South Africa

COTO

Committee of Transport Officials

TMH13

AUTOMATED ROAD CONDITION ASSESSMENTS

PART C: ROUGHNESS

Committee Draft Final

May 2016

Committee of Transport Officials

TECHNICAL METHODS
FOR HIGHWAYS

TMH 13

AUTOMATED ROAD CONDITION ASSESSMENTS
Part C: Roughness

Committee Draft Final
May 2016

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Synopsis

TMH13 provides the guidelines and procedures to assist road authorities to plan, execute and control automated road conditions assessments for: roughness, skid resistance, texture, rutting, deflections and distress imaging. Automated measurement concepts as well as background to different devices are provided. TMH 13 is a companion document to TMH 22 on Road Asset Management Systems and as such includes aspects of data capturing, analysis and documentation.

Withdrawal of previous publication:

This publication is new publication.

Technical Methods for Highways:

The Technical Methods for Highways consists of a series of publications in which methods are prescribed for use on various aspects related to highway engineering. The documents are primarily aimed at ensuring the use of uniform methods throughout South Africa, and use thereof is compulsory.

Users of the documents must ensure that the latest editions or versions of the document are used. When a document is referred to in other documents, the reference should be to the latest edition or version of the document.

Any comments on the document will be welcomed and should be forwarded to coto@nra.co.za for consideration in future revisions.

Document Versions

Working Draft (WD). When a COTO subcommittee identifies the need for the revision of existing, or the drafting of new Technical Recommendations for Highways (TRH) or Technical Methods for Highways (TMH) documents, a workgroup of experts is appointed by the COTO subcommittee to develop the document. This document is referred to as a Working Draft (WD). Successive working drafts may be generated, with the last being referred to as Working Draft Final (WDF). Working Drafts (WD) have no legal standing.

Committee Draft (CD). The Working Draft Final (WDF) document is converted to a Committee Draft (CD) and is submitted to the COTO subcommittee for consensus building and comments. Successive committee drafts may be generated during the process. When approved by the subcommittee, the document is submitted to the Roads Coordinating Body (RCB) members for further consensus building and comments. Additional committee drafts may be generated, with the last being referred to as Committee Draft Final (CDF). Committee Drafts (CD) have no legal standing.

Draft Standard (DS). The Committee Draft Final (CDF) document is converted to a Draft Standard (DS) and submitted by the Roads Coordinating Body (RCB) to COTO for approval as a draft standard. This Draft Standard is implemented in Industry for a period of two (2) years, during which written comments may be submitted to the COTO subcommittee. Draft Standards (DS) have full legal standing.

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C.1 Introduction

C.1.1 Context and Scope

TMH 13 *Part C* is the third of seven parts on Automated Road Condition Assessments. Part C provides guidance and methodologies on the planning, execution and control of roughness (or riding quality) measurements. This part should be read in conjunction with TMH 13 Part A which provides a brief overview of the main concepts related to roughness measurement. Key definitions are provided, and the road profile and its relation to roughness discussed. Part A also covers general aspects related to the planning of automated road condition surveys.

TMH 13 Part C is a companion document to TMH 22 which is the official requirement for Road Asset Management of the South African Road Network. Part C complements TMH 22 on requirements for the collection of roughness data, and specifically the International Roughness Index (IRI) used as a condition parameter in road asset management. Whilst the document addresses aspects of data management and reporting, reference is made to TMH 22 and TMH 18, respectively, for supplemental information and detail requirements. In general, reference is made to other documents in the series along with appropriate standards.

The scope of these guidelines are primarily concerned with the needs of roads agencies or managers of road networks. Although some details of measurement procedures are discussed, the emphasis remains on the needs of the network manager, and not on the needs of the contractor in charge of the actual roughness measurement.

C.1.2 Objectives

The primary objective of TMH13 Part C is to assist road network management personnel to plan, execute and control the measurement of road roughness (or riding quality) over a road network.

C.1.3 Layout and Structure of Part C

The document is written in a concise format that would enable network managers to use this document firstly as a practical guide, and only secondly as a source of general information on roughness measurement. Complex, but non-essential aspects are relegated to appendices to ensure that the guidelines can be helpful on the first reading.

Extensive use is made of concept summaries and checklists, which are clearly highlighted. The discussion of basic concepts is limited to the most essential and frequently used aspects of roughness measurement. A comprehensive reference list is provided and more complex but non-essential aspects are discussed in appendices. Sidebar boxes are used to highlight useful references for further reading, and other essential supporting information. The guidelines are structured as follows:

In **Section C.2**, the main types of measuring devices for network level use are discussed. The two main device types covered are Response Type devices and Profiler devices. A brief discussion of static or slow moving devices is also provided.

The process of device calibration and measurement control for Response Type devices is discussed in **Section C.3**. The section covers the selection of calibration sections, calibration procedures and control procedures. Supporting details for the methods provided in this section are provided in **Appendix C-1**.

Section C.4 covers the validation and control of profiler devices. The selection of validation sections is discussed, and schemes for different levels of device validation and measurement control are outlined. Supporting details for the methods presented in this section are provided in **Appendix C-2**.

Section C.5 covers operational procedures for different device types, and also discusses data capture, troubleshooting and documenting aspects. Guidelines for checking data consistency are provided in **Appendix C-3.**

References are provided in **Section C.6**, while **Section C.9** provides a glossary.

C.2 Roughness Measurement Classes and Devices

In this section, the different classes of measurement accuracy for roughness are first defined. The two main types of roughness measurement devices that are used for network level surveys are then discussed. These two types were defined in Part A.2 and are (i) Response Type devices and (ii) High Speed Profiler Devices. For each type of device, a brief background or history is provided. The operational principles are then discussed and the advantages and disadvantages of the equipment are noted.

Other types of roughness measurement devices include slow-moving profilers, which are not used to conduct network level surveys, but which are important for purposes of setting out calibration sections and general benchmarking of measured profiles. These device types are discussed in Section C.2.4.

C.2.1 Measurement Classes

Methods of measurement differ in terms of the methods of operation as well as the repeatability and reproducibility of the measurements.

Sayers et al (1986) developed a general classification of roughness measurement devices that distinguish between all types of roughness measurement on the basis of (i) whether or not the profile is measured; and (ii) the required precision and reproducibility of the devices. The main classes of roughness measurement devices, as defined by Sayers et al (1986) are summarized in Table C.1. It will be noted from Table C.1 that all devices that are capable of measuring an accurate road profile fall into Classes 1 and 2. Response type devices that have been calibrated before measurement fall into Class 3. Subjective ratings and uncalibrated response type devices constitute Class 4.

Since profiler devices fall into two classes (Classes 1 and 2), a further definition is needed to distinguish between Class 1 and Class 2 profilers. This classification is generally based on the sampling interval and the precision of the elevation measures. Sayers et al. (1986) developed accuracy requirements for Class 1 and 2 devices. These requirements are specified in terms of the required sampling interval and vertical measurement resolution, and are summarized in Table C.2.

Table C.1 Roughness Measurement Classes

Device Class	Class Requirements or Characteristics
Class 1: Precision Profiles	• Highest standard of accuracy measurement • Requires precision measurement of road profiles and computation of the IRI • 2 per cent accuracy over 320 m • IRI repeatability of roughly 0,3 m/km on paved roads • IRI repeatability of roughly 0,5 m/km on all road types
Class 2: Non-precision Profiles	• Requires measurement of road profiles and computation of the IRI • Includes profiling devices not capable of Class 1 accuracy
Class 3: IRI Estimates from Correlations	• Does not require measurement of the road profile • Includes all response type devices • Devices are calibrated by correlating outputs to known IRI values on specific road sections
Class 4: Subjective Ratings and Uncalibrated Devices	• Includes subjective ratings of roughness • Includes devices for non-calibrated response and profilometric devices

The measurement devices in Class 3 generally include response type devices (as defined in Part A.2), provided that the devices are properly calibrated by correlating the measurements to known IRI values on several calibration sections. Details of this calibration procedure are provided in Section C.3.

Given the options for roughness measurement that currently exist, Class 4 measurements are no longer regarded as being suitable for network level surveillance, and are therefore excluded.

Table C.2 Accuracy Requirements for Inertial Profilometers (ASTM E950-98)

Device Class	Maximum Longitudinal Sampling Interval (mm)	Vertical Resolution (mm)
Class 1	< 25	≤ 0,1
Class 2	25 < and ≤ 150	0,1 < and ≤ 0,2
Class 3	150 < and ≤ 300	0,2 < and ≤ 0,5
Class 4	> 300	> 0,5

C.2.2 Response Type Devices

Response type devices were the first type of device used to measure road roughness. These types of devices almost always consist of an instrument installed in a vehicle or trailer to record the up-and-down movement of the suspension (called the suspension stroke). These device types appeared as early as the 1920s, and are still widely used today.

Response type systems are relatively inexpensive and can measure roughness of up to 300 km per day. Although modern profilometric devices tend to overshadow response type devices, the latter type is widely acknowledged to provide a reasonable estimate of roughness. Engineers generally agree that measures obtained with response type systems match their experience of pavement roughness and overall condition [Sayers and Karamihas, 1998].

Response type devices are also called Response- Type Road Roughness Measuring Systems (RTRRMS), or Road Meter systems. In these guidelines, the term Response Type devices will be used throughout.

C.2.2.1 Operational Concepts

A response type system consists of the following main components (Sayers et al, 1986):

- The measurement vehicle;
- A transducer that detects the relative movement of the suspension;
- A recording system and display which is connected electronically to the transducer, and
- Automatic speed control and accurate distance measuring instruments.

The transducer, recording system and display are normally manufactured and sold as a single system (often called a Roadmeter), which measures the response of the vehicle to the road profile at the measurement speed.

The transducer measures the movement of the suspension in “counts” or millimetres. When the counts or total mm are summed, a parameter is obtained which gives an indication of the total suspension stroke that occurred over the length of road travelled. When the total count of summed mm of travel is divided by the length of the test section, the Average Rectified Slope (ARS) is obtained.

Important!

Response measurement device should be installed in vehicles with coil springs and not leaf springs, as the latter has increased Coulomb friction and may cause sudden changes in the suspension characteristics.

Sayers et al. (1986) state that the shock absorbers are the most critical element of response type vehicles. The vehicle should be equipped with stiff shock absorbers, and recalibration of the measurement system is needed if there is any change in the shock absorbers.

Further Reading: Response Type System Operations

A comprehensive discussion of the operation of response type devices can be found in World Bank Technical Paper 46 [Sayers et al., 1986]. This reference is aimed mainly at system operators. Guidelines for controlling and monitoring the operation of response type devices for network managers are provided in Section C.5 of this manual.

ASTM Standard E1082-90 specifies a procedure for measurement of roughness using a response type device. This standard covers device calibration and preparation before testing.

In South Africa, the Linear Displacement Integrator (LDI), which was manufactured and sold by the CSIR, was a popular and cost effective response type device. The LDI was installed in a passenger car with an independent rear axle and a coil spring suspension system. Figures C.1 and C.2 show some aspects of the LDI device.

Figure C.1 Basic LDI Components, showing vertical distance measurement transducer, odometer and data capturing components

Figure C.2 Attachment of LDI suspension monitoring device to rear axle

Although the basic operational principles of most response type devices are similar, the output obtained may differ. Some devices provide an output in counts/km while others may provide output in m/km or HRI (as defined in Part A.2).

Since the preferred parameter for quantifying roughness is IRI, the output from response type devices needs to be converted to IRI. This is done by means of a procedure known as "correlation by calibration". In this procedure, the output from a response type device is correlated with the known IRI values of several selected sections of road. These sections are known as calibration sections and the IRI values of these sections need to be determined beforehand using one of the high precision profiling devices discussed in Section C.2.4.

The process of calibrating a response type device provides an equation which can be used to calculate an estimated IRI from the response type device output. It is critical to note that the calibration of a response type device is valid only as long as key aspects of the measurement vehicle (shock absorbers, tyres, loading, etc.) remain unchanged. Ideally the calibration should only be performed for a specific speed, which should be 80 km/h since this is the speed for which the IRI transform is designed, this is however not always applicable in practise where a speed of 80 km/h cannot always be maintained during surveys. Details of the calibration process for response type devices are provided in Section C.3.

