



HeRoad, Holistic Evaluation of Road Assessment

Overall road asset performance

Deliverable Nr 5

December 2012



VTI, Sweden



TRL, UK



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Project Nr. 09/16771-39

Project acronym: HeRoad

Project title:

Holistic Evaluation of Road Assessment

Deliverable 5 – Overall road asset performance

Due date of deliverable: 31.12.2012

Actual submission date: 15.03.2013

Start date of project: 01.01.2011

End date of project: 31.12.2012

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Version: FINAL

Version record

Version	Date	Description	Editor	Comments
Draft 1	15 November			27 November
Draft 2	17 December			19 December
Draft 3	4 March, 2013			
Draft 4	6 March, 2013			
FINAL	15 March, 2013			

Foreword

The HeRoad project has been possible to be performed thanks to funding from the ERA NET Road program “Effective Asset Management meeting Future Challenges”. HeRoad would like to thank Ulla Ericsson, of The Swedish Transport Administration for her work as contact person for the Program Executive Board (PEB) and Chris Britton, PEB’s technical advisor for his support in the final phase of the HeRoad work. HeRoad would also like to thank Brian Ferne, TRL and Johan Nyström, VTI for their support in reviewing selected sections and feedback. HeRoad also express its gratitude to all those people that filled in questionnaires, served at interviews or where consulted as experts.

Coordinator

Leif Sjögren

VTI, March 2013

Executive summary

The HeRoad project has investigated the road asset management situation and what practises exist to collect performance measurements in Europe. This has been done in a view from the operational level using a holistic perspective, in the sense that multiple assets and the cross relation between those are included. HeRoad's approach by addressing the need for condition performance measurements can be justified with some words from (AASHTO, 2011); "*What's measured gets done; if you do not measure results, you cannot tell success from failure.*" This implies that the view of investigation has been from the operational level more than from the strategic level (bottom-up).

HeRoad is one of seven projects financed by the ERA NET Road programme "Effective Asset Management meeting Future Challenges". HeRoad focuses on the programs specific theme and objective "understanding asset management". More information on HeRoad can be found on www.fehrl.org/Heroad and about the Asset program on <https://sites.google.com/site/assetcall/home>.

The HeRoad method has been to collect information by doing interviews with road authorities, literature reviews and own expertise and after evaluation complementing with renewed stakeholder interviews as well as one workshop.

The work has been structured by looking at a number of assets and trying to find best practise in how to measure and use indicators to assess the condition of those. In order to find best practise a number of expectations divided into requirements from different stakeholders was done. The assets that were used are pavements, highway structures (bridges and tunnels), equipment's (signs, road markings etc.) and environmental factors. The stakeholders were defined as Users, owners, operators and neighbours. The stakeholders' expectations were divided into six areas: Availability, service quality, safety, environmental impact, durability and economy. Reports were produced presenting the result from each asset (*Pavement performance assessment, D1.1 September, 2012, Structures performance assessment, D2.1 September, 2012 and Equipment performance assessment, D3.1, September 2012*) as well as the results for environmental impact (*D4.1 Report on environmental components*). Early in the project it was realized that performance data and databases also have to be treated as a valuable asset and treated as such. A report on this was also produced (*Pavement condition data and quality procedures, D1.2 September, 2012*).

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1 Introduction

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 such as life cycle analyses and climate change.
- Identifying and describing indicators at different assessment levels.
- Picking out the key areas of good practice.

To be able to conduct a fair, effective and organized asset management, which should include knowledge of asset condition, measurements of performance and goal achievement as well as cost optimization, objective indicators must exist. HeRoad has focused on these objective indicators and looked on measurable parameters that can be used to create indicators for different purposes. The need for indicators can be expressed from the strategic level (top down) or from the operational level (bottom up) view. HeRoad has looked from the bottom up perspective (Figure 1). The project has investigated what is measured and if this can be used to create upper level indicators?

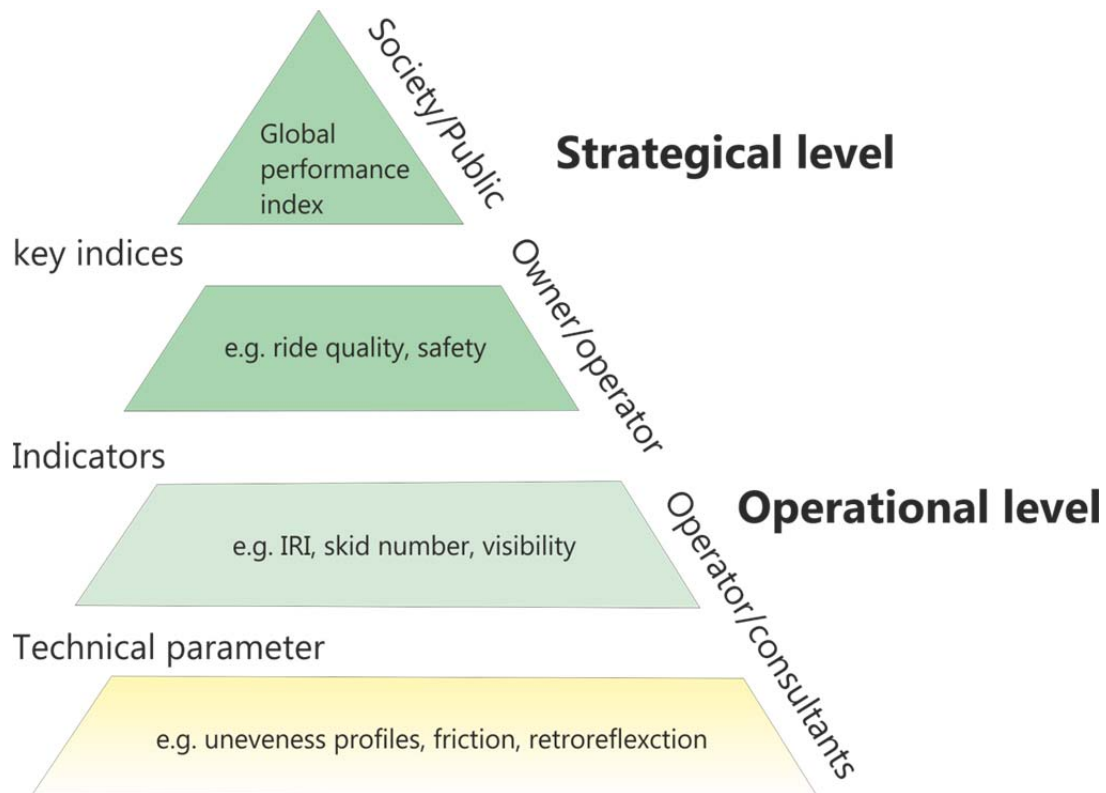


Figure 1 HeRoad has a “bottom up” approach: From the operational to the strategic level

The focus of HeRoad can be explained by some words from (AASHTO, 2011)

“What gets measured gets done;

If you do not measure results, you cannot tell success from failure;

If you cannot see success, you cannot reward it;

If you cannot see success, you cannot learn from it;

If you cannot reward success, you are probably rewarding failure;

If you cannot recognize failure, you cannot correct it; and

If you can demonstrate results, you can win public support.”

In this report the recommended state of practise assessed from the previous reports are documented. This report further discusses new possibilities, where gaps have been found and challenges as well as a problem discussion on LCC approaches in asset management and the need for indicators at higher strategic levels and how they relate to the measured lower level parameters.

A summary on recommended good practise, based on the state of practise review concerning the assets pavement, structures and equipment that has been carried out within the project, is presented in chapter 5.

- The methodology used to gather information on state of practice is described in chapter 3.
- In chapters 5.1, 5.2 and 5.3, possibilities, not yet found in state of practise are discussed, considering *service quality measures, safety measures and durability measures*. For each indicator a discussion on the cooperation between assessments of separate assets is done.

- In chapter 5.4 *environmental aspects* are discussed.
- Chapter 5.5 treats *economic aspects* and relations to indicators.
- Chapter 5.6 considers the aspect of having control of *quality and management of data*.
- Chapter 5 defines road networks and the management of low volume road management in 6.2.
- A summary on recommended good practise, based on the state of practise review concerning the assets pavement, engineering structures and equipment that has been carried out within the project, is presented in chapter 7
- The document also discusses the challenges such as *climate change, life cycle perspective* and how this are met and can be met in the view of road asset management. This is found in chapter 8 (New challenges).
- Chapter 9 discusses life-cycle approaches in road asset management.
- The use of life-cycle approaches in asset management is discussed in chapter 9. In chapter 4 the key factors to an effective asset management and the process to meet higher level (strategic) indicators from operational level perspective are discussed.

2 Scope of HeRoad

The HeRoad project is one of seven projects funded by the ERA-NET ROAD ¹(ENR) road call “Effective Asset Management meeting Future Challenges”. The call addressed four aspects of asset management

- to determine the requirements and expectations of stakeholders,
- to improve understanding of asset performance
- the development and use of Performance Indicators for managing the network
- cross-asset optimisation

HeRoad addresses the second bullet point; **to improve understanding of asset performance**.

HeRoad has looked on the holistic process (the combination of individual components, levels of assessment and the inclusion of a life cycle perspective) and how to incorporate also new challenges in the asset management. This includes

- Investigating data collection, assessment and reporting regimes
- Especially considering new challenges (climate change, traffic configuration, new materials, LCC and the focus on road users’ expectations)

¹ “ERA-NET ROAD – Coordination and Implementation of Road Research in Europe” is a Coordination Action funded by the 6th Framework Programme of the EC. Within this framework this research call was initiated and funded by the National Road Administrations (NRA) from Belgium, Switzerland, Germany, Denmark, Finland, France, Ireland, Lithuania, The Netherlands, Norway, Slovenia, Sweden and United Kingdom.

- Identifying and assessing the key technical components of these regimes and then determining whether they could be considered best available practice or not
- Identifying and describing indicators at different assessment levels (for road operators, complicated technical parameters are acceptable, for decision makers and the public more easily understandable indicators are needed. These could be built from a combination of technical parameters)
- Then pick out the key good parts and provide advice to the customer on how they could use them

As described in chapter 1, Introduction, the bullet points 1 and 3 above are documented in the previous reports and this report deals with bullet points 2, 4 and 5.

3 Methodology

The work in this project has been done in a sequential process, starting with data collection, evaluation and assessment, complementing, further evaluation and finally condensing the result into recommendations.

HeRoad decided to collect the initial needed data by making interviews with adequate people. (It was advised by the ENR group not to send out questionnaires.) A major document with questions concerning all in HeRoad covered assets was developed. Considering the scope of HeRoad this became a comprehensive document. The document was used as a base for the interviews and consultations. Initially the questions was answered as far as possible by our own expertise. Remaining questions and uncertainty was the focus for the interviews. On a more “informal” basis the PEB group was asked to give their input if respective country/organisation could report any of good practises in the area. Literature reviews was also used to support as well as cooperation with and use of other ENR-projects. To study and examine the combination of individual components, levels of assessment and the inclusion of a life cycle perspective and how to incorporate also new challenges in the asset management some limitations were done. For example only a number of all possible assets were selected to be studied, pavements, structures, road equipment and environmental impacts. It was later found that environmental impact should be considered as a common factor for all other assets and therefore treated different. Further it was clear that data and data management must be considered as an asset also with a common aspect crossing over the other assets. To analyse an overall good practise, the stakeholders had to be identified. In the stakeholders are divided into asset owner, asset manager and service providers. The expectations are of course different considering stakeholder group. An expectation matrix was set up; see Figure 2 that is the basis for all work in HeRoad. In general the requirements of users and neighbours should reflect the strategic level and the functional/operational level identified from the operators expectations, as seen in Figure 1 HeRoad has a “bottom up” approach: From the operational to the strategic level.

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

Figure 2 Expectation matrix

For each asset the matrix was filled in with the outermost requirements of each stakeholder categories. This has then been used to evaluate findings from state of practise and select recommended practise. In HeRoad, the state of practise has been documented in separate reports for each asset

- Understanding pavement performance
- Understanding performance of structures
- Environmental components
- Understanding performance of road equipment's

Furthermore it was concluded that data and data management must be considered and treated as a valuable asset as well and a separate report was produced to cover pavement data and quality.

The stakeholders' expectations for all assets and aspects were determined, along with the ideal measurements that might be needed in order to assess whether these expectations are being met. How these expectations and ideal measurements were determined is discussed in Deliverables 1.1 (Benbow & Wright, 2012), 2.1 (Žnidarič, 2012), 3.1 (Casse & van Geem, 2012) and 4.1 (Haider & Gasparoni, 2012) of the HeRoad project.

A consultation and literature review have been used to determine whether road authorities across Europe are being provided with these measures, or any parameters that may be used to determine these measures, and if so, how they are being measured. Whether any improvements can be made to what's being provided has also been determined and this is discussed in the following sections.

The consultation and literature review for pavements obtained information from the following countries: Austria, Belgium (Flemish region), Denmark, Finland (part), Germany, Ireland, Lithuania, Netherlands, Norway (part), Slovenia, Sweden and UK.

4 Key factors for an effective overall road asset management

As described in the introduction and in Figure 1 the HeRoad approach is to identify best

practise from the bottom up perspective, meeting the ERA NET Road program call's specific objective "Understanding asset performance", to further study and identify good practise in the holistic view (management between assets and in a life cycle perspective). Unfortunately the responses that were received on the HeRoad review, on both the formal and informal requests didn't, as a whole, show on much success. The OECD group on road asset management stated requirements for a successful asset management system in the early 2000 (OECD 2001):

- Include inventory information for the asset and condition measures
- Include values of condition of asset
- Include a performance prediction capability
- Ensure data integrity, enhance data accessibility and provide data compatibility
- Include all relevant components in life cycle cost analyses
- Enable the removal of outdated systems and unproductive assets
- Consider both system and project optimisation
- Output useful information on a periodic basis, ideally in real time
- Facilitate iterative analysis processes that can be performed on a regular basis

This was considered 2004 by Norway and a first step towards an integrated asset management system in Norway was presented (Sund et al, 2004). Identified parts in the Norwegian system that did not meet the requirements were;

- most management system was only designed for specific assets,
- optimisation based upon life-cycle cost analysis including all relevant components was not possible,
- users and environment cost couldn't be considered in the current system.

This seems more or less to be the truth for many road administrations. A scan tour performed by the TRB performance measurement committee (FHWA and AASHTO) (FHWA, 2010) visiting The Swedish Road Administration, The British Department for Transport and U.K. Highways Agency, The New South Wales Road and Traffic Administration, The Victoria Department of Transport and Vic Roads, The Queensland Department of Transport and Main Roads and The New Zealand Transport Agency concluded:

- Avoid national level targets - but provide a strong federal vision and policy goals.
- Less is more - Focus on achieving a few, key national policy goals and measures.
- Carrot instead of a stick - Use incentives rather than punitive actions to achieve goals.
- Do it together- Collaborate in implementing performance management processes.
- A Means not an End - Performance management is one of multiple decision tools (but cannot replace a balanced decision process or funding increases).

These are good advices to be considered as part of success factors. Especially the first point seems to be important to achieve the trans-European requirement or at least within country management. The ERA NET road call "Effective Asset Management meeting Future Challenges" do very convenient respond to the next last point Do it together. Other initiatives worth mentioning are the work done in the Netherlands (van der Velden, 2011) that introduces the key performance indicators based on reliability, availability, maintainability and safety (RAMS) and security, health, environment, economics and politics (SHEEP) for networks. The service levels agreements should be based on the RAMS performance indicators.

Meet transport policies

Political visions and the goals get developed and do change during time implying that the management systems have to be dynamic and able to meet new challenges. An example of an overall national objective of transport policy can be seen in appendix C. To manage the trans-European aspect the EU-commissions white paper “Roadmap to a Single European Transport Area” should be considered (EU White paper, 2011).

Assets

In the presentation “Asset management in the Netherlands”(van der Velde J.,) the decomposition of the networks into components is highlighted; and described as network, overall system, system, sub-system, basic object, maintenance object and inspection object. This is done to make it easier to manage the balance of cost, risk and available budget included in the service level agreements. In HeRoad the assets is limited to pavements, structures, road equipment and environment. In a complete management system more assets exists. In HeRoad the importance and need for high quality data has been identified. Therefore one recommendation is to treat data as an asset.

Service life time

A modern road asset management system incorporates a holistic approach in the sense that the whole life management of assets using a structured business approach is included. It can be concluded that life-cycle costing must be an essential part of road asset management. The concept of LCC and differences between different approaches are described in chapter 9. This approach implies that all stages of the road or assets life time is included and considered as illustrated in Figure 3. In the figure it is clear that it exists at least two “life time ends”, one that are defined by when the asset no more are useful for the user (below acceptable standard) and the other end is when the technical performance ends, this is the traditional service lifetime of wearing course end. Clearly the definition of service life time, considering either a separate asset or a whole (a combination of separate assets) is important and essential in road asset management.

Prediction models

Prediction models are necessary to be able to evaluate future conditions and effects on users to perform optimisation calculations on suggested strategies. Considering the discussion on cross asset there are a need for effect models that evaluate the cross asset performance and future effects. E.g. what happens if we in the future increase the width of a road but earlier have invested in a very long lasting (expensive) barrier construction?

The ability to predict life expectancy is a tool that is needed to make pro-active decisions (as compared to react on conditions that have already taken place) and for the ability to do optimisation calculations (NCHRP Report 713, 2012). To make the best decisions it is recommended to use the asset performance rated from the functional level when estimating the end of life. Or at least there should be a clear relation between the functional triggers and the technical parameters that may be used. As it is today, in many cases, the technical parameters are used as triggers but with none or little evidence based connection with the functional level.

Trigger levels

Triggers or criteria that can indicate acceptable levels of condition are needed. In many cases the triggers used today are not scientifically evidence based but more experience based and adjusted to realistic budget levels. In the report (Austroads, 2007) “*Process for setting intervention criteria and allocating budgets*” a literature review has been done. It was found that Safety has the highest priority in setting the levels followed by user comfort

(amenity) and accessibility. Risk assessment combined with engineering judgement is the most common process in setting intervention criteria. The use of LCCA in setting intervention criteria is very limited. The setting of trigger levels is a lot connected to risk management. Risk is also important when taking about sharing risks in contracts. Often risk is defined as a quantifiable while variability that cannot be quantified is uncertainty. Therefore it is important to make the uncertainty as low as possible and converted to calculable risk.

A complete road asset management

Pre-investigation, planning, design, building, daily operations, planned maintenance, improvement and decisions on re-cycling or removal are stages that have to be included and treated. Furthermore the road user perspective has become prioritised and during recent years the environmental impacts has become a target area to consider.

Systematic and organised approach including the whole life perspective, public's expectations, a business approach that incorporates operations, the upgrading (improvements) and maintenance as well as provision of tools are the most essential parts of a Road asset management, (RAM). Many definitions and formulations can be found, in the literature on RAM. Three often referred to are cited below. *RAM is a holistic approach that integrates the strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their life cycle. It focuses on business and engineering practises for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives.* (NCHRP Report 632, 2009)

RAM is a comprehensive and structured approach to the whole of life management of assets (such as roads, bridges, tunnels, buildings, plant and equipment, and human resources) as tools for the efficient and effective delivery of services. (PIARC)

A systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organized and flexible approach to making the decisions necessary to achieve the public's expectations (OECD, 2001).

Recently attention has been put on a dimension that may make the picture even more complicated, namely the incorporation of management of multiple assets. This is sometimes called cross- or multi-objective asset management. It should be observed that this has always been a natural and necessary part of a road asset management system. For more information many of the expressions used in this report are defined and discussed in Appendix A, Terminology.

A road asset management system is not just the separate management systems, as pavements, bridge-, equipment management systems, put together. Management considerations have to be taken across the assets in all stages (part of cross asset management) as seen in Figure 3.

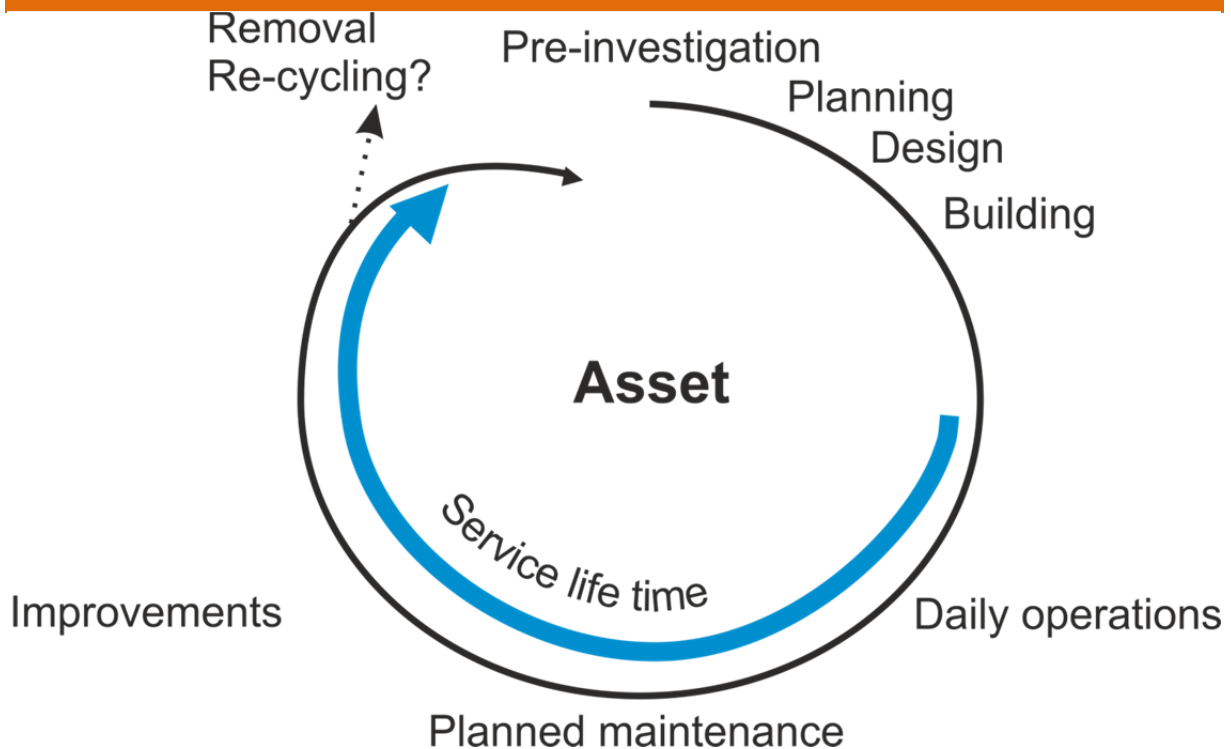


Figure 3 The life time stages of an asset

A national digital framework and adequate databases

A common base; digital framework that is asset independent, preferable geographical built upon a digital structure is needed. This is necessary to allow for all assets to be evaluated, treated and related to each other. This ability is not always the case today. Most likely most PMS are built on a geographical platform. This is good but unfortunately the systems (pavement and other assets) are not always integrated to each other. Another problem is that the PMS sometimes are only local (regional) and not connected to an over-arching system. Further factors for an effective and practical cross asset management is that the information about the existence, type of asset, location and condition of the assets is easily integrated and accessible. This implies that all assets are positioned. In the case of structures it is often only bridges that are included. In Sweden a national Bridge management system, Batman exists but this is not connected to the national PMS. Other assets such as barriers should be included, with information on type of barrier and the current condition. Work is on-going in many countries to include the separate asset management systems into a common framework.

Informed organisations

Most road administration is organisationally built up by divisions dealing with separate assets, like a bridge-, pavement- and safety department etc. For successful implementation of road asset management, the benefits as well as the political and financial implications must be understood by the entire organisation. All employees must be involved in this. However, the traditional organisation structure may be a hindrance. A lot of work to address these issues has been carried out in e.g. the Netherlands (Wijnia, 2007) and also in the United States (AASHTO, 2011).

Responsibility

The ownership and responsibility of roads and the division of road network types (motorways, highways, gravel roads and private roads), see chapter 6, is another challenge

to effective overall asset management. In some countries the roads are managed by private or separate companies, for example the motorways in Austria and France. In many countries different road types are managed by separate organisations and/or the country may be divided into regions that manage these roads. To achieve a common approach in the management of the road asset there would be significant benefit in defining national (or federal) rules or guidelines that would encourage the implementation of the approach. A good example of the introduction of common measurement systems and support tools across a country can be seen in the UK, PCIS (2009). A common standard was developed for the core components of Asset Management systems (UKPMS) for local authorities and there is a common standard for carrying out routine surface condition surveys (SCANNER). However, there is no restriction to commercial activity as any company can freely access the required information and, in the case of the SCANNER survey, can present their equipment for accreditation at any time. This has stimulated a highly competitive and yet common measurement process across all local roads (covering over 150,000km per year). The PCIS provides a web-portal with the required information to contractors and users.

For the motorways and trunk roads of the UK network the requirements for management of maintenance and inventory are described in two documents, the Routine & Winter Service Code (RWSC) and the Network Management Manual (NMM). The NMM document can be found at http://www.dft.gov.uk/ha/standards/nmm_rwsc/.

