# ENSURING QUALITY DATA FROM INERTIAL PROFILERS

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## ABSTRACT

Inertial profilers are a key component in the collection of pavement performance testing. They allow large amounts of testing, while travelling at the posted speed limit to ensure safety and the impact on traffic flow. However, the equipment is composed of a range of sensors that collect data and need to be used together to calculate values such as the International Roughness Index, rutting, and other automated condition indices.

There are several standards that outline the equipment and testing procedures required. Many of these standards classify the vehicle, provide details on how the analysis is done, and procedures for calibration and quality testing. However there are many other steps that can, and should, be taken in order to sure the data is tested accurately and consistently across the entire network.

This paper describes the types of quality control procedures that are recommended for inertial profiling. They describe the benchmark testing of the equipment, applicable standards, and routine equipment checks that should be complete. Also discussed is the development and testing of project control sites, interpretation of the data to ensure quality data collection. The procedures described are based on extensive testing experience and a range of agency specifications for data collection.

Key Words: Inertial Profiler, Roughness, Control Sites

## INTRODUCTION

Collection of data for pavement management systems is a common part of most road agencies' practices. A wide range of equipment has been developed to quickly and accurate measure the pavement condition information such as roughness, rutting, distress conditions, texture, and structural capacity. Over time these processes have been improved, modified, and developed into a range standards to ensure consistent and accurate results.

Likely the most common data collected at the network level is the pavement smoothness that is measured as the longitudinal profile and typically evaluated as the International Roughness Index (IRI). This information can be effectively collected at posted speed limits for paved roads around the world with the use of an inertial profile. The IRI has proven over time to be a robust value that can be easily understood, modeled for deterioration, and used to make network level decisions. The IRI is also being used in some cases as a quality measurement for newly constructed pavements.

There are many industry set standards that describe the potential practices and the equipment technical requirements. These standards discuss the different types of profilers (1), how the data collection should be performed (2), and how to calculate the IRI (3). However, it is important to ensure that the equipment meets the accuracy and repeatability requirements throughout a project. There are also additional opportunities to test and verify the process. These opportunities will allow agencies and testing companies to quickly verify the test results of their equipment.

Many agencies have developed specifications for the testing as well as a range of quality checks to ensure that the data meets the specifications and the need for high quality data. However, the processes can vary widely between agencies. This paper has been developed to discuss the types of processes and checks used, as well as the common levels of tolerances considered by agencies.

This paper will review the quality and calibration procedures to be performed on the inertial profilers as well as the quality checks that can be performed on the data. This will include validation and calibration of the equipment and field verification using control sites.

## EQUIPMENT VERIFICATION AND CALIBRATION

On most inertial profilers, the key components of equipment are the lasers and accelerometers. These sensors are used to measure the vertical movement of the vehicle and the distance from the vehicle to the road in order to determine a complete longitudinal road profile in each wheelpath. The Distance Measurement Instrument (DMI) and Global Positioning Systems (GPS) are most commonly used to identify the travelled length and location of the testing. It is important that all of these sensors, both independently and as one device, are capable of measuring accurately and repeatedly.


**Figure 1. Inertial Profile Enclosure Mounted on an Automatic Road Analyzer**

## Vertical Measurement or Block Test

The process to ensure accuracy of the lasers is quick and easy. The process known as the block test uses simple, prefabricated blocks of a known size to measure the accuracy of the laser.

While the testing vehicle is stationary, the testing systems are activated. The readings for each of the laser should be able to be viewed on the testing computer screen. The readings of the lasers should be stable if the vehicle isn't moving. Once the block, of known dimension, is placed under the laser, the reading should change by the dimension of the block. This process can be seen in Figure 2. It can be noted that a block with a dimension of 50mm was placed under the right laser sensor and then removed.