C.2.2.2 Advantages of Response Type Devices

- Response type devices have been used in many parts of the world for many years. Many engineers are therefore well acquainted with the operation and output of these devices.
- In general, response type device outputs are known to agree with engineers' assessment of roughness and pavement condition.
- Response type devices are relatively inexpensive. A reliable, modern response type device can generally be obtained for less than R180 000 (2015 prices, excluding the measurement vehicle). The cost of response type systems is generally less than 1/10th of the cost of a high speed profiling device.
- Although response type devices require frequent maintenance and care of operation to ensure that the calibration remains valid, the maintenance and care of the equipment is relatively simple and inexpensive to perform.
- The calibration is relatively easy and inexpensive to perform once calibration sections have been set out and measured.

Important!

It is critical to note that the calibration of a response type device is valid only as long as key aspects of the measurement vehicle (shock absorbers, tyres, loading, etc.) remain unchanged. The calibration is also performed only for a specific speed, which should be 80 km/h since this is the speed for which the IRI transform is designed.

- In South Africa, response type devices appear to be more successful on gravel roads than profiling devices.
- Response type devices can be used on gravel roads whilst Inertial Profilometers cannot.

C.2.2.3 Disadvantages of Response Type Devices

- The precision (and hence repeatability) of response type devices is significantly lower than that of a Class 1 profiling device. Furthermore, the annual deterioration of IRI on a typical road section is often smaller than the measurement error of response type devices (the measurement error occurs because of the lack of high precision, and also because of errors inherent in the calibration to correlate with IRI). This means that response type devices generally cannot track the deterioration of a road network on an annual basis (although it can perhaps do so over a 3 or 5 year period).
- In response type devices, the transformation of the road profile to an IRI value is completely dependent on the properties of the vehicle suspension system. These properties are known to change over time, and also from one response type vehicle to the next. The output of response type devices thus has a tendency to shift over time (i.e. it is not stable). Because of this, response type devices require calibration at least on an annual basis.
- Response type roughness measurement devices only measure road roughness. By contrast, many modern high speed surveillance devices can measure the lateral and longitudinal profile, and obtain high resolution photographs or videos of the road surface at the same time.

C.2.3 High Speed Profiling Devices

High speed profiling devices are capable of measuring a precision profile of one or more wheelpaths while moving at speeds in excess of 100 km/h. The first high speed profiling device appeared in the 1960's [Sayers and Karamihas, 1998]. Since this time, significant advances in precision measurement technology have greatly aided the design of high speed profilers and today these devices are used for road surveillance in many parts of the world. High speed profilers are also referred to as Inertial Profilers, owing to the use of accelerometers to determine an inertial reference which provides the instantaneous height of the measurement base at all times when the vehicle is moving.

C.2.3.1 Operational Concepts

A high speed longitudinal profiling device consists of the following main components:

- The measurement vehicle.
- A height sensor (called a transducer) to measure the distance from the measurement base to the road surface. There are four types of height sensors commonly in use. These are: laser, optical, infrared and ultrasonic.
- Accelerometers to measure vertical acceleration of the measurement base. The accelerometer reading is used in conjunction with the height sensor output to determine the elevation of the road surface.
- A distance measuring system to measure the longitudinal distance along the road.
- A computer and data storage system to process the output from the height sensor, accelerometer and distance measuring system, compute the surface profile (or profiles, if both wheelpaths are being measured), and store the computed profile with other parameters such as vehicle speed, position coordinates, etc.

The height sensors, accelerometers and distance measuring equipment are calibrated in the factory by the equipment manufacturer, and remain calibrated for a long time. For this reason, and unlike response type devices, precision high speed profilers should *not* be calibrated as part of the measurement process. Instead, the output of the device is *validated* by measurement of test sections with known IRI values to determine if all of the components of the system work correctly and that the device is capable of measuring the road profile to the required level of precision.

Most high speed profilers need to move at speeds in excess of 15 km/h to function properly. However, while static these devices can be operated in “test mode” to check that the height sensor and accelerometers are functioning properly.

Figure C.3 shows a high speed profiling device that is commonly used for network level roughness measurement in South Africa.

The most often used type of height sensor uses laser technology. Ultrasonic height sensors do not operate accurately on rough surfaces like chip seals and therefore cannot be employed for roughness measurement on many South African roads. Optical sensors are sensitive to white pavement markings (leading to “spikes” in measured profiles) and also do not always function well on dark pavement surfaces like new asphalt surfacings [Research Results Digest No. 244, 1999].

C.2.3.2 Advantages of High Speed Profiling Devices

- A validated high speed profiler is capable of measuring the surface profile very precisely. Also, since the IRI transform uses a fixed computer algorithm, the processing constants remain unchanged, and thus the measured IRI is consistent over time.
- Owing to the stability and precision of IRI values obtained with a validated high speed profiler, such IRI values can be used to track the deterioration of network sections from one year to the next.
- Modern high speed profilometers are often capable of measuring the longitudinal and transverse profile at the same time, thereby providing a roughness and rutting assessment simultaneously. Some devices are also capable of obtaining a high resolution video of the pavement surface at the same time.

C.2.3.3 Disadvantages of High Speed Profiling Devices

- Inertial profiling devices using laser height sensors are not recommended for profiling gravel roads, due to risk of dust penetration and damage from loose stones.
- Modern high speed devices are relatively expensive, and – unlike response type devices – few network agencies can afford to purchase and maintain their own profiler. In South Africa, relatively few contractors can

Figure C.3 Road Surface Profiler

perform high speed profile measurements, and equipment availability is often a problem. In the past, equipment was often imported for a few months to perform measurement on a network in South Africa. The cost of testing is therefore relatively high compared to that of response type measurements.

- Although the components of high speed profilers are calibrated by the manufacturer, extensive validation testing and control procedures are still needed to ensure that the measured profile is accurate. If rigorous validation procedures are not followed, the results of a profiler are often of little more use than those of a calibrated response type device. These validation procedures are costly and require more up-front investment of time and funds by the owner of the road network (see Section C.4 for details).
- The procedures for operation and control of high speed profiling devices are relatively complex, and require that the network manager invests time to understand and participate in the validation and control procedures (see Section C.5 for details).

Further Reading: High Speed Profiler Operations

Guidelines for the operation of high speed profiling devices can be found in NCHRP Research Results Digest No. 244 (1999). It should be noted that these guidelines are aimed at the persons responsible for daily operation of the profiler. Section C.5 provides guidelines for controlling or monitoring the operation from the perspective of the network manager.

ASTM Standard E950-98 specifies a standard test method for measurement of longitudinal profiles using an inertial profiling device. The standard covers aspects such as component calibration, system checks, test sections, data acquisition and data evaluation and reporting.

Important!

Since profiler components are calibrated in the factory, these devices are never calibrated as part of network survey operations, but only validated (i.e. correct operation is validated in the field). Response type devices, on the other hand, are calibrated as part of the survey process. For conciseness, however, the test sections on which such validation and calibration are performed will be generally referred to as **calibration sections** in Part C.

C.2.4 Static Profiling Devices

It was noted in Section C.2.2 that response type devices need to be calibrated by correlating the outputs of these devices to known IRI values on several test sections. Similarly, the outputs of high speed profiling devices need to be validated by comparing the measured profile and IRI values to the known profile and IRI values of several test sections.

A vital aspect of roughness measurement at the network level is thus the identification and profiling of test sections (or calibration sections).

The profiles and IRI values obtained on these calibration sections then become the benchmark values used for the calibration of response type devices and for the validation of profilers.

Naturally, the measurement of the profile and IRI values of the calibration sections must be performed to the highest level of precision and under the highest level of control. Class 1 profiling devices (see Section C.2.1) are therefore used to measure the profiles on network calibration sections.

Many high speed profiling devices are capable of Class 1 measurements. However, since the devices move at speeds in excess of 25 km/h, the line of measurement can never be 100 per cent controlled. Thus, to increase repeatability of measurements on calibration sections, static or slow-moving profiling devices are mostly used. Three such Class 1 profiling devices that are often used to measure the profile on calibration sections are the Precision Rod and Level, Face Dipstick™ and ARRB Walking Profiler devices.

C.2.4.1 Precision Rod and Level

The operational principles of the precision rod and level are illustrated in Figure C.4. As shown in this figure, the operation is very similar to that of a normal rod and level operation, as used for surveying, etc. However, in view of the high precision required for the profile of calibration sections, the precision rod and level equipment has a higher precision and the operation should follow the standard test method (ASTM E1364-95).

It should be noted that the test method described in ASTM Standard E1364-95 requires at least two persons and is time consuming and labour-intensive. A typical profile measurement will involve around 260 readings, and an experienced team can profile approximately 600 m per day. The method is therefore only suited for measuring profiles on calibration sections or for research or construction control purposes.

Once the profile of a calibration section has been measured, the profile is processed to determine the IRI of the section. The IRI can then be used to calibrate response type systems, while for profiling validation, both the measured profile and the IRI can be used.

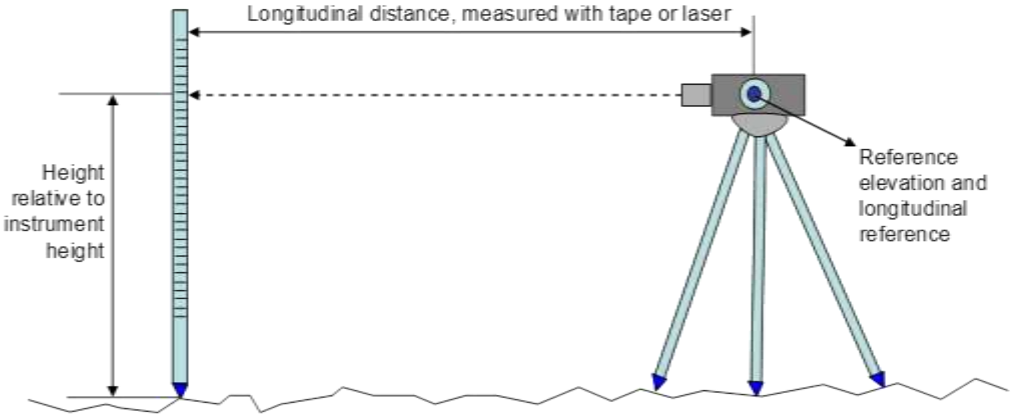
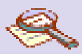


Figure C.4 Operation of the Precision Rod and Level (after Sayers and Karamihas, 1998)

It is important to note that the profile measured with a rod and level device cannot be compared to the profile measured with a high speed profiler in a simple manner (e.g. using elevation plots). This is because the inertial systems automatically filter out the longest profile wavelengths (e.g. vertical alignment). The profiles therefore have to be filtered identically before they can be compared using simple plots of elevation versus distance. [ASTM E1364-95].

C.2.4.2 Other Static or Slow Moving Devices

Two other devices that conform to the requirements for Class 1 devices and are often used to measure reference profiles on calibration sections are the Face Dipstick™ and the ARRB Walking Profiler devices.



Further Reading: Precision Rod and Level

ASTM Standard E1364-95 describes a standard test method for the measurement of profiles to determine the IRI using precision rod and level equipment.

Software such as ProVal (Profile View and Analysis) can be used to calculate the IRI and related parameters from a measured profile. ProVal is sponsored by the US Department of Transportation, the Federal Highway Administration (FHWA), and the Long Term Pavement Performance Program (LTPP). The software can be downloaded from: http://www.roadprofile.com/proval-software/current-version/

The **Face Dipstick^{TM}** (patented, manufactured and sold by the Face Corporation) is illustrated in Figure C.5. When used, the device is "walked" along the line being profiled. The device contains a precision inclinometer that measures the height between the two support feet at the base of the instrument [Sayers and Karamihas, 1998]. These feet can be spaced 20 to 500 mm apart, and in South Africa a spacing of 250 mm is typically used.

