Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

CEDR Contractor Report 2018-06

Call 2013: Ageing Infrastructure
HiSPEQ, RE-GEN and X-ARA projects

by

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Alex Wright – TRL

June 2018

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CEDR Contractor Report 2018-06 is an output from the CEDR Transnational Road Research Programme Call 2013: Ageing Infrastructure. The research was funded by the CEDR members of Denmark, Germany, Ireland, Netherlands, UK and Slovenia. The aim of the CEDR Transnational Road Research Programme is to promote cooperation between the various European road administrations in relation to road research activities. The topics covered by this Call were developed to fulfil the common interests of the CEDR members. The Project Executive Board for this programme consisted of:

- **JENNE VAN DER VELDE,** Rijkswaterstaat, Netherlands **(chair)**
- **NIELS HØJGAARD PEDERSEN,** Danish Road Directorate, Denmark
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Partners:

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Abbreviations

Abbreviation	Meaning
AIT	Austrian Institute of Technology
BIM	Building Information Modelling
CEDR	Conference of European Directors of Roads
CoF	Consequence of Failure
FEHRL	Forum of European National Highway Research Laboratories
FWD	Falling Weight Deflectometer
GDG	Gavin & Doherty Geosolutions
GPR	Ground Penetrating Radar
HE	Highways England
HiSPEQ	Hi-Speed Survey Specifications, Explanation and Quality project
IFSTTAR	Institut Français des sciences et technologies des transports, de l'aménagement et des réseaux
IM	Infrastructure Manager
IRI	International Roughness Index
LCMS	Laser Crack Measurement System
NRA	National Road Authority
PEB	Programme Executive Board
PoF	Probability of Failure
RE-GEN	Risk Assessment of Ageing Infrastructure project
ROD-IS	Roughan & O'Donovan Innovative Solutions
TII	Transport Infrastructure Ireland (Bonneagar Iompair Éireann)
TRACS	Traffic Speed Condition Surveys
TRL	Transport Research Laboratory Ltd
TSD	Traffic Speed Deflectometer
WIM	Weigh In Motion
X-ARA	Cross-Asset Risk Assessment project
WP	Work Package
ZAG	Slovenian National Building and Civil Engineering Institute

Introduction

This report summarises the work undertaken within the CEDR Transnational Road Research Programme entitled "Ageing Infrastructure: Understanding Risk Factors & High-Speed Non-Destructive Condition Assessment" which ran from April 2014 to March 2016.

Through the 2013 Call "Ageing Infrastructure", CEDR members funded research supporting the implementation of innovation in asset management solutions. The programme aimed to meet the research needs of European road authorities in three key areas:

- Understanding risk factors in managing ageing infrastructure
- Common cost breakdown framework for road assets
- High speed non-destructive condition assessment of road pavements and interacting assets.

The three projects in the programme were:

1. **HiSPEQ: Hi-speed survey specifications, explanation and quality**
2. **RE-GEN: Risk assessment of ageing infrastructure**
3. **X-ARA: Cross-asset risk assessment**

This report presents the methodology and outcomes of the three projects and provides an overview of the outcomes of the final conference on this Call, which was held in Brussels on 14th/15th February 2018.

At the end of this report recommendations are given on potential next steps in the further dissemination and implementation of the outcomes of HiSPEQ, RE-GEN, X-ARA and CEDR research projects.

PART I
The projects

HiSPEQ – Hi-speed survey specifications, explanation and quality

Project facts

DURATION: April 2014 – March 2016

PEB REPRESENTATIVE: Rolf Rabe, BaST, Germany

COORDINATOR: TRL, UK

PARTNERS:
ATI, Austria
VTI, Sweden
ZAG, Slovenia
COWI, Denmark
Fugro, Netherlands

DELIVERABLES:

Equipment Specifications and Guidance

Requirement Needs

Survey Specifications and Guidance

Training Manual

Final Report

Background and objectives

Road administrations rely on high quality condition data to understand the condition of the asset and plan and undertake maintenance programmes on their networks. High speed surveys have become a key source of this information, providing data on the shape and condition of the road surface and, in recent years, the structural robustness and the structure of the pavement itself. These high speed systems bring the advantage of network wide data collection without interfering with the traffic flow. They can provide coverage of the network that would be impractical for traditional surveys to achieve. They have lower survey costs per km than slow speed surveys and bring data that does not suffer from the subjectivity or inaccuracy of manual surveys.

High speed surveys therefore bring significant practical advantages to condition assessment, and to support robust asset management. However, research (Benbow and Wright, 2012) has found a wide range of policies across countries to define the requirements for the survey equipment, the survey frequencies and the data delivered. Each country appears to adopt its own requirements, each subtly different from one another. This is perhaps unexpected, given that the equipment used to collect this data within different countries is likely to be quite similar. A factor that contributes to this situation is the lack of standardisation for many of the measurements. Where standardisation does exist (e.g. for profile) it is limited in its practicality and may be too complex for road administrations to understand.

In May 2014 the HiSPEQ project was commissioned under the CEDR 2013 Ageing Infrastructure Management programme with the objective of developing the guidance and advice required to assist road administrations to understand high-speed road survey equipment, and to help them in specifying the survey requirements, quality regimes and processing procedures. The project has concentrated on the aspects of high-speed survey data collection that contribute to the assessment of pavement structural robustness, in particular:

- Pavement shape
- Pavement visual condition
- Pavement structure
- Pavement deflection

The underlying objectives of HiSPEQ have been to:

- Deliver templates and guidance to help road administrations define their requirements for high speed condition surveys on their networks
- Deliver templates and guidance to help road administrations understand the equipment that will be used to collect condition data at high-speed on their networks.
- Provide guidance on the achievement of high quality data collection on their networks

Description and methodology of the project

The technical approach taken in HiSPEQ has been to draw on expertise from the project consortium, reviews of previous research and existing survey specifications, and a reference group containing stakeholders (equipment manufacturers, road administrations, researchers etc.) to determine the key requirements that should be considered by a road administration when developing a specification for high-speed condition surveys of their network. This lead to the delivery of three key requirements documents describing the needs of high speed surveys of surface and structural condition, and the requirements for quality assurance of these surveys. These are described in the following sections.

Key requirements – pavement shape and visual condition

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

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

Fifteen specifications for high-speed routine monitoring were collected and reviewed to identify the current key measurement practice in the collection of surface shape and visual condition. The specifications covered the measurement of longitudinal evenness, transverse evenness and surface defects. A total of over 0.5 Million lane km of surveys were currently being undertaken against these specifications.

To review the specifications in a consistent manner a set of questions were developed and each specification was reviewed against those questions. This enabled a set of tables to be populated for each specification and conclusions and recommendations to be drawn. The review of the key requirements document hence delivered a set of recommendations for the key areas that should be considered by a road administration when defining a network survey, including:

General survey requirements:

- Whether the NRA should select a data or an equipment specification
- The minimum requirements for defining the network to be surveyed
- How the data should be locationally referenced to the network, and the use of geo-referencing
- The need to specify limits on the survey conditions (environment, measurement speed, etc.)
- The requirements for defining the data formats
- Whether an administration should request the delivery of the raw data or processed parameters.

Measurement of transverse evenness:

- The measurement width, the minimum number of transverse profile measurement points, the distribution of points, the longitudinal spacing etc.
- The importance of eliminating the effect of road markings measured within the profile on the calculation of the derived parameters
- The key derived parameters (e.g. rutting)
- The need to specify minimum requirements for accuracy and repeatability of both the raw data and the derived parameters.

Measurement of longitudinal evenness:

- The required wavelength range that must be measured by the longitudinal profiler

- The longitudinal spacing of the data, the need for collection in both wheel paths, and the need to specify the distance between the wheel paths
- The key derived parameters (e.g. IRI)
- The need to specify minimum requirements for accuracy and repeatability of both the raw data and the derived parameters.

Measurement of Surface deterioration:

- The minimum measurement width
- The minimum resolution per pixel in the longitudinal and transverse directions
- The requirements for image quality
- The types of deterioration to be identified and the need to define each of these deterioration types.

The amount that a pavement flexes under load is linked to how resilient the pavement is to this loading/unloading i.e. the pavement's bearing capacity. Road authorities need information on structural pavement condition and structure to be able to deliver safe, effective and sustainable pavements to their customers, and to support structural pavement performance prediction. In general, bearing capacity information is more important at the project level than at the network level. However, road authorities have a desire for high-speed testing devices to deliver information on the bearing capacity of their networks at the network level. The most common devices for bearing capacity testing are the deflectograph and the falling weight deflectometer (FWD). Neither of these operates at high-speed but recent development in high-speed measuring techniques has delivered a promising high-speed device called the Traffic Speed Deflectometer – TSD. Analysis of the data provided by these devices can be used to determine bearing capacity (structural condition).

However, the pavement layer thickness and material type has a strong influence on the calculation of stiffness, and therefore the structural condition. There is a clear need for any administration wishing to undertake a network level structural condition survey to have a robust understanding of the pavement structure to ensure final data accuracy. Unfortunately most administrations lack detailed information on pavement layer thickness and material type, and the slow speed method to provide this data (coring) is expensive and impractical. As an alternative, to reduce the need for coring whilst increasing the density of pavement structure information, Ground Penetrating Radar (GPR) can be used. This technology can survey at traffic speed and provides layer thickness information. Thus, the structural properties considered to be important for the high-speed assessment of pavement durability in the HiSPEQ project were:

- Pavement deflection measured at high speed using the TSD
- Pavement structure measured at high speed using GPR.

To investigate the use of the TSD and GPR for the provision of structural condition data HiSPEQ investigated the current specifications for high-speed routine monitoring of structural condition (TSD) and pavement structure (GPR). To support the review, additional information was also sourced from the research, including the HeRoad reports into pavement condition assessment and the FORMAT reports. For the TSD in particular the review included investigation of the experience gained to date in the use of the TSD as a survey device in Denmark, UK, Italy, Poland, South Africa, China, USA and Australia, and the two national survey specifications already in place for TSD surveys in UK and Italy. For the GPR a detailed technical review was undertaken on the various approaches to measuring structure with GPR and how the method can be applied. The review found that GPR is not widely applied at the network level, but survey specifications were available from the UK, Ireland, Sweden and the USA to support the assessment of key requirements.

The review of requirements for structural assessment presented a set of recommendations for the key areas that should be considered by a road administration when defining a network survey using the TSD and GPR, including:

General survey requirements: It was found that these are often similar to the general requirements discussed above for the assessment of the pavement surface, but further recommendations were made on:

- Specifying the measurement position in the lane.
- The survey frequency (which may be lower than that required for surface assessment due to the longer term stability of the road structure in comparison with the road surface).
- Specifying the survey temperature (which affects structural assessment more than surface assessment)
- The higher levels of complexity in the reporting of raw data from GPR systems and the complexity in interpreting this data.

Measurement of structural condition (TSD):

- The equipment requirements (number of lasers, sample frequency)
- The key raw data to be delivered, including ancillary information such as road temperature, tyre pressure etc.
- Options for data analysis to estimate structural condition (e.g. Surface Condition Index).

Measurement of structure (GPR):

- The survey scan interval spacing
- The requirements for measurement depth
- The legal and conformity issues (due to GPR's RF emissions)
- The requirements for interpretation of the data to determine construction (layer thickness).

Key requirements – Quality Assurance

Because of the complexity of collecting and delivering the survey data there can be problems obtaining accurate, high quality and consistent measurements across different survey devices and different networks. Indeed, there are many examples, from established high speed condition survey regimes, of delivered data being inconsistent between devices (either owned by the same survey contractor, or a different one), and delivered data not being accurate, despite a high equipment specification. There are also examples of the data quality deteriorating, or changing through the duration of a survey contract, due to wear of the equipment. The experience gained from these well-established survey regimes suggest that there is a great need for both Accreditation of survey equipment and continuing Quality Assurance, in order to obtain confidence in, and good value for money from, the data that will be delivered from network surveys. When developing a specification for survey equipment or survey data, a road Authority must therefore consider how they will obtain confidence in the data that will ultimately be delivered. Questions that should be answered by a road Authority commissioning a survey may include:

- What are my technical requirements for the consistency/accuracy and how will I ensure that the data is provided to a suitable level?
- How will I ensure that the data remain consistent during the survey?
- How will I ensure the data, or problems within it, do not introduce changes to the way the condition of the network is reported (for example in comparison with the regime that it has replaced)?
- How will I ensure that the data continues to cover the network at the level of performance required in the specification?

HiSPEQ reviewed several specifications containing descriptions of Quality Assurance and/or Accreditation regimes. These included thirteen specifications for surface condition, but only one specification was identified in which network level structural condition surveys were being carried out, and in which routine Quality Assurance testing was being applied.

The review of requirements for accreditation and quality assurance presented a set of recommendations for the key quality areas that should be considered by a road administration when defining a network survey for either surface or structural condition, including:

- The parameters and measurements that should be tested within Accreditation and QA regimes
- The aspects of data quality that should be tested
- How the data could be collected for testing
- The frequency of quality testing
- Who should be responsible for checking the data – including the concept of the independent auditor
- How you might test for the effects of external influences on the data.

Key requirements – stakeholder group and review

HiSPEQ has been supported by a stakeholder group of researchers, road owners, survey practitioners and experts in the field of condition assessment. This stakeholder group was primarily established during the first quarter of the project with additional members joining as the project proceeded. Over 80 stakeholders were contacted to ask if they would like to support the project through the provision of advice and review of the outputs, with 34 volunteering to join the reference/stakeholder group.

The key requirements documents were sent to the 34 responding members of the reference group and also made available on the project website (http://www.HiSPEQ.com), with a general invitation given to review and submit comments to the project team. By the autumn of 2015 six detailed reviews had been received for the key requirements document for surface condition, seven on the key requirements document for structural condition measurements and three on the key requirements for Quality Assurance. These were taken into account in the development of the equipment and survey specification templates and guidance.