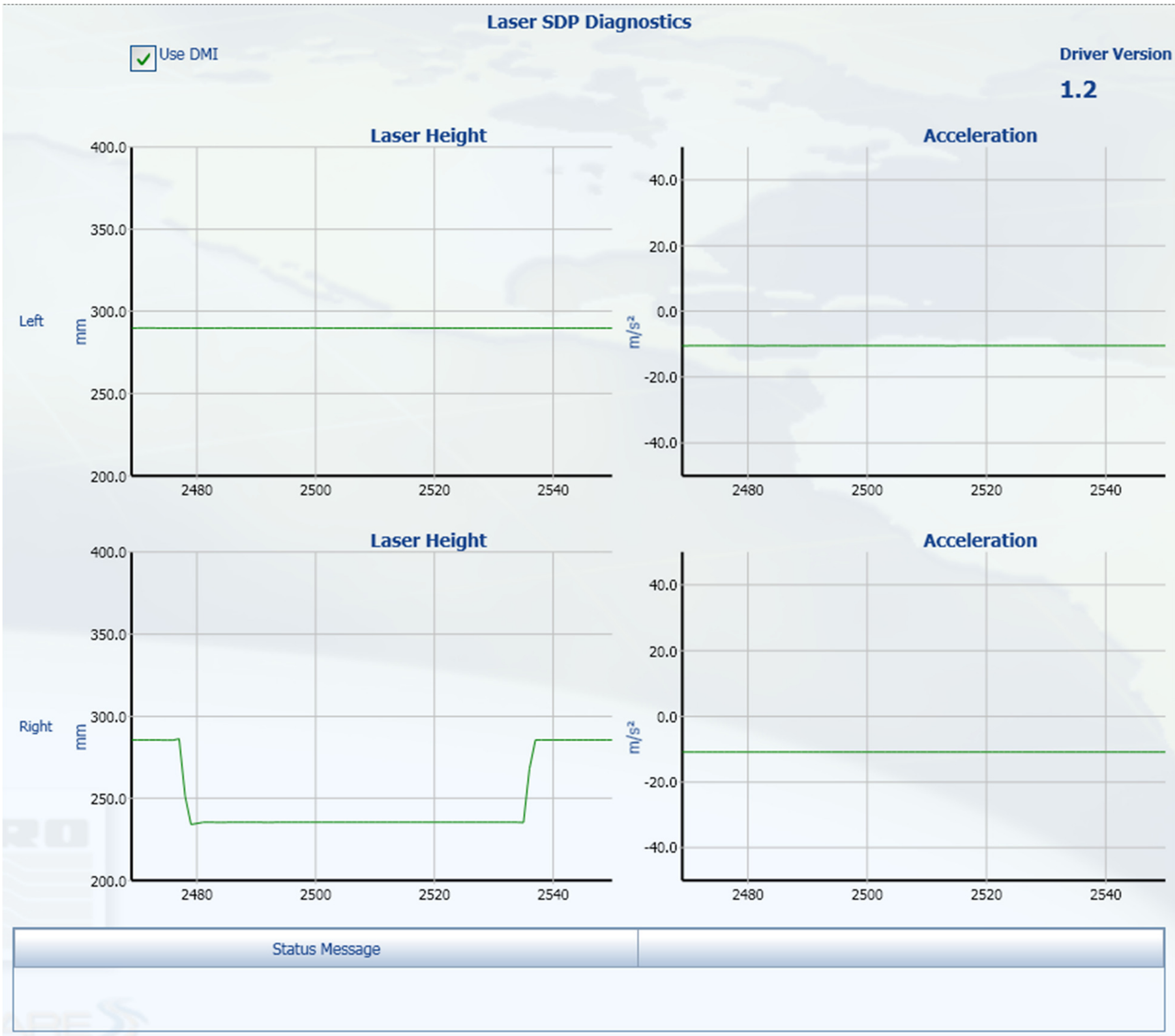


**Figure 2. Block Test**

The criteria typically used to demonstrate a successful test is that the measured deflection must be within ±0.1 mm of the block dimension (4). This test is often repeated with multiple blocks of different dimensions (ie. 10mm, 25mm, and 50mm) for consistency.

