Heroad, Holistic Evaluation of Road Assessment

Pavement performance assessment

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Executive summary

To manage the road network, road managers and operators have to consider existing policies, such as the requirement to keep the network in good condition, and to deliver this condition at minimum whole life cost. However, the condition should also meet the expectations of stakeholders. The management process has to optimise the total costs for society, whilst minimizing the effects of given condition levels on safety, reliability, environmental impact, economics and sustainability. This principle and its overall goals are common for all road managers around Europe. *Heroad* investigates this holistic process (the combination of individual components, levels of assessment and the inclusion of a life cycle perspective) of asset management. This report summarises different practices that European countries are using to assess performance of road pavements, including drains and earthworks.

The countries considered for the study were: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Lithuania, Netherlands, Norway, Slovenia, Switzerland, Sweden, and the UK. The study was carried out by analysing results obtained from a consultation with road owners, or road experts in all countries listed. All road networks were considered in the study, apart from those consisting of very low volume roads or unbound roads.

Pavement stakeholders, their expectations and the ideal measurements to assess these expectations were identified and the consultation attempted to find out whether and how these measurements were being made.

The analysis of this consultation has identified some common practice, some good practice and also some gaps in measurements made. Recommendations have been made as to what might improve the measurement of pavement condition across Europe, to either better assist in maintenance decisions, or better meet stakeholder expectations.

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1 Introduction

"ERA-NET ROAD – Coordination and Implementation of Road Research in Europe" is a Coordination Action funded by the 6th Framework Programme of the EC. The partners in ERA-NET ROAD (ENR) are United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.eranetroad.org). Within the framework of ENR this joint research project was initiated. The funding National Road Administrations (NRA) in this joint research projects are Belgium, Switzerland, Germany, Denmark, Finland, France, Ireland, Lithuania, The Netherlands, Norway, Slovenia, Sweden and United Kingdom.

To manage the road network, road managers and operators have to consider existing policies, such as the requirement to keep the network in good condition, and to deliver this condition at minimum whole life cost. However, the condition should also meet the expectations of stakeholders. The management process has to optimise the total costs for society, whilst minimizing the effects of given condition levels on safety, reliability, environmental impact, economics and sustainability. This principle and its overall goals are common for all road managers around Europe. *Heroad* investigates this holistic process (the combination of individual components, levels of assessment and the inclusion of a life cycle perspective) of asset management. This includes

- Exploring data collection, assessment and reporting regimes
- Identifying and assessing the key technical components of these regimes and identifying good practice
- Considering new challenges (climate change, traffic configuration, new materials, LCC and the focus on road users' expectations)
- Identifying and describing indicators at different assessment levels (for road operators complicated technical parameters are okay, for decision makers and public more understandable indicators that could be built from combination of technical parameters are needed)
- Picking out the key areas of good practice and providing advice on how these could be more widely applied.

This document is a deliverable reporting the outcomes from the Heroad work on the assessment of pavements.

2 Background

Across Europe a large range of methods are used to measure the condition and performance of road assets, including inspections of visual condition using manual methods, and traffic-speed surveys carried out with the normal traffic flow. The data provided could be visual (such as the level of cracking present in a road pavement), functional (such as the level of ride quality or ability of a drain to pass water), or structural (such as the level of deflection or strength of a pavement). The FORMAT project (FORMAT, 2005) reported that new technologies (such as traffic-speed surveys) had the potential to measure most of the traditional data required but a common strategy in the use of these methods had yet to be developed. As a result, there is a large inconsistency regarding how new methods are used across EU countries. This presents a barrier to both the wider scale introduction of, and good use of, this data.

In this task we have identified and reviewed how pavement condition is routinely assessed across the member groups, covering Belgium, Austria, Denmark, Finland, France, Ireland, Lithuania, The Netherlands, Norway, Slovenia, Sweden and the United Kingdom. We have particularly considered the use of new techniques for routine assessment. Within the context of this task, we have considered "pavements" to include the road layers, drainage and drainage systems, and associated earthworks.

2.1 Road networks considered

The overall objective of the Heroad project was to identify the best, or promising, practices for holistic assessment of road condition. It was thought that best practice would be unlikely to be found on the lowest road categories (e.g. unclassified roads in the UK), and therefore we have concentrated on higher road categories. For clarity of definition of road type we have used the network definitions defined by the COST 325 project (COST 325, 1996), which are:

Motorway and Primary road network: Motorways and primary roads are those roads of international importance, high traffic loading, high percentage of heavy vehicle traffic, dual carriageway road, grade separated junctions, high design speed (>100km/h) etc. For example, in the UK, this network would be the Strategic Road Network (which includes motorways and trunk roads).

Other primary road network: Other primary roads are roads of international and national importance with medium traffic loading, medium percentage of heavy vehicle traffic, mainly single carriageway road, mainly junctions at grade, medium design speed etc. For example, (non-trunk) A roads in the UK.

Secondary road network: Secondary roads are roads of national importance, low traffic loading, low percentage of heavy vehicle traffic, single carriageway road, junctions at grade, low design speed etc. For example, B and C roads in the UK.

2.2 Assessment considered

In order to make an assessment of their road network, and to prioritise maintenance work, a road owner or operator needs to know the condition of the whole of their network. This condition is typically assessed using routine condition assessments carried out over a large proportion of the network on a regular basis. Within the Heroad project, we have focussed on these routine network-level assessment methods.

3 Methodology

The work has sought to answer the following questions:

- What is the approach to collection of condition data? How is the condition assessed using traffic-speed techniques? What different approaches are being taken? What are the main barriers to using these systems and what is required to overcome them?
- What are the key pavement condition parameters measured across the road network (to include those relating to functional, structural and safety)? What are the commonalities in the parameters, where are there large differences in approaches and why?
- Which parameters are considered important? Are there any parameters considered as secondary importance (not used in decision making processes)?
- What is the approach to analysis? How does the measurement method influence the analysis? Can data collected at traffic-speed be used interchangeably with traditional data?

We have also reviewed the approaches taken to ensuring that all data collected is robust and consistent. This has been achieved by reviewing the training, accreditation and quality assurance procedures applied for the assessment of road pavements across Europe, and how this affects robustness and trust in the data at both the local and network level (there may be technical reasons for very high levels of detail and accuracy in condition data for making local decisions on maintenance but this may not be so important at network level).

3.1 Questions

Whilst it was not felt appropriate to send out a questionnaire for the Heroad project (see Section 3.2), it was felt that developing a set of questions would be a robust way to obtain the required information for each country of interest. A set of questions was therefore developed to seek information on the approach to pavement condition assessment. The questions for pavement condition are presented in Appendix A, which also includes explanations (guidance for the interviewers) for some of the key questions.

The questionnaire was split into a number of sections:

- General questions about the person providing the answers.
- General questions about the road networks for the country being asked about e.g. length, traffic loading, construction.
- General questions about what kind of drainage systems are used on each road network.
- In depth questions covering the approach to pavement assessment, drainage assessment and earthwork assessment.
- In depth questions exploring the key pavement parameters measured across the networks.
- In depth questions on how the quality of data is managed.
- In depth questions on environmental strategies and policies applied to pavements.

3.2 How answers to the questions were obtained

A number of questionnaires are sent out every year to road operators and other stakeholders. Only a few of them are answered, and the sample of answers is not necessarily representative of the full population of stakeholders. Therefore, whilst a set of questions, similar to a questionnaire, had been devised for the project, it was felt that these should not be just sent out in bulk. It was decided that the partners would try to answer as many of the questions as possible, using literature reviews and the knowledge of experts within their own organisations. Help would then be sought from external experts to obtain the missing information and to also verify the answers obtained internally.

External experts, identified as potential contacts, were initially sent an e-mail describing the Heroad project, why they were being contacted, and then a request for their help. They were made aware that the help required would involve being sent a partially completed set of questions, and then being available for a phone call, for one of the partners to discuss the validity of the existing answers and also try to complete the unanswered questions.

Those external experts, who responded positively to the request for help, were then e-mailed the partially completed questions and then telephoned at their convenience.

Those contacts used to answer the questions (both internal and external) are listed in Appendix B.

3.3 How answers to the questions were analysed

Traditionally, highway assets are managed on the basis of engineering requirements (safety, durability and value for money). However, understanding stakeholder expectations is important to ensure 'effective and efficient' management of the assets and thus a holistic road assessment requires understanding of stakeholders' needs and expectations. (Stakeholders include all groups that impact on and are impacted by the provision and management of the highway network).

The questions that have been addressed to determine what needs to be measured, in order to carry out a holistic assessment are:

- Who are the stakeholders?
- How to determine stakeholder expectations and perceptions?
- What could be measured in order to translate these expectations and perceptions into highway service levels?

How the stakeholders and their expectations were determined for Pavements is discussed in the following section.

4 Pavement Stakeholders, their Expectations and ideal measurements

The stakeholders associated with road pavements include the owners (public owners, private owners), the operators (road directorate, concessionaries, local project managers), the users and the neighbours (resident, commercial business, industries). Aspects of road management have previously been identified within the EVITA project (EVITA, 2011). These include: Reliability, Service Quality, Capacity, Availability, Environmental Impact, Durability, Safety and Economy.

This list of stakeholders and aspects of road management was reviewed for use within Heroad, and judged to be a sound basis on which to establish a matrix of stakeholder expectations. However, due to the overlap between the expectations of the operators and owners, Heroad has considered these as the same stakeholder. Also, it was felt that Reliability was actually a subset of Durability, whilst Capacity could be covered by Availability and Service Quality. This led to the development of the stakeholder expectation matrix, shown in Table 1.

Table 1: Stakeholder expectation matrix used for Heroad

Stakeholder / Expectation	User	Owner/Operator	Neighbour
Availability			
Service Quality			
Safety			
Environmental Impact			
Durability			
Economy			

In order to complete this matrix for Pavements, experts were consulted, including those involved in the EXPECT project (EXPECT, 2012), operators working for the UK Highways Agency, operators from some of the local authorities in England, and the literature was reviewed (Benbow 2011, Parsley 2005, Benbow 2006, Ahlin 2004, Dahlstedt 2003, Ramdas 2007, Ihs 2002, Guthrie 2001). This was followed up by workshop meetings of the project team, which aimed to populate the proposed stakeholder matrix with information covering two areas for each expectation: "what would the stakeholder expect?" and "How might this be measured in an ideal system?" The resulting matrix is shown in Table 2.

Table 2: Stakeholder Expectations and Ideal Measurement Practice

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Availability – what the stakeholder expects	Users expect to access the entire network at all times, or at least know in advance that they can't – they want it to be predictable. They also expect to be able to travel at a certain speed, dependent on the time of day, or season. They expect service and safety at all times.	The owner would expect to maintain some of the road network but at minimal overall cost, whilst maintaining the Service Quality i.e. owner expects nearly all of the network to be available nearly all of the time. The owner would expect the road drainage to be sufficient that the road would not need to be closed because of flooding.	Neighbours expect diversions to be put in place when the road is not available. They would expect these diversions not to cause local traffic problems, damage to their property, or similar issues.
Availability - Ideal measurement practice	The amount of delays (hours) caused by maintenance. The ability to predict the accuracy to which maintenance interventions occur in time and duration. How well the information regarding road works, and associated delays etc, reaches the users.	Percentage of time that each section and lane is unavailable due to pavement maintenance. The amount of delays (hours) caused by maintenance. The operators may only be concerned by these two things if income is affected by the amount of the availability or amount of delay experienced on the network or if there are legal implications where emergency services are unable to get accesses when required. Adequacy of road drainage.	Percentage of time that each section and lane is unavailable due to pavement maintenance. The amount of delays (hours) caused by maintenance (may only be concerned if this affects them. For example, neighbours may welcome lack of noise from a main road but not extra passing traffic past their front door). The ability to predict the accuracy to which maintenance interventions occur in time and duration. How well the information regarding road works, and associated delays, diversion routes etc, reaches the neighbours.

Stakeholder	**User (commercial and private)**	**Owner/Operator**	**Neighbours**
Service Quality - what the stakeholder expects	Users expect a level of comfort e.g. lack of vibration, jolting. They expect the road geometry to offer good handling, for the in-vehicle noise to be at a minimum, and for good visibility (minimum splash spray, dust). The users also expect the general ambience of the road to be of a certain level.	The owner expects the Service Quality to be such that the road is sufficient to meet traffic flow demands, and to satisfy the user by maintaining availability. The Service Quality should also be at a level that minimises vehicle damage, thus avoiding claims from users. The owner would also expect the road to deliver a minimum level of journey time reliability.	Neighbours expect the road drainage to be sufficient to prevent flooding of their properties by surface run off. They also expect: The splash spray not to affect their property; For the noise levels to be at a minimum. For there to be infrastructure in place to ensure that the road users stay on the road.
Service Quality - Ideal measurement practice	Assessments of: • The level of comfort (this covers transverse and longitudinal roughness). • The levels of geometry to result in comfortable handling. • The level of in-car noise. • Sufficient sight lines • Homogeneity of road surface's appearance (e.g. lack of patching) • Level of splash spray • Percentage of length affected by potholes, or significant local defects.	The measurement requirements are dependent on how the owner/operator operates their contracts. If we assume that they have user or service quality requirements built in, then they might contain all of those listed in the users' requirements. Percentage of length affected by potholes, or significant local defects. The thresholds specified may differ from user requirements.	Level of noise, including tyre/pavement interaction noise, engine noise, noise caused by significant local defects e.g. loose manhole covers [Road Equipment]. Adequacy of road drainage. The number of excursions per section.

