>
<td>• Warm up: Transmission..........................................</td>
</tr>
<tr>
<td>• Warm up: Tires....................................................</td>
</tr>
<tr>
<td>• Tire pressure ......................................................</td>
</tr>
<tr>
<td>• Visually check sensors ..........................................</td>
</tr>
<tr>
<td>• Static sensor check ...............................................</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Explain: Distance Measurement Instrument (DMI) verification procedure (Actual DMI testing will be completed at the Airport in Linn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>❑ Clean, dry, (damp ok) testing track.</td>
</tr>
<tr>
<td>❑ Warm up host vehicle tires and operating system</td>
</tr>
<tr>
<td>❑ Turn off filters</td>
</tr>
<tr>
<td>❑ Set-up the computer for profiling the testing track</td>
</tr>
<tr>
<td>❑ Line up with the cone, ready the trigger device</td>
</tr>
<tr>
<td>❑ Navigate the inertial profiler over a measured test section of 528 ft. ± 0.1 ft.</td>
</tr>
<tr>
<td>❑ Maintain the vehicle at a constant speed through out the test.</td>
</tr>
<tr>
<td>❑ Save the profile in a file, transfer to a thumb drive, hand over to the Engineer to analyze</td>
</tr>
<tr>
<td>❑ Is the result within 0.15% of the measured length?</td>
</tr>
<tr>
<td>❑ If profiler does not meet the 0.15%, make adjustments and repeat the run.</td>
</tr>
</tbody>
</table>

**NOTE:** GPS-DMI must pass within 0.15% of the measured length.
4. **Demonstrate: Laser Height verification procedure**
   **Block Test:**
   - Placed a smooth base plate under the height sensors. Allow the system to measure this height. Zero out the sensors.
   - Centered a 0.25-inch block under the height sensors on top of the base plate and recorded height measurement.
   - Replaced the 0.25-inch block with the 0.50-inch block. Record height measurement.
   - Replaced 0.50-inch block with the 1.00-inch block. Recorded height measurement.
   - Replaced 1.00-inch block with the 2.00-inch block. Recorded height measurement.
   - Gauge block height measurement recorded in the calibration log.
   - For each gauge block, the absolute difference between the height measurement and the actual gauge block thickness is less than or equal to 0.01 inch.

5. **Demonstrate: Bounce Test**
   - Vehicle parked on a level surface?
   - Performed after operating system has reached operational stability according to manufacture?
   - With the base plates in position simultaneously under both wheel path sensors, place the vehicle in an operating mode that simulates longitudinal movement and initiate profile data collection. (Vehicle is in park)
   - Subjected the vehicle to a vertical displacement of approximately 1 to 2 in. for the time required to travel 528 ft.
   - Measured profiles saved and analyzed in ProVAL.
   - System showed a passing result?

<table>
<thead>
<tr>
<th></th>
<th>Pass</th>
<th>Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail</td>
<td>Fail</td>
<td></td>
</tr>
</tbody>
</table>

Examiner: __________________________ Date: __________________________
There are numerous physical and environmental effects that can affect profile data.

Debris on pavement can artificially and adversely impact smoothness.

Hills and Grades

- Can affect accelerometer signals as axis is tilted from vertical
- Theoretical study indicated no problems expected when grade is less than 6 percent
Curves

- Tilt can affect accelerometer signals.
- Lateral acceleration on curves can contaminate accelerometer signals.
- Theoretical study indicated errors in roughness indices are not significant until lateral acceleration exceeds 0.15 g.

Transverse Variations in IRI

- Different IRI values can be obtained depending on your transverse location on the pavement.

Proiling and Surface Texture

- Longitudinal tining can affect measurements. Transverse tining to a lesser degree.
Profiling and slab curling

- Soon after construction curling effects are unlikely to be present.
- Curling is more pronounced during early morning.
- Pronounced curling can be seen on profile data.

Profiling and Wind

- Wind can make it difficult to track a consistent path.
- If consistent path is not tracked, variations may occur between repeat runs if transverse variations are present.
- High winds can affect data collected by ultrasonic sensors.

Profiling and Moisture

- Profiling wet pavements cause erroneous data to be collected; however,....
- ....profiling may be performed on damp pavement, but....
- ......do not profile pavements with standing water or if passing vehicles cause water spray
Tire Pressure

- DMI usually attached to a wheel of the vehicle
- Distance based on revolutions of the wheel
- Tire pressure affects the number of revolutions made in a given distance
- Check cold tire pressure and adjust to pressure used during calibration

Profiling Sensitivity

A few things that can affect the quality of a profile.

- Changes in speed
- Braking
- Debris in the lane
- Not familiar with the road
- Backed up traffic
- Pulling over for emergency vehicles
Smoothness Specification

MoDOT
This work shall consist of measuring the smoothness of the final pavement surface using the International Roughness Index (IRI).

Note: Pre-operational checks include:
- Check tire pressure
- Vehicle fluids
- Headlights, signals, safety strobes/beacons, signage
- Profile path project readiness – do a dry run
- Warm up: Engine transmission, and tires
- Visually check sensors
- Static sensor check
Applicable Pavement Types

a) Multi-lift asphalt construction  
   Sections 401 and 403

b) Concrete pavement construction  
   Sections 502 and 506

c) Combination of surface planning  
   (diamond grinding, milling) and single  
   lift asphalt construction

d) Single lift asphalt construction  
   Sections 401 and 403

610.2

Material Requirements

610.2.1
Inertial Profiler

- Inertial Profiler (IP)  
  - Certified annually  
  - Meeting AASHTO M 328  
    requirements
610.2.2 ProVAL Software

- (used to)
  - Compute IRI smoothness
  - Locate Areas of Localized Roughness (ALR)

Note: See MoDOT TM-59

ALR: Is any segment of roadway where the roughness contributes disproportionately to the overall roughness index value.