The block test is very quick to perform and will provide confidence in the accuracy of the laser measurements. The test is usually conducted on top of a flat plate to ensure the block is placed flat on the previous surface to ensure there are no deviations in the results. The plate and block are typically machined aluminum to ensure a consistent size and shape. It should be noted that adequate eye protection is also required when dealing with lasers and potentially reflective surfaces.

## Bounce Test

The bounce test is another common process used to validate the accuracy and timing of the accelerometer and laser sensor. Under normal operating conditions and the vehicle is travelling down the road at speed, the accelerometer measures the vertical movement of the vehicle bumper and the laser measures the distance to the pavement.  This system works to adjust for any bounce of the vehicle or differences in factors such as suspension system or tire type.

When the vehicle is not moving forward, any bounce of the vehicle should be shown in the data collection software as opposing elevation information for the accelerometer and the distance laser. When combined, the reading of the system should show that while the vehicle has moved, the elevation of the road has not changed.  It is this principle that allows elevation information to be collected that is independent of the type of vehicle.

By observing the 2 signals, It is possible to determine any issues on if the magnitude of the signals are the same and also if they are being simultaneously recorded.  Slight timing delays are the most common cause for showing excessive movement during the bounce test.  As can be seen in Figure 3, When the vehicle is bounced, the acceleration signal is synchronized to that of the laser measurements.  When the acceleration is converted to determine the vertical displacement, this will be a mirror of the vertical displacement registered by the laser sensors.