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Safety - what the stakeholder expects	Users expect there to be enough surface friction to enable them to stop within a reasonable stopping distance. Users expect the profile to be smooth enough to not lead to any safety issues. They expect suitable road geometry to enable drainage of water off the road, and also safety when cornering. They also require good visibility. Users also require earthworks to be stable and not likely to collapse.	Expect to provide a level of safety that minimises accidents, particularly major ones, since these will affect the availability of the road, and there will be an associated cost to clear up the accident, and make any repairs needed to the road surface. The owner will want earthworks to be stable and not likely to collapse. The owner will also want the level of safety to be such that it minimises liability. The owner expects to be able to provide a level of safety for road workers, to ensure they are not exposed to excessive danger.	Neighbours expect the provision of infrastructure to ensure vehicles remain on the road e.g. friction to enable drivers to stop. They expect consideration of the exposure of pedestrians and property to road users. Neighbours also require earthworks to be stable and not likely to collapse.
Safety - Ideal measurement practice	Level of surface friction (both wet and dry) and maximum stopping distance for each section, and each vehicle class. Assessments of: • The level of roughness (this covers transverse and longitudinal). • The levels of geometry to result in safe handling. • Sufficient sight lines • Ability to shed water: Both drainage and ponding. • Level of splash spray • Percentage of length affected by potholes, or significant local defects • The level of stability of earthworks.	Level of surface friction (both wet and dry) and maximum stopping distance for each section, and each vehicle class. Assessments of: • The level of roughness (this covers transverse and longitudinal). • The levels of geometry to result in safe handling. • Sufficient sight lines • Ability to shed water: Both drainage and ponding. • Level of splash spray • Percentage of length affected by potholes, or significant local defects • The level of stability of earthworks.	Assessments of: • Level of surface friction (both wet and dry) and maximum stopping distance for each section, and each vehicle class. • Kerb upstand and condition in each kerbed section. • The level of stability of earthworks

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Durability - what the stakeholder expects	Users expect the road to always be in good condition and available to use. Therefore, their expectations for durability are covered in availability and service quality.	The owner expects to have to carry out maintenance on the road, in order to secure durability. However, the owner would expect this maintenance to have minimal disruption to traffic flow, and for the cost to be within their budget. The owner will also expect to be able to predict the durability of the pavement (trending), particularly failure. If their maintenance is predictable, this will help them to inform the users of road availability.	The neighbours expect the road maintenance to be at a minimum, so they don't have to endure noise (from the maintenance itself or maintenance vehicles), or diversions which bring traffic closer to their properties. They also expect to be warned of maintenance so they can plan for it e.g. to be on holiday whilst the work is done. Their expectations for durability are covered in availability and service quality.
Durability - Ideal measurement practice	N/A	The same measurements as specified for service quality, as they will deliver parameters from which durability could be calculated. May also want to measure • the structural strength of the pavement. • Visual deterioration (e.g. fretting and cracking). • Transverse road surface shape (structural rutting).	N/A

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Economy (cost) - what the stakeholder expects	Users expect the following to be minimised: • Fuel consumption • Taxes or tolls • Congestion (this incurs delay charges) • Vehicle damage (via wear or accident).	The owners expect to incur a level of cost for maintenance and asset management (including survey costs) but they also expect this cost to be minimised. They expect the whole life costs to be minimal, or at least sensible. They also expect to minimise costs incurred by accidents, whether for liability claims, or clear up etc.	Neighbours experience the following costs: • The presence of the road may devalue their properties • They may have to pay extra tax to their local council to maintain the local roads, if the main road is regularly unavailable. • They may have large maintenance bills, due to the effects of dust, pollution and vibration, on their property. • They may have health issues from living near a main road, which also has cost implications. They would expect these to be minimised.
Economy (cost) - Ideal measurement practice	Energy rating per km travel on road per section and for each vehicle class. Costs arising from undertaking additional slower or longer journeys due to maintenance work. Cost of accelerated wear resulting from poor service quality or safety.	The amount spent on planned maintenance per vehicle km and lane km per year. The predicted cost of maintenance per whole life of the road e.g. 60 years. The incidental costs e.g. accident claims, emergency works.	The cost to neighbours as a result of the road being present (include maintenance of housing, depreciation, social costs etc).

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Environmental Impact - what the stakeholder expects	“Green” users might expect their CO_2 emissions to be at a minimum (rolling resistance, geometry, congestion/traffic flow), as well as their noise and particulates emissions	Owners want the CO_2 emissions to be as low as possible. They expect to have to consider sustainable maintenance, local nature, and consider waste management, when carrying out maintenance. They might expect their noise and particulates emissions to be at a minimum.	Neighbours expect noise, dust, fumes, water run-off to be at a minimum, to prevent property damage or illness. They expect to be protected from levels of vibration that cause either damage to their health, or their property. They expect the local wildlife to be considered and catered for e.g. mammal/amphibian tunnels.
Environmental Impact - Ideal measurement practice	Energy rating per km travel on road per section and for each vehicle class (and the resulting CO_2). Level of particulates resulting from a road, for each section. Traffic noise level, for each section.	Measure of how sustainable their operations are: • CO_2 created as a result of maintenance • How much waste is produced during maintenance. Also, they might expect the water run-off to not pollute local water courses. Level of particulates resulting from a road, for each section. Traffic noise level, for each section.	Pass by noise, particulates, CO_2 levels, other harmful gases (air quality). Adequacy of road drainage, where it drains to, what contaminants it contains. Vibration measurement. The number of animals killed on each section per year. The number of road accidents involving animals on each section per year.

As can be seen from Table 2, there are a large number of stakeholder needs which need to be addressed when managing the pavement asset. However, there is a large degree of overlap in the measurements needed to assess the performance of the highway in meeting these needs. By review of Table 2 we can extract a general set of measurements to satisfy the stakeholder needs across all expectations and aspects. These are summarised in Table 3. The way approaches that are currently being taken to meet these measurement requirements are discussed in Section 5, within the subsections shown in the second column of Table 3. To avoid repetition of discussion of the same measurement across the different aspects, they will be covered within each sub-section as shown in bold in the third column of Table 3. For example, whilst vehicle handling is an aspect of Service Quality, this topic is most related to Safety and therefore has been covered in the Safety section.

Table 3: Summary of measurement practices across each expectation

Topic	**Sec'n**	**Measurement Aspects**
Availability Measures	5.1	Location, duration and effect of maintenance on the availability of the road network.
Service Quality Measures	5.2	**User comfort**, Vehicle handling, Noise, Sight lines, Appearance of surface, Splash spray, Potholes, Adequacy of drainage
Safety Measures	5.3	**Surface friction, Vehicle handling, Sight lines, Ability to shed water, Splash spray**, Potholes, **Measurement of kerb upstands and condition**, Stability of earthworks.
Durability Measures	5.4	**Structural strength, Visual deterioration and appearance of surface, Structural rutting, Potholes**, Adequacy of drainage, Standing water
Drainage	5.5	**Adequacy of drainage**
Earthworks	5.5	**Stability of Earthworks**
Economic Measures	5.7	Energy rating per km (fuel consumption), **Costs arising from maintenance, Cost of accelerated wear, Incidental costs, Cost to neighbouring property**
Environmental Measures	5.8	**Fuel consumption, CO_2 production, Particulate levels, CO_2 and waste created during maintenance, Water run-off, Noise, Vibration, Wildlife**

5 Current measurements

Information regarding measurements on Pavements was sought primarily from individual countries by carrying out a consultation, based primarily on a questionnaire. Information was also obtained by carrying out a review of both literature and other projects in the current ERANet call. The sources of data were:

- Heroad questionnaire covering Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Lithuania, The Netherlands, Norway, Slovenia, Sweden, Switzerland and the UK;
- COST354 database (COST 354, 2007);
- FILTER project (Descornet, 1999; Willett, 2000) ;
- FORMAT project (FORMAT, 2004; FORMAT, 2005);
- ASCAM project (Turk, 2012);
- EVITA project (Mladenovic 2011, Vajdic 2011)
- Toolbox (http://www.eranetroad.org)
- MIRAVEC (Hammarström, 2013)
- HERMES (Descornet, 2006)
- HEATCO (Bickel et al., 2006; Odgaard et al., 2005).

Please note that where a country has not been listed within one of the data tables presented in the sections below, this is either because the consultation and review did not manage to obtain any information for that country, or that we were not certain enough of the information given, to include it.

5.1 Availability Measures

Availability measures have been thoroughly analysed within the ASCAM project (ASCAM, 2012) and therefore will not be pursued any further herein.

5.2 Service Quality Measures

A user's perception of the quality of service offered by a particular road will be based on their experience of comfort whilst driving on the road network, how their vehicle has handled, the level of noise they endure whilst driving, how well they can see other vehicles (i.e. sight lines) when traversing junctions, whether their vision has been obstructed by splash spray (related to how well water is drained away from the surface) and how many potholes or other severe features they have encountered on their journey.

Vehicle handling is likely to only become a problem for users when it gets so poor that they feel unsafe whilst driving, causing them to significantly reduce speed, or otherwise mitigate the risk of accident. Therefore it was felt appropriate to discuss vehicle handing within the Safety Measures section (Section 5.3). Similarly, how well users can see other vehicles at junctions and whether their visibility is affected by splash spray will affect how safe users feel (and are) and these aspects have also been discussed in Section 5.3.

Potholes are a source of irritation for users and have been identified as aspects under Service Quality, Durability and Safety (Table 3). They are of primary concern to road authorities, since they may be a source of accidents, can lead to costs incurred from users claiming for damage to vehicles, and can also indicate pavement failure. Potholes have therefore been discussed under Durability Measures (Section 5.4).

Although many aspects of Service Quality fall within other areas found elsewhere in this report, user comfort does not fall under any other area and therefore, the rest of this section will discuss this.

The level of comfort is dependent on the shape of the road surface, the vehicle in which the user is travelling and also the speed with which the vehicle travels over the surface. The way that a vehicle responds to the shape of the road will heavily influence the way that a user will perceive ride quality. Whilst users may lean towards buying vehicles manufactured in their own countries (e.g. Peugeot in France, Volvo in Sweden), a similar mix of vehicle types and models can generally be found in each country. Thus, because they are travelling in the same types of vehicles, the differences in the level of comfort experienced by users across Europe may be dominated by the different shapes of the road found in each country.

In terms of pavement shape, comfort will be primarily affected by the longitudinal profile of the road but also the transverse profile, the road geometry and the texture (e.g. a heavily fretted road is unpleasant to travel over). Table 4 shows which countries are measuring these shape parameters routinely, and also how frequently they are measured. Road geometry is the measure of gradient (the longitudinal slope of the road), crossfall (the transversal slope of the road) and also curvature (a measure of how sinuous the road is). The road authorities included in the consultation and review use the measurements of longitudinal profile to assess comfort by deriving a parameter from the measured profile that relates to ride quality. The ride quality parameters are also listed in Table 4.

As can be seen from Table 4, all countries considered measure longitudinal profile routinely on their networks. Within Europe and North America, a common approach to measure longitudinal profile is to use high-speed profilometers, which typically incorporate lasers and accelerometers. Whilst the measurements from these devices are very accurate, one drawback of the systems is that a laser will only measure profile along a very narrow line (~2mm) and thus the profile measured is very dependent on the position of the survey vehicle within the lane. The profile measured is therefore not necessarily representative of the profile experienced by the tyres of all of the different types (weights, size etc) of vehicles travelling over the road. The use of multiple measurement lines within the wheeltrack, to better represent user opinion has been considered by Ahlin et al (2004) and Benbow et al. (2006). Ahlin concluded that the use of three measurement lines covering the nearside wheelpath showed better agreement with truck wheel perceived roughness than a single measurement line. However, when applied to user perception studies carried out in passenger cars, Benbow showed that extra measurement lines within the wheelpath did not improve the agreement between user opinion (in cars) and the reported parameter. However, Benbow showed that measurement of longitudinal profile in both the nearside and offside wheelpaths would be of benefit.

As discussed previously, the vehicles driven by roads users in each country are very similar and therefore, in theory, it should be possible for one measurement method and parameter (or set of parameters) to be used to represent user comfort across the whole of Europe. This does not seem to be the case in practice. As can be seen from Table 4, the majority of countries calculate IRI but there are exceptions e.g. UK, France, Belgium, with Austria supplementing the IRI with the WLP, which was developed in Germany and adapted for experimental use in Austria. Also, the information provided in the questionnaire suggested that only three of the countries have a measure that attempts to identify the location of discontinuities (e.g. potholes) – the UK’s Bump Measure and Germany and Austria’s WLP. The scope of the questionnaire did not cover why each country has chosen the parameters they have, therefore it is not possible to conclude why different parameters are used.

Table 4: Measurements of pavement shape

Parameter/ Country	Trans profile	Long'l profile	Gradient	Crossfall	Curvature	Texture	Frequency of survey	Ride Quality parameter used
Austria	x	x	x$	x$	x$	x	5 years for PR*	IRI and Weighted Longitudinal Profile (WLP)
Belgium (Fl)	x	x	x				Annually for PR*	Coefficient de planéité: CP2.5, 10 and 40
Denmark	x	x	x#	x#	x#	x	Annually for PR*	IRI
Finland	x	x	x	x	x	x	Annually for PR*	IRI
France	x	x	x	x			3 years	Wavelength NBO: Short, Medium and Long
Germany	x	x	x	x	x		4 years for PR*	Weighted Longitudinal Profile (WLP)
Ireland	x	x				x	Annually for PR*	IRI?
Lithuania	x	x					3 years for PR*	
Netherlands	x	x		x		x	Annually for PR*	IRI
Norway	x	x	x	x	x	x	Annually for PR*	IRI
Slovenia		x				x	4-5 years	IRI
Sweden	x	x	x	x	x	x	3 years	IRI
UK	x	x	x	x	x	x	Annually for PR* 2-4 years for other roads	Enhanced Longitudinal Profile Variance: 3m, 10m and 30m eLPV on PR* network, Moving Average LPV: 3m, 10m and 30m LPV on other networks. Bump Measure on all networks.

*PR = Primary Roads

Not measured routinely – only when pavement constructed, or if there are issues

$ Routinely measured, but only evaluated if specific questions arise

Whilst it should be possible for a common comfort parameter (or collection of parameters) to be calculated in each country, this is not the case and it may be difficult to gain agreement on a single parameter. However, it would be desirable for the parameters that are used to relate equally well to user perception. In order to establish this, a large user perception study would be required, in order to compare the parameters to user opinion. This could also be used to confirm whether a single line of longitudinal profile is sufficient to assess comfort, or whether multiple lines are needed.

There have been a number of studies performed that compare user opinion of ride quality to ride quality parameters calculated from longitudinal profile (Benbow 2006, Janoff 1985, Ahlin 2004, Dahlstedt, 2003, Loizos, 2008, Prem 2008). These showed that users are affected both by the general ride quality present on and the presence of discontinuities, causing jolting and bumping. The parameters considered in these studies all relate to general ride quality (comfort), and most aren't capable of identifying locations where users would be jolted from discontinuities in the pavement's surface e.g. potholes, poor joints in concrete pavements. The results of the consultation suggest that, whilst all countries considered have a measure of general ride quality, only 3 of them had a measure that attempts to identify such discontinuities. The scope of the questionnaire did not cover why this is the case.

Table 4 shows that the frequency at which comfort is measured varies between 1 and 5 years. It is known that the longitudinal profile of pavements does not change significantly over short time periods and hence probably does not need to be measured frequently. The more frequent surveys carried out in some countries may be related to a need to measure other parameters that do change more over time (because the equipment used to measure longitudinal profile has been installed on a vehicle that also measures other aspects of condition, such as transverse profile). However, it may also be due to political, financial or commercial reasons (such as need to have a regular survey contract in place). This suggests there is a need to further review the survey practice and the optimal frequency for measurement of longitudinal profile.

The review has shown that current survey practice in Europe for assessment of comfort is based on the measurement of longitudinal profile and the calculation of a "proxy" parameter to provide an indication of the level of comfort. Different proxy parameters are used in each country, and their relationship has not been robustly established. An alternative approach would be to directly measure ride quality in actual users' vehicles. The INTRO project showed that a representation of ride quality may be obtained from "probe vehicles", by collecting data from sensors fitted routinely to production vehicles (Benbow, 2008). This probe vehicle approach could be used to provide frequent ride quality data from all types of vehicles, travelling at different speeds. Whilst the information obtained from the sensors fitted to these vehicles is likely to be less accurate than that obtained from specialist vehicles, it could potentially provide a cheap, abundant source of condition information for network managers. This is expected to be further pursued within the current TRIMM project (TRIMM, 2012).