The Dipstick^{TM} is moved by leaning all of the device weight onto the front foot, and then pivoting the rear foot around the front foot by 180 degrees. When the instrument has stabilized, the change in elevation is automatically recorded and a beep is sounded. The longitudinal distance is determined by multiplying the number of measures made with the known spacing between the contact feet [Sayers and Karamihas, 1998]. The Dipstick^{TM} can record at approximately 200 m per hour.

The ARRB Walking Profiler is shown in Figure C.6. This device was developed by the Australian Road Research Board Ltd. and is roughly the size of a lawnmower. Profile measurements are performed at walking pace or roughly 800 metres per hour, with a practical production rate of approximately 4 km per day. A built-in data acquisition system captures and stores profile data while measurements take place.

The ARRB Walking Profiler outputs include distance, grade and IRI. The profile accuracy is ±1,0 mm/50m and the IRI accuracy is ± 0,1 m/km.

Figure C.5 Face Dipstick^{TM}

Figure C.6 ARRB Walking Profiler

C.2.5 Equipment Selection and Specification

The framework provided in Part A.2 for planning surveillance surveys highlights consideration of aspects such as the intended use of the data. Table C.3 summarises the basic survey types with their potential data uses and recommended devices. This table also shows the recommended levels of calibration or validation to be considered for different survey types.

It should be noted that Table C.3 refers to general aspects of planning to illustrate its potential impact on selection of equipment type. As referred to in TMH 13 Part A, requirements provided in TMH 22 should be used to establish the data collection frequency based on road classification.

Table C.4 provides the minimum requirements for roughness equipment. Mechanical motion encoder or accelerometer type devices (which measure the response of the vehicle chassis or axle to the road) as well as inertial laser-accelerometer combination inertial profiler devices are included. Other systems such as centre-of-axis motion encoders or scanning laser may be accepted as long as they meet the validation criteria detailed in Section C.3 and C.4, respectively.

Table C.3 Network Level Planning Considerations

Frequency of Measurement (Note 1)	Data Uses	Type of Devices	Validation and Calibration Requirements (Notes 1 and 2)
Once-off assessment of network roughness	• Prioritization of maintenance and rehabilitation	• Response type devices • Class 1 and 2 Profilers	• Level 1 Calibration (response type devices) • Level 1 Validation (profilers)
Three-to-five yearly assessment of network roughness	• Prioritization of maintenance and rehabilitation • Monitoring of relative network deterioration	• Response type devices • Class 1 and 2 Profilers	• Level 2 Calibration (response type devices) • Level 2 Validation (profilers)
Annual or biennial assessment of network roughness	• Prioritization of maintenance and rehabilitation • Monitoring of absolute network deterioration • Inputs into planning models	• Class 1 and 2 Profilers	• Level 2 Validation (profilers) • Level 3 Validation (optional) at contract start or when device type is changed (Note 3)

Note 1: Refer to TMH 13 Part A and TMH 22 for requirements on data collection frequency

Note 2: Levels of calibration for response type devices are defined and discussed in Section C.3. Levels of validation for profilers are discussed in Section C.4.

Note 3: In all cases, operational checks and controls as defined in Section C.3 (for response type devices) and Section C.4 (for profilers) should be strictly implemented.

Note 4: Level 3 validation requires specialist analysis of profile data, and is recommended only where the highest level of precision is needed (for annual surveys, and to be performed at the contract start or when there is a change in device type or major maintenance on the equipment).

Table C.4 Equipment Specification Considerations for Roughness Survey Equipment

Importance or Relevance	Parameter	Minimum Specification for		
		Sensor Equipment for Response Type Devices (Note 1)	Sensor Equipment and Data Acquisition System for Profilers (Note 2)	
Required (some parameters may not apply to response type devices)	Sensor Type	Mechanical or Accelerometer Type System	Lasers & Accelerometers	Data Acquisition
	Minimum No. of Sensors: Mechanical Type or Laser Accelerometers	 2 (each wheelpath) 2 (each wheelpath)	 2 (each wheelpath) 2 (with each laser)	Not Applicable
	Measurement Speed	Not Applicable	80 km/h	Not Applicable
	Resolution: Mechanical Type or Laser Accelerometers	 1.0 mm 10 mG	 0.05 mm 10 µG	16 Bit
	Longitudinal Sample Interval	Not Applicable	50 mm	10 milliseconds
	Measuring Range: Mechanical Type or Laser Accelerometers	 0.8 mm Not Applicable	 ±100 mm ±2G	> 200 mm
	Repeatability	Not Applicable	0.1 mm	±1 Least Significant Bit (LSB)
	Operating Temperature Range (All Sensors)	Not Applicable	0°C to 50°C	0°C to 50°C
Optional if high level control is exercised during validation or calibration procedures	Frequency Response: Mechanical Type or Laser Accelerometers	 Not Applicable DC – 100 Hz	 DC – 16 kHz DC – 300 Hz	Greater than sensor output
	Long Term Drift	Not Applicable	< 0.3 per cent	< 0,003% ±1 LSB
	Filtering	Not Applicable	Not Applicable	Anti-alias filters with cut-off wavelength of twice the sampling interval.

Note 1: Either Mechanical Motion Encoder type such as LDI or Accelerometer type of devices

Note 2: Laser - Accelerometer combination

C.3 Calibration and Control Testing for Response Type Device

Since response type devices do not measure the actual road profile, the IRI cannot be calculated directly. Instead, the output of these devices is calibrated or adjusted to enable a relatively accurate assessment of the IRI to be made. This section deals primarily with the process for calibrating response type devices at the start of the network survey process, and also discusses measurement control procedures to be performed during the survey period.

It should be noted that a network manager can participate or control the calibration process, or can simply request that a calibration report be handed in before the measurement device is approved for use on the network. In the latter case, it is important for network managers to understand the key aspects related to calibration, and the preferred format of a calibration report. These aspects are covered in the paragraphs that follow.

C.3.1 Validation and Calibration Section Requirements

General aspects of the validation or calibration section requirements are included in Part A. The calibration section requirements that follow in Section C.3.1 are applicable to both response type and profiler devices. As pointed out in Section C.2, profilers are validated and response type devices calibrated as part of the survey. The term calibration section is adopted for conciseness and refers to the test site on which such validation or calibration are performed. Key aspects related to calibration sections are the selection of the sections, profiling of the sections and processing of the calibration section profile data to facilitate calibration or validation. Each of these three aspects is discussed in the following paragraphs.

C.3.1.1 Selecting Calibration Sections

Sections to be used for calibration should be selected according to the following guidelines [Sayers et al., 1986]:

- Section lengths should be at least 200 m long, but should preferably be between 300 and 500 m long. All sections should have the same length.
- The calibration sections should be selected so that there is at least one section in each of the roughness ranges shown in Table C.5. The sites should also be selected so that there are approximately an even proportion of sections in each roughness range.
- Each calibration section should have a relatively uniform roughness over its length as well as over the 50 m preceding the start of the section.
- The sections should preferably be on straight (tangent) sections of road. The sections do not need to be level, but there should be no significant change in grade within or before the section.
- The calibration sections should have different surfacing types, representing the types of surfacing frequently found on the network.

For practical reasons, it is also recommended that the calibration sites be located relatively close to the centre of operations, and that the sites selected sites are not subject to rapid deterioration. If a calibration site is rehabilitated, another site with a similar roughness range should be selected and profiled.

Table C.5 Roughness Ranges

IRI Range
1,0 to 3,0
3,0 to 4,5
4,5 to 6,0
6,0 to 8,0
8,0 to 16,0

Table C.6 presents validation criteria for response type devices. The selection of lower and higher reliability levels should take survey objectives (see Part A) into account as well as data collection frequency requirements stipulated in TMH 22.

C.3.1.2 Profiling Calibration Sections and Determining the Reference IRI

The reference device used to measure the profile of calibration sections should be able to match the criteria of a Class 1 device, as specified in ASTM E1365-95. This ASTM standard also defines the longitudinal sampling distance and vertical resolution of the device. The Precision

Rod and Level, Dipstick™ and ARRB Walking Profiler devices (discussed in Section C.2.4) are capable of meeting these criteria.

The following procedure is recommended for the measurement of reference profiles and IRI values on calibration sections:

- Each wheel path of each calibration section should be profiled four times, consisting of two runs in which the device *returns* along the same wheel path to form a closed return loop.
- The reference profiles should be stored and the IRI values calculated according to the calculation defined by ASTM E1926-98, which can be achieved using the public domain Road Ruf software.
- The IRI should be calculated for every 100 m segment of each measurement run over each wheelpath.
- The reference IRI for each wheelpath of the calibration section should be calculated as the mean of the four runs.

As a rough guideline, reference profiles can be considered acceptable if the variation in the IRI over each 100 m is less than 3 per cent or 0,2 IRI (whichever is greater). These criteria can be relaxed if special conditions prevail (like localized distress).

C.3.2 Calibration Procedure for Response Type Devices

Tables C.6 and C.7 show guidelines for setting requirements for the calibration procedure. As shown in Table C.6, the calibration procedure requires a number of repeat measurements on each calibration section. Measurements should be made at the designated measurement speed, which should be 80 km/h for IRI measurement, unless special circumstances dictate another measurement speed.

The criteria shown in Table C.7 shall be used for accepting or rejecting a calibration for a response type device. The contractor should compile a calibration report in which the details of the calibration are clearly defined. The calibration report should show the following:

- Details of calibration sections used.
- Table showing average device count or measure for each run over each section, with the average and standard variation for of all runs over each section, versus the reference IRI.
- Evaluation summary sheet, showing compliance to the criterion shown in row 3 of Table C.7 (repeatability per calibration section).
- Regression summary sheet showing compliance to regression criteria as shown in rows 4 and 5 of Table C.7.
- Raw data for each calibration section, in electronic and hardcopy format, in Appendices.

Appendix C-1 shows an example of summary sheets for calibration of a response type device in which the calibration does not satisfy the criteria in Table C.7.

It is critical that the network manager accompany the contractor during the calibration testing, and note down values observed during repeat runs, as well as details of the vehicle configuration (e.g. driver used, number of occupants, tyre details, etc). Basic elements of the vehicle configuration should be checked and controlled during the survey. These aspects are addressed in more detail in Section C.5.

C.3.3 Validation of Positioning Equipment

Validation of the distance measurement and location referencing equipment involves checking of the distance measurement instrument (DMI) and Global Positioning System (GPS). Procedures for validation of positioning equipment are included in TMH 13 Part B.

Further Reading: Response Type Devices and IRI

Definitions of response type devices and of the IRI are provided in TMH 13 Part A. The operational concepts of response type devices are discussed in Section C.2.2. Guidelines for the selection of calibration sections and measurement of the IRI on calibration sections are provided in Section C.3.1

Table C.6 Calibration Requirements for Response Type Devices

Parameter	Recommended Requirements for Application Type (Note 1)	
	Lower Reliability	Higher Reliability
Number of sites for each relevant roughness range (Note 2)	2	3
Minimum site length	200 m	200 m
Repeat runs per site	4	5

Note 1: Use the requirements for a lower reliability assessment if the objective of the survey is a once-off estimation of roughness to prioritize maintenance and rehabilitation work. Use the higher reliability requirements if the objective of the survey is to determine a relative indication of network deterioration over a period of time (See Part A and TMH 22 data frequency requirements.

Note 2: Relevant roughness range denotes the ranges shown in Table C.5. The ranges to be covered include only those ranges which may be encountered on the network to be surveyed.

Table C.7 Guidelines for Calibration Acceptance Criteria

Parameter	Recommended Criteria for Application Type :	
	Lower Reliability	Higher Reliability
Scatter plot showing IRI (Y-axis) versus measured parameter	Examine scatter plot and ensure that the relationship is linear, and that the data range covers the range of expected IRI values on the network.	
Coefficient of determination (R^2) for regression (Note 1)	Greater than 0,950	Greater than 0,975
Standard error for regression	0,45	0,35

Note 1: The regression refers to a simple regression analysis. For this regression, the dependent (Y) parameter is the reference IRI over each 100 m of the calibration section. The independent (X) parameter is the measured parameter over each 100 m segment, and for each repeat. Thus, there should be one data point for each repeat measurement on each 100 m segment of each calibration section.