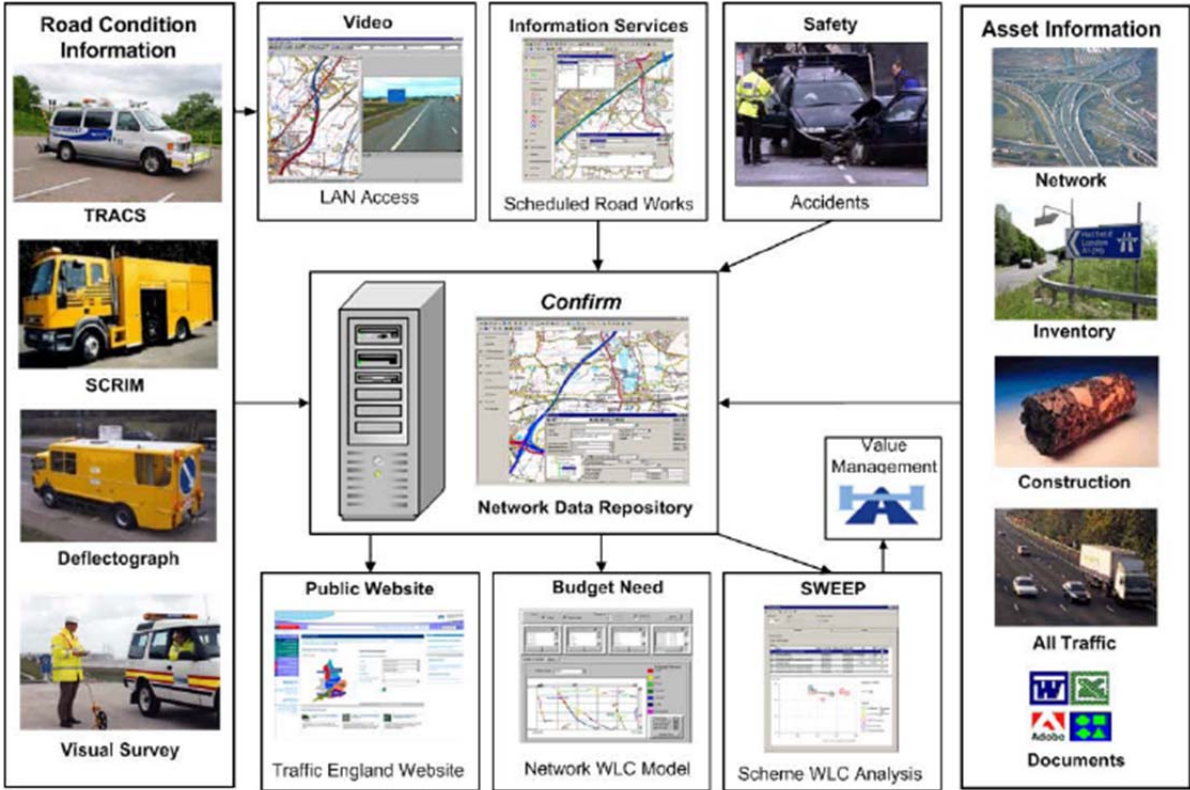


Figure 4 shows the relationship and components of the UK Highway Agency pavement management system.

It exist many examples of well-developed pavement management systems, both commercial and in-house developed. But it seems that most are only so called viewers, either by compiling information or visualize it on e.g. maps. To be a full PMS prediction and decision models should be incorporated. In the Figure 5 the new Swedish pavement database viewer can be seen (PMSv3, 2013). This is a recently developed viewer (at this moment no prognoses tools are built in). Neither are any other assets like bridges, tunnels, signs and barriers included. In some Nordic countries there are national road databases that include many of the assets, but those databases are separate from the pavement and other asset

databases. In this case the problem, at least in Sweden is to synchronise data from the two or more databases.

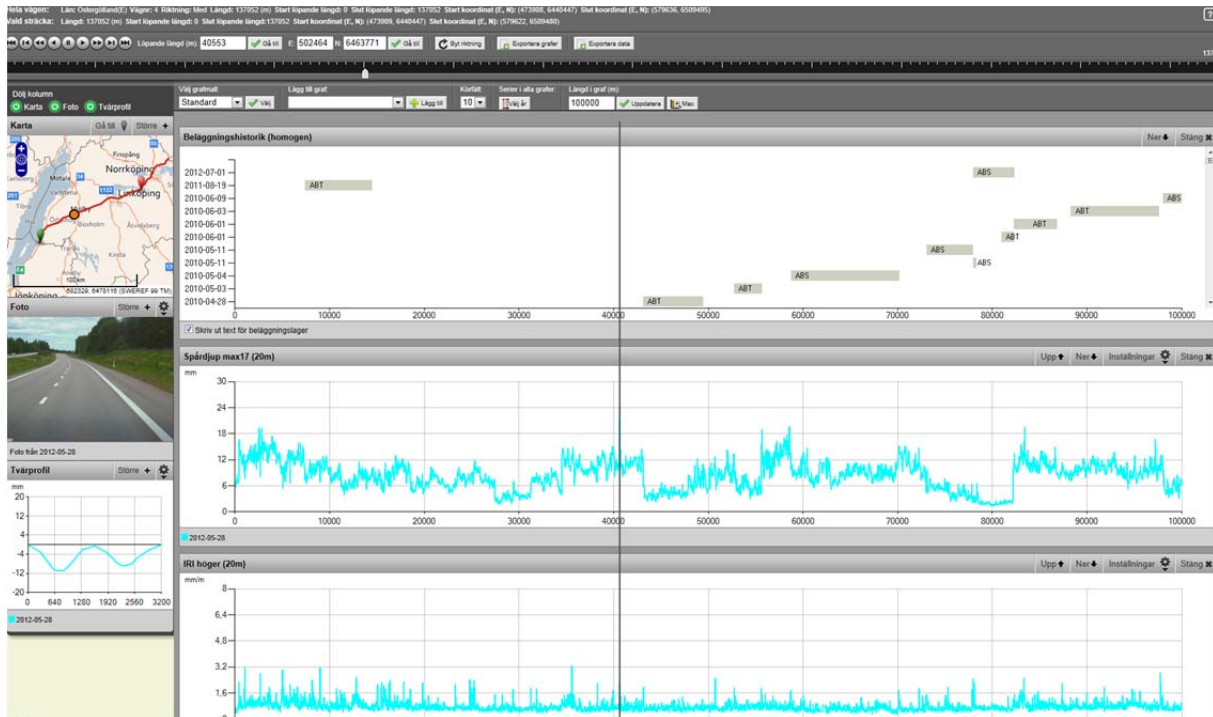


Figure 5 The new Swedish pavement data base viewer.

Trans European views

In a trans-European perspective a question arises; should views, formulations and levels on safety, environmental impact, level of comfort etc. be different considering national or regional perspectives? The dilemma can be illustrated with an example from Sweden where a vision on road traffic safety called the Zero vision (which aims to achieve a highway system with no fatalities or serious injuries in road traffic) is stated. In practise this cannot be achieved, for many reasons, one is that the vision is only implemented in Sweden and not in the neighbour countries or advertised to other traffic from other countries.

Performance measurement

In an asset management view the performance is the level of service that is delivered to the users/stakeholders with an optimised whole life cost. It is important to separate and consider the actual practical measurements on different levels. Some measurements are done to achieve the condition of separate assets. For pavement performance this is done with traffic speed profilometers. The measurements do in most cases deliver a technical parameter; see 1 in the figures 6, 7 and 8. Those indicators are not designed to measure performance on higher levels. To measure performance on the operational/functional level more information are needed in combination with the technical parameters. This next level to measure performance is here called the functional (sometimes also expressed as tactical) level, as an example of an indicators on this is safety. As an example from Sweden, on this operational/tactical level, the criteria delivered for quality/performance is interpreted to targets on condition variables in the maintenance standard (STA, 2011). The maintenance standard is expressed as limit values (trigger values) for a number of condition variables. The standard is divided according to traffic class and posted speed limit. All limit values apply to 100-m sections. Presently the condition variables in the standard are:

- Longitudinal unevenness (International Roughness Index, mm / m)

- Rut depth (mm)
- Macrotexture (mm)
- Edge Depth (mm)

Already on the functional level the indicator can be a combined index as can be seen in the figures. The figures try to illustrate how indicators on higher level of performance are built up by a combination from several lower level indicators. Of course other information than condition must be considered such as traffic volume, quality classes etc. On the strategically level the indicators have to be fewer, relevant and also more public friendly and illustrative. On this level the indicators should be very much harmonised and trans-European oriented. As an example of the strategically level approach is the Swedish National Plan for the Transport System 2010–2021, demonstrating the targets for delivery quality defined for six areas (Trafikverket, 2011):

- Accessibility and punctuality
- Robustness
- Traffic and passenger information
- Comfort
- Safety
- Usability

For each area three quality levels are defined: Base level, + level and ++ level. The road network is divided into five road types: Major city area roads, other national roads and connections with ADT > 8 000 vehicles, key commuter and service routes, including key routes for public transport, other key routes for business and roads with little traffic and private roads. For each road type the required level of delivery quality is set.

The figures 6, 7 and 8 are built up on the information that HeRoad have received. This means that those parameters are actually used in the routine work. There is one figure per asset group. The details in the strategic level are the common goals found in most countries, regions and EC. When reviewing the lower levels (functional and operational levels) it differs much more between countries and regions. The figures should be interpreted as an attempt to connect the technical parameters that was found and how they can contribute to upper level (strategically) indicators. They should be viewed by select one functional indicator e.g. road grip and then go to the left and then by observing red boxes identify to what strategically goal/ expectation it belongs to. By going even further to the left in the matrix the separate technical parameters that can be used as indicators are found. The red boxes are filled in by HeRoad and do not necessarily express any road administrations view. One should remember that HeRoad focuses on a limited number of assets. More matrixes could be created viewing other assets. It is suggested that for many of the used indicators a review and evaluation are done to determine whether they still indicates the target function.

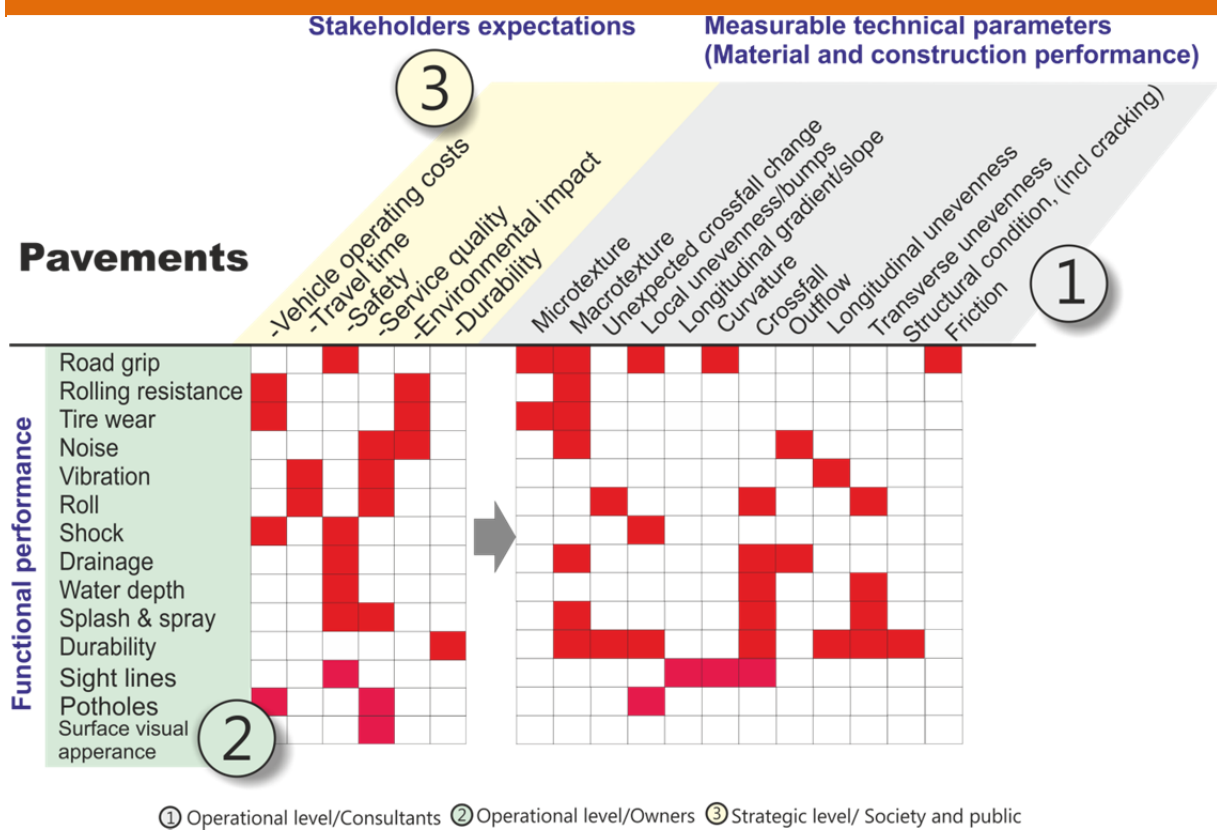


Figure 6 Indicators relation on different levels for pavements

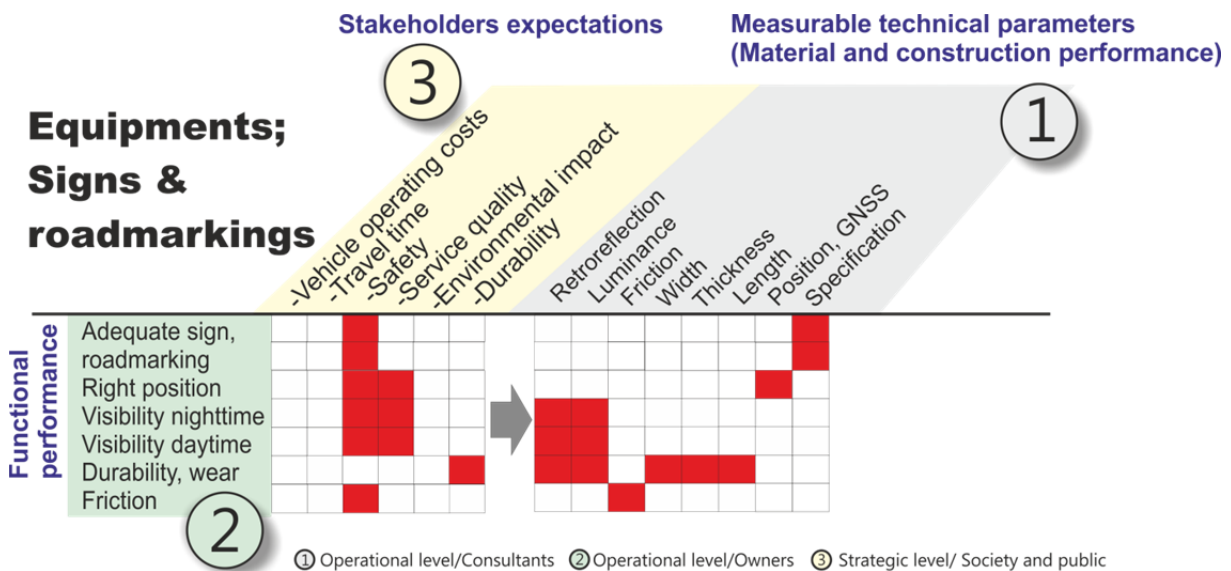


Figure 7 Indicators relation on different levels for signs and road markings

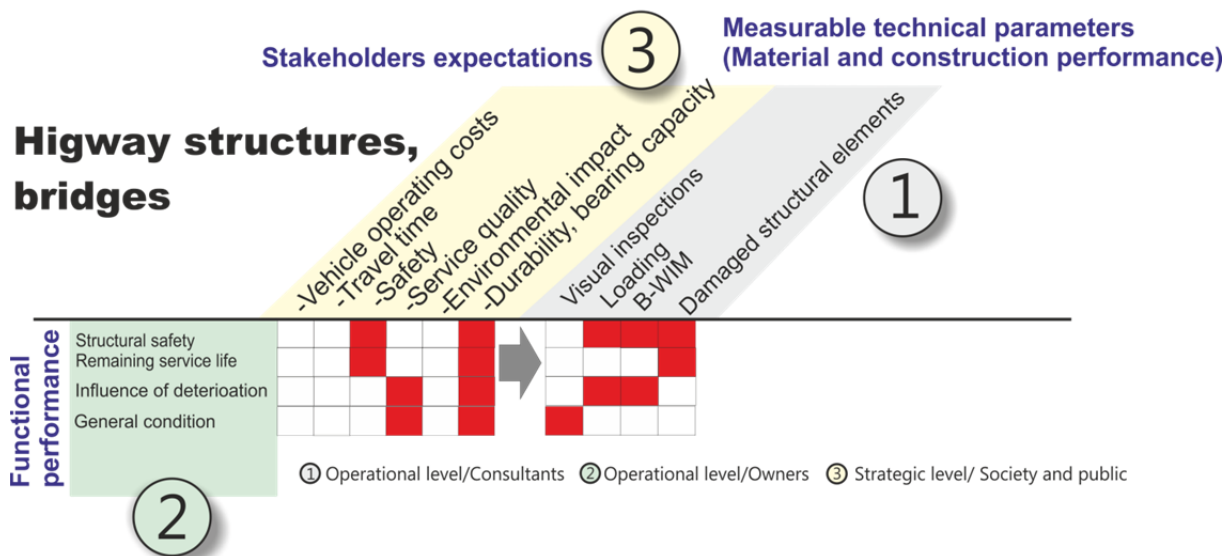


Figure 8 Indicators relation on different levels for highway, structures; bridges

5 Discussion on expectation and measures

In this chapter a more detailed discussion is done divided into the different expectation areas, *Service quality* in chapter 5.1 , *Safety* in chapter 5.2 and *Durability* measures in chapter 5.3.

5.1 Service quality measures

5.1.1 Pavements

The stakeholders' service quality expectations for pavements are given in Appendix B, along with the ideal measurements that might be needed in order to assess whether these expectations are being met. The stakeholder needs, which need to be addressed, when managing the pavement asset for service quality can be summarised as: user comfort, vehicle handling, noise, sight lines, ability to shed water, splash spray, adequacy of drainage, visual deterioration and appearance of surface.

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 handling within the Safety Measures section (Section 5.2.1). 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 5.2.1. How well the pavement sheds water and how adequate the drainage is, is discussed in Section 5.2.1.

Potholes are a source of irritation for users and have been identified as aspects under Service Quality, Durability and Safety. 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 5.3.1).

Noise is also a source of irritation to the users and neighbours and this will be discussed

under Environmental Measures (Section 5.4.1)

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.

User comfort

The level of comfort a user experiences is dependent on the shape of the road surface, the vehicle in which they are travelling and also the speed with which the vehicle travels over the surface. The definition of comfort is important since this is a concept that includes many factors that express a person's wellbeing including the experienced safety in a certain situation. *Seeing, feeling and hearing* are senses that the road user activate to evaluate the comfort. In most cases when using the word comfort in road management the vibration comfort is meant (effects from uneven road 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. A similar mix of vehicle types and models can generally be found in each country and thus 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. The road authorities included in the consultation and review use measurements of longitudinal profile to assess comfort by deriving a parameter from the measured profile that relates to ride quality.

Since the vehicles driven by roads users in each country are very similar, 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. However, this does not seem to be the case in practice 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 it would be beneficial to have data from multiple lines.

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, Ramdas 2007, Janoff 1985, Ahlin 2004, Dahlstedt 2003, Loizos 2008, Prem 2008 and Ihs 2010). These show that users are affected by the general ride quality of roads but their biggest concern is the presence of severe local defects e.g. potholes. Only three countries appear to have a measure that attempts to identify the location of such features – the UK's Bump Measure and Germany and Austria's WLP. In Sweden a parameter called local unevenness has recently been introduced..

Case Study: *Public opinions of paved surfaces on the UK Local Authority road network*

The "Highway Service Levels" project was set up to explore public opinions of paved surfaces on the UK Local Authority road network (Ramdas 2007). The overall aim of the project was to start the process of getting the user's mindset into the prioritisation process so that the services, provided by the road network, are better aligned to user needs. This project found that the types of defects identified by the users as important were:

- Cyclists - Step changes in the profile in their line of travel, caused by potholes, sunken or raised ironworks, failed patches and debris on the road;
- Motorcyclists – Lack of grip, uneven/bumpy surfaces, overbanding, tramlines and the location and condition of ironworks and potholes;

- Car drivers and passengers – Slippery surfaces, bumpiness and its effect on safety and ride comfort;
- HGV drivers – Lack of grip, edge deterioration; also, carriageway width and impact of the HGVs on carriageways and surfaces not designed to carry HGVs.

Thus, if user opinion is to be taken into account by NRAs, they do need to have access to a measure that relates to ride quality, in addition to a measure that identifies the location of severe local defects e.g. potholes, raised/sunken ironwork.

More on road user expectations can be found in the ENR project EXPECT. In a Driving simulator study that was carried out by VTI investigating road user perceptions on road surface condition it was found that the combination of vibration, visual appearance and noise was important, see Driving simulator case below. This implies that macrotexture as a proxy of noise could be considered to be added to a comfort indicator. In some cases it has been concluded that road user opinions of road condition don't match the objective measures using unevenness to assess comfort. Maybe this can be explained partly by this?

Case Study: *Driving simulator study, user expectations on road surface condition*

VTI has carried out a large project to investigate the road user's expectations on road surface condition (Ihs et al. 2010). One part of this project was a driving simulator study.

The simulator study was divided into two experiments. The first experiment tested the importance of appearance (the visual impression), sound (the auditory impression) and vibration/jolts (the tactile impression) on a rutted road surface as well as on a patched road surface. The analyses were based on driving data as well as on the drivers' assessments of how comfortable and how safe the road surface was to drive on.

There was a clear pattern where appearance, sound and vibration/jolts in isolation and in an additive way affect the drivers' subjective perception of safety and comfort. Also speed and lateral position were affected by the individual impressions separately and by various combinations of these, but in different ways depending on the type of road surface damage.

In the second experiment, eight road surfaces with different road surface conditions/properties were included. The analyses of the drivers' assessments showed that the eight different road surfaces were grouped in three different groups both according to perceived comfort and according to perceived safety, although not exactly the same way (see table below). Group 1 is perceived the most comfortable/safe and Group 3 the least comfortable/safe.

	...comfortable	...safe
Group 1 Most...	Patched road Rutted road without water Road with cracks in right wheel track	Patched road Rutted road without water Road with rough texture Road with cracks in right wheel track
Group 2	Road with rough texture	Uneven road 1- Medium vibrations Road with cracks in right wheel track and edge deformations Uneven road 2- Larger vibrations

Group 3 Least...	Rutted road with water Uneven road 1- Medium vibrations Road with cracks in right wheel track and edge deformations Uneven road 2- Larger vibrations	Rutted road with water
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Both the experiments have shown how the various aspects of impressions - in the form of visual appearance, sound and vibrations - each one contribute to a negative perception of comfort and safety. Both experiments also show that there exists a close relationship between perceived comfort and perceived safety. However, the relation is not so strong that they express the same thing, i.e. a high perception of safety affects the driver's experience of comfort, but not completely.

Some conclusions from the project regarding additional road surface indices to capture road users' experience of comfort and security were:

- Road surfaces with water-filled ruts are perceived as both more uncomfortable and unsafe to drive on than are road surfaces with dry ruts. This means that the road condition indicator rut that is used today is not sufficient to capture the road users' perception of the road surface. It is even more important with a road condition indicator that describes where water ponds may occur during precipitation.
- An uneven road surface is perceived as more uncomfortable and unsafe than a dry rutted road surface. The international roughness index IRI should be supplemented with an indicator that captures edge deformations. The reason is that the lateral roll that arises due to edge deformations is perceived as both uncomfortable and unsafe
- Since the sound/noise is an important factor for road user comfort perception, there should be a road surface indicator for the sound level. This indicator is most likely a noise relevant texture indicator (such as mean depth profile, MPD).

5.1.2 Structures

The expectations of stakeholders for highway structures, with respect to service quality, are shown in deliverable 2.1 (chapter 7, Žnidarič, 2012). Ideal measurement practices (maintenance effectiveness) are also included.

The users mainly expect a certain level of comfort, with no obstacles near or on highway structures, minimum noise and good visibility, whereas for the neighbours it is the most important that highway structures shall be not maintained too often, pollutants and noise levels from highway structures (e.g. expansion joints on bridges) should be at a minimum etc.

Owners' expectations for service quality are as follows: Highway structures should not be bottlenecks in the road network, they should not affect general availability of the network and the level of service should minimise vehicle damage. These requirements depend on how the owner/operator operates their contracts. If we assume that they have user or service quality requirements built in, then these might contain all of those listed in the users' requirements.

5.1.3 Equipment

Service quality and availability for equipment have been covered in chapter 4 of HeRoad deliverable 3.1 (Casse & van Geem, 2012). The stakeholders' needs can be summarized in the following terms: Efficient and safe trip for the users, at a minimal cost for the owner, while interference with the neighbourhood quality of life shouldn't occur.

On the availability side, the equipment condition should help to reduce the travel time in a safe and controlled way. Delays related to equipment maintenance will impact the network users as well as the owner and neighbourhood, a societal cost can be calculated per minute of delay as well as an environmental cost (associated with greater emissions).

The service quality is related to the performance of the equipment. For the road owner/operator, the equipment performance is related to the design and specifications of the equipment that should meet European and/or local standards. Tests and performance are described in European standards for road markings, restraint systems, road signs and lighting.

5.1.4 Cross asset (holistic) discussion

To holistically assess a road's ability to meet its Service Quality requirements, a road owner or operator would need access to all of the measurements that can be used to assess the road's ability to meet the stakeholders' expectations for Service Quality. Deliverables 1.1, 2.1 and 3.1 of the HeRoad project (Benbow & Wright, 2012; Žnidarič, 2012 and Casse & van Geem, 2012, respectively), have described how the stakeholder expectations for Service Quality were determined, and proposed a set of parameters that could be used to assess how a road meets these expectations.

The parameters determined for a holistic assessment of the Service Quality of a road (encompassing the pavement, structures and equipment) were identified in the above deliverables to be:

- Ride Quality (including the existence of severe local defects)
- Edge deformation
- Visual deterioration of the pavement surface
- Visibility, general condition and usefulness of information given on road signs
- The presence and condition of lighting
- The condition and reflectiveness of road markings
- The condition of VMS
- The level of noise generated by the vehicles using the road
- The performance of any noise barriers present.

Therefore, when undertaking a cross asset, or holistic, assessment of the level of performance of any particular length of a road, the road owner or operator could undertake a combined assessment based on the above set of parameters. It is noted that the parameters listed for Service Quality tend to focus on particular aspects which affect users. As a result it appears that there are no parameters included in the list which apply directly to the assessment of structures. However, Ride Quality can be used to assess the Service Quality of both pavements and structures. For example, the joints used to allow for expansion on, or at the approach to, many structures can regularly be the cause of poor ride quality and jolting sensations for users. Similarly, large steps between the slabs used to provide the base for the bridge, can cause poor ride quality, whilst the bridge is still structurally sound. Whilst a bridge engineer may be concerned that the joints are in good condition for the purpose of an assessment of durability, they may not be concerned about the ride quality that the joints offer and hence assessments of structures tend to ignore such Service Quality aspects. However, a cross-asset, or holistic, assessment should consider this requirement,

within the context of the other requirements for Service Quality.

5.2 Safety measures

5.2.1 Pavements

The stakeholders' safety expectations for pavements are given in Appendix B, along with the ideal measurements that might be needed in order to assess whether these expectations are being met. The stakeholder needs that need to be addressed when managing the pavement asset for safety can be summarised as: Surface friction, Vehicle handling, Sight lines, Ability to shed water, Splash spray, Adequacy of drainage, Potholes, Measurement of kerb upstands and condition, and Stability of earthworks.

Potholes and earthworks have been discussed under Durability Measures (Section 5.3.1).

