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HiSPEQ: Hi-speed survey Specifications, Explanation and Quality

Identifying the key requirements for surface condition measurements – report for consultation

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HiSPEQ

Hi-speed survey Specification, Explanation and Quality

Identifying the key requirements for surface condition measurements – report for consultation

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Author(s) this deliverable:

R Spielhofer (AIT)

E Benbow, A Wright (TRL)

PEB Project Manager: Rolf Rabe

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1 Introduction and purpose of this document

Road administrations rely on high quality condition data to understand the condition of the asset and plan and undertake maintenance programmes on their networks. High speed surveys have become a key source of this information, providing data on the shape and condition of the road surface and, in recent years, the structural robustness and the structure of the pavement itself. These high speed systems bring the advantage of network wide data collection without interfering with the traffic flow. They can provide coverage of the network which would be impractical for traditional surveys to achieve. They have lower survey costs per km than slow speed surveys and bring data that does not suffer from the subjectivity or inaccuracy of manual surveys. The data can be provided in a very structured manner (for example condition parameters reported every 10m accurately located relative to section, distance and geographical position) and can be easily fed into pavement or asset management systems.

High speed surveys therefore bring significant practical advantages to condition assessment, to support robust asset management. However, previous research (the HeRoad project) found a wide range of policies across countries to define the requirements for the survey equipment, the survey frequencies and the data delivered. Each country appears to adopt its own requirements, each subtly different from one another. This is perhaps unexpected, given that the equipment used to collect this data within different countries is likely to be quite similar. A factor that contributes to this situation is the lack of standardisation for many of the measurements, and where standardisation does exist (e.g. for profile) it is limited in its practicality and may be too complex for road administrations to understand. Hence there is a need for information to be made available to road Authorities to assist them in confidently defining the requirements for their surveys, to help them have confidence in selecting equipment and to help them ensure that the data that is provided is accurate and fit for purpose.

The objective of the HiSPEQ project is to develop guidance, advice and templates that can be used by road Authorities to help them understand high speed road survey equipment, to help them specify survey requirements and quality regimes, and to help obtain good value from the data delivered.

To make sure that the scope of the project is practical, the project is concentrating on the aspects of high-speed survey data collection that help in the assessment of pavement structural robustness. This does not mean that the survey methods considered are only those that measure structural robustness directly (e.g. pavement deflection), but the measurements should be related to structural condition. For example cracking is measured under surface condition surveys, but the defect arises from deterioration in the structural condition of the pavement. As a result, measurements relating to friction, e.g. skid resistance, surface texture, are excluded from HiSPEQ and we have not discussed devices whose only purpose is to measure texture.

The approach taken has been to combine technical expertise drawn from the project consortium with a review of previous research and a review of many existing survey specifications to propose the key requirements that should be considered by a road administration when developing a specification for high-speed condition surveys of their network. **This document concentrates on the requirements for surveys that measure the surface condition of the pavement (carried out under Work Package 1 of HiSPEQ). The summary findings and recommendations for the measurement of the surface condition are presented within the next section (2).**

It is the intention of HiSPEQ, within in the next phase, to develop the key survey requirements proposed in this document into a set of templates that could be used by road administrations to support the development of survey specifications. The advantage of this would be that more commonality will be achieved across Europe in the definition of surveys, enabling improved consistency between the measurements collected and also allowing survey providers to develop equipment that could be more easily adopted to carrying out surveys in different countries. The next phase will then build upon those draft survey specifications to propose templates that equipment manufacturers could use to describe their equipment that could be more easily related to the specifications, enabling potential purchasers/users of the survey equipment to better compare potential equipment capabilities with their requirement specifications.

Whilst developing these specifications and templates HiSPEQ wishes to ensure that the proposals for the key survey requirements are aligned with the experience and expectations of stakeholders. Therefore we are issuing this report to stakeholders to invite views on the recommendations that have been made. The project team welcomes comment and views from stakeholders, which will be taken into consideration when confirming the requirements summarised in section 2, and in the subsequent development of survey specification templates*.*

As a guide to this document, it contains the following key sections:

1 Introduction and purpose of this document: This introduction section

2 Summary recommendations for surface condition information from high-speed surveys: Here we present our summary recommendations for the key data requirements for surface condition measurement, for review and comment.

3 Technical background, research: This section presents a technical background for surface condition surveys and reviews previous research in this area, which we have drawn upon in developing our recommendations.

3.2 Information sources on survey data requirements: This section presents a review of current survey specifications employed in Europe and elsewhere, which we have drawn upon in developing our recommendations.
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Definitions: A summary of the definitions of technical terms used in this document

2 Summary recommendations for surface condition information from high-speed surveys

2.1 Note on types of condition data included

As reported in section 3, the assessment of durability (structural condition) using high speed surface condition surveys is usually achieved through the assessment of visual deterioration (e.g. fretting and cracking) and transverse and longitudinal road surface shape. Although these measurement are not sufficient per se to completely determine pavement durability, these parameters are generally incorporated in the estimation of how long a pavement will last and what measures are to be taken to extend its lifetime. Thus, the following surface properties are considered to be important for the assessment of pavement durability, and are the only surface properties that will be considered in the HiSPEQ project:

- Pavement shape (both transverse and longitudinal)
- Surface deterioration, including potholes, cracking, fretting or ravelling.

The review of existing specifications (section 3.2) and consultation with experts (in the project team or colleagues), has been used to propose the following key data requirements for a high-speed surface condition survey to collect data for assessment of pavement durability.

2.2 General requirements

These requirements are independent of the type of survey data to be provided.

2.2.1 Selection of a data or an equipment specification

This is a fundamental area that a road administration must address when developing a strategy for the delivery of their survey data. Two main approaches can be distinguished for specifying a high-speed condition survey: The first approach is to specify the equipment that is to be used for the survey (referred to as an “equipment specification”). The second approach would to specify the delivered data only, i.e. the output of the measurements (referred to as a “data specification”).

Regardless of the approach, the road administration must determine what data is needed for the asset management process, what accuracy is needed, what type of measurement is required, etc. Implicitly this suggests that the first stage of defining a specification should be to decide what data is needed, which fundamentally defines the data specification. The administration may then consider the types of equipment that might be able to meet this specification, in order to determine whether their requirements can actually be delivered by the industry. However, this does not suggest that the administration should then define that equipment as the required system, as this restricts the ability of the administration to achieve competition. It is therefore recommended that an administration should think very carefully before defining particular types of equipment in a survey specification.

In HiSPEQ our aim is to define key requirements for the data collected by high-speed condition surveys and our approach follows our recommendation that the specification should be based on the data requirement, not the equipment. The type of measurement equipment used is left completely to the contractor. However, HiSPEQ will be providing guidance on how equipment should be described to assist authorities in understanding how a piece of equipment under assessment would meet their data requirements.

A further area of note when developing a data specification is that, if put to the extreme, it might be that only one device from one manufacturer is able to fulfil the demands of the data specification. This is not a desirable situation, as it does not stimulate competition if every contractor then has to use the same equipment, and it also inhibits innovation. An understanding of the equipment market is therefore desirable when developing a data specification.

Where, as recommended by HiSPEQ, a data specification approach is followed, accreditation testing of devices and subsequent quality assurance is necessary to ensure the delivered data is consistent with the survey data requirements. For effective accreditation, for all three surface properties, a certain reference test method and consequently a reference device is necessary. These devices have to deliver trusted results, which is a challenge on its own. An independent accreditation body that has proven to have the necessary knowledge and capabilities is essential to make such a specification work. A dedicated proving ground and well-surveyed real roads are necessary to conduct the accreditation. These topics are the subject of Work Package 3 of HiSPEQ, for which a separate recommendation document is being produced.

2.2.2 Network

It is common practice for the specifications to include a basic definition of the network to be surveyed (e.g. length), and it is logical that this should be included in any survey specification. We found that it was less common to provide a more detailed network definition and survey strategy. However, including this information assists the survey contractor and road administration in understanding the underlying objectives of the survey and to provide well located data that is straightforward to load into the client’s databases. We recommend that information provided should include:

- the length of each road section to be surveyed
- survey direction (ascending or descending chainage)
- number of lanes to be surveyed
- time frame and frequency of the survey should be specified
- A digital network graph.

2.2.3 Location Referencing

A second general requirement is to define the approach to locating each measurement. The review identified, at one level, the use of road identifier (usually road number or section ID) and chainage, the use of geographic coordinates, or both.

Specifications should clearly state the location referencing method to be applied. It is strongly recommended that geographic coordinates are used, if a geographically defined network is available, as this method can result in improved locational accuracy. However, to achieve improved locational accuracy it is necessary to stipulate accuracy requirements, as both distance and geographical methods can be subject to large errors. It would be appropriate to require geographical position accuracies to the level of a few metres or better.

Where geographical location referencing is being used the method that will be applied to project the measured coordinates to the network map (so-called “map-matching”) should be specified as well. The measuring direction should also be reported to allow correct localisation.

We suggest that there is a need for the data quality to be tested as part of any acceptance process, under varying survey conditions.

2.2.4 Survey conditions

The environmental conditions for conducting the survey should be specified. This would usually cover road condition (dry road surface for laser devices, clean road surface), survey speed (e.g. minimum speed for measuring longitudinal profile with inertial profilers) and a minimum operating speed for a certain road category to ensure that traffic is not obstructed. One could argue that specific conditions, e.g. dry road condition, should not be specified, because there might be a device that could be able to measure in different conditions to common survey devices e.g. there may be equipment that can measure profile on a wet road. It could be left to the contractor to state which conditions their device can measure accurately in and demonstrate this during Accreditation testing. The requirement would then be that surveys are only carried out in those conditions.

2.2.5 Data format

A clear data format should be defined to ensure any raw data delivered can be processed, or that any processed data can be loaded into the road owner's Pavement Management System.