5.3 Safety Measures

Vehicle safety is affected by the shape of the pavement that it is travelling on, how fast the vehicle is travelling, how well its tyres can grip the surface of the road (surface friction - to aid both handling and stopping), how wet the surface is, and how far drivers can see. Pedestrian safety is affected by the presence of kerbs and what condition, shape and height they are.

To manage the risk of hazards and accidents on their networks Road authorities therefore take action to assess and mitigate risk by measuring characteristics that affect safety and carrying out remedial works where required. This section discusses the measurements undertaken to quantify these hazards.

5.3.1 Vehicle Handling

The shape of the pavement's surface can affect the way that a vehicle handles, with crossfall and curvature having a particularly large influence. Table 5 shows the countries measuring these parameters routinely, and how frequently they are measured.

Table 5: Country measurements of Crossfall and Curvature

Country/Parameter	Crossfall	Curvature	Frequency of survey
Austria	x	x	5 years for Primary roads
Belgium (Flemish)	-	-	N/A
Denmark			When constructed, or when issues arise
Finland	x	x	Annually for Primary roads
France	x	-	3 years
Germany	x	x	4 years for Primary roads
Ireland	-	-	N/A
Lithuania	-	-	N/A
Netherlands	x	-	Annually for Primary roads
Norway	x	x	Annually for Primary roads
Slovenia	-	x	4 – 5 years
Sweden	x	x	3 years
UK	x	x	Annually for Primary roads 2-4 years for other roads

Whilst some of the countries routinely measure these parameters, there was no evidence in the consultation that significant use of this data is being made to assist in the measurement of vehicle handling. Examples identified where use is being made are AlertInfra (AlertInfra, 2012) and MARVin (MARVin, 2012). AlertInfra, developed by CETE, is used in France and is based on Curvature, Crossfall, Gradient, Macrotexture, Friction and Unevenness data. It has been designed to automatically detect dangerous configurations on a road network. MARVin was developed by AIT and is used in Austria. It takes similar inputs to AlertInfra and attempts to detect accident black spots. At the network level, routine optimisation of road geometry is not feasible since changing this would require complete redesign. However, such tools would allow road authorities to identify where changing the geometry would provide significant reduction in risk. Most of the countries consulted already acquire the measurements needed for these models and thus implementation would not require additional data collection. The use and suitability of such models to identify schemes is expected to be investigated within the Toolbox project (Toolbox, 2012).

Table 5 shows that a number of countries make regular assessments of geometry. In theory, it should not be necessary to routinely measure road geometry, since traffic has little effect on it (i.e. it does not change significantly over time). It should be possible to take very few measurements of these parameters in a pavement's lifetime (assuming no major design changes), and this is the approach taken in Denmark. However, this relies on accurate location referencing data and also for the post-survey data handling to be efficient. This may not be the case in practice and countries may find that measuring road geometry routinely is more straightforward than to resolve the data handling and location referencing issues currently present in their management systems.

5.3.2 Vehicle Speed

Knowledge of the speed that vehicles generally travel on any length of road will help a road authority to better understand the risk present for many aspects of road safety – vehicle handling, comfort, friction, splash spray. For example, the road authority may want to ensure better skid resistance of the surface, on roads on which vehicles generally travel faster.

Whilst the signed speed may give an indication of the range of speed on a road, the actual speed may vary significantly. The consultation and review did not provide any evidence that vehicle speed is being measured routinely on the network. However, those consulted were chiefly associated with maintenance and asset management and not traffic.

There are software packages (e.g. SCOOT, http://www.scoot-utc.com in the UK) that attempt to reduce congestion by receiving traffic flow information from the network (usually from sensors embedded in the pavement) and using this to adjust traffic signal timing. Whilst these models calculate average vehicle speed over each link in an instrumented network, this speed is not recorded and stored to enable a daily traffic speed to be calculated.

Given the infrastructure that must be installed on the network to routinely assess speed at the network level, it may be worthwhile considering alternative data sources. Real vehicle speed information could be obtained by measuring it directly in the vehicles. "Probe vehicles", such as those used within the INTRO project (Benbow, 2008) could be used to provide location and speed data. As with ride quality data obtained from such sources, the data obtained would not necessarily be as precise as if it were measured with specialist equipment, however, the frequency of measurement that could be achieved by such a method, would mean that a good representation of the actual speed travelled on each road could be obtained.

5.3.3 Skid resistance (wet and dry)

The contribution of the road surface to the overall friction available between the tyre and road surface is known as skid resistance. Pavement skid resistance affects vehicle handling and the maximum stopping distance (Turk, 2012). If a road authority allows skid resistance to decrease, there is an increased risk of accidents. As can be seen in Table 6, nearly all road authorities (in the countries consulted) measure skid resistance on a routine basis, with Denmark, Finland, Lithuania and Sweden, the only exceptions.

Table 6: Routine measurements of skid resistance

Country	Routine skid resistance measurements?	Frequency of measurement
Austria	x (RoadSTAR)	5 years
Belgium (Flemish)	x (SCRIM)	Annually on Primary roads
Denmark	Only at project level (RoAR device)	N/A
Finland	-	N/A
France	x (SCRIM)	3 years
Germany	x	4 years on Primary roads
Ireland	x (SCRIM)	2 years
Lithuania	Only at project level	N/A
Netherlands	x (DWW-trailer)	2 years
Norway	x (RoAR)	N/A
Slovenia	x (SCRIMTEX)	4 years
Sweden	Only at project level	N/A
UK	x (SCRIM)	Annually

The British Pendulum (SRT) test is the only internationally standardised procedure for measuring skid resistance (EN 13036-4:2011). This test is static and not practical for use at a network level. Therefore, a large variety of methods and devices are used for routine skid resistance measurement (Descornet, 2006), as reflected in Table 6. All the countries that routinely measure skid resistance use devices that measure the wet skid resistance of the road (Descornet, 2006). This is because wet skid is perceived to be the worst case scenario (HD28, 2004). Similarly, a smooth tyre is used to collect measurements, as this is not only the worst case scenario but also gives more consistent readings than a tyre with a tread pattern that can wear as testing progresses. It is noted that Antilock Braking Systems (ABS) have been required on all new passenger cars sold in the EU since 2007. ABS attempts to keep the vehicle at or near the peak friction by releasing and then reapplying the brakes when the tyres begin to slide. The measurement systems in Table 6 do not work in this way and may overestimate the risk for this large proportion of vehicles. However, because the current measurement systems measure the worst case scenario, they allow authorities to identify locations at highest risk. This knowledge helps the authority to manage the risk of increased accidents. The current approach for most countries of measuring the worst case scenario appears to be a practical way of managing this risk.

Section 5.2 noted there is an increasing commonality in the vehicles and tyres used across the vehicle fleet in Europe. As for the measurement of comfort in Section 5.2, this suggests that it should be possible to identify an approach to measure the skid resistance using a common technique and measurement parameter which could be applied across the European network. However, whether the effort required to establish this is worthwhile is not clear. Perhaps the focus should be on ensuring that each measure has a broadly similar relationship with how well vehicles will stop. If this could be achieved then it may be possible to allow wider application of different devices, which could improve survey efficiencies across Europe.

The frequency of skid resistance measurement varies between countries, from annually to every 5 years. Interestingly, this appears to be similar to the frequency with which pavement shape is measured (compare Table 6 and Table 4) and is sometimes less frequent. This is surprising given the likely higher level of importance placed on safety measures.

The skid resistance on asphalt pavements tends to reach an equilibrium level, if the levels of traffic that it is exposed to do not change greatly. However, deterioration such as fretting/ravelling, fatting up/bleeding can all cause changes to the skid resistance that a pavement offers. Also, surfaces such as concrete, can wear out after a period of time (roughly 25 years) and at this point of failure, the skid resistance can reduce significantly. Similarly, a high friction surface in good condition will have a different skid resistance when new than when it has deteriorated and the surface of the layer below starts to show.

The ASCAM project suggested that monitoring at 3-5 year intervals is reasonable "depending on the financial and legal situation" (Turk, 2012), but there was no technical basis offered for this opinion. The optimal frequency of survey carried out is likely to be related to the construction of the pavements on a road authority's network and the age of the pavements on the network. For example, an authority with a lot of thin surfacing may want to survey more frequently than every 5 years, since thin surfacing only has a life expectancy of 10 years. The inconsistency of approach across those consulted suggests that there is a need to further review the most appropriate frequency of measurement for skid resistance as this may allow efficiency improvements to be achieved whilst maximising risk reduction.

An alternative to using infrequent but highly accurate data may be to use probe vehicles to identify locations with poor skid resistance. Data collected from the traction control systems on such vehicles may help to supplement routine machine surveys, or even to replace them if sufficient coverage could be achieved with these vehicles.

5.3.4 Standing Water and Splash Spray

The presence of water on the surface of the road can increase stopping distances and may lead to aquaplaning. The effects of vehicle splash and spray are well known to motorists who have traveled in wet weather conditions and research suggests that in addition to the nuisance it causes to users, splash and spray contributes to a small, but measureable, proportion of road traffic accidents (Sanders, 2009). Thus, surface water can pose a higher risk of accidents occurring.

The amount of water that can sit on a road's surface is dependent on the amount and shape of rutting present (i.e. the shape of the transverse profile), the surface texture, the gradient and crossfall of the road and also the efficiency of nearby drains. Table 7 shows which countries are measuring these shape parameters routinely, and also how frequently they are measured (the effect of drainage is discussed in Section 5.5). Note that whilst rutting does not develop on concrete pavements the shape of such roads will still have an effect on the amount of water able to sit on the surface. The measurement of rutting for the assessment of durability is discussed in section 5.4.

Table 7: Routine measurements relating to standing water

Country	Transverse profile	Texture	Gradient	Crossfall	Frequency of measurement
Austria	x	x	x	x	5 years
Belgium (Flemish)	x	-	x	-	Annually for PR*
Denmark	x	x			Annually for PR*
Finland	x	x	x	x	Annually
France	x	x	x	x	3 years
Germany	x	-	x	x	4 years for PR*
Ireland	x	x	-	-	Annually for PR*
Lithuania	x	-	-	-	3 years for PR*
Netherlands	x	-	-	x	Annually for PR*
Norway	x	x	x	x	Annually for PR*
Slovenia	-	-	-	-	N/A
Sweden	x	x	x	x	3 years
UK	x	x	x	x	Annually for PR* 2-4 years for other roads

*PR = Primary Roads

The consultation only identified France as employing a method specifically to estimate water depths at the network level. The method employs transverse profile and crossfall data. Since crossfall and transverse profile are measured by most countries (considered in the consultation), models for water height, such as that used by the French, could be applied in other countries. However, this model does not include texture or gradient, which also affect the level of standing water possible on a road (Sanders, 2009). It is therefore only an estimate for the actual water height for fairly straight, longitudinally flat, roads.

The development of a more wide ranging model that is capable of predicting both water depth and the splash spray propensity of pavements may be useful to aid highway engineers' decisions regarding highway maintenance and design. This could build on existing complex models that use combinations of input parameters such as pavement geometry, rainfall rate, pavement texture, and drainage variables such as Manning's roughness coefficient, pavement porosity, and angle of rainfall (Sanders 2009), to deliver a more practical network level measure. However, as with ride quality parameters (Section 5.2), this may require significant work to assess the models, involving collection of measurement data and reference water depth or splay spray data. Some studies are currently being undertaken. In the UK, a trial of spray measurement was carried in which it was found that a mobile photographic method provided a feasible way of measuring spray in traffic under moderate rainfall conditions (Roe, 2008). The FHWA are currently sponsoring work to deliver a robust model to predict splash and spray generation (VTTI, 2012).The measurement of spray will draw on texture data, which is measured routinely in many countries using traffic speed surveys (Table 7). However, such measurements are typically limited to the nearside wheelpath, which may not be representative of the texture across the whole lane width. This will affect the performance of the model. Emerging technologies such as the PPS (Phoenix Scientific Inc.) or LCMS (Pavemetrics) laser profiling systems may offer a future solution to this problem.

An alternative to modeling the water from knowledge of pavement properties would be to measure the actual depth of water present. There are a number of different devices that have been developed to measure water depth, for example the limnimeter probe (Coiret 2005) and the water film measurement device (Kulakowski 1990). However, none of these devices could be used at traffic speed and therefore it would be impractical to routinely survey the network with them.

5.3.5 Sight Lines

Sight lines are the clear lines of sight a driver has of other vehicles at a road junction. These are usually set when roads are constructed and the amount of visibility enforced is generally dependent on the speed of the road, the traffic loading present, and also the purpose of the roads joining at the junction.

EuroRAP produces risk maps of roads in Europe – these are based on accident and traffic flow data. Roads are given a star rating, which is an indication of how well the road protects users from a disabling injury or death when a crash occurs. The star rating is based on an assessment carried out by a drive through inspection. This assessment measures how well traffic lanes are separated, checks for roadside protection (e.g. safety fencing protecting rigid poles, lampposts and trees). Checks for junction layout and frequency and sight lines are a part of the assessment.

Sight lines at a junction are affected by the gradient and curvature of the roads meeting at the junction, but probably more so by the position of road signs, trees, vegetation, buildings etc near to the junction. The geometry of a road does not change over time but buildings and signs will be replaced, adjusted, or added and trees and vegetation will grow. Thus it is these things and not the geometry that could degrade the sight lines at a junction. No routine assessments are currently carried out to undertake this type of monitoring. Indeed, this would not be practical at a routine network level. A more practical solution would be for owners to assess their junctions to identify those at highest risk and to undertake routine monitoring of that subset of junctions. This could be achieved using targeted inspection of forward-facing panoramic video, collected as part of routine traffic speed surveys. The consultation showed that this is collected routinely in Slovenia and UK, and it is the understanding of the project team that its collection is expanding elsewhere. However, we have not identified evidence of it being used in the application to sight lines. Our current understanding is that such video data is more frequently applied to the collection of inventory information.

Although there is expanding use of forward video data collected in traffic-speed surveys, new internet data sources such as Google's Street View (http://maps.google.co.uk/help/maps/streetview/) may reduce the need to collect it routinely. However, if such a source were to be used, the frequency of image collection would need to be assessed for its suitability to measure sight lines.

Regardless of the data source, the assessment of sightlines would be a manual assessment, even if it could be carried out in the office. Engineers may be more likely to undertake this if the data were presented within an application that allowed them to visualise, manage and interpret the data. This kind of system has been achieved by Yotta DCL in the UK with their Horizons visualised asset management tool (http://www.yottadcl.com/software/horizons-visualised-asset-management/). The Horizons software is a web-based mapping application, based on Google maps and combines GIS with data collected from routine and scheme-based surveys. This kind of system could be used to manage the risk of accidents at junctions, due to poor sight lines, by identifying and undertaking on-going monitoring of high risk locations.

