South Africa

COTO

Committee of Transport Officials

TMH13

AUTOMATED ROAD CONDITION ASSESSMENTS
PART D: RUTTING

Committee Draft Final

May 2016

Committee of Transport Officials

TECHNICAL METHODS
FOR HIGHWAYS

TMH 13

AUTOMATED ROAD CONDITION ASSESSMENTS
Part D: Rutting

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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.

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Final Standard (FS). After the two-year period, comments received are reviewed and where appropriate, incorporated by the COTO subcommittee. The document is converted to a Final Standard (FS) and submitted by the Roads Coordinating Body (RCB) to COTO for approval as a final standard. This Final Standard is implemented in industry for a period of five (5) years, after which it may again be reviewed. Final Standards (FS) have full legal standing.

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D.1 Introduction

D.1.1 Context and Scope

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

TMH 13 Part D is a companion document to TMH 22 which is the official requirement for Road Asset Management of the South African Road Network. Part D complements TMH 22 on requirements for the collection of rutting data, and specifically the average rut depth in the left and right wheel path 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 As such, 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.

D.1.2 Objectives

The primary objective of TMH13 Part D is to assist road network management personnel to plan, execute and control the measurement of road rutting over a road network.

D.1.3 Layout and Structure of Part D

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 rut measurement. Typical example calculations and reports, or 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:

Section D.2 introduces the main types of rut or transverse profile measurement devices. This section covers both static reference devices as well as high-speed devices used in operational network level surveys. The section also addresses equipment related factors on measurements and minimum equipment requirements.

Section D.3 covers validation and control of transverse profilers. Schemes for the selection of validation sections and typical validation criteria are presented

Section D.4 addresses operational procedures for transverse profilers, and also covers data capture, troubleshooting and documenting aspects. Operational, pavement, and environmental influences that affects rutting measurements are outlined.

References are provided in **Section D.5**, while **Section D.6** provides a glossary.

D.2 Rut Measurement

THM 13 Part A covers the significance of measuring rutting and refers to the use of traditional straightedge measuring equipment as well as more sophisticated non-contact high-speed profilers. In this section, reference devices are introduced followed by profilers used to perform network level surveys. More detailed aspects are provided on systems commonly used in South Africa including minimum equipment requirements.

D.2.1 Reference Devices

Reference devices produce a standard against which measurements can be validated. The process of validating profilers is described in Section D.3 of the document.

D.2.1.1 Straightedge

In South Africa, rut depth measurement in both project and network level applications is defined under a 2 meter straightedge (TRH6, TMH9, TRH12). According to ASTME 1703 rut depth is the maximum measured perpendicular distance between the bottom surface of the straightedge and the contact area of the gage with the pavement surface at a specific location.

The ASTM specification provides generic requirements for both the straightedge and measuring gage. The straightedge should be at least 19 mm wide (max. 75 mm) with sufficient length to span the two highest points on either side of the rut (min. 1.73 m). The finish and rigidity of the straightedge are evaluated against trueness specifications. The bottom surface of the straightedge is required to be true within ±0.4 mm/m in length and 2.5 mm/m in width. The minimum gage width is 19 mm (max. 75 mm) with length sufficient to accommodate the measurement range. The gage is to be graduated to 1 mm (or finer).

Further Reading: Rut Depth Measurements using a Straightedge

ASTM E 1703/E 1703M – 95 (2005): Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge

D.2.1.2 Reference Profiler Beams

The precision of traditional rutting measurements using a straightedge depends largely on operator skill. In addition, the equipment is only suitable for measuring maximum rut depth. For this reason manually operated (as opposed to high-speed) devices have been developed, capable of accurately measuring the full reference transverse profile at a chosen location.

The **Transverse Profile Beam** (**TPB)** showed in Figure D.1 was developed in New Zealand by Data Collection Limited. This device consists of a 3.6 meter beam with a motorised carriage. The carriage moves the beam across the pavement and vertical and horizontal transducers monitor the position of the wheel and its elevation (Bennett, 2002)

Figure D.1 Transverse Profile Beam (Bennett, 2002)

The **Manual Rut Reference Profiler** (**MRRP)** showed in Figure D.2 is a South African product originally developed for Specialised Road Technologies (SRT) to facilitate accurate measurement of the surface transverse profile for rut validation purposes. The device comprises a horizontal aluminium bar with measurement width of 2 meters and a motorised vertical tower equipped with a notebook stand for automated data collection. A "sled" type foot guides the vertical tower across the pavement to minimise the effect of texture.

Figure D.2 Manual Rut Reference Profile (ScienceWare, 2008)

D.2.2 High-Speed Profilers

High-speed profilers are instrumented vehicles that travel over a road using non-contact technologies to measure the transverse profile of the pavement. In this document, profilers are distinguished based on the following technologies:

- Ultrasonic point sensors
- Laser point sensors
- Laser Imaging
- Scanning lasers

Whilst systems using point sensor units (rut bars) can be regarded as traditional technologies, laser imaging and scanning lasers are new generation technologies.