It was found that defined data formats are already in use for (national) road administrations, but there is no internationally recognized format. This means that each contractor might have to develop many different file format delivery systems for their deliverable data to cover the various survey contract that might have.

The format has to define:

- The location and content for each data value
- The meta-data like time of survey, contractor etc.
- The resolution of each value (e.g. 10^{ths} mm).

2.2.6 Data delivered: raw or processed

This is a fundamental area that a road administration must address when developing a strategy for the delivery of their survey data. The review identified two main options for data delivery:

Delivery of the raw data e.g. transverse profile

Delivery of raw data requires that the data processing (i.e. the calculation of parameters from the measured raw values) is done centrally. The survey contractor would deliver e.g. the transverse profile data points and central software would then calculate rut depth and other parameters for reporting over a certain reporting length. The benefit of this option is that the indicator calculation is consistent over all contractors. Also, if the calculation changes in subsequent years, if the raw profiles are delivered, the whole survey can be re-calculated and re-evaluated, using the new calculation. Thus data consistency can be ensured.

Having the raw data at hand also opens possibilities of use of the data beyond current parameters and even beyond pavement management, e.g. for a detailed site evaluation after an accident. This would not be possible if, for example, only averaged rut depth parameters over 100m are delivered.

The downside of the raw data approach is that the road administration must develop the algorithms to calculate the parameters and then define them for implementation by the contractor, or implement them into software owned by the administration.

Delivery of processed parameters. E.g. the rutting measurements calculated from the transverse profile

To deliver processed the contractor processes the data into parameters such as a rut depth parameter before delivery. There is no need to define the algorithms centrally and potential data volumes and handling by the administration is reduced. There is however a greater risk of inconsistency especially if changing from one contractor to another. It is also more difficult to track down issues with quality in the data.

2.3 Measurement of transverse evenness

The review identified a wide range of requirements for the delivery of transverse profile, covering various transverse spacings and measurement point distributions, and longitudinal spacings. There did not appear to be much consistency between the specifications and many of the specifications probably do not define a requirement that would enable the optimum measurement of rut depths. Many specifications only define the delivery of the derived indicator/parameter. It is felt that this presents some risk to the administration regarding the achievable accuracy and repeatability.

It is recommended that a requirement for the raw transverse profile measurements should be included as this will lead to higher consistency in the data delivered by multiple devices or contractors. The data specification for the raw transverse profile measurements would specify that a number of transverse profiles should be measured or delivered including

- A definition for the measured width – we suggest this should be more than 3m (perhaps as high as 4m for highways?)
- The minimum number of transverse profile measurement points – we suggest a minimum of 20 points, preferably more, ensuring a maximum transverse spacing of 150mm between points.
- A defined distribution of points - we suggest evenly distributed across the transverse profile measurement.
- A defined maximum longitudinal spacing (we suggest a minimum of 100mm)
- A requirement to identify and/or eliminate the effect of road markings measured within the profile.
- A specified required valid speed range for the measurements.

The specification for the delivered data (whether it is raw or processed) would also specify

- The required repeatability of the data collection of the transverse profile measurements
- The required accuracy of the collected transverse profiles with respect to a reference method (which also needs to be defined)
- The required accuracy of any derived parameter (e.g. rutting) with respect to a reference method (which also needs to be defined).

Where processed parameters are required to be delivered then either software to calculate them should be provided, or a definition for how the calculation is to be performed should be clearly defined.

We suggest that there is a need for the data quality to be tested as part of any acceptance process, under varying survey conditions

2.4 Measurement of longitudinal evenness

Even if the requirement is only that processed parameters be delivered by the survey, it appears to be good practice to define the raw measurements from which the processed parameters are calculated, as this will lead to higher consistency in the data delivered by multiple devices or contractors.

Thus, a data specification would specify the delivery of a (number of) “longitudinal profile(s)” with the following requirements:

- Must cover a certain wavelength range (we suggest a minimum of 0.1m to 50m – but this requires investigation in terms of its effect on derived parameters to be calculated from the longitudinal profile)
- Must have a maximum longitudinal spacing (we suggest somewhere between 25mm and 100mm)
- Must be collected in both wheel paths as a minimum. The specification should formally define the geometry of the wheel paths.
- Has a specified required valid speed range for the measurements
- Has a specified distance between the wheel paths.

The specification for the data delivered (whether it is raw or processed) would also specify

- The required accuracy of the collected longitudinal profile(s) with respect to a reference method (which also needs to be defined).
- The minimum level of repeatability of the collected longitudinal profile(s).
- The required accuracy of any derived parameter (e.g. IRI) with respect to a reference method (which also needs to be defined).

Where processed parameters are required to be delivered then either software to calculate them should be provided, or a clear definition for how the calculation is to be performed. It is not recommended that reference is only made to a standard. It will at least require clarification of the standard (e.g. defining the pre-filters or the reporting length), but a more robust result is likely to be achieved by stating the specific requirements for calculation.

We suggest that there is a need for the data quality to be tested as part of any acceptance process, under varying survey conditions.

2.5 Measurement of Surface deterioration

Surface deterioration, collected by high-speed surveys, is commonly obtained from analysis of 2D or 3D downward facing images. To obtain consistent results, the images need to be of good enough quality and high enough resolution for the required deterioration parameters to be obtained. We propose that the image requirements have such a significant effect on the resulting parameters that there is a need to specify the core requirements for the images. Thus, a data specification for surface deterioration would specify:

- A minimum measurement width (we suggest 3m or more)
- A minimum resolution per pixel in the longitudinal direction (we suggest 1mm or better)
- A minimum resolution per pixel in the transverse direction (we suggest 1mm or better)
- For 3D images, a minimum resolution in the vertical direction (we suggest 0.5mm or better)
- A requirement for image quality that covers: brightness across the picture (i.e. no banding, or darker/lighter patches), focus, etc.
- The required valid speed range for the measurements.

We suggest that there is a need for image quality to be tested as part of any acceptance process, under varying survey conditions, to ensure that the system will be able to operate under different ambient light conditions. Or the specification should define the time of year or day that surveys should be carried out.

In terms of the derived parameters, we suggest that any specification should clearly state

- Whether the analysis must be automatic or whether manual intervention is permitted.
- The types of deterioration to be identified
- A definition for each of these deterioration types.
- The accuracy to which each deterioration type should be reported with respect to a reference method (which also needs to be defined).

3 Technical background, research and current specifications

3.1 Surface condition data for structural deterioration / durability

In recent years there have been several research projects carried out that investigated the application of high-speed routine monitoring of road surface condition in Europe. COST 354 (2003-2007) investigated the methods used for determining longitudinal and transverse evenness, texture, friction, noise, air pollution and bearing capacity and developed single and combined performance indicators (La Torre et al., 2007). This found that asset management systems mainly use combined indicators which make use of surface condition parameters (which are measured) and other parameters like age of the pavement, thickness of layers, etc. (static data).

HeRoad (2011-2012) asked road operators about their needs for road condition data and what an ideal measurement practice would look like. For service quality, the assessment of the level of comfort (covering transversal and longitudinal evenness), the level of splash and spray and the percentage of length affected by potholes or significant local defects were mentioned. For safety, the assessment of the level of roughness, the ability to shed water, the level of splash spray and again the percentage of length affected by potholes, or significant local defects were mentioned, among others. For durability, the assessment of the structural strength of the pavement, visual deterioration (e.g. fretting and cracking) and transverse road surface shape (structural rutting) was considered essential (Benbow et al., 2012).

Although the measurement of transverse and longitudinal evenness and surface deterioration are not sufficient per se to completely determine pavement durability, these parameters are generally incorporated in the estimation of how long a pavement will last and what measures are to be taken to extend its lifetime. The ingress of water into the pavement’s structure will lead to a reduction in the pavement’s structural strength and hence its durability. Thus the presence of surface defects that allow such ingress, e.g. cracking, fretting, are likely to shorten a pavement’s life. Therefore, deformation of a pavement’s shape and visual condition are powerful indications of the structural condition of the pavement, and hence its durability.

Thus, the following surface properties are considered to be important for the assessment of pavement durability/structural robustness, and are the only surface properties that will be considered in the HiSPEQ project:

- Pavement shape (both transverse and longitudinal)
- Surface deterioration, including potholes, cracking, fretting or ravelling.

3.2 Information sources on survey data requirements

Fifteen specifications for high-speed routine monitoring were collected and reviewed to identify the current key measurement practice in the collection of surface condition. The specifications cover the surface measurements identified above as being related to pavement durability i.e. the measurement of longitudinal evenness, transversal evenness and surface defects. Although some of the specifications did cover other pavement surface properties not relating to pavement durability (e.g. texture), these were outside the scope of this project.

In order to review the specifications in a consistent manner a set of questions were developed and each specification was reviewed against those questions. This enabled a set of tables to be populated for each specification. The following sections break down the findings into a set of topic areas and summarise the findings within that topic.

To support the review additional information was also sourced from the HeRoad reports into pavement condition assessment (Benbow & Wright, 2012; Sjögren, Benbow et al., 2012; Žnidarič, 2012; Casse & van Geem, 2012; Haider & Gasparoni, 2012, Sjögren et al., 2012).

3.3 General observations

All of the specifications reviewed were for network-wide surveys. The surveys carried out under the specifications cover the networks and lengths listed in Table 1 below.