C.3.4 Control Testing

Control testing should be performed from time to time during the survey to ensure that the calibration is still relevant for the device. Control testing is specifically used to determine if there is a gradual shift in the measurements taken by the device, or if the repeatability of the device has changed.

Control testing can be performed on the calibration sections, or special control sections can be identified in different areas within the network. For the control tests, the reference IRI is not needed, since the control check is performed against the raw measurement of the response type device (typically counts per km or metre).

In either case, it is important that the reference values for control sections be determined as soon as possible after calibration, and that the control sections be representative of smooth and rough pavements (relative to the overall range of roughness expected on the network). At least two control sections should therefore be selected, but more if possible.

Control testing should be performed on a regular basis as part of the survey process (discussed in more detail below). If calibration sections are not used for control testing, then control sections can be identified at various locations within the network, which will minimize the travel time to control sections.

Control sections should be at least 400 m in length, and preferably more than 800 m. The general requirements for calibration sections, as discussed in Section C.3.1, should be taken into account when identifying control sites.

Values measured for the control sections after calibration should be used as reference for future testing. For each control section, the IRI values should be determined over each 100 m segment. These IRI values will serve as control values.

Control testing performed during the survey should consist of a once-off remeasure of the IRI over each 100 m segment, and each 100 m IRI value should then be compared with the control IRI values. Each 100 m, IRI values should be within a specified percentage of the reference values on each control site. A maximum deviation of 5 to 10 per cent (using the reference values as a basis) can be considered as a guideline for control testing.

If control testing performed during the survey shows that the measured values had drifted by more than the specified percentage, then the measurement device should be checked for obvious defects. If a defect is found and corrected, and the control testing is acceptable, then the survey can proceed.

However, if an obvious defect is not found, then the device needs to be recalibrated and any data collected since the last successful control test should be discarded and remeasured. *Under no circumstances should control test data be used to adjust the calibration equation for the device*.

It should be obvious that the cost and time implications of a failed control test are severe. For this reason, control testing should be carried out as frequently as possible within the constraints of the network and the survey budget.

The frequency of testing is basically a compromise between the cost of control testing (which not only delays the survey, but requires additional time and travel), and the risk of remeasuring all data collected since the last control test.

As a rough guideline, control testing can be requested at five stages (equally spaced in terms of length surveyed) during the survey process.

Important!

The calibration of a response type device is valid only for the vehicle configuration used during calibration. Thus, all vehicle parameters that may impact on vehicle response should be noted down and should be checked when the calibration report is completed. The vehicle parameters that influence the measurement are discussed in more detail in Section 6.1.

Acceptance criteria for calibration of response type devices should not be enforced too rigidly. It is important that the network manager be involved in the calibration process to assess when special circumstances prevail; which may require a slight relaxation of the calibration criteria. The contract specifications should therefore make provision to allow certain requirements to be overridden by the client where needed.

C.4 Validation and Control Testing for Profilers

The objective of profiler validation is to determine if all of the components in the profiler system work correctly and to validate that all individual components are correctly calibrated. It is important to understand that the objective of profiler validation is not to adjust the profiler outputs to match a predetermined benchmark. A profiler is either accurate and calibrated (i.e. the profiler is "valid") or it is not. If it is not, the profiler should be fixed by the manufacturer.

Another objective of profiler validation is to confirm that the measurement approach adopted by the contractor can provide consistent results in the required format. Validation is therefore carried out for a specific operator and measurement protocol adopted by the contractor.

Important!

The measurement of a surface profile is a complex process which is impacted on by many variables. Calibration of a profiler using comparison to a processed output (such as IRI) should not be attempted under any circumstances.

Whilst the following subsections provide methods and general requirements for the validation and control testing of profilers, it should be noted that the specific requirements should be determined on the basis of the survey objectives, which should incorporate an assessment of available resources and required precision.

C.4.1 Validation Requirements

The same requirements apply for the selection and reference profiling of calibration/ validation sections for response type and profiler devices. Requirements are included in Section C.3.1. Table C.8 presents validation criteria for profilers. The selection of lower and higher reliability levels should take survey objectives (see Part A) into account as well as data collection frequency requirements as stipulated in TMH 22.

The requirements are intended for validation at the start of a contract, and for devices and contractors that have been used before in the network region. When a new device type or a new contractor is being used on the network for the first time, then a higher level validation in which a detailed spectral analysis of the profile wavelengths is performed can be considered. Such validation, however, requires specialist tools and experience and is not covered by these guidelines.

C.4.2 Validation Criteria

A profiler can be accepted as being valid if the measured IRI values over different parts of each validation section have acceptable levels of bias (i.e. if the error between the reference and measured IRI is acceptable) and precision (i.e. if the variation amongst repeated measurements is acceptable). These two aspects should be validated over different speeds. Guidelines for setting validation criteria for profilers are shown in Table C.9.

As shown in Table C.9, the repeatability and bias of the profiler can be validated through the following checks and approaches:

- Checks should be run on the variability of measurements between different repeat runs. This can be done by evaluating the coefficient of variation of the measured IRI at each 100 m subsection for different repeat runs.
- Checks should be run on the level of correlation between the average measured IRI and the benchmark IRI for each 100 m segment within *each individual* validation section. A normal linear regression can be used and limits can be set on the confidence limits for the regression equation slope and intercept. Limits can also be set on the coefficient of determination (R^2). These checks should be performed for all validation sections and at all measurement speeds.
- Checks should be run on the level of correlation between the average measured IRI and the benchmark IRI for each 100 m segment *over all* validation sections. A normal linear regression can be used and limits can be set on the confidence limits for the regression equation slope and intercept. Limits can also be set on the coefficient of determination (R^2). These checks should be performed for all validation sections and at all measurement speeds.
- Absolute limits (in units of the IRI) can be set on the errors between the measured and benchmark IRI values. These errors can then

be monitored for each 100 m segment of each validation section. The limits should be achieved in each repeat run and for all measurement speeds.

- The mean IRI for each 100 m, recorded over several repeat runs, as recorded on a specific day should be checked against the mean IRI for each 100 m recorded on another day.

Further Reading: Example Validation Calculations

Appendix C-2 shows some calculations for the validation of profiler data for a specific validation section and a specific measurement speed. It should be noted that the actual validation should include similar checks on all validation sections and at all measurement speeds.

Important!

The configuration of the vehicle, including the operators, should be noted as part of the validation. The validation exercise should also be used to demonstrate the capability of the vehicle and operator to perform the necessary operational control checks, as discussed in Section C.5.2.

The validation criteria should not be too rigidly enforced. For specific validation sections, special circumstances such as localized distress or high texture combined with low roughness may require special considerations. The network manager should participate in the validation process and should be able to relax validation criteria if needed. However, at all times there should be a high level of confidence in the ability of the profiler to meet general required levels for repeatability and accuracy.

Further Reading: Validation through Spectral Analysis

Appendix A-2 (Part A) contains a basic outline of Spectral Analysis of Profiles. For another basic outline, the Little Book of Profiling [Sayers and Karamihas, 1998] can be consulted. For more information on the use of Spectral Analysis for profiler validation, the following references can be consulted: Prem (1998), Robertson (1998), and Fong and Brown (1997)

For full reference details on the above noted documentation, consult the reference list in Section C.6.

Table C.8 Validation Requirements for Profilers

Parameter	Recommended Requirements for Application Type (Note 1):	
	Lower Reliability	Higher Reliability
Number of sites for each relevant roughness range (Note 2)	1 (minimum of 3 sites)	2 (minimum of 5 sites)
Minimum site length	200 m	200 m
Repeat runs per site	6 (3 runs each at 60 and 80 and/or 100 km/hr, Note 3)	9 (3 runs each at 40, 60, 80 and/or 90 km/hr, Note 3)
Repeated measurements (i.e. repeat of all runs) per site	2 repeats within a day of each other on 2 selected sites	2 repeats within a day of each other on 4 sites
Validate filtering of long wavelengths	1 site of 1 km length	2 sites of 1 km length

Note 1: Use the requirements for a lower precision assessment if the objective of the survey is conducted every two years or more to prioritize maintenance and rehabilitation work. Use the higher precision requirements if the objective of the survey is to determine an absolute indication of network deterioration on an annual or biannual basis (See Section C.2.5 and Part A for details).

Note 2: Relevant roughness range denotes the ranges shown in Table C.5. The sections need only cover those ranges which may be encountered on the network to be surveyed.

Note 3: The road condition may dictate the selected speed range

Table C.9 Guidelines for Validation Acceptance Criteria

Check For	Parameter	Suggested Acceptance Criterion	Scope of Calculations
Error of IRI over 100 m segments	Absolute difference between measured and benchmark IRI over 100 m for each repeat run	80% of values to be less than 8%	Check for each 100 m segment at each speed and on each validation section.
Bias and Variability in measured IRI over 100 m segments (all parameters are calculated from a linear regression between average 100 m IRI from repeat runs and benchmark 100 m IRI values)	R^2 of linear regression	> 0,95	Check for the combined validation data set which includes all repeat runs and all measurement speeds. In this data set, each data point represents a pair of measured (X-axis) and benchmark (Y-axis) values over a 100 m segment of each calibration section. There should be a data point for each 100 m segment of each calibration section and for each measurement speed and repeat run.
	Standard Error of Linear Regression	< 0,3	
	Slope of linear regression	Between 0,9 and 1,1	
	Intercept of linear regression	Between -0,1 and 0,1	
	95% Confidence interval of Slope of linear regression	Should bracket 1,0	
	95% Confidence interval of intercept of linear regression	Should bracket 0,0	
Bias in measured IRI over 100 m segments	Difference in mean 100 m IRI value from repeat runs measured on different days	< 3 %	Check for each speed and on individual validation sections

C.4.3 Validation of Positioning Equipment

Validation of the distance measurement and location referencing equipment involves checking of the distance measurement instrument (DMI) and Global Positioning System (GPS). Procedures for validation of positioning equipment are included in TMH 13 Part B.

C.4.4 Control Testing

Control testing should be performed from time to time during the survey to ensure that the profiler output is still valid and that the accuracy and precision of the device is still within specification.

It is recommended that control testing be performed on the validation sections, and that the same criteria as used for validation (Table C.9), be used for control testing. However, control testing need not be performed on all validation sections, and normally control testing on two or three sites would suffice.

Control testing should be performed on a regular basis as part of the survey process (discussed in more detail below). If control testing performed during the survey shows that the measured values are no longer within the specified limits, then any data collected since the last successful control test should be discarded and remeasured. *Under no circumstances should control test data be used to adjust or calibrate the profiler outputs*.

It should be obvious that the cost and time implications of a failed control test are severe. For this reason, control testing should be carried out as frequently as possible within the constraints of the network and the survey budget.

The frequency of testing is basically a compromise between the cost of control testing (which not only delays the survey, but requires additional time and travel), and the risk of remeasuring all data collected since the last control test.

As a rough guideline, control testing can be requested on a monthly basis or at five stages (equally spaced in terms of length surveyed) during the survey process.

C.5 Operational and Quality Control Procedures

This section of Part C deals with the daily checks and procedures that need to be carried out during the course of a roughness survey. It should be noted that, while this section cover the basic operational aspects and their influence on measurement, the procedures are intended mainly for network managers, and not for contractors.

The network manager is not responsible for performing daily checks or following of proper operational procedures. However, a proper understanding of the elements that influence measurement and of the procedures that a contractor should perform each day, will allow a network manager to exercise better control over the measurement process. The section thus focuses on how operational procedures can be controlled.

The *operators* of measurement devices should – in addition to the elements covered in this section – have an in-depth understanding of the influence of all operational elements on the measurement process. Detailed guidelines for device operators can be found in Sayers et al. (1986), and in NCHRP Research Digest 244 (1999). Additional information can be obtained in the relevant standards for specific device types

C.5.1 Operational Procedures for Response Type Devices

Response type devices directly measure the response of the vehicle suspension to the travelled profile (as discussed in Section C.2.2). For this reason, the characteristics of the vehicle, and specifically the tyres and suspension are critical to the accuracy and repeatability of the measurements.