Managers should note that no standardization of measurements or analysis techniques exist between manufacturers. In this regard, factors such as sampling frequency, number of sensors, sensor spacing, and the analysis algorithm used can influence the results and compatibility between results obtained with different devices. A more detailed discussion on the influence of device related factors on rutting parameters are presented in Section D.2.3.

D.2.2.1 Ultrasonic Point Sensors

Profilers with ultrasonic point sensors were commonly used in South Africa in the 1990s. Ultrasonic sensors are the lowest cost sensors and a relatively high number of sensors can therefore be accommodated in these units without significant cost implications. Examples of ultrasonic-based systems are the **ARAN Smart Rutbar** and **ROMDAS Transverse Profile Logger (TPL)**. The sensors are typically spaced at 100 mm centres over any measurement width, i.e. up to 37 sensors can be used to cover a full lane width of 3.6 m.

Transducer or sensor units (measurement bars) normally consist of a main section (limited width to facilitate safe normal travelling) and detachable or hinged extensions to cover the specified width during surveys. Due to the speed of ultrasonic sound waves, these systems typically sample at 2 to 5 meter intervals along the road.

Ultrasonic signals interfere with one another when sensors are placed at intervals less than approximately 300 mm. For this reason modern ultrasonic profilers use arrays of sensors (usually five sensors per array) where sensors in the same array are fired sequentially (also called ‘progressive sampling’). Firing of all sensors in all arrays takes approximately 0.125 seconds. This sampling process means that the transverse profile is in fact a ‘composite’ profile. Lasers are not influenced by this phenomenon and therefore sample simultaneously.

Ultrasonic and laser systems should yield similar results when there is limited longitudinal variation in rut depths. Suppliers of ultrasonic systems argue that whilst ‘progressive sampling’ is inferior to lasers when the longitudinal variation is large, their use of more sensors offers improved results through better characterization of the transverse profile (Mallela and Wang, 2006)

D.2.2.2 Laser Point Sensors

Modern laser profilers are the most popular high-speed systems used in South Africa. Lasers are relatively expensive and even the addition of one laser can have a significant cost implication. Sensor units are therefore manufactured according to the client's needs and budget. For rut measurements, a minimum of three sensors are required. However, because the accuracy of rut calculations is highly sensitive to the number of sensors (and spacing configuration) used, modern devices are seldom equipped with less than 13 sensors. Laser light is much faster than ultrasonics and transverse profiles can therefore be measured as close as every 10 mm along the road.

Figure D.3 shows a typical rut measurement system and apart from the sensor technology used, most of the components are similar for ultrasonic and point laser systems. Similar to ultrasonic systems, laser units normally have detachable extensions to improve transport safety. Whilst lower frequency lasers (typically 16 kHz) are required for profile measurements, one to three of these lasers are normally of a high frequency (typically 64 kHz) to include texture measurements. In addition, units are fitted with an Inertial Motion Sensor (IMS).

IMS data are used to calculate road cross-fall (in conjunction with transverse profile data), gradient, and curvature. One or two accele-rometers may be added to measure vertical body movement which is used in road roughness calculations (see Part C for more details).

The **Dynatest Road Surface Profiler (RSP)** is manufactured with one (roughness only) to 21 lasers (transverse rut profile). The Dynatest system operated locally by Specialised Road Technologies (SRT) is equipped with 17 lasers as shown in Figure D.3. The figure also depicts the typical configuration of normal lasers and angled lasers as well as the IMS and two accelerometers. The laser in the middle and the two in the wheel paths may be specified at a higher frequency to measure texture (Sorensen, 2004; Dynatest, 2010).

Figure D.4 shows the South African Roads Agency Ltd (SANRAL) Road Survey Vehicle (RSV) equipped with a **Greenwood Profilograph.** This sensor unit can accommodate up to 48 point lasers. The SANRAL system currently uses 17 lasers.