Table 1: Network length

What length is the network that is surveyed?	
Australia	Australia is split into "member authorities" and they do different levels (digital images detailed below as discussed in appendices to AP-T169-10) RTA: 15000 to 20000 km over annual 6-8 month collection season. VICROADS: 22 000 lane-km with roughly half the network surveyed each year. DTMR: 30 000 lane km of sealed, 5575 km of unsealed. MRWA: 35 000 lane-km DTEI: about half of 13 000 km carriageways DIER: 3500km for the total road length of the survey done in the first year; further years depend on region size. approx. 7000km lane-km ACT TAMS: 1800 lane-km over three years DLP: Full sealed road network survey is approx. 11 900 lane-km including 5500 lane-km for the national network. Unsealed network survey length is up to 15 600km.
Austria	4400 km carriageway length
British Columbia, Canada	Not stated within specification
France	Not stated within specification
Germany	52.000 km (12900 km motorways, 39100 km primary roads)
Ireland	5400 km
Morocco	1024km (Fez-Oujda 321km)
Netherlands, national roads	3760 km
Netherlands, regional roads	The total length of the regional road network in the 11 participating provinces is approximately 14,000 km of traffic lanes. Approximately 5,000 km surveyed annually.
New Zealand	22,000 lane km
Slovenia	Motorways and expressways: 1320 km carriageway length; other roads: 5960 km
Sweden	Yearly 75 000 km (total paved network ~ 98 500 km)
UK	>150,000km
UK 2	40,000 lane km
USA: California	About 4,500 miles (72,400km)
USA: Louisiana	20,600 directional miles

3.4 Survey conditions and survey speed

In this area we were seeking to determine whether it is current practice to define limits on the range of conditions under which surveys should be carried out (e.g. are they limited to certain seasons, temperatures, daytime, or road condition).

The results are shown in Table 2. In summary, many specifications demand dry and clean road conditions. This may be seen in connection with laser sensors being the most common measurement devices for transverse and longitudinal evenness. The accuracy of laser measurements are usually only defined for dry targets, as the laser is scattered when measuring in water. On the other hand, every surveyor should know about the technical limitations of his device, meaning that dry surface conditions would not have to be specified explicitly. Implicitly, based on current measurement equipment, it is not possible to deliver correct data on wet roads.

Survey speed is – if specified at all – often specified as “traffic speed” only, ensuring the speed is high enough to not disturb traffic flow. If too strict a definition of survey speed were to be specified, this could lead to large lengths of missing/invalid data if roads with high traffic volume are to be surveyed. As long as the measurement itself does not depend on speed, the possible obstruction of traffic should be the main constraint for the survey speed. One should bear in mind that the very commonly used inertial profilers are speed dependent due to the accelerometer they use and so a minimum speed is required for correct results.

Table 2: Survey conditions and survey speed

Country	**Are survey conditions specified? (road condition, temperature, season)**	**Is the measurement speed defined?**
Australia	Testing must be terminated if conditions are such that difficulty is encountered maintaining the required test lane and/or minimum test speed resulting in the collection of invalid data. Testing must not be performed during periods of rain or where the road surface is wet. If a localised section of wet road is encountered it must be noted and/or flagged Arrangements shall be made to test the section when weather conditions are more favourable, if required.	Throughout the survey the vehicle must be driven in a smooth manner, and care must be taken to ensure that the speed of travel is within the manufacturer’s operating range wherever possible. In validation it requires "highest test speed (nominally 100 km/h)"
Austria	Dry and clean road	Not specified, but 60 km/h is considered as standard measurement speed
BC, Canada	Not specified	Not specified
France	No obstructing traffic	70 km/h (>30km/h)
Germany	Dry and clean road	Not specified
Ireland	Not specified	Prevailing traffic speed
Morocco	Not specified	Not specified
Netherlands national roads	Not specified	Not specified

Country	**Are survey conditions specified? (road condition, temperature, season)**	**Is the measurement speed defined?**
Netherlands, regional roads	The measurements may only be taken in the daytime, after sunrise and before sunset, on a dry road surface.	Minimum and maximum speeds are set, depending on the speed limit of the road: Speed limit (max speed)/Min speed <50 / 0 50 / 40 60 / 50 80 / 70 100 / 80 120 / 80 If the motorised traffic on a road section is moving more slowly than the applicable maximum speed limit, the minimum surveying speed may be up to 10 km/h less than the speed of the motorised traffic on that section.
New Zealand	Not specified	Not specified, but all vehicles must be sufficiently powered to be able to travel at the normal highway operating speed when fully loaded
Slovenia	Dry and clean road, min air and surface temp 5°C	Depending on device.
Sweden	No measurement in night-time since images are collected, measurements should not be carried out in wet road conditions.	Traffic speed but maximum 90 km/h and minimum 15 km/h when collecting usable data.
UK	Not directly specified but all of the contractors know that they shouldn't survey in the wet, as this will affect all measurements made with lasers: This is likely to be identified by the QA tests	The surveys have to be carried out at traffic speed, so within the speed limit but also limited by the surrounding traffic. The range of speeds and accelerations for which valid data can be collected are determined within the Accreditation tests.
UK 2	Not specified	The speed of the vehicle should match the surrounding traffic. The range of speeds and accelerations for which valid data can be collected are determined within the Accreditation tests.
USA: California	Not specified	Not specified
USA: Louisiana	Not specified	Not specified

3.5 Survey strategy

The term "survey strategy" covers many aspects. The concept is fundamentally one of making sure that the road owner has a clear plan for the application of surveys and that this is being made clear to the survey contractor when asking them to undertake surveys. It can include items such as:

- frequency of survey
- definition of the network: ranging from a list of road numbers and begin/end kilometres to detailed road network graphs
- road classes covered by the survey
- number of lanes covered in the survey
- sequence of network parts measured each year
- delivery of measured data: format, time, quality assurance
- payment: according to survey progress, according to milestone plan, ...
- etc.

Our review found that the survey strategy is not well described in most survey specifications, although a few do cover some of the above areas.

3.6 Location referencing

Each measured value has to be related to a certain location on the network. This can be achieved using different approaches, e.g. linear referencing the data to road number and chainage or geographically locating the data to a nationally defined coordinate grid. For geographic coordinates, a global navigation satellite system (GNSS) is often used for location referencing.

Regarding accuracy, the simplest approach for linear referencing may be just pushing a button when passing a milestone. However, GNSS can achieve different levels of accuracy depending on the use of augmentation systems or the combination with inertial measurement systems. With the help of this, position data is available even when no satellite reception is possible, e.g. in tunnels.

As shown in Table 3, the review of the specifications reflected all approaches. We found everything from distance and chainage to mandatory use of sophisticated GNSS coupled inertial measurement devices. However, a specification for the spatial accuracy of the delivered coordinates was defined only in the UK specs, meaning that the other specifications were open to a wide range of potential location inaccuracies. Accuracy requirements for the measurement of the distance travelled were also rarely defined.

Usually the measured coordinates are used to fit the survey data to a road network using a map matching algorithm. The specifications remain unclear on how this is done. From experience we know that this is done in Germany using mandatory software provided by the client. This ensures that the map matching is done similarly for each survey provider. A detailed network specification is provided by the client as well. This is very similar to the situation found in the UK.

Table 3: Location referencing specifications.

Country	How is the data related to the network being measured? (i.e. Use of GPS and distance measurements to fit the data to a road and distance)
Australia	Not defined in general spec, added by authority network.
Austria	Distance, Chainage
BC, Canada	GPS measurements (collected with a differential GPS system) are collected concurrently with the linear distance
France	Use of GPS and ground survey control points
Germany	Use of GPS mandatory, each second 1 position
Ireland	The data is location referenced to the network and distance measurement and GPS coordinates are used.
Morocco	Referencing all measures should be done both in XY, referencing differential GPS (with a typical accuracy less than 1m) and curvilinear abscissa PR +. The minimum specifications are: Distance Sensor: optical encoder, Accuracy: ≤ 0.2%, Resolution: 0.4 mm GPS accuracy in X, Y ≤ 1 m Indicators: curvilinear distance, GPS coordinates X, Y.
Netherlands, national roads	There are hectometre markers along the whole network and the survey vehicle is expected to identify where is it on the network in relation to these.
Netherlands, regional roads	The data is related to kilometre markers on the network and also GPS data is collected.
New Zealand	GPS, inertial measurements and distance
Slovenia	Distance, Chainage
Sweden	Combination of coordinates and distance measurement. Nodes identified by coordinates and distance measurements in between.
UK 2	The UK road network is split into named sections and the data is related to this via location referencing measurements (GPS and distance) Distance shall be measured with an accuracy of ±1m up to 1000m. For elapsed distances greater than 1000m all data measured shall be referenced to within an accuracy of ±0.1%. The accuracy should be unaffected by the speed of the equipment, or by the Road Geometry and the measurement must be consistent and stable throughout any period of data collection, being unaffected by changes in the Equipment (for example resulting from “warming up” of vehicle tyres). National Grid Co-ordinates must be provided to an accuracy such that: • At least 90% of the measured positions lie within a horizontal error of 2m or better from the True position • At least 95% of the measured positions lie within a horizontal error of 4m or better from the True position • The horizontal error between the measured position and the True position shall never exceed 20m.