Some of these elements, such as shock absorber selection and installation of the measurement device in the vehicle, are not within the control of the network manager, but are implicitly controlled by ensuring that the device calibration meets a minimum specification (as suggested in Table C.7). Apart from these elements, there are several operational aspects that should be checked on a daily basis, and which may impact significantly on measurements taken with response type devices. These are [Sayers et al., 1986]:

Further Reading: <u>Guidelines for Contactors and Device Operators</u>

A detailed outline of operational procedures can be found in World Bank Technical Paper 46 [Sayers et al, 1986]. Although this document is now somewhat outdated, it contains detailed discussions of device operation and the control thereof during surveys. The reference is especially useful for operators of response type devices.

ASTM Standard E1082-90 discusses a standard test method for measurement of roughness using a response type device. The standard covers aspects such as preparation before testing, and elements that have an impact on measurement. The standard also specifies a format for output of data and for the summary report.

For profilers, a more updated reference on operational procedures is NCHRP Research Digest Number 244 (1999). This reference discusses all operational aspects relating to profilers with the influence of some parameters on IRI values.

ASTM standard E950-98 covers a standard test method for the measurement of a longitudinal profile using an inertial profiler. The standard covers system checks before measurement, lead in distances before section start and data evaluation for correctness. The format of the output report is also discussed.

- <u>Vehicle Loading</u>: an increase in vehicle weight typically results in an increase in measured roughness. Care should therefore be exercised to ensure that the loading configuration (number of occupants, cargo load and load distribution) is approximately the same as that which was used during calibration. Since the amount of fuel in the vehicle also impacts on loading, a minimum fuel content should be maintained (one third tank is suggested).
- <u>Tyre Pressure</u>: roughness increases with increasing tyre pressure, and the tyre pressure should therefore be checked every morning before the vehicle is started.

- Linkages: all mechanical linkages should be inspected on a daily basis. If some linkages are loose, then the measured roughness may be inaccurate.
- Tyre Imbalance and Out-of-Roundness: high quality tyres should be used, and damaged or worn tyres should be replaced. Control testing, as discussed in Section 4.3, should be performed whenever tyres are changed or balanced.
- Temperature Effects: the damping characteristics of the vehicle suspension have the greatest effect on roughness measurement. Damping characteristics of the suspension are temperature sensitive, especially when the operating temperature is below roughly 5°C. Since the suspension heats up when the vehicle is travelling, temperature effects can be minimized by ensuring that adequate warm-up time is allowed before measurements start each day. Typically, a warm-up time of 10 to 30 minutes is needed, with the longer time being applicable for colder operating temperatures.
- Water and Dirt Contamination: If the vehicle was calibrated in dry conditions, then measurements taken during heavy rain or when the road is very wet may be inaccurate. Care should thus be taken to ensure measurement conditions approximate those of the calibration. The tyres should also be checked periodically during the day to ensure they are free of mud, snow or ice.
- Automatic Speed Control: To ensure that the survey vehicle maintains a constant speed throughout, it must be fitted with a cruise control. In addition to reducing speed variations, this will substantially affect the ease with which the measurements can be done.

As part of the Quality Plan (TMH 13 Part A, Section A.4), the contractor should submit a checklist of items which should be completed and signed off each morning by the operator. This checklist should at least contain checks on all of the elements noted above, with additional vehicle-specific elements as needed.

Obviously, the network manager cannot ensure that all of the checks are rigorously performed each day. However, as a minimum form of control over operating procedures, spot checks should be performed from time to time. These checks should be performed randomly on a weekly or two-weekly basis. During each check, the contractor should be asked to stop the

vehicle and a control check should be performed by the network manager. Table C.10 provides guidelines for items to monitor during random control checks on response type devices.

C.5.2 Operational Procedures for Profilers

Before profiling operations start each day, system checks should be performed to ensure all inertial and distance measurement components are working correctly. The checks should also monitor vehicle parameters such as tyres.

The contractor shall submit a detailed checklist which outlines daily checks that will be performed (see TMH 13 Part A, Section A.4). The contractor's checklist will depend on the vehicle type and the recommendations from the manufacturer. However, as a minimum, inertial profilers should be subjected to the following daily checks [NCHRP Research Digest 244, 1999]:

- Warm-Up Time: adequate time should be allowed for all electronic components to warm up before measurement starts. For the profile measurement components, the manufacturer's recommended warm-up time should be used. The vehicle should be driven for 10 to 30 minutes (longer when operating temperatures are low), to allow the tyres to warm up.
- Check Electronic Components: the measurement components should be checked to ensure cleanliness and correct configuration. Specifically, height sensors should be wiped clean (this may also be necessary several times during the day). If height sensors are covered when not in operation, the covers should be removed.
- Output and Data Collection: the profile output display should be checked (preferably in graphical format) to ensure the system is working correctly. Manufacturer's warm-up times should be adhered to.

- Bounce Test: this test is performed with the profiler stationary on a flat surface. An up-down and sideways rocking motion is induced in the vehicle while the resulting "profile" is recorded. The measured profile should be flat (within 1 per cent of the bounce amplitude).

Table C.10 Checklist for Operational control Checks on Response Type Devices

Control or Decision Aspect
1. Check vehicle to ensure it is the same as used in the calibration exercise.
2. Ensure that the driver is the same as the one who conducted the calibration exercise.
3. Request and inspect the daily checklist. Ensure it meets the Quality Control plan format.
4. Check the number of occupants and cargo configuration to ensure it matches the calibration setup.
5. Check the fuel gauge and ensure that the minimum fuel level is maintained.
6. Check the type of tyres and ensure there is not excessive wear or damage. Confirm the correspondence to the calibration setup.
7. Check the type and condition of the shock absorbers and confirm correspondence to the calibration setup.
8. Check all linkages on the roughness measurement equipment (measurement device and odometer).
9. Confirm the correct operation of the GPS.

- Height Sensor Accuracy Check: this check involves the placement of a stepped block, of which the height of each step is known precisely, under the height measurement sensor. The height to the top of each step is measured and the differences in height are checked against the known heights.

As with response type devices, the network manager cannot ensure that all of the checks are rigorously performed each day. However, as a minimum form of control over operating procedures, spot checks should be performed from time to time. These checks should be performed randomly on a weekly or two-weekly basis. During each check, the contractor should be asked to stop the vehicle and a control check should be performed by the network manager. Table C.11 provides guidelines for items to monitor during random control checks on profilers.

C.5.3 Data Capture and Documenting

The contract specifications should provide details on the format required for the captured roughness data. As a minimum, the specifications should state the format of the required files (e.g. Comma Delimited ASCII file, Spreadsheet format) and the required columns. For roughness data, the required columns would typically include at least the following:

- Operator name;
- Section details (separate columns for Section name, lane, direction, region, etc.);
- GPS latitude, longitude and height;
- Km Position;
- Left and right wheelpath IRI, and
- Measurement speed.

The contractor should also provide a definition sheet to define any codes or abbreviations used in the file and column naming. Details of the format in which the output will be provided should ideally be submitted with the contractor's quality control plan.

The detailed format for reporting on road roughness is included and should comply with the requirements of TMH 18.

Table C.11 Checklist for Operational Control Checks on Profilers

Control or Decision Aspect
1. Check the vehicle and ensure it is the same as used in the validation exercise.
2. Ensure that the driver is the same as the one who conducted the validation exercise.
3. Request and inspect the daily checklist. Ensure it meets the Quality Control plan format.
4. Inspect the vehicle and ensure that the height sensors are free of excessive dirt, mud, etc.
5. Request the operator(s) to perform a height check using a height calibration block. Check to ensure that the measured heights are within limits and ensure that the operator is capable of performing the test consistently.
6. Request the operator(s) to perform the bounce check. Check the output to ensure the measured profile is flat, and ensure that the operator is capable of performing the check consistently.
7. Confirm the correct operation of the GPS.

The specifications (see TMH 13 Part A) should stipulate the deadline for delivery of data files on completion of the survey. It is important to minimize delays between the time of survey and data analysis, in order for errors to be identified as soon as possible. Ideally, some data files should be given to the network manager while the survey is in progress, so that the data can be checked and any inconsistencies identified at an early stage.

The contractor should flag any data files or parts thereof for which measurements are regarded as unusual or in which excessive variations may occur because of environmental effects. Operators should therefore be trained not only in the vehicle operation aspects, but also in the interpretation of IRI and perceived roughness. Also, operators should be aware of the impact of certain pavement and environmental parameters on the precision of measurement, so that files recorded under non-optimal conditions can be clearly flagged for detailed analysis.

C.5.4 Data Checking and Troubleshooting

When the roughness data has been received, the network manager should perform some control checks on a few data files. The objective of these checks should be to ensure the measured roughness corresponds with basic engineering judgement, and that the data are consistent with that of earlier surveys.

For these control checks, the network manager should select a few sections for which the manager is familiar with the roughness properties (e.g. sections with poor riding quality or newly reconstructed sections with good riding quality).

The control check should look at the detailed plotted profile (over 10 or 100 m intervals, depending on the reporting frequency) as well as the segment averages for IRI. If surveys were undertaken in preceding years, then the roughness data can be graphically compared to the data collected in previous years.

Appendix A-3 shows some examples of trends for such comparative plots, and provides guidelines for interpreting each situation. The visual interpretation of data shown in Appendix A-3 can be enhanced by a quantified comparison of the IRI values measured over segments in different years. This comparison could, for example, consist of a correlation between IRI values measured over segments in different years. The coefficient of determination (R^2) can be used as an indicator of the strength of the correlation.

If a data check reveals an inconsistency between the measured roughness and the pavement condition, or between the measured roughness and the roughness of the previous year, then the data file should first be checked for comments from the operator regarding the pavement condition and measurement environment. These aspects are discussed in the following section.

C.5.5 Pavement and Environmental Influences

There are several parameters related to the pavement condition and the measurement environment that can significantly affect measured roughness. Operators and network managers should ensure that they are familiar with key effects, and data files should be flagged if conditions are observed that could impact negatively on the precision and accuracy of measurement. In the event that inconsistencies in roughness data are suspected, the data file should first be checked to determine if the file was flagged and for what reason. The paragraphs below summarize the key parameters that can impact on the repeatability of roughness measurements [NCHRP Research Digest 244, 1999].

C.5.5.1 Pavement Related Influences

The condition and type of the pavement surface has an effect on the repeatability of measurements. This effect is to a large extent caused by the transverse variation of distress within the wheelpaths, and by the inability of the driver to maintain the exact measurement line at all times. Factors that have the greatest impact on measured roughness are:

- Crocodile cracking: if crocodile cracking is present, then the measured IRI from one run to the next may differ by 0,2 to 0,5 m/km. The impact of crocodile cracking on measured IRI is greatest on roads with a low IRI (roughly below 2,0).
- Transverse cracking: this type of cracking also increases the variability of measured roughness for profilers. The significance depends on whether or not a crack is detected by the profiler. Differences in IRI with repeat runs may differ by 0,1 to 0,2 m/km.
- Coarse Texture: the surface texture of the pavement can significantly affect the roughness measured with profilers. Coarse surfaces like single or double seals sometimes lead to anomalies in the measured profile, and ultrasonic sensors should not be used at all on course textured surfacings. Laser profilers also sometimes measure false increases in roughness. The significance of such errors is greatest when the IRI value is relatively low (say, below 2,0 m/km) and texture is high (mean texture depth greater than 1 mm). The magnitude of these errors can be reduced through proper anti-aliasing filter techniques, but some anomalies may persist. Texture does not have a significant impact on roughness measured with response type devices.
- Potholes and Patching: potholes and rough patches are an obvious source of roughness, and as expected the measured roughness will determine whether or not the pothole or patch was hit by one of the wheels. Variation in the travelled line, or change in the severity of potholes from one year to the next may cause significant differences in measured roughness.
- Daily Profile Variations: on concrete pavements, and because of temperature effects, the time of measurement may significantly impact on the measured roughness. Roughness will generally be higher in the early morning hours than in the afternoon, and the difference in IRI measured in the morning and afternoon can vary by roughly 0,1 to 0,3 m/km, depending on the times of measurement. It is thus important to ensure that roughness measurements on concrete pavements are made at the same time of the day, as far as possible.
- Seasonal Variations: movement in the pavement subgrade may impact on measured roughness. These movements will be most severe where there are significant moisture sensitivity or frost heave effects present in the subgrade. To minimize the impact of seasonal variations, roughness surveys should be conducted as far as possible in the same season, and preferably in the same month.