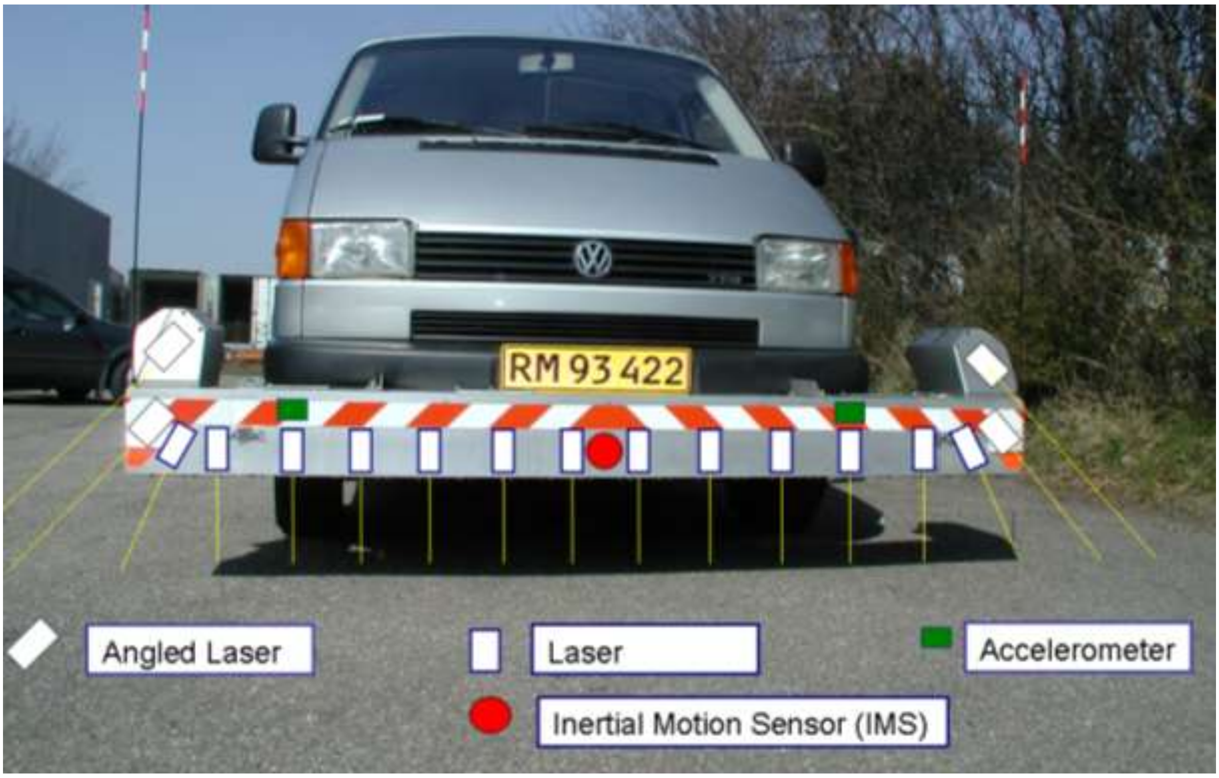

Figure D.3 Dynatest Road Surface Profiler – Typical Configuration (Sorensen, 2004; SRT, 2010)

Figure D.4 Greenwood Profilograph (SANRAL, 2010)

D.2.2.3 Scanning Laser Systems

This technology acquires rutting data utilising processes commonly employed in industrial applications to capture 3D information of surfaces. In these processes lasers project either lines (line scan mode) or point clouds (rotating scan head) on the objects under consideration. Images of the transverse profile are digitized from pavement surface data.

The **Laser Rut Measurement System (LRMS)** by INO uses two laser profilers that digitize transverse profile sections of the pavement. Custom optics and high-power pulsed laser line projectors allow the system to operate in full daytime or night time conditions. This system can produce 1280 points per profile over a nominal width of 4 meters (INO, 2008).

Figure D.5 LRMS (INO, 2008)

Phoenix Scientific's **Pavement Profile Scanner (PPS)** uses Laser-Radar (Ladar) technology to sample the full pavement width from a scanning laser mounted 2.3 m above the ground. This system can sample 950 points across the transverse profile every 25 mm along the pavement. Whilst scanning lasers can measure profiles with high accuracy they are relatively expensive (Wang, 2005).

D.2.3 Device Related Factors Influencing Measurements

This subsection focuses on traditional profilers equipped with rut bars that sample transverse profiles at discrete points. The information presented follows from a study on 'Harmonising Automated Rut Depth Measurements' conducted by Bennett and Wang (2002) and Mallela and Wang (2006).

Profiler designs differ in the way they collect and process data. The following system related aspects can affect the reported measurements:

- Algorithms used for profile analysis, and
- Sensor type
- The number and spacing configuration of sensors.

The main factor that drives the accuracy of measurements is the ability of the profiler to locate high and low points in the profile measured.