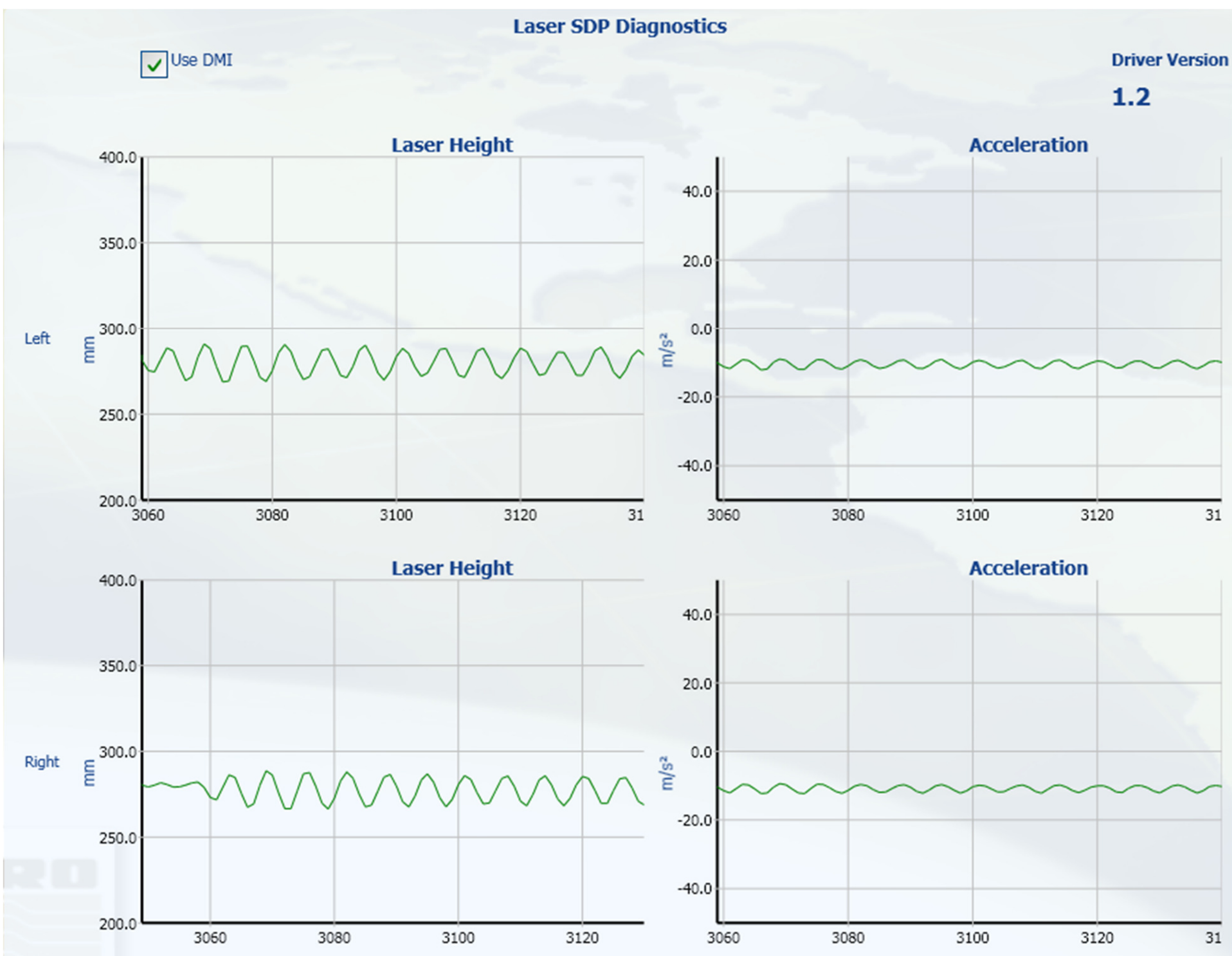


**Figure 3.  Bounce Test Results**

Assuming that the block test was successful at measuring distance, this test will also confirm the accuracy of the accelerometer at measuring changes in elevation to match the laser results.

Typically, the bounce test acceptance criteria is set as an IRI measurement of under 0.1 m/km. This will demonstrate that the results of the test will not be outside the acceptable range for the final readings.

### Calibration of the DMI

Most of the DMI systems in use require a location of known distance to be setup and run. By comparing the length measured by the DMI to the known length of the selected section, a calibration factor is used to ensure that the measurements will reflect an accurate distance. The DMI process measures a number of pulses that occur as the vehicle wheel turns.

The DMI system is calibrated by establishing a section of known length and having the vehicle travel that distance. A calibration factor can then be set to ensure that the measurement precisely matches the measured length. To increase the accuracy of this calibration, optical sensors are often setup to be triggered based on reflective markers at the start and end of the test site. This process is typically performed after the vehicle has been driven for a reasonable time (typically 15 to 20 minutes) to ensure that the tires are operating under typical temperature and pressure conditions. (4)

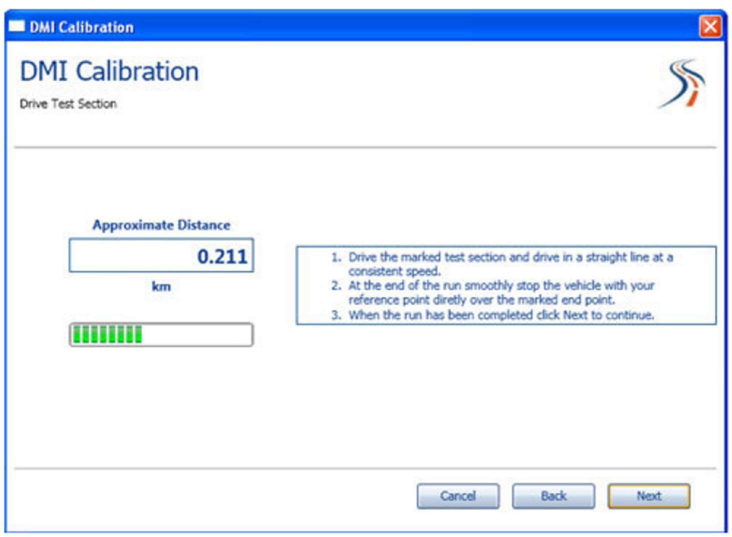


**Figure 4. Sample DMI Calibration in progress**

The DMI will have to be recalibrated when there is any reason to believe that the radius of the tire has changed. Specifically, the DMI will need to be recalibrated if the tires are changed, rotated, or if the tire pressure is adjusted.

