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HiSPEQ: Hi-speed survey Specifications, Explanation and Quality

Summary of Review of Key Requirements for Survey Specifications

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HiSPEQ
Hi-speed survey Specification, Explanation and Quality

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Table of contents

1 Introduction

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 was to combine the technical expertise of 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. In particular the requirements for surveys that measure the surface condition of the pavement (carried out under Work Package 1 of HiSPEQ), the requirements for surveys that measure the structural condition of the (carried out under Work Package 2) and the Accreditation and Quality Assurance regimes that could be applied to ensure the quality of the data delivered (carried out under Work Package 3).

Three documents were prepared by the project, covering each of these three subjects, namely:

- Identifying the key requirements for surface condition measurements –report for consultation;
- Identifying the key requirements for structural condition measurements –report for consultation and
- Identifying the key requirements for Accreditation and Quality Assurance –report for consultation.

These three documents were sent to the 34 members of the reference group and also made available on the project website (http://www.hispeq.com), with an invitation to review and submit comments to the project team.

The following sections summarise the feedback received.

2 Review of the key requirements for surface condition measurements

At the time of writing, a total of six reviews had been received for the key requirements for surface condition measurements. Some of these contained requests to update to the data presented for the specification reviews, or clarification for some of the data. The key requirements proposed and the comments relating directly to these are listed in the following sub-sections.

2.1 General requirements

Comment 1: *I agree with the set of chosen parameters in this document. They reflect the RWS monitoring practice and are mostly combined in one survey-vehicle. From these parameters the resting lifetime of the pavement is derived in the asset management process.*
Comment2: *The aims in section 1 "more commonality across Europe" and in section 2 "ability of administrations to achieve competition" are useful and of interest to clients and those that procure these types of survey contract. However, from my perspective the key requirement from these types of survey are consistency and repeatability.* (This is addressed in the Guidance for Accreditation and QA regimes).
Comment 3: *Based upon the experience of the SCANNER specification there appears to still be variability between individual vehicles and a greater variability between different suppliers/contractors. The RCI is now being used not solely for performance indicators (that are benchmarked and reported) but also for Gross and Deprecated costs. In the very near future these survey outputs will be used to produce valuation figures that will be included in a Council's accounts and it is important that any changes relate to the actual change of carriageway condition and not a change of survey provider. Any changes that occur that do not relate to a change in the condition of the road will be the subject of a great amount of scrutiny and have the possibility to undermine the whole of the industry so it is important that we have good value, high quality surveys rather than the cheapest contractor.*
I have no issue with the introduction of new or different measures or outputs if they enhance the survey outputs or provide measures that are closer to those that engineers use to determine the need for maintenance. I can also see the attraction of utilising those measurements/outputs that comprise the best from all of the different surveys currently being carried out across Europe. The one caveat that I would have with this is that it will be necessary to trend data from past years to compare with the new outputs. Ideally this would be the re-processing of historic data to present and compare it against the new survey output. If this was not possible then I think it would be necessary to produce both the new and old outputs for the (length to be determined) transitional period.
Comment 4: *As far as friction is considered as an important feature of the pavement, it shall be included. Moreover, other features, as macrotexture, noise emission – absorption, or road signs optical condition shall also be included as they are part of the pavement condition. These features are related with the good quality and condition of road network. May be they do not or cannot be introduced into prediction models for evaluate the age of the pavement in a structural approach, but their values can force to road administrators to carry important maintenance expenses, which need to be coordinated with the reinforcement of structural bearing or repairs.* (HiSPEQ has concentrated on developing guidance and specifications for surveys of pavement durability. Surface friction does not affect this and whilst it is a good thing for maintenance, due to structural condition, to be coordinated with maintenance for friction, it was not the aim of HiSPEQ to determine maintenance need or planning and thus this has not been considered.)

2.1.1 Selection of a data or an equipment specification

It was recommended that a data specification approach should be taken.

Comment 5: *In general I agree with this observation. However it could be that there's only one device in the market that meets minimum specifications, like we experience with the measurement of ravelling. However this can't be a reason to relax the specs, rather an invitation to other equipment manufacturers to enter the market. Of course the specs should be then on the data level.*

Comment 6: *Given the scope of HiSPEQ, I fully agree. The parameters under consideration here are pure geometric properties of the road, which can be measured equally with different equipments. (As opposed to friction and deflection measurements where the measurement included an interaction between the equipment and the road, so the equipment is part of the measurement value).*

Comment 7: *I agree with this suggestion*

2.1.2 Network

It was recommended that the specifications include a basic definition of the network to be surveyed (e.g. length) and also 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.

Comment 8: *A list of the section IDs should be given, along with starting and ending points (by coordinates or by milestone and meters to milestone reference)***.** (This information would be included in the digital network graph. We have used a different terminology in the guidance).

Comment 9: *How lanes should be referenced should also be specified: Merging and diverging lanes, slip roads*. (This is important but should be included in a data reporting section, not in the general description of the network)

Comment 10: *Is a digital network graph the same as a spatial map or some kind of visual representation of the road network to be surveyed? (*We have used a different terminology in the guidance).