Survey and Equipment Specifications

Having determined the key requirements for high speed surveys HiSPEQ sought to translate this information into a form that could be used by road administrations to help in the development and implementation of surveys on their networks. The approach of the project has been to develop templates that can be used by the administration to procure surveys, covering two broad areas:

- Templates that can be used to define the survey data requirements. These are called the survey specification templates, they define the requirements for the data to be collected and delivered. They are accompanied by a guidance document that explains the content of the specification.
- Templates that can be used to define the equipment itself. These are called the survey equipment templates. They have been developed to allow survey providers to explain how their equipment works in a common format that contains sections directly relevant to the data being requested in the survey specification. They are accompanied by a guidance document that explains the content.

Survey Specifications

The survey specification requirements were developed from results of the key requirements work, and the peer review of those findings. A set of templates has been developed defining each area of collection of pavement condition data. The survey specification templates are delivered in “volumes”. The core items that a road administration should always include within any survey specification are included in the first “volume” of the survey specification, called ***HiSPEQ1: Specification for Pavement Condition Measurement,*** which contains:

The definition of the network and the survey strategy, to include: The location and length of each road section to be surveyed, the direction of survey, number of lanes to be surveyed, time frame and frequency of the survey etc.

- The location referencing method. HiSPEQ recommends that geographic coordinates are used for location referencing if a geographically defined network is available, as this can result in improved locational accuracy. To achieve high locational accuracy it is necessary to stipulate accuracy requirements to the level of a few metres or better. This is achievable in practice.
- The environmental conditions for conducting the survey, covering road condition (dry road surface for laser devices, clean road surface), survey speed (e.g. minimum speed for measuring longitudinal profile with inertial profilers), pavement temperature (for TSD data) etc.
- The data formats. HiSPEQ found that although defined data formats are already in use for (national) road administrations, there is no internationally recognized format.
- Coverage requirements. This is the percentage of the surveyed network for which valid data will be delivered. It allows the specification to recognise that no survey equipment can measure and deliver valid data all the time and some survey equipment can deliver more valid data than others.

When specifying a survey an administration would always include the areas recommended in the first volume, HiSPEQ1. The remaining volumes may then be included if the administration requires the inclusion of that data within the survey (e.g. ride quality). A set of survey data specification templates have been developed for each data type, each containing sections the administration should include to ensure all core requirements are covered. These include:

- The core decision on how the data is to be delivered (processed/raw data). Requiring the delivery of raw data provides the benefit that derived values (rutting, ride quality) can be calculated consistently over all contractors.
- The raw data to be delivered, including the technical requirements (resolution, accuracy, frequency etc.)
- The parameters that will be delivered, for example rutting, IRI, TSD deflection slope
- Accreditation requirements, including suggested tests, reference devices or methods to provide reference data, the frequency with which the test will need to be repeated, suggestions for who will be responsible for checking the data and requirements for the accuracy of any parameters delivered or calculated from delivered data.
- Quality assurance requirements to be employed by the survey contractor on the data, including a description of the tests (calibration, surveys of road network sites, number of repeat surveys required, whether accuracy and fleet consistency will be tested, in addition to system consistency), a description of the road network sites (i.e. length, characteristics etc.) to be surveyed and the frequency with which they should be surveyed, suggestions for who would be responsible for assessing and checking the data, how the data would be assessed etc.

These HiSPEQ survey data specification templates have been labelled as follows:

- **HiSPEQ2:** ***Specification for Referencing Data to the Network***
- **HiSPEQ3:** ***Specification for Pavement Transverse Evenness Measurement***
- **HiSPEQ4:** ***Specification for Pavement Longitudinal Evenness Measurement***
- **HiSPEQ5:** ***Specification for Pavement Surface Deterioration Measurement***
- **HiSPEQ6:** ***Specification for Pavement Structure Measurement***
- **HiSPEQ7:** ***Specification for Pavement Traffic Speed Deflection Surveys***

A guidance document has been developed for road administrations to help them understand the requirements of each template volume (**HISPEQ:** ***Guidance for Road Administrations for Specifying Network Surveys***). It is intended that each section in the guidance can be used by road administrations to assist them in completing the requirements in the corresponding specification template document.

The guidance includes suggested specific requirements that a road administration may wish to use within their specifications (Figure 1). These requirements have been obtained from examples of common and good practice observed in Europe and elsewhere. Therefore the guidance is supported by more than 75 Case Studies and more than 50 Examples to demonstrate the application of good current practice, or emerging new approaches in data collection. The suggestions have also been derived from knowledge of existing equipment availability and capability, to assist administrations in ensuring that the requirements they define are achievable in practice. However, administrations will inevitably have their own requirements as a result of specific concerns on their networks, and therefore the ultimate selection of a certain requirement remains the decision of the administration.

HiSPEQ recommendations for transverse profile measurements:
- minimum width: 3 m, maximum width: 4 m (full lane width coverage)
- recommendation for major network roads (highways): 3.5 m to 4 m .
- the required width should be chosen according to the predominant lane
- transverse profile shall contain at least 20 measurement points (maximum spacing: 150 mm i.e. 27 measurement points for a 4 m width coverage
- for rutting assessment alone 50 measurement points are considered to be sufficient

Figure 1 Example HiSPEQ recommendations for specifying transverse profile measurement

Equipment Specifications

The equipment specification templates have been developed to allow survey providers to explain how their equipment works in a format that is directly relevant to the data being requested in the survey specification for that data. There are six Equipment templates:

- **HiSPEQ2E:** ***Equipment to measure location***
- **HiSPEQ3E:** ***Equipment to Measure Transverse Evenness***
- **HiSPEQ4E:** ***Equipment to Measure Longitudinal Evenness***
- **HiSPEQ5E:** ***Equipment to Record Downward Facing Images***
- **HiSPEQ6E:** ***Equipment to Measure Pavement Structure***
- **HiSPEQ7E:** ***Equipment to Measure Traffic Speed Deflection***

The Equipment templates were developed after the structure for the survey specification template had been determined so that sections could be included that could be cross referenced to the data requirements defined in the survey specification.

Each equipment template includes guidance to assist the equipment provider in completing the template. In addition a separate guidance document has been prepared that explains the technical content of the templates for road administrations. As for the guidance document for the survey specifications, the equipment template guidance includes Case Studies and Examples to help explain the technical content.

Training materials

The final component of HiSPEQ has been to deliver a set of training materials to assist road administrations in the implementation of the HiSPEQ approach – i.e. how an administration could use the templates to support the development of survey regimes on their network.

Evaluation and outcomes of the project

High speed surveys have become a key source of information to support condition assessment and management of pavement assets. These surveys can be applied network wide to obtain data on the surface condition and structural robustness of the pavement. The success of high speed surveys is demonstrated by the growth in the survey industry and the wide range of measurement equipment that has become available. However, these advances bring challenges to road administrations in determining the most appropriate survey to specify for their networks, in selecting the equipment, and in ensuring that the condition parameters delivered will be suitable to support asset management decisions.

HiSPEQ has proposed a set of core requirements for high-speed surveys of pavement surface and structural condition, covering the data to be collected and the condition parameters derived from the collected data to evaluate pavement structural condition. These requirements have been used to develop survey specification templates for road administrations developing survey requirements for their own networks. Guidance has been developed to accompany the templates, to assist road administrations understand the technical requirements and the implications of different levels of resolution and accuracy on the use of the data. The project has also proposed a set of quality assurance processes to consider when specifying condition surveys.

It is anticipated that the HiSPEQ guidance and template specifications could help reduce the wide range of policies that exist across countries with regard to high-speed survey equipment, survey frequencies and the data delivered. It will contribute to improving the value of these surveys and the efficiency of the commissioning process, whilst also assisting in the delivery of higher quality survey data that will support more robust decision making.

RE-GEN – Risk Assessment of Ageing Infrastructure

Project facts

DURATION: April 2014 – March 2016

PEB REPRESENTATIVE: Tom Casey, TII, Ireland

COORDINATOR: ROD-IS, Ireland

PARTNERS:
GDG, Ireland
ZAG, Slovenia
IFSTTAR, France
Ramboll, Denmark
TU Delft, Netherlands

DELIVERABLES:

D1.1	Quality Assurance Plan
D1.2	RE-GEN project website
D2.1	Report on Climate Change Predictions (including key variables)
D2.3	Ranked List of models for Different Damage Processes
D3.1	Guidelines on Collecting WIM data and forecasting of traffic load effects on bridges
D3.2	Review of the most critical existing structures under growing traffic and advice for precise assessment
D4.1:	Report of the literature review on risk frameworks and definition of road infrastructure failure
D4.2:	Risk Optimization in Road Infrastructure Elements
D5.1:	Risk analysis software tool
D5.2:	Final Report on optimization of management strategies under different traffic, climate change and financial scenarios.

Background and objectives

The majority of infrastructure components for road transport system were constructed during the 1960's and the 1970's, and many of the structures built during this period are now in need of repairs or no longer can adequately serve the road users. As infrastructures age, deterioration caused by heavy traffic and an aggressive environment becomes increasingly significant, resulting in a higher frequency of repairs and possibly a reduced load carrying capacity. The need for safe effective asset management to maintain environmentally friendly traffic routes is increasingly urgent.

Asset management systems have been developed by many countries to serve as a tool to track inventory data and to analyse maintenance and improvement needs for existing infrastructures. These systems aim to combine management, engineering, and economic input in order to help determine the best action to take for the management of all structure elements of the network over time. The actions can involve enhancement of safety, providing additional structural capacity, and preservation of existing facilities.

In the context of climate change under scarce capital resources, the need for risk-based prioritization and optimization of budgets/resources for maximized service life performance of road infrastructure seems urgent. This report is aimed at presenting an overall approach, considering performance aspects such as structural degradation, increasing loads, and natural hazards in the decision making process for management of ageing structures.

Description and methodology of the project

The framework proposed in the RE-GEN project is summarized in Figure 2, where module M1 is concerned with degradation modelling and considers ageing, traffic volume and environmental conditions, as potential factors in the degradation process; module M2 considers an integrated risk analysis, while module M3 considers maintenance strategy optimization.

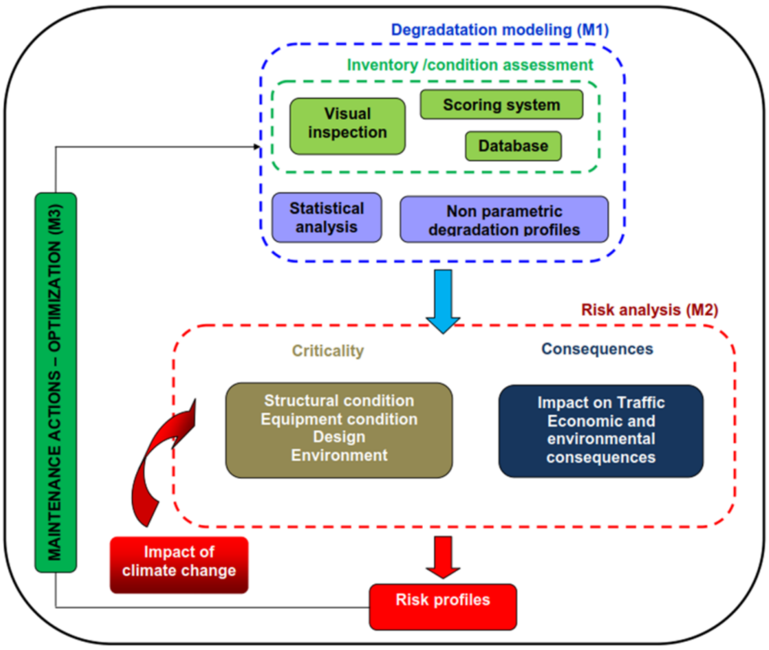


Figure 2 Proposed risk-management framework

This framework includes (a) the modelling of vulnerability under the impact of climate change, (b) consideration of potential impacts of traffic growth, (c) risk assessment and (d) risk management and development of decision tools. The objective is to provide road owners/managers with the best practice tools and methodologies for risk assessment of critical infrastructure elements, such as bridges, retaining structures, and steep embankments. The proposed methodology can consider risk from a variety of perspectives, e.g. safety risk, financial risk, operational risk, commercial risk and reputational risk, while considering both the current situation and the challenges posed by projected traffic growth, climate change and limited funding.

Degradation Modelling

The objective of the proposed framework developed by the RE-GEN project is to deliver an asset management framework based on visual inspection. To do so, a stochastic Markov chain approach is used for predicting the performance of infrastructure components. Examples of this approach have been explored in the project including from the French (used in France on the non-concessionary state managed national roadway network), Danish and Irish scoring systems. Such scoring systems exemplify an approach to provide a global assessment of road infrastructures at a national level.

Two methods are provided to determine transition matrices: the first uses the breakdown per age and per condition state at the scale of the overall stock. The second one considers transition sequences in the inspection database. It should be noted that these two methods to determine the degradation process are detailed so that any infrastructure manager can determine their own deterioration processes based on their inventory and the condition assessment of their stock. The second one considers transition occurrences for each structure in the database during a certain period of time.

Approach based on the breakdown per age and per condition

The approach proposed in this section can be used to determine transition matrices from an inspection database. Instead of considering each element and corresponding transition occurrence in the database, the overall breakdown in condition states with age is considered. The main assumption is that the categorization of the different states for each age is the same as the one which would be observed during the i^{th} inspection of the stock. This method can be applied to an inspection database once the classification according to the age and condition is known. The main advantage of such an approach is in the case of recent scoring systems with only one or two inspection campaigns (that is, when there is few transition occurrences between some scores), or when the time interval between two inspections is not consistent.

Approach based on transition occurrences

This approach is applied by comparing condition scores between different years (a_0 and a_f). The probability P_b (q_1, q_2) of a component b weighted by a characteristic value (e.g., the deck or wall area) moving from one score to another (q_1 to score q_2) can be defined as the total characteristic unit (area, length, width, etc.) rated q_1 at year i and q_2 at year i + 1 divided by the total characteristic unit rated q_1 at year i for i between a_0 and a_f .

Applying this approach is relevant if several inspection campaigns exist in the database with regular inspection intervals. To obtain pure degradation matrices, all sequences associated with a condition improvement (due to maintenance) are replaced by some degradation in subsequent scores, considering several possible assumptions. For example, whether the components would or would not have deteriorated by one unit if no maintenance had been performed. Such assumptions lead to a pure degradation matrix.