The impact of pavement texture and distress can be minimized if the operator consistently maintains the same tracking line (i.e. if the wheels maintain the same distance from the yellow line). A monitor system or windshield target can assist in consistently positioning the vehicle in the travelled lane.

The impact of seasonal and daily variations on roughness values measured in different years can be minimized by ensuring that the survey is executed in the same season (or month, if possible), each year. For concrete pavements, roughness should preferably be measured consistently in the mid-morning or mid-afternoon periods.

C.5.5.2 Measurement Environment

The environment in which measurements are performed may impact on the repeatability of measured roughness. Operators and network managers should be able to identify conditions that may impact on roughness.

In severe cases, operations should be stopped while the conditions persist. In less severe cases, the operator should flag the data file to indicate that the measurements were taken under non-optimal conditions, and should specify the nature of the problem. Environmental factors that may impact on roughness measurements are:

- Wind: Heavy wind and gusts may affect measured roughness. This effect is more severe for profilers that use ultrasonic height measurement. The effect will also be more severe if there is sand, snow or other contaminants (e.g. leaves or grass) present.
- High Temperature and Humidity: in extreme temperature or humidity situations, the operator should check to ensure that the conditions are still within the operating range for components as specified by the manufacturer.
- Surface Moisture: operations should not be undertaken if there is water standing or flowing on the pavement surface.
- Contaminants: a data file should be flagged if the operator observes contaminants over large parts of the measurement section. Such contaminants may include spilled sand, cement or loose gravel.

Table C.12 Troubleshooting Procedure for Inconsistent Data

Possible Causes of Data Inconsistency
1. Check to see if the data file was flagged by the operator.
2. Check to see that distance markers were not changed between surveys.
3. Check absolute difference error between the IRI of this and the previous survey. If the difference is less than 0,5 m/km, the cause may be inconsistent tracking or normal deterioration.
4. Check the pavement condition as reported in the previous survey year and in the current year.
5. Pavement condition: does the pavement have a coarse texture? This could cause accuracy problems, especially if the IRI is low.
6. Pavement condition: does the section have severe crocodile cracking?
7. Pavement condition: does the section have potholes or patching?
8. Pavement condition: if the pavement is jointed concrete, was the time of measurement roughly the same?
9. Pavement condition: was the pavement possibly flooded, or is the drainage inadequate? Moisture effects will be worse if the subgrade contains active clay.
10. Pavement condition: were the measurements taken in the same season or month (if comparing the results from two surveys)?
11. Environment: were wind conditions severe at the time of measurement? Check for comments or flags in the data file.
12. Environment: was there construction in the measurement area that could have contaminated the pavement surface (spilled sand, loose gravel, etc.)?
13. Environment: check rainfall records in the area of measurement. Was there rainfall during the time of measurement or a possibility of standing water?
14. Environment: check the temperature and humidity records. Were these perhaps outside the operating range of the equipment?

References

Fong, S., Cenek, P.D. and Paterson, D.O. 1998. **IRI Error Estimation by Transfer Function Analysis**. 9th REAAA Conference, Wellington, New Zealand, May, 1998.

Fong, S. and Brown, D.N. 1997. **Transfer Function Based Performance Specifications for Inertial Profilometer Systems**. Opus International Consultants. Central Laboratories Report 97-529351, December, 1997, Lower Hut, New Zealand.

NCHRP Research Results Digest. 1999. National Cooperative Highway Research Program. Transportation Research Board, National Research Council, Washington, D.C. (**Research Results Digest Number 244**, November, 1999).

Prem, H. 1998. **Development and Evaluation of a Method for Validation of Pavement Roughness Measurements**. Contract Report RE7135, April, 1998. ARRB Transport Research Ltd., Vermont South, Vic.

Robertson, D.A. 1998. **Towards a Specification for Validating International Roughness Index Measurements from Road Profilers**. 9th REAAA Conference, Wellington, New Zealand, May, 1998.

Sayers, M.W, Gillespie, T.D. and Robertson, D.A. 1986. **Guidelines for Conducting and Calibrating Road Roughness Measurements**. World Bank Technical Paper Number 46. The World Bank, Washington, D.C.

Sayers, M.W and Karamihas, S.M. 1998. **The Little Book of Profiling: Basic Information About Measuring and Interpreting Road Profiles**. University of Michigan, Ann Arbor, 1998.

Sayers, M.W. 1989. **Two Quarter-Car Models for Defining Road Roughness: IRI and HRI**. Transportation Research Board, Washington, D.C. (Transportation Research Record 1215).

Wikipedia. The Free Encyclopaedia. 6 Feb, 2007. <**http://en.wikipedia.org/wiki/**>

Relevant Standards:

ASTM Standard E 950-98 (Re-approved 2004). **Standard Test Method for Measuring the Longitudinal Profile of Travelled Surfaces with an Accelerometer Established Inertial Profiling Reference**. ASTM International, 100 Bar Harbor Drive, West Conshohocken, PA, USA.

ASTM Standard E 1082-90 (Re-approved 2002). **Standard Test Method for Measurement of Vehicular Response to Traveled Surface Roughness**. ASTM International, 100 Bar Harbor Drive, West Conshohocken, PA, USA.

ASTM Standard E 1364-95 (Re-approved 2000). **Standard Test Method for Measuring Road Roughness by Static Level Method**. ASTM International, 100 Bar Harbor Drive, West Conshohocken, PA, USA.

ASTM Standard E 1656-94 (Re-approved 2000). **Standard Guide for Classification of Automated Pavement Condition Survey Equipment**. ASTM International, 100 Bar Harbor Drive, West Conshohocken, PA, USA.

ASTM Standard E 1926-98 (Re-approved 2003). **Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements**. ASTM International, 100 Bar Harbor Drive, West Conshohocken, PA, USA.

Glossary

Calibration: The process of determining the relationship between the output of a measuring device (e.g. the ARS measured by a Response Type device) and the value of the input quantity (e.g. the IRI). Calibration is often regarded as including the process of adjusting the output of a measurement instrument to agree with the value of the applied standard (definition after Wikepedia, 2007).

DGPS: Differential Global Positioning System. A system that uses a network of fixed ground based reference stations to broadcast the difference between the positions indicated by the GPS satellite systems and the known fixed positions (definition after Wikepedia, 2007).

Dipstick: Commonly used term for the slow moving profiling device named the Face Dipstick™ (patented, manufactured and sold by the FACE Corporation).

Filter: A mathematical function used to process a measured profile, normally with the objective of removing certain wavelengths from the profile. The moving average is an example of a simple filter.

GPS: Global Positioning System.

HRI: Half Car Index. A roughness index calculated by means of the IRI transform, but using the point-by-point average of the two profiles measured in both wheelpaths (as opposed to the IRI, which uses the profile of only a single wheelpath). The HRI is always lower than the IRI.

IRI: International Roughness Index. A roughness parameter determined from a measured road profile in a single wheeltrack. In the IRI calculation, the measured profile is processed using a mathematical transform which filters and cumulates the wavelengths encountered in the profile.

LDI: Linear Displacement Integrator. A response type device manufactured and sold by the CSIR in South Africa.

Profilometer: A mobile device used for measuring the longitudinal profile of a road. The measured profile may or may not be the true road profile, depending on the wavelengths that have been filtered out of the measured profile. High speed profilometers are capable of measuring at normal road speeds. Static profilometers operate at walking speeds or slower (definition after Sayers et al., 1996).

Repeatability: The expected standard deviation of measures obtained in repeated tests, when using the same instrument and measurement team on a single, randomly selected test section (definition after Sayers et al., 1996).

Reproducibility: A measure of the ability to reproduce a measured result (such as the IRI measured over a 100 m segment of road) by another measurement device or measurement team working independently (definition after Wikepedia, 2007).

Resolution: The resolution of a device specifies the smallest measurement increment that the device is capable of.

Riding Quality: Term used to describe the relative degree of comfort or discomfort a road user experiences when using a road. The terms riding quality and roughness are often used interchangeably. In these guidelines, the term roughness is preferred.

Roughness: Term used to describe the relative degree of comfort or discomfort a road user experiences when using a road.

True Profile: The actual profile of the road, relative to a fixed reference point, without any filtering out of certain wavelengths.

Validation: The process of determining if a measurement device, when operated according to a established procedure and within established operating ranges, can operate effectively and reproducibly (definition after Wikepedia, 2007).

Verification: The process of proving or disproving the correctness of a system or measurement device with respect to a certain formal specification.

APPENDIX C-1

CALIBRATION REPORT DETAILS

(RESPONSE TYPE DEVICES)

The figure on the next page shows an example of a calibration dataset as it should be summarized in a Calibration Report. The figure shows the section summary data as prepared for determining the calibration equation. As can be seen from the figure, the data has been ordered to systematically show data in the following columns:

- Calibration section name (shown here as A,B,C, etc)
- Repeat run number
- Measurement speed (shown only for confirmation, since calibration should always be done at the IRI reference speed of 80 km/h)
- Start position for each 100 m segment of the calibration section (note that in this case each calibration section is 200 m long)
- The measured value (ARS) from the response type device
- The reference IRI over each 100 m segment of each calibration section

The graph shows the relation between the measured values (on the X-axis) and the reference IRI values. The clusters of data that are visible on the graph generally represent the measurements of different repeat runs on each 100 m segment of different calibration sections. It should be noted that, for two calibration sections with a similar roughness, the data clusters can overlap significantly and may appear as a single cluster in such a case.

The graph should first be checked to ensure that the relation between the measured ARS and benchmark IRI values is generally of a linear form. If it seems that the relationship is curved or logarithmic, then the calibration data and equation are not valid, and the equipment and data should be checked.

The linear regression data shown below the graph can be obtained with a spreadsheet program. The acceptance criteria for the calibration data are highlighted in green. In this case, the two parameters of interest are:

- The Coefficient of Determination (R^2) which has a value of 0,965;
- The Standard Error which has a value of 0,37.

The acceptance criteria guidelines shown in Table 8 of Section 4.1 are essentially as follows:

<u>Lower Reliability Applications</u>:

- Minimum Coefficient of Determination (R^2) of 0,950
- Maximum Standard Error of 0,45

<u>Higher Reliability Applications</u>:

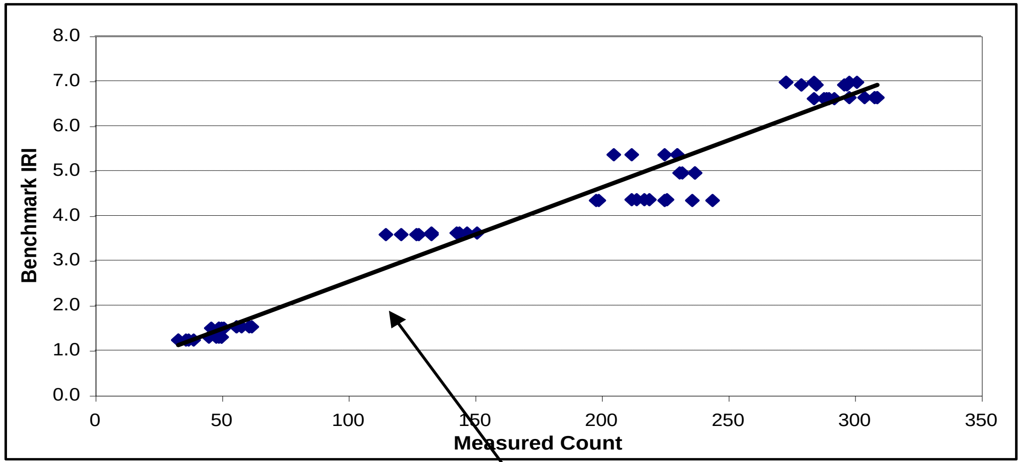
- Minimum Coefficient of Determination (R^2) of 0,975
- Maximum Standard Error of 0,35

Thus this example calibration data set would satisfy the requirements for a lower reliability application (e.g. required only for prioritization or a once-off survey), but not for an application that requires a higher reliability (e.g. annual survey to be used for long term planning).