2.1.3 Location Referencing

It was recommended that specifications should clearly state the location referencing method to be applied and that geographic coordinates are used, if a geographically defined network is available. It was also recommended that accuracy requirements are stipulated, as both distance and geographical methods can be subject to large errors.

Comment 11: *I strongly disagree* (with the use of geographic coordinates)*. When measuring linear infrastructure, the most reliable way of referencing is by distance and milestones, for which this should be the reference. Obviously geographic coordinates can (and should) be added to enable mapping and other GIS-like applications. Precision of GNNS systems is not (always) sufficiently accurate to ensure a correct reference, let alone differentiate between lanes or directions. Moreover, there is the issue of overlapping roads, tunnels, etc.*
GPS usually update position every second, at 90 km/h this is 25 meters. Although inertial systems can estimate the intermediate position, the simple odometer reference is unbeatable for precision and reliability! (HiSPEQ has recommended the use of distance measurements in addition to just GPS and the experience of the project team is that milestones get overgrown with foliage, moved and are not always easy to record at traffic speed. However,

the use of GPS type measurements is just a recommendation and the guidance does not specify that this is the only way to locationally reference data to the network).
Comment 12: *UTM system should be used for mapping of data, as this system is much more accurate. Specify the band or datum to be used.* (A section discussing coordinate systems will be added to the HiSPEQ2 section of the guidance)

2.1.4 Survey conditions
It was recommended that the environmental conditions for conducting the survey should be specified.

Comment 13: *This* ***(ensuring that the road is free from detritus)*** *is responsibility of the road owner.* (Yes, in general. However, there may still be items on the road surface that have not been cleared away when the survey occurs e.g. from a recent collision, roadkill).

Comment 14: *Moreover, testing should be carried out under representative conditions, this may include the presence of contaminants on the surface. The contractor will notify any conditions that may influence the measurement in the testing report.* (Data collected during surveys where there are conditions that influence the measurements cannot be reported as valid data and should not be used in parameter calculations, as this will cause inconsistency in the data).

2.1.5 Data format
It was recommended that a clear data format should be defined and that 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).

No specific comments received

2.1.6 Data delivered: raw or processed
It was recommended that a road administration must decide whether they want raw or processed data when developing a strategy for the delivery of their survey data.
Comment 15: *At the downside of the raw data approach the handling and storage of large data volumes is not mentioned.* (This is implied in the text in the section discussing processed data: It has been included explicitly in the guidance).
Comment 16: *No recommendation is made. In my opinion the (future) road administration doesn't want to be bothered with storing large amounts of data and maintenance of data processing software, regarding the decrease of technical staff. Quality risks when changing to another provider could be coped with by the use of detailed standards, accreditation and QA-processes of the contractor overseen by an independent auditor. Of course this puts heavy demands on the data specification.* (We feel that the decision should be left to the road administration, so have not made a specific recommendation. Text has been included in the guidance to help the administration make an informed decision).
Comment 17: *The use of the word 'raw' might make someone think of binary or unprocessed data. Typically, some sort of pre-processing needs to be undertaken to generate a transverse or longitudinal profile* (We have included a definition of what we mean by raw data in the guidance and explained that this is not completely raw)

2.2 Measurement of transverse evenness

It was recommended that a requirement for the raw transverse profile measurements should be included in the specification which 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 and 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.

Comment 18*: On highways the measured width should be 4 m, provided the algorithm to calculate rut depth handles side irregularities correctly.* (This has been suggested in the guidance and the inclusion of kerbs, road markings etc. on the accuracy of the rut depth calculation will be noted in section 2 - parameters).

Comment 19*: A specified required valid speed range is suggested. However this depends on the equipment.* (We agree, and this is discussed in the guidance, with a suggestion that valid speed ranges are determined within the accreditation testing)

A general remark about clearly defining the algorithms to calculate the reporting parameters instead of referring to a standard: obviously this is necessary in the present situation, however I would like to plead for more detailed standards that can be referred to in specifications. This would ease drawing up specifications for administrations that can be met more easily by contractors. (Indeed!)

Comment 20: *Reference should be made to EN-13036-8. Specs should be coherent with current regulations. If these are considered insufficient, specific comments to CEN TC227 WG5 are expected.* (This standard has been referenced in the guidance and several of the project partners are members of the committee, so we hope that the findings of HiSPEQ will make it into this standard).

Comment 21*: Why (recommend that the measurements are evenly spaced)? It is more efficient to have a better resolution in the wheelpaths!* (This is true when the vehicle is travelling perfectly in the wheelpaths. However, studies have shown that vehicles wander up to ±200mm from the mid-line of the lane and thus, it would be too much to expect a human survey driver to keep a perfect driving line. Hence HiSPEQ has suggested more measurement points but evenly spaced, so as to always measure the high and low points of the ruts. This is discussed more in the guidance).