Once the transition probabilities are determined, the objective is to quantify the performance of each bridge/retaining wall component through the use of an adequate lifetime indicator. This indicator is determined herein by the probability of a component to be scored in a certain condition with time. If (i) the probability of a component to be quoted in any score is known at year i (for example, after a visual inspection of the bridge) and stored in a vector q^i_b and (ii) the associated homogeneous Markov chain, associated with a transition matrix P_b, is determined.

Assuming a homogeneous Markovian process, the scoring probability can then be forecasted if the transition matrix and the initial probability vector are known. The potential impacts of climate change and ageing of infrastructures are modelled through the combination of several degradation matrices for different ranges of age of bridges, walls and slopes. These degradation matrices can be determined for different national assets, depending on the availability of scoring system database.

Risk analysis

In the context of climate change resulting in an increased frequency of extreme weather conditions and with an expected increase of traffic, a risk-based approach is proposed for identifying and qualifying hazards and quantifying vulnerability and consequences. Such an approach can be applied to existing structures whilst several years of operation, distresses, or characteristics may increase their vulnerability, and reduce their level of service and the safety of users. The aim herein is to make a clear relationship between the degradation of components and the risk profiles. Such risk profiles quantify a joint measure of hazards, vulnerability and consequences of inadequate level of service considering several failure modes. Risk levels are time dependent since the performance of structures decreases with time due to progressive deterioration of the infrastructure components. Two following failure modes are considered:

- Loss of serviceability (minor structural failure or equipment failures that need some urgent repair actions)
- Structural failure (major structural failure that needs some urgent major rehabilitation).

To determine a relationship between degradation and risk, a system analysis is performed to determine a performance indicator at a system level. Indeed, an infrastructure consists of several components, and each component has its own failure probability; the interaction between components determines the overall failure probability of an infrastructure. Therefore, there is a need to develop a systematic method to evaluate the system-level failure probability considering the interaction of different system components. In the proposed approach, two groups of components are considered: structural components (transition matrix P_s) and equipment (transition matrix P_e).

The evaluation and the condition rating is carried out for components, taking into consideration the degree of distress or deterioration of the component and its ability to fulfil its function. The fault tree used to switch from a component level to a system level. The fault tree used in the RE-GEN project to switch from a component level to a system level is illustrated in Figure 3 for bridges (for failure modes 1 and 2, respectively) and in Figure 4 for walls (for failure modes 1 and 2, respectively). For such series systems, the failure state is reached if at least one of the components fails. For bridges, a loss of serviceability refers to a series system of expansion joints, waterproofing, and other equipment. A structural failure refers to a series system of bridge deck and bearings. For walls, a loss of serviceability refers to a series system of sewerage/drainage and equipment. Likewise, a structural failure refers to a series system of the zone of influence and structural condition.

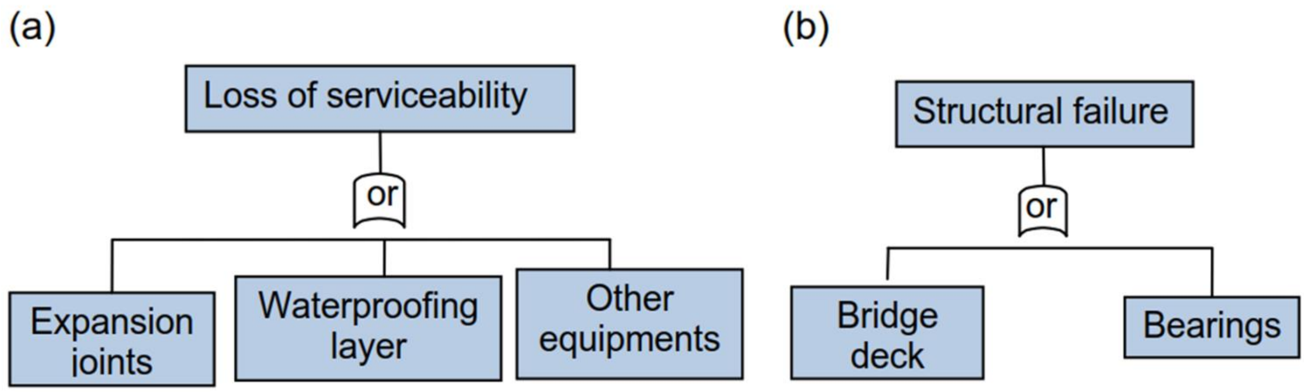


Figure 3 Fault tree model used for bridges (French case study) (a) loss of serviceability and (b) structural failure.

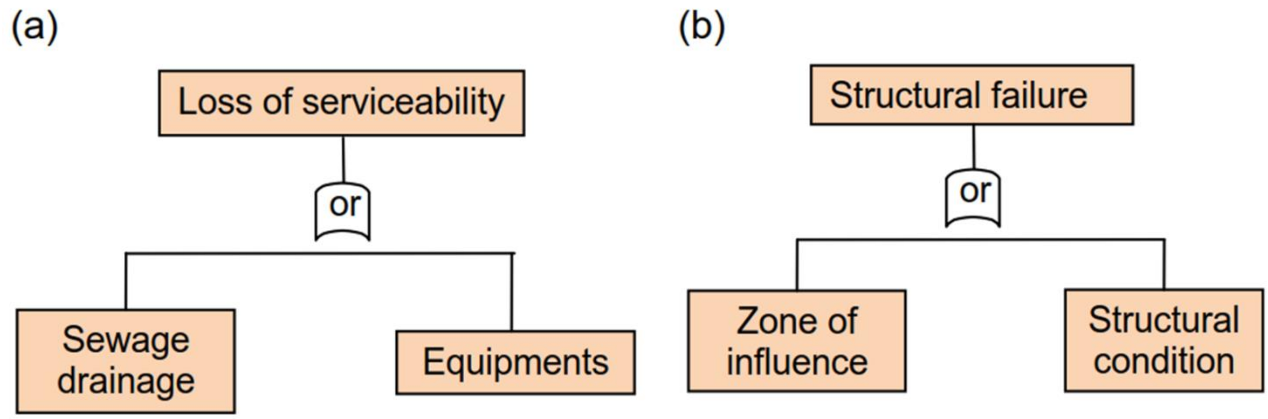


Figure 4 Fault tree model used for walls (French case study) for (a) loss of serviceability and (b) structural failure.

It was found that the predictions of the model and the observable trends in the database do not perfectly match and so the second approach based on transition occurrences was used instead. For bridges and walls, condition scores are assessed for equipment condition or structural condition by considering the worst score shown in the corresponding fault tree. Table 1 and Table 2 give an example on how new annual transition sequences can be built from existing databases.

Score	2010	2011	2012	2013	2014
Expansion joint	1	2	2	2	2E
Waterproofing layer	1	1	1	1	1
Other equipment	2	2	2E	2	2
Series “Equipment” system	2	2	2E	2	2E

Table 1 Identification of annual transition sequences for worst scores among equipment.

Score	2010	2011	2012	2013	2014
Bearings	1	1	1	3	3U
Desk	1	1	2	2E	2E
Series “Structural” system	1	1	2	3	3U

Table 2 Identification of annual transition sequences for worst scores among structural components.

To determine the annual transition matrices associated with equipment and structural components, the new sequences identified with the approach exemplified in Table 1 and Table 2 were used (and not the initial database). An example of matrix developed based on a sample of the database of pre-stressed concrete bridges is provided below:

$$\boldsymbol{P_s} = \begin{pmatrix} 0.74 & 0.19 & 0.06 & 0.01 & 0 \\ 0 & 0.89 & 0.10 & 0.01 & 0 \\ 0 & 0 & 0.91 & 0.09 & 0 \\ 0 & 0 & 0 & 0.94 & 0.06 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \qquad \boldsymbol{P_e} = \begin{pmatrix} 0.80 & 0.17 & 0.03 \\ 0 & 0.88 & 0.12 \\ 0 & 0 & 1 \end{pmatrix}$$

The probability of failure is associated with the probability to be in the worst condition class (i.e. 2E for the equipment-component system and 3U for the structural-component system).

Once the degradation model is built, it is expected to deliver for climate change exceptional degradation matrices that suddenly deteriorate the component to the worst condition and may lead to a major structural failure of some part of the structure or even to the full collapse. The objective of this methodology is then to (i) indicate how each component is affected by each extreme event, and (ii) help assess the consequences associated with each impact on critical parts of the structure. Such matrices have to be in agreement with the scoring system used by NRAs.

It is worth noting that these additional degradation matrices are not meant to model a change in the annual degradation rate (e.g., for carbonation) due to the temperature/CO_2 concentration increase. Instead, they model the occurrence of a sudden event (storm, flood, heavy rains, etc.) that results from climate change for which we will control the frequency of occurrence and the percentage of the stock affected by this event.

For traffic increase, it is expected that the initial degradation matrix is slightly transformed by increasing the terms of degradation. This process will be performed for components most likely to suffer from traffic increase (e.g., bridge equipment).

Optimisation of Maintenance Strategies

The optimisation approach developed by RE-GEN has been formulated in a general way so that it can be easily adapted to any condition scoring systems. Optimisation can be performed via single (mono-) objective optimisation and multi-objective optimization.

Several prospective scenarios can be defined in the proposed framework. These scenarios can give priority either to preventive or corrective actions, with the aim of controlling the budget and ensuring the preservation of the asset. Each degradation/maintenance strategy is associated with a transition matrix.

The ultimate step of the framework in Figure 2 integrates performance aspects in the decision process for ageing structures, including structural degradation, increasing loads, and natural hazards translated into risk profiles. The variables in the optimization process are the maintenance actions and times for bridge, walls, and slopes. Optimal parameters are those that minimize the overall risk while minimizing the maintenance costs. Such optimization procedures should allow NRAs to assess the necessary additional effort to satisfy performance constraints under different scenarios of traffic growth and climate change.

The objective is to determine the optimal annual combination of the different strategies to maintain the bridge stock in good condition with limited budgets. A new challenge herein is to include the effects of climate change in the procedure and to see how it impacts financial allocation in a long-term perspective. A number of equations were examined to calculate the annual cost for the equipment series system. Several optimization scenarios are possible and two are explored in detailed; the first aimed to minimize the annual cost for every year of the planning and the second is aimed at minimizing simultaneously the total maintenance cost and the risk cumulated during the overall planning horizon.

The optimization framework considered in the RE-GEN project is chosen by considering several cases. The main objective is to show how (i) considering risk, (ii) considering different levels of quality constraints, (iii) applying or not additional degradation due to climate change, and (iv) applying continuous additional degradation due to traffic growth can impact optimal maintenance and repair strategies.

The optimization process is used to determine the maintenance strategies for the next 30 years considering initial distributions for structural and component series systems, respectively. Results include:

- Evolution of condition for structural series system
- Evolution of condition for component series system
- Annual maintenance costs for structural series system
- Annual maintenance costs for component series system
- Total annual maintenance cost.

Evaluation and outcomes of the project

Managing assets is about collecting information and making decisions. Due to the complexity of the decision-making process and the diversity of the assets to which to allocate the funds, the asset management is seen as an ongoing and long-term effort.

Dealing with ageing infrastructures, increase of traffic demand, and climate change, several important questions arise for road assets. These relate to the determination of the lifecycle of a new, maintained, rehabilitated or retrofitted structure and its expected performance along the lifecycle.

The proposed optimization framework is based on visual inspections (e.g., condition rating) and enables to determine optimal asset management strategies for bridges, retaining walls and steep embankments considering the age of infrastructures, traffic volume, and environmental conditions.

Using as input the inventory of the asset and condition assessment, the proposed method aims to determine some degradation profiles for bridge components and retaining walls. Once the degradation profiles are determined, they are used to characterize how the degradation of infrastructures evolves with time. Different types of hazards are then considered (including the potential impact of climate change and traffic increase), and risk is defined as a joint measure of vulnerability and consequences of failure.

Optimal management strategies, based on the consequences of possible actions on the future condition of the system, are determined through an optimization process under uncertainty. The aim is to minimize the risk level while maximizing the performance level of structures. The optimization problem can be employed to minimize both one objective and multi-objective functions aiming at simultaneously minimizing several impacts. The effect of uncertainties on some parameters is also investigated. Such an optimization procedure can allow NRAs assessing the necessary additional effort to satisfy performance constraints under different scenarios of traffic changes and climate change.

It is noted that a risk analysis tool has been developed to apply the analysis to ageing infrastructures under alternative climate change and traffic growth scenarios. The proposed package runs in MATLAB programming environment and is designed to be easily used by end users in Europe.

X-ARA – Cross-asset Risk Assessment

Project facts

DURATION: April 2014 – March 2016

PEB REPRESENTATIVE: Alex Tam, Highways England, UK

COORDINATOR: AIT, Austria

PARTNERS:
Parsons Brinkerhoff, UK
PMS-Consult GmbH, Austria
IFSTTAR, France
University of Belgrade, Serbia
EGIS, France

DELIVERABLES

D1.1	Desk Study
D1.2	Risk Framework and modelling specifications
D2.1	Risk modelling methodology
D4.1	Dissemination – Education program for users of X-ARA
D4.2	Implementation and User Guidance Document for Risk tool X-ARA

Background and Objectives

The primary objective of the X-ARA project was the development of a comprehensive risk assessment framework including a set of guidelines and a practical software tool (X-ARA risk tool) for the network level assessment of asset risks and impacts. The approach takes into account the requirements and needs of different stakeholders, considered in an initial desk study, and is focused on delivering a working model fit for use by National Road Administrations around Europe. The project builds on earlier European projects, including aspects of the ERA-NET 2010 Asset Management Programme, as well as drawing on the direct experience of operational asset-managing organisations.

An outcome of the project was model account internal and external factors affecting the different assets in an ageing road infrastructure, such as

- Climate Change
- Asset performance
- Funding/politics
- Demand (traffic)
- Macro-economic factors
- Social factors.

•

To cover these aspects three high level influence factors were defined within the X-ARA model (complemented by a factor reflecting the functional importance):

- Environment/climate change
- Economy/funding
- Safety/safety regulations.