610.2.3 Straightedge

- A rolling 10-foot straightedge shall be used for checking longitudinal elevation changes.
- A 4-foot straightedge shall be used for checking transverse elevation changes.

610.3 Certification
All inertial profilers shall be annually certified at the MoDOT certification site in accordance with TM-59. State Technical College of Missouri (STC) at Linn is the current site.

Per MoDOT TM-59, an inertial profiler shall have ≥ 90% average cross-correlation accuracy for five test runs.

Operator of the Inertial Profiler shall hold current certification issued by the Technician Certification Program (TCP).
610.4

Construction Requirements

610.4.1

Smoothness Increments

a) Section – A section is a day’s paving and shall begin and terminate at the construction joints. Interruptions designated by the engineer which cause placement to cease and begin at a new location will be considered as a separate section for that day’s operation if the separate section is greater than 250 feet.

b) Segment – Sections shall be divided into segments of 0.1 mile (528 ft.) lengths except for the last segment.
   - If the last segment is greater than 250 feet and less than 0.1 mile, the segment shall be measured as an independent segment.
   - If the last segment is 250 feet or less, the profile for that segment shall be included in the evaluation for the previous segment.
   - The combined segment IRI shall be weighted for the length.
610.4.2 Profiling Areas

- 610.4.2.1 Profiling will be applicable to the surface of all the following:
  a) Mainline paving
  b) Auxiliary lanes, turning lanes and ramps for projects consisting of more than 0.5 mile of total profitable pavement.

610.4.2 Profiling Areas

- 601.4.2.2 Profiling will not be required for the following exceptions:
  a) Bridge decks, bridge approach slabs and concrete approach pavements.
  b) Pavement on horizontal curves with a centerline radius of curve less than 1000 feet and pavement within the super elevation transition of such curves.
  c) Pavement on vertical curves having a “K” value less than 90 and a length less than 500 feet.
  d) Pavement width transitions.
  e) Fifty (50) feet in the direction of travel on each side of utility appurtenances such as manholes or valve boxes.
610.4.2 Profiling Areas

- (f) Fifty (50) feet in the direction of travel on each side of intersecting routes with special grade transition.
- (g) Shoulders
- (h) Interruptions designated by the engineer which provide independently placed sections shorter than 50 feet.

610.4.2 Profiling Areas

- (i) The last 15 feet of any section where the prime contractor is not responsible for the adjoining surface.
- (j) Any lane which abuts an existing lane not constructed under the same contract.

610.4.2 Profiling Areas

- 610.4.2.3 – In addition to the exceptions in Section 610.4.2.2, profiling may be waived by the engineer if staging of the overall project; such as multiple entrance lane gaps, lane staging, etc.; affects the normal paving operation, or if multiple profile exceptions continuously exist on a large portion of the same roadway. Upon waiver, exempted areas shall be checked with a 10-foot straightedge.
610.4.3 Longitudinal Straightedging

- Any pavement surface not measured with an inertial profiler shall be measured with a 10-foot straightedge.
- The straightedge path in the longitudinal direction for driving lanes will be located 3 feet from the outside edge and for shoulders will be located in the center.

610.4.3 Longitudinal Straightedging

- Shoulders that are paved integrally with an adjacent driving lane will not require straightedging.
- Any variations in the longitudinal direction exceeding 1/8 inch (1/4 inch for shoulders) in 10 feet shall be marked for correction in a manner approved by the engineer.

610.4.3 Longitudinal Straightedging cont.

- Regardless of the smoothness measurement method used, the engineer may check any location of the paved surface with a straightedge for unacceptable bumps or low spots.
610.4.4 Transverse Straightedging

- The engineer shall randomly check driving lanes for variations in the transverse direction with a 4-foot straightedge.
- Any variations in the transverse direction more than 1/4 inch shall be marked for correction in a manner approved by the engineer.

610.4.5 Full Depth Pavement and Multi-lift Overlays

- These construction procedures apply to pavement treatment described in Section 610.1 (a) and (b).
  a) Multi-lift asphalt construction (Sections 401 and 403)
  b) Concrete pavement construction (Sections 502 and 506)
610.4.5.1 Quality Control Testing

- The contractor shall perform quality control (QC) testing in accordance with MoDOT TM-59 procedures on all eligible profiling areas and provide electronic files for smoothness in .PPF format. QC testing may be performed daily, or the contractor may elect to profile at the end of paving.

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- Reported IRI for each segment is the average of both wheel paths.
- Furnishing inaccurate test results may result in decertification of the operator.

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610.4.5.2 Quality Assurance Testing

- The engineer will perform quality assurance (QA) testing with a MoDOT inertial profiler to verify the QC test results.
- The engineer shall select a continuous portion of roadway that constitutes at least 10 percent of the project lane-miles.

30
610.4.5.2 QA Testing

Both the contractor and engineer shall profile the same QA test length.

The QC and QA profile data collection shall be automatically started and stopped with electronic triggers.

The contractor shall provide the electronic file for the QA test length run in .PPF format to the engineer within 24 hours of testing.