Comment 22: *Transverse unevenness (rutting) is a rather long-wave phenomenon. A transverse profile every 1 m is more than enough.* (Research has shown that more consistent rut depth calculations are achieved if the transverse profile is measured every 0.1m and then an average transverse profile reported every 1m. So, we would agree that reporting every 1m is enough, however, we would still recommend that it is measured every 0.1m)

Comment 23: *Unless the speed range is determined by the type of road and traffic intensity, the valid measurement speed depends on the type of equipment.* (Yes. This is explained less ambiguously in the guidance)

Comment 24: *It would also be good to ensure the transverse profile is limited to the pavement surface so that it is unaffected by the kerb & channel or pavement drop off.* (The inclusion of kerbs, road markings etc. on the accuracy of the rut depth calculation will be noted in section 2 – parameters of the guidance)

2.3 Measurement of longitudinal evenness

It was recommended that the 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.

Comment 25: *A specified required valid speed range is suggested. However this depends on the equipment. If specified, acceleration/deceleration thresholds related to the equipment should be defined as well.* (Yes: this is covered in the guidance)

Comment 26:*Guidance should be given (not in this document, but maybe in relation to the templates) to relate desired accuracy of the reported parameters to the profile requirements.* (Yes: this will be discussed in HiSPEQ4:2 of the guidance).

Comment 27: *An advanced draft of EN13036-5 is available to members of this consortium. Specs should be coherent with this standard. If these are considered insufficient, specific comments to CEN TC227 WG5 are expected.* (Many of the project team have had input to this document and we believe that the proposals given in HiSPEQ do not conflict with this).
Comment 28: *For longitudinal evenness indicators, such as IRI, this wavelength range is good enough. Moreover, longitudinal evenness (– or unevenness) is well defined in ISO standards as "deviation of a pavement surface from a true planar surface with the characteristic dimensions along the surface of 0,5m to 50 m (corresponding to wavelengths with one-third-octave bans including the range 0,63m to 50 m of center wavelengths) Thus,* (a longitudinal spacing of) *0,25m should be good enough for characterize this feature.* (This has been explained in the guidance).
Comment 29: *Unless the speed range is determined by the type of road and traffic intensity, the valid measurement speed depends on the type of equipment.* (Yes. This is explained less ambiguously in the guidance)
Comment 30: *This* (the distance between the wheel paths) *is part of the geometry of wheelpaths.* (This was ambiguous: We meant the distance between the measurements lines, not the vehicle wheel paths. This has been written more clearly in the guidance).

Comment 31: *What do you mean by "The minimum level of repeatability of the collected longitudinal profile(s)" exactly? The repeatability of the measurements or the repeatability of the calculations?* (We will ensure that this is clear in the guidance)

2.4 Measurement of Surface deterioration

It was recommended that 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.

It was also recommended 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).

Comment 32: *Minimum vertical resolution should be accompanied with the relative height accuracy* (Addressed)
Comment 33: *Valid speed range depends on the device* (Yes, this is discussed in the guidance)
Comment 34: *Image resolution is usually defined as pixels/mm* (Ok)
Comment 35: *Be careful with "subjective" specs when defining image quality* (We will try to avoid subjectiveness by defining quantitative tests that can be performed to test image quality)

Comment 36: *Manual intervention is a must in this kind of analysis. Automatic analysis by their own are not good accurate enough* (Manual analysis is very time consuming and expensive (and subject to the operator's subjective opinions) and automatic analysis is carried out by a number of the countries for which we obtained specifications. Therefore, we felt that it was something that needed to be allowed for in the HiSPEQ documents. The guidance will discuss the relative pros and cons of the two approaches in the parameters section).

Comment 37: *There should also be defined the minimum dimensions that these systems must identify, in terms of minimum crack width or depth.* (This is very hard to prove quantitatively, which is why an image resolution has been suggested instead)

3 Review of the key requirements for structural condition measurements

At the time of writing, a total of seven reviews had been received for the key requirements for structural condition measurements. The key requirements proposed and the comments relating directly to these are listed in the following sub-sections.

Comment 38: *Well-structured report and with that stating and answering to all important questions necessary for NRA.*
Comment 39: *The curviameter (http://www.roadsurveydevice.com/curviameter/) has not been mentioned at all in this document. In Spain we use 5 of them to survey our network.* (The Curviameter has been mentioned in the guidance as one of the commonly used slow speed survey devices).
Comment 40: *Nothing is said about the type of pavement. It is possible to use the TSD on concrete pavements, for instance?* (This will be discussed in the guidance).
Comment 41: *The report is very well written and covers the bases very well*
Comment 42: *This report introduces TSD and GPR as separate tools but my opinion is that a key issue for the future is the integrated analysis of TSD and GPR data in combination with other road survey data* (The need for accurate construction data (and hence GPR surveys) is discussed in section HiSPEQ7: 1.4).
Comment 43: *This report, especially when discussing GPR, has been written only from the perspective of users from England. This will cause major problems for the reader because England has adopted a much different way of using GPR in road surveys than other EU countries or USA.* (The main difference between the UK and rest of the world is antenna choice (air coupled or ground coupled). We do not intend to specify which should be used, only the depth penetration and resolution which is required for the task. The guidance covers the use of both types of antenna as this is the reality of the market)
Comment 44: *England is almost the only country using ground coupled antenna systems. A general opinion concerning this is that the air coupled systems are superior in network level surveys because the results are repeatable and it is possible to measure many material properties from the pavement structure with a horn antenna. Ground coupled antennas couple with the pavement surface and the changes in the pavement surface properties (wet or dry) cause changes in ground coupled antenna frequency and further to its properties which finally affects the repeatability of the results. This makes no sense. (*We do not intend to specify which should be used: the objective is not to specify a type of antenna but to specify the desired output and accuracy of the testing, whilst guiding the specifier on the pros and cons of different approaches)
Comment 45: *The terminology, for instance, used in the report is different than in other countries or that used by GPR manufacturers. One such example found in the report recommends to “collect scans at closer than 300 mm increments” when every GPR system has a setup system for “scans/m”* (The aim of HiSPEQ is to create a specification template which road administrations will understand not just radar operators. Scans/m is equipment based but the concept of a recording increment is universal. A scans/m equivalent has been added in brackets to help understanding).
Comment 46: *Also the terminology word “transducer” confuses non-English readers, why would you not use the word “antenna” which everyone understands.* (The word antenna has been used in the template and guidance)
Comment 47: *The report focuses on network level surveys* (This is the aim of HiSPEQ)