Country	How is the data related to the network being measured? (i.e. Use of GPS and distance measurements to fit the data to a road and distance)
UK	The UK road network is split into named sections and the data is related to this via location referencing, distance measurement, 3D spatial coordinates (GPS) Accuracy required is: • 95% of the measured Section lengths fall within ±1m (or ±0.1%, whichever is larger) of the Section lengths measured using the Reference Method. • 95% of the measured National Grid Co-ordinates are within ±2m of the National Grid Co-ordinates measured using the Reference Method for those Sections having better than 70% availability of the signal used by the equipment for the calculation of National Grid Co-ordinates • 95% of the measured National Grid Co-ordinates are within ±10m of the National Grid Co-ordinates measured using the Reference Method for those Sections having less than 70% availability of the signal used by the equipment for the calculation of National Grid Co-ordinates. • All of the measured National Grid Co-ordinates are within ±50m of the National Grid Co-ordinates measured using the Reference Method. • 95% of the measured Altitudes are within ±5m of the Altitudes measured using the Reference Method for those Sections having better than 70% availability of the signal used by the equipment for the calculation of National Grid Co-ordinates • 95% of the measured Altitudes are within ±10m of the Altitudes measured using the Reference Method for those Sections having less than 70% availability of the signal used by the equipment for the calculation of National Grid Co-ordinates • All of the measured Altitudes are within ±50m of the Altitudes measured using the Reference Method.
USA: California	GPS and distance measurement
USA: Louisiana	GPS and distance measurement

3.7 Summary of Measurements delivered

The review found that all of the specifications required a measurement of the transverse and longitudinal evenness, but data delivery is handled differently throughout the specifications (Table 4). For transverse evenness, most specifications demand only the delivery of ruts, the raw data in terms of transverse profile is often not required. The situation for longitudinal evenness is similar, with only 6 of 15 specifications demanding the raw profile. Germany and the UK2 specification (SCANNER) require only the raw data to be delivered for transversal and longitudinal evenness. This means that derived parameters (condition indicators) are centrally computed which can help to add consistency to the derived data.

Surface deterioration was a requirement in fewer of the surveys. Of those requiring this defect, the majority required delivery of the images and the derived surface defects.

The following sections discuss each of the measurements separately.

Table 4: Overview of measurements and parameters delivered by high-speed surface condition surveys

Specification	Transverse Profile	Rutting	Longitudinal Profile	Ride Quality	Images	Surface defects
Australia		✓		✓		
Austria		✓		✓	✓	✓
British Columbia, Canada		✓		✓		x
France		✓		✓	✓	
Germany	✓		✓		✓	✓
Ireland	✓	✓	✓	✓	✓	✓
Morocco		✓	✓		✓	x
Netherlands, national roads	✓	✓	✓	✓		
Netherlands, regional roads		✓		✓		✓
New Zealand	✓	✓		✓		
Slovenia		x		✓		x
Sweden	✓	✓	✓	✓	✓	
UK		✓		✓		✓
UK 2	✓		✓		✓	✓
USA: California		✓		✓	✓	✓
USA: Louisiana		✓		✓	✓	✓

x: Not automatic or high speed measurement

3.8 Transverse evenness

The reviewed specifications showed a large variation in the requirements for the hardware required to carry out transverse evenness measurements, with the hardware not always meeting the specification for a class II device in the CEN standard for transverse profile (CEN 13036-6). The covered width, the number of points per profile and the distribution of points across the profile varied significantly. Most countries specify that the whole lane width is covered (which may be different between road categories) or specify a width large enough that ensures that the full lane is covered. However, it should be noted that if a larger width than the actual lane width is measured, the rut depth calculation should take this into account to prevent distorted results.

Table 5 and Table 6 summarise the findings of the review for the definitions of transverse profile measurement. It can be seen that there was a significant variation in the requirements across the specifications:

- The number of points per profile showed a large variety from 11 up to 200 points per profile.
- For the distribution of the points, usually an even spacing is required. Taking the number of points, covered width and spacing into account, the distance between points across the profile varies from 0.025 to 0.3 m.

- In the longitudinal direction, the most common spacing between profiles is 0.1 m, sometimes defined as the maximum spacing and sometimes as a fixed value. The largest spacing found was 1.22 m (4 ft).
- There is a wide variation in the requirements for the sensors to be used for the measurements. One specification explicitly asks for a certain device from a certain manufacturer (USA: Louisiana). The other specifications range from “nothing specified at all” to a certain vertical measurement accuracy up to a detailed requirements of sensors regarding frequency, resolution and accuracy.

Table 7 presents the summary findings on the delivery of the data and the derived parameters. The delivered content is often the raw transverse profile and rut depth. Further parameters are edge deformation, theoretical water film thickness and profile variance. Two main methods exist for rut depth calculation – tension wire and simulated straight edge. The reviewed specifications rarely provide detailed calculation algorithms but sometimes reference other calculation methods to be used. The reporting length of rut depth ranges from 1 to 100 m. Figure 1 gives an overview on the numbers. Variations in algorithm definitions of these parameters will lead to different rut depths being calculated from the same transverse profiles, as will subtle variations within the algorithms such as the length of wire or straight edge to be used. Similarly, if no rules, determining the position of the wheel path rut depths are specified, this will also lead to different rut depths being obtained.

In addition to differences in the algorithm definitions, if the transverse profile does not have enough points, it will poorly cover the highest and lowest point of the profile, and a subsequent calculation of rut depth will yield distorted results, see Figure 2. Interestingly, many of the specifications do not require a sufficient number of points to satisfy the observations of Figure 2. As well as the number of transverse points, the lateral position of the survey vehicle also has an influence on the calculated rut depth. Figure 3 shows these two influences in one graph.

Research has also shown that the inclusion of transverse profile measurements made over road markings may increase the rut depths reported on a road network (Dhillon, 2009). Thus using a road marking profile, in addition to the transverse profile, within the rut depth calculation, may also lead to different results. If these markings are not considered during the rut depth calculation, it may lead to distorted results. However, only one specification (UK2) explicitly demands consideration (and delivery) of road markings.

Table 5: Covered lane width, number of points per profile and point spacing

Country	Is the lane width that measurements should be made over specified?	Is the number of data points in the transverse profile specified?	Is the distance between each transverse profile data point specified?
Australia	It is recommended that a minimum of 11 lasers be used to cover as a minimum a three metre transverse profile.	Preferred configuration -1500, -1350, -1150, -950, -750, -450, 0, 450, 750, 950, 1150, 1350, 1500mm	Preferred configuration -1500, -1350, -1150, -950, -750, -450, 0, 450, 750, 950, 1150, 1350, 1500mm
Austria	3.3 m	23	0.15 m
British Columbia, Canada	Not specified	A minimum of 11 measurement points	Not specified
France	Survey width: 2.50 m	Not specified	Not specified
Germany	Covered lane width is 3.2 m	33 points	0.10 m

Country	Is the lane width that measurements should be made over specified?	Is the number of data points in the transverse profile specified?	Is the distance between each transverse profile data point specified?
Ireland	No but the system must be capable of calculating accurate rut depths over the full range of lane widths encountered on the NRA's network	Not specified	Not specified
Morocco	Profile width: 3 to 4 m	At least one measurement every 0.10 m.	A maximum of 0.1m
Netherlands, national roads	The requirement is for the whole lane width to be measured. When the width of the lane is smaller than the width of the profile measurement, the profile must be adjusted to the width of the lane. It is not stated how this should be done.	No	There must be at least 1 point for every 0.10m across the width of the lane.
Netherlands, regional roads	Not specified	Not specified	Not specified
New Zealand	At least 3.3m	A minimum of 20 points	No
Slovenia	Whole width (varies depending on the road class)	Not specified	Not specified
Sweden	3.2 m	At least 17 points	Not specified, but some strategic points are specified.
UK	Yes, a minimum of 3.2m, maximum of 4m	A minimum of 20 points, maximum 100	No
UK 2	A minimum width of 3.8m, centred on the middle of the Lane, up to a maximum width of 5.0m	A minimum of 100, maximum of 200	No, the points just need to be evenly spaced
USA: California	Whole lane width	Not specified	A maximum of 25mm between measurement points
USA: Louisiana	Not specified	A minimum of 40 points shall be used to produce the transverse profile	The positioning of the sensors/scanners have to be submitted to the DOTD for approval.

Table 6: Equipment used to measure transverse profile and point spacing

Country	Does the specification state what type of equipment should be used to collect the data?	Is the longitudinal spacing of the profiles specified?
Australia	A multi-laser profilometer consisting of the following: § a vehicular platform capable of transporting testing equipment, mounting the transverse profile measuring equipment and travelling at a range of speeds up to the limit of the operating range of the profile measuring equipment § multiple displacement transducers (laser devices) which measure the distance between a horizontal datum and the travelled surface. The displacement transducers shall be mounted to ensure mid-range operation during normal operation. Note: The measurement system must have a sufficient number of lasers to produce an accurate representation of the transverse profile to a minimum width of three metres. § a distance measuring transducer capable of measuring the distance travelled to an accuracy of ±0.1%. The transducer shall provide input to the data logger to record the distance travelled from the start of the collection survey. § a data logger capable of continuously capturing the output data from the transducers at known equal intervals, not greater than 250 mm.	0.25 m
Austria	vertical accuracy of 0.01 mm	1 m
British Columbia, Canada	Not specified	Not specified
France	A vehicle equipped with a CAD system or a camera system or video system Deformations of the transverse profile will be measured in accordance with the procedure "*T1 de la Méthode LPC no 49*."	
Germany	Vertical resolution of 0.2 mm, linearity of <0.2 over the whole measurement range	1 m
Ireland	Non-contact sensors must be used	A maximum of 0.1 m
Morocco	Laser vertical resolution: 0.025 mm rut depth accuracy: ± 1mm, The output indicators are: depth and width of rut	Not specified
Netherlands, national roads	Non-contact equipment is specified	1 m
Netherlands, regional roads	No, just that rut depths must be delivered, which meet a (specified) level of accuracy and repeatability.	Not specified

Country	Does the specification state what type of equipment should be used to collect the data?	Is the longitudinal spacing of the profiles specified?
New Zealand	Equipment required is an accelerometer/laser combination. Either a minimum of 20 non-scanning lasers or a scanning laser providing a scan line length of at least 3.3m. The frequency response of the lasers should be 16kHz, with a resolution of 0.05mm and a range of 0-180mm.	0.1 m
Slovenia	Rutting: is part of so called Modified Swiss Index (MSI); used to assess pavement condition in terms of surface distress and is determined by visual inspection). Quantified with 3 levels of severity and 3 levels of extent. Deviation from 4-m straightedge: used to assess transverse evenness	Rutting: As part of MSI information is given per each 20 m. 4-m straightedge: Usually a number of measurements per km defined.
Sweden	It's not specified how to collect data but there are accuracy specs for the gauges used and how often measurement should take place (frequency).	A maximum of 0.1 m
UK	No, it just asks for transverse profile, consisting of a minimum of 20 points, max 100 points.	A maximum of 0.1 m
UK 2	No, it just asks for transverse profile, consisting of a minimum of 100 points, max 200 points evenly spaced across the width of the measured Transverse Profile.	A maximum of 0.1 m
USA: California	No, just that it should be capable of measuring across the lane width	A maximum of 0.25 m
USA: Louisiana	Rutting shall be measured by an INO Laser Rut Measurement System (LRMS)	A maximum of 4ft (1.22m)

Table 7: Specifications concerning the methods for rut depth calculation.