D.2.3.1 Rut Depth Algorithms

All systems are based on the concept of measuring the elevation at each sensor to establish the transverse profile. Whilst manufacturers use proprietary algorithms to calculate rut depth, three basic models exists:

a) **The Straightedge model** is widely used since it relates directly to manual rut measurement methods. As previously indicated, the 2 m straightedge is the standard reference for rut depth measurements in South Africa. The FHWA algorithm is an example of an analytical procedure used to emulate manual straightedge measurements.

b) **The Wire model** is popular due to its analytical simplicity. This model stretches an imaginary wire between the high points on the profile and the maximum distance between the pavement and the wire constitutes the rut depth. Wire model rut depths relate to straightedge model rut depths in the following ways:

- When the high points are spaced at a distance *less than or equal* to the straightedge length, the rut depth measurements from the two models should be *equal*, and

- When the high points are spaced at a distance *greater* than the straightedge length, the wire model ruts will be *greater* than those from the straightedge model.

c) The Pseudo-rut model is more commonly used in systems equipped with limited sensors – such as 3 or 5 point sensor units – which have not been used in South Africa. The pseudo rut is simply the difference in elevation between the highest and lowest points measured. Bennett and Wang (2002) reports that even under a full profile, the pseudo-rut statistic yields a poor correlation with rut depth measured under a 2 m straightedge. The use of this statistic is not recommended.

Further Reading: Rut Depth Algorithms

The following aspects are presented in more detail by Bennett and Wang (2002):

- Evaluation of basic rut depth algorithms
- FHWA Straightedge Algorithm

D.2.3.2 Number and Spacings of Sensors

Figure D.6 illustrates two different hypothetical systems measuring the same profile. The difference in number of sensors and spacing configuration will result in recording of different high and low points, and therefore different rut depth estimates.

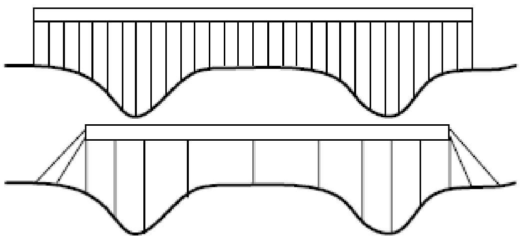

Figure D.6 Impact of number of sensors and spacing configuration

The impact of the number of sensors for *equal spacing* designs are summarised below.

- An increase in the number of sensors significantly improves the measurement accuracy;
- The degree of improvement declines with increasing sensors and little improvement results from using more than 25 sensors;
- Discrete measurements result in underestimation of rut depth. Even with 60 sensors, the rut depth would still be underestimated with approximately 1 mm, and
- With less than about 15 sensors, there can be a significant underestimation of the true rut depth.

The spacing configurations of point sensors are often irregular by design to assist in locating the high and low points by focusing the measurements where they are most relevant. Aspects of *optimised (irregular) spacing* design are summarised below:

- The measurement error can be up to 15 percent depending on the design of the profiler (equal spacing or optimal design), and
- The gain in accuracy form sensor rearrangement is more significant for units with 10 to 16 sensors. As the number of sensors increase the gain from rearrangement diminishes.

The ability of profilers to locate the high and low points of profiles under operational conditions is also influenced by the number and configuration of sensors. In this regard, an increase in the amount of lateral variation of the survey vehicle (or wander) significantly impacts on the accuracy of the measured rut depth. Hence:

- The greater the number of sensors and the closer they are spaced, the greater the probability of locating the low and high points, and the lower the error
- On pavements with kerbs or without surface shoulders, the potential exists to measure outside the pavement area. With a modest number of sensors (10 to 16), i.e. large spacing, key profile data are missed if additional readings are not performed on the on the kerb/ shoulder side of the profile.

D.2.4 Data Sampling, Storage, Recording, and Processing

As discussed in the previous sub-section, network level profilers can sample at high frequencies which depends on the type of sensor employed (e.g. 16kHz, representing a maximum sampling rate of 16 000 observations per second). Some systems calculate and record rut depth statistics for the selected segment length in real time. These systems do not, however, store all the raw data and the operator typically has to specify the storage interval. Other systems rely on the data stored at the selected storage interval to calculate rutting parameters during post-processing. The selected storage interval may therefore vary from 50 to 1000 mm depending on the system used. Systems that record rut depth statistics in real time do not need a small storage interval, whilst systems that rely on post-processing require storage intervals in the order of 100 mm. In either way, raw transverse profiles are available for post-processing using the manufacturer's software or other software. In network level applications, 10 meter segment lengths are commonly used to report rutting parameters as required by TMH 22 for South African road networks.

Manufacturer's software typically offers a selection of rut depth statistics for reporting, such as: Discrete value at a specified interval, average value over segment length, and the maximum value over the segment length. Although the range of parameters and statistics available for reporting depends on the software, the raw data allows a more detailed assessment of the data if required. In some cases, service providers use their own customized software to perform quality control checks and to calculate additional parameters such as pond width and pond depth.

TMH Requirements: Data sampling, storage, recording and processing

TMH 22 Part D provides requirements for data collection and reporting. The average rut depth in each wheel path should be recorded and stored in 10 m intervals whilst data reporting is required for 100 m intervals.

D.2.5 Equipment Specification

The equipment specification defines the minimum requirements and should cover aspects such as instrument type, precision and recording intervals.