3.1 General requirements

The following was recommended:

- The specification should define the network that is to be surveyed (including denomination and length of each road section to be surveyed, the survey direction (ascending or descending chainage), the number of lanes to be surveyed). Network information in the form of digital tables and a network map should also be specified.
- The specification require the data to be location referenced to the network and that a method to project the measured coordinates to the network map (so-called "map-matching") should be specified as well.

Comment 48: *This is probably inferred but should also include spatial coordinates of section extents (start and end points)*

- The position of the measurement line should be specified for both TSD and GPR surveys and the GPR should measure in the same line as the TSD.

Comment 49: *An*

- The specification should define the format that the data should be reported in.

Comment 50: *An issue for GPR is how layers are dealt with in the pavement management system (PMS). GPR measures 'interface depth' which can only be related to layer thickness if the interface at the top and the bottom of the layer can be measured. Therefore it can only be certain if the number of layers is already known so that GPR interfaces can be counted against the known layers or that only major layers are required. This also requires the layers and interfaces to be labelled consistently e.g. layer 1 is always the bottom most layer and that the data is updated when maintenance is carried out.* (Noted and will be addressed in section HiSPEQ6: 2 of the guidance)

- The specification should define whether raw or processed data should be delivered. It was recommended that processed data be delivered for GPR.
- A survey frequency of every 3 years for TSD and 5-10 years for GPR.

Comment 51: *GPR surveys every 5-10 years are ok, so long as records are updated following maintenance intervention.* (Noted)
Comment 52: *I do not agree with the statement "However, if the quality of the PMS/AMS data is not good and maintenance records are not kept accurately, then GPR data may be needed on the same frequency as the TSD data." (Page 35 3.5). If the quality of PMS DATA is not good enough, you have to improve it by using GPR Then PMS DATA will be good. After you can record GPR data every 5-10 years.* If you record GPR data with the same frequency as TSD data, You will have data "at least every 3 years". What will be the benefit (cost) to have so much data to process? (Noted and included in HISPEQ1: 4 of the guidance)

- That the specification define the survey conditions required for GPR surveys (dry surface) and TSD surveys (dry surface, temperature, speed).

Comment 53: *The requirement for a set range of temperatures at a depth of 40mm should be translated to a temperature at the surface, otherwise it is not verifiable. Alternatively the pavement temperature could be estimated by means of the mean temperature of the previous day, as the BELLS 3 method.* (Noted and included in the guidance)
Not only the temperature should be considered. The wet condition of the foundation has a great influence. For this reason it is advisable to carry out the structural surveys in the same period of time (spring and autumn in our case) (Discussion of this has been added to guidance)

3.2 Technical requirements for TSD surveys

It was recommended that TSD surveys would require the use of a device with dimensions and layout of testing device similar to 2nd generation devices i.e. 7 Doppler sensors, delivering 800 samples/second. Also that the equipment include instrumentation to monitor all of the key aspects which affect data collection and analysis such as equipment and road temperatures, tyre conditions etc.
Comment 1: *The delivered data rate is the same for lasers in the first and second generation TSD.* (Noted and included in the Guidance).

It was also recommended that TSD reported data should include as a minimum

- 3-D coordinates of equipment position during testing
- Operating speed (40-80km/h)
- Equipment longitudinal profile in nearside wheel path
- Deflection slopes
- Beam temperature
- Tyre pressures
- Tyre temperatures
- Air and road surface temperatures
- Dynamic and static loads
- For network analysis: Surface Curvature Indices at 200 and 300 mm.
- For project analysis: Deflection basin

Comment 54: *The statement blends pavement related phenomena with equipment phenomena.*

I would write something like:

Driving speed is in the range 40-80 km/h. It is verified that the TSD measures correct from 2.5km/h, but data measured at low speeds will include significant contributions from eventual speed dependent visco-elastic pavement response, where data measured at speeds above 30-40km/h will contain almost pure elastic pavement response that is not speed dependent. To keep the data analysis relatively simple for flexible pavements the lower limit for network surveys is recommended to be approximately 40 km/h. The reason for the upper speed limit is that TSD was developed where the general legal speed limit for trucks was 80 km/h. This upper limit coincides well with the optimal performance of the Doppler laser. Decreasing Doppler data rate on dark pavement surfaces has been observed from 60 km/h. Furthermore, 40-80km/h driving speed is comparable to the speeds of hGVs; a fact that improves the representativeness of the TSD results. (Noted and included in the Guidance).
The AUTC method was pioneering the exploitation of the first generation TSD output with the simple beam model matching 3 Dopplers . Since then based on the ph.d. project of Louis Pedersen, the TSD processing software has been released with both the original beam model, and an absolute deflection basin that can benefit from Doppler lasers positioned behind the wheel load and reveal both asymmetry (visco-elastic) and deflection delay between center of load and maximum deflection (inertia). The user can select which model to apply. This is the stage, more advanced than the early AUTC, and opens for advanced pavement analysis and new future key indicators. (This will be included in HiSPEQ7: 2 of the Guidance).
Comment 55: *Regarding the proposal for SCI300 to be international unit (Section 2.2.4): I'd prefer that the common unit be one that is directly produced by the equipment, and not be a derived unit. There are already two established calculation methods for determining SCI300 from laser output. I prefer TSD slopes when comparing data and examining repeatability issues, etc.* (This will be addressed in WP4).

Comment 56: *This report focuses only on what has been done at present and does not examine the possibilities of how TSD data could be used in network level data evaluation. Discussions concerning subgrade related problems are totally ignored. Roadscanners has also analysed BCI (90-1200) from TSD data and found an excellent correlation with Mode 2 rutting. Roadscanners has also calculated strain using the TSD data and found a good correlation with performance.* (This will be considered in WP4).

3.3 Technical requirements for GPR surveys

Scan Interval It was recommended that the collecting system be required to collect scans at closer than 300 mm increments across all channels at speeds up to of 100 km/h and that the scans should be evenly spaced regardless of speed.
Comment 57: *There are more variables than just sample interval that affects maximum survey speed and some of these things can affect data quality. This is very system dependant though and therefore may not be relevant.*
Comment 58: *What about the transverse direction? Is one antenna enough? Should it be in the lane center or in the wheel path?* (Recommendations about where to measure and how many lines etc. have been made in the guidance)

Depth Requirement It was recommended that the specification clearly state the minimum and maximum depths to which layers within the pavement structure should be reported.
Comment 59: *This should be called "Depth and Resolution". It needs to discuss resolution requirements too, in terms of minimum thickness of layers (minimum horizontal distance between upper and lower interface of a layer at which both interfaces can be resolved). This is governed by pulse frequency and therefore increases with depth as frequency decreases, therefore is relatively easy to define. It also should be in terms of the minimum contrast between two overlying layers such that the interface between them can be resolved; this is much more difficult to define.* (Noted and included in the Guidance).
Comment 60: *The penetration depth depends also on the type of material (asphalt concrete, cement concrete, unbound granular materials, etc). Would it be possible/better to specify the frequency range of the antenae?* (HiSPEQ has recommended a data specification, not an equipment specification. Therefore, we believe that the survey commissioner should inform the survey contractor of the general construction of their network and the depth to which the equipment will need to measure).

Legal Conformance It was recommended that the specification should require that all GPR equipment conforms to ETSI standards on the use of Ultra Wide Band Technology and any national regulations.

Certification, maintenance and calibration testing It was recommended that the procuring body requires the GPR vendor to produce documentation to demonstrate that the equipment has been regularly maintained and tested to ensure it is working correctly.

Post-processing of the Raw Data It was recommended that there should be a requirement statement for post processing of the GPR data to be carried out

Interpretation into Construction Data it was recommended that the specification include a minimum requirement for what features are reported out of the data.
Comment 61: *Regarding reporting GPR data (various sections): I really like an idea I heard proposed: GPR analysis is difficult, and so a data quality level should be reported for each reported result, allowing good quality data to be distinguished from guessed data, whilst still allowing the provision of lower quality data.*

Section 3.3.8: The use of determining the full deflection bowl in Australia could lead to use of the full bowl in back-analysis – but that is some time off. The primary immediate use for the AUTC method is to provide a better estimation of maximum deflection. Thus allowing a third (!) method of calculating SCI300. (These comments will be considered in WP4)

Reporting interval It was recommended that the GPR data be reported at the same interval as the TSD data.

Comment 62: *Reflection technique is totally ignored in the report, why? The reason should not be that this technique is not used in England while many other countries use it.* (The technique is used in England…This was an oversight, it should be discussed in section 3.4.5 along with the other depth correct methodologies).

Comment 63: *The report talks about GPR signal velocities while in other countries GPR users and customers are talking about dielectric value and dielectric properties. When discussing velocity exclusively you are ignoring dielectric dispersion which is a very valuable parameter when evaluating pavement properties. We also need to acknowledge that 200 MHz antennas give slightly different "velocities" in certain materials compared to 2 GHz antenna.* (It was felt that there is a broader understanding in the engineering community of the term 'velocity' whilst 'dielectric constant' is the talk of (geo)physicists. Since the specification is to be used by road administrators more likely with an engineering background, it was felt that using velocity makes more sense).