The IRI value for each segment within the QA test length shall be computed as the average of both wheel paths.

The absolute value of the difference between the contractor and engineer IRIs shall be computed for each segment within the QA test length.
610.4.5.2
QA Testing

- The average of the absolute values of the IRI difference shall be 8 inches/mile or less.
- The absolute value of the IRI difference for any single segment shall be 12 inches/mile or less.

610.4.5.3
Areas of Localized Roughness

- All Areas of Localized Roughness (ALR) shall be corrected
- ALRs are defined as
  - any length of pavement, having a final posted speed greater than 45 mph, with a continuous section 25-foot average IRI of 125.0 inches or greater
  - any length of pavement, having a final posted speed of 45 mph or less (or AADT ≤ 3500 for ≤ 3” overlays), with a continuous section 25-foot average IRI of 175.0 inches or greater.

610.4.5.3
Areas of Localized Roughness (ALR)

- After correcting ALRs, additional correction may be necessary to reduce any profile segment in a pavement with a final posted speed greater than 45 mph, to an average IRI of 80.0 inches or less; or reduce any profile segment in a pavement with a final posted speed of 45 mph or less to average IRI of 125.0 inches/mile or less.
610.4.5.4 Method of Correction

- Corrective action to eliminate ALRs and improve the average IRI shall be accomplished by a method approved by the engineer. Diamond grinding may be used, but the use of an impact device will not be permitted.

- Total grinding depth shall be limited to \( \frac{1}{4} \) inch.

610.4.5.4 Method of Correction

- Satisfactory longitudinal grinding is acceptable as the final surface of the corrected pavements.

- All corrective work shall be completed prior to determination of pavement thickness.

610.4.5.4 Method of Correction

- The contractor shall repave the corrected lengths to verify smoothness compliance and submit an electronic data file in .PPF format to the engineer within 48 hours after testing.
610.4.6 Multi-treatment Overlays

- These construction procedures apply to pavement treatments described in Section 610.1 (c).

610.4.6.1 (Multi-treatment) Quality Control Testing

- The QC requirements are the same as Section 610.4.5.1, except pavements with \( \leq 3500 \text{ AADT} \) shall meet requirements for multi-lift \( \leq 3" \).

\[ \text{AADT} = \text{Average Annual Daily Traffic} \]
610.4.6.2 (Multi–treatment) Quality Assurance Testing

- The QA requirements are the same as Section 610.4.5.2.

610.4.6.3 Areas of Localized Roughness

- All ALRs, as defined in Sec 610.4.5.3, exceeding 175.0 inches/mile shall be corrected.

\[ \text{ALR} = \text{Areas of Localized Roughness} \]

610.4.6.4 Method of Correction

- The requirements are the same as Section 610.4.5.4.
610.4.7

Single Lift Overlays

These construction procedures apply to pavement treatments described in Section 610.1 (d)
- Single lift asphalt construction (Sections 401 and 403)

Prior to performing any resurfacing work, the contractor shall profile the outside wheel path in accordance with TM-59.

This control profile will serve as the baseline for calculating percent improvement for the project.
610.4.7.2 (Single Lift Overlays) Post-Construction QC Testing

- As soon as practical after resurfacing, the contractor shall profile the outside wheel path again.
- The same stationing shall be used to ensure a direct comparison with the pre-construction profile.

610.4.7.3 (Single Lift Overlays) Post-Construction QA Testing

- Same as Sec 610.4.5.2, except that testing shall only be performed in RWP.
  
  **RWP = Right Wheel Path**

610.4.7.4 (Single Lift Overlays) Post-Construction QA Testing

- As soon as practical after resurfacing, the contractor shall profile the outside wheel path again.
- The same stationing shall be used to ensure a direct comparison with the pre-construction profile.
610.4.8  
Marred Surface Area

- Any area of a segment that has corrective grinding performed without covering the entire segment shall be defined as a marred surface area.

610.5  
Basis of Payment
### 610.5.1 Fixed Value Improvement

- The following basis of payment procedures shall apply to all pavement treatments described in Section 610.1 (a), (b) and (c).
  - a) Multi-lift asphalt construction contained in Sections 401 and 403.
  - b) Concrete pavement construction contained in Sections 502 and 506.
  - c) Combination of surface planning, such as diamond grinding or milling, and single lift asphalt construction contained in Sections 401 and 403.

### 610.5.1.1 Smoothness Adjustment

- Smoothness adjustments will be paid per segment based on the profile index before any corrections.
  - Except for the allowances in Section 610.5.1.5 (Section Correction).
- Any segment with an IRI above the maximum limit in Tables 2 and 3 must be corrected through a method approved by the engineer to achieve the desired smoothness.

- When paving widths are greater than the travel lane widths, incentive payment will apply to the driving lane design driving width only.
610.5.1.2 Incentives

- Incentive payment for smoothness shall be based on either **Table 2** or **Table 3**.
  - **Table 2** shall be used for pavements having a final posted speed greater than 45 mph, except multi-lift overlays ≤ 3” and multi-treatment overlays on routes with ≤ 3500 AADT.
  - **Table 3** shall be used for pavements having a final posted speed of 45 mph or less, and multi-lift overlays ≤ 3” and multi-treatment overlays on routes with ≤ 3500 AADT.
- Constant-width acceleration and deceleration lanes shall be considered as mainline pavements.