It includes the framework for the necessary input parameters (indicators), the definition of sub-risks and cumulated risks (in form of risk factors) and the procedures to implement the solution on a road infrastructure network. The output methodology and model is generic and adaptable by different NRAs, under the auspices of CEDR, using their own local data and parameters. The assets themselves, as well the economic, geographic and social factors differ in each country so it will always be necessary for each country to calibrate the risk model to its own environment, using the provided guidelines.

X-ARA enables an NRA to execute a risk-based assessment and comparison of different maintenance strategies at a network level, and then 'overlay' the effects of broad influencing factors to assess 'what if' outcomes, in the medium to longer term. To produce a reliable high-level model, it considers a bottom-up approach (using real data) that can be used to measure sub-risks, as well the high-level top-down influences. The X-ARA risk tool is based on real, available and affordable data, and the software is independent of any proprietary database or software platform. It considers the risk-specific effects on safety, operation, and traffic, of high- to low- or non-coordinated maintenance activities but does not include new construction programmes (schemes). Hence, a NRA is able to examine a worst case/best case set of scenarios for their own environment and socio/political situation, and consider the implications on funding as well as economic and social outcomes for stakeholders, while meeting the requirements of environmental and other legislation.

X-ARA has the potential to aid a NRA to provide better prognosis of risk against different funding scenarios, and thus will be a powerful tool when juggling ever-reduced budgets against ever-increased demand and uncertainty. It adds real value to existing asset data and is capable of further exploitation across CEDR member countries and gives transnational benefits by providing a common framework for assessing risk which can be configured for each country location.

Description and methodology of the project

Figure 5 shows the major activities in the project together with the main outputs.

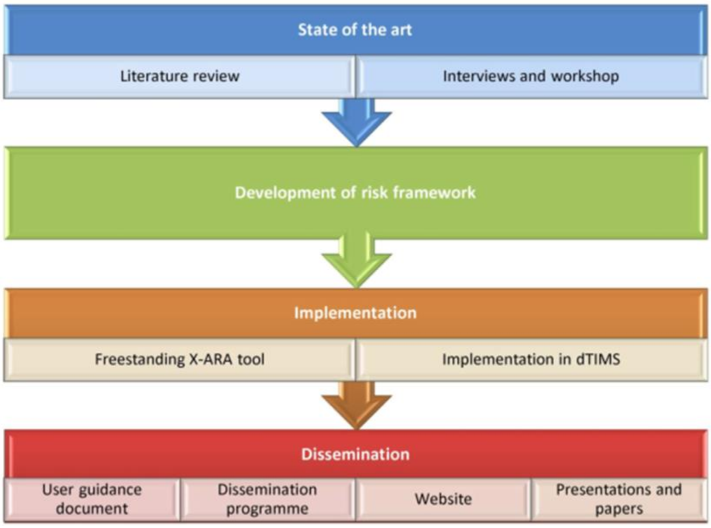


Figure 5 Activities and outputs in the X-ARA project

The project started with a literature review on the topic of risk assessment and management in transport infrastructure. The literature review has brought up many definitions of the term “risk”, all with slight deviations, but many of them referring to risk as the product of probability of failure multiplied with the consequences of failure.

For the X-ARA project it was decided to follow the definitions that maintenance risk is a function of distress probability depending on asset condition or age and the consequences (effects) with respect to the affected stakeholders in the context of asset maintenance management. It is “the risk for the road operator to either perform non-cost-efficient maintenance on his network, or to provide unsatisfying services to the other stakeholders (users, neighbours, society, owner…).”

As not all these "elementary" risks could be developed within the X-ARA project, it was decided to illustrate the approach by considering:

- The risk for the road operator to lose money (too expensive maintenance, excessive loss in asset valuation, etc.) in the short, medium and long terms by applying maintenance strategies which do not adequately anticipate on high level influencing factors
- The risk for the road operator to provide users with significantly unsatisfying services after some improbable event(s).

The same approach could be used to assess other risks (to users or other stakeholders) that the road operator could have to face. It is assumed that these different "elementary" risks could then be merged into a single "overall" risk by a weighted sum. The weights would reflect the relative importance of each risk.

The literature review also showed a common approach to risk management. Regarding risk management frameworks, many sources suggest a five-step procedure that starts with:

1. Defining the context, then
2. Risk identification,
3. Risk analysis,
4. Risk evaluation and ends with
5. Risk treatment.

Other approaches use a four-step approach where the steps (2) and (3) or (3) and (4) are treated together in some way.

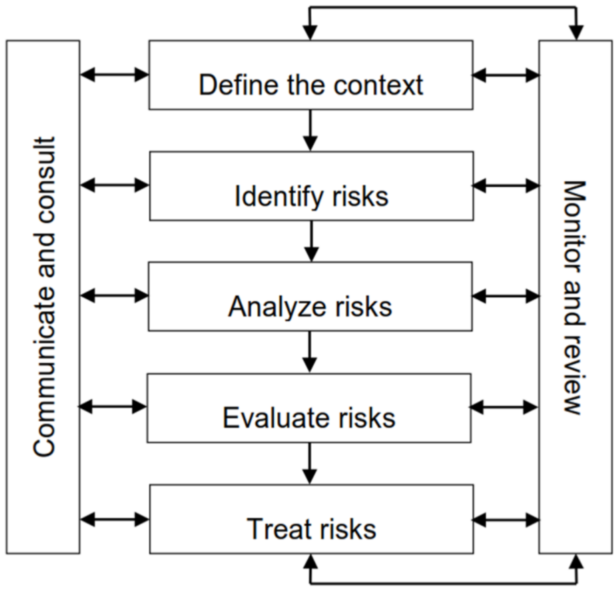


Figure 6 Common approach to risk management in transport infrastructure

The literature review was complemented by a workshop and a series of interviews where road operators have been asked about three topics:

- External factors are currently considered in their asset management work,
- Extent risk assessment is currently implemented in their systems and
- Developments expected for the future.

This procedure was then taken to compare the approaches of different road operators and the how far they got with the implementation of risk management in their asset management processes.

It was found that this straight-forward methodology has not been fully implemented in any of the road operators that have been interviewed. Parts of the risk-assessment framework are implemented at each road operator, although sometimes they are not labelled as such. While for construction projects dedicated risk management procedures are commonly used, in asset management risk assessment is only partly implemented, e.g. for structures or tunnels. In maintenance systems, routine monitoring is often considered sufficient as some form of risk treatment.

External factors are considered to a varying degree. Climate change is considered by some road operators in the form of scenarios that allow a forecast of maintenance and operation cost. Funding is tightly linked to macroeconomic factors, even more if the maintenance budget comes from toll revenues. There is a common feeling that the maintenance budgets are not in danger of a sudden dramatic cut. Regarding demand, a constant conservative growth is largely anticipated with no sudden deviations. Social factors and politics are considered to have a certain influence, however difficult to anticipate.

The availability of data upon which maintenance decisions are taken is considered sufficient for pavements and structures. For these assets, routine monitoring was in place for several years at each interviewed road operator. For street lighting, gullies and drainage there is still some work to do to reach the level of completeness and quality of pavement data, although there are data collection strategies in place to catch up in these areas. What needs improvement is the trust and understanding in the collected data and their central availability.

The results of the literature review and the interviews were documented in “D1.1 Desk study” in detail and were the basis for the development of the risk framework (”D1.2+2.1 Risk Framework”) and the tool that is derived from the framework (“D3.3 X-ARA-Tool”).

Development of risk framework

The main objective of the project X-ARA is the development of a comprehensive risk assessment framework including a set of guidelines and a practical software tool (X-ARA risk tool) for the network level assessment of asset risks and impacts. At the beginning of the development, some basic definitions were made:

- As the Probability of failure (PoF) is very difficult to determine for transport infrastructure assets (and the aim of the asset management is to avoid a failure of any asset), the Probability of Failure is replaced by a dimensionless condition indicator (see Figure 3). This is also found in the literature and has the advantage that for most assets some form of condition indicator already exists.
- X-ARA uses a data driven approach. The more data about the assets on a maintenance section is available, the more benefit can be made from the risk framework. The availability of condition data varies largely for different asset types. For pavements and structures, most CEDR countries have well-maintained time series of condition data available. For drainage or road furniture, only basic information or no condition data at all may be available. However, a consistent dataset over all assets is the prerequisite for a holistic cross-asset management.
- For the description of the consequences (Consequence of Failure, CoF), suitable measures like Traffic volume or sensitivity to erosion have been chosen.

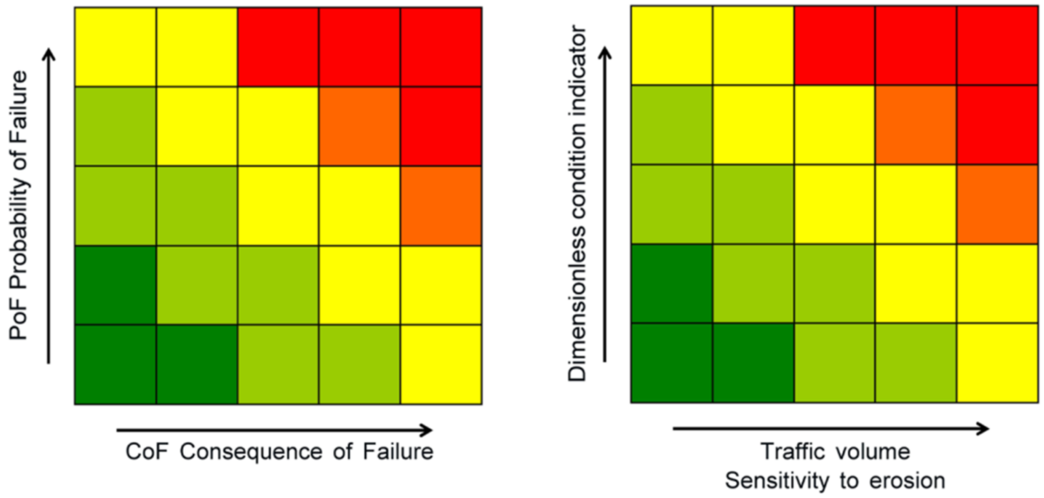


Figure 7

Conventional risk matrix (left), risk matrix used in X-ARA (right)

The risk modelling methodology itself – as the core part of the X-ARA project – covers the following topics:

- Which input-data is needed?
- Which high-level influence factors are considered in the approach?
- How does the risk model work?
- What is the output of the risk calculation?
- How is the maintenance risk defined in general?
- How is the maintenance risk defined for different types of asset?
- What is the output of the risk assessment?

The input data is defined for the underlying network that is structured as maintenance sections that represent homogeneous conditions (number of lanes, type of pavement, traffic volume, etc.).

The asset types considered in the risk tool are:

- Pavements,
- Structures (bridges and retaining walls),
- Tunnels,
- Road furniture,
- Drainage and
- Geotechnical assets.

For each asset type, condition indicators have been defined based on literature or common practice. High level influencing factors have been defined:

- Climate change, which includes all aspects associated with climate change and its consequences;
- Funding, which covers the availability of funding for proper maintenance and
- Safety regulations, which allows the introduction of safety related improvements.

These three external factors are complemented by a “functional” high level factor that reflects changes in the functional importance of a road or sub-network.

For each high level influencing factor three categories are proposed: ‘positive’ to reflect a situation that lowers the asset specific risk; ‘standard’ to reflect the expected development and ‘negative’ to reflect a development that increases the asset specific risk. The influencing factors are established for each asset of the network.

The risk for each asset will then be calculated using pre-defined matrices that cover condition of asset and the importance of the asset or – in other words – the consequences of failure of this asset. At first, the risk per each single asset (on object level) is assessed and cumulated on the maintenance section. Following up, for each maintenance section, an overall risk score is calculated to combine the asset specific risks using different transformation laws.

Evaluation and Outcomes of the project

Practical Implementation

The framework developed was implemented in two ways. The first implementation was done using commercial asset management software (dTIMS). This was mainly used during the development of the risk framework as a prototypical implementation. Using commercial software with an already filled database and the easy possibility to implement, modify and optimise calculation procedures was very helpful and speeded the development process. On the other hand it is also a proof that the X-ARA risk framework can be implemented into already existing asset management software.

The second implementation was done in freestanding software, the X-ARA Tool. The tool is able to use the existing CEDR network as a starting point. If the user wants to use their own network (“custom network”), this is possible as well. The user needs a geographical representation of the network (a “Shape file”, which is the most common file format in today’s GIS systems) and can import their network into the tool.

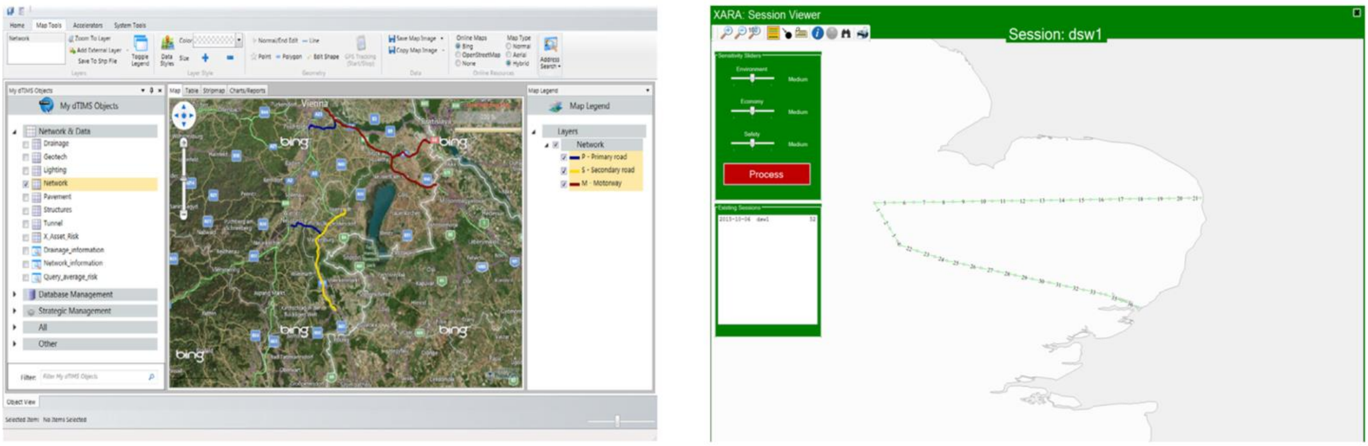


Figure 8 X-ARA prototype in commercial asset management software (left) and X-ARA freestanding software tool (right).