5.3.6 Kerbs

Kerbs are present on the network to separate the carriageway from either the verge, or a footpath. If they are in good condition and the right height and shape, they can prevent vehicles from overriding the verge and thus provide support to the edge of the road. Perhaps more importantly, they can also prevent vehicles from mounting a neighbouring footpath, thus ensuring pedestrian safety.

The consultation did not specifically ask whether kerb condition, shape and height were measured. However, no one reported that these measurements were collected routinely. Certainly in the UK, the condition of kerbs is monitored during the regular safety surveys, which are carried out by engineers, driving over the network for which they're responsible, and noting if any kerbs have been damaged, or require replacement.

Traffic speed technology exists that may offer potential for routine measurement of kerbs e.g. wide, high resolution transverse profile systems and LiDAR. However, no evidence was found that suggested that these technologies were being used in this way.

5.4 Durability

5.4.1 Potholes

Potholes cause users great irritation, not only because of the discomfort experienced by driving over them but also the potential damage caused to vehicles, which then leads to claims of compensation being made to the road authority. Accidents can be caused by vehicles swerving to avoid potholes, or through loss of vehicle control that can arise from hitting one. Most potholes are formed due to fatigue of the road surface. As fatigue fractures develop they typically interlock in a pattern known as crocodile cracking. The chunks of pavement between fatigue cracks are worked loose and may eventually be picked out of the surface by continued wheel loads, thus forming a pothole. Potholes can develop in a matter of weeks, particularly on thin surfacing systems exposed to water and below freezing temperatures. Therefore, most road authorities rely on the maintaining engineers to identify the existence of potholes by regularly performing coarse visual surveys (from a vehicle being driven at traffic speed) on the network for which they are responsible, or to respond to complaints from the general public.

The consultation and review found little evidence that potholes are measured routinely using network level surveys. Only three countries calculate a parameter that is related to these features (Table 8): The Bump Measure and WLP, which are both derived from longitudinal profile measurements. These parameters have been developed to identify locations where any discontinuities are present, for example, step changes in concrete slabs, failing bridge joints, sunken patches, not just potholes.

Potholes are 3-dimensional features and therefore would not always be represented sufficiently by a 2-D measurements such as Longitudinal Profile. Also, any pothole lying outside of such discrete measurement lines would not be identified. Thus, to accurately identify a pothole, a high resolution 3-D profile of the road surface would be needed, which would not be provided by most of the systems used currently to measure pavement shape.

In addition to the inadequacy of current measurement systems, another disadvantage is that the surveys commissioned to measure the shape of the road surface are not frequent enough to be useful in identifying potholes, since they can develop so quickly.

An alternative to using infrequent but highly accurate data may be to use probe vehicles to identify pothole locations. Data from such sources may help to supplement safety inspections: It might be possible to identify jolts caused by driving over such features, or rapid direction change to avoid them, in the data collected and the frequency of data collection should enable significant, rapidly developing, defects to be identified.

Table 8: Discontinuity measures identified during review

Country	Measure used to routinely identify discontinuities	Frequency of survey
Austria	Weighted Longitudinal Profile (experimental)	5 years
Belgium (Flemish)	-	N/A
Denmark	-	N/A
Finland	-	N/A
France	-	N/A
Germany	Weighted Longitudinal Profile	4 years for Primary Roads
Lithuania	-	N/A
Netherlands	-	N/A
Norway	-	N/A
Slovenia	-	N/A
Sweden	-	N/A
UK	Bump Measure	Annually

5.4.2 Structural strength

The consultation showed that most road authorities are interested in knowing what the bearing capacity or structural strength of their network is. However, this is a difficult measure to obtain, since it is mainly the foundation and non-surface layers of the pavement that provide its structural strength. To avoid invasive measurement techniques that allow access to these lower layers, structural strength is usually calculated by measuring the pavement's deflection when a load is applied to it. This deflection measurement is then combined with knowledge of construction (e.g. material, layer thickness) to back-calculate structural strength – a complex and convoluted calculation that also involves correcting for temperature.

Most devices that can measure deflection are either stationary (e.g. FWD) or are very slow moving (e.g. Deflectograph, Curviameter). Thus, either traffic management or road closures are required in order to perform the measurements. This impracticality of measurement is reflected in the routine measurement regimes identified by the consultation and review (Table 9): Only Slovenia currently performs network-level deflection surveys with a stationary or slow-speed device (FWD), with most countries restricting their measurements to project level.

Table 9: Measurement of deflection

Country	**Extent of deflection measurement and device used**	**Frequency of routine survey**
Austria	Project level (FWD)	N/A
Belgium (Flemish)	Project level (FWD and Curviameter)	N/A
Denmark	Routine (FWD and High Speed Deflectograph)	3 years
Finland	Project level (FWD)	N/A
France	Project level (Deflectograph Flash)	N/A
Ireland	Project level (FWD)	N/A
Lithuania	Project level (FWD)	N/A
Norway	Project level (FWD)	N/A
Slovenia	Routine (FWD)	4 years
Sweden	Project level (FWD)	N/A
UK	Currently project level (Deflectograph) Two annual surveys have been carried out on the Primary network using the Traffic Speed Deflectometer, TSD). A routine survey is expected to be introduced on this network in the next 12 months.	N/A (Expected to be) 1 or 2 years

Until recently, durability data could only be collected with slow speed devices. The Danish engineering company, Greenwood, has developed the Traffic Speed Deflectometer (TSD) (http://www.greenwood.dk/tsd.php), which is a rolling wheel deflectometer, using Doppler technology to measure the deflection of roads while travelling at up to 80km/h. Such a device has been used by the Danish Road Directorate for over 5 years now. TRL have also tested the TSD for use by the UK Highways Agency and have commissioned 2 network wide surveys. The device is expected to start network level surveys of the English Primary Road (motorway and trunk road) network within the next 12 months. Later models of the TSD (fitted with more Doppler lasers) are also owned by ANAS in Italy, IBDiM in Poland and Greenwood are constructing a fifth for SANRAL in South Africa. The TSD appears to be becoming a recognised tool for the collection of durability data at a network level for Primary Roads.

Whilst the TSD is a promising breakthrough in technology for the measurement of deflection, the vehicle used to transport the measurement devices is a large truck and thus would not be suitable for the Secondary road network, and possibly a large amount of the “Other Primary” network, due to the relatively small lane widths present on such roads. It is expected that this will be investigated further within the TRIMM project (TRIMM, 2012).

In order to calculate pavement strength from deflection measurements, accurate pavement construction and layer thickness data needs to be available. To have access to such data, a road authority's Pavement Management System (PMS) will need to contain not only the construction data of the pavement when it was first built but also any maintenance carried out since construction e.g. resurfacing, inlaying with a different material. This requires excellent data handling, which, as discussed previously (Section 5.3.1), is not always available. To update or correct this data Ground Penetrating Radar (GPR) can be used to estimate pavement layer thickness, supported by cores to calibrate the GPR data (HD29/08 2008). The consultation did not specifically ask whether GPR surveys were performed. However, through consultation with a commercial provider of GPR surveys (Saarenketo, 2012), use of GPR has been found to be as shown in Table 10.

Table 10: Use of GPR Surveys

Country	Extent of use of GPR
Austria	Project level
Belgium (Flemish)	Project level
Denmark	Project level
Finland	Routine network-level surveys carried out on Primary roads and also project level.
France	Project level
Germany	Some network-level surveys carried out on Primary roads but mostly project level.
Ireland	Project level
Lithuania	Project level
Netherlands	Some network-level surveys carried out on Primary roads but mostly project level.
Norway	Project level
Sweden	Project level
UK	Project level

As can be seen from Table 10, most countries use GPR surveys at a project level but only Finland carries out surveys at a network level, with Germany and Netherlands carrying out partial network surveys. As the use of traffic-speed measurements of deflection become more prevalent, the use of GPR at a network level is likely to increase also.

5.4.3 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 (Figure 1) and structural rutting (Figure 2). 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 wheelpath 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.

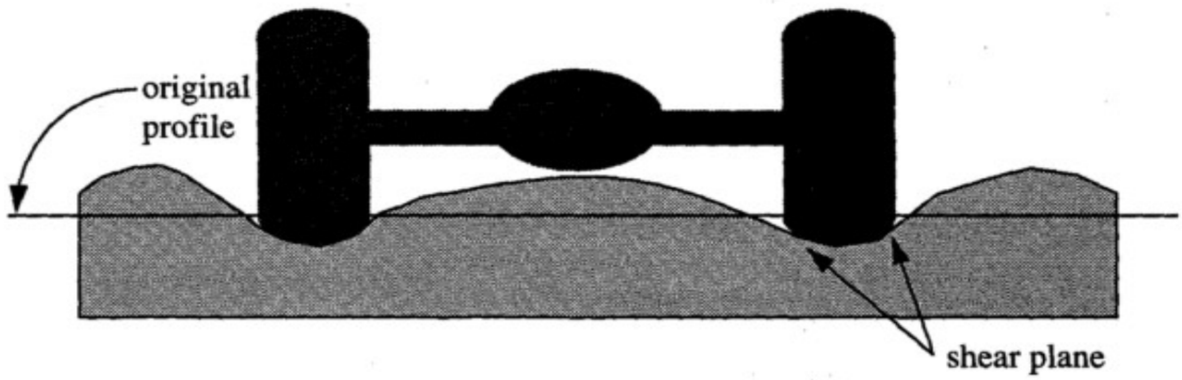

Figure 1: Surface course rutting (Image sourced from Drakos, 2012)

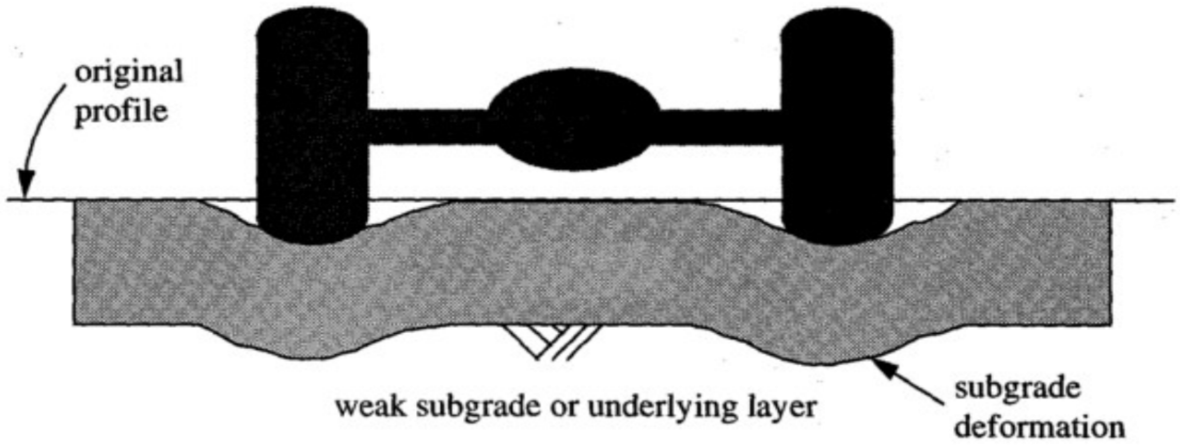

Figure 2: Structural rutting (Image sourced from Drakos, 2012)

All countries consulted included a measure of rutting in their routine pavement assessment regime (Table 11), with most calculating rut depth from transverse profile data. There was no evidence from the consultation or review that, beyond the calculation of rut depth, any methods were being implemented to determine whether the rutting present is structural. Whilst structural rutting can only truly be confirmed by taking a cross section of the pavement, or using a GPR survey, sometimes the shape of the rut can be indicative. The presence of rutting can affect ride quality and can lead to water sitting on the surface. Hence rutting is of concern for durability and safety (Section 5.3.4). As a result, the depth at which rutting is considered excessive is controlled by its effect on water depth, not on structural condition.

Table 11: Measurements of rutting

Country	Rutting measured?	How rut depths calculated
Austria	Yes	From transverse profile
Belgium (Flemish)	Yes	From transverse profile
Denmark	Yes	From transverse profile
Finland	Yes	From transverse profile
France	Yes	From transverse profile
Germany	Yes	From transverse profile
Ireland	Yes	From transverse profile
Lithuania	Yes	From transverse profile
Netherlands	Yes	From transverse profile
Norway	Yes	From transverse profile
Slovenia	Yes	Extent and severity estimated from visual inspection
Sweden	Yes	From transverse profile
UK	Yes	From transverse profile

As for other measurements discussed in this report, the frequency at which transverse profile measurements are obtained varies between countries from every year to once every 5 years (Table 4). Again there is little evidence to relate this to the actual rate of change of the defect. In comparison with comfort (longitudinal profile), which changes little year on year, rutting is broadly thought to increase by up to 1mm a year on asphalt roads (HDM-4).

Because rutting is subject to change, the consultation has found that there is a desire to be able to trend this data. However, noise in the measurements makes this difficult at any more than the network level. Work has been undertaken in the UK to improve the accuracy of rut depth measurement on the Primary road network. This has been achieved by a combination of high resolution transverse profile measurements and the removal of measurements made on road markings.

5.4.4 Edge deformation

Experience in the UK has shown that edge deterioration or deformation is a widespread problem on the minor roads, particularly on rural roads without defined edge kerbs. Engineers, responsible for these roads, highlighted it as one of the main causes of pavement maintenance expenditure (Watson, 2005). Edge deformation can be calculated from transverse profile measurements. Table 12 shows which countries measure transverse profile and which calculate an edge deformation parameter from this.

Table 12: Measurement of edge deformation

Country	Transverse profile	Edge deformation parameter?
Austria	x	-
Belgium (Flemish)	x	-
Denmark	x	-
Finland	x	-
France	x	-
Germany	x	-
Ireland	x	-
Lithuania	x	-
Netherlands	x	-
Norway	x	x
Slovenia	-	-
Sweden	x	x
UK	x	x

Edge deformation is calculated on all Norwegian and Swedish road networks considered for the Heroad project and also on "other primary" and "secondary" roads in the UK (where appropriate). There was no evidence from the consultation that other countries feel that a measure of edge deformation would be an important parameter. However, this may be because the parameter would not be relevant on the network for which most answers were obtained (e.g. motorways) or because owners are not aware of the potential for the use of their current measured data in this application.

It would be worth publicising the current knowledge to countries who routinely survey Other Primary and Secondary roads for transverse profile, to see if they could use it.

5.4.5 Visual Condition

The visual condition of a road is a further indicator of the level of durability offered by a pavement. Visual deterioration includes cracking, fretting/ravelling, bleeding, failing patches, potholes, and homogeneity of the surface. The parameters, measured routinely by each country considered in the consultation and review are listed in Table 13. As can be seen, the most common way of obtaining the data is by manual visual inspections.