### Table 2

<table>
<thead>
<tr>
<th>International Roughness Index, Inches Per Mile</th>
<th>Percent of Contract Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.0 or less</td>
<td>105</td>
</tr>
<tr>
<td>40.1 - 54.0</td>
<td>103</td>
</tr>
<tr>
<td>54.1 - 80.0</td>
<td>100</td>
</tr>
<tr>
<td>80.1 or greater</td>
<td>100a</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>International Roughness Index, Inches Per Mile</th>
<th>Percent of Contract Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>70.0 or less</td>
<td>103</td>
</tr>
<tr>
<td>70.1 - 125.0</td>
<td>100</td>
</tr>
<tr>
<td>125.1 or greater</td>
<td>100b</td>
</tr>
</tbody>
</table>

*a* After correction to 80.0 inches per mile or less.

*b* After correction to 125.0 inches per mile or less.

610.5.1.3 Segment Correction

- If the contractor elects to diamond grind an entire segment and the corrected surface drops below the maximum IRI limits in Table 1 or 2, then the contractor cannot receive any incentives, but the marred surface area deductions for that segment will be waived.
610.5.1.4 Section Correction

› If the contractor elects to diamond grind an entire section then all segments within the section will be eligible for their respective incentives and the marred surface area deductions for that section will be waived.

610.5.2 Percent Improvement

› The following basis of payment procedures shall apply to all pavement treatments described in Section 610.1 (d).
  ◦ [Single lift asphalt construction Sections 401 and 403]

610.5.2.1 Percent Improvement

› The contract price for resurfacing will be adjusted based on the improvement in the profile index for each segment with an initial IRI greater than 60 inches/mile according to Table 3.

<table>
<thead>
<tr>
<th>Table 4</th>
<th></th>
<th>Percent Improvement (Change in IRI / Initial IRI) X 100</th>
<th>Percent of Contract Unit Price For Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.0 or greater</td>
<td>103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.0 to 34.9</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0 to 19.9</td>
<td>97c</td>
<td>After correction to 0.0 or greater.</td>
<td></td>
</tr>
</tbody>
</table>

63
610.5.2.1 Percent Improvement

▶ Any segment with an initial IRI less than or equal to 60 inches per mile shall receive no percent improvement price adjustment if the segment IRI after placement of the overlay is also less than or equal to 60 inches per mile.

610.5.2.1 Percent Improvement

▶ Any segment with an initial IRI less than or equal to 60 inches per mile that has an IRI greater than 60 inches per mile after placement of the overlay shall be paid at 97 percent of the contract unit price for pavement, but no correction shall be required.

610.5.3 Deductions

› A minimum deduction of 20 percent of the contract unit price of the paving quantities will be made for marred surface areas as defined in Section 610.4.7.
› The deduction will be applied to an area of pavement extending from edge of the pavement to a longitudinal joint or between longitudinal joints in that section of pavement affected.
› If the length of the section affected is less than 10 feet, the deduction will be computed for 10 feet.
610.5.4 Testing Cost

- The contract unit price for pavement will be considered as full compensation for all items entering into the construction of the pavement including the cost of smoothness testing.

610.5.5 Dispute Resolution

- Any dispute between the engineer and contractor regarding IRI QC/QA comparisons that cannot be settled at the project level shall be arbitrated with the MoDOT reference profiler per the test procedure in TM-59.
- The results of the reference profiler shall be binding for the engineer and the contractor.

622.30

- Diamond Grinding
  - Existing Concrete Pavement
After completion of any pavement repairs, the contractor shall run the control IRI profile in the outside wheel path in accordance with TM-59.

Areas where excessive subsidence or faulting prevent diamond grinding coverage may be excluded from IRI testing by the engineer.

After diamond grinding each segment shall be reprofiled and after analysis with the ProVAL software have a final IRI per segment of 65 percent of the control IRI or 80 inches per mile, whichever is greater.

After achieving minimum required smoothness the contractor cannot grind into bonus.
622.30.4
Smoothness Requirements

- The contract unit price for diamond grinding will be adjusted based on the final IRI for any segment before corrections, according to the following schedule:

<table>
<thead>
<tr>
<th>IRI, inches per mile</th>
<th>Increase in Contract Unit Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.0 or less</td>
<td>$0.25</td>
</tr>
<tr>
<td>40.1 to 54.0</td>
<td>$0.15</td>
</tr>
<tr>
<td>54.1 to 80.0</td>
<td>None</td>
</tr>
<tr>
<td>80.1 or greater</td>
<td>None*</td>
</tr>
</tbody>
</table>

*After correction to either equal to or less than 65 percent of the control IRI or 80.0 inches per mile.

Questions?

Jason.Blomberg@modot.mo.gov
(573)526-4338

ProVAL PSD Analysis Examples
PSD Analysis

Inadequate Roller Freq/Amp Settings on HMA

Concrete Paving Stringline

PSD Analysis

Stringline Sags
MoDOT - TM59
Test Method
106.3.2.59, Determination of the International Roughness Index

From Engineering Policy Guide

This method describes the procedure for determining the international roughness index (IRI) of pavement surfaces in English units.