The X-ARA Tool is complemented by a user guide that explains the hardware and software requirements, explains the installation of the tool and gives a detailed description of the functions of the tool including export of results.

Conclusions

The X-ARA project successfully demonstrated an approach to implement risk assessment into transport infrastructure asset management. The framework is based on available asset condition data and introduces the concept of risk on the network level.

The approach was practically implemented using commercial asset management software as well as a free standing software tool, the "X-ARA-Tool" developed within the project. Depending on the available resources, a potential user could start to work with the X-ARA tool to explore the concepts developed in X-ARA. To fully exploit the risk assessment approach it would be beneficial to implement the framework into an asset management system already in use as the maintenance planning and condition degradation over time is not implemented in the tool.

The condition indicators defined for each asset type were taken from literature and/or best practice. They can be adapted by the specific user. The sensitivity of the asset to high level influencing factors has to be determined and given as attribute to each asset. This provides the availability to adjust the procedure to the given local situation. Thus each NRA can use the proposed approach and framework using the given experience and the asset management systems currently in use.

The step forward from condition monitoring and derived maintenance strategies to the inclusion of the concept of risk and consequences in the case of failure has the potential to optimize the allocation of maintenance budget.

X-ARA uses a cross-asset management approach based on different asset types on so-called maintenance sections (homogenous road sections) and all asset types contribute to the total risk of a section. The cross-asset consideration is another step to find the most sensitive or vulnerable part of the network.

It has to be kept in mind that the approach is data-driven or even "data hungry" and needs a thorough organisation of network and asset condition data, all location-referenced to an underlying road network. But this is the foundation for all cross-asset management activities and for several asset types (pavements, bridges) time series of condition data is already available to most road operators. From the interviews with the road operators we learned that the status of condition data for other assets like drainage and road furniture is being worked on and to be improved soon. This will then make the risk management approach fully exploitable.

PART II
Implementation

Outcomes from the workshop

A final workshop was held to present the outcomes of the three projects and discuss implementation with interested parties. This workshop was held in Brussels on 14th/15th February 2018 and was attended by representatives of CEDR; the National Road Authorities of England, Ireland, Belgium-Flanders, Netherlands, Denmark, and Hungary; research organisations; consultancies and maintenance contractors. The conference was organised by Transport Research Laboratory Ltd, a list of attendees is given on the next page.

The workshop was comprised of an opening and discussion session held on the first day and a second discussion, plenary and conclusion sessions were held on the last day. The opening session introduced the three projects and described the outcomes from the work. The first discussion session focussed on these outcomes. The second discussion session was used to explore current implementation of the project outputs and next steps required to build on the work undertaken in this call and how to ensure wider uptake of the outputs by NRAs.

List of Attendees

Name	Organisation
Aaron Barrett	Transport Research Laboratory Ltd (UK)
Alex Tam	Highways England (UK)
Alex Wright	Transport Research Laboratory Ltd (UK)
Arco Blanken	Rijkswaterstaat (NL)
Arjen van Maaren	Rijkswaterstaat (NL)
Darko Kokot	Slovenian National Building and Civil Engineering Institute (SI)
Emma Benbow	Transport Research Laboratory Ltd (UK)
Ferenc Varga	Hungarian Public Road Nonprofit PLC (HU)
Henrik O. Nielsen	Danish Road Directorate (DK)
Jacob Cronholm	Danish Road Directorate (DK)
Jenne van der Velde	Rijkswaterstaat (NL)
Margo Briessinck	Agency for Roads and Traffic (BE)
Niels Groenen	Agency for Roads and Traffic (BE)
Niels Højgaard Pedersen	Danish Road Directorate (DK)
Peter Holt	Danish Road Directorate (DK)
Pierre GILLES	SPW-Département Expertises techniques (BE)
Robert Corbally	Roughan & O'Donovan Innovative Solutions (IE)
Roland Spielhofer	Austrian Institute of Technology (AT)
Ronan Cunniffe	Conférence Européenne des Directeurs des Routes (EU)
Ruud Smit	Rijkswaterstaat (NL)
Steve Phillips	Conférence Européenne des Directeurs des Routes (EU)

Opening Session

Ronan Cunniffe provided an introduction to the research strategy of the CEDR Transnational Research Programme. He explained the history of the programme and its goal to serve the requirements of National Road Authority (NRAs) by producing results that can be implemented. He discussed how topics of interests are identified and the roles of Programme Managers, Programme Executive Board (PEB) and CEDR Research Coordinator in describing and guiding research needs.

Call 2013: Ageing Infrastructure

Jenne van der Velde introduced the background to the projects and the issues that were addressed in the Call 2013: Ageing Infrastructure, namely "*how do we adapt to the needs of our ageing infrastructure?*" The Dutch road network was used as an example to demonstrate the challenges presented by ageing infrastructure over the European road network. It is predicted that a large proportion of this network (including structures) will need replacement in coming decades (2030 – 2050). This is due to the large expansion of the road network undertaken during the 1960s and 1970s now approaching life expiry. Such predictions of accumulative failures have potentially costly consequences. It is therefore imperative that the right information and models are available to ensure efficient maintenance planning.

Modelling should account for risk by considering condition as well as other factors including network usage, predicted changes to traffic volumes/characteristics and external factors such as increased frequencies of extreme weather events due to climate change. For condition monitoring, Jenne explained the importance of predicting maintenance needs through accurate and more efficient inspection methods e.g. High-speed surveys. He also highlighted the importance of knowledge sharing between NRAs in identifying what new inspection methods are available, and how they improve on those previously employed. The three projects together (HiSPEQ, RE-GEN and X-ARA) were commissioned to improve NRAs' ability to collect relevant data and effectively analysis giving a better understanding of current and future maintenance needs of the road network.

X-ARA

Alex Tam presented for Highways England and explained their role in the development of assessment methods for determining maintenance needs. It was stated that, whilst a number of methods for condition monitoring used to identify maintenance requirements have been developed before the project (e.g. SCRIM and TSD), an integrated asset management system was yet to be developed. Alex explained that the CEDR call for ageing infrastructure offered the opportunity to develop a tool that could take condition data from different assets, assess maintenance needs and develop maintenance strategies across entire section of the network.

Roland Spielhofer presented the outcomes of the X-ARA project, which aimed to understand and manage risk cross-asset on a section. Roland then identified all the partners in the project; it was asked how partners were identified when developing the consortium in response to the call? Roland explained that all the partners had worked with at least one other member before, and in many cases numerous times on other European projects. A theme of previous professional relationships between personnel in the different organisations was identified as key when building consortia. It was additionally noted that, whilst members did not know exactly when this CEDR call was to be made, they were aware of the current issues of interest - so when the call was made, a consortium formed relatively easily.

In developing a qualitative method of network-level assessment of assets risk, the project identified a risk framework, which was implemented in prototype in asset management software (dTIMS). The two major outputs of the project was i) a "heat map" which shows the distribution of asset risk and ii) application of "what-if" scenarios for high-level influencing factors such as climate change providing asset manages a tool to model future outcomes. The two major outputs are contained within a standalone software tool (the X-ARA tool) - publicly available on the project's website, http://www.x-ara.net/.

RE-GEN

Tom Casey introduced the RE-GEN project. He explained that, in terms of asset management tools, the focus has previously been on pavements. However networks are more than just these asset types. Structures are very important, so in response to this call, this project aimed to bring to together analysis of structures on the road network.

Tom explained that in asset management a balance of three considerations must be made; i) performance of the asset, ii) cost of maintaining the asset and iii) risk of asset failure in terms of functionality and operational capacity. This project's stated aim was to analyse the changes in the risk of failure of structures (which have historically been overlooked) when environmental and socio-economic (traffic loading) factors are considered. This project aimed to capture the key elements that affect the operational performance of the asset, and identify how they can be measured and evaluated. This would allow NRAs to get the balance between risk, performance and cost.

Robert Corbally presented the outcomes of the RE-GEN project. This project focused on bridges, retaining structures and steep embankments. It was noted that whilst pavements were not considered for the analysis, the methodologies explored/developed in this project could also be applied to them. Robert discussed the deliverables and the work packages (WP). WP2 (modelling vulnerability considering climate change) identified the factors likely to change the service life of the infrastructure elements of interest and gave recommendations into how climate models can be incorporated into degradation models. WP3 (traffic effect forecasting) examined the use of traffic weight data in predicting the effects to bridges. WP4 (Risk Profiling) explored risk frameworks relating to road infrastructure failures and produced a risk optimisation process. WP5 (Risk management & Decision Tools) produced a software tool (found on the RE-GEN website using the processes identified in the other work packages (http://www.RE-GEN.net/). WP1 (Management & Dissemination) encompassed the other WPs to in part facilitate knowledge sharing of the project outcomes.

The question of partner identification for the project was raised again and Robert built on the notion of previous professional relationships between specific organisations and specific personnel within them. Robert noted his company is involved in a number of these collaborative style research projects and typically they would "go to people we know" when consortium building.

HiSPEQ

Jenne van der Velde introduced the HiSPEQ project, stating that for good asset management accurately predicting maintenance needs is imperative. To do this, condition monitoring in necessary through network surveys. Newer high-speed surveys offer a more efficient way of monitoring. This is because the slower speed surveys require part of the network to be shut whilst the survey takes place, causing network disruption. It is therefore important that NRAs are aware of what high-speed surveys are available and are able to understand and evaluate relevant data that can be collected.

Alex Wright presented the outcomes of HiSPEQ. The project reviewed traditional and novel high speed surveys. The aim of the project was to propose a way to develop and define traffic speed surveys with a focus on surface condition, structural condition and road structure. The project developed survey specification templates for NRAs to use, which accommodate innovative survey techniques when a prospective bidder tenders for work. Guidance documents were also produced to aid NRAs in understanding “what the surveys are about and how they should be commissioned so that that they deliver a quality ensured service”. The project also produced a number of equipment specification templates and guidance documents to complement the survey specification documents.

A brief discussion on consortium forming was undertaken. Alex explained that the “what you know, who you know and who you have worked with before” approach of identifying partners is the most important, as previously noted by other members. Additionally Alex discussed the role of FEHRL (Forum of European National Highway Research Laboratories), of which TRL and a number of the partners are members, noting that it had been a good source in the search for partners when forming consortia. For this project the partners had worked together on previous projects and were able to bring in additional members where knowledge and skill gaps were identified.

1st Discussion Session

Jenne van der Velde introduced the first discussion session stating the aims here were to focus on the results/outcomes of the project, how they were reached and difficulties that had to be overcome.

X-ARA Outcomes

Roland Spielhofer began by discussing the results of the X-ARA project. He began with the desk study and interviews stage. This work explored the maturity of risk analysis undertaken by NRAs. A number of questionnaires were sent to NRAs. Ronan Cunniffe noted that it was often hard to obtain responses or feedback from road operators and asked how was this managed in the context of X-ARA? Roland explained this was overcome by contacting individuals where good personal relationships already existed. Known contacts were used to identify other relevant people within organisations. Workshops were also held and, where it wasn't possible to hold face to face meetings, skype was used instead and moderators were used to guide discussions. Roland stated that to ensure a good outcome, it was essential to "know the people" (often through previous projects).

Ronan Cunniffe also asked *when* particular experts and stakeholders were identified. Roland elaborated that organisations were initially identified at the proposal stage, but individuals were identified after the project was underway. It was also noted that CEDR now encourage consultations and questionnaires to be co-ordinated through CEDR itself, as a step to ensure high participation. Alex Tam suggested it may be useful for NRA directors to be copied into the requests via CEDR to support pushing for responses.

It was expected that the NRAs approached had well established asset management systems in place, thus the interviews and questionnaires were used to identify the level at which risk is considered by the asset managers when maintenance decisions are taken. It was found in the round that risk is considered but is not specifically named. Additionally as condition surveys are common, relevant data is available for risk analysis. However, mature asset management processes are essential as they facilitate the collection of high quality data and its storage. It was noted when looking at the risk associated with traffic furniture, accumulative condition measures are used due to the complexities of holding data for every item (e.g. every signpost) on the network.

Jenne asked "When considering the data, what was the biggest barrier to NRA's implementing a risk-based analysis methodology, was it the amount and/or the quality of data?" Roland explained that it is asset specific. NRAs consulted were generally found to have good condition data for pavements (due to routine surveys). Whilst detailed inspection data was usually available for bridges and tunnels, this is not as forensic as pavement condition data. Condition data was also often lacking for common, non-safety critical assets such as signposts, road markings and noise barriers (in some cases details like the total number of that asset type were not available). It was also noted that older assets (e.g. retaining walls) often have data missing (e.g. detailed construction designs), which can be problematic. Roland concluded that, whilst the availability of high quality detailed data is crucial, just having the accumulated condition data is a "good starting point" when calculating risk, as demonstrated by the analysis performed in X-ARA for road furniture.

The X-ARA tool assesses pavements, structures, furniture, drainage, geo-tech and tunnels by calculating the probability of failure and the consequences. Road owners stated they want simple metrics to help in the decision making process and this approach means the tool can meaningfully compare “apples with pears” in simple categorised outputs. The probability of failure is determined per asset using condition indicators based on COST354, categorised from 1 (very good) to 5 (very poor). Consequences are split into three categories (low medium and high) and determined by traffic volume. The risk for each asset is then calculated from these two values on a per asset basis. A discussion about defining the risk categories highlighted there was no formal procedure; the tool defines the risk by the effect on road users.