Manual visual inspections are labour intensive, and known to be inconsistent, due to the subjective nature of human assessment. Therefore, some countries use automatic assessment of downward facing video images to perform visual condition assessments. Some concerns have been raised over the accuracy, repeatability and consistency between systems (both the video recording systems and the visual analysis systems) for these automatic visual condition surveys. For example, the UK is surveyed by many different vehicles, operated by a number of different survey companies. Despite a stringent QA regime the consistency in the level of cracking reported by each device is lower than that for other condition parameters measured at traffic-speed (such as rutting and ride quality). The automatic crack identification systems can be affected by non-defect features such as road markings and often can't distinguish one type of feature from another. However, the surveys bring the benefit of a practical frequent survey at lower cost than manual alternatives. Indeed, the data can be collected using the same survey vehicle as that employed for other measurements, such as comfort.

Whilst visual condition obtained from automatic analysis of images collected at traffic-speed may not currently be accurate enough for use at the detailed, or scheme level, the images themselves can be used. An image of a road surface that has good focus, and sufficient resolution and contrast for the human eye to identify visual condition features can be subjected to a manual analysis. It has been found that such an analysis can generate results similar to those obtained on site by an inspector. Using images in this way is an approved method for carrying out visual surveys on the English Primary Road network (http://www.dft.gov.uk/ha/standards/dmrb/vol7/section3/hd2908.pdf).

Current traffic-speed visual condition assessments are focussed on the assessment of cracking. Surface fretting is not always visible on downward facing video images (even to the human eye), with its visibility being highly dependent on the angle of the lighting system. Therefore, 3D laser measurements of the surface are being explored. In the UK a method has been developed to measure fretting using multiple line laser texture measurements. This method, which automatically adjusts itself to work on different surface types, is expected to be implemented as a routine annual measure on the Primary road network in the Autumn of 2012.

KOAC-NPC has also implemented a model, using texture lasers, to detect fretting/ravelling on Other Primary and Secondary roads in The Netherlands. The model works by establishing a reference distribution of a parameter, where there is no ravelling and then compares this to the distribution on other lengths, to determine the amount of ravelling present, the levels reported being none, slight, moderate or severe. The model has been recently updated to identify ravelling on thin surfacings. Despite this improvement, it was found that the model was not robust enough for daily practice for the "other Primary roads" and Secondary road networks. Therefore, combining texture laser data with image data is currently being researched. It is hoped that the addition of the images will help to identify changes of surface, thus ensuring that the correct reference distribution is used for comparison.

There is also a more simple method, developed by Rijkwaterstaat, to measure ravelling on the Primary road network in The Netherlands. Known as Stone(a)way, it is based on the detection of free space (where aggregate has disappeared from the surface) in the texture profile measured by lasers on Porous Asphalt surfaces. The model was developed for Porous Asphalt only, since this pavement surfacing is found on a high proportion of the Dutch Primary road network. Originally, this model used texture data collected using a single texture laser. However, 3D technology, such as the LCMS (Laser Crack Measuring System) by Pavemetrics, is being used to improve the performance. The LCMS allows measurement of a 3D texture profile with a grid size of 1x5mm at 120km/h. Currently, the results from this system are supplemented/corrected with (manual) visual condition surveys. However, it is hoped that it can be used on its own by 2013.

Table 13: Measurement of visual deterioration

Country	Cracking	Fretting/ Ravelling	Bleeding	Patches	Potholes	Surface homogeneity	Frequency of survey	Method used to measure visual deterioration
Austria	x	x	x	x	x	x	5 years	Semi-automatic analysis of images
Belgium (Flemish)	x	-	-	-	-	-	Annually	Automatic analysis of downward facing images, supplemented by visual inspections
Denmark	x	x	x	x	x	-		Visual inspection
Finland	x	x	x	x	x	-	3 years	Visual inspection
France	x	x	x	x	x	-	3 years	Manual analysis of video record, or operators recording distress from moving vehicle
Germany	x	-	-	-	-	-	?	
Ireland	x	-	-	-	-	-	Annually	Automatic analysis of downward facing images
Lithuania	x	-	-	-	-	-	3 years	Automatic analysis of downward facing images
Netherlands	x	x	-	-	-	-	2 years	Cracking obtained by visual inspection. Fretting obtained using texture measurements.
Norway	Project level						N/A	Visual Inspection
Slovenia	x	x	x	x	x	x	2 years	Visual inspection
Sweden	Project level						N/A	Visual Inspection
UK	x	x	-	x	x	x	Annually on Primary Roads, 2-4 years on others	Primary Road network: Presence of fretting is determined by use of multiple line texture measurements from traffic-speed surveys. Other parameters: Automatic analysis of downward facing images. All visual deterioration features reported as one parameter – “Surface Deterioration”. Other road networks: Cracking is obtained with automatic analysis of downward facing images.

5.5 Drainage

The performance of drainage systems will influence the likelihood of flooding and the amount of water sitting on the pavement surface. The consultation and review identified that blocking of drainage systems by impermeable material, such as plant roots, overgrowth, leaves, snow and ice was a common problem, in addition to collapse of drainage layers, crushed pipes and general damage. The consultation also showed that not many countries have implemented routine inspection of their drainage systems. Of those that do, most visually monitor the drains for signs of flooding or obvious problems (Table 14). Due to the time, cost and likely disruption to traffic, more thorough surveys (e.g. CCTV) will only be used if malfunction or blockages are suspected.

Table 14: Drain inspections

Country	Method of inspection
Austria	Routine visual inspections carried out immediately after construction and once a year for drainage pipes, shafts, precipitators, well drains, control reservoirs and twice a year for drainage basins, ditches, bridge drainage. The visual inspections may include use of mirrors/lighting for inaccessible locations but the more advanced methods will likely only be used when malfunctions or blockades are suspected.
Ireland	There is no routine collection of drain performance data at a network level
Lithuania	Visual inspection is mainly used (on visible sections of drain) but sometimes laboratory tests of pavement construction materials for filtration are used.
Netherlands	No routine monitoring carried out
Slovenia	Visual assessment of surface of drain from video images and also at-site inspections for signs of flooding or problems at the surface. CCTV inspection performed on drains for new motorways (before opening to traffic). Drains located in water protection areas are tested to be watertight or air tight. Frequency of every 2 years for assessment of video. On a rolling basis for at-site inspections.
Sweden	No overview monitoring. Operators rely on local knowledge of the condition in each region, with repairs/treatments performed when a problem arises.
UK	Pipework is regularly flushed to clear debris/blockages but surveying (CCTV) is only generally carried out if flooding has been prevalent in the area, or problems have been identified during regular safety inspections.

5.6 Earthworks

Earthworks raise or lower the existing land to reconfigure the topography of a site to a suitable level so that road construction may begin. The earthworks can take the form of either excavation in the form of cuts or the construction of embankments to carry an elevated highway. Failure of earthworks can cause serious problems, including loss of life or serious injury to users or neighbours, disruption to the network, and durability and availability issues.

On the whole, the consultation and review suggest that earthworks are not routinely assessed (Table 15). However, in Slovenia, some earthworks are instrumented to aid monitoring after construction, whilst in the UK, they are subject to visual assessment. The Swedish monitor only those earthworks thought to be at high risk of failure, and the situation is similar in Lithuania.

Although not routinely implemented, our investigations have found that emerging technology exists, whereby an earthwork could be instrumented to measure such properties as slope inclination, strain within the structure and for these instruments to broadcast measurements to a survey vehicle passing at traffic speed. Also, LiDAR surveys, coupled with high resolution aerial imagery could also be used to routinely monitor earthworks (HA LiDAR Guidance, 2008). Whilst these technologies would not completely remove the need for site inspections, it would enable such inspections to focus on detection of smaller features, such as tension cracks and seepages. This would reduce both engineer time and also traffic management on site when carrying out such surveys. Current LiDAR systems also have a good penetration through most vegetation types to provide ground surface data below the canopy. This is very useful on restricted access areas, or earthworks covered in dense groundcover.

However, even with this technology available the cost of routinely implementing such instrumentation or LiDAR surveys may not be justified (due to the relatively low risk of earthwork failure). Therefore the focus of in-depth monitoring for selected important sites, as found in the review, may be the most appropriate approach.

Table 15: How earthworks are assessed

Country	Assessment regime of earthworks
Austria	Assessment and acceptance testing is part of the construction project. However, there is no routine monitoring/assessment on a network level.
Belgium (Flemish)	Earthworks are managed on a project level and parameters are only measured before/during/just after construction.
France	Assessment and acceptance testing is part of the construction project. For embankments >15m long, the advice is to use inclinometers, however, this is not mandatory. If an issue is identified (through routine safety surveys) an earthwork will be subjected to further tests.
Germany	Assessment on project level
Ireland	No routine assessment of earthworks once construction complete.
Lithuania	Assessment and acceptance testing is part of the construction project. Routine visual inspections carried out on earthworks near bridges or retaining walls. Composition and amount of surveys determined by developer, considering the geotechnical category of the project.
Netherlands	No routine measurement of conventional embankments, made of natural granular material post-construction. Indirect measurements of settlements on pavement surface.
Slovenia	What gets measured and how often depends of the geotechnical category of the earthwork and performance during construction. There are no routinely measured parameters, although on some earthworks, monitoring systems are established during construction and these enable monitoring to be performed after construction. The frequency of monitoring differs a lot.
Sweden	Assessment and acceptance testing is part of the construction project. Only sections that are specified as risk zones are monitored after construction.
UK	Geotechnical assets are inspected annually for condition and are subjected to a Principal inspection every 5 years. During the Principal Inspection, the slope angle, slope width and slope bearing are measured. The amount and type of vegetation present is recorded, along with the amount of water visibly present within the earthwork, any features present e.g. slips, bulges, dislocations, what kind of drainage is present and whether any reinforcement has been used. (http://www.dft.gov.uk/ha/standards/dmrb/vol4/section1/hd4103.pdf)

5.7 Economic Measures

The consultation did not specifically ask about economic measures. Therefore the principal source of information has been the review.

The HEATCO project (Harmonised European Approaches for Transport COsting and project assessment) had a primary objective to develop harmonised guidelines for project assessment and transport costing at an EU level. Information was sought on existing practice in infrastructure appraisal and transport costing within EU Member States and Switzerland (apart from Norway, all countries included in the Heroad consultation were included in HEATCO). HEATCO considered the following topics: Construction related costs, User benefits and vehicle operating costs, Safety, Environmental impacts and Indirect socio-economic costs (Odgaard, 2005). HEATCO considered how the main elements of cost benefits analyses were treated in the surveyed countries and grouped these main elements into 11 categories: Construction costs, Disruption from construction, System operating cost and maintenance, Passenger transport time savings, User charges and revenues, Vehicle operating costs, Benefits to goods traffic, Safety, Noise, Air pollution – local/regional and also Climate change. We have drawn on the results of HEATCO in the following sections.

5.7.1 User Costs - arising from Maintenance

Road maintenance influences user costs as a result of congestion and slower/longer journeys. Before maintenance is approved, road owners will carry out an economic assessment of the proposed maintenance. This may include assessing its likely effect on users as a result of changed journey times (expected to be increased during the maintenance but decreased after the maintenance).

HEATCO found no consensus on how the disruption arising from maintenance is costed. Of the 13 countries considered for Heroad that were also included in the HEATCO review, 7 countries include costs associated with disruption within their cost benefit analysis, whilst Switzerland includes them qualitatively in the appraisal of the project. Disruption from construction is considered to include delays to "private" traffic, delays to public transport/schedules services, Effect on neighbourhoods (noise, dust etc), change in risk of accidents and "other". Table 16 summarises how user delays are considered.

HEATCO also identified models to estimate the cost savings due to the decrease in journey time achieved as a result of the maintenance. The majority of countries that have guideline values for business travel time savings use the cost saving approach (or wage rate approach) to evaluate these cost benefits. The cost saving approach is based assumes that all the savings in travel time can be transferred to productive output. However, Sweden and the Netherlands use a more sophisticated approach that allows for the fact that not all travel time is unproductive and hence not all savings are transferred to extra work. This is termed the Hensher approach (Hensher, 1977). Other countries use less sophisticated approaches based on GDP/capita or the value of non-work trips. This is detailed in Table 17. A similar mixture of approaches exists for countries outside the EU (Bickel, 2005).

Unfortunately, whilst road authorities were able to confirm the components included in their cost benefit analyses, the actual equations used in these analyses do not appear to be published. Therefore, it is not possible to comment herein on whether the user costs are treated similarly for the countries that do include them in their cost benefit analyses for maintenance projects.

Table 16: Consideration of user delays during construction – from HEATCO review

Country	Delays to "private" traffic	Delays to public transport/ scheduled services
Austria*	No	No
Belgium (Flemish)	Yes	No
Denmark	Yes	Yes
France	-	-
Germany	-	-
Ireland	Yes	Yes
Lithuania*	Yes	Yes
Slovenia	-	-
Sweden	-	-
Switzerland	-	-
UK*	Yes	Yes

*varies by mode/appraisal, "-" = not relevant

Table 17: Approaches for estimating values of travel time – from HEATCO review

Values	Method	Countries
Work Values	Cost Saving	Denmark, Finland, France, Germany, Ireland, Slovenia, UK.
	Hensher	Sweden
	WTP	Netherlands
	Other	Austria, Switzerland, Lithuania.
Non-work	% of Wage Rate	Denmark, Finland, Ireland, Slovenia.
	WTP	Germany, Netherlands, Sweden, Switzerland, UK
	Other	Austria, France, Lithuania.
Average	Wage Rate Studies	Belgium (Wallonia region)

5.7.2 User costs arising from condition

A rough and ill-maintained road surface can cause accelerated wear to vehicles' suspensions and tyres and also increased fuel consumption. All countries considered within the HEATCO project include vehicle operating costs as part of a cost benefit analysis (CBA) for the appraisal of road transport projects. The components included in the CBA are listed in Table 18.

Table 18: Vehicle operating costs included in cost benefit analyses

	Standing cost component								Operating cost element				How are the VOC calculated?		
Country	Depreciation	Interest on capital	Repair and maintenance costs	Materials costs	Insurance	Overheads	Admin	Other	Personal Costs	Depreciation	Fuel and lubricants	Other	Standard Values	Standard Model	Bespoke Model
Austria	Y	Y	Y	Y	N	N	N	N	Y	N	Y	N	Y	N	Y
Belgium	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	N
Denmark	Y	N	Y	Y	N	N	N	N	N	Y	Y	N	Y	N	N
Finland	Y	Y	Y	Y	N	N	Y	N	N	Y	Y	N	Y	N	N
France	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	N	N
Germany	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N
Ireland	Y	N	Y	Y	N	N	N	N	Y	N	Y	N	N	Y	N
Lithuania	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	N	N	Y	N
Slovenia	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	N
Sweden	Y	Y	Y	Y	N	N	N	N	N	N	Y	Y	N	Y	N
Switzerland	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	N
UK	Y	Y	Y	Y	N	N	N	Y	N	N	Y	N	Y	Y	N

As with user costs, due to lack of access to the equations used within the cost benefit models, it is not possible to say for definite whether vehicle operating costs are calculated in a similar way between countries. However, due to the difference in parameters calculated from measurements, such as longitudinal profile, it is likely that different models are implemented, to take account of these different parameters.