Contents

- 106.3.2.59.1 Equipment
- 106.3.2.59.2 Inertial Profiler Certification Procedures
- 106.3.2.59.3 Construction Acceptance Procedures
  - 106.3.2.59.3.1 Segment Smoothness
    - 106.3.2.59.3.1.1 Inserting Leave-Outs
    - 106.3.2.59.3.1.2 Reversing Stations
  - 106.3.2.59.3.2 Areas of Localized Roughness
- 106.3.2.59.4 Dispute Resolution

106.3.2.59.1 Equipment

Inertial Profiler. The International roughness index (IRI) shall be measured with an inertial profiler (IP). The IP shall meet the equipment requirements of AASHTO M 328, which include the following three primary transducers: (1) a height sensor that measures the distance between the pavement and a vehicle reference point, (2) an accelerometer that measures the vehicle vertical acceleration in response to the pavement profile and (3) a distance sensor that provides a location reference as the vehicle moves longitudinally (see Fig. 106.3.2.59.1). The IP shall also be equipped with an automated triggering system that can automatically start and stop data collection using a reference mark. The IP shall store the profile elevation data at an interval of 2 in. or less and have a vertical measurement resolution of 0.001 in. or less. The IP equipment may be either the low speed or high speed type. The IP shall be capable of exporting unfiltered raw profile data to an electronic file (conforming to ASTM E 2560) that can be imported into the ProVAL software program.

![Diagram of Inertial Profiler System](Fig. 106.3.2.59.1)

ProVAL. The profile file shall be evaluated using the ProVAL software program. ProVAL is a free program developed by The Transtec Group under contract with the FHWA. The current program version is ProVAL 3.4 (http://www.roadprofile.com/) and can be downloaded.

106.3.2.59.2 Inertial Profiler Certification Procedures

Each IP used for construction acceptance testing on a MoDOT project shall be annually certified (verified) at the Linn State Technical College.
test site. The test site will have a known IRI in two wheel paths, measured with a reference profiler.

The inertial profiler (IP) shall have its low- and high-pass filters set to zero prior to the certification test. The IP shall have any other controls set according to manufacturer's specifications. The two sensors in the profiler shall be spaced 6 ft. apart.

The IP operator may perform trial profile runs prior to the certification testing. The IP shall start far enough in advance of the test section to reach data collection speed. The IP operator shall perform five profile runs on the test section collecting data in both wheel paths. The IP shall move at a constant speed over the test section. An IP with two sensors shall measure both wheel path profiles in a single pass. An IP with one sensor shall measure each wheel path profile individually. Upon completion of testing, the IP operator shall provide the certification engineer the unfiltered profiles in .ppf file format on a readable electronic storage device such as a flash drive. Each file shall be labeled in the following format:

Contractor_IP Manufacturer_IP TypeUnique Equipment ID #_Wheel Path Tested Test Run #.ppf
For "IP Type" enter "HS" for high speed and "LS" for low speed.
For "Wheel Path Tested" enter "L" for left, "R" for right and "B" for both.
For "Test Run #" enter 1, 2, 3, 4 or 5.
Ex. CBI_Ames_HS_600406_B_1.ppf.

MoDOT will analyze the submitted data using ProVAL. Based on AASHTO P6-10, the test results of the inertial profiler (IP) shall meet the following requirements:

- Minimum average cross-correlation repeatability shall be 92%.
- Minimum average cross-correlation accuracy shall be 90%.

A ProVAL certification report shall be generated for each inertial profiler (IP) that receives acceptable test results at the certification. The report shall be digitally signed with the State Construction and Materials Engineer signature and shall be electronically stored on the MoDOT V-drive and sent to the contractor or testing consultant. Inertial profilers that do not pass the certification test shall be corrected offsite by their respective owners and re-certified at a later date.

106.3.2.59.3 Construction Acceptance Procedures

Testing Conditions. All objects and foreign material shall be removed from the pavement surface. There shall be no standing water in the wheel paths during testing. Inertial profiler high- and low-pass filters shall be set at zero.

Testing Limits. The inertial profiler shall measure the surface of a pavement section in both wheel paths that are located 3 ft. from and parallel to the edges of the lane, running in the direction of travel.

- The starting point shall be 50 ft. before the start of the day's paving.
- The starting point shall be a known station or logmile measured to the nearest foot.
- The IP shall use an automated triggering mechanism to initiate data collection at the starting point and end data collection at the ending point.
- The starting point shall be visibly marked for the duration of the project so that subsequent profile measurements may be closely matched.

Data Submittal. The contractor shall submit an electronic file in .ppf format containing the unfiltered raw data collected at the section. Data shall be submitted within 24 hours of the testing on each section. A day's report may consist of more than one section. Inertial profiler files with QC data results shall be submitted to MoDOT using the naming convention in Table 106.3.2.59.3.

Table 106.3.2.59.3, Categories of Warning Signs and Plaques

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>YYMMDD-###</td>
<td>Contract ID (Letting Date-Call Number)</td>
</tr>
<tr>
<td>YYMMDD</td>
<td>Test Date</td>
</tr>
<tr>
<td>Q</td>
<td>Type of quality test (C for control, A for assurance)</td>
</tr>
<tr>
<td>D</td>
<td>Direction of Lane (N, E, W or S)</td>
</tr>
<tr>
<td>L</td>
<td>Lane number (1 for inside lane, increasing by one for each lane to the right)</td>
</tr>
<tr>
<td>W</td>
<td>Wheel path (L, R, or B)</td>
</tr>
<tr>
<td>S</td>
<td>Beginning station (rounded to nearest foot)</td>
</tr>
</tbody>
</table>

*Example: 100528-501_111102_C_N2R105045.PPF
Data Analysis. The engineer shall use the ProVAL program to analyze the QC file. ProVAL shall also be used for quality assurance (QA) test data. The analysis will consist of two primary components: 1) segment smoothness evaluated with the "Ride Quality" module and 2) areas of localized roughness (ALR) evaluated with the "Smoothness Assurance" module.