The cross asset risk per section is calculated based on a ratio (weighting) of risk of the different assets. Additionally these ratios are changed for different regional situations (flat areas, mountainous, etc.) to reflect the changes to risk. Alex Wright asked how these ratios where calculated? Roland explained that there are suggested values, but these are for guidance and should be changed to reflect the local particularities. There is a current deficit in the understanding how to perform detailed cross-asset risk analysis. This is an area NRAs will need to invest in to get the benefits. He continued that infrastructure managers like the idea of a cross-asset management approach, but in practice find it difficult to implement. This is in part due to the different expended lifespans of different asset types whereby the likelihood of needing rehabilitation is low. One future consideration when constructing new assets or replacing old ones is to design them with standardised expected life spans e.g. in Austria assets are designed to have an expected lifespan with a multiple of five years. This makes it easier to combine multiple asset rehabilitation into a single maintenance scheme.

In concluding the session’s discussion on the X-ARA project, it was asked if any organisations have been able to implement this approach in their organisation and what challenges were presented during implementation. **Alex Tam** explained that HE has tried to implement a risk based approach but it was difficult, citing that different assets require different experts and collating the available data was problematic. Additionally, truly understanding/quantifying the consequences of failure is a challenge with regards to safety, traffic/delays and environment/pollution; more data is needed. It was noted that whilst this data is needed for more detailed risk assessments, it is also required for wider asset management and so NRAs should have the data anyway. These current challenges have meant that only “baby-steps” have been made towards the implementation of risk-based assessment systems.

RE-GEN Outcomes

Robert Corbally led the discussion on the RE-GEN project. He reintroduced the project and explained the quantitative approach of the RE-GEN model. It was noted that a number of previous EU-funded projects have developed risk frameworks and risk assessment methodologies used to evaluate risk to transport infrastructure.

The RE-GEN project tool suggests the spend-per-year required to optimise reduction of risk over a network. This is calculated with user input, listed below:

- Previously identified changes in condition for individual assets over time
- Costs for different maintenance types
- Target condition ratios by proportion of the network.

The model requires a variety of input data including:

- Asset inventory
- Inspection history
- Climate change effects
- Traffic information and growth trends
- Consequences information.

Implementation of these frameworks has proven very difficult due to the amount of data required to accurately quantify the risk, echoing previous statements made by Roland Spielhofer and Alex Tam. Robert noted that where they have been implemented, qualitative approaches have been preferred as they:

- Are more easily understood and applied to networks
- Highlight the important factors on networks
- Produce data that asset managers have reasonable confidence in.

Whilst qualitative/semi-quantitative methods are still preferred, the implementation of more sophisticated quantitative risk assessment methodologies and frameworks is being made easier. This is due to the increased availability of data through increased digitisation of condition information, improved data collection, storage and analysis facilities and as BIM becomes more prevalent.

Alex Wright posed a question about what data is required and how was it used when modelling the effects of climate change? Robert explained that the model uses matrices which define how a weather event would degrade the infrastructure. First, the type of weather events should be defined; the model considers flooding and erosion, landslides and avalanches, droughts and windstorms. Next, the extent to which these events affect the infrastructure need to be defined and what the expected frequency of them is i.e. how much degradation is caused over time by such events. As an output of the RE-GEN project, recommendations are made but the user will ultimately need to define these parameters. He noted that it isn't necessarily pure data that is needed but rather a thorough understanding of how such weather events degrade the infrastructure further. Whilst the events arising from climate change can be generalised in the RE-GEN model, the effects of the events will need to be asset specific to account for different criticality elements with differing levels of susceptibility to the range weather event types.

The importance of input data for the model consequences was explored. To calculate the consequences of failure, the state at which an asset has failed needs to be defined (i.e. what is considered failure?) and the effects on the network (e.g. how long does that divert traffic for and what is the volume of that traffic) will need to be identified.

Continuing discussions on the importance of input data, Tom Casey commented that the cause of failure is often not due to one event, rather a combination of things such as increased traffic and or materials failing. This means that to determine the true cause of failure, a forensic analysis would need to be undertaken; because of this, the model does not determine the exact failure mechanism. Robert explained the model uses predefined degradation relationships that ultimately lead to a failure modelled on previously identified data.

The model considers climate change and increased traffic loads as accelerating factors, this allows sensitivity studies of the network's susceptibility to these external factors to be performed whilst not requiring extensive user inputted data. Whilst the tool provides an indicator to such susceptibilities, Robert noted it may be the case that further in-depth modelling may be required if certain factors are shown to have major impacts, this is to allow more detailed predictions to be made. Throughout the discussion it was noted that the framework is dependent on the (high) quality of the data an NRA has. Robert discussed the current importance of visual inspections and the need to ensure consistency between inspections as this represents the degradation over time.

Finally, in response to a question by Ronan Cunniffe about accessibility of the tool and potential use by NRAs in the future, Robert noted that the tool will be available on the RE-GEN website and whilst it won't be updated he expects that the algorithms in the background could be used and integrated into future asset management systems (further explored in the second discussion session).

HiSPEQ Outcomes

Alex Wright led the discussion on the project. He introduced the project by noting that the importance of high quality data when making asset management decisions was highlighted by the X-ARA and RE-GEN projects. HiSPEQ was about ensuring the data that is collected to make these decisions is the right data by providing template specifications and guidance information when putting out survey work for tender. This project focused on data collection for pavements through traffic-speed measurement surveys. One particular example highlighted was the use of traffic speed deflectometers (TSDs) to establish structural condition. TSD surveys are becoming increasingly common on the European road network, but there is a lack of knowledge about them, so clearly defining the requirements with regards to the condition measurements produced (quality and quantity of the data) would be a worthwhile exercise.

To establish the knowledge base, a stakeholder review was undertaken with around 50 individuals who stated they were interested in this work and willing to comment on the outputs and review them. Due to the nature of the review, stakeholders were approached on an individual basis. This included individuals from NRAs and service providers; this allowed HiSPEQ members to extract what they considered best practise and get these conclusions peer-reviewed by the stakeholder group, thus "closing the knowledge loop". In addition, the project team was made up of individuals that had in-depth experience and knowledge in doing network-level condition surveys and processing the data that they provided.

During the consultation and dissemination phases of the project, HiSPEQ gathered a lot of interest. It was suggested that training activities should be further developed with a focus on organisations outside the group of NRAs involved in this consortium (for these members, it might be that some of the components HiSPEQ recommends are already well understood).

A number of case studies were developed with stakeholder input that have proven useful for demonstrating how the specifications and guidance documents should be used when considering what information should be included when creating specifications and why. Arco Blanken, from Rijkswaterstaat, asked how the specific individualities and demands (e.g. requirements for specific Laser Crack Measurement System (LCMS) software) for condition monitoring over their own network can be accommodated using the templates developed in HiSPEQ. Alex explained that the templates were written specifically so they could be adopted, an example was given were the development of a road marking survey requirements specification. Road Markings were not specifically included in HiSPEQ, but Highways England were able to use the HiSPEQ Framework to develop a specification for Road Markings.

It was noted that a decision was made early on, when developing the HiSPEQ Frameworks, to develop "data" specifications, not "equipment" specifications. Building on this it was stated that road administrations should be "encouraged" not to write specifications linked to one type of survey vehicle/device as this stifles competition (potentially against EU competition rules) and prevents contractors from innovating.

In developing more open specifications around surveys, it is important that accreditation and quality assurance (QA) is undertaken. Alex explained that high confidence reference data sets will be needed and Accreditation regimes will need to be applied by individuals with high-level knowledge of how the reference method should be undertaken. An example in the UK was given for crack detection, where the reference method is manual assessment of images. This enables a quantitative reference that can be directly compared with the data coming from the contractor. Adding to this, Alex explained that the Accreditation process needs to be considered, in the case of cracking, as directly assessing the roads manually may not be a fair comparison to what the machine is measuring.

Repeatability and consistency tests are also integral to the accreditation process, whereby contactors should perform repeat measures under different ambient conditions (e.g. performed in different seasons of the year). Additionally, if a fleet of vehicles/devices are employed to perform the surveys, repeat measures should undertake to compare the data collected between them. It is also important to consider what reference data is chosen. Reference data needs to be representative of the network being surveyed e.g. 100 km of manual surveys are undertaken in the UK to provide an adequate reference data set for cracking.

Alex also discussed the need for quality assurance for any survey covering a large distance or being undertaken over a period of more than 2 months. This is to ensure that the quality of the data remains throughout the duration of the survey. He stated that QA regimes should be less onerous to implement than Accreditation, and could e.g. only test repeatability, only test parameters.

Summary of key points and observations (Day 1)

A number of notable points have been identified as a result of the opening and 1st discussion sessions of the workshop described above. These are highlighted listed below:

Identifying project partners and stakeholders

- Partner identification when consortium building is important and is most effective when previous relationships exist (often through previous collaborations on other EU-wide projects).
- Similarly the consultation process is most effective if project partners have previous relationships with the stakeholders that are engaged, this ensures quick but considered response (and speaking to stakeholders directly is more effective than e-mailing questionnaires to organisations).
- CEDR now encourage consultations and questionnaires to be co-ordinated through themselves to encourage more responses.
- Organisations for the stakeholder process were identified during the project inception, in some cases the individuals within the organisation were identified later on in the project.

Observations on the stakeholder consultations

- Many partners and stakeholders already have mature asset management systems and processes in place.
- The quality and quantity of data held varies between asset type and NRA. Generally NRAs hold good quality data on pavements and some structures but not on other assets (such as older structures and non-safety critical assets, e.g. signposts).
- In relation to X-ARA and RE-GEN: Risk is often considered by NRAs at some level during their asset management level but not formalised or named. Infrastructure managers “like the idea” of cross-asset and risk based approaches to asset management but are put off by having even more software tools – it would be preferable to build such tools into existing systems. Perhaps as a result of this, qualitative risk-based methodologies are currently used by NRAs due to *perceived* complexities associated with implementing quantitative methodologies.

Results

- The outcomes of each project have been delivered on their respective websites.
- For many NRAs the data already collected may be sufficient to perform the network level risk analyses developed in X-ARA and RE-GEN, suggesting that implementation trials of the X-ARA and RE-GEN approaches should be achievable on a number of NRAs.
- However, high confidence in the quality and quality of data used is key to good decision making. It will affect strongly the successful application of the outputs of these projects.
- The formalisation of collection, reporting and QA defined in HiSPEQ could assist to deliver this confidence, as HiSPEQ includes the repeatability and consistency tests that are integral to ensuring good data and understanding of the data by the user.

- However, even with condition data, it is complex to perform cross-asset risk analysis as different assets along a section are in different stages of their lifecycle mostly require will require interventions at different times.
- RE-GEN and X-ARA are better applied to “what-if” scenarios and stress testing networks. Modelling the effects of climate change and traffic growth requires detailed knowledge and predictions by these tools can only be based on the scenarios the users test.

2nd Discussion Session

Live demonstrations of the RE-GEN and X-ARA tools were giving in the morning before **Jenne van der Velde** opened the 2nd discussion session. This session focused on implementation of the project outcomes and posed the following questions:

- What level of implementation has been achieved
- What were the lessons learned from the achieved implementation
- What are the next steps to further implementation
- What are the barriers/enables to further implementation

The second session was split into three parts; **Alex Tam** led the discussion of the X-ARA tool's implementation at over the English Strategic Road Network, the implementation of the RE-GEN tool over the Irish Road Network was led by **Robert Corbally** and **Alex Wright** led discussions of the implementation of HiSPEQ's outputs by Highways England.

Implementation of X-ARA outcomes

As an introduction, **Alex Tam** showed Highways England's updated "Value Management Guidance Manual" for their asset management processes, changed to reflect new priorities over the network. Principles developed in X-ARA have been implemented in this updated version. He noted that though ideas may be simple, implementation is often complex and this guidance manual took over two years to develop. Alex highlighted again the complexities arising from trying to compare the different types of assets where we have varying levels of understanding of maintenance needs and where the assets are in different parts of their life-cycle.

To overcome these challenges Highways England have developed a priority score for schemes which accounts for "asset health" (condition), and a criticality score (consequence of failure). The criticality score accounts for a number of elements including Network Impact, user impact, safety and environment).

A discussion about the "criticality elements" revealed the flexibility this approach has given Highways England to prioritise different high-level goals. For example, the UK is committed to the EU directive of reducing emissions by 50% by 2030 and in high population areas, changes to emissions are further prioritised when making asset management discussion. On the point of emissions, a further comment was made that better understanding of how failures influence air pollution is still needed and this should be the focus of further work.

Moving on the discussion, Tom Casey asked how Highways England agreed a "satisfactory level of risk" and how the weightings for each criticality element were set. Alex Tam noted that this was the most complex part of implementation, as priorities over the network vary and the levels of acceptable risk needed to reflect this. Expert opinion and local knowledge was used to determine the thresholds and weighting over different parts of the network accounting for a number of different criteria defined in the guidance manual. Additionally, calibration of the network in terms of traffic volume, delays, location etc. has been completed and a number of pilot trials across the network were undertaken.

Alex Wright then asked, on the subject of calibration and application, “X-ARA gave a good framework but there are known gaps in knowledge of how to implement it. There was knowledge gained from implementation by Highways England but how do we ensure that these lessons are learned and shared with other NRAs?” This point has been acknowledged by CEDR. CEDR propose that, to overcome this, the PEB should come together a year after the project has ended and discuss lessons learned from implementation and produce a short report. This will ensure lessons learned are in the public forum and shared between the NRAs. It was suggested in some cases one year may not be enough time to implement and reflect on the lessons learned, and the time should depend on what is thought to be required.

The work undertaken during the X-ARA project highlighted the advantages of a common framework. However, it was noted that every NRA has different asset management methods, priorities and needs. Most NRAs already have their own asset management systems and work should be undertaken to identify how tools such as X-ARA can be integrated into these systems. Alex Tam noted that Highways England didn’t adopt the X-ARA tool itself, but the principles developed through the project were implemented into their asset management framework. Roland Spielhofer added that a strong message given during consultation was that another standalone tool was not something desired by NRAs. He expects that the project output that will be implemented is the principals and framework that has been developed as opposed to the demonstrator X-ARA tool itself.