Surface friction

The "Highway Service Levels" project (Ramdas 2007) found that all motor vehicle users, on the UK Local Authority road network, are concerned with the level of grip, or skid resistance that a pavement surface has to offer. Pavement skid resistance affects vehicle handling and the maximum stopping distance (Turk, 2012) and if a road authority allows skid resistance to decrease, there is an increased risk of accidents. Therefore, it would seem important for a road owner to be able to identify locations where there is a high risk of skidding.

Nearly all road authorities measure skid resistance on a routine basis, however a large variety of methods and devices are used for routine skid resistance measurement (Descornet, 2006). This is because the British Pendulum (SRT) test is the only internationally standardised procedure for measuring skid resistance (EN 13036-4:2011) but this test is static and not practical for use at a network level.

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.

The systems used cannot take into account the effect that Antilock Braking Systems (ABS) will have on vehicle skid and therefore may overestimate the risk for the large proportion of vehicles with this installed. However, because the current measurement systems measure the worst case scenario, they allow authorities to identify locations at highest risk, thus helping 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.

As mentioned above, there is an increasing commonality in the vehicles and tyres used across the vehicle fleet in Europe, which 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. This is discussed further in the following case study.

Case Study: *The TYROSAFE project review of practice across Europe in the use of skid resistance data*

Skid resistance varies from place to place and over time as a result of traffic action on the surface and different seasonal conditions. The values measured decrease with increasing speed, a phenomenon affected by other factors related to the road surfacing, particularly its macrotexture, as well as the operating principle of the measurement device.

There are many different types of measurement device, ranging from small static devices through pedestrian-propelled devices up to large-scale long-distance routine monitoring machines that some countries operate in large fleets. The devices operate on a number of different principles and are used in different test conditions. Consequently they give different measured values.

For this reason, there has been considerable effort over the last twenty years or so, both in individual countries and in international co-operative studies, to attempt to standardise measurement procedures with individual devices and to harmonise the results that different device types give. The TYROSAFE project (<http://tyrosafe.fehrl.org>), in particular, analysed in detail the various studies that have been undertaken and noted that harmonisation has proved very difficult to achieve, primarily because the way in which road surface texture affects measurements at different speeds, with different tyres and test principles, is not sufficiently well understood.

Measurements of skid resistance may be used for contractual control purposes on new surfaces but are arguably of greatest value when used for as part of a maintenance management process. However, because the property is related to safety, this aspect can dominate thinking and leads to different approaches to selecting the measurement technique, setting appropriate thresholds and on what to do when the thresholds are not met.

The skid resistance properties of a newly-laid road change as a result of weathering and the action of traffic and can be expected to decrease over a period of about three years until equilibrium is reached. If appropriate materials are used, most road surfaces should be able to deliver adequate equilibrium skid resistance for their working lives. However, over time there may be areas that deteriorate to a level that is potentially unacceptable and monitoring is needed both to identify them before they become a hazard and to provide an evidence base for overall network condition.

The TYROSAFE project reviewed practice across Europe in the use of skid resistance data. The best approach for network management purposes was one in which threshold levels in different locations are linked to an assessment of the risk of skidding accidents occurring, with some scope for investigation before a decision to treat the surface is made. This should be backed up with routine monitoring. Such an approach has been used successfully in the UK since the late 1980s, in New Zealand since the late 1990s and has recently been introduced in the Netherlands and Ireland.

Best practice might be to provide for routine measurement of a network on an annual basis. Until a reliable harmonisation strategy is established, for any one network machines of the same device type should be used. Where such fleets are used, best practice also incorporates a process for accreditation in which machines are (typically, annually) compared with one another to verify that they give consistent results, as is the practice, for example, in the UK and Ireland, Germany, Spain.

Vehicle handling

The way that a vehicle handles on a length of road will be affected by the suspension of the vehicle, its tyres, the skid resistance of the road, road geometry and also the shape of the surface. Whilst most of the countries consulted routinely measure pavement shape parameters and road geometry, 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 is a new project within the ERA NET Road 2012 call Mobility, Design and Energy.

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.

Given the infrastructure that would need to 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. Data obtained from such sources 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.

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.

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 its collection is expanding elsewhere. However, evidence was not identified of it being used in the application to sight lines – it 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 is commercially available and 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.

Ability to shed water and splash spray

The presence of water on the surface of the road can increase stopping distances and can also lead to splash and spray. 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, 2012). 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 geometry of the road and also the efficiency of nearby drains. 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 consultation identified France and Sweden (Sjögren et al, 2011) as employing a method specifically to estimate water depths at the network level. The method employs transverse profile and crossfall data and since most countries measure these parameters, this model 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, 2012). 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. However, this may require significant work to assess any models developed, involving collection of measurement data and reference water depth or spray data.

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, however, none of these devices could be used at traffic speed and therefore it would be impractical to routinely survey the network with them.

Case Study: Spray measurement trial in UK

Studies are currently being undertaken to measure splash spray. In the UK, a trial of spray measurement was carried out in which it was found that a mobile photographic method provided a feasible method to measure 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. However, such measurements are typically limited to the nearside wheel path, which may not be representative of the texture across the whole lane width and thus 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.

Adequacy of 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 but 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.

Kerb upstands

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.

None of the countries consulted reported that kerb condition, shape and height were measured 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.

5.2.2 Structures

From the structures point of view the term safety is primarily related to structural safety not traffic safety. In addition, many safety factors explained above are also valid for structures which constituent part is typically also pavement.

Apart from structural condition, the structural safety is the second important performance indicator of highway structures, especially bridges. Their relationship is described in detail in the deliverable D2.1. Both are important requirements of an efficient bridge assessment and management process presented in Figure 9.

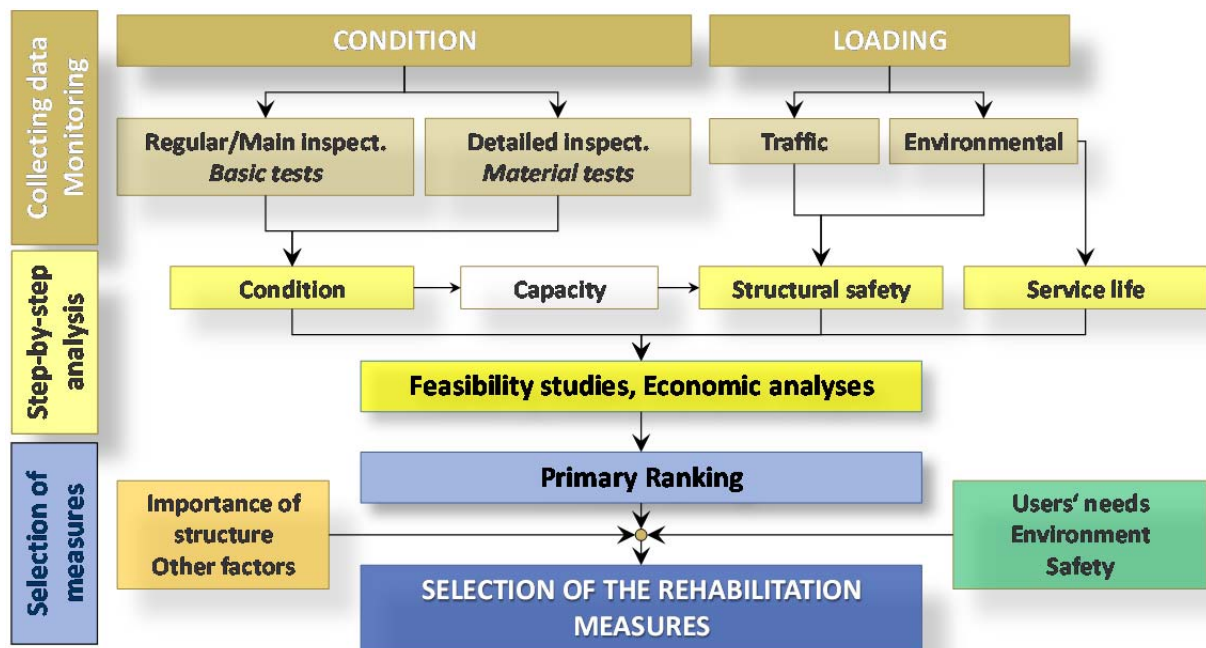


Figure 9 Phases of efficient bridge assessment and selection of rehabilitation measures

The three phases of the process that constitute optimal assessment of highway structures, particularly bridges are:

Collecting data and monitoring of structures, which includes condition monitoring (inspections at different levels and collecting information about deterioration) and monitoring of actions, i.e. traffic loading and effects of environment on the structure (aggressiveness of environment, wind and earthquake loads...).

The second phase suggests step-by-step analyses, starting with available information and using simple analytical methods. If results do not pass the requested thresholds, more data is collected, monitoring/measurements are performed and more sophisticated analytical tools and applied. Typical technical parameters to be assessed are *condition* and *structural safety*, linked over *bearing capacity* of the structure and its critical elements, and often its *service life*. Feasibility studies and economic analyses complete the assessment phase.

In the third stage the measures are selected. The primary ranking based on technical and economic parameters is fine-tuned by the sustainability factors (users' needs, environmental impacts / effects of climate changes, traffic safety and security issues...). Other factors, such as the importance of the structure, also influence the final decision about the intended rehabilitation measures.

Condition assessment

Condition assessment derives functional capability and the physical condition of highway structures, including the extent of deterioration and its influence on traffic safety. The condition assessment can be either qualitative, in the form of definition of classes, or quantitative, in the form of a value that indicates the global state of conservation of the bridges and their ranking according to its value.

All European countries use a system for bridge inspections which are typically divided into *superficial*, *general* or *regular*, *major* or *main* inspection and *detailed* inspections. Their description and inspection practices in Europe can be found in chapter 3 of deliverable 2.1

(Žnidarič, 2012).

Structural safety

Structural safety assessment is the process where, starting from the actual resistance of the structure (up-dated with the results of the inspection and testing) and the actual loading (chapter 4.2 in deliverable 2.1, Žnidarič, 2012), the remaining safety is derived.

The key objective of structural safety assessment is to demonstrate the actual level of bridge safety, based on (1) true structural capacity, which has likely changed since bridge was constructed, (2) real loadings which, especially the traffic ones, may have increased since bridge was designed, and (3) a multistep approach that begins at the lowest level (available information, simple analytical procedures, higher levels of target safety, low-cost) and is, in the case of a negative result, repeated on a higher levels, using more and more elaborated analytical techniques, results of monitoring, modified target safety levels, probabilistic assessment. Furthermore, structural safety assessment should consider that all bridges may have reserves that were not accounted for during the design, e.g. (1) conservatism and simplifications of the structural model, (2) better material characteristics, (3) less severe traffic load effects than assumed in the structural models.

Whilst bridge inspection and condition assessment are well established methods to collect and monitor the state of bridges, structural safety assessment is less common and very diverse around Europe. The BRIME (2001), COST 345 (2004) and SAMARIS (2006) project reports have already made an inventory of procedures used for structural safety assessment in European countries, and the situation has not changed a lot since:

Only a few European countries use special codes and standards for assessment of existing bridges; some examples in Europe are Denmark (DRD, 2004), Germany (BASt, 2010) and the UK (TSO, 2007).

Progressive use of procedures different from design will only be possible provided that they are supported with appropriate flexible guidelines that can be adopted progressively and according to sophistication levels of the analyses.

Case study: *Bridge safety assessment practices in Europe*

Bridge safety assessment practices in Europe vary considerably from one country to another. Practically all countries do some kind of bridge safety assessment, particularly for old and deteriorated bridges for which capacity might be jeopardised. On the other hand, countries rely on different legislative documents that support the assessment procedures. The Eurocode (EN 1991 - Eurocode 1, 2009) allows using alternative procedures as long as the levels of safety are proven to be on the requested levels, which is a legal allowance to apply optimised safety assessment procedures. Still, not all countries take benefits from this. Some countries, like Belgium and Lithuania, apply the design rules also for assessment, others, like Germany, have employed modifications (reductions) to the design code rules or have developed specific structural assessment codes (Denmark, UK, Sweden) that account for realistic information about the structural capacity and loadings. Several countries use recommendations or guidelines that are adopted in practise although they do not have a form of a formal code or standard (France, Slovenia). Ireland is using British bridge assessment codes. Dutch ministry is developing a risk based approach to assessment of all aspects of road management, not only bridges, but also pavements, economy, users... Summary of all these practices is given in Table 2 in deliverable 2.1. Furthermore, the appendices C and D of 2.1 present two case studies of optimised structural safety assessment, including the financial benefits of doing it, one from Denmark and one from Slovenia.

Traffic loading

Traffic loading is a key factor when assessing structural safety. In Europe, there is a great variation in policies of collection of truck weight statistics. In some countries no statistics are available whilst in others there are comprehensive networks of measuring and monitoring devices. There is also a great variation in overload enforcement policy and activity, with fines for offenders that range by a factor of 100 from some countries to the others. In this context, it is not surprising that characteristics of freight traffic, especially the extremely heavy vehicles that govern the bridge assessment, are very different throughout Europe and that, for a given bridge capacity, the differences in weight histograms means that there is a significantly greater safety margin in some countries than others.

When a bridge is strengthened or replaced, it should be designed for full design, i.e. Eurocode loading which allows for future traffic growth. However, there are many existing bridges around member states which can function safely without being strengthened or replaced *because traffic loading is considerably less than in others*. This is most significant as it can prevent a great deal of unnecessary strengthening and replacement of bridges.

Chapter 4.2 and Table 3 in deliverable 2.1 summarises practices in different European countries for collection of traffic loading information for bridge assessment purposes.

The specific *additional* expectations of stakeholders for highway structures, with respect to safety, are the following:

Users: highway structures should not collapse, in tunnels there shall be no danger of spalling of material, drainage shall be sufficient to prevent safety issues (aquaplaning, splash & spray);

Owner/Operator: measurements/monitoring should help from jeopardising structural safety of highway structures, especially bridges and tunnels, and from traffic safety problems, such as icing on the bridges;

Neighbours: they have similar expectations as for the entire road network.

5.2.3 Equipment

Safety expectations for equipment have been covered in chapter 4 of HeRoad deliverable 3.1 (Casse & van Geem, 2012).

Equipment has different functions from a safety point of view: minimise the risk of an accident, minimise the consequences if an accident should occur. Moreover, the equipment should not represent an obstacle for the user.

The length of network equipped with safety increasing devices is an indicator as long as the adequacy of the equipment is demonstrated. For example, experiments demonstrate that lighting is not always an accident reducing factor, the location of the lighting is important on black spots but not always on the whole length of a road. Other equipment is always adequate: “motor biker friendly” markings, frangible poles for road signs, ...

Variable Message signs are also contributing to safety, for example in adverse weather conditions (icy road surface, windy weather on bridges,) or if a crash has occurred downstream. The length of network equipped with such VMS, inter-distance between the VMS and frequency renewal of the information can be used as measurements. The continuity of the service is crucial since the users will expect up-to-date information. From the owner’s point of view, the service continuity can be measured and recorded (fault logging).

5.2.4 Cross asset discussion

To holistically assess a road's level of safety, a road owner or operator would need access to all of the measurements that can be used to assess the road's ability to meet the stakeholders' expectations for safety. Deliverables 1.1, 2.1 and 3.1 of the HeRoad project (Benbow & Wright, 2012; Žnidarič, 2012 and Casse & van Geem, 2012, respectively), have described how the stakeholder expectations for Safety were determined, and proposed a set of parameters that could be used to assess how a road meets these expectations.

The parameters determined for a holistic assessment of the Service Quality of a road (encompassing the pavement, structures and equipment) were identified in the above deliverables. They are listed here per asset:

Pavement :

Roughness level, Geometry for safe handling, Sufficient Sight Lines, Drainage and Ponding ability, level of splash spray, admissible percentage of local defects, stability of earthworks

Equipment :

From the owner's point of view, measurements/monitoring that prevents from jeopardising safety on roads (e.g. Remote control of lighting) and Measurements/monitoring that prevents from causing traffic safety problems (e.g. icing) are related to the user's expectations that can be measured with the length of network equipped with safety related devices such as lighting and restraint systems, VMS giving instructions about the road and/or traffic condition, "motor biker friendly" markings...

Structures :

Safety is here defined following the Structural Safety concept. Traffic Safety issues are of course important, they are related to the pavement and equipment performance for which the previous parameters are also applicable. Additional users expectations are related to the stability of the structure and the drainage issues (aquaplaning, splash spray); the owner will monitor the structure with a "structural safety" view and also with a "traffic safety" view (icing on bridges,)

When undertaking a cross asset, or holistic, assessment of the level of performance of any particular length of a road, the road owner or operator could undertake a combined assessment based on the above set of parameters. Pavement and Equipment parameters are also applicable for the structures, taking into account that "structural safety" goes beyond the monitoring techniques for these two assets.

5.3 Durability measures

5.3.1 Pavements

The stakeholders' durability expectations for pavements are given in Appendix B, along with the ideal measurements that might be needed in order to assess whether these expectations are being met. The stakeholder needs that need to be addressed when managing the pavement asset for durability can be summarised as: Structural strength, Visual deterioration and appearance of surface, Structural rutting, Potholes, Adequacy of drainage, Standing water, Stability of earthworks.

Adequacy of drainage and standing water has been discussed in Section 5.2.1.

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 provides 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: 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.

Traffic speed devices are beginning to emerge for the measurement of deflection, and this is discussed in the following case study. In (Flintsch, 2012) two systems for traffic speed of deflection measurements are selected the TSD described in the case study below and the Rolling Wheel Deflectometer (RWD). The RWD is a system stationed in US and is currently being tested together with the TSD in a FHWA sponsored SHRP project.

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, 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). 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.

Case study: *Trials with the Danish TSD on UK roads*

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, whilst TRL have tested a 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).

Edge deterioration

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) and HGV drivers are particularly bothered by it (Ramdas, 2007).

Edge deformation can be calculated from transverse profile measurements and 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 beneficial to publicise the current knowledge to countries who routinely survey Other Primary and Secondary roads for transverse profile, to see if they could use it.

Visual deterioration and appearance of surface

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 and the most common way of obtaining data, for these features, 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 user 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 (HD29, 2008).

Case Study: *Method to measure fretting*

Current traffic-speed visual condition assessments are focussed on the assessment of cracking and 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 has been recently updated to identify ravelling on thin surfacings but despite this improvement, was found to not be 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 laser 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.

Structural rutting

Rutting is the permanent deformation of pavement layers which can accumulate over time. It is limited to asphalt roads, and can be indicative of pavement failure. There are two types of rutting that can develop on a road: Surface course rutting and structural rutting. Surface course rutting only occurs in the top ~50mm of the pavement and is caused by the surface course mixture being displaced by vehicle wheels, usually during hot weather. Structural rutting is the result of excessive consolidation of the pavement along the 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.

All countries consulted included a measure of rutting in their routine pavement assessment regime, 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. As a result, the depth at which rutting is considered excessive is controlled by its effect on water depth, not on structural condition.

Case Study: UK study on improving rut depth measurements

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.

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 and 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: 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 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.

Stability of 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, 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.

Structures

Durability is key to the optimised management of highway structures. It can be primarily ensured with quality design and construction and quality control associated to them.

During the lifetime of highway structures the key difficulty is that deterioration processes are often not inhibited and as such accelerate damages and thus increase costs for repairs or reconstructions. Typical critical defects that cause durability problems due to accelerated deteriorations are (Figure 10): Damaged drainage pipes and water-proofing membranes (especially if roads are salted during winter) and damaged expansion joints and bearings.



Figure 10 Typical damages that result in costly durability problems on bridges: corroded drainage pipe, damaged pavement and waterproofing membrane, displaced bearing, damaged expansion joint

The expectations of stakeholders for highway structures, with respect to durability, are collected in deliverable 2.1 (chapter 7). Ideal measurement practices (maintenance effectiveness) are also included.

The users expect that highway structures with low durability shall not prevent the road from being available and providing adequate service quality. For the neighbours durability is appreciated as it prevents disturbances from maintenance. The ideal measurement practice for both, users' and neighbours' expectations are similar to those for the entire road network.

From the owner's point of view structures shall be measured/monitored in order to prevent premature deterioration. These measurements shall provide indicators from which durability could be estimated. The owner expects that durability of structures is predictable, particularly failure, and that durability should be such as to minimise maintenance on highway structures. This is related to mobility and economy issues.

5.3.2 Equipment

Durability for equipment has been covered in chapter 4 of HeRoad deliverable 3.1 (Casse & van Geem, 2012). The unavailability of the equipment is a simple measurement to express the users' expectations. The owner will improve his knowledge of the equipment condition with inspections and / or planned maintenance measures.

5.4 Environmental measures

The environmental impact of road assets should ideally meet both the stakeholder expectations and the legal requirements and limits. The basic stakeholder expectations in the field of environment are given in Appendix B.

Stakeholder expectations with regard to the environment were also investigated in the EVITA project (Lepert, Mladenović et al. 2011). The results showed that the stakeholders most concerned with environmental issues of road infrastructure are the neighbouring residents, the general public and the road administrations. Formal communication of these expectations to the road administrations typically takes the form of specific policies, legislation and regulations.

Major environmental concerns covered in HEROAD which can at least partly be addressed by monitoring and maintenance of relevant road infrastructure assets are:

- Noise
- Greenhouse gas emissions
- Air pollutant and particulate emissions
- Water and ground pollutants

Each of these concerns and the pertaining findings and recommendations are covered in the following sections. A detailed discussion can be found in deliverable 4.1 (Haider & Gasparoni, 2012).

5.4.1 Noise

The emission of noise from road traffic is a major environmental concern with rising importance despite many attempts to keep this development at bay. The major groups of influencing factors on the noise levels at the resident's location can be summarised as follows:

- traffic volume, composition (vehicles types) and speed
- local topography and relative positions of source and receiver
- ground and air absorption along the sound propagation path
- presence of noise barriers or other natural or artificial sound propagation obstacles
- pavement type and maintenance condition

Considering this list, it is very clear that rising traffic volumes are a key driver for noise increases, which are only partially offset by advances in vehicle noise reduction technology. Factor groups 2 and 3 are either fixed at the time of construction or cannot be easily monitored and influenced during the operational phase of high-level roads. The key road assets with influence on noise levels which are accessible to condition monitoring in the operational phase are pavements and noise barriers.

Low-noise pavements can substantially reduce the tyre/road noise generation from road

vehicles. The potential bandwidth from very noisy to very quiet road surfaces is given as up to 15 dB in (Sandberg & Ejsmont 2002). Low noise emission can be achieved by texture optimization, by introduction of sound absorption through use of porous asphalt and by using more elastic pavements. However, low-noise pavements with advanced noise reduction features often show a deterioration of their noise reduction capability due to loss of material or clogging of pores. Acoustic pavement monitoring helps to recognize the onset of problems and to establish the acoustic performance over time.

The noise emission of road pavements can be directly monitored using the Statistical Pass-By method (SPB) (ISO 11819-1, 1997) and/or Close Proximity method (CPX) (ISO/CD 11819-2, 2000) measurement methods. The SPB method can characterize pavement influence on overall vehicle noise emission, separately for passenger cars and heavy vehicles. It is most suited for characterization of pavement noise emission at specific locations, less for continuous monitoring of long sections. It is comparably time-consuming, valid only for a short section of road and somewhat dependent on the measured vehicle collective. The CPX method can be performed at traffic speeds over long distances, and is therefore more suitable for network monitoring. Its drawback is that it cannot account for the overall vehicle emission, but only for the tyre/road portion.

Ideally SPB and CPX are combined, with SPB used for initial characterization of pavement types and CPX used for approval testing and long-distance monitoring. However a common European noise characterization method for pavements is currently not available, as the national methods are tied to the differing national noise calculation systems. However, with the anticipated introduction of a common noise calculation method in the framework of the Environmental Noise Directive (EU, 2002), acoustic pavement characterization will need to be put on a common basis.

Noise barriers prevent direct sound propagation from the source to the receiver and are a very common means of noise abatement. Their key properties are high sound insulation, high sound absorption and low sound diffraction over the barrier top. Degradation of these properties over time will reduce the acoustic performance of noise barriers and lead to increased noise levels at the receiver position. However, the traditional determination of sound insulation and sound absorption is performed in the laboratory according to EN 1793-1 (EN 1793-1, 1997) and EN 1793-2 (EN 1793-2, 1997), preventing acoustic monitoring in the installed condition. Therefore current condition monitoring of noise barriers is limited to visual inspections to detect damage, ensure the structural integrity and prevent safety hazards. Maintenance activities for noise barriers will typically consist in the replacement of damaged elements or even the rebuilding of sections of the barrier.

With new methods developed in the last decades in-situ monitoring of noise barriers has become possible. The methods according to CEN/TS 1793-5 (CEN/TS 1793-5, 2003) and prEN 1793-6 (prEN 1793-6, 2011) could be used to monitor the sound insulation and sound absorption of installed noise barriers over time. This is currently not standard practice, but the ongoing QUIESST EU project (www.quiesst.eu) on these methods may help to facilitate their practical application in the near future.

To some extent also the **management of the traffic flow** using variable message signs can contribute to noise reductions, especially if lower speed limits are imposed. The condition monitoring of these assets will be limited to ensuring their functionality.

According to the 2010 report of the CEDR noise group (Bendtsen et al., 2010) 65% of the surveyed countries do include noise emission as a parameter in the selection of new road surfaces, and only 10% have it included in their national pavement management systems. The following three examples are taken from (Goubert et al. 2007).

In the Netherlands the use of low-noise pavements is very widespread and is even fixed in the legal framework. In 2007 approximately 70% of the high-level road network was covered

with single-layer porous asphalt, which is higher than in any other European country. However, on the high-level road network the noise performance is established only once in a type test, and there are no further conformity of production (COP) tests. Evenness, skid resistance, rutting, ravelling, and tearing are annually monitored on those pavements, but no acoustic properties. Low-noise pavements on the local road network are however treated differently, as the noise performance has to be proven to obtain funding from the national government. In this case both an initial COP test and checks after 2, 5, 8 and 11 years are carried out using the CPX method. In contrast to the initial test the following checks do not have financial consequences. The results are converted into SPB values and compared to the required noise reduction. The pavement has to be replaced with one which is at least as silent as the current one.

In Switzerland the use of noise abatement solutions is guided by the calculation of a so-called “Index of Economical Sustainability”, which is based on a cost-benefit analysis of the noise reductions achieved at the neighbouring residents’ locations for the different possible combinations of noise barriers and low-noise pavements. Porous asphalt and asphalt concrete with smaller chipping size are used as standardized low-noise pavements. While there is acoustic monitoring of pavements from the start (using CPX), it has no consequences.