5.7.3 Cost of Planned Maintenance

All countries include construction and maintenance costs within their cost benefit analyses. The elements included in maintenance costs are detailed in Table 19. It is a well-known fact that many transport infrastructure projects experience budget over-runs, whereas few end up less costly than originally estimated. The majority of countries have systematic methods to tackle uncertainty/bias in the maintenance cost estimate. Most often, this comprises a form of standard mark-up on construction costs, which can vary with the stage of the process.

Denmark and the UK are two of the countries which are using more advanced methods for handling uncertainty/optimism-bias. The UK uses a “top-down” approach where information from a class of similar or comparable (finalised) projects is used to estimate the average budget over-run. Contrary, the Danish approach is a “bottom-up” approach, which focusses on project specific risks. These approaches are detailed in Deliverable 2 from the HEATCO project (Bickel, 2005).

Table 19: Elements included in maintenance costs

Country	Material/labour /energy etc	Planning costs	Mitigation	Add-on bias in estimate for construction cost	Other
Austria	Yes	Yes	Yes	Yes	Yes
Belgium	Yes	Yes	Yes	No	No
Denmark	Yes	Yes	No	No	No
Finland	Yes	No	Yes	Yes	No
France	Yes	Yes	No	No	Yes
Germany	Yes	Yes	Yes	No	No
Ireland	Yes	Yes	Yes	Yes	Yes
Lithuania	Yes	Yes	No	No	No
Netherlands	Yes	Yes	Yes	No	No
Slovenia	Yes	Yes	No	Yes	No
Sweden	Yes	Yes	Yes	No	Yes
Switzerland	Yes	Yes	Yes	Yes	Yes
UK	Yes	Yes	Yes	Yes	Yes

5.7.4 Incidental Costs

The incidental costs associated with a road include compensation claims for damage to vehicles, the cost of managing and clearing vehicle accidents and also emergency works. These were not included in the HEATCO project and the review did not find any road owners that had published such figures. Therefore, we cannot to comment on countries’ approach to these costs.

5.7.5 Cost to Neighbours

The HEATCO project found that costs to neighbours were not often included in the appraisal carried out before construction work (Odgaard, 2005) and the review did not identify any existing models to estimate the cost of a road’s presence to users.

5.8 Environmental Measures

Consideration of environmental measures within a holistic evaluation of roads is discussed in more detail in Deliverable 4.1 of the Heroad project (Haider, 2012). However, those topics specifically relevant to Pavements are briefly considered herein.

5.8.1 CO_2 and waste generated by maintenance

The consultation and review found identified four countries monitoring the CO_2 and waste generated during maintenance (Table 20). This shows that whilst some countries do monitor the environmental effect of maintenance, this is not a wide-spread practice, and is not always mandatory.

Table 20: CO_2 and waste monitoring during maintenance

Country	CO_2 monitoring	Waste monitoring
Austria		Mandatory for most motorway projects
Ireland		Currently driven by best practice, rather than legislation
Slovenia	Only measured if specifically demanded	
UK	The amount of carbon generated is measured quarterly by the Primary Road network owners and their service providers via their "carbon calculator". This includes maintenance and operational carbon emissions as well as those due to construction.	It is a legal requirement for the contractors maintaining or constructing the Primary Road network, to keep records of waste generated. However, there is no legal requirement for them to pass this on to the owner of these roads.

5.8.2 Water Run-off

A number of countries monitor the content of water running off the surfaces of the pavements on their networks. Some monitor water quality for the life of the pavement, whilst others test during or just after construction (Table 21).

5.8.1 Wildlife

Wildlife is considered during the construction of new roads (large projects), for example the impact that the road will have on the local wildlife. This consideration can lead to provision of wildlife tunnels (to provide safe passage across the road), wildlife fences (to prevent animals straying onto the road) and also such things as bat homes. However, no evidence was found that provision for wildlife was routinely monitored during the road's life.

Table 21: Water quality monitoring

Country	Water quality monitoring
Austria	Drainage capability is tested just after construction but the chemicals in the water running off the pavement are not.
Ireland	Water content is considered during construction, although this is driven more by best practice than legislation. However, it is not routinely monitored after construction.
Lithuania	Consideration is given to pollution of water around the working site during construction and water and ground pollution parameters are monitored during the life of a road.
Slovenia	Only monitored if specifically demanded
UK	The chemical content of water run-off is tested just after construction and then regularly monitored throughout the life of the pavement (and the results overseen/regulated by the Environment Agency).

5.8.1 Vibration and Noise

Some countries monitor the noise and vibration produced during construction of large road projects, and this may also be measured when the road is first opened to traffic. However, once the road is fully in service, no routine measurements are generally made and often monitoring is only commissioned when complaints are received from the public (**Fel! Ogiltig självreferens i bokmärke.**).

Table 22: Noise and vibration monitoring

Country	Noise and vibration monitoring
Austria	On larger infrastructure projects (including all motorway projects), the noise and vibration are monitored during construction. The noise generated by traffic on a newly opened road is measured but then is unlikely to be measured again during the rest of its lifetime. This is because noise is generally only measured for specific projects or in the case of general regional monitoring networks.
Ireland	The noise generated by traffic on a newly opened road is measured and assessed, to ensure it meets requirements. Through its lifetime, a pavement will only be monitored for noise if numerous complaints are received about it (this would be flagged through the noise action planning).
Lithuania	The noise around a road construction site will be monitored. Noise is not routinely measured once the road is open to traffic.

Table 22: Noise and vibration monitoring, continued

Country	Noise and vibration monitoring
Slovenia	No systematic or regular measurements made, only when specifically demanded or needed
UK	Noise and vibration can be measured during construction but there is no legal obligation for this. Noise (particularly at night) is sometimes measured when the road is first opened to traffic. However, noise and vibration will only be monitored where there have been complaints from the public. Traffic-speed surveys of texture are used to estimate noise at the tyre/road interface but it is uncertain as to whether this data is used much in maintenance assessment.

5.8.2 Air Quality

The main emission gasses monitored during testing for air quality are NO and NO_2 (known collectively as NO_x). These gasses can cause respiratory problems for receptors (people affected by air quality), for example diseases such as asthma. Sometimes SO_2 can also be monitored but modern vehicles are much cleaner and so problems arising from this gas are not so prevalent. The presence of CO and VOC's can also be measured, along with particulates, which can cause respiratory problems and lung cancer; the main particulates of interest being PM_{10}, $PM_{2.5}$ and PM_1. The consultation and review found that some countries monitor the air quality near to roads in their networks but accurate measurements are only collected on a project level (Table 23).

Table 23: Air quality monitoring

Country	Air quality monitoring
Austria	Air quality is not routinely monitored, only for some specific projects or in the case of general regional monitoring networks.
Ireland	Air quality is checked through monitoring particulate matter at a project level e.g. nitrogen dioxide, benzene, carbon dioxide and all that have limit values under legislation.
Netherlands	Air pollution measured at project level
Slovenia	Air pollution measured at project level
UK	Air quality is crudely monitored at a network level using diffusion tubes (and the results overseen by the Environment Agency). However, accurate measures of air quality are only collected at project level.

5.8.3 Fuel Consumption

The amount of fuel consumed by vehicles travelling on a network will directly affect the amount of CO_2 produced by these vehicles, as well as other gasses/particles that are harmful either to the environment, or receptors.

We did not find any evidence that fuel consumption was regularly monitored on the road network in any of the countries considered. However, the majority of the countries do measure condition parameters that are known to have an effect on fuel economy, as summarised in Table 24. This suggests that, by implementing a model, a network level estimate of fuel consumption could easily be obtained by most countries.

Table 24: Routine measurements of parameters with an effect on fuel economy

Parameter/ Country	Trans. profile	Long'l profile	Gradient	Crossfall	Texture	Deflection	Rolling resistance
Austria	x	x	x		x	Project level	
Belgium (Flemish)	x	x	x			Project level	
Denmark	x	x	x	x	x	x	
Finland	x	x	x	x	x	Project level	
France	x	x	x	x		Project level	
Germany	x	x					
Ireland	x	x			x	Project level	
Lithuania	x	x					
Netherlands	x	x		x	x	Project level	
Norway	x	x	x	x	x		
Slovenia		x			x	Project level	
Sweden	x	x	x	x	x	x	
UK	x	x	x	x	x	Project level	

6 Quality Assurance Regimes

QA regimes and calibration processes check that devices providing data for road management are working and providing accurate measurements. More advanced regimes include "accreditation", which is a process which controls the types of equipment used and ensures that only independently approved contractors and equipment will be used. Accreditation covers the whole process, from measuring a pavement property, all the way to delivering data to the customer. All countries which responded to the consultation calibrate their measurement systems against manufacturers' recommendations, using such standards as ISO 9001. However, only four countries claimed to run "accreditation processes". This is summarised in Table 25.

Table 25: Data quality regimes implemented

Country	**Data quality regime**
Austria	Use of accredited test laboratories and institutes, standardized measurement procedures, e.g for skid resistance monthly recalibration of RoadSTAR device
Belgium	Measurement protocols exist and they include calibration by independent and competent organisation and round Robin test are organised. The AWV is ISO9001 certified and an ISO17025 accreditation is planned.
Finland	Devices subjected to an accreditation test.
Germany	Regular comparison tests are carried out by BASt, which is an independent organisation for this.
Ireland	SCRIM and FWD devices take part in UK accreditation trials. Other devices are checked by the contractor
Lithuania	Measurement devices are regularly calibrated, some have QA regime in place
Netherlands	Quality control measurements: ISO9001
Slovenia	Measurement devices are regularly calibrated, some have QA regime in place
Sweden	Devices subjected to an accreditation test, which happens every 4 years. Within this period, the contractor is not allowed to modify the system. They are also required to carry out repeat surveys on 5% of the data collected.
UK	All survey devices must be accredited before starting any survey work. They are then subjected to regular QA regimes, to ensure consistency in the data delivered. This applies for all network types.

It was found that the UK employs an in depth approach to accreditation and QA processes for their network level condition surveys. We have made this the subject of a case study in the rest of this section.

6.1 UK Accreditation

Skid resistance is measured routinely on the Primary road network in the UK at traffic speed using SCRIM devices. Pavement deflection is measured on a project level by either FWD or Deflectograph. Routine traffic-speed surveys to measure other aspects of pavement condition are known as TRACS (TRAffic-speed Condition Survey) on the English Primary Road network and SCANNER (Surface Condition Assessment of the National Network of Roads) surveys on the other road networks in England. Similar surveys are commissioned within the other countries in the UK e.g. SCANNER surveys are used on all road networks in Wales and Scotland.

Any of these measurement devices wanting to survey the UK road network must first pass an accreditation test. The purpose of the accreditation testing is to ensure that the survey equipment is capable of measuring and reporting the defined parameters consistently under carefully controlled conditions. The accreditation testing is carried out at a number of different levels:

- Site tests compare the individual parameter(s) measured by the survey equipment against those measured by a reference method.
- Network tests assess the operational capabilities of the survey equipment (and survey crews) on one or more routes located on the public road network.

Sites are specifically chosen to provide a range of levels of pavement condition over which to assess the machines. For example, an accreditation test for a SCRIM device will require it to survey sites consisting of different pavement surfacings and differing skid resistance, whilst an FWD will be expected to survey lengths with differing construction and pavement stiffness.

Any accredited survey device should be capable of reporting data that is both reproducible and also repeatable. Whilst repeatability can be tested by assessing data collected during repeat surveys, reference data is required to test reproducibility. For many pavement condition measurements reference data can be obtained by taking measurements with specialist reference devices e.g. 2m straight edge for rutting, or a slow speed reference profiler for ride quality. However, it is not possible to define an absolute value for skid resistance, nor for pavement deflection. Rather, at any particular time, the “correct” result can only be estimated. Therefore, for SCRIM, FWD and Deflectograph devices the accreditation is undertaken by testing a set of machines for consistency, whereas for TRACS and SCANNER the survey devices are tested individually against a set of reference data.

The tests are supervised by an independent auditor who issues an accreditation certificate to all successful devices. The devices are then required to undergo and pass re-accreditation testing every 12 months (3 months for TRACS).

6.2 UK Quality Assurance (QA)

The purpose of QA is to ensure that the survey equipment remains able to produce consistent and reliable results throughout the year, between the re-accreditation testing. In order to provide comprehensive quality assurance for accredited surveys of the UK road network, QA is provided by a combination of 'first party' QA, operated by the contractor and 'third party' Audit, provided by an independent auditor.

In the first party QA the contractor applies an on-going Quality Assurance regime covering all aspects of the accredited surveys, including:

- vehicle operation and maintenance
- driver and operative training and instruction
- survey operation and record keeping

- data recording, processing, and analysis
- delivery of survey results.

The auditor monitors these internal QA processes to ensure they are of suitable quality and are correctly implemented.

The third party QA is a process where additional surveys are carried out to check the consistency of the data. This includes contractor's repeat surveys (CRS) and auditor's repeat surveys (ARS).

The contractor's repeat surveys (CRS) are used demonstrate the repeatability of the survey equipment. Originally, CRS were carried out by requiring the contractor to deliver repeat surveys of ~5% of the network that they had surveyed - similar to the process currently used in Sweden (Table 25). However, it was found that the repeat survey would often have been carried out within a matter of days of the original survey. This prevented slow deterioration in the equipment being identified. Also, there were often large gaps in time between each CRS and thus, when issues were identified with the data, this would lead to doubt being cast on the quality of a large amount of delivered data. Therefore, the CRS process was enhanced so that the survey contractor is now required to carry out checks based on four levels:

- Contractor's Calibration Site;
- Primary Reference Sites;
- Secondary Reference Sites;
- Daily Test Sites.

The survey contractors use the Contractor's Calibration Site to regularly calibrate the survey equipment and to monitor long term data trends. One or more Primary Reference Sites are established, which test the satisfactory operation of the equipment and these must be surveyed at least once a month. Secondary Reference Sites are similar but must be surveyed at least once a week and Daily Test Sites are used to check the equipment on every day that it is being used to survey. Specific requirements are laid down for each type of site and the contractor is required to obtain approval from the auditor for sites that they choose. The contractor is required to keep the data from any surveys of these QA sites and the auditor may request to see it at any time. In addition, results from tests carried out on the data from Secondary and Calibration sites must be sent to the auditor each time such a site is surveyed. Both data and test results from Primary sites must be sent to the auditor. The frequent nature of these repeat surveys and the fact that the same sites are repeatedly surveyed enable issues with the survey equipment, or data delivered, to be identified promptly. Gradual degradation in data quality can also be identified using the data from the Calibration Site.