Comment 64: *GPR quality tests should at least be mentioned in 2.3.3. They are used in USA and in Nordic countries. They also assure the GPR users that their system is working properly.* (This was discussed in the key requirements document prepared for WP3)

Comment 65: *The report presents quite an old view on the pavement properties that can be measured using GPR. Recent research has contributed valuable information concerning how GPR can be used to measure moisture in the pavement structure, detect cracking and early phase pavement distress, determine moisture susceptibility of pavement materials etc.* (Since the GPR data will be used to enhance the output from TSD data, the information given was deliberately confined to just consider simple measures of pavement structure which can be reliably delivered).

4 Review of the key requirements for Accreditation and Quality Assurance

At the time of writing, a total of three reviews had been received for the key requirements for accreditation and QA testing. The key requirements proposed and the comments relating directly to these are listed in the following sub-sections.

There is a great need for both Accreditation of survey equipment and continuing Quality Assurance, in order to obtain confidence in, and good value for money from, the data that will be delivered from network surveys. Therefore, HiSPEQ has recommended the implementation of Accreditation and QA regimes.

Comment 66: *I think the document gives a useful overview of QA and accreditation processes of the European road administrations and guidelines, as such I think it's a valuable document that will be certainly of help to give guidance when commissioning surveys.*
Comment 67: *Tolerances in the document are given sometimes as a suggestion and sometimes as an example. In both cases it's not clear, but especially not when suggested, why these values should be chosen. Shouldn't those figures relate to specified accuracy requirements at the level of the reporting parameter? Or is this meant to give figures that in general could be met with the present state of the art equipment?* (This will be addressed in the guidance: The tolerances chosen will need to depend on how the administration will use the data).
Comment 68: *Well-structured report and with that stating and answering to all important questions necessary for NRA.*

4.1 Requirements for Accreditation

Which parameters and measurements to test It was recommended that all parameters delivered by the survey, or calculated from delivered measurements, e.g. rutting, IRI, deflection slope are tested during accreditation, in addition to the location referencing of the data e.g. distance measurements, GPS coordinates.
It was also recommended that the measurements used to calculate parameters e.g. transverse profile were also tested.

What aspects of data quality to test It was recommended that Accreditation assesses core/fundamental Accuracy, system repeatability, and fleet consistency (if multiple devices are employed to deliver data).

How to collect data for testing It was recommended that the tests for Accreditation include measurements on a private road or test track and measurements on selected sites on the road network, which represent the range of conditions found on the network.

How often to test It was recommended that accreditation testing should occur at the start of survey contract for all survey contracts and again at every year of the survey contract, or more frequently if the survey length presents a risk of significant volumes of poor data being delivered.

Who should test the data Three levels were recommended for checking the data quality:

- Highly recommended: Checks carried out by Independent Auditor;
- Recommended: Checks carried out by survey commissioner;
- Acceptable: Checks carried out by contractor, but only if overseen (e.g. by an auditor or by the survey commissioner).

Testing for the effects of external influences on the data It was recommended that specific tests be included in the accreditation tests to determine the effect of speed, to determine the conditions in which surveying can take place and an assessment of the ability of the survey crew.

4.1.1 Requirements for Accreditation testing of Location Referencing

The following accuracy requirements were suggested:

- Distance should be tested to an accuracy and repeatability of ±0.1% of the actual distance, with a minimum tolerance of 1m allowed. Test sites should be chosen so that it can be demonstrated that Road Geometry and vehicle speed do not affect the measurement.
- If GPS data is used, the test sites chosen should include a range of lengths where there is good and/or poor GPS signal. A requirement that 95% of the measured locations lie within a horizontal distance of 2m from the actual location, with a maximum error of 10m was suggested.
- Where the location of node points is measured, the requirement will vary, depending on how the node points are located. If GPS or distance are used the above requirements would be appropriate.

4.1.2 Requirements for Accreditation testing of transverse profile

If tests of transverse profile are included in the accreditation:

- There is a need to manually align the data
- The difference between the profile heights of the measured profile and the reference profile should be calculated. 85% of the measured profile heights should lie within 0.5mm of the reference, 95% within 1mm.

Comment 69: *These values are quite tight especially if a laser based device is being compared against a transverse profile that's been measured with a rolling wheel type reference device or a rod&level with a flat base if the surface texture is coarse* (Noted. This is discussed in section HiSPEQ3: 3 of the guidance)

- The test should also include an assessment of the shapes of the profile, to ensure that the shape of the measured profile is similar to the reference. This could either be via a visual assessment of the profile, or by calculating the correlation coefficient between the two profiles. It was suggested that the requirement for this is $r^2 \geq 0.9$.

Comment 70: *We've had success with this but boy, does it take a long time when you've got 13 lasers or more.* (Noted. This is discussed in section HiSPEQ3: 3 of the guidance)

- Test system repeatability in the same way.