As described in preceding sections, accuracy of rutting is dependent on the number of sensors, sensor spacing and sampling rate. Different types of equipment were introduced which vary considerably in terms of capability and cost. For this reason any of the systems may be used as long as they meet the validation requirements outlined in Section D.3.

Table D.1 provides the minimum requirements that will produce optimum results for vehicle-mounted equipment designed to measure the pavement transverse profile. In addition, specifications may be included to for the survey vehicle, survey computer and operating systems as well as software requirements. General guidelines on these aspects are outlined in TMH 13 Part A.

Table D.1 Validation Requirements for Profilers

Primary Sensor Parameter	Minimum Specification for	
	Sensor Equipment	**Data Acquisition System**
Equipment Type	Laser or Ultrasonic Sensor	Not Applicable
Minimum No. of Sensors	15	> No. Sensors
Minimum Measurement Width	32000 mm (Note 1)	Not Applicable
Measurement Speed	80 km/h	Not Applicable
Resolution	0.05 mm	16 Bit
Longitudinal Sample Interval	50 mm	10 milliseconds
Measuring Range	±100 mm	> 200 mm
Repeatability	0.1 mm	±1 LSB
Frequency Response	DC to 16 kHz	> Sensor Output
Operating Temperature	0°C to 50°C	0°C to 50°C
Long Term Drift	< 0.3 %	< 0.003% ±1 LSB
Number of sensors	≥ 13	> Sensor Output
Measurement width	≥ 3.4 m	Not Applicable
Stand-off distance	≥ 300 mm	Not Applicable
Simulation Capabilities	Not Applicable	2m Straightedge model with anti-alias filters to control anomalies due to kerbs, shoulder drop-offs etc.
Legend: IMS = Inertial Motion Sensor; LSB = Least Significant Bit		
IMS Parameter (Note 2)	**Minimum Specification for Inertial Motion Sensor**	
Equipment Type	Gyros + Accelerometer sensor (minimum 1 sensor)	
Resolution	≥ 10 µG	
Measuring Range	± 2G	
Bandwidth	DC – 300Hz	
Minimum Sampling frequency	10 Hz	
Operating Temperature Range	0°C – 50°C	

Note1: The equipment should be adapted (where possible) to accommodate the surface width characteristics or anti-alias filters should be used to control data anomalies.

Note 2: For systems that include an inertial sensor to measure discrete distances from the road surface to the inertial platform to establish the absolute position of the measured transverse profile.

D.3 Validation and Control Testing

TMH 13 Part A introduces general aspects of calibration and validation that require consideration during the survey planning process. Calibration refers to the individual components or units of a system that has to measure to a given standard, whilst Validation tests the accuracy, repeatability and reproducibility of the system as a whole under normal survey conditions.

Important!

Calibration of the equipment only confirms that a measurable or specified tolerance can be achieved for individual system components. Calibration does not confirm the appropriateness of the parameter measured from a moving vehicle on the network under consideration.

Validation confirms that the equipment, operator, and adopted measurement protocol can provide meaningful data of sufficient accuracy while operating under normal surveying conditions.

A validation program should be conducted prior to acceptance of the equipment and/or before data collection starts. Equipment is either accurate or calibrated or it is not. If it is not, the equipment should be fixed by the manufacturer. In the context of this document, validation encompasses equipment calibration, including the effects of operational variables. Section D.3 provides a framework for selection of validation sections and provides validation criteria for acceptance and control testing of transverse profilers.

D.3.1 Validation Requirements

General considerations when planning a survey and aspects to be covered in the specifications are outlined in TMH 13 Part A. This section should therefore be read in conjunction with Part A. Key aspects related to validation sections are the selection of the sections, profiling of the sections and processing of the calibration section profile data to facilitate validation. Validation requirements are presented in Table D.3.

D.3.1.1 Selection of Validation Sections

The same profilers system is often used to measure roughness (longitudinal) and rutting (transverse). To ensure efficiency and therefore compatibility of the validation processes it is recommended that requirements for selection of roughness validation or calibration sections be considered (see Part C). Aspects specific to the selection of rut measurement validation sections are outlined below.

- Validation using manual reference profilers or straightedges can be time consuming and a section length of 200 m is therefore recommended. Where manufactured profiles are used, such sections are sometimes omitted. It should be noted, however, that availability of a data set to investigate the correlation between reference and high speed measurements can be valuable and this practice is recommended.
- Validation of specified parameters, such as average rut depth over 100 m, requires longer validation sections. For this reason, it is recommended that a combined data set be used.
- Representative rut depth ranges should be determined based on the characteristics of the network. It should be attempted to allocate sites approximately proportional to the ranges identified. Table D.2 provides rut depth ranges for consideration when selecting sections.