## CONTROL SITES

For network level testing, the use of control sites is one of the most common and easiest solutions to confirm that data is being collected in a consistent and reliable manner. By having a location with known conditions, the equipment can be monitored to ensure that the results are accurately and precisely recorded.

For every project, a set of representative controls should be performed. These controls should be tested prior to the start of testing and at the conclusion of testing. This will ensure that the longitudinal profiles measured are consistent. For longer periods of testing, control sites can be repeated at regular intervals to ensure that any changes or issues are noted quickly during the testing process. The key is to establish that there are no drift in the results and to identify any potential testing issues early to prevent costly mistakes.


**Figure 5. Control Site Testing**

## Establishing a Control Site

There are many factors that should be considered when establishing a control sites to ensure that the results measured can be evaluated fairly and consistently.

**Site Location** – The control sites should be centrally located in the testing area. This is important to ensure that the sites can be accessed quickly and easily at regular intervals. If the sites are located away from the location of the testing, additional costs and reduced production rates will be incurred due to the extra travel required. If several control sites are used, to represent a range of typical conditions, the sites should be located in close proximity to each other whenever possible.

**Site Access** – The sites that are to be used for controls must be easy and safe to access by the inertial profiler. This includes making sure that the roads are not frequently closed or have high traffic volumes that make it difficult to maintain the required testing speeds. If benchmark testing is going to completed using a walking profiler, it will also be important that a traffic closure can be safely implemented to allow uninterrupted access to the complete section length.

**Site Dimensions** – The site should be at least 500m long preferably closer to 1,000m in length. This length will show some variable through the section and allow better identification of any features when reviewing in depth. When possible, clearly defined lane markings should be present and the lane width should not be too wide. A clearly identified lane will make is easier for drivers to identify and repeat the same travel path within the lane.

**Site Conditions** – Many agencies are tempted to find a section that is in poor condition for use as a control section, however this should be avoided if possible. Sections of advanced deterioration are often very difficult to get repeatable results due to the large differences in road profile with minor deviations in vehicle wander due to the distresses within the wheelpath. Some agencies recommend a maximum level of 2.0 m/km (120 in/mi) (5). Also, deteriorated sections are often in the process of being repaired which will make it difficult to reuse the section for several years and develop a reliable condition history. Sections that have been open to traffic for over a year make good choices and any settlement expected will have likely already occurred.

**Number and Type of Control Sections** – It is important that the control sites represent the majority of conditions encountered over the network to be tested. As an example, additional control sites can be used for different pavement types. For large networks, it may be recommended to have several control sites with good history scattered over the network to reduce transit times to sites. In many cases it may only be necessary to have one control site.

## Knowing the True Profile of the Control Site

The two purposes for a control site are to ensure accuracy and to ensure repeatability. The repeatability it the relatively easy part of the process. Through regular testing of any site, a clear understanding of the potential range of values can be well documented.

Ensuring accuracy can be more difficult, specifically if you only have one inertial profiler in use. The best way to determine the accuracy is to perform benchmark testing to determine what the true profile of the road is. Benchmark testing usually consists of testing the profile using a rod and level (6) or with a walking profiler (7).

Using these slower methods are often times more difficult to implement because they require the active traffic lanes to be shut down to allow workers inside a traffic closure to perform the testing. This makes the work time consuming and adds expense for additional equipment and closure costs. Many agencies use the inertial profilers to prevent an unnecessary risk to staff that are caused by work inside of traffic closures as well.

Just as control sites are repeated several times with inertial profilers, it is important to ensure that walking style profilers repeat the testing as well. Maintaining a consistent travel path can be difficult and any variation during this testing should be noted and considered when comparing the high speed inertial profilers.