Implementation of the RE-GEN outcomes

Robert Corbally opened the discussion on RE-GEN by introducing Ireland’s Bridge Management System (EIRSPAN database). This database aims to promote the coordination and integration of inspections and maintenance works across Ireland’s bridge stock. It contains an inventory of assets and condition rating information for bridges including location, construction, the type of roads carried, inspection and condition data. The RE-GEN tool used the information found in the EIRSPAN database. This meant implementation of the tool was made easier as the data required to perform the risk optimisation procedure analysis was already collected by the Irish Road Authority. Further integration of the RE-GEN tool allows comparisons and evaluation of:

- different maintenance strategies
- different climate change scenarios
- traffic growth effects
- costs required to maintain specific condition levels across bridge stock.

Robert noted that during the two years of the project a tool has been developed and it is very useful but may not give answers to the questions every NRA asks. Further implementation by different authorities will require additional time to allow:

- New users to understand the tool
- New users to know what they need/want as the outcome of analysis.

It is acknowledged that, whilst NRAs often like these types of innovation, more tools are undesirable and integration into existing systems is the key. An implementation phase with dedicated time and resources is needed to overcome the research “valley of death” to ensure these innovations are adopted and integrated into existing systems. Extending the period over which the PEB is active (as being implemented by CEDR) after the project has formally concluded will act as a bridge to close the gap between invention and further real-world implementation but extra resource is key.

The RE-GEN tool is a sophisticated piece of software, which used data from the EIRSPAN database. Ireland's bridge management system was based on the Danish system (which has not ceased) and an additional point was made that continued maintenance and updates to such software tools can become problematic as the people tasked with this change.

In implementing these types of systems in-depth knowledge of each asset is critical. Users need to know how each asset performs and "how it feels". To effectively use the RE-GEN tool, the level of knowledge about each asset in terms of both the quality and quantity (and confidence) of data has to be very high. This may be a barrier to wider implementation of the tool across different NRAS as it may be the case currently that they do not collect all the necessary information needed to perform the risk optimisation procedure. However adoption of a tool like RE-GEN will encourage best practice across NRAs.

It is noted that confidence in the data is always paramount and NRAs are often working with an inherited network, with some structures well over a century old. The knowledge of these structures has to be based on past behaviour. For example the major method of surveying for bridges is visual inspection, this is to some level subjective and so detailed knowledge of the assets' past behaviour is vital in making risk base decisions. Understanding additional/more accurate data is also important and Tom Casey highlighted an example previously given by Alex Wright whereby a new more accurate way of measuring rutting had caused problems. This was because it had wider implications for the predefined thresholds for failure based on the old system and subsequently meant that the value of the pavement network would be vastly different. Instead of rejecting the new method it may have been more useful to understand the consequences of the measured values and to revise the thresholds. This demonstrated that for implementation of new systems it is important to establish the organisation's knowledge of their assets and the consequence of what's there.

In the case of RE-GEN it is critical to know the mode of failure and how/when an asset transitions from one condition to the other. To establish the right assumptions have been made, it is important to test the constancy of the answer the tool provides across different parts of the network. Tom Casey suggested such testing could be performed by applying both the X-ARA and RE-GEN tools to the same section of network and to compare the results of both analyses.

It was stated during the discussion that the RE-GEN tool can use either detailed condition data or general inspection data. Alex Wright suggested implementing the tool using general network inspection data would be more easily achievable as most organisations have a general inspection that delivers a general measure that they could apply. It was noted that a barrier to implementation is the perceived complexity of the tool's logic but the fundamental concept is looking at asset degradation over time. To overcome this barrier it might be practical to implement a simple version initially. This can become more complex as the NRA becomes more familiar with it and working alongside the developers is key for NRAs to gain that initial understanding that will ensure buy in to the innovation.

Implementation of HiSPEQ outcomes

Alex Wright introduced this section by explaining that Highways England has implemented the HiSPEQ draft specifications and guidance documents for their network condition surveys over the strategic network. A case study was also presented by Alex, where the HiSPEQ documents were applied when preparing the specification for the latest contract for traffic speed condition surveys for Highways England. The specifications were flexible enough for Highways England to define what they needed and guided the user through specific considerations with regards to data quality and quantity that should be made considering road types. Additionally, it was able to be adapted HiSPEQ for new measures. For example the retro-reflectivity of road markings was not covered by the templates developed in HiSPEQ but the process was there. HE has thus been able to adapt existing templates to create a specification for retro-reflectivity profiling.

It was shown that the TRACS contract was successfully let in 2017, and feedback gained from the contractor stated that the specifications clearly defined what was required of them. Auditors also stated that the requirements for accuracy details, what is tested and how are clearly defined, along with what will happen if the level of accuracy is not met. This results in clarity and leaves no room for the contractor to “wriggle out” of their obligations.

Equipment templates and guidance can be used by manufacturers and survey contractors to describe their equipment in a standard way. This is useful as it makes assessing tenders more straightforward and easier to identifier if the tender meets the following:

- Will the equipment be capable of meeting the specification requirements and
- Is there independent proof that equipment meets the claims being made by the contractor?

It was noted that following this process does often result in large specifications and thus the production of large “weighty” contracts. Some procurement departments may not like such large contracts, as they may feel that it acts as a potential barrier to further implementation. However the experience with Highways England was that the opposite was true, since all angles are covered procurement were be happy with it.

The processes defined in the specification and guidance documents focus on the data that is required to be collected not the equipment which gives the NRA more choice of contractors when putting contracts out to tender. It also means NRAs will be less likely to be tied to one piece of equipment or manufacturer as is the case for TSD. For the next national survey contract for structural condition, Highways England are intending to use the principles demonstrated in HiSPEQ and thus avoid being locked in to using the TSD.

As part of the project a “Dummies guide to HiSPEQ Templates” training guide was produced, an additional use of these materials has been identified as a teaching guide to train individuals with less experience in the field and/or as part of succession planning for replacement of individuals tasked with specification writing.

The HiSPEQ documents may need to be updated periodically, to keep them up to date and relevant. Currently a potential barrier to future implementation of the specification and guidance documents is the fact the documents are deposited online for people to download; this is likely to result in issues with version control. During the discussion it was noted that in some areas advances in technology are moving rapidly such as 3D imaging and so multiple updates might occur over a relatively short space of time. This highlights the advantages to moving these documents to a centralised tool that could be updated to reflect updated measuring techniques.

Plenary Session

This session focussed on how further implementation of the projects outcomes can be achieved and what general points need to be addressed to do so.

Routes to implementation through further research

Ruud Smit introduced another research project, AM4INFRA. It is a Horizon 2020 funded project aimed to deliver a common European asset management framework approach that enables consistent and coherent cross-asset, cross-modal and cross-border decision making in the context of the White Paper on Transport. This work has been undertaken to create a “line of sight” that translates policy decisions into the operations in the field. The project is exploring how to support this line of sight with models for risk management and life cycle management as well as the data and information structures in place. The AM4INFRA project is currently in the process verifying the frameworks utilising three living labs:

- Data and Information structures: Rome
- Risk and Life-cycle Modelling: London
- Line of Sight: Netherlands

The living labs are used to facilitate different asset managers working together and see how they can optimise their decision making and link together different systems (breaking the silo mentality). Ruud highlighted that a number of contributors during the day suggests the need for other NRAs to look into their work. He suggested a next step to implement the results of the X-ARA, RE-GEN and HiSPEQ projects could be via the living labs developed as part of AM4INFRA. This could facilitate the integration of projects’ outcomes and move towards a common objective.

The need to remove silo mentality is becoming more important as asset managers move towards cross-asset management processes and sharing/collating data is a key enabler for this. To do this it is important infrastructure managers across Europe have a common understanding so it is possible to come to solutions for the big problems facing all.

The discussion identified that harmonisation in procurement processes could be beneficial. Using living labs to explore this may be beneficial. It was noted that “cultural differences” may restrict cross-border tendering. Developing common procurement procedures (e.g. through HiSPEQ) may increase competition as markets are opened and hence deliver between outcomes.

Common experience from the three projects

A theme around ensuring open data was common in all projects. When discussing the need to share data it was noted that barriers are often erected due to lack of foresight of what data might be needed. It was found that collecting and collating data is time critical. If data needs are identified towards the end of a project, the relevant partner may not have time to gather the data requested. Additionally, the unavailability of relevant experts within NRAs to explain the data can cause delays to project progression if complex datasets cannot be easily understood.

Margo Briessinck suggests open data platforms may provide part of the answer to a comprehensive data sharing approach. However problems may arise if big databases with large amounts of data are available, but specific knowledge and understanding what the data means is not present. It was also noted that sometimes NRAs, but particularly contractors and equipment manufacturers, can be unwilling to share data due to commercial sensitivities. This can be a major barrier to innovation within projects like these as comparisons between different data sets and different data collection methods cannot be made. **Steve Phillips** noted that discussions are currently taking place within CEDR to identify what data (if any) should be put in the public domain.

Alex Wright commented that it would be useful to identify what barriers to data sharing exist and how these can be overcome. CEDR are currently investigating the principals to better data sharing and have identified the need for some standardisation one part of the solution. **Ronan Cunniffe** added that the European Commission is pushing to be able to compare the performance of different NRA. This will require additional standardisation of network level condition reporting across member state networks. This will aid in the ability to share data between NRAs as common reporting methods will be employed.

Summary of key points and observations (Day 2)

The 2nd discussion and plenary sessions of the workshop examined how the implementation of the project outputs was achieved, what were the challenges to further implementation, and how can these be overcome. A number of key points were identified:

Key findings from achieved implementation

- Each project was implemented into real asset management strategies on some level:
  - The HiSPEQ templates and guidance documents have been used to successfully specify and tender new network condition survey contracts by Highways England.
  - The risk framework developed for the tool in the X-ARA project has been adapted in Highways England's updated "Value Management Guidance Manual" for their asset management processes.
  - The RE-GEN tool has been applied to bridges on the Irish road network by TII directly, utilising their EIRSPAN database.
- The demonstration and calibration of the methodologies developed in projects such as X-ARA and RE-GEN is key to showing NRAs their usefulness and getting NRA "buy-in" to their application. Further promulgation of the experience gained would be worthwhile.
- The lessons learned from the implementation are also useful, and should be shared with other NRAs.
- However, the current implementations have been directly linked to the projects (e.g. as part of the project or via a closely related partner) and therefore have been practical using the currently developed tools. The wider implementation of standalone tools to implement the RE-GEN and X-ARA outcomes is not the most desirable route. NRAs prefer that new frameworks and methodologies are integrated into their existing systems/processes.
- Each NRA has their own data collection and asset management methodologies. Work should be undertaken to identify where harmonisation is beneficial and where it is not. This will help drive innovation as focus will be on areas where there is a common interest.
- Harmonisation should not be restricted to technical outcomes. The discussion identified harmonisation in procurement as beneficial. "Cultural differences" may restrict cross-border tendering. Developing common procurement procedures (e.g. through HiSPEQ) may increase competition as markets are opened and hence deliver between outcomes.

Enablers to further implementation

- **The data:** Before implementing new frameworks and guidance, it is important to establish the organisation's knowledge of their assets; what data has been collected, how the data is stored and what the consequences of implementation would be.
- **The data:** In many cases, the data required by X-ARA and RE-GEN risk-based frameworks is already being collected by NRAs, offering the potential for implementation.

- **The data:** The design of the HiSPEQ documents and guidance is flexible, to allow different NRAs to adapt them to their own needs and priorities whilst still adhering to the HiSPEQ processes. The HiSPEQ approach hence offers the potential to allow NRAs to establish the network level data required to implement new tools. However, it would require development to cover the different asset types not included in HiSPEQ, such as lighting, barriers. However adoption for structures would probably not be possible.
- **The data:** Data sharing and knowledge transfer is key to successful integration of these new innovations. It may be worthwhile considering the creation of a common forum to facilitate the semi-open availability of data where access is membership only and monitored/restricted by CEDR where necessary.
- **The skills:** The confidence of an NRA in their own ability to use these methodologies is key to getting NRAs "buy-in" to their application. Therefore training and promulgation is required.
- **The skills:** The implementation of these projects will allow best practice to be identified, facilitating knowledge transfer between NRAs, which is heavily encouraged by the European Commission. The problems facing all NRAs can only be overcome through co-operation.
- **The tools**: To overcome the reluctance to implement standalone tools in each NRA there is a need to determine how they could be implemented in existing tools. This is likely to require adding new functionality to existing tools, and implies that there would be a need for open-source definitions of the developments delivered in these projects so that they can be implemented by third parties.
- **The tools:** Adoption of "Living labs" to implement and test new innovations is becoming more common place. This will encourage increased knowledge transfer and data sharing within and between organisations and encourage future adoption of the project outcomes and identification of best practices improving confidence in the techniques and frameworks.

Challenges to further implementation

- **The Data:** Condition surveys for different assets types are at different levels of maturity and the level of detail and objectivity can vary. The most common type of inspection for structures like bridges is still visual inspection which to some level subjective so there may be some questions around consistency between inspections. Adopting the HiSPEQ pavements approach for network surveys to assets such as structures is likely to be impractical. There is a hence need to determine what types of survey regimes could be employed to deliver the data required by the tools, to meet the coverage, quality and practical constraints.
- **The data:** Accessing data can present a significant barrier to progress. Steps need to be taken during the project inception to identify what data will be needed and how it should be handled. The project proposal phase could also be required to clarify the expectations of the project with respect to data.
- **The data:** Having access to data isn't enough; partners need to be able to understand what the data is and what it is telling them. When data is shared, someone with in-depth knowledge of it should be available intrinsically involved in the project – part of the PEB or stakeholder group? As the project outcomes should be relevant across CEDR, projects should also ensure that data requirements are relevant and practical in the light of data availability in different NRAs, so that routes to implementation are not closed.