Table D.2 Rut Depth Ranges

No of Sites (Note 1)	Section Length*	Rut Depth Range
> 3	200 m or > 500 m	0 to 5 mm 5 to 10 mm 10 to 20 mm 20 to 30 mm > 30 mm

Note 1: Also refer to Table D.3

To set-up the validation criteria using Table D.3, 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 Part D.

D.3.1.2 Rut Depth Reference Surveys

Validation sites need to be characterized independently through reference surveys before the network survey starts. Reference devices were introduced in Section D.2. Reference transverse profiles should be measured using a special reference profile beam, traditional survey equipment or other approved method. The reference survey method must be static and capable of measuring the transverse profile at 100 mm centres to a vertical accuracy of ±0.25mm.

Whilst the reference profile approach is preferred, the straightedge and wedge method (for measuring rut depth; see Section D.2) can be used if manual profiler equipment is not available or for other valid reasons.

The following procedure is recommended for the measurement of reference transverse profiles on validation sections:

- Identify sections representing different rut depth ranges (Table D.2). Record and mark-out start and end positions of validation sections.
- Positions for measuring reference profiles should be marked out every five meters along the entire length of each validation section. Each position should be labelled.
- Normally the starting position of the validation section is used to locate the reference positions in the data file. This is often done by marking the starting position on the surface with a sensor-sensitive material or adhesive system. This will facilitate automatic recording of the starting position during high-speed data collection. If this approach is followed, the average profile over a 500 mm length in the vicinity of the estimated reference position can be calculated.
- Alternatively, a sensor-sensitive adhesive system can be applied on the surface at each of the reference profile positions which will enable automatic detection and flagging of these positions in the data file. Although this approach ought to be more accurate, practical considerations will require some experimentation.
- Calculate left and right wheel path rut depths and other relevant rutting parameters from the reference transverse profiles using the specified analysis method (see Section D.2).

D.3.2 Validation Criteria

A profiler can be accepted as being valid if the measured rut depth (or other parameters) have acceptable levels of accuracy (or bias, i.e. the error between validated and reference measurements) and precision (or repeatability, i.e. acceptability of the variations between repeated measurements) of the parameters under consideration. These two aspects should be validated stationary and over different speeds. Guidelines for setting validation requirements and criteria for profilers are shown in Tables D.3 and D.4, respectively.

D.3.3 Validation of Positioning Equipment

The validation of positioning equipment involves checking of the Global Positioning System (GPS), Inertial Navigation System (INS), and Distance Measuring Instrument (DMI). *Checks and approaches to validation these systems are included in TMH 13 Part B*.

D.3.4 Control Testing

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

Control testing should be performed on validation sections and the same criteria as used for validation apply. Normally testing on two or three sites would suffice. Control testing should be performed as frequently as possible (to effectively control risk) within the constraints of the network and survey budget. If control testing 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 re-measured.

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

Table D.3 Validation Requirements for Profilers

Parameter	Requirements for Application Type (Note 1):	
	Lower Reliability	Higher Reliability
Number of sites for each relevant rut depth range (Note 2)	1 (minimum of 3 sites)	2 (minimum of 5 sites)
Section length – Reference (Note 3) Section length (min.) – High speed	200 m 500 m	200 m 500 m
Repeat runs per site	6 (2 runs each at 60 and 80 km/h or according to condition)	9 (3 runs each at 40, 60 and 80 km/h or according to condition)
Repeated measurements 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

Note 1: Use the requirements for a lower precision assessment if the survey is conducted every two years or more, or if the objective is 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 Part A). Also refer to data collection frequency requirements as stipulated in TMH 22 Part D.
Note 2: Relevant rutting depth range denotes the ranges shown in Table D.2. The sections need only cover those ranges which may be encountered on the network surveyed.
Note 3: Reference measurements always include static measurements and may include both static and high speed measurements.

Table D. 4 Guidelines for Validation Acceptance Criteria

Check For Example	Parameter	Typical Acceptance Criterion	Scope of Calculations
Error of transverse profile height measurements (static and high-speed)	Relative difference between static/ high-speed measured transverse profile heights and the heights at the same points from reference transverse profiles	90% of values to be within ±2 mm	Include each measurement point on each profile for each validation section. For high-speed measurements this check is done at each speed.
Error of static rut depth	Maximum wheel path rut depth	Each rut depth to be within ±1 mm or 10% (whichever one is greater) of the reference	At least five locations on validation sections OR five manufactured artificial profiles representing different rut ranges
Bias and Variability in Rut Depth over 100 m segments	R^2 from linear regression	≥ 0.9	Check for combined validation set (all sections) including both wheel paths, all repeat runs and all speeds
	Slope of linear regression	Between 0.9 and 1.1	
	Intercept of linear regression	Between -2.5 and 2.5 mm	
Repeatability of Rut Depth over 100 m segments	Coefficient of Variation for individual segments and each series of repeat runs	90% of values to be less than 7%	Check at each speed for combined validation set (all sections) including both wheel paths
	Average Coefficient of Variation (Std. Dev)	≤ 5%	
	R^2 from linear regression between individual segment values (Y-axis) for each run and mean values over series of runs (X-axis)	≥ 0.90	
Bias in measured Rut Depth over 100 m segments with time (drift)	Difference in mean value from repeat runs measured on different days	≤ 3%	Check at selected speed for combined validation set over both wheel paths