106.3.2.59.3.1 Segment Smoothness

The data will first be analyzed for ride quality, which will determine the average IRI for each wheel track on a per segment basis. The steps are as follow:

- Open ProVAL program.
- Select "New".
- Select "Add Files" to import PPF file with QC/QA profile data.

File(s) will contain either right and left track profiles or single wheel track profiles.
- Select left elevation and right elevation.

The following example uses a file containing both wheel paths. The program will correctly align files with individual wheel paths, provided the data collection was initiated at the same starting station for both files. The next screen shot shows the actual change in elevation along the profile length.

- Select "Ride Quality" in the "Analysis" module.
Select "Fixed Interval" in the "Analysis Type" dropdown box.

Change "Threshold" limit to 80 (in/mi). *(Note: this threshold applies to pavement with posted speeds over 45 mph. The threshold is 125 (in/mi) for lower speed routes.) The "Segment Length" should show the default value of 528 ft. and the "Ride Quality Index" should show the default name of "IRI".

Check box for "LElev." and "RElev." and make sure the "Apply 250mm Filter" box is checked for both.

Select "Analyze".
The average IRI of a wheel path for each 528 ft. long segment will be shown on the screen. The drop down menu above table at left can be used to view either left or right wheel path IRI values.

- Select "Excel" in the "Report" dropdown box.
- Open the Excel file.

Average IRI for each segment for both wheel paths is listed in the Excel spreadsheet.

- Copy and paste this data into the "IRI Inertial Profiler Report with Bonus" Excel spreadsheet in the V:\Smoothness folder. Select the appropriate individual worksheet in the "Start" worksheet (first tab); based on posted route speed, pavement type and pay unit type. The worksheet will automatically generate pay factors for each segment.
There may be exempted areas per Sec 601.4.2.2 (http://www.modot.org/business/standards_and_spécis/SpecbookEPG.pdf?page=9) within the section profile limits. The engineer should verify that the limits do not go beyond the eligible exemption area. The contractor may elect to:

1) Stop the profile run at the beginning of the exemption and begin a new section profile at the end of the exemption.
2) Manually enter exemption boundaries in the data acquisition software during the profile run (typically performed with high speed IPIs).
3) Enter a "leave-out" area in ProVAL during the ride quality analysis. The instructions for performing this are as follows:

- Select "Editor". Select the file from the File dropdown menu.
- Select the IP file from the "File" dropdown box.
Select "Sections in the "Navigate" dropdown box.

Select "Add Section".

Enter section(s) Start Distance, Stop Distance, Type (Leave-out) and Name.

For this example, assume there are two leave-out areas: one at the beginning where a bridge approach on the upstream side is within limits and another over a mile farther where there is another bridge.
- Select "Analysis" and select "Ride Quality".
The ride quality summary shown below now excludes the exempted areas of the profile and abbreviates the associated segments accordingly.

- Select "Excel" in "Report" dropdown box.
- Open the Excel report.

Since the first leave-out was at the beginning of the project, ProVAL has shifted the boundaries of the original segments to maintain 528-ft. lengths. However, it truncates the segment preceding the second bridge, so that it can again begin with 528-ft. lengths on the other side of the bridge. This means leave-outs should be established and analyzed in ProVAL prior to exporting the results to the "IRI Inertial Profiler Report with Bonus" Excel spreadsheet in the V:\Smoothness folder.
106.3.2.59.3.1.1 Inserting Leave-Outs

Prior to analyzing ride quality some reformatting of the stationing will probably be necessary. In this example, assume the beginning of the inertial profiler run is at log mile 132.2.

- Select "Navigate" dropdown box
- Select "Basic"
- Enter 132.2 in "Beginning Milepost (mile)" box
- Select "Save"

ProVAL has now reformatted the stations to represent actual project limits for the profile section.
106.3.2.59.3.1.2 Reversing Stations

Another situation that may arise is when the direction of travel is in a station descending direction. ProVAL can also easily make this adjustment in the "Editor" mode. For this example, the starting log mile 132.2 will be retained.

- Select "Profiling Direction" dropdown box
- Select "Reverse"
- Select "Save"
Re-running the ride analysis and creating the Excel report file will provide segment data in the reverse direction.

- Select "Analysis" and select "Ride Quality".
- Select "Excel" in "Report" dropdown box.
- Open the Excel report.
106.3.2.59.3.2 Areas of Localized Roughness

- Select "Smoothness Assurance" in "Analysis" dropdown box.
- Change "Threshold" value for "Short Continuous" analysis to 125 (in/mi) in the "Ride Quality" section. (The segment length for "Short Continuous" should be set at the default value of 25 ft.). Change "Threshold" for "Long Continuous" and "Fixed Interval" in the "Profile" section to 80 (in/mi). (The "Segment Length" for both "Long Continuous" and "Fixed Interval" should be set at the default value of 528 feet.)

- Check "Right Elevation" only in the "Profile" section (ensure "Apply 250mm Filter" is also checked).

- Select "Analyze".
- Select "Grinding" in the "Navigate" dropdown box.
- Enter 0.25 inches for "Maximum Grinding Depth" in "Grinder" section. (The following parameters should show the default values, which are Head Position = 0.50, Wheelbase (ft) = 18.00, Tandem Spread (ft) = 2.49 and Short Cut-Off Wavelength (ft) = 0.820 ft.)