Country	If delivery of rutting is a requirement, does the specification state exactly how rut depths should be calculated?
Australia	Wheelpath Rut depths are required, Lane rut depth is optional. Refers to straight edge method (length of straight edge 2m).
Austria	Simulated 2 m straight edge on each side
British Columbia, Canada	Rut depth measurements are to be equivalent to those that would be achieved manually, via ASTM E1703/E1703M as determined for each individual wheel-path referenced to a 2 metre straight-edge model but exactly how this would be achieved is not stated.
Germany	Only profile points are delivered, central software does all calculations
Ireland	No
Morocco	The calculation of all parameters related to geometric characteristics of the roadway and the cross section must be in accordance with NF P 98219-1 and NF P 98219-2 and the test method No. 49 LCPC.

Country	If delivery of rutting is a requirement, does the specification state exactly how rut depths should be calculated?
Netherlands, national roads	It is required that there are no effects of coarse surface texture on the rutting measurement, and no effect from road markings, kerbs or raised edges. The tense-wire method is used to calculate rutting and this is briefly described in the specification.
Netherlands, regional roads	It states that the method of calculation should be based on that described in CROW publication 146a and b (Dec 2011 edition), whereby a 1.2m straight edge and 20mm wide wedge are simulated
New Zealand	No, it just states that the rut depth under a 2-metre straight-edge (mm) measured in both wheelpaths should be calculated. It also states that the measurement system and processing algorithms must correct data when narrow roads, kerbs or narrow bridges result in the outer sensors measuring artificially high values on both the left and right hand side of the vehicle but again it does not say how this should be done.
Slovenia	Reported with 3 levels of severity (according to the method used for assessment - MSI).
Sweden	Yes, it's defined in a description from the Transport Administration.
UK	Yes, an algorithm is defined in Volume 5 of the specification (2m straight edge).
UK 2	The contractor is not required to deliver rut depths, however, since they are tested on this parameter during Accreditation and QA, the rut algorithm is defined (2m straight edge).
USA: California	The measurement and calculation method must produce the same measured values as using the definition included in ASTM E1703-95(2005)
USA: Louisiana	The specification states that the calculation of rutting shall be as directed by DOTD

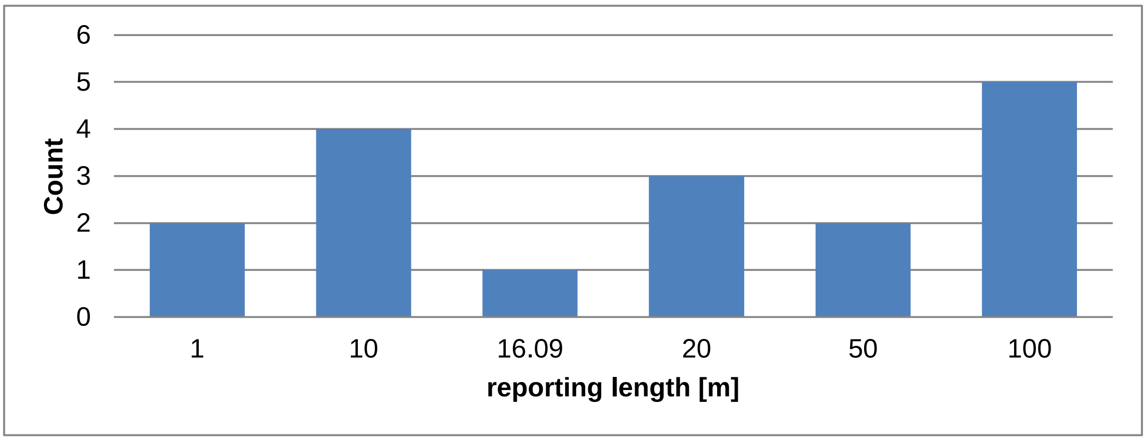


Figure 1: Distribution of reporting length of rut depth

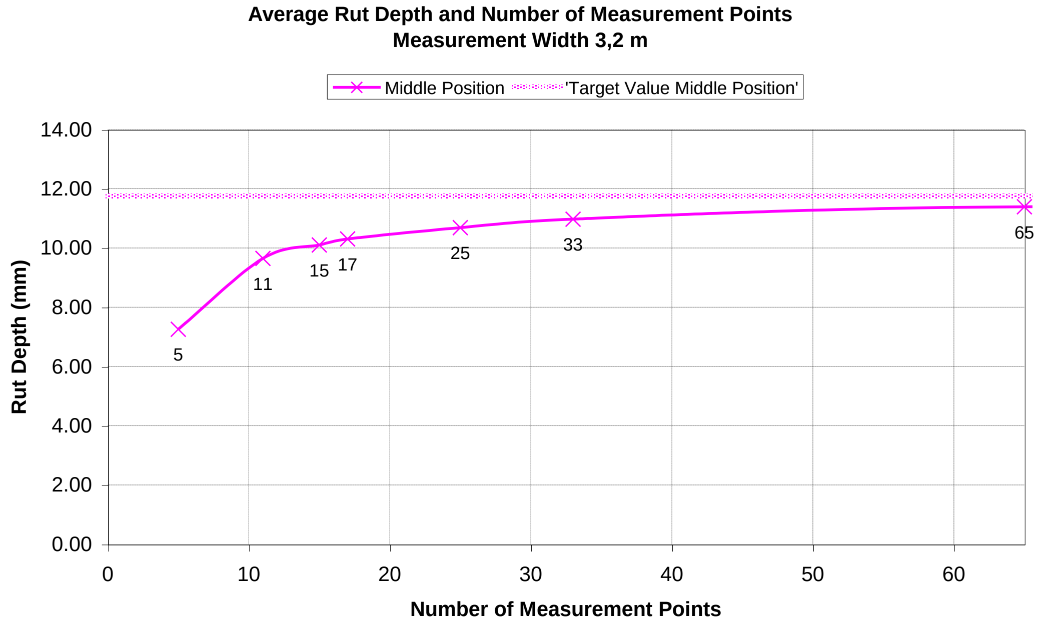


Figure 2: The influence of number of measurement points on rut depth at 3.2 m measurement width; from Sjögren et al., 2005

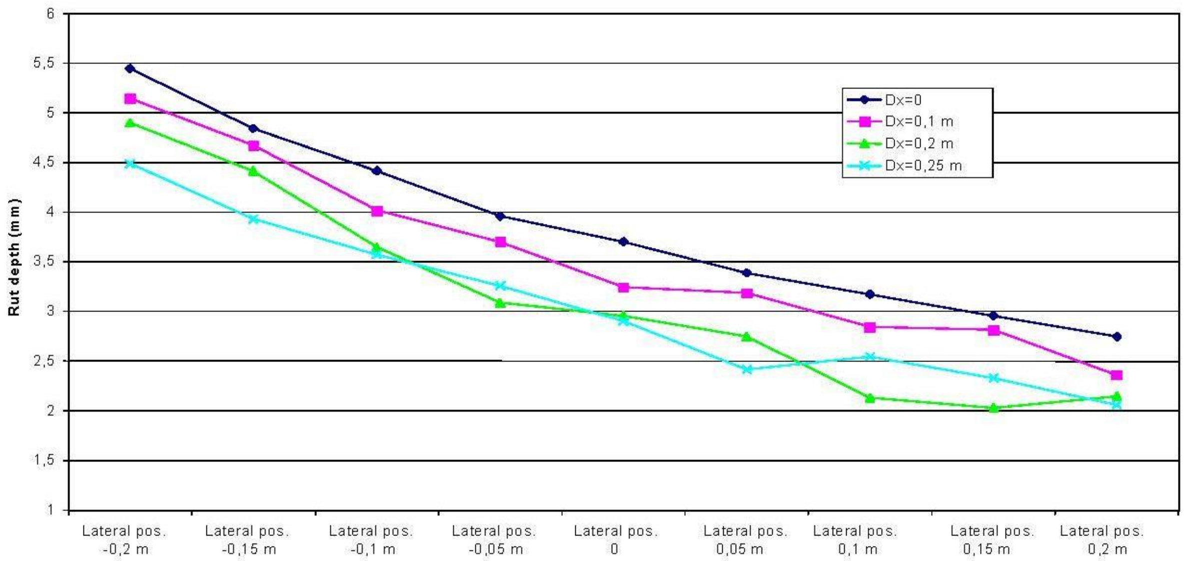


Figure 3: Effect on rut depth in left wheel track when varying lateral position of profile and lateral spacing using a profile of 3 m width; from La Torre et al., 2007.

3.9 Longitudinal Evenness

In comparison to transverse evenness, the variety of measurement methods identified in the review was smaller for longitudinal evenness. In fact, as highlighted in Table 8 there are only two major system types in use: HRM beam and inertial (GM type) profilometer. Some specifications insist on a certain method (Austria and Germany on the HRM beam, US states an inertial profiler) while others leave this open and specify only the output. Both methods are able to produce accurate longitudinal profiles, but both methods have their limitations: The HRM beam has limitations when measuring in sharp bends, as the re-sampling of identical points on the surface cannot be guaranteed. The inertial profiler suffers from inevitable drift of its accelerometer, which leads to incorrect results at low survey speeds (e.g. in stop-and-go traffic). This could be reflected in the specifications with geometric or speed constraints.