4.1.3 Requirements for Accreditation testing of rutting parameters

It was recommended that accreditation tests always assess the rut parameters and it was proposed that an accreditation requirements could include:

- 95% of measured rut depth values lie within ±3mm of the reference.
- 95% of repeat rut depth values lie within ±2.5mm of the original data. In addition, the standard deviation of the repeat runs could be calculated, with the requirement that the standard deviation between the repeat runs be within ±3mm

- The tests should include an assessment of the effect of road markings and kerbs on the rut depths calculated.

Comment 71: *What about ensuring the rut measurements are confined to the lane?* (This will be considered in section HiSPEQ3: 3 of the guidance)

4.1.4 Requirements for Accreditation testing of longitudinal profile

If tests of longitudinal profile are included in the accreditation:

- It may be necessary to align and stretch/compress the measured raw data with the reference data, depending on the accuracy of the location referencing, as local differences in alignment can cause significant problems.
- To ensure that the survey device is responding correctly to the range of wavelengths of interest for ride quality, it is recommended that the profile is filtered before assessment. For example, to attenuate longer wavelengths. Potential filter lengths are 3m, 10m, 30m.
- The differences in height between the filtered measured profile and the filtered reference profile should then be calculated and a tolerance defined for the required performance. We suggest that 95% of differences between the measured Longitudinal Profile and the Reference Profile should fall within a specified limit (e.g. ±2.0mm)
- We have observed that some specifications also define a requirement for checking the phase between the reference and measured profile.

The data from tests for the effects of speed and deceleration can be used to determine the range of speeds and accelerations for which the equipment delivers acceptable data, using these criteria.

4.1.5 Requirements for Accreditation testing of ride quality parameters

It was recommended that accreditation tests always assess the ride quality parameters. Many different parameters are used across Europe, and these will require different tolerances for the accuracy. However, the same approach should be used to assess them:

- Calculate the parameter values from the measured and reference longitudinal profiles, for the reporting length required by the survey specification.
- Calculate the differences between these parameter values.
- The requirement will then be that x% of the differences lie within a range of $\pm y$. A commonly used ride quality parameter is IRI and we suggest for IRI that 95% of the measurements should lie within 0.5% of the reference.

If the implementation of the ride quality parameter(s) calculation is left to the contractor, then the initial Accreditation should also include tests of this calculation.

4.1.6 Requirements for Accreditation testing downward facing images

It was recommended that accreditation tests include manual visual assessment of the quality of the downward facing images on selected test sites, providing a subjective assessment of whether the images are capturing the correct level of detail for surface deterioration assessment. The subjective assessment needs to consider the evenness of the illumination, the focus and the resolution. The use of a controlled test carried out on a test mat, which includes specific patterns, was recommended to assist in this test. Further “network” tests would be carried out via examination of the Downward Facing Images collected on the accreditation network sites. Network tests should be carried out under varying ambient conditions to check that the system is able to perform consistently under the range of conditions to be encountered during the survey.

It was suggested that quantitative methods be considered to enable more objective assessment of the image quality.

3D Images: Where 3D images are used, there is a need to also test the height measuring equipment. A standardised approach for this is to survey calibration surfaces with the device (described in Annex D of ISO 13473-1).

4.1.7 Requirements for Accreditation testing of surface deterioration (visual condition)

It was recommended that accreditation tests always include assessment of the surface deterioration parameters delivered by a survey. Many different approaches are used across Europe to report the level of surface deterioration in any length, and these will require different tolerances for the accuracy. Likewise, there are different approaches used to obtain these parameters (fully automatic assessment, semi-automatic, and manual). The key objective, as for the measures such as ride quality, is to determine that these are reported accurately and that they are repeatable.

It was recommended that survey commissioners obtain a robust and comprehensive reference dataset against which to check the performance of systems, as the measurement of surface deterioration is recognised to be the most challenging (and inconsistent) component of network surveys.

- The reference test sites should be extensive (several km) and include examples of the types of surfaces over which the survey will be carried out;
- It is not recommended that the tests be restricted to a single site, especially not a closed test track;
- The reference data should kept up to date, as the surface is subject to change over relatively short lengths of time;
- The reference should be collected in a way such that the data can be practically and objectively compared with the test data. E.g. by quantifying the differences between the reference and test data, and that performance criteria (e.g. for the size of the differences) are specified.

If the system under test uses manual analysis to obtain the surface deterioration, then all the manual raters used for this should be subject to accreditation tests, to ensure consistency in the data delivered.

4.1.8 Requirements for Accreditation testing of structural condition (TSD) data

It was recommended that:

- Accreditation tests of the slope sensors are carried out which check the raw deflection slope. We would recommend the requirement that the measured data lie within ±0.050 of the reference, with the reference data being provided either by a reference TSD, or a previous survey using the same TSD;
- Each TSD slope laser should be checked separately;
- The lasers to control the height of the slope sensors above the pavement are checked during accreditation testing to check that they are working correctly. In the UK this is achieved by treating the output of the device as a longitudinal profile sensor and applying the requirements for longitudinal profile measurements to this data;
- The temperature sensors are tested for accuracy and consistency against a suitable reference device.