In the UK the use of low-noise pavements is a key tool of the UK Highways Agency for preventing noise pollution (target: 60% of high-level network). The decision has been taken to use thin surfaces with RSI (road surface influence) values < 2,5 dB(A) within the UK HAPAS system. HAPAS contains a procedure for issuing noise performance certificates for low-noise surfaces, which include monitoring of noise levels after 12 months and of texture depth after 24 months. They are supposed to have a lifetime of 8-12 years. Once the certificate has been issued, no further monitoring of laid surfaces is performed.

5.4.2 Greenhouse gas emissions

Emission of CO₂ and other greenhouse gases in the operational phase of roads is mainly due to the emissions from the fuel consumption of road vehicles traveling on the road infrastructure. The following groups of factors influence fuel consumption and greenhouse gas emission:

- Traffic volume, composition and speed profiles
- Fuel composition
- Vehicle technology (engine, transmission, suspension, tyres)
- Air resistance
- Road layout (gradients, curves, intersections)
- Road surface (evenness, texture, rolling resistance)

Only a few of these factors are linked to road assets properties. Apart from traffic management, only road layout and road surface are fully under the control of road owners. However, road layout is typically fixed in the planning and construction phases, so that the pavement remains as the major road asset that can be influenced and monitored by national road administrations during the operational phase. To some extent the management of the traffic flow using variable message signs can also contribute to emission reductions, especially if speed limits are imposed. The condition monitoring of these assets will be limited to ensuring their functionality.

The main characteristic of pavements that influences fuel consumption of road vehicles is the rolling resistance (Hammarström, 2009; Descornet, 1990). Rolling resistance is a measure for the force opposing propulsion that arises from tyre-road interaction. Current models

assume that the pavement-dependent portion of rolling resistance mainly depends on macrotexture (MPD) and unevenness (IRI), apart from speed dependence.

Rolling resistance of pavements is the most important road surface property accessible to management by national road administrations which can influence this total greenhouse gas emission. Measurement of the pavement contribution to rolling resistance can be carried out in one of the following ways:

- Measurement with dedicated rolling resistance trailer at traffic speeds
- Coast-down measurements with standard road vehicles
- Drum measurements using a steel drum (ISO 28580, 2009)
- Drum measurements using selected tyres and a drum coated with a pavement surface
- Fuel consumption measurement in controlled drive cycles

Coast-down measurements have been investigated in the ECRPD project (Hammarström, 2009). The resulting model incorporates the relevant mechanisms, however the uncertainties of the experimentally determined parameters are still deemed too high.

None of these methods is currently ready to be used for the measurement of road surface properties in an asset monitoring context. The development of a stable and reliable method for long-distance rolling resistance monitoring of pavements is part of on-going research effort like the MIRIAM project (<http://www.miriam-co2.net>).

Fuel consumption on the road network is currently not monitored in any of the countries considered in HEROAD. However, the majority of the countries do measure condition parameters that are known to have an effect on fuel economy. This suggests that, by implementing a reliable model, a network level estimate of fuel consumption could be obtained by most countries.

In the UK the amount of CO₂ 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.

Air pollutant and particulate emissions

The monitoring of air pollutants and particulate emissions such as PM 2.5, PM10, NO_x, SO₂, NMVOC, CO, Hg, Pb, and HC are typically performed using fixed or mobile monitoring networks not specific to emissions from road traffic. EU Directive 2008/50/EC (EU, 2008) specifies the requirements for monitoring and reporting as well as limit values and action planning, which leads to the availability of good overall information on air pollution. The measurement devices operate according to standardized measurement methods (e.g. EN14211, EN 12341, EN14907) and determine the overall ambient air pollutant concentrations. These concentrations are typically generated by several sources, road traffic being only one of them. The background is generated e.g. by industry or domestic fuel burning. Therefore in many cases there is no direct link between overall air pollutant concentrations and road asset performance. One notable exception are NO_x emissions, where road traffic plays an important role. In the UK road transport accounts for around one third (33.5%) of total NO_x emissions, which is comparable to Austria (50%), France (54%) or Slovenia (58%).

The main influencing factors which can be controlled by national road administrations in the operational phase via road assets are rolling resistance of pavements, which is linked to fuel consumption, and winter maintenance. To some extent also the management of the traffic flow with variable message signs can contribute to emission reductions. However, significant influencing factors like gradients and general road layout are fixed at construction time.

The future development of reliable rolling resistance measurement methods will make it possible to monitor pavement surface influence on fuel consumption. PM generation from winter maintenance is closely linked to weather conditions and winter maintenance procedures. This problem is usually addressed by optimizing those procedures and not by any road asset properties.

VMS are used in the UK together with management of the road layout and gradients during the construction phase in order to ensure a continuous traffic flow and avoid congestion. Condition monitoring of the VMS in this case, however, will be focused on keeping the system components functional and in good order.

The generation of particulate matter through abrasion of tyres and road surface gives rise to substantial local concentrations of PM. These concentrations depend on speed, tyre and pavement type. There are indications that the choice of pavement can influence the resulting PM concentrations (Haider & Folkesson, 2006). However, currently no asset-specific condition monitoring systems of PM apart from the ambient monitoring according to the requirements in (EU, 2008) are currently in place.

Water and ground pollutants

Water and ground pollutants are released by road vehicles, the road materials or are introduced by winter maintenance. Important groups of pollutants are heavy metals (Cd, Cu, Pb, Cr, Zn, Fe, Ni, Na), hydrocarbons (polynuclear aromatic, hydrocarbons, PAH), and de-icing salts (sulphate, calcium chloride, sodium, cyanide).

The relevant condition parameters for water and ground pollutants are the levels of pollutant concentrations found in water and soil. However, water and ground pollution measurements are usually not conducted in association with road condition monitoring. In the case of road accidents with suspected contamination, specific investigations may be launched.

Water and ground pollution levels can be readily measured or modelled, but this is usually not part of regular condition monitoring of roads. Pavements and their associated drainage systems form the most important asset for controlling the water and ground pollution levels. They are subject to regular condition monitoring concerning its functionality; however the monitored parameters are not specific to this environmental issue.

The presence of de-icing salts in the runoff water can be addressed via optimization of winter maintenance. Moreover, reduced fuel consumption due to low-rolling resistance pavements will also contribute to a reduction of water and ground pollution.

In the UK drainage data for the drains present on the Highways Agency network is stored in the Highways Agency Drainage Data Management System (HADDMS). This is populated with inventory data for an estimated 40% of the network. However, drain performance data is not collected on a routine basis on any of the road networks. Chemical testing of the content of water run-off is performed.

In other countries no environment-specific condition monitoring and maintenance was reported. As a typical example in Austria drainage system inspection and maintenance is based on visual inspections, one immediately after construction followed by inspections once or twice a year depending on the type of drainage system component. These inspections are mainly concerned with detecting damage and obstructions of the drainage systems and ensure its proper functioning.

Countries with a high percentage of porous road surfaces like the Netherlands also benefit from the avoidance of aerial dispersal, as long as the pavement remains unclogged. De-clogging and correct disposal of the cleaning water are essential to maintain this beneficial aspect. Currently de-clogging as a standard maintenance measure is only performed in the Netherlands.

In Lithuania and the UK the chemical content of water run-off is tested just after construction

and then regularly monitored throughout the life of the pavement.

5.4.3 Relationship of asset-specific environmentally relevant parameters and E-KPIs

The EVITA project has evaluated environmental key performance indicators (E-KPIs) related to stakeholder needs which are currently in use (Lepert, Jamnik et al. 2011). The focus of HEROAD is on the relevant asset-specific parameters that are known to influence the E-KPIs and which are accessible to asset condition monitoring. The chain of influences is shown in Figure 11.

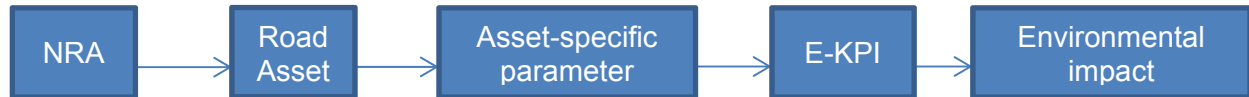


Figure 11 Chain of influences from assets to E-KPIs

The following table details the E-KPIs proposed by EVITA and shows the link to the influencing asset parameters.

Table 1 E-KPIs and associated asset-related parameters

Area	E-KPI (Environmental Key Performance Indicators)	Asset-specific parameters	Remarks
Noise	Equivalent continuous sound level L_{eq} or $L_{Aeq,T}$ Day-Evening-Night equivalent level L_{den} Night time level L_{night} Sound absorption coefficient	SPB Index CPX Index Sound absorption coefficient VMS functionality	SPB results provide the best indicator for L_{eq} , $L_{Aeq,T}$, L_{den} , L_{night} if a sound propagation model is available. Sound absorption is actually an asset parameter, which is mainly relevant for porous surfaces.
Greenhouse gases	Emission of CO_2 equivalent (CO_{2e})	Road layout parameters Rolling resistance based on e.g. MPD, IRI VMS functionality	Asset parameters will be needed as an input for models which need to include other information like traffic volume, composition, speed, etc.
Air pollutants and particulate emissions	Concentration of pollutants (PM _{2.5} , PM ₁₀ , NO _x , SO ₂ , NMVOC, CO, Hg, Pb, HC)	Road layout parameters Rolling resistance based on e.g. MPD, IRI VMS	Asset parameters will be needed as an input for models, which need to include other information like traffic volume, composition, speed, as well as localized information on other sources.

Area	E-KPI (Environmental Key Performance Indicators)	Asset-specific parameters	Remarks
		functionality	
Water and ground pollutants	Concentration of heavy metals (Cd, Cu, Pb, Cr, Zn, Fe, Ni,Na), total hydrocarbons (polynuclear aromatic hydrocarbons, PAH), de-icing salt (sulphate, calcium chloride, sodium, cyanide)	Drainage system condition Pavement condition (especially for porous pavements)	Asset parameters will be needed as an input for models, which need to include other information. Winter maintenance strategies will have an important influence.

5.5 Economic measures

In order to manage a road network in an optimal way, the road manager has to take costs into consideration. All NRAs has a budget constraint, if not there would not be any problems with the pavement, safety or the environment as enormous amount of money could be spent. Hence, the budget constraint forces the NRAs to prioritise between different assets.

More than the cost for undertaking an action i.e. new pavement, one has to control for the effects from that action.

The section below maps the stakeholder's perspective on these effects.

5.5.1 Pavements

The stakeholders' economic expectations for pavements are given in Appendix B, along with the ideal measurements that might be needed. The stakeholder needs that need to be addressed when managing the pavement asset for economy can be summarised as: Energy rating per km (fuel consumption), Costs arising from maintenance, Cost of accelerated wear, Incidental costs, Cost to neighbouring property.

The consultation did not specifically ask the respondents to appraise these features. Since most of them have a market value and can be observed, it's better to try and get the real cost. HEATCO (Harmonised European Approaches for Transport COsting and project assessment, <http://heatco.ier.uni-stuttgart.de/>) points out that this is very hard to do on a European level, since maintenance is dependent on the standard of the country's infrastructure which differs a lot.

5.5.2 Structures

The expectations of stakeholders for highway structures, with respect to economy, are shown in Žnidarič A: "HeRoad Deliverable 2.1 (chapter 7). Ideal measurement practices (maintenance effectiveness) are also included.

The users expect that fuel consumption, taxes or tolls, congestion (this incurs delay charges), vehicle damage (via wear or accident) shall be minimised and that the maintenance work shall not incur costs arising from detours and delays. Neighbours' expectations with respect to economy are as follows: presence of highway structures shall not devalue their properties; effects of dust, pollution and vibration shall not increase their maintenance bills; there shall be no health issues from living near a structure, which would have cost implications. The ideal measurement practice for both, users and neighbours expectations, are similar as those for the entire road network.

From owners' point of view measurements/monitoring shall provide information that will optimise expenditures on maintenance of structures and will extend life-time of bridges by providing realistic information about traffic loading and bridge capacities (Woodward, McKenzie, Žnidarič, Denarié, & Richardson, 2006). These measurements are needed to assess the owners expectations (costs for maintenance and management of structures (including survey costs) shall be minimised; the whole life costs shall be minimal, or at least sensible; costs incurred by accidents, whether for liability claims or clear-ups, shall be minimal).

However, maximising outcome from a social point of view does not include all of the above

measurements. Taxes, tolls and congestion could be a social cost when the imposed fee causes consumers to change behaviour i.e. buying less and thereby lowering the tax revenue. This effect is however hard to verify and HEATCO (2006) recommends not to include this as a cost.

5.5.3 Equipment

Economic measurements for equipment have been covered in chapter 4 of HeRoad deliverable 3.1 (Casse & van Geem, 2012).

If correctly designed, located, monitored and maintained, equipment can have an influence on the societal cost of accidents. Accident statistics are a complex discipline related to databases sometimes managed by different administrations and authorities. The root cause analysis for accidents is therefore not an easy task for data availability or data existence. From the owner's point of view, good monitoring practice will have a direct impact on maintenance measures, their cost and their planning.

5.5.4 Cross asset discussion

The above section portrays what the stakeholders find important when managing a road network. This is important input to the NRA's work. However, the decision on how to spend money in order to maximise benefit under a budget has to be taken out of a societal perspective. This means that even though every stakeholder is pushing for his interest, a road asset management model needs to take a societal perspective. Such an approach is considered in a LCC or a CBA model.

5.6 Quality Assurance

5.6.1 Pavements

For network condition data to be useful, it is necessary that it has a level of quality that ensures stability in time, adequate measures (indicators) with specified documented construction and known accuracy. Stability in time is necessary since the data will be used to predict future condition (from models built up and based on the data). HeRoad has reviewed the quality control applied to the pavement condition data measured.

Quality Assurance (QA) regimes and calibration processes check that devices providing data for road management are working and providing accurate measurements. More advanced regimes include "Certification" or "Accreditation". These are organisation/management systems which, amongst other things, control the types of equipment used and ensure that only independently approved contractors and equipment will be used. Certification and Accreditation covers the whole process, from measuring a pavement property, all the way to delivering data to the customer. All countries that responded to the consultation calibrate their measurement systems against manufacturers' recommendations, using such standards as ISO 9001. However, only five countries claimed to run "accreditation processes".

Experience in the UK has shown that, without Accreditation and ensuing Quality Assurance procedures, very different data can be delivered by calibrated devices, either when the same device carries out a repeat survey, or when a separate device carries out the second survey.

To reach a trans-European asset management framework, the measurements need to be standardised or at least harmonised. This can only be achieved by firstly agreeing on common indicators, requirements on how they shall be measured and finally how they can

be quality approved. A number of initiatives have been conducted, are on-going or proposed, to harmonise indicators. Very little has been done to have common European quality approval procedures, despite the internal data quality control in an organisation being so important. Therefore, HeRoad recommends that effort is made to develop a common European quality assurance concept including selection of reference methods to be used in the process.

5.6.2 Structures

Quality assurance procedures for inspection of highway structures vary from one country to the other. Very few countries like Finland and Lithuania issue and require certified bridge inspectors. Several countries perform formal or informal training courses for bridge inspectors; many others require only formally educated engineers with adequate practical experience in bridge design, maintenance and, for detailed inspections, specific knowledge. Exceptionally, like in Czech Republic, they perform selective *control inspections* to verify results of regular general and major inspections. Many countries do not require formal training of bridge inspectors and rely on their general experience.

There also seems to be no quality assurance system in place in any European country that would consistently check for errors in the reports, such as copy-pasting of all reports, impossible records, improvement of condition without any action taken on the bridge, etc.

Nearly all considered countries reported the necessity of working out universal guidelines for condition assessment, which allow for consistent condition analysis and a reliable decision making process.

Table 4 in (Žnidarič A: “HeRoad Deliverable 2.1) summarises quality assurance practices in different European countries related to bridge condition and safety assessment ((ATKINS, 2009), (NCHRP Synthesis 375, 2007), (IABMAS, 2010)).

As an example of good practice, Figure 12 illustrates the control system that the Finnish Road Administration applies in order to ensure quality of bridge inspection information.

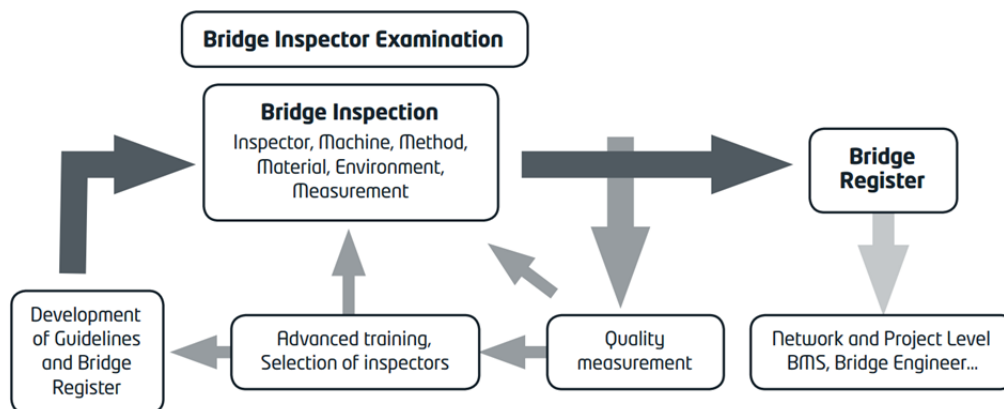


Figure 12 Control system of the bridge inspection system in FinnRA (ITSP, 2010)

5.6.3 Equipment

Equipment management is mainly linked to inspections and parameters that can be measured. These parameters are mainly linked to retroreflectivity that is well described in the literature and automated monitoring devices exist and are commonly used (such as Ecodyn).

Inspection methodologies exist but following the interviews, a need to harmonize what is checked, how is it recorded and what are the expected qualifications / competences / skills for the personnel conducting such inspections, was identified.

Personnel certification can be formalized and a certifying body can perform a conformity assessment, this is covered by ISO/IEC 17024:2012, Conformity assessment – General requirements for bodies operating certification of persons. Such a standard can be used to help organizations that certify individuals in a variety of occupations and professions protect the integrity and ensure the validity of individual certification programmes.

6 Road networks across Europe

6.1 Road networks

It has been found that different condition measurement regimes may be applied on roads with different classification, but this is not necessarily consistently applied across nations. For example a regime applied across all road classes in one country may be limited to only the highest class of roads in another. One objective of HeRoad has been to investigate how the regimes identified in the project could be applied more widely, and in particular on different classes of road in Europe, including lower volume (or in our terminology lower classification) roads. However, before doing this it is necessary to suggest a way of defining a common classification system. The COST 325 project (COST 325, 1996) proposed the following definitions:

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.

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.

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.

In addition to these network definitions, we have also considered one further network:

Tertiary road network: Tertiary roads are roads of local importance; low traffic loading; very low percentage of heavy vehicle traffic, sometimes unsuitable for HGV traffic; single carriageway road, sometimes only single lane width, junctions at grade; low design speed etc. This network can include unbound roads.

We have attempted to apply these definitions of road types in the network classifications used in each country (for example in the UK the Motorway and Primary road network is given the classification “M” and the Other primary road network “A” etc.) as shown in Table 2 Road network definitions. Note that this requires a certain amount of generalisation and assumption regarding the roads. However, it does simplify the discussion of how different measurement regimes could be applied across road types.

Table 2 Road network definitions

Country/network	Motorway and Primary road network	Other primary road network	Secondary road network	Tertiary road network
Austria	Class A (“Autobahnen und Schnellstraßen”): Motorways(Autobahn) and expressways, managed by ASFINAG	Class B (“Landesstraßen B”): Federal roads, owned by province	Class L (“Landesstraßen L”): Provincial roads, owned by province	Local roads, owned by municipalities
Belgium (Flemish region)	Main Roads, with a connecting function on international level (motorways) Primary roads (Cat. I) with a connecting function on regional level (motorways, 2x2 or 2x1 roads with separated lanes) Owned and managed by the Flemish Region	Primary Roads (Cat. II) with a collecting function on regional level (2x2 or 2x1 roads with separated lanes). Owned and managed by the Flemish Region	Secondary Roads with a connecting or collecting function on local level (2x2 or 2x1 roads with or without separated lanes) Owned by the Flemish Region and managed by the Flemish Region or the Provinces	Local Roads enabling access to the network (small roads without lane separation) Owned and managed by the Provinces or the Municipalities
Finland	Class I (Valtatiet) Main road 1 st class Owned by the NRA	Class II(Kantatiet) Main road 2 nd class Owned by the NRA	(Seututiet) Regional roads Owned by NRA	Class Pt (Yhdystiet) Connecting roads Owned by NRA?

Country/network	Motorway and Primary road network	Other primary road network	Secondary road network	Tertiary road network
France	Class A and RN: Autoroutes (motorways) and Routes Nationales Owned by NRA	Class RD and R: Routes Départementales Owned by Départments	Class C: Communal roads Owned by Communes	Class C: Communal roads outside of towns and cities Owned by Communes
Germany	Class A: Motorways (Autobahnen) Owned by NRA	Class B: Federal roads Owned by NRA	Class L: Regional roads Owned by Bundesland	Class K Local roads Owned by Kreis, Gemeinde
Ireland	Class M and N: Motorways and National Primary Routes Owned by NRA	Class N: National Secondary Routes Owned by NRA	Class R and Class L Primary, defined as being ≥4m wide: Regional and local roads Owned by NRA	Class L Secondary and Tertiary: Local Secondary (<4m wide) and Tertiary (cul-de-sac and other minor) roads Owned by NRA
Lithuania	Class A: State Main Roads Managed by the Latvian State Roads		Class P Regional Roads Managed by the Latvian State Roads	Class V Local roads Managed by the municipalities

Country/network	Motorway and Primary road network	Other primary road network	Secondary road network	Tertiary road network
Netherlands	Class A, Motorways Class N, Part of National road network Owned by NRA	Class N, Rest of National road network Owned by NRA	Class ??, Regional Roads Owned by municipality	Class ??, Local Roads, Owned by municipality
Norway	Class E: Stamveg network Owned by NRA	Class Rv: National roads Owned by NRA	Class Fv: County Roads Owned by municipalities	
Slovenia	Class AC and HC: Motorways and expressways Managed by DARS (Motorway Company of the Republic of Slovenia)	Class G1 and G2: Main roads Managed by DRSC (Slovenian Roads Agency)	Class R1, R2, R3 and RT: Regional roads Managed by DRSC (Slovenian Roads Agency)	Class LC: Local roads Owned and managed by local municipalities
Sweden	Class E and Rv National roads (including European highways) Owned by NRA	Class Plv Primary county roads Owned by NRA	Class SOT Secondary and tertiary county roads Owned by NRA	Class private and other Private roads, owned by local authorities
Switzerland	Class N National Motorways and Owned by the NRA	Class N: Principal routes, national highways Owned by NRA	Class Kantonsstraße Regional roads Owned by Kanton	Class Local Municipal roads Owned by local authorities, private roads

Country/network	Motorway and Primary road network	Other primary road network	Secondary road network	Tertiary road network
UK	Class M and A: Motorways and Strategic roads Owned by NRA (Highways Agency)	Class A: Principal Roads Owned by local authorities	Class B and C: Classified local roads Owned by local authorities	Class U: Unclassified local roads Owned by local authorities

6.2 Low volume roads and low volume road management

The low volume road network is estimated to be 80% of the world's transportation infrastructure (Tingle and Jersey, 2007). Internationally, roads with a traffic volume of up to 2000 vehicles per day are denoted as low volume roads (AASHTO, 1993). In many parts of Europe a more stringent definition is used; usually between 500 and 1000 vehicles per day. The majority of these roads are unpaved. In Sweden, roads with a traffic intensity above 250 vehicles per day, or more than 125 vehicles per day for roads with boundary settlements (i.e. houses along the road), should be paved to limit disturbance from dust emission.

In all the Nordic countries, unbound or thinly sealed road surfaces are common. These types of road pavements are usually constructed from one or more layers of crushed rock material, laid on the subgrade soil. The surface of these pavements consists of either an unbound layer or a thin bituminous seal. In both cases, the unbound layers represent the main structural strength of the pavement. (Dawson and Kolisoja, 2006).

In Sweden, the low volume road network includes the following types of roads:

Private roads (which also includes forest roads),

Private roads eligible for grants,

Municipal and state public roads.

Private roads with government grants must be kept open to the public. A Government grant is sought from the Swedish Transport Administration and works as compensation since the private roads are open for public use and thus provide an important complement to the national road network. Most private road communities only have a few kilometers of road network and the management of these roads is done by the property owners themselves or by hired local contractors. (Blomkvist, 2010)

Low volume roads play important social and economic roles. These roads provide the ability for people to live and work in rural areas and they provide access to leisure areas. The maintenance of these roads, therefore, helps to ensure traffic safety and quality of life as well as low vehicle operating costs. Low volume roads have low traffic intensity but it may be noted that it is the same people who often use the roads and therefore incur increased operating costs and reduced comfort. The traffic volume of these roads is also often higher than what they were designed for and they are also often subjected to more heavily laden vehicles than they were intended to bear (Gallego *et al.*, 2008).

The road condition will also influence road users' behavior on the road, e.g. forcing a reduction in speed or averting movement, and the number of accidents that occur. An American study, on the risk of accidents on low volume roads (annual daily traffic < 2000), has shown that the number of accidents on paved low volume roads decreases with decreasing road width, enhanced roadside areas and flatter surrounding terrain (Zegeer *et al.*, 1994). On gravel surfaced roads, the number of accidents increases with increasing road width, which is probably explained by higher speeds on wider roads. However, the study showed that the risk of accidents did not differ between the paved road and the gravel surfaced road for traffic volumes of up to 250 vehicles per day. On roads with a traffic volume of more than 250 vehicles per day, the risk of accidents was lower for paved roads. This means that from a traffic safety point of view, it is beneficial to pave roads that have an annual daily traffic greater than 250.

Previous research in the area of low volume roads focussed on condition measurements and reinforcement, particularly methods for these. However, there is not much research on the

actual road network status, degradation models and life-cycle costs published. Degradation of low volume roads is more complex than on heavy trafficked roads where traffic is the most important parameter. For low volume roads, there is a longer time horizon as well as the fact that several parameters, such as the aging of the pavement and excavation of streets, interact.

On the paved low volume roads, road users are bothered most by potholes, unevenness and poor pavement repairs (Persson, 2000). On gravel roads, the corresponding types of defects are potholes, corrugations and frost damages. These types of defects, on paved as well as gravel roads, also cause most damage to vehicles. According to tests performed by Granlund (2008), the worst road surface unevenness is found on low volume roads. Unevenness is often caused by subsidence, usually at culverts. The worst bumps on the road exposes truck drivers to spinal cord compressions of over 0.5 MPa, even at speeds as low as 40 km/h. This level represents a health risk according to ISO 2631-5.