Part C: Roughness

Prepared Calibration Data				
Section	Repeat	Station	Measured	IRI Bench
C	Run 1	7.3	46	1.49
C	Run 1	7.4	56	1.52
C	Run 2	7.3	49	1.49
C	Run 2	7.4	58	1.52
C	Run 3	7.3	49	1.49
C	Run 3	7.4	61	1.52
C	Run 4	7.3	51	1.49
C	Run 4	7.4	56	1.52
C	Run 5	7.3	50	1.49
C	Run 5	7.4	62	1.52
D	Run 1	7.7	45	1.29
D	Run 1	7.8	37	1.22
D	Run 2	7.7	48	1.29
D	Run 2	7.8	39	1.22
D	Run 3	7.7	50	1.29
D	Run 3	7.8	33	1.22
D	Run 4	7.7	50	1.29
D	Run 4	7.8	33	1.22
D	Run 5	7.7	49	1.29
D	Run 5	7.8	36	1.22
Q	Run 1	37.3	308	6.62
Q	Run 1	37.2	297	6.91
Q	Run 2	37.3	304	6.62
Q	Run 2	37.2	296	6.91
Q	Run 3	37.3	298	6.62
Q	Run 3	37.2	285	6.91
Q	Run 4	37.3	309	6.62
Q	Run 4	37.2	279	6.91
Q	Run 5	37.3	309	6.62
Q	Run 5	37.2	279	6.91
R	Run 1	19.1	230	5.35
R	Run 1	19	237	4.94
R	Run 2	19.1	230	5.35
R	Run 2	19	237	4.94
R	Run 3	19.1	205	5.35
R	Run 3	19	232	4.94
R	Run 4	19.1	212	5.35

Etc. **Etc.**



Check graph for non-linear trends (there should be none). Also, ensure data covers expected IRI range.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.977
R Square	0.956
Adjusted R Square	0.955
Standard Error	0.44
Observations	70

Acceptance Criteria

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	278.3813858	278.3814	1460.212	1.08829E-47
Residual	68	12.9638248	0.190644		
Total	69	291.3452106			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.396533307	0.109552921	3.619559	0.000563	0.17792386	0.615143
X Variable 1	0.020445697	0.000535049	38.21272	1.09E-47	0.019378022	0.021513

APPENDIX C-2

VALIDATION CALCULATION DETAILS

(PROFILERS ONLY)

The figure on the next page shows an example of a validation dataset as it should be summarized in a Calibration Report. It should be noted that the dataset shown on the next page has been abbreviated for conciseness. In an actual validation, there will be more rows of data representing more repeat runs and/or more measurement speeds.

The figure shows the section summary data as prepared for validation. As can be seen from the figure, the data has been ordered to systematically show data in the following columns:

- Repeat run number and validation section number
- Start and end positions for each 100 m segment of the calibration section (note that in this case each calibration section is 200 m long)
- Measurement speed (shown only for confirmation, since calibration should always be done at the IRI reference speed of 80 km/h)
- The benchmark and measured IRI values for each 100 m segment of each calibration section
- The calculated absolute percentage difference between the measured and benchmark IRI values, using the benchmark IRI as base value

The graph shows the relation between the measured IRI values (on the Y-axis) and the benchmark IRI values (on the X-axis). It should be noted that, for two calibration sections with a similar roughness, the data clusters can overlap significantly and may appear as a single cluster in such a case.

The graph should first be checked to ensure that the relation between the measured and benchmark IRI values is generally of a linear form. A line of equality should be plotted on the graph, and a check should be done to ensure the data lies randomly distributed around the line of equality.

If it seems that the relationship is curved or logarithmic, then the calibration data and equation are not valid, and the equipment and data should be checked. Similarly, if the data consistently lies above or below the line of equality, or if the data moves away from the line of equality for higher or lower IRI values, then this indicates a systematic measurement error, and the equipment should be checked.

The linear regression data shown below the graph can be obtained with a spreadsheet program. The acceptance criteria for the calibration data are highlighted in green. For easy reference, the recommended validation criteria shown in Table C.8 of Section C.4.2 are partially reproduced here as Table C-2.1.

It will be noted from the data on the next page that, for this abbreviated example data set, the validation data pass all of the recommended criteria shown in Table C-2.1.

Table C-2.1: Guidelines for Validation Acceptance Criteria

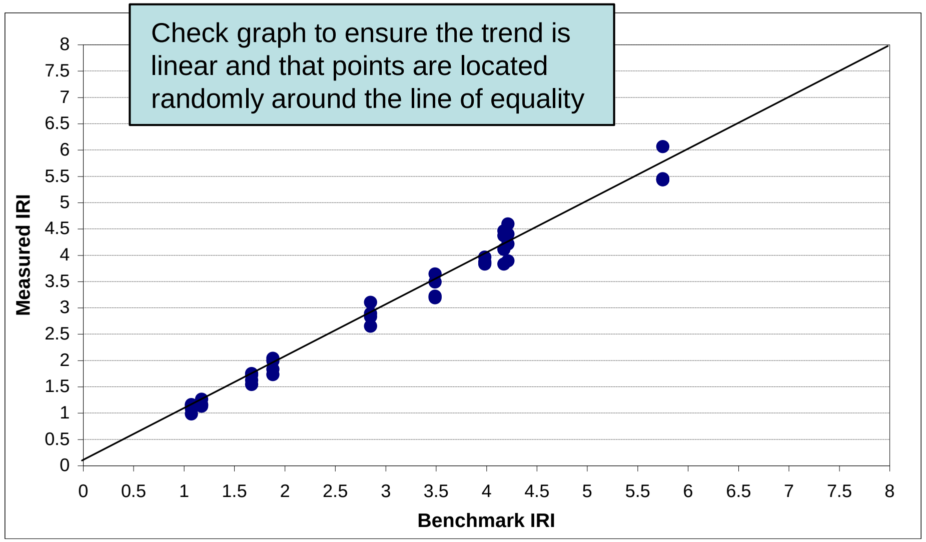
Check For	Parameter	Suggested Acceptance Criterion	Scope of Calculations
Error of IRI over 100 m segments	Absolute difference between measured and benchmark IRI over 100 m for each repeat run	80% of values to be less than 8%	Check for each 100 m segment at each speed and on each validation section
Bias and Variability in measured IRI over 100 m segments (all parameters are calculated from a linear regression between average 100 m IRI from repeat runs and benchmark 100 m IRI values)	R^2 of linear regression	> 0,95	Check for the combined validation data set which includes all repeat runs and all measurement speeds. In this data set, each data point represents a pair of measured (X-axis) and benchmark (Y-axis) values over a 100 m segment of each calibration section. There should be a data point for each 100 m segment of each calibration section and for each measurement speed and repeat run.
	Standard Error of Linear Regression	< 0,3	
	Slope of linear regression	Between 0,9 and 1,1	
	Intercept of linear regression	Between -0,1 and 0,1	
	95% Confidence interval of Slope of linear regression	Should bracket 1,0	
	95% Confidence interval of intercept of linear regression	Should bracket 0,0	

Part C: Roughness

Repeat	Section	From	To	Speed	IRI_Bench	IRI_Meas	% Error
1	A	0.2	0.29	60	1.177	1.15	2%
1	A	0.3	0.39	60	1.076	0.98	9%
1	B	14.5	14.59	60	4.215	3.89	8%
1	B	14.4	14.49	60	3.493	3.64	4%
1	C	3	3.09	60	2.852	2.65	7%
1	C	3.1	3.19	60	3.985	3.85	3%
1	D	3.2	3.29	60	4.176	4.11	2%
1	D	3.3	3.39	60	5.75	5.43	6%
1	E	3.6	3.69	60	1.884	1.99	6%
1	E	3.7	3.79	60	1.673	1.75	5%
1	A	0.2	0.29	80	1.177	1.13	4%
1	A	0.3	0.39	80	1.076	1.16	8%
1	B	14.5	14.59	80	4.215	4.59	9%
1	B	14.4	14.49	80	3.493	3.49	0%
1	C	3	3.09	80	2.852	2.83	1%
1	C	3.1	3.19	80	3.985	3.83	4%
1	D	3.2	3.29	80	4.176	4.37	5%
1	D	3.3	3.39	80	5.75	5.43	6%
1	E	3.6	3.69	80	1.884	2.04	8%
1	E	3.7	3.79	80	1.673	1.54	8%
1	A	0.2	0.29	100	1.177	1.26	7%
1	A	0.3	0.39	100	1.076	1.14	6%
1	B	14.5	14.59	100	4.215	4.4	4%
1	B	14.4	14.49	100	3.493	3.22	8%
1	C	3	3.09	100	2.852	2.89	1%
1	C	3.1	3.19	100	3.985	3.96	1%
1	D	3.2	3.29	100	4.176	4.46	7%
1	D	3.3	3.39	100	5.75	5.45	5%
1	E	3.6	3.69	100	1.884	1.73	8%
1	E	3.7	3.79	100	1.673	1.62	3%
2	A	0.2	0.29	60	1.177	1.16	1%
2	A	0.3	0.39	60	1.076	1.08	0%
2	B	14.5	14.59	60	4.215	4.21	0%
2	B	14.4	14.49	60	3.493	3.19	9%
2	C	3	3.09	60	2.852	3.1	9%
2	C	3.1	3.19	60	3.985	3.87	3%
2	D	3.2	3.29	60	4.176	3.83	8%
2	D	3.3	3.39	60	5.75	6.06	5%
2	E	3.6	3.69	60	1.884	1.83	3%
2	E	3.7	3.79	60	1.673	1.72	3%

Data Set Continues (abbreviated here because of space constraints)…

Percentage Absolute Errors Greater Than 8% = 18%



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.992
R Square	0.984
Adjusted R Square	0.984
Standard Error	0.188
Observations	40

Green Cells denote acceptance criteria

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	85.37438849	85.3743885	2407.58388	5.611E-36
Residual	38	1.347503107	0.03546061		
Total	39	86.7218916			

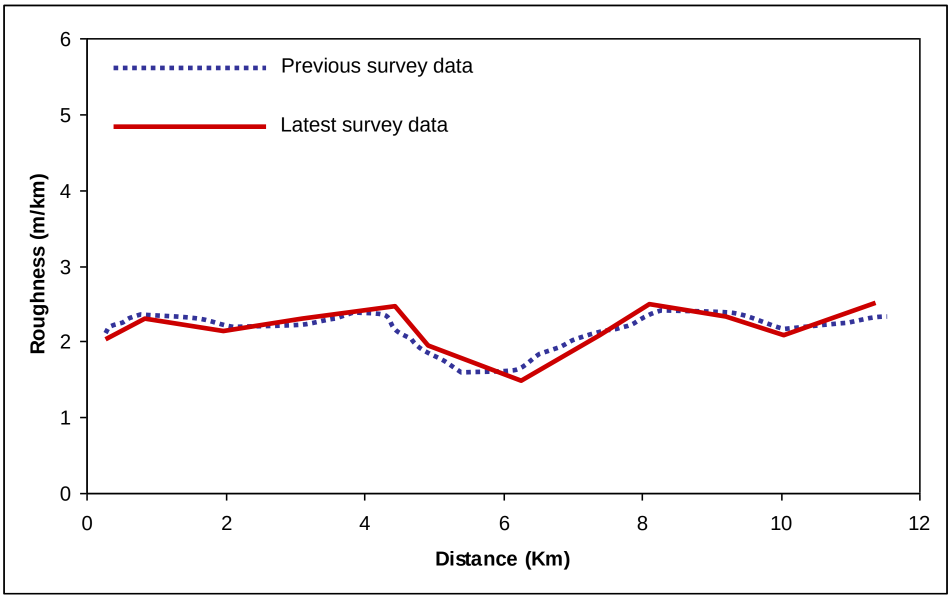
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.002	0.068	0.030	0.976	-0.137	0.141
X Variable 1	1.008	0.021	49.067	0.000	0.967	1.050

APPENDIX C-3

GUIDELINES FOR CHECKING CONSISTENCY

The following paragraphs illustrate typical scenarios that may arise when roughness data from different years are compared. Each situation is illustrated graphically and a description of the general trend is provided. Guidelines for interpretation, including possible causes of problem situations, are then provided.