Different parameters are calculated from the raw TSD data in different countries. These will require different accuracy tolerances to be applied but the approach of comparing the parameter values, for the reporting length required by the specification, can be used for all of them.

4.1.9 Requirements for Accreditation testing of GPR data

It was recommended that accreditation of the GPR is achieved by undertaking a GPR survey of a route that includes a representative range of the construction found on the network. Repeat surveys would need to be carried out in similar conditions (e.g. temperature, humidity) with the requirement for no rainfall between the runs. Cores from (at a minimum) locations where the construction changes should be provided to the contractor for calibration of velocity measurements, and for use in assessing the accuracy of layer thicknesses obtained from the analysis.
The Accreditation test for GPR data should include:

- Calibration of the equipment, to the manufacturer's recommendations;
- Assessment of the accuracy of the interpreted data, including layer thickness and velocities;
- Assessment of the consistency of results from different analysts;
- System repeatability tests of the time/amplitude or velocity data.

4.2 Requirements for Quality Assurance

Which parameters and measurements to test It was recommended that all parameters delivered by the survey, or calculated from delivered measurements, e.g. rutting, IRI, deflection slope are tested during QA, in addition to the location referencing of the data e.g. distance measurements, GPS coordinates.

What aspects of data quality to test It was recommended that the QA regime assesses accuracy, system repeatability, and fleet consistency (if multiple devices are employed to deliver data).

How often to test It was recommended that the survey commissioner and contractor consider their approach to risk and their confidence in the stability of the survey device, in order to determine how often to perform QA testing. Appropriate periods between QA checks are daily, weekly and monthly. The regime could include checks over all of these periods, but to increasing levels of complexity.

Who should test the data It was recommended that the contractor be made responsible for checking the data collected during the QA regime. If any of the data requirements are not met, the Auditor or survey commissioner should be informed immediately. The contractor should provide the QA data to the Auditor or survey commissioner.

Testing for the effects of external influences on the data It was recommended that specific tests be included in the accreditation tests to determine the effect of speed, to

General approach to QA tests It was recommend that the QA approach is to:

- Carry out Surveys of a number of QA reference sites soon after accreditation, with the sites being representative of the condition found on the network;
- Undertake QA test surveys of these sites, at regular intervals throughout the survey contract.

Comment 72: *Has some thought been given towards the use of historical data to QA data?*
(This will be considered in the guidance (HiSPEQ3:3 etc.))

4.2.1 Suggested technical requirements for specific parameters

It was recommended that, in general, the tests consider:

- Location Referencing: Consistency test for measured distance (e.g. within 3m or 0.1%);
- Location Referencing: Consistency of measured position (GPS data) (e.g. within 4m of the actual location);
- Transverse Profile: Consistency test of rutting (e.g. 95% within ±3mm, all within ±10mm);
- Longitudinal Profile: Consistency test of ride quality parameters. Will require different tolerances to be applied depending on the parameter (e.g. IRI measurements within 10%);
- Surface Deterioration: Consistency test of surface deterioration parameters. Different approaches to reporting the level of surface deterioration are used across Europe, which will require different tolerances. However, the tests would in general compare the measured and original/reference surface deterioration, reported in the same way and for the same reporting length required by the survey specification and calculate the differences between these parameter values;
- Downward facing images: It is particularly important that image quality remains consistent due to the effect on any parameters obtained from images. However, quantitative tests are difficult to apply. We suggest that tests be considered that:
  - Check the footprint of the image;
  - Check for changes in greyscale values over time;
  - Check for changes in image contrast and focus over time.
- Structural Condition (TSD): Consistency test of deflection slope from each sensor (e.g. 95% within ±0.05, all within ±0.2);
- GPR data: Calibration tests. The equipment should be calibrated in line with the recommendations of the manufacturer i.e. it should be tested for time measurement, and anything else that the manufacturer recommends, at a frequency recommended by the manufacturer. It is possible that the equipment will only need to be calibrated once within the survey contract.
- GPR data: Consistency of GPR data. A requirement for consistency in the time and amplitude values for each reporting length (e.g. 95% of the average time and amplitude values within ±5% of the measurements made at the start of the survey). It may be that a larger tolerance would need to be considered when comparing data collected during the summer months, with data collected during the winter, as the moisture content of the pavement will cause changes in the measurements made.

4.2.2 Summary of information/requirements to be contained in the QA specification

It was recommended that the following always be included in a specification for QA

- A description of the tests included in the QA regime i.e. calibration, surveys of road network sites, number of repeat surveys required, whether accuracy and fleet consistency will be tested, in addition to system consistency;
- A description of the road network sites (i.e. length, characteristics etc.) to be surveyed and the frequency with which they should be surveyed;
- If appropriate: A description of the reference devices used to provide reference data, including how often this data will be updated;
- Who will be responsible for assessing and checking the data;
- How the data will be assessed;
- Requirements for the system consistency required for all parameters delivered or calculated from delivered data;

- If appropriate: Requirements for the accuracy of the parameters, requirements for the fleet consistency.

No specific comments received

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