Table 9, Table 10 and

Table 11 present the findings of the review with regard to the equipment required and the raw data delivered. It can be seen that only two specifications refer to international standards (ASTM E 950-98(2004) Class 1, NFP 98 218-3). The other specifications define a range of technical requirements, covering measurement frequency, accuracy of the measurement output and spacing of the measurement in the longitudinal direction (generally between 0.01 and 0.1 m). This requirement can be considered in the context of the definition of longitudinal evenness, which is in the wavelength band of 0.5 to 50 m according to CEN 13473-5. With respect to the Shannon-Nyquist theorem, the profile spacing has to be half the smallest wavelength at maximum, which would be 0.25 m. This requirement is met by all specifications (Table 10).

The longitudinal evenness is usually determined in the wheelpath. However, have been found: the specifications range from only one wheelpath, even three wheelpaths (left, right, and a third one for heavy vehicles middle). The majority of specifications require both wheelpaths to be of the wheelpath in the lateral direction is usually not defined and the following the actual wheelpath on his own. There are many different distance between left and right wheelpath, some specifying the of the measurement vehicle, some just the distance or a range between the two wheelpaths.

Table 11 lists the different specifications and Figure 4 shows the distances between the wheelpaths where specified. If the transverse position of the wheel paths is not clearly specified, then a different part of the pavement may be measured, leading to different values for the profile and any reported derived parameter.

Usually a derived parameter or index for evenness evaluation is required, the most common being the International Roughness Index (IRI), but others are used (e.g. in some English speaking countries, the LPV (Longitudinal profile variance)). For the IRI, different documents provide a specification for the calculation procedure. The earliest one is the World Bank technical paper 45 (Willet et al., 2000), but it can be found in (CEN 13036-5), (Sayers et al., 1986) and (ASTM E1926-08) and other standards as well. What usually is omitted by these specifications is the reporting length, the speed of the quarter car used and the specification of necessary lead-in and lead-out sections for filter adjustment. The reporting length of the derived indices varies from 10 to 160 m (a quarter mile), with 100 m being the most common (7 times mentioned) and 10 m (5 times mentioned). There is no “optimal” reporting length; the reporting length has to be seen in relation to the network class that is surveyed and the other surveyed parameters. Table 12 shows the specified indices and their according reporting lengths. Different values of IRI will also be obtained, depending on how the longitudinal profile is filtered before being processed through IRI calculation. Similarly, the parameters used within the calculation and the actual method of calculation, will affect the results.

It is noted that the derived index may also be affected by the longitudinal spacing of the raw data. If the spacing of the longitudinal profile measurement points is too large, not all necessary wavelengths of the profile would be covered. Even if the spacing is not so large that essential wavelengths are missing from the profile, the derived indices may still be affected, for example, the 95th percentile of absolute percentage error for IRI increases 1000 fold, when the measurement spacing increases from 1mm to 1000mm (Figure 5).

One level above the raw measurement, the calculation procedure of the derived indices needs thorough specification as well. For example, different values of IRI will be obtained, depending on how the longitudinal profile is filtered before being processed through IRI calculation. Similarly, the parameters used within the calculation and the actual method of calculation, will affect the results.

Table 8: Specification of measurement equipment for longitudinal evenness

Country	Is a certain type of equipment mandatory? (HRM beam, inertial profiler)
Australia	§ Accelerometer(s) to establish the inertial reference which enables reference to be maintained at the level of resolution and accuracy required for the displacement measurement transducer(s). § A displacement transducer (laser device) which measures the distance between the accelerometer and the travelled surface. The displacement transducer(s) shall be set to ensure mid-range operation during normal operation. Note: When measuring the profile of two wheelpaths simultaneously, a laser transducer/accelerometer combination shall be used for each wheelpath.
Austria	2 m HRM beam
BC, Canada	Not specified
France	Profilometer as defined in the standard "NFP 98 218-3"
Germany	HRM beam mandatory, other types have to qualify
Ireland	No, however, the specification does require that the profile measurements are independent of vehicle speed and vehicle acceleration over the normal range of traffic speeds. In particular, measurements must be accurate and repeatable down to speeds of 10 km/h or less due to the particular characteristics of lower volume National routes in Ireland, which suggests that only an HRM device would be suitable.
Morocco	Not specified
Netherlands, national roads	Not specified
Netherlands, regional roads	Not specified
New Zealand	No
Slovenia	Profilometer (profiler) as defined in the Technical Specification for Roads (TSC 06.610:2003 Lastnosti voznih povrsin Ravnost).
Sweden	No, the profile should just be measured with a certain accuracy
UK	No, equipment is not specified at all, only the data required. (In the UK 2 different

Country	Is a certain type of equipment mandatory? (HRM beam, inertial profiler)
	methods are used for collection, HRM & GM principle)
UK 2	No, the contractor can choose what they like, so long as the measurements meet the requirements
USA: California	Inertial profiler
USA: Louisiana	The use of lasers & accelerometers (inertial profiler) is specified

Table 9: Specifications for measurement equipment

Country	Does the specification state what type of equipment should be used to collect the data?
Australia	An inertial laser profilometer consisting of the following: § A vehicular platform capable of transporting testing equipment, mounting the profile measuring equipment and travelling at a range of speeds up to the limit of the operating range of the profile measuring equipment. § A distance measuring transducer capable of measuring the distance travelled to an accuracy of ±0.1% and capturing wavelengths within the range of 0.5 m and 50 m. The transducer shall provide input to the data logger to record the distance travelled from the start of the collection survey. § A processing computer to analyse the profile data, and by applying the 'quarter car' model obtain IRI for a single wheelpath and Lane IRI.
Austria	Vertical accuracy of 0.01 mm
British Columbia, Canada	Laser sensors with a minimum 32 kHz sampling frequency are to be used, with a vertical resolution of ≤0.1 mm.
France	The measuring device must be a device type "Profilomètre" as defined in the standard "NFP 98 218-3"
Germany	Vertical resolution of 0.2 mm, linearity of <0.2 over whole measurement range
Ireland	The profiling system must meet ASTM E 950-98(2004) Class 1 requirements for the measurement of Longitudinal Profile: § The accelerometer range shall be large enough to accommodate the levels of acceleration expected from the bounce motions of the measuring vehicle (typically 61 g). The accelerometer shall be biased to account for the 1-g acceleration of gravity. The accelerometer shall have a minimum resolution to allow profile calculation and accuracy and bias to meet the requirements. § The displacement transducer shall measure the vertical distance to the travelled surface continuously, or sample at intervals not greater than 25mm, with vertical resolution of <0.1mm.
Morocco	Sensors: Laser Measuring range: ± 100mm Vertical resolution: between 0.025 and 0.1 mm, Not Acquisition: 5 mm, Wavelength range of view: 0.7 m to 45 m. The implementation of this sub-system must enable assessment notes NBO and IRI Probing sections.
Netherlands, national roads	Only that non-contact measurements should be used, with a sampling frequency of 16kHz, to measure wavelengths between 0.6m and 90m
Netherlands, regional roads	No. Just that IRI, to a certain level of accuracy should be delivered.

Country	Does the specification state what type of equipment should be used to collect the data?
New Zealand	Non-scanning laser and accelerometer combination with a resolution of 0.05mm, a measuring range of at least 0-180mm and frequency response of 16kHz. A scanning laser is permitted as an acceptable alternative to a non-scanning laser provided it meets or exceeds the specifications for the non-scanning laser plus having a minimum scan rate of 450 Hz so that the scan separation is less than 50 mm at a survey speed of 80 km/h.
Slovenia	No, but there are specs for the accuracy of used equipment: Measurements at traffic speed (40 - 120 km/h); digital recording of profile; registering of wavelengths at least 0.8 m - 30 m; measurement point at least every 10 cm; distance accuracy +/-0.3 %.
Sweden	No, but there are specs for the accuracy of used gauges.
UK	Longitudinal profile is measured at points separated by no more than 0.01 m of longitudinal distance travelled and then reported at 0.1 m intervals.
UK 2	A longitudinal separation of ≤ 25mm is required for the measured points.
USA: California	A Class I inertial profiler i.e. longitudinal sampling of ≤25mm, vertical measurement resolution between ≤0.1mm
USA: Louisiana	Lasers & accelerometers, using a Class II laser type profiler i.e. longitudinal sampling between 25 and 150mm, vertical measurement resolution between 0.1 and 0.2mm

Table 10: Specification of measurement spacing in longitudinal direction

Country	Is the spacing of the measurements defined?
Australia	Not greater than 50 mm
Austria	Measurement spacing of 5 cm, derived profile of 10 cm
BC, Canada	The longitudinal spacing should be ≤25 mm
France	Not specified
Germany	Measurement spacing of 1 cm, derived profile of 10 cm
Ireland	The longitudinal profile should be measured at points separated by ≤0.01m of longitudinal distance travelled.
Morocco	Not specified
Netherlands, national roads	Maximum measurement interval is 100mm
Netherlands, regional roads	Not applicable
New Zealand	50 mm
Slovenia	At least every 10 cm.
Sweden	The surface must be measured at least every 0.1m.
UK	Longitudinal profile is measured at points separated by no more than 0.01m of longitudinal distance travelled and then reported at 0.1m intervals.
UK 2	The longitudinal separation of measurements should be at most 25mm.
USA: California	Measurements should have a spacing of ≤25mm

Country	Is the spacing of the measurements defined?
USA: Louisiana	Measurements should have a spacing of between 25 and 150mm