In the auditor's repeat surveys (ARS) the auditor carries out repeat surveys by selecting a site and repeating the survey carried out by the contractor, but using an independent survey vehicle. The data from this independent survey will then be compared to that delivered by the contractor and the auditor will determine if the assessment has been successful and if any further action is required.

In 2011 a further QA check was introduced for UK SCANNER surveys where the auditor is provided with all of the survey data collected by the contractors, at regular intervals during the year (this amounts to over 100,000km of data each year). The auditor maintains a national database of SCANNER data against which the current survey data is loaded. The auditor can then make statistical comparisons against previous year's data to identify deterioration in the measurements.

6.3 Survey Specification

One of the benefits of the UK system appears to be the provision of a well defined technical specification for each condition survey type. For example, the SCANNER specification is published and can be found at http://www.pcis.org.uk/index.php?p=6/8/0/list,0,58, whilst the specifications for FWD and Deflectographs are defined in the Highways Agency's Design Manual for Roads and Bridges (DMRB) and can be found at http://www.dft.gov.uk/ha/standards/dmrb/vol7/section3/hd2908.pdf. The specification for SCRIM devices is both in the DMRB (http://www.dft.gov.uk/ha/standards/dmrb/vol7/section3/hd2804.pdf) and has also been published as a British Standard, BS7941-1. The review has found that it is much more difficult to find out the requirements for other countries.

The published specifications are both technical and also result specifications for raw data. The fact that any survey equipment manufacturer in the world can view these specifications and find out what technical requirements are needed to be able to survey road networks in the UK, opens up the market to anyone capable of building a device to these specifications. This increases the competition within the survey equipment market. For example, there are currently four SCANNER suppliers in the UK, running 12 vehicles between them. This competition has the benefit that it significantly reduces the costs to road owners for commissioning the surveys.

The availability of the specifications also allows road owners in other countries to adopt similar requirements for their condition surveys, for example, a device is currently being accredited against the SCANNER specification in the UK, for surveys in China, and the profile survey in New Zealand specifies the SCANNER requirement. It also allows individuals to determine whether devices, accredited for use in other countries, could deliver raw data that fit the requirements to be used to calculate the parameters used in their country. Having access to such other devices could potentially reduce the risk of non-availability of data and could also help clear any survey backlog present in their system.

7 Summary and Recommendations

The above sections have presented the results of the consultation and review. This aimed to identify the current practices carried out in Europe for measurement of pavement performance in a range of areas including service quality, durability, drainage, earthworks, economy and environment. We have seen that there are many approaches applied, some of them common across countries and some of them different. Within this summary section our objective is to highlight the key areas identified within the above sections which could be taken forward to improve the measurement of pavement performance. We have grouped these within the context of the stakeholders' expectations and the ideal measurement requirements discussed in section 4.

Stakeholder expectation	Measurement	Comments	
Service Quality	User Comfort	**Common Practice**	The majority of those consulted employ routine surveys to assess comfort, and it is apparent that regular surveys of longitudinal profile provide a good source of information for estimating user comfort
		Good practice identified herein, that could become common practice	Research shows that user opinions are strongly affected by bumps, but only three countries have a measure that attempts to identify these – the UK's Bump Measure and Germany and Austria's WLP. Such measures could be considered for implementation in other countries.
		Other observations	The routine longitudinal profile surveys provide a good source of information for estimating user comfort but the surveys provide different comfort parameters. It would be desirable to understand how each parameter relates to user perception, to make it possible to have commonality in comfort assessments across the EU. Practical and/or theoretical comparison of the wide range of parameters could be undertaken to deliver this.
		Recommendations for potential new development	The review has identified the potential of a new approach to measurements using probe vehicles. These could be used to better assess comfort. To implement the probe vehicle methodology would require a concerted effort on the part of road operators to put in place the infrastructure needed to obtain the data, but the benefits could be large.

Stakeholder expectation	Measurement	Comments	
Safety	Vehicle handling	**Common Practice**	There is little evidence that measurements are routinely used within vehicle handling models to assess pavement performance.
		Good practice identified herein, that could become common practice	Two models have been identified that could be used to improve road owners' ability to automatically detect dangerous handling configurations on a road network. These models may need to be assessed for suitability for use but could easily be implemented by many of the countries using existing data. This would help to provide a measure that would be better focussed on user's expectations.
Safety	Vehicle speed	**Common Practice**	There is little evidence that measurements of vehicle speed are being routinely used to assess pavement performance
		Recommendations for potential new development	The review has identified the potential of a new approach to measurements using probe vehicles. These could be used to better assess comfort, identify significant defects (e.g. potholes), identify areas of low friction, monitor vehicle speeds etc. To implement the probe vehicle methodology would require a concerted effort on the part of road operators to put in place the infrastructure required to obtain the data, but the benefits could be large.

Stakeholder expectation	Measurement	Comments	
Safety	Skid resistance	**Common Practice**	Friction is commonly measured across most of the countries consulted.
		Good practice identified herein, that could become common practice	The current common approach of measuring the worst case scenario using a routine survey appears to be a practical and cost effective way of managing risks and meeting stakeholder expectations.
		Other observations	There is an array of measurement techniques in place for assessing friction. It would be desirable to ensure that each technique can be interpreted to provide a broadly similar indication of how well vehicles will stop. The frequency of measurement is not consistent across Europe. It would be of benefit to determine the optimal and minimum frequency for the measurement of skid resistance. This would contribute to improved efficiencies in the survey regime.
		Recommendations for potential new development	The review has identified the potential of a new approach to measurements using probe vehicles. These could be used to better identify areas of low friction. To implement the probe vehicle methodology would require a concerted effort on the part of road operators to put in place the infrastructure needed to obtain the data, but the benefits could be large.

Stakeholder expectation	Measurement	Comments	
Safety	Water retention and splash spray	**Common Practice**	With a few exceptions, there does not appear to be any common use of measurements to assess pavements for splash spray or accurate levels of ponding (rut depth is commonly used as a less accurate proxy). This may leave pavements at risk of developing this defect and failing to meet users expectations.
		Good practice identified herein, that could become common practice	A model has been identified for the measurement of water depths, which could be employed more widely to assess the risk of ponding. We have found that many countries should already have the measurement data required to use this model. Alternatively, new water-depth measuring technology could be developed but this may not be as cost effective as implementing a model based on current measurements.
Safety	Sight lines	**Common Practice**	There does not appear to be any routine assessment of sight-lines on the network. However, properties of the road layout affecting sight lines (e.g. gradient, geometry) are steady and will not change with time. Conversely, external factors such as increase in vegetation or poorly placed road signs will affect sight lines. However, these can be assessed using routine safety inspections which are employed in many countries.
		Good practice identified herein, that could become common practice	Many countries now employ traffic speed surveys which collect forward video information. This could be used to identify high risk junctions i.e. those that may be likely to have the sightlines reduced by plant growth, or other. This could then re regularly reviewed on a risk-basis.

Stakeholder expectation	Measurement	Comments	
Safety	Kerb upstand height and condition	**Common Practice**	We have not identified any routine network level assessments of kerb upstands.
		Recommendations for potential new development	Traffic speed technology exists that may offer potential for routine measurement of kerbs e.g. wide, high resolution transverse profile systems and LiDAR. However, no evidence was found that suggested that these technologies were being used in this way. Thus, investigation would be required into these systems, in order to determine their suitability
Durability	Structural strength	**Common Practice**	Many countries undertake assessments of durability via the measurement of deflection but there are larger differences in practice in terms of equipment and frequency of survey. The equipment is typically slow speed and impractical for network level assessment.
		Good practice identified herein, that could become common practice	The routine measurement of durability has been identified as desirable, but is currently impractical. A new traffic-speed system (TSD) has been introduced which may make this practical on the Primary Road Network. However, further work is required to explore its use on lower classes of road.
		Other observations	In order for deflection data to be used to estimate pavement strength, good construction data is needed.
		Recommendations for potential new development	Technologies such as Ground Penetrating Radar offer the potential to resolve the construction data problem, but work is required to make this a useful network wide tool.

Stakeholder expectation	Measurement	Comments	
Durability	Potholes	**Common Practice**	Potholes are identified during visual surveys, carried out during regular safety inspections.
		Other observations	Many countries use traffic-speed measurements of road condition which collect 3D surface profiles. These could technically be used to measure potholes. However, the consultation shows that these surveys commissioned to measure the shape of the road surface are not frequent enough to be useful in identifying potholes, since they can develop so quickly.
		Recommendations for potential new development	The review has identified the potential of a new approach to measurements using probe vehicles. These could be used to identify significant defects such as potholes. To implement the probe vehicle methodology would require a concerted effort on the part of road operators to put in place the infrastructure required to obtain the data, but the benefits could be large.
Durability	Rutting	**Common Practice**	Most countries calculate rutting from measurements of transverse profile.
		Good practice identified herein, that could become common practice	It has been demonstrated that the use of high resolution transverse profile and the removal of profile measurements made over road markings, can improve the accuracy of rutting measurements.
		Other observations	The frequency of measurement is not consistent across Europe. It would be of benefit to determine the optimal and minimum frequency for the measurement of rutting. This would contribute to improved efficiencies in the survey regime.

Stakeholder expectation	Measurement	Comments	
Durability	Visual deterioration	**Common Practice**	Most counties employ a type of visual condition survey, but at a wide range of frequencies.
		Good practice identified herein, that could become common practice	The application of automated routine surveys is becoming more common, but with a range of specifications and requirements. These surveys have strong potential but may benefit from standardisation and improvement in performance (see Recommendations for potential new development)
		Other observations	The image data collected at traffic speed has been shown to be suitable for use in scheme level assessment when using office-based manual analyses. This could be used to improve scheme assessments and design, removing the need for a manual survey. Indeed, the review has found that large quantities of data are being collected which could be used in focussed applications, e.g. to assist in assessing high risk locations or undertaking scheme level inspections using data collected at traffic speed. Engineers may be more likely to use such data if it were presented within an application that allowed them to visualise, interpret and manage the network data. More user-friendly software tools that do this are becoming available that do not have to be built on the large database front ends that are traditionally used by pavement engineers.
		Recommendations for potential new development	Routine network level assessments of visual condition at traffic speed have been implemented in at least 4 countries. However, there is still concern over the consistency and accuracy of the data. The surveys offer strong benefits in terms of cost and efficiency and it would be desirable to drive forward enhancements through cooperation in developing the performance standards for these systems. It would also be desirable to determine the optimal and minimum frequency for the measurement of visual deterioration on different road types. This would contribute to improved efficiencies in the survey regime.

Stakeholder expectation	Measurement	Comments	
Durability	Edge Deformation	**Common Practice**	This defect is not commonly routinely measured across countries, although it is an important defect on narrower roads and affects both users and owners.
		Good practice identified herein, that could become common practice	The measurement of edge deformation using traffic speed survey methods has been implemented routinely in 3 countries. It is possible that other countries could calculate this measure, since most of them already collect the transverse profile data upon which it is based.
Drainage		**Common Practice**	There do not appear to be any routine network level assessments of drainage systems. Regimes appear to be based on risk or the assessment of condition after an issue is identified. This may be cost effective, provided that a robust approach is employed in assessing the risk.
		Recommendations for potential new development	Few countries have implemented routine inspection of their drainage systems and of those that do, most just visually monitor the drains for signs of flooding or obvious problems rather than performing thorough inspection of the drainage system not visible from the surface. It is possible that the implementation of new technology that could detect narrowing/blockages using a much shorter survey method than the traditional methods e.g. CCTV survey, might encourage more routine surveys to be carried out.
Earthworks		**Common Practice**	There do not appear to be any routine level assessments of earthworks. Usually only earthworks considered to be high risk, or located in critical locations are assessed routinely. This seems to be a cost effective way of managing risks.
		Other observations	New technology may help to assist in continuous monitoring of earthworks.

Stakeholder expectation	Measurement	Comments
Economic	**Common Practice**	Most countries take account of the costs of delays to users as a result of construction or maintenance but each country uses a different way of making the cost estimate. Most countries also calculate vehicle operating costs and the effect that road condition has on these, using published models.
	Other observations	It is unclear how each country calculates user delay costs, since the models are unpublished. However, it may be beneficial to consider standardising this.
Environment	**Common Practice**	Monitoring of the environmental impact of pavements is not widespread.
	Good practice identified herein, that could become common practice	Noise is routinely estimated from traffic-speed surveys of texture in the UK. This is potentially good practice, if the good use is made of the data. Technical development might be needed, to ensure that the prediction model works on all surface types used across Europe.
	Recommendations for potential new development	Many parameters are already being measured, that could be used to calculate fuel consumption. This could then be combined with non-pavement factors, such as volume of traffic, congestion etc, to classify the fuel efficiency of a length of road, or, perhaps more usefully, a route.

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Appendix A. Questions for Pavement Assessment

HEROAD: Holistic evaluation of road assessment

Guidance for Pavement Interviewers (Version 1.0)

A.1 Overview of HeRoad

The European road network consists of a wide range of assets, such as pavements, structures, tunnels, signs and other road equipment, which has led to a large number of approaches being proposed to model the behaviour of the assets, and the use of many different parameters. Ultimately, the Heroad project desires to combine these models in an integrated management system that combines and includes all assets, to assist Road Managers in making overall decisions that balance the needs of each component of the network.

Therefore, the work within the HeRoad project is focussing on developing a clear understanding of the performance and behaviour of individual assets and how this understanding can then be used to benefit asset management across Europe. The first stage of this work involves identifying and assessing the parameters, models and criteria used for managing the condition and performance of assets.

Partners in the HeRoad project are: VTI (Sweden), TRL (UK), BRRC (Belgium), FEHRL, ZAG (Slovenia) and AIT (Austria).

The project has been split into four technical Tasks: Pavement Performance, Performance of Structures, Performance of Road Equipment and Environment Components, and you will have been asked to conduct interviews with experts on one of more of these subjects.

Information is being sought regarding road assessment at a network level in the countries listed in the following table.

Country	Partner responsible for obtaining information
Austria Germany Switzerland	AIT
Belgium	BRRC
The Netherlands	FEHRL
France Ireland UK	TRL
Denmark Finland Norway Sweden	VTI
Lithuania Slovenia	ZAG

A.2 Questions

A list of questions have been provided, which should form the basis of your questions during the interview, however, you should not feel restricted to these should the interviewee offer additional information that may also be relevant.

The questions have been divided into 3 sets: “Pavement Performance”, “Performance of Structures”, and “Performance of Road Equipment”. This set of questions covers only the assessment of pavements.

Prior to interviewing, a literature search has been carried out, along with a review of previous relevant research and this has been used to answer as many of the questions as possible. Please check with the interviewee that the answers given are actually correct.

A.3	General information	
	Question	**More information for Question**
A.3.1	Country	
A.3.2	Organisation	
A.3.3	Name	
A.3.4	Address	
A.3.5	Telephone number	
A.3.6	E-mail address	
A.3.7	Role within organisation and area of knowledge	Please give details as to what interest the person being interviewed has in road assessment e.g. are they a researcher developing techniques to measure condition, someone who develops policy, someone who uses the data to target road maintenance, an engineer?