Operation and maintenance of low volume roads in the Northern Periphery can generally be divided into four critical areas (Saarenketo, 2006). These four areas are winter operation, management of the functional condition of the road during the period when the ground is free from frost, management of the road's structural condition and management during the spring thaw period. As an addition, in the future a fifth area may be "environmental condition", as mentioned in recent EU statements.

In Europe, the average temperature has increased by nearly 1°C in the last century (region.<http://europa.eu>). This has already led to changes in the amount of precipitation received in different regions. Some regions have received more rain and snow whilst others have been more subjected to drought. The most vulnerable regions are southern Europe and the Mediterranean Basin, mountain regions, coastal zones, densely populated floodplains, Scandinavia and the Arctic. In the future, the amount of precipitation, especially in the form of rain, will increase, in the entire Northern Periphery (Hudecz, 2012). By seeing how the roads are damaged in today's climate and at today's extreme weather, it is possible to predict how they will react to future climate change. Between the years 1995 and 2002, 200 observations of road damage caused by precipitation and high flows were recorded, solely in Sweden (SRA, 2002). Of these, 50% were washed away roads, 25% flooded roads, 20% landslide, and 5% flushed bridge supports. Ongoing research aims to develop forecast methods, such as development of sensors for sensing groundwater pressure and pore pressure, in the hope that these will provide reliable analyzes of soil stability condition to anticipate subsidence and landslides (Holgersson *et al.*, 2007; Nordlander *et al.*, 2007).

The structural condition of the road is the most critical parameter for the asset value of the low volume road network. Many factors affect the structural condition of a road; such as the quality of the bound material, the quality of the unbound layers, the quality of the subgrade material, and the quality of the drainage system (Saarenketo, 2006). For example, a drainage system in poor structural condition can cause sudden accessibility problems, especially after heavy rain, and potentially erosions. (Berntsen and Saarenketo, 2005)

The life length of a road increases significantly when the drainage is improved. Calculations have shown that the life length of a road construction increases by a factor 2.2 to 2.6 when the drainage system is improved from poor to good condition (Berntsen and Saarenketo, 2005). Thus, life cycle costs (LCC) calculations show that it is profitable to keep drainage in good condition. If the pavement's life length can be doubled and the discount rate is 4%, the drainage system may cost 8,400 €/ km every five years and life cycle costs would still be longer than without renovation of the drainage system. This means that even more expensive drainage improvements than just ditch cleaning can be used.

The structural condition of the road also affects accessibility for freight transports and is therefore of great importance to the forest industry. Every year about 20 000 km of roads in Sweden get frost restrictions, whose cost for forestry companies solely is estimated to be between 80 and 100 million Euro per year (Arvidsson and Holmgren, 1999; SRA, 2003).

Therefore, the most viable solution, to address the problem of reduced bearing capacity, is to reinforce weak sections. However, this requires that sufficient resources are available to take long-term measures. Major problems have arisen when the road section has been reinforced with a design that is too weak (Aho and Saarenketo, 2006).

New technologies will play a major role in maintenance and improvement of the aging low volume road network. In addition, improved focus is required, i.e. focus on road user needs, timing, location, and problem diagnosis and correct procedures for maintenance and reinforcement. In order to create a better focused system, where more accurate information is handled, the systems need to be designed for working with an accuracy of 1-10 meters instead of 20-100 m sections of road as currently used. Today's positioning systems (GPS) are able to handle this. In recent years there has also been a rapid development of modern sensor technology, e.g. laser scanners reproducing the shape of the road surface. When this effectively can be combined with GPS and wireless communications and information technology, many new opportunities for more effective management of low volume roads will open. (Saarenketo, 2006)

By recording road condition, vehicle load, traffic intensity, road hazards, etc. of each road section directly on a map, e.g. a GIS map on a web site, the actual status of the road network can be clarified. GIS maps also provide possibility for planning and coordinating various maintenance activities in different parts of the network, which will make maintenance cheaper and help keeping the road condition at an acceptable standard. The method can also be used to verify that maintenance measures have the desired effect. With a simple survey method, data collection can occur relatively frequently. (Johansson *et al.*, 2007)

The limited resources for low volume roads force low volume road managers to focus on minimizing life cycle costs (LCC). When it comes to low volume roads, it is very difficult to find economic motives to justify good condition of these roads. A major improvement in road condition on low volume roads gives a very small reduction in socioeconomic costs as compared to a slight improvement on heavy trafficked roads. Socioeconomic models do not involve costs and benefits of impacts on social life and industrial production. In fact, several reports from the World Bank show that the general use of cost-benefit analysis for investments in infrastructure is insufficient to provide an accurate profitability. The reason for this is that the benefits of increased social welfare, as well as improved opportunities for access to education, healthcare and other services are not included. This means that additional methods and models are required to justify a good standard also on low volume roads. These roads must have a minimum acceptable standard, so called "shame limit", which at least allows people to get to and from home/work safely. A minimum acceptable standard should be based on scientifically based analyses. However, such standard is lacking today. (Johansson, 2006; SRA, 2008)

7 Findings and recommendations from state of practise

In this chapter the key base parameters found in the state of practise reviews (Benbow E., Wright A., 2012, Casse C., van Geem C., 2012, Haider M., Gasparoni S., 2012, Žnidarič A, 2012) are prioritised and presented (chapter 7.1).

A case study from the UK on extending automated road carriageway condition surveys to the Tertiary Road Network is also presented.

In chapter 7.2 possible and suggested improvements to those key parameters are presented. Finally in chapter 7.3 other parameters that are only measured in few countries or new developments are presented. In chapter 5 a deeper discussion on the expectations and measures for each functional area; service quality, safety and durability is done.

7.1 Key base parameters

Reviewing stakeholder expectations and what can currently be practically measured on a network level, it is possible to determine the key base parameters that any NRA, wishing to determine the condition of their network should have access to. These are listed per asset in the following table, along with their suggested priority, which has been determined by consideration of their current use, practicality and accuracy.

Table 3 Key condition parameters, listed in order of priority

Asset	Parameter	Measurement needed for this	Priority*			ES? †	Ind'r**	Comments
			U	O	N			
Pavement	Surface friction	Skid resistance	H	H	M	[1]	S	Complicated European standardisation situation, where presently 15 equipment's/ methods are considered. A common proxy method or a harmonized friction index would be preferred. Parameter not measured in all countries. The parameter is only and directly aimed for safety.
Pavement	Rutting	Transverse profile	M	H	L	[2]	D, S	A common European definition of rut depth is needed. The parameter is directed to durability but also in some countries to safety. This needs to be clear when using the parameter.
Pavement	Ride quality	Longitudinal profile	H	M	L	[3]	SQ, S, D	International Roughness Index (IRI), wave band indices and weighted longitudinal profile (WLP) are used as ride quality measures today. Studies have indicated that internal noise and other factors should be included in ride quality but no existing measure includes this. A function for the costs associated with ride quality is missing.
Pavement	Severe localised defects	Longitudinal profile	M	M	M		SQ, S, D	Measure not implemented by many countries. May need more than one measurement line for this to be useful

Asset	Parameter	Measurement needed for this	Priority*			ES? †	Ind'r**	Comments
			U	O	N			
Pavement	Edge deformation	Transverse profile	M	M	L		SQ, D	Measure not implemented by many countries. Only needed on roads for which this is appropriate
Pavement	Pavement strength	Deflection	L	L	L		D	This is an important parameter that is needed to judge the road quality. However, it is missing from most routine survey regimes. Traditional measurement methods are slow speed and therefore have safety issues, as well as being time consuming. Traffic-speed measurement is an emerging and not yet fully proved technology.
Pavement	Visual deterioration, including cracking		L	L	L		SQ, S, D	Manual surveys are very time consuming. Both automatic and manual surveys have issues with consistency/accuracy. The state of art using image detection may need to be reconsidered. Maybe a proxy method using 3D roughness could be an alternative?
Structures	Condition rating	Inspections	L	H	M		SQ, S, D	Conditional rating is the key result of conditional assessment. It is based on the inspection results and is generally presented in terms of cumulative or highest condition rating (see chapter 3 of deliverable D2.1).
Structures	Safety index, Rating factor, Probability of failure	Detailed inspections, Material testing Traffic measurements Structural monitoring	H	H	L		SQ, S, D	Structural safety, as the second key parameter of structural assessment, is dealt with in several different ways. Some countries use the design rules, original or modified, and only some countries have implemented the assessment codes that imply true behaviour of structures obtained with measurements and monitoring (see chapter 4 of deliverable D2.1).

Asset	Parameter	Measurement needed for this	Priority*			ES? †	Ind'r**	Comments
			U	O	N			
Equipment – Road Signs	Visibility	Retro-reflectivity	H	H	L		SQ, S, D	The signs should always be visible
Equipment – Road Signs	General Condition	Inspection	M	M	L	[7]	SQ, S, D	Condition is important but classified as medium for owners and users because the visibility is the main characteristic. The general condition of this asset will be important in case of an accident, the condition should not aggravate the consequences of an issue.
Equipment – Lighting	Condition	Inspection	H	H	L	[6]	SQ, S, D	Condition includes the bulb and the general condition.
Equipment - Markings	Visibility	Retro-reflectivity	H	H	L	[4]	SQ, S, D	
Equipment - Markings	Erosion	Percentage area of marking still existing	H	H	L		SQ, S	
Equipment – VMS and other technologies	Condition	Inspection and fault logging	M	M	L		SQ, S	The classification as “medium” for owners and users is coming from the level of use of the VMS. The VMS can be used as a complimentary item or can be used to deliver compulsory directives; therefore the priority will be variable depending on the use.
Equipment – Restraint	Condition	Inspection	H	H	M	[5]	SQ, S, D	

Asset	Parameter	Measurement needed for this	Priority*			ES? †	Ind'r**	Comments
			U	O	N			
systems								
Environment	Noise emission of pavements	Measurement of SPB and CPX levels, measurement of sound absorption	L	M	H	***	E, SQ	***SPB (ISO 11819-1) and CPX (ISO/CD 11819-2) are used in acoustic condition monitoring and approval testing in different variants in some countries, characterization methods are not harmonized and often linked to the different environmental noise calculation procedures
Environment	Sound insulation and sound absorption of noise barriers	In-situ measurement of sound insulation and absorption	L	M	H		E, SQ	Determination of the acoustic performance of noise barriers types are currently performed in the laboratory with production samples. In-situ monitoring is limited to visual inspections of the general condition. In-situ acoustic measurement methods (CEN/TS 1793-5, EN 1793-6) are available.
Environment	Pavement influence on fuel consumption	Measurement of rolling resistance of pavements	M	M	M		E	Reduced fuel consumption leads to reduced greenhouse gas and air pollutant emission. However, currently no measurement method for monitoring is available.
Environment	Removal of water and ground pollutants	Performance of the drainage system	L	M	H		E	The drainage system is the key component for the efficient and safe removal of these pollutants. Monitoring practice varies from visual inspections to occasional performance testing

*Priorities given for each stake holder – Users, Owner/Operators and Neighbours, H=High, M=Medium, L=Low

†Does a European Standard exist?

**What indicators might this parameter be used for? Service Quality (SQ), Safety (S), Durability (D), Environmental (E)

[1] prEN 13036-4:2003 “Road and airfield surface characteristics — Test methods — Part 4: Method for Measurement of Slip/Skid Resistance

of a Surface. The Pendulum Test“

[2] prEN 13036-8:2008 “Road and airfield surface characteristics — Test methods — Part 8: Determining parameters or indicators for transverse evenness: Measurement method“

[3] prEN 13036-5:2005 “Road and airfield surface characteristics — Test methods — Part 5: Determination of longitudinal unevenness indices“

[4] EN 1436+A1 - Road marking materials - Road marking performance for road users, DIN EN 1790 Road marking materials - Preformed road markings, CSN EN 1424 - Road markings materials - Premix glass beads, SN EN 1790 - Road marking materials - Performed road markings, CSN EN 1871 - Road markings materials - Physical properties

[5] EN 1317-1 Road restraint systems - Part 1: Terminology and general criteria for test methods, EN 1317-2 Road restraint systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets, EN 1317-3 Road restraint systems - Part 3: Performance classes, impact test acceptance criteria and test methods for crash cushions, EN 1317-4 - Road restraint systems - Part 4: Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety, EN 1317-5 Road restraint systems - Part 5: Product requirements and evaluation of conformity for vehicle restraint systems, CEN/TR 1317-6 - Road restraint systems - Pedestrian restraint system - Part 6: Pedestrian Parapet

[6] EN 13201-3 - Road lighting - Part 3: Calculation of performance, EN 13201-4 - Road lighting - Part 4: Methods of measuring lighting performance

[7] EN 13422 - Vertical road signs — Portable deformable warning devices and delineators — Portable road traffic signs — Cones and cylinders

Applying key base parameters to different road networks

The need for the key parameters, listed in Table 3, varies, depending on the road network being considered, and the method used to measure the parameters may also need to be tailored to the road network: Whilst traffic-speed machine survey may be the best practice for nationally important road, such as motorways, it may not be practical, or value for money, to use such surveys on the Tertiary road network.

Table 4 shows which road networks it would be appropriate and/or practical to measure the key parameters on and case studies are given, to discuss measurement regimes and pavement asset management used currently on the road networks of lower national importance.

Table 4 Road networks for which key base parameters are applicable

Asset	Parameter	Current measurement suitable on*...				Comments
		M&P	OP	S	T	
Pavement	Surface friction	Y	Y	Y	N	The devices currently used to measure skid resistance at traffic speed are relatively large and would be impractical to use on most of the roads in the Tertiary network.
Pavement	Rutting	Y	Y	?	?	Rutting is not a key defect on Secondary and Tertiary roads.
Pavement	Ride quality	Y	Y	Y	Y	Traffic speed surveys may not be suitable on the Tertiary road network – see case study below.
Pavement	Severe localised defects	N	Y	Y	Y	These defects do not often occur on the major roads and if they do, tend to develop very quickly, due to the high traffic loading on these roads. Thus, they would not be efficiently identified by infrequent automated surveys. Traffic speed surveys may not be suitable on the Tertiary road network – see case study below.
Pavement	Edge deformation	N	N	Y	Y	Secondary and Tertiary Roads are relatively narrow the poorly supported edge is damaged by heavy vehicles
Pavement	Pavement strength	Y	?	?	N	Although routine pavement strength measurements have been demonstrated on M&P roads, there may be a need for development of the equipment to cover other primary and secondary networks, or slow-speed technology could be used As with skid resistance, it is not practical or economical to measure deflection on the Tertiary road network.
Pavement	Visual deterioration, including cracking	Y	Y	Y	Y	All road networks
Structures	Condition rating	Y	Y	Y	Y	All road networks
Structures	Safety index	Y	Y	Y	N	Although suitable for all road networks it is unlikely that these procedures

Asset	Parameter	Current measurement suitable on*...				Comments
		M&P	OP	S	T	
	Rating factor Probability of failure					would be used on tertiary roads.
Equipment – Road Signs	Visibility	Y	Y	Y	Y	As far as safety is concerned, it's compulsory to consider these assets as crucial to monitor. The frequency should of course be adapted following the traffic.
Equipment – Road Signs	General Condition	Y	Y	Y	Y	As far as safety is concerned, it's compulsory to consider these assets as crucial to monitor. The frequency should of course be adapted depending on the traffic.
Equipment – Lighting	Condition	Y	Y	Y	Y	As far as safety is concerned, it's compulsory to consider these assets as crucial to monitor. The frequency should of course be adapted depending on the traffic.
Equipment - Markings	Visibility	Y	Y	Y	Y	As far as safety is concerned, it's compulsory to consider these assets as crucial to monitor. The frequency should of course be adapted depending on the traffic.
Equipment – VMS and other technologies	Condition	Y	Y	N	N	As far as safety is concerned, it's compulsory to consider these assets as crucial to monitor. The frequency should of course be adapted depending on the traffic. VMS are rarely found on secondary or tertiary road networks
Equipment –	Condition	Y	Y	Y	Y	As far as safety is concerned, it's compulsory to consider these assets as

Asset	Parameter	Current measurement suitable on*...				Comments
		M&P	OP	S	T	
Restraint systems						crucial to monitor. The frequency should of course be adapted depending on the traffic.

* M&P Motorway and Primary road network, OP Other Primary road network, S Secondary road network, T Tertiary road network

Case Study: Extending automated road carriageway condition surveys to the UK Tertiary Road Network

Initial research into the feasibility of extending routine traffic-speed condition surveys to the whole of the UK Tertiary road network was commissioned by the Department for Transport. This investigated how current equipment could be used on this network. The work concluded that the survey would not be practical because productivity would be very low and there would be risk of continued costs arising from minor body work repairs to the vehicles as a result of narrow road widths and other manoeuvrability issues (Kennedy, 2006). The Department therefore took the view that it would be neither practical nor cost-effective to extend current automated carriageway condition surveys onto all Tertiary roads.

Further research was therefore commissioned with the objective of determining how automated road carriageway condition surveys could be modified and extended to Tertiary roads in a practical and cost effective manner (Gallagher et al., 2009). The research proposed a survey regime for the Tertiary road network which combined manual and automated methods. It was suggested that a walked coarse manual survey would be the most appropriate survey for the majority of Tertiary roads in built-up areas. A driven coarse manual survey was proposed for those Tertiary roads where automated surveys or walked surveys were not practical or cost-effective. However, for roads where machine surveys are considered both practical and cost effective it was recommended that automated traffic-speed surveys be carried out. However, it was noted that current automated carriageway condition surveys had been developed for primary roads and did not always deliver the information of interest for Tertiary roads. Therefore it was suggested that automated traffic-speed surveys of Tertiary roads should be carried out to a specification developed to deliver information on the key defects required by engineers on the Tertiary network. A draft specification was proposed.

However, the research also recommended that the need for and type of regular condition surveys (be they walked, driven, manual or automated) should be determined locally, depending on each authority's particular requirements for asset management and maintenance management. It should also be based on local needs and capabilities, including levels of resource, and should reflect the physical characteristics of the network and the practicalities and economics of carrying out the survey in the local area.

Case Study: Use of visual inspections to evaluate a quality index for local road sections to be used in a network pavement management system

In Belgium, few municipalities use pavement management systems. BRRC and KOAC-NPC have developed a network PMS specially designed for their type of network. The model is based on the experience gained by both partners, BRRC bringing the knowledge on visual inspections and quality indices linked with specific evolution laws and KOAC-NPC bringing the know-how on the design of software based on the CROW methodology for visual inspections and road network quality assessment. ViaBEL software is the outcome of this partnership and results were presented during the EPAM congress in Malmö (ViaBEL, 2012).

Visual inspection is one solution for network pavement quality assessment for local and rural roads, the main advantages being the facility to perform the inspection, the relatively fast speed and accuracy of the method. Specific training is necessary for the inspectors and is based on a list of predefined defects dependent on the type of pavement. For each section a quality index is issued at the end of the survey. This quality index is input in the software and different maintenance scenarios are described and illustrate the evolution of the network quality and the related costs for the coming years for each section and for the whole network. This tool can then be used at different levels: budget, political strategy, work planning.

This tool is a modern version of methodologies developed by BRRC during the last thirty

years and this actualisation reflects the needs of simple inspection methodologies in order to manage local roads.

The approach consists of a dedicated visual inspection method that delivers a “visual index” for which “evolution models” have been developed over the years. These models take several parameters into account: type of road surface, intensity of heavy traffic loads. The objective of the visual inspection is to provide information to facilitate the decision process in pavement management. The inspector reports on the existence and extent of predefined defects without indication on the possible causes. Different weights are given to the predefined defects. Defects are periodically surveyed for every predefined road section; these are defined by logical boundaries for maintenance measures (homogeneity, crossings etc.). The approach compares several maintenance strategies applied to the whole road network. Each strategy envisions a selection of maintenance measures. Index thresholds determine whether or not a particular type of maintenance measure can be applied to a section. Based on the evolution models and thresholds, more intensive maintenance interventions may be considered. The BRRC approach proposes an “economic evaluation” in order to help the road manager to clarify the relationship between budgets and quality preservation, or between quality enhancement and budget needs. Average costs are attributed to each type of maintenance intervention. The evolution models represent an “average” behaviour, visual inspections performed every two or three years allow to fine tune the predictions. Based on the practical experience of KOAC•NPC with their PMS system that follows the CROW directives in The Netherlands, KOAC•NPC have now implemented the BRRC approach in the “ViaBEL” software.

7.2 Suggested improvements to measurement of key parameters

As discussed in chapter 5, the measurements of skid resistance, and transverse profile are well developed in most countries and, whilst the approach taken may differ slightly, the underlying principles and techniques are generally similar for all countries included in the consultation.

However, several different approaches are used to determine ride quality, whilst severe localised defects and edge deterioration are not measured in many countries, and the measurement of cracking has issues with accuracy, whether collected through manual or automatic methods. Therefore, these parameters need improvement, in order to meet the needs of any NRA wishing to use this data, and satisfy stakeholder expectations. Suggestions for these improvements are given in Table 5, along with an indication as to how much work would be needed to implement them and thus whether they could be implemented in the short, medium, or long term.

Table 5 Improvements to key condition parameters and measurement regimes

Improvement	Comments
Pavement: Measurement of severe local defects (Short term)	Users are affected by the general ride quality of roads but their biggest concern is the presence of severe local defects e.g. potholes, poor bridge joints. Since all countries consulted measure longitudinal profile already, implementing a measure, such as Germany's WLP, the UK's Bump Measure or Swedish Local Unevenness measure, would be relatively simple. However, additional, or different measuring equipment would be needed if it was found that multiple measurement lines improved the usefulness of the data.
Pavement: Edge deterioration (Short term)	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. Countries who routinely survey Other Primary and Secondary roads for transverse profile may find benefit in implementing a measure for this defect e.g. those used in Sweden, Norway, or the UK.
All Assets: Quality Assurance (Short term)	<p>The data should be treated as a very valuable asset that needs to have enough resources to be managed, since it makes up the essential part of a functioning asset management system.</p> <p>To reach a trans-European asset management framework, the measurements need to be standardised or at least harmonised. This can only be achieved by firstly agreeing on common indicators, requirements how they shall be measured and finally how they can be quality approved. A number of initiatives have been conducted, are on-going or proposed, to harmonise indicators. Very little has been done to have common European quality approval procedures, despite the internal data quality control in an organisation being so important. Therefore, HeRoad recommends that effort is made to develop a common European quality assurance concept including selection of reference methods to be used in the process.</p>

Improvement	Comments
Pavement: Survey frequency (Medium term)	There is a great range of survey frequency across Europe, varying from annual surveys to once every 5 years. It would be beneficial to determine what the optimal and minimum frequency should be for all parameters measured, on different road types.
Pavement: Visual condition (Long term)	There is concern over the consistency and accuracy of the data obtained from current automatic visual condition surveys. 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.
Pavement: User comfort (Long term)	The routine longitudinal profile surveys provide a good source of information for estimating user comfort but the surveys provide different comfort parameters in different countries. 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. This would ensure that the ride quality parameters used do actually relate to user perception and thus be used to better meet the users' needs in this area. The importance of the effect of surface conditions on user perception has been investigated in a driving simulator study showing that a combination of all senses; sound, vibrations and seeing is important. E.g. internal noise is important and could be measured with a proxy indicator built from macrotexture parameters. When comparing or replacing objective measured data with road user opinions care must be taken how to evaluate and judge. In most cases the results are not comparable but complementary only.
Pavement: User effects (Long term)	The effect from road unevenness on heavy vehicles differs from those on private cars. Indicators reflecting this are suggested to be developed. One possibility is the Australian HATI, Heavy Articulated Truck Index. This is an index built on the same principles as IRI but with other vehicle parameters (Austroads, 2012).
Structures Visual inspection and condition assessment (Medium term)	While bridge and tunnel inspection practices in Europe are similar, the condition assessment methodologies, based on inspections, are incoherent. They take similar factors under consideration, but present different outcomes. Furthermore, a similar rating might have different meaning due to different damage tolerances that are used in these systems. Inspection/monitoring practices also differ considerably from one country to the other. The future may result in higher unification, not only due to likely administrative actions, but thanks to further development of BMS software that might force bridge owners to use more coherent condition assessment systems. Future should also bring more efficient training for inspectors and improved quality control of the inspection results.

Improvement	Comments
Structures Structural safety (Medium term)	<p>Not all countries have assessment codes or recommendations for highway structures that apply modern rules for optimised safety assessment of bridges that includes realistic information about structural capacity, true behaviour of structures (obtained with measurements and monitoring) and actual loading. Such assessments prevent from suggesting too severe rehabilitations and thus results in more optimal use of budgets.</p> <p>The future will likely bring better implementation of measurement and monitoring results in structural analysis, among others true traffic characteristics which affect the structural safety considerably.</p>
Environment Noise emission of pavements (Medium)	<p>The combination of the SPB and CPX method into a harmonized European pavement noise assessment method would greatly enhance the knowledge transfer and help to open the European market for low-noise pavement solutions. This method should also be compatible with future common environmental noise calculations method developed by the CNOSSOS-EU project. This would also help to build databases for the long-term acoustic performance of pavements.</p>
Environment Acoustic performance of noise barriers (Medium)	<p>The in-situ measurement methods of the EN 1793 series were investigated in the QUIESST EU project and can be used for acoustic monitoring of noise barriers in the installed condition. Complementing current visual inspections with acoustic measurements will enable the monitoring of their acoustic performance over time.</p>
Environment Pavement influence on fuel consumption (Medium term)	<p>Pavement rolling resistance measurement methods suitable for long-distance monitoring would help to quantify the pavement contribution to fuel consumption. A complementary alternative would be modelling on the basis of other parameters, e.g. texture or unevenness. Rolling resistance of pavements has been or is investigated in the ECRPD, MIRIAM and MIRAVEC projects</p>
Environment Drainage system (Short term)	<p>Regular monitoring of the actual performance of drainage systems can help to reduce water and ground pollution and is a significant improvement over simple visual inspection of the components.</p>

7.3 Other improvements

Whilst the key condition parameters can be considered to be the essential parameters needed by any road owners wishing to know the condition of their network assets, there are many others that are measured currently in some countries, or could be used to provide a better indication of asset condition. For example, rutting is currently used as a proxy to indicate the depth of water that could potentially sit on the pavement's surface. However, a more accurate water depth calculation would include measurements of road gradient, crossfall, curvature, and surface texture, in addition to rutting.