The other option that can be used to determine a benchmark value for comparison is repeat testing of the site using multiple inertial profilers and drivers. By using a range of equipment, it may be possible to identify a bias in any one piece of equipment. This approach however does require access to several profilers and can be time consuming to accumulate enough data to determine an acceptable benchmark.

Lastly, it is important to note, that many of the control sites are established and used for many years. The reason that IRI is a common measurement as a part of pavement management systems is because it is expected to deteriorate over time. When substantial time has passed since benchmark testing, the results may need to be adjusted to account for this deterioration.

## Evaluating the results of an Inertial Profiler

In general, inertial profilers are commonly used because they provide results that tend to be repeatable. This means that seeing results that are consistent over a completed pavement section should be easy to track and issues or problems can be flagged.

Generally, the IRI values are generally expected to be within a range of ±5.0%, however there are lots of reason for additional variation. This range is typically very effective when comparing lengths of 100 m or greater. Smaller sections are more prone to error due to the influence of small bumps and road debris.

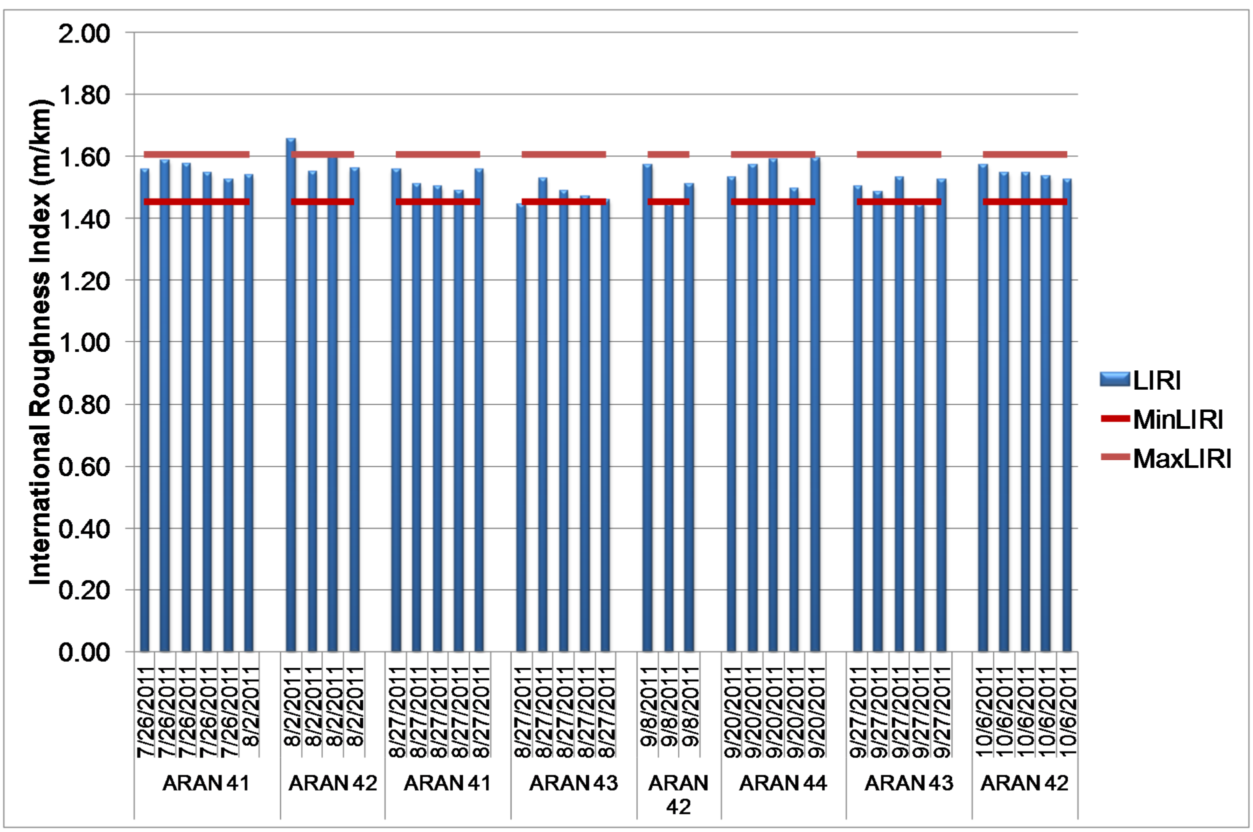


**Figure 6. Example Variation Between Multiple Runs of a Control Site**

As shown in Figure 6, some variability is expected in the measurements and there are a few tests that fall outside the ±5.0% limits shown. In this example a series of 4 vehicles were used on a project and tested this control site on several occasions.  This graph shows that often times the variability is just as high between runs using the same vehicle and driver as the variation is between vehicles or runs completed on different dates.

The level of variability within runs with the same equipment on the same day is often attributed to vehicle wander within the wheelpath.  The vehicle wander can detect different profile variations near the wheelpath such as debris, longitudinal cracking, concrete tining.  These obstacles may be measured by the equipment for some passes and not others.

Rougher roads (>180 in/mile, >3.0 m/km) will typically have more variability in IRI results than smoother roads.  This happens due to the amount of distress present in the wheelpaths.  Slight differences in the driving path can cause a large difference in the measured longitudinal profile.  Rough roads are not recommended for inertial profiler validation purposes, but they can be useful if the objective is to quantify the variability that can be expected in real conditions.  On rough roads the pass/fail tolerance may need to be relaxed for this reason.