Table 11: Measurement position and definition of lateral measurement position

Country	Is the measurement position in the lane specified?	Is a certain displacement from the lane margin mandatory? Has the lateral measurement position to be documented?
Australia	Both wheelpaths	The lateral distance between the displacement transducers to measure in the wheelpaths shall be 1.5 m (i.e. 0.75m from the centreline of a lane).
Austria	Right wheelpath	No
BC, Canada	Both wheelpaths	Not specified
France	Both wheelpaths required, third wheelpath in the middle optional	
Germany	Middle of right wheelpath	No
Ireland	Both wheelpaths	This isn't stated in the spec, however, in ASTM E 950-98(2004), it states that the displacement transducers shall be mounted 1.5 to 1.8 m apart
Morocco	The longitudinal profile function must meet the standard and method: Method of test No. 46, LCPC and NF P98-218-3	Not specified
Netherlands, national roads	Both wheelpaths	Not specified
Netherlands, regional roads	Both wheelpaths	Not specified
New Zealand	Both wheelpaths	Wheelpath roughness measurements must be made using a wheelpath spacing of 1.5 m
Slovenia	Not specified, but it is always measured in the right wheelpath.	Not specified
Sweden	Left, right and "heavy" right	Yes, centred and 1,5 m in between the left and right wheel track and the third 0,25 m to the right of the right wheel track (for heavy vehicles)
UK	Both wheelpaths	The left wheelpath is defined as a measurement line located between 0.75 and 0.9m to the left of the centre line of the survey vehicle. Similarly for the right wheelpath.
UK 2	Both wheelpaths	The measurements should be taken +/- 0.9-1.05m from the centre line of the vehicle.

Country	Is the measurement position in the lane specified?	Is a certain displacement from the lane margin mandatory? Has the lateral measurement position to be documented?
USA: California	Both wheelpaths	The left wheelpath is defined to be 0.45 to 1.35m to the left of the centre line, whilst the right is 0.45 to 1.35m to the right.
USA: Louisiana	Both wheelpaths	If two wheel tracks are measured, the displacement transducers shall be mounted 1.5 to 1.8 m apart (ASTM E950)

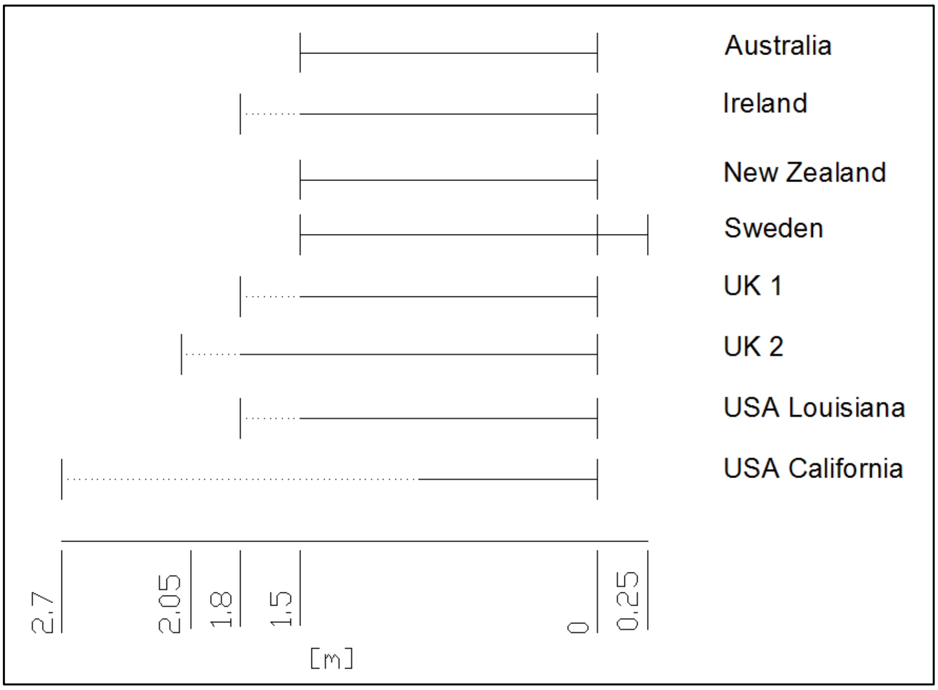
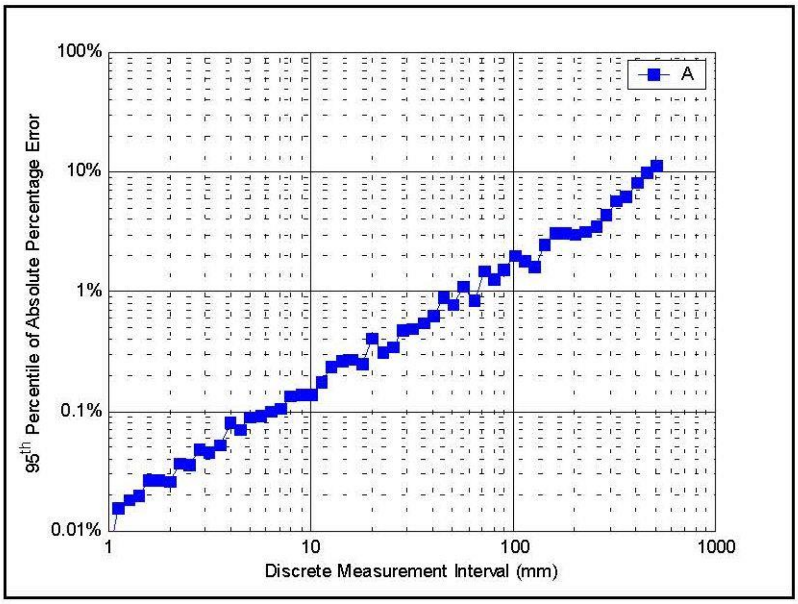


Figure 4: Specification of distance between the two major wheelpaths (left and right) in different countries. Dotted lines show variable widths. Zero marks the position of the right wheelpath.

Table 12: Derived condition parameters and reporting lengths

Country	Which derived indices have to be delivered?	What is the reporting length of the derived indices?
Australia	IRI is required, NAASRA is optional	100m
Austria	IRI	50 m
BC, Canada	IRI for each wheelpath	50m
Germany	Only the profile	100 m
Ireland	IRI, 3m and 10m LPV	10m
Morocco	International Roughness Index (IRI)).	Not specified

Country	Which derived indices have to be delivered?	What is the reporting length of the derived indices?
Netherlands, national roads	HRI	HRI is determined every 100mm and then averaged over 100m
Netherlands, regional roads	IRI	10m and 100m
New Zealand	IRI, IRIqc and NAASRA (counts/km), where NAASRA = 26.49 x lane IRIqc – 1.27	≤200mm (raw data), 20m (detailed data) and 100m (aggregated data)
Slovenia	Profile + deviations from true plane by simulated positioning of 4-m straightedge over measured profile, IRI for 20 m and 100 m sections.	IRI for 20 m and 100 m sections.
Sweden	IRI (left and right wheel track) (the transport Administration also calculates some indices from the profile)	20 m
UK	LPV, eLPV, Bump Measure	10m
UK 2	Just the profile is delivered	10m and 100m
USA: California	IRI	10m
USA: Louisiana	IRI (Quarter car)	0.1mile (160.9m)



Series A is the Error in IRI resulting from different discrete Measurement Intervals.
A detailed artificial profile, which is indistinguishable from a real profile, was created with a measurement interval of approximately 0.520mm. The evenness of the profile corresponded to the centre of ISO 8608 class A. From this, a reference value of the index was calculated. The detailed profile was then resampled, using a cubic spline interpolation, at measurement intervals between 1.0mm and 512mm. The absolute percentage error was then calculated.

$E_{\%} = | (V - V_{Ref}) / V_{Ref} | * 100$

This was repeated for 300 different artificial profiles. The error is shown in terms of the 95th percentile of the distribution of absolute percentage error

Figure 5: Influence of discrete measurement interval on calculated IRI; from La Torre et al., 2007.

3.10 Surface Deterioration

The review found that the evaluation of surface deterioration is commonly achieved by collecting images of the surface using a downward facing camera. The images are then evaluated by a machine vision algorithm (automated evaluation) that identifies deterioration in each image (often cracking). Alternatively, a human operator assesses each image (manual evaluation). For manual evaluation, usually a catalogue of surface defects exists against which the manual assessor compares the images to identify and classify defects.

In comparison to transversal and longitudinal evenness, the requirements for surface deterioration were least well defined in the specifications. The reason for this may be the short history of this parameter in comparison to the other parameters. There was also quite a range of measuring system requirements defined, covering a range of survey widths, image resolutions etc. Table 13 and Table 14 highlight the results of the review of specifications in terms of equipment, image resolution, lane width covered and use of lighting systems. Note that these tables only list the specifications requiring a measure of surface deterioration.

- It is typically assumed that a digital camera system will be employed for collection of road surface images. However, there was an example of requirements being specified for 3D images, as opposed to the conventional 2D images provided by standard cameras. Our impression of where this requirement is being specified is that it may be linked with particular commercial equipment, and hence the specification may have been equipment-led.
- The specifications for the resolution of the images have two main characteristics: Some define the minimum resolution per image pixel on the ground; some define a minimum crack width to be determined from the images. The demands are high, with minimum crack width between 1 and 2 mm and image resolutions from 0.5 to 2 mm.
- Most specifications ask for data over the full lane. However this is often not expressed as a number. As lane widths may change over a network, the definition of a minimum width covered seems beneficial. During the evaluation of surface defects, the width then may be limited to the actual lane width to avoid double evaluation on neighbouring lanes.
- It is known that high quality image collection requires control on the level of illumination if consistency is to be achieved. However, only a few specifications define requirements for the image illumination. Likewise only a few formally assess image quality.