Table 6 Improvements to condition measurement

Improvement	Comments
<p>Pavement: Vehicle handling models (Medium term)</p>	<p>The use of vehicle handling models to identify lengths where there is a high risk of accidents would improve safety assessment on the European road network. Existing models use measurements currently collected by most countries but these models would need to be proved and implemented, in order to be useful. Alternatively, a new model may need to be developed.</p>
<p>Pavement: Sight lines (Medium term)</p>	<p>Sight lines are not routinely measured and this is likely because it is not usually the changes in the pavement that cause changes to the visibility at a junction. Owners could assess their junctions to identify those at highest risk and to undertake routine monitoring of that subset of junctions. Many countries are already collecting forward-facing panoramic video data, as part of routine traffic speed surveys and its use is increasing. Routine monitoring of the subset of high risk junctions could be achieved using targeted inspection of this collected video data.</p>
<p>Pavement: Probe vehicles (Long term)</p>	<p>As mentioned in Chapter 5, the use of probe vehicles, to measure such parameters as vehicle speed, severe defects and areas of low skid, may be extremely beneficial. It's possible that this technology may be used to measure other parameters also.</p>
<p>Pavement: Water depth and splash spray (Long term)</p>	<p>The development of a 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, to deliver a more practical network level measure. However, this may require significant work to assess the models, involving collection of measurement data and reference water depth or splay spray data.</p>
<p>Pavement: Kerb upstands (Long term)</p>	<p>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 currently being used in this way. Thus, investigation would be required into these systems, in order to determine their suitability</p>
<p>Pavement: Fretting (Long term)</p>	<p>Fretting is often difficult to perceive on downward facing images of the road surface, such are used for automatic visual deterioration detection, even by the human eye. Therefore, fretting algorithms have been developed, that use texture data to determine the location of this defect. Assessment of the performance of these algorithms on the most common surfacings found on the European road network would enable more NRAs to implement these algorithms, or realize the need to develop alternatives.</p>
<p>Structures: Weigh-in-</p>	<p>Even the countries that have dedicated bridge assessment codes too often rely on traffic counting when accounting for the traffic loading on</p>

Improvement	Comments
motion (Short term)	bridges. Using weigh-in-motion data would improve this information considerably (available results show that error in traffic load model can easily exceed $\pm 50\%$, if it is not based on weighing of heavy vehicles).

8 New challenges

8.1 Pavements

8.1.1 Climate change

Climate change will affect Europe's cities in different ways. To give an overall impression of the challenge for European cities to adapt to climate change, the European Environment Agency (EEA) has published a series of detailed interactive maps, allowing users to explore data from more than 500 cities across Europe (EEA, 2012).

Whilst the effects may be different, nearly all European regions are expected to be negatively affected by some future impacts of climate change (BBC, 2007):

- Central and Eastern European countries could face less summer rainfall and more frequent heat waves.
- Southern European countries are very likely to see reduced water supplies, lower crop production, more wildfires and health impacts from increased heat waves.
- Northern countries are likely to see milder winters and increased rainfall.
- By 2020, most areas of Europe are likely to see an increased flood risk.

The possible impacts of climate change on pavements include:

- Disruption of the network by extreme weather events (rain, snow, high temperatures)
- Damage to roads through deterioration, deformation and subsidence
- Flooding from rivers, seas and inadequate land drainage
- Severance of routes by landslides and avalanches

For those countries experiencing hotter, drier weather and increased heat waves, there may be an initial increase in rutting on the road networks, including on the lower classes of roads, where it is not usually an issue at the moment. This will lead either to an increase in the importance of this defect, or to new or different rut-resistant materials being used on the networks. These materials may fail through different deterioration processes, to currently used materials, thus increasing the importance of other key parameters.

For those countries experiencing more rain, the accurate measurement or attenuation of splash and spray will become more important as will the measurement of drainage performance. Currently, there are no traffic-speed measurements of water depths but, as discussed in Table 6, it should be possible to model this from parameters (such as gradient, rutting, texture) that are currently measured at traffic speed by most countries included in the consultation.

Already in the UK, there have been incidents of flooding resulting in lengths of the Motorway and Primary road network not being available, for example a recent flooding incident on the A1 near to Catterick in North Yorkshire:

http://www.youtube.com/watch?v=6z6oWToRbrM&feature=player_embedded

Some of these flooding incidents have been blamed, in part, on poor drainage. Current drainage performance measurement technologies are very expensive and very time consuming to use and any routine network-level measurement of drain performance would incur great cost to the road owner/operator. There is emerging technology, however, such as the “Sonic Sewer Survey”, developed by TRL (Harrington, 2010). This is currently being tested on the UK Motorway and Primary road network but if proved to be suitable for routine use, could be implemented on other networks too.

Whilst a number of flooding incidents can be attributed to drainage issues, there are many that are not and to be able to identify and improve road sections vulnerable to flooding would be of great value. Given the vast distances covered by roads, an effective tool to assist in finding the weak sections would be very useful. Thus, the ERA-net Road project, SWAMP (Storm Water prevention -Methods to Predict damage from the water stream in and near road pavements in lowland areas)' focused on methods to predict damage from the water stream in and near road pavements in lowland areas (Hansson et al., 2010). Areas close to roads, that are prone to flooding, were referred to as blue spots in the SWAMP project reports, corresponding to e.g. black spots denoting serious accidents on the road network. The project considered the critical issue of finding the most vulnerable parts of the road network, and how to prepare them for flooding, which included determining the structure and requirements of a model to find blue spots and also to produce guidelines on how to reduce vulnerability to flooding at blue spots.

Milder winters in Northern Europe may also lead to a change in the winter maintenance currently carried in these countries. Also, skid resistance is not routinely measured in Denmark, Finland or Sweden currently, as it is not felt that such a measurement is needed. This is because roads are covered in snow for part of the year, for which users have special winter tyres, then the act of frost and the extra grit brought by snow, makes the roads rough. However, less snow and frost may change the need for skid resistance to be measured.

In the long term perspective the requirement to lower and minimize fuel consumption needs to be met. Some national, European and international initiatives have started to investigate this. The concept MIRIAM (Models for rolling resistance In Road Infrastructure Asset Management Systems) is such an initiative (<http://www.miriam-co2.net/>). In MIRIAM fuel consumption models have been developed that include measurable performance of the pavement, e.g. IRI (International Roughness Index) and MPD (Mean Profile Depth), with both measures giving performance of the unevenness on fuel consumption.

8.1.2 Traffic configuration

To try to reduce the amount of traffic on the road network, and also to reduce the number of unnecessary journeys made, many countries have either implemented, or are considering the implementation of tolling on their main arterial roads. Such schemes are being seriously considered in the UK, with different levels of toll being charged for different vehicle classes and time of day. It is thought that this is likely to change the traffic configuration on the network, particularly for HGVs. Whilst business users, travelling to and from places of work, are unlikely to change their travel habits, casual or leisure users may choose to travel at cheaper times of the day, thus adjusting the distribution of light vehicles on the network at different times of the day. Also, if tolls are introduced that make it cheaper for HGVs to travel at night, then it is likely that a reduction in the number of HGVs traveling during the daytime will be seen.

Models are often used to determine the optimal time to carry out maintenance, particularly on the Primary road network, where maintenance can cause the severest disruption to traffic flow and user delays and pose the most serious risk to road worker health and safety. These models use known traffic configuration to suggest when to carry out maintenance. Thus, the

change in traffic configuration that could happen due to the introduction of tolling will introduce the need to adapt these models and may also change the way that maintenance is planned and carried out. For example, road closures, due to maintenance on the UK motorway network, are usually implemented during the night, since this is when the least number of vehicles are travelling, thus reducing the likelihood of travel disruption and also reducing the risk of injury to road workers.

Change in traffic configuration may also change the way that the road network will deteriorate e.g. the development of rutting may be slower if heavy vehicles travel on the roads during the (generally) colder night time period. This will result in the potential need for condition prediction models to also be updated.

Some countries in Europe allow longer and heavier goods vehicles to travel on their road networks e.g. Sweden. If these were to be introduced to the whole of Europe, this may affect the type of pavements being laid on the road network e.g. the pavements may need to be strengthened and surface types used that are less prone to rutting.

8.1.3 New materials

The introduction of new materials may also pose new challenges to condition measurement and may change which parameters are considered key.

For example, thin surfacing courses (TSCS) have been used in the UK since 1995 and use of these surfacings has resulted in the need for existing standards and specifications to be reviewed. The use of these modern materials has obvious benefits, in that they provide a high performance, rut resistant, low noise and skid resistant layer that supports the high volume of traffic found on the Motorway and Primary road network (IAN157, 2011). However, experience has led to the identification of issues with early life friction and the development of mitigation for this safety issue.

When an asphalt road surfacing is newly laid, the aggregate and mortar are covered with a film of bitumen binder (Roe, 2005). TSCS often have a thicker initial binder film than traditional materials, which may both increase the risks of possible skid-related problems occurring and the time that any effects last. Research into the effect of these increased risks on accidents on the UK Motorway and Primary road network concluded that there is a small increase in accident risk in the initial months after laying TSCS, compared to more traditional asphalt materials. However, the additional accidents were in the "slight" severity category (Greene, 2008) and usually the TSCS offer higher friction throughout the rest of their service life (Roe, 2005) than traditional surfacings. Thus, when resurfacing with TSCS, a further risk assessment is usually carried out, to determine whether grit should be added to the surfacing, to increase friction for the first months of the pavement's life.

Use of new materials may also change the way in which measured parameters are used to estimate pavement properties. For example, a model developed to predict water depth on traditional, negatively textured pavement surfaces, may need to be further developed and changed for positively textured surfaces.

Tests have shown that smaller aggregates give greater friction after polishing and can also offer similar skid resistance to equivalent, larger aggregates (Roe, 2008). The texture depth of a TSCS made using smaller aggregate is, however, much lower. If such small aggregate surfaces are implemented on a wide scale in the future, it may no longer be appropriate to imply skid resistance from texture depth, as is the current practice in a number of countries included in the consultation.

Some countries also predict noise, based on surface type and texture depth. These models will need to be reviewed and possibly updated, to ensure their suitability for noise prediction on any new materials used.

8.2 Structures

A new challenge with respect to the inspection and conditional assessment is that more should be done on quality of the results, which as one of the first steps includes better training of the inspectors. As cooperation between different CEDR member countries increases it would be beneficial if condition assessment results could be unified to provide comparable results. This would allow the future results to be compared between the national administrations and would thus facilitate common transport policies.

New challenge with respect to the structural safety is optimization of assessment procedure which leads to reduction of unnecessary rehabilitation measures (strengthening, replacements). They are extremely costly and, due to the construction sites, substantially reduce mobility and traffic and road workers safety, as well as being sources of severe air pollutions.

While most focus is given to highway bridges and tunnels, there are a lack of information about other highway structures, such as culvers and retaining walls. This also should be changed in future.

8.2.1 Climate change

Climate changes may considerably affect highway structures. Most likely negative influences of climate change related to highway structures are:

- increased frequency and severity of extreme rainfall and high tide events will cause significant flood damage not only to roads, but also to bridges and other highway structures; excessive and accelerated scour may occur; sea level rise may affect highway structures close to the coast through increased tidal and salt gradients, ground water pressure and degradation of materials.
- bridges, especially those with longer spans are susceptible to extreme winds, which may become more frequent and stronger;
- higher temperatures may stress steel in bridges through expansion, increased or restrained movement;
- extreme snow falls may result in higher consumption of salt which will have a negative effect on the durability of highway structures;
- increased ground movement and changes in groundwater would accelerate degradation of materials, structures and foundations of highway structures; the result would be reduction in life expectancy, increased maintenance costs and potential structural failure during extreme events;
- in general, the projected increase in storm activity may increase the cost of maintenance and replacement of highway structures.

8.2.2 Traffic configuration

The main challenge in the area of traffic configuration is how to apply more realistic and optimised traffic loading on structures, particularly bridges. Traffic not only differs from one country to another, as illustrated in Figure 13, which presents the calculated expected load effects (bending moments) from five European countries for 30-m long bridges on motorways (Enright, OBrien, & Dempsey, 2010), but even more within individual countries based on the purpose of the road (urban on transit), traffic density and load enforcement practices. More extensive use of weigh-in-motion measurements in structural analyses has the potential to

considerably optimise remedial measures on bridges, especially strengthening treatments.

A challenge for the European bridge stock, which has an average age of around 50 years, will also be how to sustain the new longer, heavier and more advanced freight vehicles, which may have a modest effect on pavements but could rate many older bridges as unsafe. This must be considered when decisions about increased traffic loadings, often influenced by trucking industry and politics, are proposed.

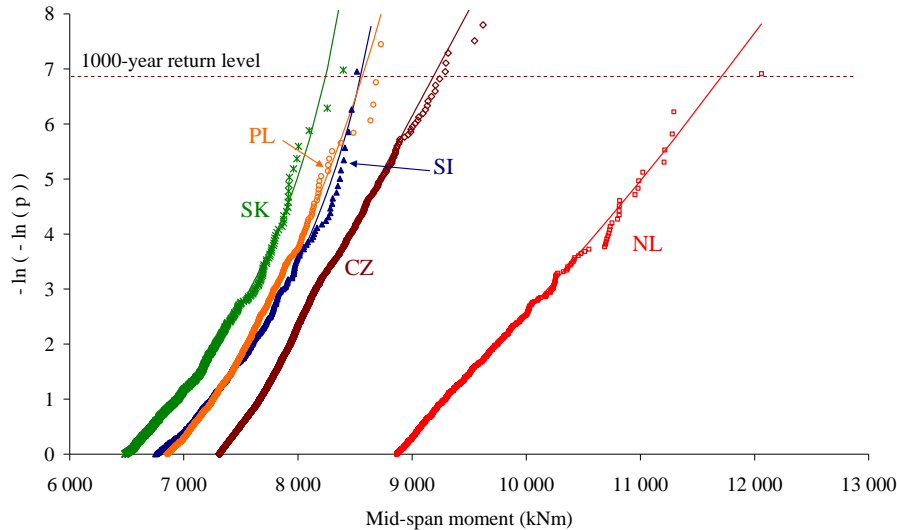


Figure 13 Expected load effects (bending moments) for a 30-m simply supported span based on weigh-in-motion measurements (ARCHES D08, 2009)

8.2.3 New materials

Considerable potentials exist for using new materials in highway structures. Some examples are:

- low alloy steel for price efficient improved durability of reinforced concrete structures,
- ultra high performance fibre reinforced concrete to improve durability of existing structures,
- geotechnical meshes in bridge construction,
- plastics and glass in bridge construction,
- self-repairing materials,
- etc.

Long-term structural monitoring plays an important role in verification of the use of new materials in highway structures.

Although these materials have been shown as cost-effective and environment-friendly, and even improve mobility due to much faster application than the traditional materials, the main challenge is their implementation. More efficient, potentially transnational development and introduction of legislation (codes and specifications) that would not only permit but also stimulate the use of novelties in construction of highway structures could considerably improve the present situation.

8.3 Equipment

8.3.1 Climate change

Different scenarios are possible following the models used to determine the potential climate changes. Owners should be ready to assess the influence of some “worst case scenarios” : visibility issues due to an increase of cloudy conditions or high intensity rains leading to extra lighting, safety issues due to an increased seasonal contrast leading to the necessity of additional and more forgiving restraint systems, and markings better adapted to skid hazards. Warning systems such as VMS will possibly be used as a communication tool for drive style adaption.

The energy use is an issue related to this climate change options, specific developments such as intelligent triggering systems for Lighting and low energy LED bulbs give good results to meet this challenge.

8.3.2 Traffic configuration

Equipment presence has a direct impact on the level of comfort for the users. Equipment that will enhance the safety, the average traffic speed, the level of comfort is susceptible to influence the number of users on a particular road section. Owners will have to assess the potential influence of specific equipment on the usage and therefore a potential increase of the degradation's rate of this road section.

8.3.3 New materials

More equipment and more measurements / monitoring are not the only answer to future challenges. In some cases, the answer may be more efficient location or more efficient timing for the use of equipment. Climate and Society changes can though influence the need of more equipment. Recycling is one answer to the limited resources as well as material innovation: energy cost of production, raw material used in the production process, etc.

9 Life-cycle approaches in asset management

Introduction

Many of our road administrations have challenging and sometimes contradictory objectives to fulfil. The assets represent large capital values which have to be operated, maintained, replaced and constructed with limited financial resources and often with a high degree of scrutiny by the public (OECD 2001). The expectations of what the road administrators should accomplish is at the same time changing. Today it is expected, to a larger extent, to have a customer perspective where the road user costs in normal conditions should be minimized while at the same time limit the impacts on the level-of-service when road works are performed. Additionally, it is also expected that societal costs need to be considered in higher degree in order to fulfil for example aims regarding health, environmental impact and safety. At the same time as the requirements of road administrators' objectives are increasing, they must comply with budget constraints which mean the increases in road administrators' costs have to be limited as well. To accomplish this it is necessary for the road administrators to have the right tools to prioritize between the objectives.

Life-cycle costing has been raised as key element for successful asset management (AASHTO 2012). This chapter has the purpose to examine the use of life-cycle costing

approaches in asset management. The aims include to:

- Examine the state-of-the-art within life-cycle costing (LCC)
- Review the use of life-cycle approaches in asset management
- Examine the implementation and implementation issues for successful use of LCC in asset management
- Link the needs of LCC to other aspects of asset management
- Discuss the impacts of different life-cycle cost related decisions
- Life-cycle methodologies

To consider an asset's life-cycle implies that an analysis attempts to take into account the asset's complete life from the cradle to the grave. This includes the project's initiation, planning, design, construction, service life as well as disposal. The term life-cycle is often used to emphasize that an asset's whole service life is considered rather than just the construction phase. In ISO 15686 (ISO 2007) the term whole-life costing (WLC) is used to define the methodology for economic evaluation of products' or assets' whole life benefits and costs during a predefined period of analysis. Often the term cost-benefit analysis (CBA or BCA) is used synonymously for the methodology to evaluate different alternative WLCs. While WLC considers both costs and benefits, the life cycle cost (LCC) can be considered to be a subset of WLC for which only the asset's costs is included. CBA is normally used in planning stages which emphasise societal benefits and costs, as opposed to WLC and LCC who focus on decisions in the later stages with more emphasis on road manager costs.

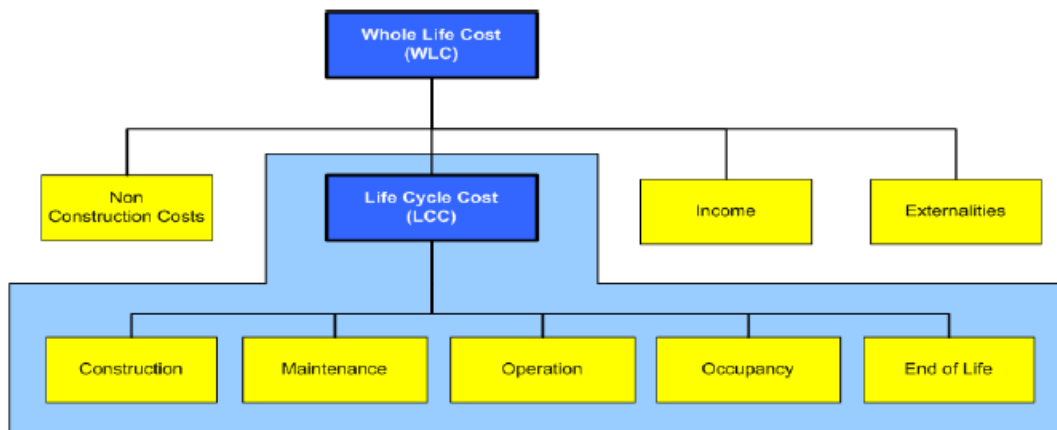


Figure 14 ISO 15686 definition of WLC and LCC (ISO 2007).

In traditional LCC or WLC all of the asset's costs or benefits are usually included in the analysis. For large projects, such as infrastructure investments, this can result in complex calculations. However, the complexity can be significantly reduced when comparing two or more design alternatives if the costs or benefits that are equal among the alternatives are ignored. In this case the term life-cycle cost analysis (LCCA) is usually used to define the methodology to find the optimal design alternative among several alternatives with respect to the LCC. The analysis can, in these cases focus on costs that differ between the alternatives. For example, if one of the alternatives has lower costs for some of the cost posts and if all other costs and benefits are considered to be the same, then that alternative can be considered to be the best alternative with respect to LCC. However, if only the asset owner's costs are included when performing an LCCA for publicly owned assets, this may result in skewed results. In LCCA it is therefore necessary to include the road user and societal costs that differ among the alternatives. In (FHWA 2002) LCCA and CBA have been compared. It describes that an LCCA is commonly used when it is already decided that a project should be undertaken but when still trying to find the most efficient means to fulfil the project's

objectives. An LCCA should therefore only be used to compare alternatives that yield equal or similar level-of-service or benefits. In Table 7 there are recommendations presented by (FHWA 2002) for which cost components to include in LCCA and CBA. They recommend that in addition to agency costs, the road user costs in normal and work zone conditions are included as well.

Table 7 Recommendations of cost and benefit components to be included in LCCA and CBA (FHWA 2002).

Project Element	LCCA	CBA (WLC)
Agency construction, rehabilitation, and maintenance expenditures	Yes	Yes
User costs during construction, rehabilitation, or maintenance	Yes	Yes
User costs during normal operations	Yes	Yes
User benefits resulting from project	No	Yes
Externalities	No	Yes

Discounting of future cash flows is a technique that is shared between all of the above-mentioned methodologies. Discounting is necessary in order to take into account the time value of money, to make present and future cash flows comparable. Therefore a discount rate is necessary that sets the desired valuation (discount factor) for each time period. The discount factor for the time t is computed as in equation Equation1. The discount factor is thereafter used to calculate the present value by multiplying with the cash flow.

$$DF_t = \frac{1}{(1 + dr)^t} \quad \text{(Equation 1)}$$

Where t is the year, DF_t is the discount factor in year t and dr is the discount rate. Commonly the discount rate is positive which means future cash flows are valued less than present cash flows. For public organizations a social discount should be used for economic appraisals in contrast to financial appraisals where a financial discount rate should be used (HEATCO 2005). The social discount rate should in first hand reflect the pure time preference (people prefer utilities today more than in the future) and expectations on future growth. Secondly it should to some extent include a catastrophe risk factor (HEATCO 2005). In LCCA the discount rate sets the importance for if a cost or saving is delayed into the future (AASHTO 2012). In other words it sets the appropriate trade-off between the asset owner desiring to make savings today and postpone costs to the future. If it is assumed that the discount rate used truly reflects the above-mentioned factors and that the LCCA is correctly performed (correct costs and timings), then the discounting should optimally value present savings and future costs.

The discount rate has a large effect on future costs for infrastructure assets with long life expectancies. If a discount rate of 4% is used, then the discount factor for year 40 is 0.2. In other words, costs or savings that occur in year 40 are valued at one-fifth of those today. The social discount rate used varies considerably among different European Union members and time. In Germany a discount rate of 3% is used, in Sweden 4% and in France it was 8% until 2005 (now 4%) (Evans, 2006). This variation reflects inconsistencies in the methodologies used to estimate the social discount rates and also the difficulty, for example, to estimate our

time preferences. This uncertainty, amongst others, emphasizes the importance of not blindly accepting the direct results from an LCCA without performing some kind of sensitivity analysis.

Another uncertainty in the recommended economic values is the economic period. Different design alternatives will result in different costs and benefits at the end of the economic period. The discounting will partly diminish the impact on the resulting life-cycle costs. Nevertheless, this is still important to consider, in order not to obtain biased results. The term salvage value is used in (FHWA 1998) which reflects two important components; the residual value and the remaining serviceable life. The residual value is the value if a structure's components would be sold on the market. For infrastructure assets, the possibility to sell materials is usually limited and in conjunction with discounting this usually results in the residual value being negligible in life-cycle costing approaches. In contrast, the residual serviceable life reflects the asset's cost and benefits for the remaining life, which may have significant impacts on the final results. If for example an asset requires rehabilitation at year 38 while another had one at year 20, the estimation of the estimation of the remaining serviceable life should value that this asset is in better condition and will require less resources from the asset's owner as well as benefits for the road users during the years beyond the economic period.

Finally, the life-cycle costs can be calculated by using Equation 2.

$$LCC = I + \sum_{i=1}^N \frac{C_i}{(1+dr)^i} + \frac{S_N}{(1+dr)^N} \quad \text{Equation 2}$$

Where I is the investment cost, C_i is all costs in year i , dr is the discount rate, N is economic period and S_N is the salvage value at the end of the economic period.

Below are the key activities for LCCA presented based on suggestions in (Ozbay, Jawad et al. 2004) on the current state-of-the-art within LCCA:

- Find the suitable design alternatives
- Define the common project and economic values
- Use deterioration models to find timings for operation, maintenance and rehabilitation (O, M & R) activities. This also includes models for the effectiveness of the activities.
- Estimate the costs for each activity that is different among the alternatives. This should include road administrator costs, road user costs and societal costs
- Calculate net present values for each alternative
- Analyse the results including sensitivity analysis and statistical interpretations
- Improve the design alternatives by new designs or O, M & R strategies and redo 3-6. End if minimum life-cycle cost has been found.

Ideally, this would result in it being possible to plot a diagram as presented in Figure 15.