Where concerns about data quality or the equipment are identified, often it is helpful to evaluate the measured profile data, not just the calculated IRI.  The most common issue is starting or stopping the testing at the wrong location which can be identified as a skew within the data.  However if there are any short areas within the control section that display different results, these areas can be investigated for changes in the road such as advanced deterioration and localized maintenance (ie. crack sealing or pothole repair).  Through the use of GPS equipment, location issues may also be identified and addressed to ensure consistent test locations.

Other factors must also be considered when performing control site testing.  Since roads are expected to deteriorate under normal conditions, it is expected to see some trends for a reduced performance for sites that have been in use for extended periods of time (> 6 months).

## Determining the Frequency of Control Site Testing

Control sites should be completed, at a minimum before and after testing a project that lasts for at least 5 days.  Control sites should also be completed for shorter projects if multiple profilers are in use on the same project.

When running a control site, multiple tests should be run for each vehicle to ensure that a reasonable level of variation is seen between runs.  Most agencies require between 3 and 10 runs per control site to determine the level of variability and ensure repeatability.  (8)

Testing on either side of the project will verify that the results collected on the last day will match the results collected on the first day.  For longer projects, controls should be considered on a monthly basis to identify any potential issues early.  Control sites may be completed more frequently (as often as weekly), but there should be a balance between rate of production and ensuring quality data.

## CONCLUSIONS

The use of inertial profilers is a standard procedure for most large road agencies in North America. This testing has been proven over time to produce repeatable and reliable results that can be used to make valuable decisions.

The testing to be provided should be established with equipment that is expected to meet the requirements of many of the standards such as ASTM E 950 (2) and AASHTO R 56-10 (9). However, these standards should be used in conjunction with a plan to assess, monitor, and control the quality of the results throughout the entire testing phase. Routine tests of the equipment should be completed to demonstrate that the equipment is performing in peak efficiency. This includes routing performance of both the block and the bounce test to ensure that the lasers and accelerometers are properly measuring the movement of the vehicle and road surface.

Control Sites should be established for every network level data collection project. This will include testing a common section multiple times throughout a project. This will ensure that the equipment will collect consistent and repeatable data and identify any potential issues.

Developing a quality plan prior to starting testing will ensure that the data will meet the needs of any project and provide a balance of quality and cost effective data collection.

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