In terms of the delivered derived parameters, there was no evidence provided for the use of a specific algorithm in any of the specifications. The specifications demand the use of either a computer vision algorithm or explicitly a human operator, or leave it to up to the contractor which method to use. Table 15 and Table 16 show the detailed results. We suspect that this will lead to significant differences in the evaluation of the same picture or the same defects. From the types of surface defects that are evaluated, different types of cracking (longitudinal, alligator cracking etc.) are included in all specifications. Some specifications demand more features to be evaluated, like potholes, construction joints, fretting, stone loss etc. No correlation between number and type of features to be evaluated and the use of image processing has been observed.

Table 13: Specification of hardware to collect data on surface deterioration.

Country	Is the device for capturing the road surface specified or is the output of the device specified (i.e. the pictures) or both?
Austria	Line scan camera and picture size
Germany	Structure width of 1 mm on the ground has to be determined over the whole width
Ireland	The NRA requires that the vehicle be fitted with a camera system to provide a forward view of the pavement surface to enable a visual distress survey to be subsequently carried out using the video images. Video resolution on this camera system to be a minimum of 720 x 576 pixels. For cracking: The automated system required shall be composed of two high performance 3D laser profilers that are capable of measuring complete transverse road profiles with 1mm resolution at normal traffic speeds. The high resolution 3D data acquired by the automated system should be processed using algorithms that were developed to automatically extract crack data including crack type, severity and intensity. The equipment should be capable of gathering the required data at normal traffic speeds or as otherwise agreed with the NRA. The automated system should meet the following specification unless otherwise agreed with the NRA:2 Laser Profiles, maximum sampling rate of 11,200 profiles, max vehicle speed 100km/h, adjustable profile spacing, 4096 3D points per profile, 4m transverse field of view, 250mm depth range of operation, 0.5mm Z axis Range of accuracy, 1mm X Axis Resolution.
Morocco	Digital cameras synchronized with an illumination system or laser strobes; image acquisition: every 1 mm, Width of the lane covered between 4 and 4.5 m, the output indicators are: Assessment of the status of the network, Qualify and quantify every degradation and to deduce accurate notes by section The record of degradation should allow, in 1 m, all aspects of deterioration of surface damage in accordance with test methods listed below and specified by the contractor: M1 and M3 test method No. 38-2 LCPC, Test Method No. 52 catalog LCPC pavement surface distress. The Licensee shall also submit photographs of all lengths of pavement assessed.
Netherlands, regional roads	Not specified.
UK	Just the output is specified
UK 2	The device is not specified but there are requirements to ensure that image quality is sufficient to ensure all defects can be identified.
USA: California	No
USA: Louisiana	Images shall be collected with two cameras oriented normal to the pavement for distress identification/quantification

Table 14: Specifications for lighting system, image resolution and lane width covered.

Country	Is the use of a lighting system mandatory to level the brightness across the pictures?	Is there a specification on ground resolution or is a certain minimum observable crack width required?	Is the lane width that measurements should be made over specified?
Austria	Yes	Minimum observable crack width: 2 mm, image width of 2048 pixels	4 m
France	Not mandatory	No	The lane width is not specified
Germany	"Uniformity" of brightness across the picture width is checked at accreditation	1 mm crack width has to be determined	Asphalt: lane width, Concrete: slab width
Ireland	Not specified	Fine cracks (≤1mm) are expected to be identified.	The survey is required over the full lane width on single carriageway roads (a range of 2.5m to 5m).
Morocco	Digital cameras synchronized with the illumination system or laser strobes	Not specified	Profile width: 3 to 4 m
Netherlands, regional roads	Not applicable	On non-porous bituminous or concrete pavements, cracks of ≥1mm must be detected, on porous bituminous pavements, cracks of ≥2mm must be detected	Full lane width, although cracking should not be reported within 0.25 of the edge of the road.
UK	The use of images is not mandatory, so no requirement is set for lighting.	No	At least 80% of the width of the traffic lane, for lanes ≤3.65m and a minimum of 2.9m for lanes >3.65m
UK 2	It is not mandatory but brightness levels are tested within Accreditation.	The images shall have a resolution of at least 2.5mm, and a maximum resolution of 0.5mm	Yes, a minimum width of 3.8m is required.
USA: California	Not specified	Not specified	Not specified
USA: Louisiana	Not specified	2 mm resolution, sufficient to identify cracks of 0.078 inch (2mm) width in both the transverse and longitudinal directions in all pavements	Minimum of 12ft (3.66m) transverse road sections

Table 15: Evaluation procedure and types of surface defects considered

Country	Are the images evaluated by humans or is a computer vision algorithm?	Which types of surface defects have to be evaluated?
Austria	Humans	Alligator cracks, single cracks (width+length), patches, loss of stone, fretting, open joints, bitumen accumulation, edge breaking, broken corners, spalling, potholes
Germany	Humans	Asphalt: Alligator cracks, single cracks, patches, loss of stone, open joints, bitumen accumulation. Concrete: lateral and longitudinal cracking, slab length, edge breaking, asphalt patches, broken corners, spalling
Ireland	A computer algorithm is used to process the images	Network cracking is quantified in terms of the dominant crack type, severity and extent for each segment: o Linear - discrete transverse and longitudinal, o Interconnected – widely spaced block cracking and closely spaced crocodile or alligator cracking o Irregular or Meandering cracking
Morocco	The monitoring system must be equipped with software for processing images for the identification of surface distress to assess the level of service.	Cracking, crazing, tearing, bleeding, feathering, etc.
Netherlands, regional roads	Not specified.	Cracking, including all cracking types, open joints, filled longitudinal joints
UK	All current survey contractors use a computer algorithm but this is not specified to be a requirement.	All types of cracking
UK 2	A computer algorithm is used.	Open cracks, Sealed cracks Patches, Trenches, Potholes, Reinstatements, Joints at surface changes / construction joints, Cores, Fatting up are all reported as part of the surface deterioration parameter. There is no distinction between different types of deterioration within this parameter (i.e. just one number is delivered). Fretting is delivered as a separate parameter and is derived from texture measurements, not images.

Country	Are the images evaluated by humans or is a computer vision algorithm?	Which types of surface defects have to be evaluated?
USA: California	Humans	Transverse cracking, longitudinal cracking (outside of wheelpath), wheelpath cracking, cracking outside of wheelpath, potholes, patches
USA: Louisiana	The specification allows for the data to be either automatically detected, or for manual analysis of the images	For asphalt pavements: Cracking (alligator, Block Cracking, Longitudinal Cracking, Transverse Cracking, Reflective Cracking @ Joints); Patching and Potholes. For concrete: Cracking (Longitudinal Cracking, Transverse Cracking);Patch\Patch Deterioration; Punchouts (CRCP only); Blowups

Table 16: Use of algorithm for image evaluation.

Country	If there is an algorithm used in the evaluation, does every contractor have to use the same - is it provided by the client?
Ireland	No, the contractor develops their own algorithm.
Netherlands, regional roads	Not applicable
UK	There is no algorithm. Each survey contractor develops their own image processing algorithm (where images are used), although the spec does suggest algorithms for identifying false cracking (Volume 5, Annex 1)
UK 2	The contractor is expected to develop their own algorithm to process the images.
USA: Louisiana	The contractor provides their own software

4 Definitions

The following subsections list the technical terms to be used, along with the definitions of the terms as they will be used within the HiSPEQ project.

Accreditation

Accreditation is a process that is usually implemented at the start of a survey regime. The aim of the process is to demonstrate whether a high-speed survey device is capable of delivering the data required by the survey, and to the level of accuracy required.

Accuracy

A system's accuracy is how closely its measured data reproduces reference data.

Derived Parameter

A parameter, such as rutting, IRI or area of cracking, calculated from the measured raw profile or image data.

Filter

In the context of this work a Filter can be considered to be a mathematical transformation applied to measured profile data to remove features (wavelengths) considered undesirable in the calculation of a derived parameter.

Fleet consistency

Fleet consistency is how closely matched data is, when collected by multiple (different) devices surveying the same route.

IRI

International Roughness Index, a parameter calculated from longitudinal profile data

Longitudinal Profile

The longitudinal profile is a measure of the shape of a road surface, in a single line parallel with the direction of travel. It is usually measured in the wheel paths and sometimes measured in the middle of the lane.

Quality Assurance (QA)

Quality Assurace (QA) is the process that is implemented during the course of a survey regime, to ensure that the data quality has remained at an acceptable level.

Ride quality

Ride quality is indicated by a parameter or parameters that are derived from the longitudinal profile. These parameters attempt to quantify the level of comfort or discomfort that road users will experience when driving down the road.

Rutting

Rutting is the permanent deformation of pavement layers which can accumulate over time. It is limited to asphalt roads, and can be indicative of pavement failure. There are two types of rutting that can develop on a road: Surface course rutting and structural rutting. Surface course rutting only occurs in the top ~50mm of the pavement and is caused by the surface course mixture being displaced by vehicle wheels, usually during hot weather. Structural rutting is the result of excessive consolidation of the pavement along the wheel path due to either reduction of the air voids in the surface layers, or the permanent deformation of the base or subgrade. It is this type of rutting that causes most concern to road engineers, since it is most indicative of pavement failure.

Surface deterioration

In general surface deterioration includes any deterioration in the condition of the road surface, for example, cracking, fretting/ravelling, pot holes, fatting up, bleeding. Since the HiSPEQ project is concerned with measuring the durability of a pavement, we will only be considering defects that either effect the structural integrity of the surface layers, or might allow water ingress into the lower layers of the pavement i.e. cracking and pot holes (fretting tends to develop into cracking or potholes when it gets severe enough to effect the structural integrity of the surface layers).

System repeatability

The repeatability of a system is how precise an individual device is i.e. how closely matched data is when collected by the device during two separate surveys.

Transverse Profile

The transverse profile is a measure of the shape of a road surface, in a single line running across the lane, perpendicular to vehicle travel.

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