D.4 Operational and Quality Control Procedures

This section of Part D deals with the daily checks and procedures that need to be carried out during the course of a rutting survey. While this section covers basic operational aspects and their influence on measurement, these 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 the network manager to exercise better control over the measurement process.

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. Relevant standards and operational manuals should be consulted for detailed procedures.

D.4.1 Operational Procedures

Device specific operational procedures should be those furnished by the manufacturer of the device. 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.

As part of the Quality Control Plan (see TMH 13 Part A) the contractor should submit a detailed checklist which should outline daily checks that will be performed. As a minimum, the following daily checks should be performed.

- Survey Requirements: A job card or similar system should be used to accurately communicate the survey requirements. For example, these may include: Definition of test sections (e.g. road/ interchange name and number, description/location of start and end positions); facility (e.g. slow lane, slow, middle and fast lanes, off-ramp)
- Safety: Check that the vehicle is generally safe, that all components are correctly mounted, and that no foreign objects are present. Ensure that all warning signs and devices are in place. Check that safety equipment (such as fire extinguishers) and first aid kits are in place and in good condition. Where applicable, ensure that only personnel trained in laser safety procedures are involved in validating or handling of the measurement system.
- Calibration: Check that calibration of all sensors is traceable and that all requirements are up to date, especially after a service or replacement of components. If the sensor equipment is dismountable, ensure that calibration is performed after reinstallation.
- General Maintenance: A daily maintenance inspection checklist should be available and followed before departing for testing. Some components should be checked on a daily basis, whilst others require checking on a weekly or monthly basis according to the manufacturer's recommendations. Check that the essential tools and spare parts are available.
- 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.
- Electronic Equipment: 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).
- 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.
- Straightedge Test: A quick validation of the height sensors and system output should be performed by placing a metal straightedge at a fixed distance from the sensors (close to middle of sensor operating range). The measured rut depth should be negligible (i.e. less than 1 mm).

Since the network manager cannot ensure that all checks are rigorously performed each day, spot checks should be performed from time to time. Table D.5 provides guidelines for items to monitor during random control checks.

Table D.5 Checklist for Operation Control Checks on Transverse Profilers

Control or Decision Aspect
1. Check the vehicle and test device 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. Ensure that the calibration records are up to date and valid and inspect the service record of the vehicle.
4. Check that that the vehicle is safe, and equipped with fire extinguishers, hazard triangles, first aid kit etc.
5. Request and inspect the daily checklists. Ensure it meets the Quality Control Plan format.
6. Inspect the vehicle and ensure that height sensors are free of excess dirt, mud etc.
7. Request the operator(s) to perform straightedge tests. Check that the measured rut depth is less than 1 mm in all cases.
8. Confirm the correct operation of the distance measurement instrument, GPS and inertial sensors

D.4.2 Data Capture and Documentation

The contract specifications should provide details on the data format required. 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 (or fields). For rutting surveys, the required columns would typically include the following:

- Operator name;
- Date and time of record;
- Section details (separate columns for section name, lane, direction, region, etc.);
- Km Position
- GPS latitude, longitude and elevation;
- Measurement speed, and
- Rutting parameters (Left wheel path or left and right wheel path), for example:
  - Average Rut Depth
  - Maximum Rut Depth
  - 90th Percentile Rut Depth

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 specifications 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 because of operating conditions or any other cause. Operators should therefore be trained not only in vehicle operation aspects, but also in the interpretation of perceived deflection values. With adequate knowledge of the impact of different conditions on the precision of deflection measurements, files recorded under non-optimal conditions can be accurately flagged for detailed analysis.

The detailed format for reporting on road rut measurements is included and should comply with the requirements of TMH 20.

TMH Requirements: Data Format and Reporting

The detailed format for reporting on road rut measurements is included and should comply with the requirements of TMH 20.

D.4.3 Data Checking and Troubleshooting

After receiving the rutting data, the network manager should perform control checks. The objective of these checks should be to ensure the measured values correspond with basic engineering judgement, and that the data are consistent with that of earlier surveys.

For these control checks, a few sections with known rutting characteristics should be selected. If surveys were undertaken in previous years, the data can be graphically compared to the data collected in previous years.