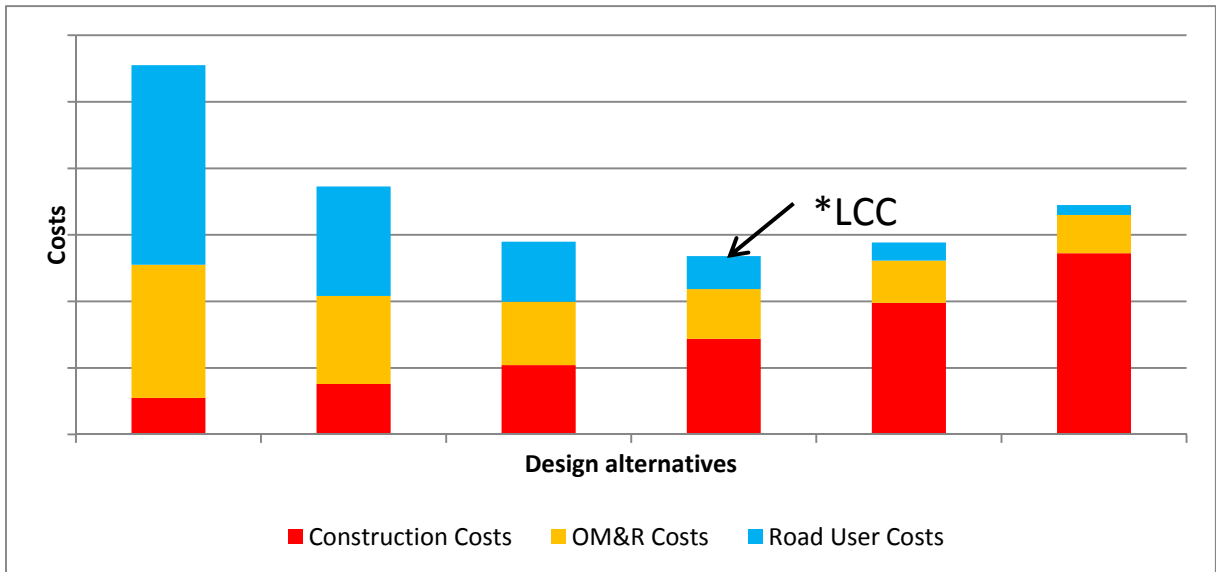


Figure 15 Principle of finding optimal design alternative from a life-cycle cost perspective

An asset can also be evaluated from an environmental point of view by applying life-cycle assessment (LCA) methodologies. An LCA focuses on an investment's environmental impacts on a local, regional and global level. LCA can also be combined with other life-cycle costing approaches by assigning economic values to the environmental impacts in order to approach a complete view of an investment's impacts.

Applications of life-cycle approaches in asset management

The responsibilities in the asset management of roads vary depending on which level of management is considered. Depending on if it is operation and maintenance of existing roads, construction of new roads or long-term planning, the type of decision that needs to be taken differs and consequently also the needs of the life-cycle approaches. Road maintenance has in (Robinson, Danielson et al. 1998) been categorized into four project steps in a project cycle. These can also be related to common stages in the planning and design of road constructions.

Table 8 Different levels for life-cycle decision making

	Project level	Operation & Maintenance	Investments
1	Identification	Planning	Planning and preliminary studies
2	Feasibility	Programming	Investigation studies
3	Design and commitment	Preparation	Design plans
4	Implementation, operation and evaluation	Operations	Construction plans

The identification phase concerns the long-term strategic planning with estimates of the expenditure on investments and preservation of existing infrastructure assets. This allows for development of different strategies for how to prioritize between actions with the limited resources. The forecasted outcome of different strategies should be related to the fulfilment

to the established policies, objectives and key performance indicators at a network-wide level (Robinson, Danielson et al. 1998). The needs of new roads and treatment objects are identified. The life-cycle approaches used are usually at a coarse level of detail. Typically the benefits of increased accessibility, safety or health compared to the costs are the main considerations at this level. WLC/CBA methodologies and HDM-4 can typically be applied at this level.

In the feasibility step, the main activity is usually to consider different means to fulfil the project aims. In road management this concerns further analysis of the identified candidate links for which expenditure programmes are established for different scenarios, treatment types, treatment timings and other possible measures. In the construction of new roads this may include the assessment of different corridors and different road types. While the benefits are the main concerns still, there is a shift towards technical solutions and whole life-cycle costs.

In the design and commitment steps the road projects are prepared for the construction phase. This includes more detailed designs, eventual legal processes and preparation for procurement. In these phases the budget has usually already been approved. Typical LCC decisions that need to be taken concern pavement design, road design and selection of contractual forms. Since the design alternatives typically yield similar benefits, an LCCA is typically applied. However, road user and societal costs that differ between the design alternatives should be included.

During the implementation, operation and evaluation phases the on-going organisational activities are planned, managed and executed. In road management this concerns construction, operation and maintenance activities with scheduling, construction methods, equipment and material control (Robinson, Danielson et al. 1998). In an LCC perspective this includes quality management, quality assurance and quality control of material selections, working and end results. Monitoring and assessment provide feedback for evaluation of the realization of planning and designing of life-cycle costs and allow for new decisions in management cycle.

As a concluding remark the planning and design phases can be reviewed as a process of changing focus. In earlier planning stages the focus is towards the benefits for the society and road users in which the wider CBA/WLC methodologies are applied. In the design phases the focus is on selecting among different technical solutions in which case LCC/LCCA models are applied typically. Even if the approaches of the life-cycle analyses differ between the project levels, it is important that the models harmonize. This means firstly that the models give consistent results despite varying level of detail. Secondly, the models need to be developed for an integral process. Decisions with consideration to the life-cycle cost taken at higher levels should be able to be integrated in models at lower levels. This is important in the planning phases in order to be able to grant a project with an appropriate project budget in order to later enable for correct decision with respect to the life-cycle cost.

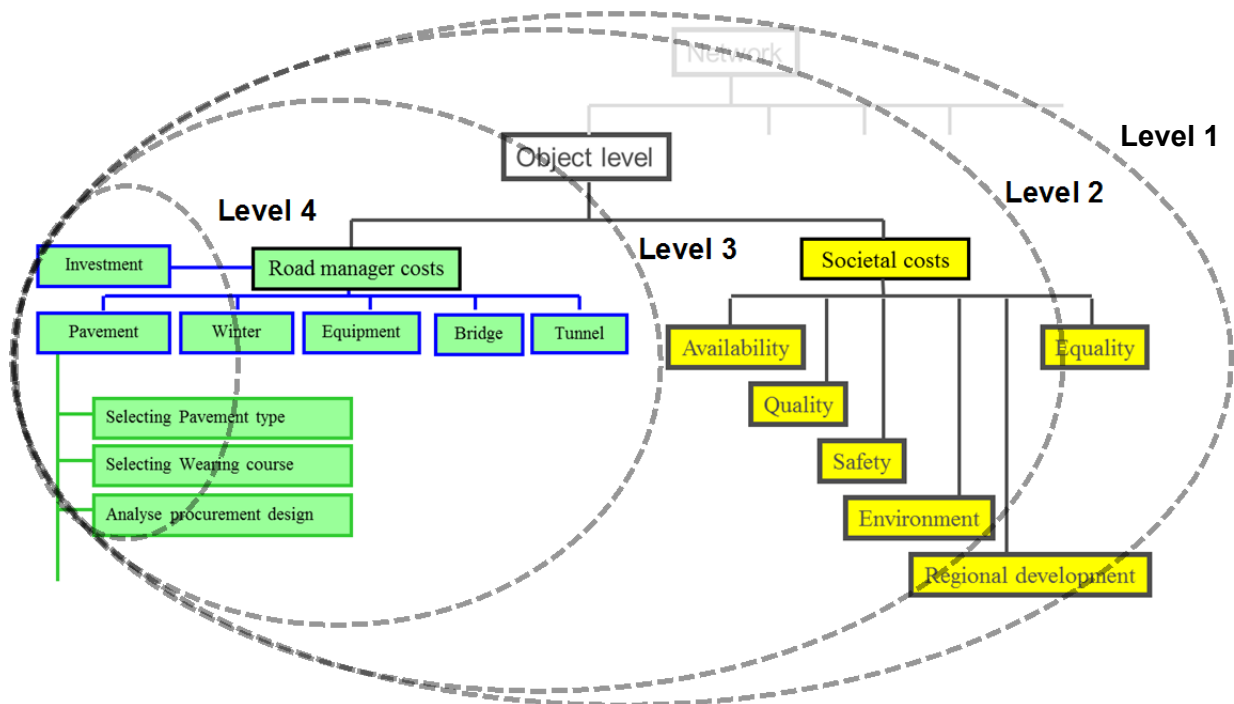


Figure 16 Examples of cost posts in Swedish road planning and design and possible ranges of LCC

Implementation and implementation issues of LCC in asset management

As the suggestion for an activity list for LCCA indicates, activity timings, cost estimations and treatment effectiveness are three key components for a successful implementation of LCC.

Good estimations of the cost of different materials and measures are central to be able to perform an LCC. This is especially true when more detailed analyses need to be performed. Cost databases that include costs for key elements such as treatment, material and labour costs are therefore essential in order to successfully implement life-cycle cost approaches in asset management. Without good estimations of costs for investment, operation and maintenance activities it is not possible to draw fair conclusions on investment decisions. This also includes variations in costs. A complicating matter in LCC is that the future costs should be reflected if known. Fluctuations in prices need to be evened out while long term changes in prices of labour and resources as well as efficiency should be accounted for if possible.

The second key component for successful implementation is the access to good condition data including the indicators available today but also new indicators in order to find the measures with the lowest life-cycle costs. The availability of good and multifaceted condition data is also of necessity in order to update and develop deterioration and other performance models. Even if the level of detail needed for the condition data and deterioration models varies depending on in which function of the asset management the LCC is applied, it is generally required to have more detailed models in order to make coherent decisions between strategic to operational levels. For example, if a section has been identified as a candidate for treatment, during the planning phase, simply based on maximum rut and linear deterioration models the project may be granted money for simpler treatments such as milling and a thin overlay. However, if the rutting has mainly occurred in subgrade or base layers, the existing models will underestimate the actual life-cycle costs. A general problem in managing assets in public organizations is that appropriations are based on the needs identified during strategic planning. Failure to do so results in a mismatch between the appropriations and actual need in order to take the correct decisions from a life-cycle perspective. In the example above, even if the actual cause of the rutting could be identified in the preparation stages it may be too late to get the appropriate funding for the adequate

action that would result in the minimal life-cycle costs. Access to more and better condition data and deterioration models would probably reduce this gap.

The third key to successful implementation is to quantify needs for maintenance, to identify adequate treatments, to quantify resources needed and finally estimate the resulting influence on future condition.

A changing focus towards the road user and societal costs also require that the developments of the design tools have a focus on the actual functional properties affecting the road users and the society. (Nilsson 2001) states that the pavement tools until then mainly focused on fatigue cracking in bound layers and vertical strains on the subgrade. However, when pavement engineers ranked the most important functional properties these were ranked 7 and 13. This exposes a mismatch between the design tools and needs of life-cycle costing. This includes, for example, forecasting of effects for different operation, maintenance and rehabilitation strategies as well as to relate these to the impacts on the road users. New challenges of road asset management will require the introduction of new materials to minimize the impacts on the road users and society. However, this also requires careful evaluation before implementation from a full life-cycle perspective. To accomplish this, it is of high importance to have strategies of how to match the development of pavement analysis tools and the needs of life-cycle approaches.

Prioritising can be seen as one of the main aspects in asset management. Different life-cycle approaches are of necessity for optimal decision making of how to make the best use of limited resources with a perspective on the long-term consequences on the future road management. This includes for example prioritising between new infrastructure and preserving existing infrastructure, taking actions today or tomorrow, road corridor A or B and concrete or flexible pavement. While today's LCC models may have limitations for a complete view of roads' future conditions, there are always risks involved in decision making. The management of different types of risks should be an integral part in life-cycle decision making process, including the uncertainties in the models. The models' limitations should therefore not be justification for not increasing the life-cycle perspectives on the decisions making.

10 Conclusions and recommendations

The following are issues that HeRoad have found important to highlight to improve the possibility to have a successful development of the implementation of a modern working asset management of roads. Even if some of them are obvious it was found that, despite this, they are not treated with enough importance. Regarding best practise related to the most important new challenges such as noise, particulates, fuel consumption-emissions, water levels and extreme weather conditions few best practise solutions exists. Many promising initiatives have however started and are on-going.

10.1 The overall road asset management

Transport policies and informed organisations

For a successful implementation of road asset management, the benefits as well as the political and financial implications must be understood by the entire organisation.

Federal requirements and targets

Avoid national level targets - but provide a strong federal (trans-European) vision and policy goals. Targets should consider the EU-commissions white paper "Roadmap to a Single

European Transport Area". The different situations in Europe's countries with the road manager being responsible for only a region or a special selection of road types e.g. motorways makes this more complicated.

Multiple assets

The decomposition of the networks into components described as network, overall system, system, sub-system, basic object, maintenance object and inspection object is important to facilitate the balance of cost, risk and available budget. But also nonphysical assets must be considered as data, data management, maintenance work and skills.

Service life time

A clear view of the definition of service life time that meets the expectations of users must be considered, since this affects the necessary inclusion of Life Cycle Cost (LCC) in asset management. The road works time, removal, re-cycling and re-use phase are important in the availability calculations.

User expectations

In an asset management system, the user expectations must be the focus. This seems not always to be the case. The environment should also be seen as a user and be considered.

Digital frameworks and adequate databases

As a base for all assessment and optimisation, a structure must exist that integrates all considered assets and products (maintenance, road works) to facilitate and even make it possible to make calculable solutions. This sounds obvious but is not at all the common practise. There is a need for a construction database to support the LCC calculations. One basic need is that if data are in separate databases a common key (coordinates) is necessary to synchronise data. This has been found to be a major source of problems/Errors.

Indicators and trigger levels

The use of objective and measurable, implementable indicators, justified by strategies and fulfilling the needs from the top level, must be improved. Today, if performance is monitored it is often done by using old existing technical parameters collected with high technology equipment. The indicators have not been developed to the same extent as the data collection techniques. To make the assessment reliable more "evidence" based trigger levels for the performance indicators should be used. There is a lack of documentation proving this. Today the levels are often set based on historical experience. To make the trigger levels reliable and trusted the levels need to be scientifically established and documented, e.g. why should a road be repaired when the rut depth has reached a certain level?

10.2 Common evaluation tools

The condition monitoring needs to be developed for many assets. It seems to be well developed on the pavement asset but less for other assets. Pavement management has a long tradition and is well developed, which may mean that it is difficult to change and adapt to incorporate newer ideas. Anyway, the use of PMS as guidance for the basis to include other assets is a good possibility. In the work of improving old and introducing new indicators the need for prediction models arises. As described above the need for common database frameworks is necessary, especially considering the possibilities to create prediction models that could be used to assess future condition and strategy alternatives in the LCC. Many of the prediction models that exist are built on data from old constructions not used today (outdated data). Few prediction models are documented.

10.3 Recommendations on QA procedures to control data quality

The role of data and data quality used in asset management must always be recognised as extremely important. The assessment of performance quality from data influences decisions covering considerable amounts of money. Many countries report their use of quality procedures. Despite this reported use, when exploring data, major problems are found in the databases. No European consensus exists on data quality procedures. It is suggested to develop a European view on this issue including requirements on data quality before, during and after collection. The pavement condition data quality procedures used in Sweden, Finland and UK can be used as good examples.

10.4 New challenges

Many initiatives are going on to meet new challenges. The MIRIAM project works on indicators for rolling resistance. The TRIMM project evaluates the TSD and geo-radar techniques. Many projects have evaluated the possibilities to measure noise. Proxy equipment to measure the tyre/pavement noise has been developed. Research on particulates from pavements and its effect on traffic users are on-going. In former ERA NET Road projects methods to assess and predict the risk for changing water levels has been developed. For new challenges the opportunity to build up common harmonised European models are obvious. Considering new challenges a possibility to establish requirements on what needs to be measured derived from what needs to be assessed is clear: How should this performance be measured and with what indicator? Starting by looking from the user perspective, the measurement requirements can be clearly specified and help make the measurement methods effective.

10.5 New technologies

A lot of initiatives are going on to investigate new techniques and to improve and develop new indicators, such as the FP7 project TRIMM (new techniques), MIRIAM (rolling resistance) and other ERA NET Road projects. The results from some of these projects can fill some of the identified gaps or add to the promising methods/techniques that are in a development phase and not routine or best practice yet. Some promising new techniques that deserve to be mentioned are *Traffic speed structural condition monitoring*, *Traffic Speed Deflectograph*, *TSD*. For many years, information on the road network' structural condition has been needed. This could be defined as the condition of the layers below the surface. Today a system called TSD, The Danish Traffic Speed Deflectometer has been evaluated in many countries with promising and successful results. Another new technique is the *Ground penetrating radar (GPR)* to measure layer thickness in pavements. The GPR is monitoring the structure of the road below the surface, measured at traffic speed, giving information on actual pavement layer thickness. This could fill in the needed information for the construction database.

Another promising technique is the laser based *Lidar system (LIDAR)* that measures 3D surface models. The Lidar system is a technology to monitor the road side geometry and can complement the traditional road surface monitoring to give needed information for risk management regarding flooding, for safety assessment by comparing actual alignment to sight lines.

Finally the use of smart phones and in-car sensors should be mentioned as emerging technologies. On-going projects are investigating the possibilities and many commercial concepts have been introduced. The recommendation is to really consider and evaluate use of this information. Does it fill in the gaps? What are the risks? Introducing less accurate

measures can create confusion and misuse.

10.6 Guidance to authorities on the benefits of adopting/implementing the ‘best practice’ techniques/processes identified in the report

“Good practice” concerning separate assets and condition monitoring have been identified and are reported in the separate asset reports of HeRoad. The identified indicators and how they relate to upper levels can be seen in Figures 6, 7 and 8 of this report. Few countries seem to have made any major efforts to introduce asset management. The Netherlands, Norway and UK are exceptions, at least based on the information collected within HeRoad. Considering this, a suggestion is to really look over the efforts done with regard to the asset management. By using some measure of the organisation’ “maturity” it is possible to identify and set the next management steps. As an example what could be used, is a scale developed by AASHTO (AASHTO, 2011) and presented in Table 9.

Table 9 AASHTO maturity scale

Maturity scale level	Generalised description
Initial	No effective support from strategy, process or tools. There can be lack of motivation to improve.
Awakening	Recognition of need and basic data collection. There is often reliance on heroic effort of individuals.
Structured	Shared understanding, motivation and coordination. Development of processes and tools.
Proficient	Expectations and accountability drawn from asset management strategy, processes and tools.
Best practise	Asset management strategies, processes and tools are routinely evaluated and improved.

Concerning identified indicators on the operational level it can be argued if there is a harmonised trans-European view. France, Germany and UK use individual indicators for defining longitudinal evenness. Few countries use the same indicators for transversal evenness. There is a variety of devices measuring pavement properties over European roads, e.g. more than 19 different devices are used to measure friction. One way to harmonise them is to define common scales, another is to introduce standards for them all. With regard to the collected data for pavements and structures, a suggestion is to make arrangements for raw data to be stored. This would easily allow calculating future measures (indices) on both new and on old collected raw data. In case of road equipment’ and environment’ indicators it seems that possibilities to come together at trans-European level

are much higher.

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Appendix A. Terminology

The definitions of some of the terms used within this report are given within this Appendix. If the definition is from PIARC, OECD, ARCHES or Procross it is referenced in parenthesis after the definition, otherwise it is a HeRoad suggestion. Some definitions are expanded further in the report. This is also referenced.

AASHTO: American Association of State Highway and Transportation Officials

Actions: See Treatment.

Asset: It seems that asset in traditional road asset management has been understood as physical entities. In financial accounting, assets are economic resources, anything that can be allocated an economic value and be part of business benefits. HeRoad strongly suggest that in current road asset management, entities such as regulations, competence, skills, expertise/knowledge, data and data management shall be treated as assets to increase the status of those entities. Doing this may incentivise the allocation of resources to such assets.

Asset management: A comprehensive and structured approach to the whole life management of assets (such as roads, bridges, tunnels, buildings, plant and equipment, and human resources) as tools for the efficient and effective delivery of services. See also the definition of Road asset management. (PIARC)

Bearing capacity/ structural condition: The structural condition or bearing capacity can be explained as the structure's ability to resist the traffic load that is applied to it. No equipment measures this directly. Instead, in most cases, the deflection of the surface is measured when it is exposed to a known load and used as an indicator of structural condition. The deflection is used to calculate strength or stiffness parameters or used as a direct measure of the strength.

CBA: Cost Benefit Analysis, analysis to maximize benefits of expenditures used in decision making in policy or planning stages, as opposed to LCC/LCCA and WLC which focus on

minimising road operator respectively road user costs in the later design stages. (See chapter 9)

Condition assessment parameters/ condition indicator: A parameter used to quantify an attribute of condition (e.g. numerical evaluation of damages, condition rating). (PIARC)

Condition: Assessment of the type, severity and/or extent of deterioration of a component at a given point in time. (IABMAS)

Condition monitoring: to keep watch over condition, recording progress and changes with time (according to fib)

Condition rating / condition indicator: a quantified, numerical value that describes condition of a structure or structural component

Cross-asset management: Cross-asset management is a relatively new expression also named multi-objective asset management. This is a natural and necessary part of a road asset management system and It incorporates the management of many different asset categories. "Cross-asset management is the combination of management tasks and activities over different assets of the total road infrastructure asset within a pre-defined management process. These tasks and activities can to various degrees have technical, economic, strategic and environmental objectives/ considerations." (Procross, 2012)

Comfort: The definition of comfort is important since this is a concept that includes many factors that express a person's wellbeing including the experienced safety in a certain situation. Seeing, feeling and hearing are senses that the road user activates to evaluate the comfort. (Also see chapter 5.1.1)

Deterioration: worsening of condition with time, or a progressive reduction in the ability of a structure or its components to perform some aspect of their intended function

Deterioration model: A mathematical description that can be used to predict future asset (bridge, pavement etc.) deterioration based on present asset condition, deterioration factors (traffic, climate, and environment) and the effect of maintenance. A deterioration model can also be defined for part of an asset. (PIARC)

Comment: The definition is modified from original PIARC definition by consider and include other assets than pavement.

Durability: Ability to perform over a long period: Long lasting lifetime capacity whilst keeping acceptable performance.

Dynamic amplification factor (DAF): The increase in the effect of a dynamic (total) load effect versus the static load effect, typically expressed as maximum load / maximum static load.

Expectation: Anything that a stakeholder is expecting from the road infrastructure. This may include services, benefits, or it may be the reduction of nuisances.

Highway structures: Typically bridges, tunnel, culverts and retaining/supporting walls.

LCA: Life Cycle Assessment, a management tool that assesses all the stages involved in the life of a product such as raw materials acquisition, manufacturing, distribution and retail, use and re-use and maintenance, recycling and waste management. (PIARC)

LCA is also defined as life cycle analysis, including life cycle inventory (LCI) and environmental impact assessment (EIA) of a given product or service throughout its lifespan.

LCC: Life-Cycle Cost, is the sum of all costs for an asset or product during its whole life cycle or predefined period. In ISO 15686 LCC is considered as a subset of WLC, where the later includes a wider range of costs including externalities, non-construction costs and incomes while the former often has an emphasis on the asset owner's costs.

LCC/LCCA: Life-Cycle Costing or Life-Cycle Cost Analysis is the method to systematically evaluate an asset's *life-cycle cost*, *LCC*. The evaluation may include the asset's whole *life-cycle cost*, *WLC*. However, if the alternatives otherwise fulfil the performance requirements and yields the same benefits, the evaluation can be reduced to only include the *life-cycle costs* that differs between the alternatives in order to select an optimal investment alternative.

Load test: Process of testing a structure and measuring its response; performed to determine a system's behaviour under load conditions in order to help identifying the maximum capacity of a structure.

Maintenance: Operational activities primarily intended to continue the safe use of facilities and contribute to realizing the expected service life. (IABMAS)

Maintenance can be divided into two major types; planned (pro-active) and unplanned (reactive) maintenance. In one sense unplanned maintenance could be called operations (daily activities on day to day basis) even if operations can be planned. Predictive maintenance decisions can be statistical or condition based. Maintenance can be of the type improvement, corrective or preventive and predictive.

Maintenance management system: The process of coordinating and controlling a set of activities in order to maintain an asset (such as a road or road network) within an agreed policy of asset management, while making the best possible use of resources available. (PIARC).

Management systems can often have quite different characteristics. A modern management system is more than an information system; it also incorporates a decision support tool. Traditionally a separate management system exists for each asset.

Pavement management system (PMS): is a planning tool used to aid pavement management decisions. It normally consists of three major components,

- a system to regularly collect highway condition data
- a computer database to sort and store the collected data
- an analysis program to evaluate repair or preservation strategies and suggest cost effective projects to maintain highway conditions

Bridge management system (BMS): Formal procedures and methods for gathering and analysing bridge data for the purpose of predicting future bridge conditions, estimating network maintenance and improvement needs, determining optimal policies, and recommending projects and schedules within budget and policy constraints. (IABMAS)

Winter road, gravel road, road markings, signs etc. could all have a separate management system. The process to integrate the separate management systems into a whole could be called a **Road asset management system (RAM)** or if even more are included, a **Transport Management system (TAM)**. See also definition of Road asset management and Transport asset management.

Monitoring: Collecting data on a structure and assessing the status of current conditions and their development over time. (PIARC)

Measures: This word may be interpreted two ways; either as a unit specified by a scale or as treatment (maintenance action), see definition of Treatment.

Multi-objective asset management: See definition of Cross asset management.

Operations: see definition of maintenance.

Performance: A quantitative or qualitative characteristics describing the quality or service provided by a transport facility or service.

Plant: All equipment and structures (signs, pavement, road equipment's, barriers and road side) building up a transport infrastructure from A to B. The complete collection of all assets in a specified area.

Road maintenance: All actions undertaken to maintain and restore the serviceability and level of service of roads. (PIARC)

Rehabilitation: Work undertaken to restore serviceability and to extend the service life of an existing facility. (PIARC)

Road Infrastructure/ road asset: All constructions (pavements, bridges, drainage structures...) and equipment (safety barriers, signs, lights...), including all the land devoted to the highway corridor.

*Comment: In the work of HeRoad it has been concluded that **condition data** should also be treated as an asset and this should be treated and maintained with as much effort as the physical assets would.*

Road asset management (RAM): Many definitions of road asset management can be found in the literature. The three most referred to are cited below. Systematic and organised approach including the whole life perspective, public's expectations, business approach that incorporates operations, upgrading and maintenance as well as provision of tools are the most essential parts of a RAM.

RAM is a holistic approach that integrates the strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their life cycle. It focuses on business and engineering practises for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives. (NCHRP Report 632, 2009)

RAM is a comprehensive and structured approach to the whole of life management of assets (such as roads, bridges, tunnels, buildings, plant and equipment, and human resources) as tools for the efficient and effective delivery of services. (PIARC)

A systematic process of maintaining, upgrading and operating assets, combining engineering principles with sound business practice and economic rationale, and providing tools to facilitate a more organized and flexible approach to making the decisions necessary to achieve the public's expectations (OECD, 2001). See also the definition of Maintenance Management System.

Comment: As long as condition data is considered a physical asset the definitions fit well for the HeRoad project. An asset doesn't necessarily need to be a physical object; it can be an entity that can be allocated a value, see definition of Asset.

Partial safety factors, reliability index, probability of failure: Different measures to evaluate structural safety, applying different degrees of complexity, from deterministic to probabilistic.