- Select "Auto Grind".
- Select "Grind".
- Select "Short Continuous" in "Navigate" dropdown box.
- Select "PDF" in "Report" dropdown box.
The grinding report is generated showing locations of areas of localized roughness (ALR). The grinding simulation numerically indicates what the expected improvement in smoothness should be when the ALRs are diamond ground. This information serves as a guide for both the contractor and the engineer for determining which ALRs can be corrected with conventional grinding and which may require other corrective measures.
Comparisons for IRI before and after grinding are shown in tabular and bar graph form.

106.3.2.59.4 Dispute Resolution

In the event that the QC/QA results are not within tolerance (after the absolute value of the difference between the contractor and engineer IRI values is computed for each segment within the QA test length, the average of the absolute values of the IRI difference shall be 8 in./mile or less and the absolute value of the IRI difference for any single segment shall be 12 in./mile or less), the MoDOT SurPro reference profiler shall arbitrate the dispute. The engineer shall randomly select a 528 ft. area within the disputed pavement length and run the MoDOT reference profiler in the left and right wheel paths. The arbitration profile shall be correlated with its corresponding QC and QA profiles in ProVAL. Whichever of the average QC/QA IRI profiles is closer to the arbitration IRI profile shall be the binding profile for the purpose of construction acceptance.


Category: 106.3.2 Material Inspection Test Methods

- This page was last modified on 8 June 2016, at 12:39.
Glossary
Glossary

**Accelerometer** – a sensor that measure acceleration. An inertial profiler uses the signal from the on-board accelerometer(s) to compute the inertial reference value (i.e., relative height) that can be combined with the height sensor data to produce a complete profile. See also Height Sensor.

**Aliasing** – The error that can result when a signal is sampled at a rate less than twice the frequency of the various sinusoidal components that compose the signal. To avoid aliasing, the signal is band limited so that the sampling frequency used will be greater than twice as high as the highest frequency component in the signal. It is also described as the error that results from sampling a long wavelength signal that is mixed with a short wavelength noise signal.

**Anti-aliasing filter** – A low-pass analog filter that suppresses short-wavelength contamination of longer-wavelength measurements to improve the accuracy of the sampling process.

**Accuracy** – Lack of error. The root-mean-square value of the error when comparing measured values with “deemed correct” or reference values. See also Repeatability.

**Amplitude** – the maximum value of a periodic curve measure along its vertical axis with reference to the horizontal axis.

**Bias Error** – Error stemming from systematic problems, including inaccurate calibration, physical damage, or a defect in the profiler’s design.

**Blanking Band** – A band that is placed over a profilograph trace to “mask” the portion of the trace that is not counted as roughness.

**Bode Plot** – A frequency response plot made on log-log axes.

**Bounce Test** – A test performed on an inertial profiler when stationary in order to check the measurement system.

**Calibration** – The process of correcting the scale of a transducer.

**Continuous IRI** – A series of IRI values calculated over a running interval, one for each profile data point throughout the test section. Each IRI value is provided at the midpoint of the running interval.

**Correlation Analysis** – Analysis that describes how one variable relates to another.
**Digital Filter** – A calculation procedure that transforms one signal into another to eliminate irrelevant data.

**Dipstick** – A static, inclinometer-based proprietary device used to measure elevations at individual points (originally used for measuring floor flatness).

**Distance Measurement Instrument (DMI)** – A transducer used to determine the longitudinal distance that the measurement vehicle has traveled.

**Filtering** – Procedure to extract desired information from a signal that also contains unwanted information (commonly called noise). Digital filtering is a calculation procedure that takes one set of numbers and transforms them into another set in which the noise is reduced. Moving average is one type of such transformation or filter.

**Frequency Response** – The ratio of output amplitude to input amplitude for a sinusoid.

**Gain** – The ratio that a filter amplifies or attenuates an input signal component at a given wavelength or frequency.

**Golden Car** – The quarter-car model used in IRI computation. See also IRI.

**Half-car Roughness Index (HRI)** – A number calculated by applying the IRI algorithm to the average of two profiles.

**Height Sensor** – A sensor used in an inertial profiler to measure the vertical distance between the sensor and the pavement surface.

**High-Pass Filter** – A digital filter that produces an anti-smoothing effect that reduces the effect of long wavelengths. See also Low-Pass Filter.

**Index** – Measure of standard. Within the context of this test method, a suitably chosen index quantifies the ride quality of a pavement.

**Inertial Profiler** – A profile measurement device that measures the pavement profile using an accelerometer to form an inertial reference and a height sensor to measure the pavement surface height relative to that reference.

**International Roughness Index (IRI)** – A statistic that summarizes the roughness qualities impacting vehicle response based on the Golden-Car vehicle model at a standard simulation speed of 49.7 mph (80 km/h).

**Lead-In** – The distance required for an inertial profiler to reach an acceptable speed and for the data collection filters used in the profile computation to stabilize. See also Lead-Out.
Lead-Out – A safe distance for an inertial profiler to operate to a stop position or until the data collection system is turned off. See also Lead-In.

Light-Weight Profiler – An inertial profiler that is relatively light-weight (golf cart, ATV, etc.) compared with high-speed profilers (vans, trucks, cars, etc.). It is often operated much slower than prevailing traffic speed. See also High-Speed Profiler.