Concepts of troubleshooting are illustrated in Part C for roughness measurements, Appendix C-3. If the data check reveals an inconsistency between measured rutting and the pavement condition or between the measured rutting and rutting reported in the previous year, then the data file should first be checked for comments from the operator regarding survey conditions. These aspects are discussed in more detail in the following section.

TMH Requirements: Data Management

TMH 22 Part D includes criteria and considerations for Data Management and Quality Control and Acceptance.

D.4.4 Operational, Pavement and Environmental Influences

Section D.2 introduced equipment related factors (number of sensors, sensor spacing and sensor type) that influence transverse profile measurements. These aspects are therefore excluded from this section. All equipment should be calibrated and validated according to the guidelines presented in Section D.3.

There are several parameters related to operation, pavement, and environment that can significantly affect rut measurements. 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 rutting data are suspected, the data file should first be checked to determine if the file was flagged and for what reason. The following paragraphs summarise key parameters that can influence rutting measurements. Since the profilers are used to measure both transverse and longitudinal profiles, influences on these measurements are similar (see Part C on roughness).

D.4.4.1 Operational Influences

These types of influences are inherently part of any survey and are normally induced by road features such as potholes, traffic lights etc.

- Lateral placement: Because the vehicle cannot be positioned in exactly the same wheel path between successive operational surveys, lateral placement variation occurs. This variation depends on the amount of lateral wander, shape of the profile and number of sensors. The impact of this effect is especially significant when trying to monitor rutting between years.
- Speed and manoeuvring: Test speeds outside the specified operating range, especially low speeds, can impact on the measurements. Other factors are hard acceleration/ deceleration and cornering.

D.4.4.2 Pavement Related Influences

Modern survey vehicles are equipped with high quality cameras that enable capturing of the road and road side features. These technologies can be used effectively to identify pavement related influences on measurements, such as:

- Geometry: Tortuous road geometry induces cornering effects, acceleration and deceleration.
- Edge effects: Anomalies introduced by kerbs and shoulder drop-offs are common and should form part of standard post-processing of the data.

- Joints and crossings: Bridge joints, culverts, and railway crossings are typical features that can influence the data.
- Traffic calming installations: The presence of speed bumps and traffic circles should be noted.
- Potholes/ Failures and Patching: The condition of the pavement surface exacerbates variation in the travelled line. A change in the severity of potholes (either from deterioration or patching) from one year to the next may cause significant differences in measured rutting.

D.4.4.3 Environmental Influences

The environment in which measurements are performed may impact on the repeatability of measured profiles. In severe cases, operations should be stopped while conditions persist. In less severe cases the operator should flag the data file to indicate that the data was collected under non-optimal conditions, and should specify the nature of the conditions. Environmental conditions that may impact on profiler measurements are:

Wind: Heavy wind and gusts may affect profiler measurements. This effect is more severe for profilers that use ultrasonic sensors. The effect will also be more severe in the presence of sand, snow and other contaminants.

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 of components as specified by the manufacturer.

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 of 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 or loose gravel.

D.6 References

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Relevant Standards:

ASTM E 1703/E 1703M – 95 (Reapproved 2005). Standard Test Method for Measuring Rut-Depth of Pavement Surfaces using a Straightedge.

D.7 Glossary

Accuracy: The difference between a measured value (or average) and a target or standard value. See Bias.

Bias: Also known as Accuracy. Bias is also linked to the stability of an instrument. For example, an instrument may be zeroed during calibration or verification which implies that bias changes with instrument use, also known as drift.

Calibration: The process of determining the relationship between the output of a measuring device and the value of the input quantity. Calibration is often regarded including the process of adjusting the output of a measurement instrument to agree with the value of the applied standard (definition after Wikipedia, 2007)

Deformation: A change in the road surface profile.

Drift: See Bias.

DPGS: 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 Wikipedia, 2007).

GPS: Global Positioning System.

Precision: The variation among repeated measurements. See Repeatability.

Profilometer or Profiler: A mobile device used for measuring the transverse surface profile using contact or non-contact sensors. High-speed profilers are capable of measuring at normal highway speeds. Static profilers are commonly used as reference devices.

Repeatability: Also known as Precision. 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.

Reproducibility: A measure of the ability to reproduce a measured result by another measurement device or measurement team working independently (definition after Wikipedia, 2007).

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

Rut depth: In South Africa, rut depth is commonly defined as the maximum permanent deformation measured under a two meter straight edge placed transversally over the rut. Rut depth is one of several parameters that can be used to characterise the transverse surface profile, or rutting.

Rutting: Rutting is the longitudinal permanent deformation that occurs in the wheel paths of flexible pavements.

Transverse Surface Profile: Two-dimensional sample of the pavement surface in the transverse direction measured by sensors (such as lasers).

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 Wikipedia, 2007).

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