Performance Indicator: A comprehensive term which quantifies the impact of the road. It can be expressed in the form of a technical parameter (dimensional) and/or finally in form of an index (dimensionless) evaluating the performance indicator on a predefined scale

Performance Index: An assessed Technical Parameter or dimensionless number on a scale that evaluates the Technical Parameter involved (e.g. Noise assessed from MPD)

Ride quality: Ride quality refers to the degree of protection offered vehicle occupants from uneven elements in the road surface, or the terrain if driving off-road. (Also see chapter 5.1.1)

Reconstruction: to reinstate all or part of the functionality of a structure or component which is in a changed, defective or deteriorated state to its original or higher level of functionality without restriction upon the methods or materials employed.

Rehabilitation: Work undertaken to restore serviceability and to extend the service life of an existing facility. (PIARC)

Road owners;

- **Public owners:** Strictly speaking, the owners of a public road network are the citizens. Practically, the owners are the legal representatives of these citizens. In accordance with this definition, the owners may be different entities, bodies, organisations depending on the road network they own. Usually for the national road networks the owner would be government or one of its bodies (e.g. Ministry for Transport), whereas in the case of local road networks it would be the local authority (e.g. municipality or one of its bodies, local council). PIARC Technical Committee 4.1 specifies that the owner of the road assets is the entity which carries the primary responsibility for this road infrastructure. It is responsible for its long-term strategic management to the best interest of the users and community, and of the allocation of budget.
- **Private owners:** These stakeholders own the roads in the traditional sense of the word: they own the ground on which the roads are constructed and the roads themselves since they entirely paid for their construction and maintenance. Forest and mining companies are examples of private road owners. In some housing estates, the house holders may also own the streets.

Road Stakeholder: All people (physical or social persons), all organisations, and more generally all bodies, which have some interactions with road infrastructure. The road network can provide benefits to stakeholders as well as imposing constraints upon them. Conversely, the needs of stakeholders may also impose constraints on, or determine the requirements of, the infrastructure.

Comment: This definition fits well with the work carried out within the HeRoad project as long as the environment is considered as a stakeholder. This is to ensure that the interest of the impact of the environment is considered even if no human represents the specific area.

Road performance: Generally, the ability of the road to meet expectations, to provide a stakeholder with what he is expecting from the road. More specifically, road performance is a measure of this ability to meet expectations, of the quality of the road regarding the expected service or characteristics or impacts.

Road operator: As previously stated, road operators are also road stakeholders, but have no expectation from the network. Their role is to ensure the satisfaction of other stakeholders' expectations. For completion of the work, the three sub-categories identified amongst road operators are listed below.

- **Road directorate:** Any organisation that assumes the management of a public road network. This means that it makes, in the name and with the agreement of the owner, all decisions regarding construction, extension, development, maintenance and operation on this network; its role is central, e.g. there is only one Road Directorate for a given network. This service reports to the network owner, the medium and long terms decisions of which it is preparing, decisions that it is implementing with the budget delegated to it.
- **Concessionaries:** Private and/or public organisations to which the public authority delegates all or part of the financing, construction, extension, development, maintenance and operation of a road network, and which is allowed, in return for it, to directly collect toll from the Users or from the Owners. The respective missions and duties of the public authority and the concessionary are defined and governed in a (long term) contract, which especially mentions the conceded network characteristics, the end of the concessionary, the level of toll and the rules to update it.
- **Local project managers:** Local organisations that execute maintenance and

operational decisions made by the Road Directorate (on public networks) or by the concessionary (on conceded networks). Districts may operate their own pieces of equipment, especially for road operation purposes.

Road users:

- **Daily users:** People who use road infrastructure very frequently as a driver or passenger of a vehicle; the purpose of the journey may be: work, education or business.
- **Truck & Bus:** Transport service operators using road infrastructure. This sub-class includes public or private companies, whose aims are the transport of goods and people.
- **Tourist:** This sub-class includes people that use road infrastructure occasionally for tourism purposes as drivers or passengers of vehicles.
- **Vulnerable user:** Cyclists and motorcyclists using road infrastructure occasionally or frequently (their journey purpose may be: work, education, entertainment, etc.) and pedestrians, meaning persons moving by walking on road infrastructure occasionally or frequently.

Road neighbours:

- **Resident:** Any person who lives along a road or a street.
- **Commercial business:** Any shop or retail building located along a road or a street.
- **Industries:** Any industrial facility, plant or other production site that have direct connection (entrances, exits) to the road network.
- **Users of public areas:** People who use or work in public places such as schools, hospitals, administrative buildings, and more generally buildings which are opened to the public.

Service quality measures: Indices or parameters that could be measured to rate performance of service quality

Society:

- **Developed countries:** The national community in countries with a high level of prosperity.
- **Countries in (economic) transition:** The national community in countries currently transforming drastically their economic organisation.
- **Developing countries:** The national community in rapidly transforming countries aiming at a global progress and rising prosperity.

Service life: The life of an asset until its functional, physical, technological, economic, social or legal condition or status (whichever is sooner) dictates replacement. (PIARC)

Asset life expectancy is the length of time until the asset must be retired, replaced, or removed from service. Determining when an asset reaches the end of its service life generally entails consideration of the cost and effectiveness of repair and maintenance actions that might be taken to further extend the asset's life expectancy. Different types of assets, such as pavements, bridges, signs, and signals, will have very different life expectancies. Asset life expectancy also depends on the materials used; demands actually placed on the asset in use; environmental conditions; and maintenance, preservation, and Rehabilitation activities performed.

Expected service life (wearing course): The average time until the intervention threshold is

reached, this can be expressed in years, cumulative ESALs etc.

Soft load test: diagnostic load test of a structure, typically a bridge that employs traffic loading weigh-in-motion data instead of pre-weighed heavy vehicles (ARCHES)

Special inspection: Inspection that covers particular items of concern not covered by the general inspection, and usually requiring extra time and equipment. Examples are fatigue, seismic, and underwater investigations. (IABMAS)

Structural management: Part of asset management that includes highway structures. See also definition of Asset management.

Sustainable: Capable of being continued with minimal long-term effect on the environment.

Transport asset management (TAM): “TAM involves the collection and integration of multiple practises into a coherent and managed whole. TAM addresses five core questions:

- What is the current state of my assets?
- What are my required levels of service and performance delivery?
- Which assets are critical to sustained performance delivery?
- What are my best investment strategies for operations, maintenance, replacements and improvements?
- What is my best long-term funding strategy?” (AASHTO)

See also Road asset management and Transport asset management.

Technical Parameter: A physical characteristic, derived from various measurements, or collected by other forms of investigation (for example, MPD (Mean Profile Depth, a technical measure of macrotexture).

Treatment: The act of maintaining.

Weigh-in-motion (WIM): Weighing of vehicles at normal speed. WIM is the process of measuring the impact forces or dynamic loads produced by the wheels or axles of a moving vehicle. (PIARC)

WLC: *Whole-Life Cost* is all of an asset’s costs, incomes and benefits during its life-cycle or predefined period. *WLC* considers a wider range life-cycle cost for the users or the society and sometimes also incomes and benefits.

-WLC, *Whole-Life Costing*, is the method for economic evaluation of an asset’s *Whole-Life Costs*, *WLC*. *Whole-Life Costing* is closely related to cost-benefit analyses. However, the later often considers a wider range of economic benefits while the former’s scope is within the asset’s ownership and usage. In the same way as LCC/LCCA, the evaluation can be reduced if the alternatives yield the same costs and benefits.

Appendix B. Matrices

Stakeholder Expectation

Table A-10 Stakeholder expectations and ideal measurement practice for pavements

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Availability – what the stakeholder expects</p>	<p>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.</p> <p>They expect service and safety at all times.</p>	<p>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.</p> <p>The owner would expect the road drainage to be sufficient that the road would not need to be closed because of flooding.</p>	<p>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.</p>
<p>Availability - Ideal measurement practice</p>	<p>The amount of delays (hours) caused by maintenance.</p> <p>The ability to predict the accuracy to which maintenance interventions occur in time and duration.</p> <p>How well the information regarding road works, and associated delays etc, reaches the users.</p>	<p>Percentage of time that each section and lane is unavailable due to pavement maintenance.</p> <p>The amount of delays (hours) caused by maintenance.</p> <p>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.</p> <p>Adequacy of road drainage.</p>	<p>Percentage of time that each section and lane is unavailable due to pavement maintenance.</p> <p>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).</p> <p>The ability to predict the accuracy to which maintenance interventions occur in time and duration.</p> <p>How well the information regarding road works, and associated delays, diversion routes etc, reaches the neighbours.</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Service Quality - what the stakeholder expects</p>	<p>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).</p> <p>The users also expect the general ambience of the road to be of a certain level.</p>	<p>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.</p> <p>The owner would also expect the road to deliver a minimum level of journey time reliability.</p>	<p>Neighbours expect the road drainage to be sufficient to prevent flooding of their properties by surface run off.</p> <p>They also expect:</p> <p>The splash spray not to affect their property;</p> <p>For the noise levels to be at a minimum.</p> <p>For there to be infrastructure in place to ensure that the road users stay on the road.</p>
<p>Service Quality - Ideal measurement practice</p>	<p>Assessments of:</p> <p>The level of comfort (this covers transverse and longitudinal roughness).</p> <p>The levels of geometry to result in comfortable handling.</p> <p>The level of in-car noise.</p> <p>Sufficient sight lines</p> <p>Homogeneity of road surface's appearance (e.g. lack of patching)</p> <p>Level of splash spray</p> <p>Percentage of length affected by potholes, or significant local defects.</p>	<p>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.</p> <p>Percentage of length affected by potholes, or significant local defects.</p> <p>The thresholds specified may differ from user requirements.</p>	<p>Level of noise, including tyre/pavement interaction noise, engine noise, noise caused by significant local defects e.g. loose manhole covers [Road Equipment].</p> <p>Adequacy of road drainage.</p> <p>The number of excursions per section.</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Safety - what the stakeholder expects</p>	<p>Users expect there to be enough surface friction to enable them to stop within a reasonable stopping distance.</p> <p>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.</p> <p>They also require good visibility.</p> <p>Users also require earthworks to be stable and not likely to collapse.</p>	<p>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.</p> <p>The owner will want earthworks to be stable and not likely to collapse.</p> <p>The owner will also want the level of safety to be such that it minimises liability.</p> <p>The owner expects to be able to provide a level of safety for road workers, to ensure they are not exposed to excessive danger.</p>	<p>Neighbours expect the provision of infrastructure to ensure vehicles remain on the road e.g. friction to enable drivers to stop.</p> <p>They expect consideration of the exposure of pedestrians and property to road users.</p> <p>Neighbours also require earthworks to be stable and not likely to collapse.</p>
<p>Safety - Ideal measurement practice</p>	<p>Level of surface friction (both wet and dry) and maximum stopping distance for each section, and each vehicle class.</p> <p>Assessments of:</p> <p>The level of roughness (this covers transverse and longitudinal).</p> <p>The levels of geometry to result in safe handling.</p> <p>Sufficient sight lines</p> <p>Ability to shed water: Both drainage and ponding.</p>	<p>Level of surface friction (both wet and dry) and maximum stopping distance for each section, and each vehicle class.</p> <p>Assessments of:</p> <p>The level of roughness (this covers transverse and longitudinal).</p> <p>The levels of geometry to result in safe handling.</p> <p>Sufficient sight lines</p> <p>Ability to shed water: Both drainage and ponding.</p>	<p>Assessments of:</p> <p>Level of surface friction (both wet and dry) and maximum stopping distance for each section, and each vehicle class.</p> <p>Kerb upstand and condition in each kerbed section.</p> <p>The level of stability of earthworks</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
	<p>Level of splash spray</p> <p>Percentage of length affected by potholes, or significant local defects</p> <p>The level of stability of earthworks.</p>	<p>Level of splash spray</p> <p>Percentage of length affected by potholes, or significant local defects</p> <p>The level of stability of earthworks.</p>	
<p>Durability - what the stakeholder expects</p>	<p>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.</p>	<p>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.</p> <p>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.</p>	<p>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.</p> <p>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.</p> <p>Their expectations for durability are covered in availability and service quality.</p>
<p>Durability - Ideal measurement practice</p>	<p>N/A</p>	<p>The same measurements as specified for service quality, as they will deliver parameters from which durability could be calculated.</p> <p>May also want to measure:</p> <p>The structural strength of the pavement.</p> <p>Visual deterioration (e.g. fretting and cracking).</p> <p>Transverse road surface shape (structural rutting).</p>	<p>N/A</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Economy (cost) - what the stakeholder expects</p>	<p>Users expect the following to be minimised:</p> <ul style="list-style-type: none"> Fuel consumption Taxes or tolls Congestion (this incurs delay charges) Vehicle damage (via wear or accident). 	<p>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.</p> <p>They expect the whole life costs to be minimal, or at least sensible.</p> <p>They also expect to minimise costs incurred by accidents, whether for liability claims, or clear up etc.</p>	<p>Neighbours experience the following costs:</p> <ul style="list-style-type: none"> 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.
<p>Economy (cost) - Ideal measurement practice</p>	<ul style="list-style-type: none"> 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. 	<ul style="list-style-type: none"> 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. 	<p>The cost to neighbours as a result of the road being present (include maintenance of housing, depreciation, social costs etc).</p>

Table A-11 Stakeholder Expectations and Ideal Measurement Practice for Structures

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Availability What the stakeholder expects</p>	<p>That the entire network is accessible at all or most times Closures must be predictable, Travel shall be possible at a minimum speed, dependent on the time of day, or season, service Safety should be present at all times.</p>	<p>Maintenance of highway structures shall be minimal, whilst maintaining the Service Quality i.e. structural repairs should have minimal effect on network availability, Structures are kept in such a condition that roads would not need to be closed because of repeating repair works.</p>	<p>Diversions are put in place when the road is not available; these diversions do not cause local traffic problems, damage to their property, or similar issues.</p>
<p>Availability What the ideal measurement practice might be</p>	<p>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.</p>	<p>If operators' income is affected by network availability or amount of delay due to pavement maintenance, the <i>amount of delays (hours) caused by maintenance</i>, If there is a chance of being sued if the emergency services can't get to where they're needed.</p>	<p>If affected: Unavailability of road network due to highway structures maintenance, Delays due to maintenance. Otherwise they may enjoy less traffic noise. Accurate predictions of time and duration of maintenance interventions, Efficiency of information regarding road works, and associated delays, diversion routes etc</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Service Quality</p> <p>What the stakeholder expects?</p>	<p>Certain level of comfort, e.g. lack of vibration,</p> <p>No obstacles near or on highway structures,</p> <p>Minimum noise (due to expansion joints...),</p> <p>Good visibility (minimum splash spray, dust, snow deposits...).</p>	<p>Highway structures should not be bottlenecks in the road network</p> <p>Highway structures should not affect general availability of the network,</p> <p>Level of service should minimise vehicle damage, thus avoiding claims from users.</p>	<p>Highway structures shall be not maintained too often,</p> <p>Noise levels from highway structures (e.g. expansion joints) should be at a minimum,</p> <p>Infrastructure to be in place to ensure that the road users stay on the road.</p>
<p>Service Quality</p> <p>What the ideal measurement practice might be</p>	<p>Level of comfort (bumps on bridge approaches, potholes ...).</p> <p>In-car noise at expansion joints.</p> <p>Level of splash spray</p> <p>Ice on bridges.</p>	<p>These requirements depend on how the owner/operator operates their contracts. If we assume that they have user or service quality requirements built in, then these might contain all of those listed in the users' requirements.</p> <p>Thresholds specified may differ from user requirements.</p>	<p>Level of noise, particularly from expansion joints, but also tyre/pavement interaction noise, engine noise, noise caused by poor fastening of road equipment...</p> <p>Adequacy of road drainage, leakage through the bridges...</p> <p>Number of excursions per section.</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Safety What the stakeholders expect?	Highway structures should in general not lead to any safety issues, in particular: Bridges, tunnels, culverts and retaining-supporting walls should not collapse. In tunnels there shall be no danger of spalling of material Drainage shall be sufficient to prevent safety issues due to water (aquaplaning, splash spray...)	Level of safety shall: Minimise accidents, which affect the availability of the road, are costly to clear up the accident, and make any repairs needed to highway structures. Minimise liability. Ensure that road workers are not exposed to excessive danger	As for the entire road network, nothing specific for highway structures
Safety What the ideal measure-practice might be	Interventions related to structural and traffic safety should minimise interruptions of traffic flows	Measurements/monitoring that prevents from jeopardising structural safety of highway structures, especially bridges and tunnels Measurements/monitoring that prevents from causing traffic safety problems, such as icing on the bridges	As for the entire road network, nothing specific for highway structures
Environmental Impact What the stakeholder expects?	“Green” users might expect their CO ₂ emissions to be at a minimum (congestion/traffic flow), Provision of structures (where appropriate) to reduce fuel consumption, through reduction in gradient.	Unnecessary maintenance should be avoided (since this generates noise, dust and CO ₂), To consider local nature and consider waste management, when carrying out maintenance, Structure should not pollute its surrounding area (e.g. leaching of chemicals into the table water).	Noise, dust, fumes, water run-off to shall be at a minimum, to prevent property damage or illness. Level of vibration that cause damage to their health or their property, shall be at minimum
Environmental Impact	As for the entire road network, nothing specific for highway structures	measurements and monitoring should provide necessary information to avoid	adequacy of road drainage, where it drains to, what contaminants it

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
What the ideal measurement practice might be		unnecessary interventions that have environmental impact (Casas, 2010)	contains, equal for splash and spray vibration control/measurement, wildlife consideration e.g. mammal/ amphibian tunnels.
Durability What the stakeholder expects?	highway structures with low durability shall not prevent the road from being available and providing adequate service quality.	durability should be such as to minimise maintenance on highway structures. This is related to mobility and economy issues. durability of structures shall be predictable, particularly failures (risk assessment).	durability is appreciated as it prevents from disturbances listed above
Durability What the ideal measurement practice might be	As for the entire road network, nothing specific for highway structures	measurements/monitoring that will prevent from premature deterioration, and will deliver parameters from which durability could be calculated. measurements of structural strength and loading on structures visual inspections that predict deterioration problems	As for the entire road network, nothing specific for highway structures

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Economy (cost)</p> <p>What the stakeholder expects?</p>	<p>fuel consumption, taxes or tolls, congestion (this incurs delay charges), vehicle damage (via wear or accident) shall be minimised,</p> <p>maintenance work shall not incur costs arising from detours and delays</p>	<p>costs for maintenance and management of structures (including survey costs) shall be minimised</p> <p>the whole life costs shall be minimal, or at least sensible</p> <p>costs incurred by accidents, whether for liability claims or clear-ups, shall be minimal</p>	<p>presence of highway structures shall not devalue their properties</p> <p>effects of dust, pollution and vibration shall not increase their maintenance bills</p> <p>there shall be no health issues from living near a structure, which would have cost implications.</p> <p>at least, these effects shall be minimal</p>
<p>Economy (cost)</p> <p>What the ideal measurement practice might be</p>	<p>As for the entire road network, nothing specific for highway structures</p>	<p>measurements/monitoring shall provide information that will:</p> <p>optimise expenditures on maintenance of structures</p> <p>extend life-time of bridges by providing realistic information about traffic loading and bridge capacities (Woodward, McKenzie, Žnidarič, Denarié, & Richardson, 2006)</p>	<p>As for the entire road network, nothing specific for highway structures</p>

Table A-12 Stakeholder expectations and ideal measurements, equipment

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Availability <i>What the stakeholder expects</i>	Users expect that the necessary equipment for an efficient and safe trip are present	The owner shall maintain a minimum level of service at minimal cost (maintenance/repairs)	Presence of equipment shouldn't interfere with the quality of living (global environment) or should be available i.e. present in order to improve it.
Availability <i>What is ideal measurement practice?</i>	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	If the operators' income is affected by network availability or amount of delay due to equipment maintenance, the <i>amount of delays (hours) caused by this maintenance.</i> If there is a risk of being sued if the emergency services can't get to where they need or if there is an economic impact: quantification of possible loss	Hindrance due to equipment is difficult to quantify and is related to an assessment of the quality of life Presence and efficiency of equipment designed to reduce the hindrance is related to its design and condition (e.g. noise barriers)

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Service Quality</p> <p><i>What the stakeholder expects</i></p>	<p>The users expect the equipment to meet their own criteria.</p> <p>There may be a discrepancy between the owner's objective and user's perception.</p>	<p>The owner expects any in-place equipment to fulfil, in an optimal way, the objectives for which the equipment was selected.</p> <p>In other words, was the right equipment implemented at the right place?</p> <p>Support to the users for safety and/or traffic fluidity.</p>	<p>N/A</p>
<p>Service Quality</p> <p><i>What is the ideal measurement practice?</i></p>	<p>Visible signs and markings : presence</p> <p>Accuracy and readability of VMS messages</p> <p>Adequate signalisation, non-equivocal signs and messages is difficult to measure, can be assessed with an on-site inspection</p>	<p>These 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 these might contain all of those listed in the users' requirements : initial performance is often described in the specifications</p> <p>Thresholds specified may differ from user requirements in certain circumstances</p>	<p>Level of noise (hindrance limiting equipment)</p> <p>Level of lighting (hindrance due to the equipment)</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Safety</p> <p><i>What the stakeholders expect</i></p>	<p>The users expect the equipment to have a positive impact on their trip's safety. The equipment should not be hazardous obstacles.</p>	<p>Owner wants to provide equipment that will prevent accidents from occurring, or minimise the damage and injury if accidents do occur.</p> <p>Owner wants to optimise the use of forgiving equipment by selecting the best location following the risks. Balance between benefits and investment cost is crucial.</p>	<p>Safety from the neighbour's point of view may be considered as indirect and related to a specific interest. A shop owner wants safe access for his customers, an individual wants a safe street for his relatives, a school wants a safe area near its entrance for the pupils.</p> <p>Thus, the neighbours expect provision of equipment that prevents vehicles from leaving the carriageway, where there is high risk that this may happen.</p>
<p>Safety</p> <p><i>What is the ideal measurement practice?</i></p>	<p>Length of network equipped with lighting and restraint systems</p> <p>Length of network equipped with VMS giving instructions about the road and/or traffic condition</p> <p>Length of network equipped with "motor biker friendly" markings</p>	<p>Measurements/monitoring that prevents from jeopardising safety on roads (e.g. Remote control of lighting)</p> <p>Measurements/monitoring that prevents from causing traffic safety problems, such as icing</p>	<p>As for the entire road network, nothing specific for equipment.</p>

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
Durability <i>What the stakeholder expects</i>	Users expect the equipment to be continuously present and to be constant in its performance	Lifetime expectance should be predictable.	Durability of the equipment will limit the nuisance
Durability <i>What is the ideal measurement practice?</i>	Days of service unavailability	Measurements/monitoring that will prevent from premature deterioration, and will deliver parameters from which durability could be calculated. Visual inspections that predict deterioration problems	N/A
Environmental Impact <i>What the stakeholders expect</i>	Users are increasingly “environment” minded. The road equipment can have a positive impact on the travel time (VMS messages...). This will have a positive impact on the emissions (less fuel used)	Less emissions = less costs for curative measures	Less emissions and nuisances can be achieved with appropriate equipment.
Environmental Impact <i>What is the ideal measurement practice?</i>	Time for the home-work daily trip...	Monitoring of traffic speed on strategic sections Monitoring of noise, weather data and pollutants level	Pass by noise, particulates, CO2 levels, other harmful gases.

Stakeholder	User (commercial and private)	Owner/Operator	Neighbours
<p>Economy (cost) - what the stakeholder expects</p>	<p>VMS can limit the time spent in traffic jams</p> <p>Total costs for the society (accidents...) may be reduced due to safer and efficient restraint barriers (e.g. for motor bikers), safer poles (frangible), presence of road markings.</p>	<p>The owners expect to incur a level of cost for maintenance and asset management (including survey costs).</p> <p>They expect the whole life costs to be minimal, or at least sensible.</p> <p>They also expect to minimise costs incurred by accidents, whether for liability claims, or clear up etc.</p>	<p>Neighbourhood can be impacted if the equipment needs in energy and maintenance increase, resulting in potential extra taxes to cope for the electricity bills (lightings) and maintenance.</p> <p>The equipment can also have a negative impact on estate value (landscape...)</p>
<p>Economy (cost) - Ideal measurement practice</p>	<p>Maintenance work shall not incur costs arising from detours and <u>delays</u></p> <p>Percentage of the road network equipped with efficient and safer equipment</p>	<p>Measurements/monitoring shall provide information that will optimise expenditures on maintenance of equipment</p>	

Appendix C. Example of national policy objectives from Sweden

Ministry of Enterprise, Energy and Communications, Sweden

“The objective of the Swedish transport policy is decided by the Swedish government (2009). The overall objective of transport policy in Sweden is to ensure the economically efficient and sustainable provision of transport services for people and businesses throughout the country. This is further distinguished in two major objectives, **Functional** and **Impact** objectives that are described in the following.

FUNCTIONAL OBJECTIVE: *Accessibility*

The design, function and use of the transport system will contribute to provide everyone with basic accessibility of good quality and functionality and to development capacity throughout the country. The transport system will be gender equal, meeting the transport needs of both women and men equally.

IMPACT OBJECTIVE: *Health, safety and environment*

The design, function and use of the transport system will be adapted to eliminate fatal and serious accidents. It will also contribute to the achievement of the environmental quality objectives and better health conditions.

Details of the functional and impact objectives

To achieve the functional and impact objectives the following is proposed:

FUNCTIONAL OBJECTIVE

Travel for people will be improved through increased reliability, security and convenience.

Transport quality for the business sector will be improved and will strengthen international competitiveness. Accessibility will be improved inside and between regions as well as between Sweden and other countries. The working methods, implementation and outcomes of transport policy will contribute to a gender-equal society. The transport system will be designed to be accessible for people with disabilities. Opportunities for children to travel independently and safely using the transport system, and be present in traffic environments, will be enhanced. Public transport, pedestrian and cycling options will be easier to choose.

IMPACT OBJECTIVE

The number of road fatalities will be halved and the number of serious injuries will be reduced by a quarter between 2007 and 2020. The number of commercial shipping and pleasure boat fatalities will be reduced continuously and the number of serious injuries will be halved between 2007 and 2020. The number of rail and air fatalities and serious injuries will be reduced continuously. The transport sector will contribute to the achievement of the environmental quality objective, reduced climate impact, by gradually increasing energy efficiency in the transport system and decoupling from dependence on fossil fuels. By 2030, Sweden should have a vehicle fleet that is independent of fossil fuels. The transport sector will contribute to the achievement of other environmental quality objectives and lower levels of ill health. Priority is given to the targets of environment policy where the development of the transport system plays an important role in the achievement of the set objectives.”