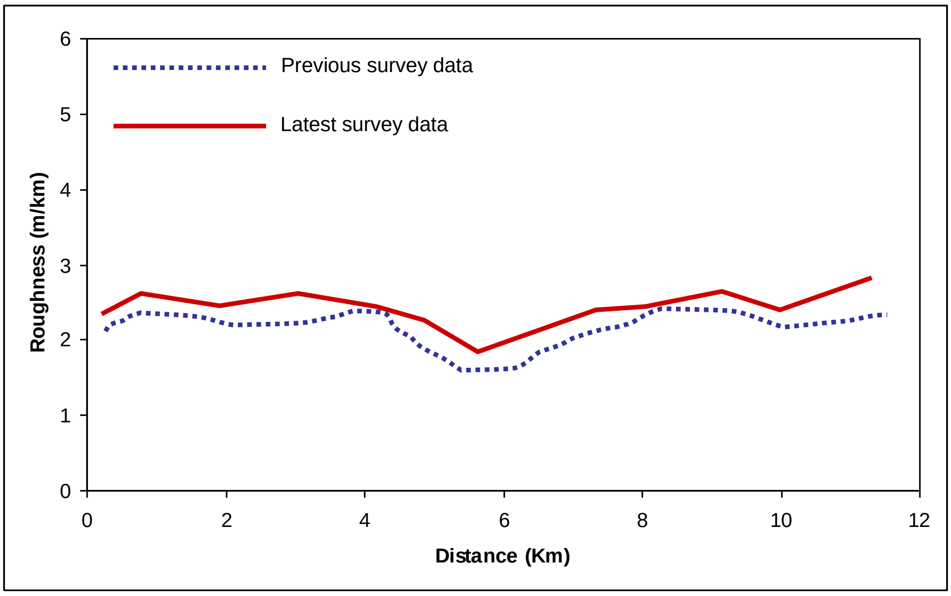
Situation C-3.1



Description: The new data follows the same trend as that of the previous survey. The average IRI value for the section is roughly the same.

Interpretation: Roughness on the section deteriorated little or not at all. The data can be accepted into the database.

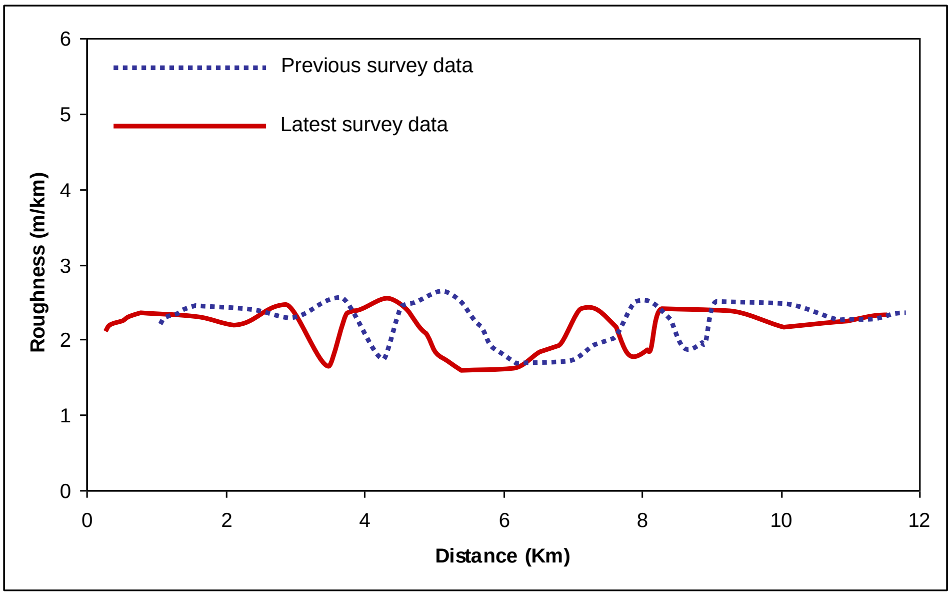
Situation C-3.2



Description: The new data follows the same trend as that of the previous survey, but the average IRI value for the new survey is slightly higher.

Interpretation: Roughness deteriorated within acceptable limits. Data can be accepted into the database.

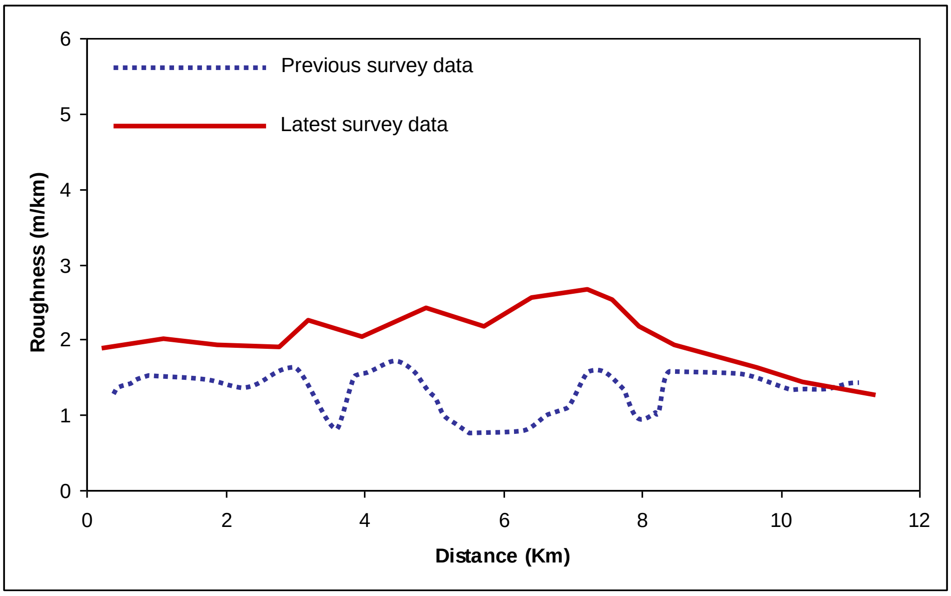
Situation C-3.3



Description: The new data follows the same trend as that of the previous survey, and the average IRI is the same. However, the IRI at specific distance readings differs significantly.

Interpretation: There is a phase difference in the trend of the data. This is most likely caused by inaccurate distance measurement or triggering at the start of the section. The cause of the phase change should be investigated and the problem should be corrected before the data is accepted into the database.

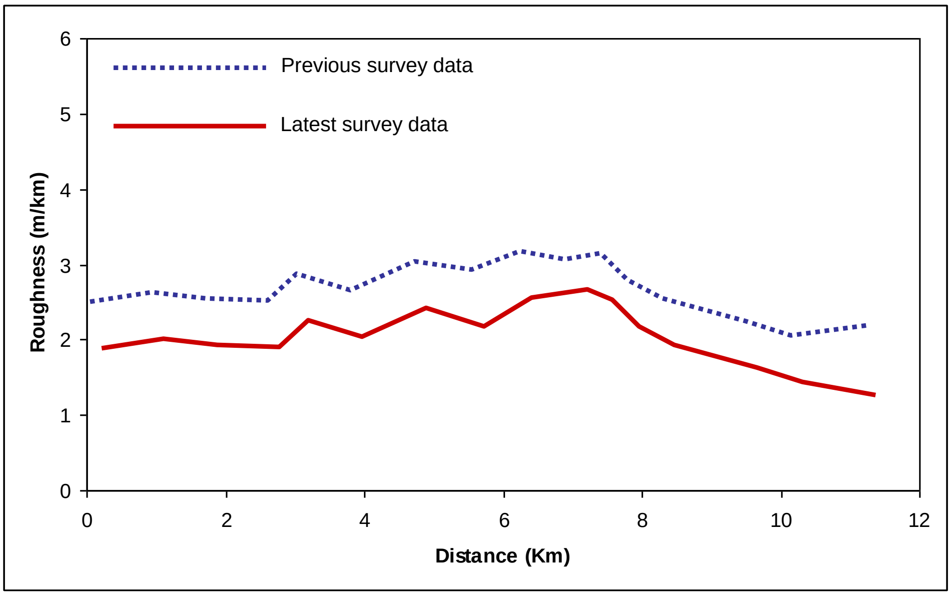
Situation C-3.4



Description: The average IRI for the section is visibly higher and the trend in the IRI data is not the same for the two surveys.

Interpretation: First ensure that the correct section was measured. It may be possible that the section name or starting distance is incorrect. If it is confirmed that the section location and number is correct, perform a visual assessment to determine the cause of the deviation in the data. Possible causes may include severe water infiltration, severe cracking or extensive failures. If the visual condition or road history does not suggest severe deterioration, faulty measurements should be suspected.

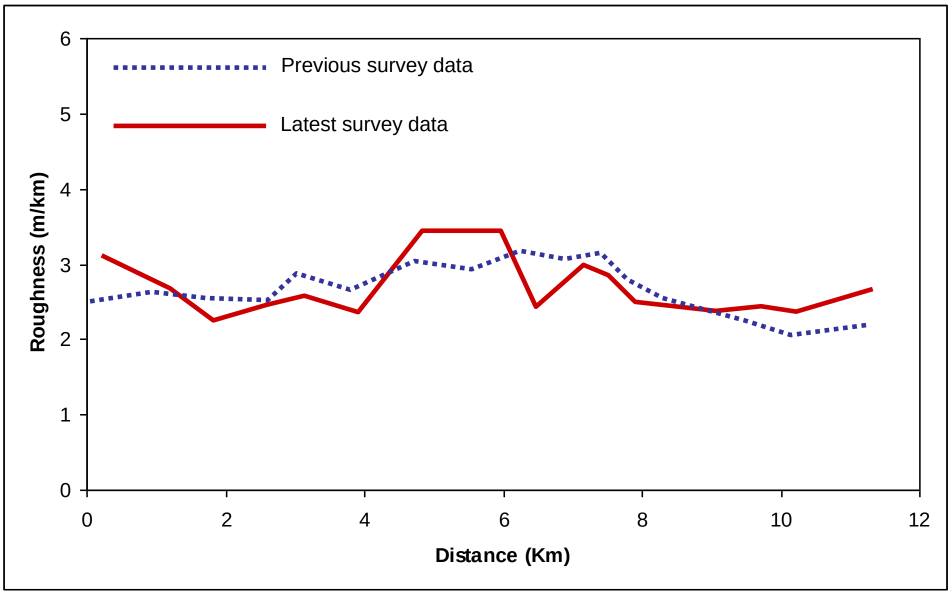
Situation C-3.5



Description: The average IRI for the latest survey is lower than that of the previous survey, but the data trend is the same.

Interpretation: If the data for the previous survey is assumed to be correct, then possible explanations could be that the section received a surface seal or other light maintenance treatment. It could also be that the device is not properly calibrated, or an operational error occurred during measurement. The data can be accepted into the database after a small adjustment is made, provided that the cause of the inconsistency is determined with confidence.

Situation C-3.6



Description: The average IRI for the two surveys is similar, but the data trend is significantly different.

Interpretation: An adjustment to the distance measurement would not address this situation. Since the average roughness for the latest survey is similar to that of the earlier survey, likely causes may include: incorrect section name or starting position; lateral wander; significant variations in measurement speed or a coarse textured surface. Data should not be accepted into the database unless the cause of the inconsistency can be determined with confidence.