A.4	The Pavements	
	Question	**More information for Question**
A.4.1	Length of motorway and primary road network	Motorways (primary roads) are roads of international importance, high traffic loading, high percentage of heavy vehicle traffic, dual carriageway road, grade separated junctions, high design speed (>100km/h) etc How is the network categorised? Motorways, primary roads, local roads etc. and who own or manage the different categories?
A.4.2	Further criteria for network description	Optional but use this to fill in anything specific to that country's motorway network e.g. only 3-lane carriageways are classed as motorways, only rural roads etc
A.4.3	Which of the networks described above (motorway, other primary and secondary etc) do you have knowledge and/or experience of, to be able to answer questions on pavement condition monitoring?	
A.4.4	Level of traffic loading found on motorway	We would like to know the traffic loading on the pavements (e.g. MSA, daily flow (including

	network	percentage of HGV)). This will enable us to know that we are comparing equivalent roads for each country.
A.4.5	What percentage of the motorway network has rigid pavement construction, flexible pavement construction, semi flexible pavement construction?	We would like to know what the pavement construction is like for the network, as it will likely have an influence on the answers to the questions in the following sections Rigid pavements are those with cement-bound material throughout the whole of the pavement construction. (Concrete pavements overlaid with thin surfacing, or surface dressing should be considered to be rigid). Flexible pavements are those with bituminous material throughout the whole of the pavement construction. Semi-flexible pavements are those that have a cement-bound road base with bituminous upper layers.
A.4.6	Length of other primary road network	Other primary roads are roads of international and national importance with medium traffic loading, medium percentage of heavy vehicle traffic, mainly single carriageway road, mainly junctions at grade, medium design speed etc.
A.4.7	Further criteria for other primary road network description	Optional – see A.4.2
A.4.8	Level of traffic loading found on other primary road network	See A.4.4
A.4.9	What percentage of the other primary roads network has rigid pavement construction, flexible pavement construction, semi flexible pavement construction?	See A.4.5

A.4.10	Length of secondary road network	Secondary roads are roads of national importance, low traffic loading, low percentage of heavy vehicle traffic, single carriageway road, junctions at grade, low design speed etc
A.4.11	Further criteria for secondary road network description	Optional – see A.4.2
A.4.12	What percentage of the secondary roads network has rigid pavement construction, flexible pavement construction, semi flexible pavement construction?	See A.4.5

A.5	**Drainage**	
	Question	**More information for Question**
A.5.1	What kinds of drains are there on each of the three network types?	For example gullies, filter drains, gravel filled trench, channels, grips.
A.5.2	What percentage of each kind is there?	

A.6	Environment-related data and parameters	
	Question	**More information for Question**
A.6.1	Are pavements recognized to influence road traffic emissions in your country?	Which assets factor into the modelling of emissions?
A.6.2	Are pavements specifically designed to reduce road traffic emissions in your country?	Are pavements constructed or modified to combat emissions?
A.6.3	Which environment-related parameters are monitored or checked during road construction?	Monitoring – construction phase
A.6.4	Which environment-related parameters are monitored or checked during acceptance tests after road construction?	Monitoring – acceptance testing
A.6.5	Which environment-related parameters are continually monitored during the working life of pavements?	Monitoring – working life
A.6.6	Which models for determining the emissions due to road traffic are employed for the following emission categories: 1. Greenhouse gas emission (CO2) reductions 2. Air pollutants (e.g. NOx) 3. Particulate emissions 4. Water and ground pollutants 5. Noise emission	Models, calculation schemes, software etc.

A.7	**Current measurement regime and the data it provides**	
	Question	**More information for Question**
	Note: The majority of the following questions ask for the interviewee to provide an answer for all three networks defined in Section A.4.2, however, they are only expected to provide an answer for those networks for which they have some knowledge or experience (see answer to question A.4.3*).*	
A.7.1	How is the collection of pavement condition measurements managed and commissioned on each of the three networks defined in Section A.4.2?	For example, is it all done at national level, with a central survey contract, or is the survey commissioned by individual areas?
A.7.2	For each of the road networks (discussed in Section A.4.2), please describe the approach to the routine collection of pavement condition data at a network level.	We would like to know what approach is used to measure pavement condition at a network level: – How is the condition of the pavement surface assessed for friction, ride quality, rutting, visual condition e.g. cracking etc? – How do they assess pavement strength? Please provide an answer for all of the different road types - motorway, other primary and secondary – for which the interviewee has experience. Does the approach vary, depending on pavement construction type? We're trying to find out whether different techniques (e.g. traffic-speed, driven, walked surveys) are used on the different types of network, or different pavement construction types.
A.7.3	What are the pavement condition parameters measured routinely on each road network? How often are they measured?	This should include: Visual Condition parameters e.g. fretting, ravelling Functional parameters e.g. ride quality Structural parameters e.g. such as pavement deflection/strength, rutting, cracking Safety parameters e.g. skid resistance Please provide an answer for each (relevant) network type.
A.7.4	Which parameters do you consider to be most important?	Which of the parameters that they measure are essential to assessing pavement condition i.e. are given priority in decision making processes, and why?

	Why are they important?	For each network type.
A.7.5	Do you consider any of the parameters measured to be unimportant or measured unnecessarily? Why are they unimportant?	Are any parameters measured that are not used in decision making? For each network type.
A.7.6	Are there any parameters that would be really useful to measure that aren't currently? Why they are not measured?	Please provide an answer for each network type.
A.7.7	Which parameters are most reliable, in terms of their accuracy, repeatability etc?	
A.7.8	Which parameters are most unreliable?	

A.8	The use of traffic-speed data	
	Question	**More information for Question**
A.8.1	Of the parameters listed in question A.7.3, which are measured by traffic-speed devices?	Use answers given to question A.7.3 to determine which are measured at traffic speed.
A.8.2	How are these parameters measured by traffic-speed devices? (on each network type)	What traffic-speed devices are used to measure the parameters? How do they actually measure these parameters e.g. a profilometer measures transverse profile, from which rut depths are calculated?
A.8.3	How are these key parameters measured by traffic-speed devices? (on each network type)	What traffic-speed devices are used to measure the parameters? Please provide an answer for each network type. How do they actually measure these parameters e.g. a profilometer measures transverse profile, from which rut depths are calculated?
A.8.4	What are the barriers to measuring important parameters at traffic speed?	Refer to the answers given to A.7.4 and A.7.6. If they don't obtain all essential measurements with traffic-speed devices, we'd like to know why e.g. do they think that the data is unreliable, the technology required does not exist or is not robust enough yet?
A.8.5	What is being done to overcome these issues/barriers?	What developments are being undertaken on traffic-speed surveys to enable measurement of the important parameters? For example, to improve performance, or accuracy, or introducing a new capability.

A.9	How data is analysed and used at network level	
	Question	**More information for Question**
A.9.1	How is the data stored and made available to those who want to use it?	We don't want software details here – just information such as "the data is stored on a central database that pavement engineers can access remotely. They only have access to the analysed data, not to raw measurements made by the traffic speed devices"
A.9.2	What routine analysis is carried out on the data collected?	How is the data used for analysis at network level: Is it processed to calculate condition indicators, used to give an overall network condition, identify sites requiring maintenance, for lifecycle cost analysis, asset valuation etc?
A.9.3	Is data collected at traffic-speed treated separately from data not collected at traffic-speed, during analysis?	For example, do rutting values, collected during a traffic-speed survey, get combined with cracking data from a walked visual survey, to provide a national indicator, or are the traffic-speed parameters used to calculate one indicator, and those from a walked survey used to calculate another?
A.9.4	How does the reliability of the parameters affect the use of the data	Cross-reference the answers given to questions A.7.7 and A.7.8. Whilst certain measurements are deemed to be essential by policy makers, the engineers may not find that the information given relates to the actual performance of the pavement, or is too unreliable to use.

A.10	How data is analysed and used at scheme or project level	
	Question	**More information for Question**
A.10.1	How is the network data used for analysis at project level?	Is it used to present a case for maintenance?
A.10.2	Is traffic-speed data used at project level?	Reference answers to A.8.1
A.10.3	If traffic-speed data is not used at project level, what do you think is preventing this?	We are trying to find out how the traffic-speed data is used at project level and how this data can be used efficiently and prevent a further survey being needed at project level.
A.10.4	How does the reliability of the parameters affect the use of the data	Cross-reference the answers given to questions 2.6 and 2.7 Whilst certain measurements are deemed to be essential by policy makers, the engineers may not find that the information given relates to the actual performance of the pavement, or is not something that they're interested e.g. rutting is not generally an issue on rigid pavements

A.11	Ensuring Quality	
	Question	**More information for Question**
A.11.1	What regimes are applied to ensure the quality of routine network data?	Do they regularly calibrate their measurement devices, have a QA regime in place etc? Where they have listed more than one approach to network surveys in A.7.2, please obtain an answer for each of the network survey approaches.
A.11.2	Do you have Accreditation processes?	If they do, please obtain a brief description for each network survey approach for which they have Accreditation
A.11.3	Do you have independent Quality Assurance auditing, to monitor data collection and/or data analysis?	If they do, please obtain a brief description for each network survey approach
A.11.4	Do you have experience of issues arising from poor data quality?	If they do, please obtain a brief description for each network survey approach

A.12	Assessing drainage systems	
	Question	**More information for Question**
A.12.1	For each of the road networks (discussed in Section A.4.2), please describe the approach to the routine collection of drain performance data at a network level.	We would like to know what approach is used to measure drain performance at a network level: Please provide an answer for all of the different road types - motorway, other primary and secondary – that the interviewee has experience in. Does the approach vary, depending on drain type?
A.12.2	What are the common problems that you experience with drainage systems	For example filling with impermeable material, collapse of drainage layers, crushed pipes, poor outlet conditions, root penetration, insufficient capacity.
A.12.3	What are the drain performance parameters measured routinely on each road network? How often are they measured?	Please provide an answer for each (relevant) network type.
A.12.4	How are drain performance parameters measured routinely?	For example, CCTV survey, use of flood database
A.12.5	Which parameters do you consider to be most important? Why are they important?	Which of the parameters that they measure are essential to assessing drain performance i.e. are given priority in decision making processes, and why? For each network type.
A.12.6	Do you consider any of the parameters measured to be unimportant or measured unnecessarily? Why are they unimportant?	Are any parameters measured that are not used in decision making? For each network type.
A.12.7	Are there any parameters would be really useful to measure that aren't currently? Why are they not measured?	Please provide an answer for each network type.
A.12.8	Are you carrying out any work that will enable these to be measured?	
A.12.9	Please describe the reliability of the parameters collected, in terms of their accuracy, repeatability etc?	

A.12.10	What routine analysis is carried out on the data collected?	How is the data used for analysis at network level: Is it processed to calculate condition indicators, used to give an overall drainage system condition, identify drains requiring maintenance, for lifecycle cost analysis, asset valuation etc?
A.12.11	How does the reliability of the parameters affect the use of the data?	

A.13	**Earthworks (Geotechnical Assets)**	
	Question	**More information for Question**
A.13.1	What routine assessments are carried out to determine the performance of earthworks at a network level?	Earthworks are generally cuttings or embankments, where a cutting is a passage cut for a road e.g. through a hill or rock and an embankment is a bank or ridge made to carry a road.
A.13.2	What parameters are measured routinely for earthworks? How often are they measured?	
A.13.3	How are routine earthwork parameters measured?	
A.13.4	Are there any parameters would be really useful to measure that aren't currently? Why are they not measured?	
A.13.5	Are you carrying out any work that will enable these to be measured?	
A.13.6	What routine analysis is carried out on the data collected?	How is the data used for analysis at network level: Is it processed to calculate condition indicators, identify earthworks requiring maintenance, for asset valuation etc?
A.13.7	How does the reliability of the parameters affect the use of the data?	
A.13.8	Is the data collected subjected to any accreditation or quality assurance regimes?	If yes, please give details.

Appendix B. Experts consulted to answer pavements questions

Country	Partner responsible	Experts consulted/Literature reviewed
Austria	AIT	Manfred Haider, AIT, carried out literature review and interviews of: Alfred Weninger-Vycudil, PMS-Consult GmbH Johannes Gragger and Christian Krall, ASFINAG Markus Petschacher, Petschacher Consult
Germany	AIT	Manfred Haider, AIT, carried out literature review and interviews with BASt. Karen Scharnigg, BASt.
Switzerland	AIT	-
Belgium	BRRC	Christophe Casse and Carl van Geem carried out literature review and interviews of: Margo Briessinck and Erik De Bisschop, AWV (Road and Traffic Agency)
The Netherlands	FEHRL	Adewole Adesiyun performed the interviews of Bert de Wit, Ann-mon San, Rijkswaterstaat DVS
France	TRL	Jean Iaquinta at TRL conducted the literature reviews and interviews of: Alexandre Leduc at SETRA (Service d'Etudes sur les Transports, les Routes et leurs Amenagements) provided information regarding drains on the French National Road Network. Yasmina Boussafir at IFSTTAR (Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux) provided information regarding earthworks and a small amount of information on drains. The COST 354 database (http://cost354.zag.si/) was used by Emma Benbow (TRL) to provide Pavement information. Further people consulted: Hervé Guiraud (SETRA) Veronique Cerezo (CETE de Lyon) Lydie Deloffre, Hugues Odéon, Daniel Stanczyk (CETE de l'Est) Ludovic Simon (CETE Ile-de-France) Rodolphe Chassande-Mottin (DIT) Yann Goyat, Marie-Line Gallenne, Francois Derkx, Jean Dumoulin, Jean-Luc Sorin (IFSTTAR)

Country	Partner responsible	Experts consulted/Literature reviewed
Ireland	TRL	Brian Ferne, TRL, carried out literature reviews and performed the interviews. Tom Buckland, TRL, carried out literature reviews. Interviewed: Albert Daly, Christian Nea, Conor Fitzgerald, NRA
UK	TRL	Emma Benbow carried out literature review Internal experts consulted (TRL): Alex Wright, Brian Ferne, Richard Abell, Murray Reid, Stuart McRobbie, Mike Hill, Richard Woodward, Vijay Ramdas, Geoff Crabb. External experts consulted: Ramesh Sinhal, Hideo Takano Highways Agency; Dave Johnson, Transport for London, Ray Privett, Portsmouth CC.
Denmark	VTI	Leif Sjögren carried out literature review
Finland	VTI	Leif Sjögren carried out literature review, contacts with FTA(Finnish Transport Agency)
Norway	VTI	Leif Sjögren carried out literature review, complemented with contacts NRA(Norwegian Road Administration)
Sweden	VTI	Leif Sjögren carried out literature review, contacts with TRA (Swedish Transport Administration)
Lithuania	ZAG	Arunas Rutka, Lithuanian Road Administration under the Ministry of Transport and Communications
Slovenia	ZAG	Aleš Žnidarič, Darko Kokot (ZAG) Anton Švigelj (SRA)