- **The data:** Whilst frameworks across different NRAs are converging, systems and data collection/storage remain un-harmonised and silo mentalities in departments and organisations still exist. This is a barrier to directing implementing and integrating new models into the different NRAs' asset management systems.
- **The skills:** The experience of implementing new asset management methodologies is that ideas may be simple, but implementation is often complex and takes a substantial amount of time, training and experience.
- **The skills:** There is a "not-invented" here mentality across NRAs. It is important that findings and outputs of these projects are shared and well understood to stop NRAs and partners from "reinventing the wheel".
- **The tools:** Every NRA has different asset management methods, priorities and needs, the tools and specifications may require some updates to reflect the priorities of individual organisations.
- **The tools:** Agreeing satisfactory thresholds for risk mitigation is complex and requires in-depth understand of how specific assets behave over time, this historic construction and condition data may not always be available. Expert opinion and local knowledge is vital to identifying these thresholds.
- **The tools:** The life time of this project (2 years) probably wasn't sufficient to implement all of the outcomes of these projects and embed them within NRAs. An Implementation phase with dedicated time and resources is needed to overcome the research "valley of death" and ensure these innovations are adopted and integrated into existing systems.

PART IV

Conclusions & Recommendations

This report has summarised the work undertaken within the CEDR Transnational Road Research Programme entitled “Ageing Infrastructure: Understanding Risk Factors & High-Speed Non-Destructive Condition Assessment”, which ran from April 2014 to March 2016. The three projects were presented at the final workshop of the Call, held in February 2018. The above sections of this report have summarised the work undertaken in the projects, and the discussion held on these projects in the final workshop. As noted in the sections above, the final workshop identified a number of key points concerning the lessons learnt in the projects, and their implications for future development and implementation of the results. These key points are not replicated here, however we present a summary of the conclusions and recommendations drawn from the project outcomes and the workshop. We have also drawn on these to propose outline “roadmaps” for the next steps to take in each of the projects.

Conclusions

Each project in this call utilised a consultation to understand the questions, propose solutions, and to peer review these. The consultation process is key to good project outcomes. Questionnaires, workshops and interviews were important enablers to understanding what the current asset management practices were in place. This allowed best practice to be identified. Previous relationships were key to identifying potential partners and invested stakeholders for the consultation process. A lesson learnt is that, where individual experts were better engaged, successful outcomes were more likely to be achieved. However, all the projects experienced challenges in undertaking the consultation process. Support and encouragement within NRAs (driven by CEDR) would assist in delivering successful consultations in future projects.

Two of the projects have delivered tools to assist improved risk based approaches in asset management. They have been demonstrated and implemented in example networks. Many challenges remain to overcome in further implementation, as discussed above. However, we not in particular that NRAs may be put off implementing the frameworks developed in these projects due to perceived complexities of novel approaches. Further promulgation and explanation would be of benefit. However, providing simplified versions to implement first may overcome some of the perceived barriers to full implementation – a staged approach.

However, while it was noted that the risk analysis methodologies are novel, the condition data required to perform the analyses is not. Indeed both X-ARA and RE-GEN use data that should be already collected by the NRAs as part of their current network asset management processes. The main challenge to overcome in this area is to make sure the regimes are in place, and to make sure the data is managed and delivered effectively. HiSPEQ could contribute to this process.

Finally, it is clear that cross-NRA co-operation will be essential in answering the challenges posed by the ageing road networks across Europe. Throughout the workshops collaboration was highlighted as a key driver in facilitating the innovation of asset management on the European road networks.

Roadmaps

This research programme has been a significant investment for NRAs, both directly via the project funding and indirectly via the input from stakeholders during the research and peer review process. It is important that consideration be given to the future programme for each area. To begin this process we have developed summary roadmaps for all three projects, drawing upon the experience of the project partners and the feedback from the workshop. These are presented in Part V below. Each contains recommendations and directions as to what the next steps should be to ensure further future implementation of the tools and processes developed as part of this call.

Recommendations

To complement the key points presented in the previous sections, a number of recommendations are made with respect to specific areas of this programme/future programmes.

Efficient access to, and handling of, data:

- **Open Data (improved access):** The efficiency of the research is improved significantly when all partners have access to the data required to undertake the work.
- **Clear understanding of the available data:** When data is shared, someone with in-depth knowledge of it should be available and intrinsically involved in the project.
- **Clearly identified role for CEDR to facilitate data sharing:** Creation of a common forum to facilitate the semi-open availability of data (open source database) maintained and regulated by CEDR would enable data sharing between organisations and improve the effectiveness of the projects.

Knowledge / consultation

- **Focus on consultation with engaged experts:** Experts should be identified during the initiation phase of a project and these individuals should be fully engaged throughout the entirety of the project. CEDR should support and encourage involvement of individuals within NRAs.
- **Identity where harmonisation between NRAs is desirable:** This will help drive innovation as focus will be on areas where there is a common interest. Harmonisation should not be restricted to technical outcomes, but could include contractual/procurement aspects.
- **Establishing confidence in new analysis techniques:** Project providers should be encouraged to allocated time to assist stakeholders in implementing and understanding the specific outcomes. This would be focussed on implementation. Users' confidence in their ability to use new methodologies and interpret the results is key to getting NRAs "buy-in" and uptake.
- **Develop a central repository for knowledge on data:** CEDR should also ensure that data handling knowledge gained is captured and shared (potentially user guidance documents) via a central repository.

Identifying the application of the projects' current (and future) outputs

- **HiSPEQ:** A process should be implemented to ensure updates to the HiSPEQ draft specification and guidance documents are undertaken periodically. Version control should be implemented.
- **X-ARA:** Identify routes to integrate X-ARA into NRA's current systems and frameworks.
- **RE-GEN:** Make refinements to the algorithms, parameters and outputs of the tool, on an NRA-specific basis – this should be an iterative process.
- **Individual demonstrations of tools:** CEDR should facilitate in-situ demonstrations of the new tools/frameworks using, and adapting to, individual NRAs' networks and data
- **Develop the link between value for money and risk analysis:** Comparing additional maintenance scenarios may improve the decision making process.
- **Identify outcomes desirable for NRAs at project inception:** The project feedback showed antipathy for introducing new individual software tools, but high interest in the methodology of risk-based processes. There is a need to ensure that research project outputs reflect NRAs' requirements – i.e. they contain sufficient detail to enable outputs to be implemented within NRA systems.

PART V

Appendix

Roadmaps

X-ARA

RE-GEN

HiSPEQ

X-ARA Roadmap

	Timeframe	2018	2019	2020	2021	2030	Goals
Dissemination	**Disseminate project outputs and promote current implementation**						Promote awareness of risk -based asset management.
	Identify where most benefit would be gained						Examine how current NRA practices can be extended to implement risk assessment
	Training and knowledge sharing						Deeper understanding
Development & Implementation	Review implementation of risk based approach and identify lessons learnt (including feedback from NRAs)						Help NRAs understand how a risk based approach works
	Specify data basis and organisation of data for risk assessment implementation						Make existing condition and asset data useable for risk assessment
	Develop bespoke applications X-ARA risk based approach for individual NRA						Build confidence across NRAs in risk based approaches

Relevant outputs

Dissemination

- Disseminate outputs: NRAs need to be made aware of the application of the knowledge delivered by this project, particularly those already work with risk assessment within their organisation.
- Identify: Identify NRAs who would most benefit from this work and make them aware of the outputs.
- Training: Training material has been provided by the project, Individuals from the project should work directly with NRAs to ensure full understanding of the processes and their benefits.

Development & Implementation

- Review Implementation: Highways England has adopted the X-ARA approach to a certain extent in their value management process, review challenges and enablers to its implementation.
- Feedback: A regular review of any implementation should be carried out and feedback obtained and incorporated into the methodology and guidance material as part of the review process.
- Data specification: The X-ARA approach relies on consistent condition and asset data. The awareness of this consistency over all asset types is fundamental for successful implementation.
- Work with individual NRAs to develop their risk based approaches: Confidence in a risk based approach can only be gained if it is in practical use. A comparison/evaluation with the conventional management approach will identify the benefits.

Trends/Factors to consider

- **Risks assessment is already used by NRAs in their asset management processes, although sometimes it is not explicitly named.**
- **Awareness for risk based approach and the possible benefits should be raised in NRAs.**
- **Data collection and consistent data management is getting more common in NRAs.**
- **Risk based approaches developed in the X-ARA has been implemented.**

RE-GEN Roadmap

	Timeframe	2018	2019	2020	2021 →	Goals
Dissemination	Advertise project & Demonstrate RE-GEN Tool					NRA & general industry awareness of the work
	Identify NRA requirements					Application of RE-GEN tool to individual NRA needs
	Training					Train NRA staff in the use of RE-GEN tool
Development & Implementation	Lessons Learnt and feedback					Help NRAs understand the outputs and improve them, based on feedback
	Refine RE-GEN tool					Refine based on individual NRA requirements
	Implement tool into asset management					Deliver final asset management solution to NRAs

Relevant outputs

Dissemination

- Advertise project: There is a need for NRAs to be made aware of the resources delivered by this project, particularly in relation to the consideration of climate change data and traffic loading information into the assessment of their asset safety & standardising risk assessment approaches for assets.
- Identify: Identify NRAs who would most benefit from this work and identify NRA-specific requirements for risk assessment, including countries who have appropriate records of asset condition which could be directly imported into the RE-GEN tool.
- Training: Training of NRA staff in the use of the tool and implementation of guidelines, this should also elicit feedback on country specific requirements.

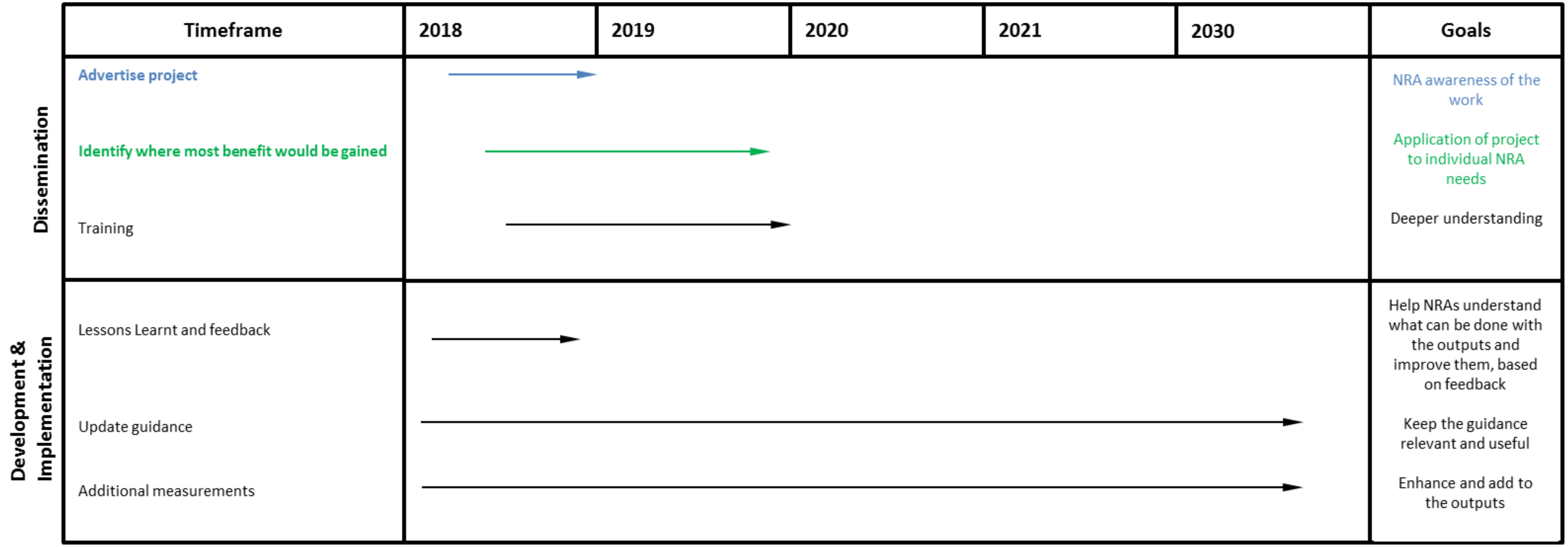
Development & Implementation

- Lessons learnt & Feedback: Through consultation with NRAs, the suitability of the tool and other RE-GEN outputs should be assessed and any required updates or changes recorded.
- Refine RE-GEN tool: Following feedback received from various NRAs, make refinements to the algorithms, parameters and outputs of the tool, on an NRA-specific basis – this should be an iterative process.
- Implement tool: When NRA-specific versions of the RE-GEN tool have been refined and finalised they should be provided to NRAs for use in asset management, or alternatively, where preferred, the underlying risk optimisation algorithms should be incorporated into existing asset management software systems.

Trends/Factors to consider

- **NRAs have similar but often different approaches for assessing and recording the condition of their assets. The RE-GEN tool uses databases of dimensionless condition scores to predict asset degradation and optimise maintenance strategies, however slight tweaks to the tool may be required to ensure that it is suitable for a specific asset type/scoring system used by a given NRA.**
- **A project champion, in each NRA wishing to adopt the RE-GEN approach should be identified. This project champion will be the primary contact for providing feedback on testing and implementation of the tool within their specific NRA.**

HiSPEQ Roadmap



Relevant outputs

Dissemination

- Advertise project: There is a need for NRAs to be made aware of the resources delivered by this project, particularly those who do not currently have survey specifications, or who might be investigating survey equipment.
- Identify: Identify NRAs who would most benefit from this work and make them aware of the outputs
- Training: It may be beneficial to run a training course, to help anyone trying to use the resources.

Development & Implementation

- Lessons learnt: Highways England have already implemented this work. Any lessons learnt should be shared.
- Feedback: A regular review of any implementation should be carried out and feedback obtained and incorporated.
- Update guidance: The guidance should be kept up to date as technology develops or emerges, to keep it relevant.
- Additional measurements: Further templates and guidance could be added for measurements not currently covered by HiSPEQ e.g. skid resistance, texture, fretting.

Trends/Factors to consider

- **In order to manage assets, there is a need for information about the assets e.g. condition. High speed surveys can provide pavement condition data in a cost effective manner. However, there is a need to specify the surveys well, in order to obtain best value for money from them. Thus all NRAs should be made aware of the project outputs**
- **A project champion should be identified, who will encourage the use of the project and ensure that it remains up to date and relevant, over the long term.**

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Call 2013: Ageing Infrastructure Management
HiSPEQ, RE-GEN and X-ARA projects

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