Line Laser – A line laser obtains a series of data points along a line, which is typically perpendicular to the travel direction, with the line typically being 4 in. long. A single, bridged elevation value is computed from the data.

Linear System – A system in which the output is directly proportional to the input.

Localized Roughness – Short sections of roadway that contribute disproportionately to the overall roughness index value. Also referenced as “hot spots”

Longitudinal Profile – A longitudinal two-dimensional slice of a road surface taken along an imaginary line that consists of elevation values and a distance reference for each elevation.

Low-Pass Filter – A smoothing filter, such as moving-average, that reduces the effect of short wavelengths. See also High-Pass Filter.

Mean Panel Ratings – A subjective rating system whereby automobile passengers rate the smoothness of a given road after driving on it.

Mean Roughness Index (MRI) – A number calculated by averaging the IRI values from the two-wheel path profiles.

Measurement Range – The detectable range of heights, accurately measurable by the sensor.

Moving Average – Filtering process whereby each data point is replaced with the average value of several adjacent points or elevations. It is a smoothing process because the changes from one elevation point to the next will not be as significant due to the fact that the difference in elevation has been divided by the total number of data points in the averaging scheme. It is a type of low-pass filter.

Moving Average Filter – A digital filter that replaces each profile elevation point with the average of several adjacent points.

Portability – The ability to obtain consistent results when using different types of measurement devices.

Power Spectral Density (PSD) – A method that describes how the power of a signal (i.e. a time average of signal energy) or time series is distributed with frequency.
**Precision** – The measure of variation between multiple measurements, expressed in standard deviation.

**Profile Index** – A generic summary number calculated from a profile. This term should be avoided since it may be confused with Prl or RN. See also Prl and RN.

**Profiler** – An instrument used to measure road profiles.

**Profiler Certification** – A procedure used to determine whether a profiler satisfies a specific set of performance criteria.

**Profiler Operator Certification** – A procedure used to determine whether a profiler operator passes a specific set of written and field operational tests in order to be certified for operating profilers.

**Profilograph** – A device used to measure smoothness by measuring the deviations of a pavement surface using a mid-point measuring wheel from the reference established by a set of wheels (6 for a California-type) at either end of the device.

**Profilograph Index (Prl)** – A smoothness index that is computed from a profilograph trace. This is sometimes called Profile Index (PI), but is more specifically called Prl.

**Reference Device** – A device used to obtain the true profile of a pavement. Devices such as rod and level, Dipstick (TM) and walking profiler are considered reference devices.

**Repeatability** – The expected standard deviation of measurements obtained in repeated tests using the same device on a single, randomly-selected pavement surface.

**Reproducibility** – The standard deviation of the error included in a single measurement, relative to a reference measurement. The reproducibility of a device included errors that are systematic with respect to that device, but random with respect to a particular test.

**Report interval** – The longitudinal distance between the outputs of a profile index value.

**Ride Number (RN)** - A calculated roughness index, between 0 and 5, that approximates the Mean Panel Rating for a pavement surface. See also Mean Panel Ratings, IRI, and Prl.

**Ride** – Also spelled out as “Ride Quality”. Measured as accelerations in the vehicle body.

**Road Roughness** – The deviations of a pavement surface from a true plane surface with characteristic dimensions that affect vehicle dynamics and ride quality.
**Rod and Level** – Static equipment used to measure elevations at individual points, commonly used for land surveying.

**Rolling Straightedge** – Profiling equipment generally consisting of a rigid beam (or frame) with support wheels on either end and a measuring wheel at the middle, which is rolled over the surface to be profiled.

**Roughness Profile** – A plot that shows the variation of roughness over a section of pavement. This is also referred to as a “continuous roughness report.”

**Response-type Road Roughness Measuring System (RSRRMS)** – A system that measures suspension deflection of either one or two wheels of either a passenger car or a towed trailer and records these deflections as “counts” or as actual measured deflection.

**Running interval** – A set longitudinal distance that is stepped through a test segment by an increment shorter than its length.

**Sample Interval** – The longitudinal distance between captured data points.

**Sampling Rate** – The rate at which the height sensor measures vertical displacement. A typical sampling rate provides many height measurements from which a single value is derived for reporting at the sample interval.

**Segment Length** – The length of section of pavement where a smoothness index is recorded.

**Signal Processing** – The mathematical transformation and analysis of signals.

**Signal** – A series of numbers.

**Sensors** – devices that measure physical quantities. They are responsive to a change in a physical measurement such as distance, temperature, and acceleration.

**Sinusoid** – A periodic curve defined by wavelength, amplitude and phase.

**Smoothness** – Lack of roughness or lack of significant bumps and dips from the pavement surface that cause discomfort to motorists.

**Standard Error** – The portion of the total error due to random effects.

**Transducer** – Device that converts variables of one type (i.e., distance) into those of another type (i.e., voltage). These conversions must conform to a known transformation (i.e., proportional) to be useful.

**True Profile** – The undistorted shape of a pavement surface.
**Valid Profiler** – A profiler that provides the same statistical values that would be obtained from the true profile.

**Verification Site** – A pavement section used to periodically check if an inertial profiler is functioning properly.

**Wave Band** – A range of frequencies. In profile analysis, wave band often refers to spatial frequencies. See also Wave Number.

**Wave Number** – The number of wave cycles per unit length.

**Wavelength** – The distance between peaks or crests of a wave or sinusoid.