CEDR

Conférence Européenne des Directeurs des Routes

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INFRACOMS

Innovative and Future-proof Road Asset Condition Monitoring Systems

Appraisal methodology

Deliverable D2.1

Final Version 1.0

June 2023

TRL THE FUTURE OF TRANSPORT

COWI

ZAG

vti

Belgian Road Research Centre Together for sustainable roads

TU Delft

Danish Technological Institute

Project acronym: INFRACOMS

Innovative & Future-proof Road Asset Condition Monitoring Systems

Report D2.1

Final Version 1.0

Appraisal Methodology

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Executive Summary

The application of consistent, reliable information is a key component of highway asset management. The information and the tools to help interpret and apply data have continuously evolved. However, NRAs are not yet fully exploiting their potential in the highway environment. By bringing these components of sensing and measurement together, NRAs could better understand highway assets and improve both reactive and proactive asset management decisions.

INFRACOMS is a CEDR Transnational Road Research Programme Call 2022 project (July 2022 – June 2024). It aims to equip NRAs with the capability better to leverage the technological evolution in data/monitoring. By investigating the technologies that are becoming available to understand the performance of highway assets, their current and future capabilities and the benefits they bring, INFRACOMS will establish the potential that could be achieved through these technologies. INFRACOMS will develop a database of technologies and provide a structured method to evaluate technologies. It will provide the tools to help NRAs keep the database up to date in future and a roadmap and a maturity assessment tool to help NRAs implement changes.

This report represents INFRACOMS deliverable D2.1 Appraisal Methodology. It builds upon the deliverables of INFRACOMS Work Package 1 which identified the information needs, gaps and priorities of NRAs in terms of their approach to data collection and monitoring, and a list of current and emerging measurement technologies.

This report includes a review of several commonly-used appraisal methodologies that can be used to evaluate the effectiveness, suitability and potential impact of new technologies for an organisation. These methodologies include Technology Readiness Levels (TRLs), Cost Benefit Analysis (CBA), Life Cycle Cost Analysis (LCCA), Risk Assessment, and Multi-Criteria Decision Analysis (MCDA). Elements of these commonly used methodologies are included in the INFRACOMS Appraisal Methodology. The report also includes key highlights from a workshop with NRAs conducted in January 2023 which also fed into the design of the appraisal methodology.

The INFRACOMS Appraisal Methodology described here is designed around the technology use case, that is, a particular application of a technology by a NRA. It incorporates three core processes for Pre-Evaluation, Evaluation and Case Studies of technology use cases. It also includes processes for NRAs to define their strategic and technical priorities so that the appraisal process can be tailored to addressing their individual requirements, as identified from Work Package 1.

INFRACOMS will ultimately deliver a Technology Database and a Technology Appraisal Toolkit. WP2.2 will develop that toolkit to implement the Appraisal Methodology. That toolkit will be the subject of a future deliverable D2.2 under INFRACOMS.

Glossary

In the following, the most relevant terminology used throughout this document and INFRACOMS project are listed and addressed in order to align definitions and elaborate on the meaning of used terms.

Table 1. List of terms and meanings.

Term	Meaning
Availability (Carriageways)	The ability of an item to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided (1. This ability depends on the combined aspects of reliability, maintainability and maintenance supportability. 2. Required external resources, other than maintenance resources, do not affect the availability of the item) [EN 13306, PIARC, 2022)
Availability (Bridges)	The proportion of time a bridge is open for service. It does not include failure-related service outages but the ones due to planned maintenance interventions. Alternatively, availability can be measured as the additional travel time required due to an imposed traffic regime on the bridge.
Big data	A term that describes or relates to complex and large datasets where advanced analytics methods are employed to extract information or value from data.
Bridge	A civil engineering structure that affords a passage to pedestrians, animals, vehicles, waterways and services above obstacles or between two points at a height above the ground [COST 323]
BIM / Building Information Modelling	A process supported by various tools and technologies for creating and managing information on a construction project across the project lifecycle.
Carriageway	Part of the road or highway constructed for vehicular use (1. Reserved lanes, lay-bys and passing places are included. 2. The carriageway may include traffic lanes and the shoulder) (PIARC Road Dictionary, PIARC, 2022)
Common Data Environment	A platform that centralizes project data storage and access
Economy	The financial management of an asset, particularly considering the focussed long-term costs of maintenance activities over the asset's service life.
Environment	The environmental impacts of an asset (bridge or carriageway), in particular in relation to minimizing any adverse influence that the asset has on the environment during the service life of a bridge or carriageway.
IoT / Internet of things	A system of interrelated computing devices, mechanical and digital machines, and objects, with the ability to connect, exchange and transfer data over a communication network without requiring human-to-human or human-to-computer interaction.

Term	Meaning
Life Cycle Cost Analysis	A process of evaluating the economic performance of an asset over its entire life. Sometimes known as total cost of ownership.
Key Condition Data	Data which is of key importance to understanding the condition of an asset and hence its likely availability, reliability etc.
Key Imperatives	Capabilities, properties or performance that are considered essential for an asset to meet its requirements and expectations.
Key Performance Indicator	A term that describes and/or measures the fitness for purpose of the physical asset.
Performance Indicator	A term describing a particular technical characteristic of the condition of an asset.
Reliability (Bridge)	The probability that a bridge will be fit for purpose during its service life. It complements the probability of structural failure (safety), operational failure (serviceability) or any other failure mode. (reference)
Remote sensing/ monitoring	The practice of using sensors and software to monitor the condition, performance and behaviour of an asset, remotely rather than directly inspecting or observing the asset in person. Sensors may be attached to or embedded in the asset, but also included other sources such as satellites, aircraft, drones and other mobile sources (e.g. mobile devices, sensors built into vehicles).
Safety	The impacts of an asset (bridge or carriageway) on the health and safety of stakeholders/users. Structural failure is not included by this definition as it is contained within Reliability.
Socio-economic	The financial management of an asset, considering the maintenance/ management of the asset, and the costs related to society (e.g. costs of accidents, travel times, maintenance etc.
Technical Parameter	A parameter that describes a particular physical value/characteristic of an asset. This may be derived from various measurements, or collected by other forms of investigation
Technology Readiness Level	A method for estimating the maturity of technologies during the acquisition phase of a program. Originally developed by NASA in the 1970s for space exploration technologies.
Unmanned Aerial Vehicle	Commonly known as a drone, it is an aircraft (not exclusively) without any human pilot, crew, or passengers on board.

Abbreviations

Table 2. List of abbreviations.

Abbreviation	Definition
AADT	Annual Average Daily Traffic
AE	Acoustic Emission
AI	Artificial intelligence
AM/AMS	Asset Management / Asset Management System
APL	Analyseur de Profil en Long
AR	Augmented Reality
AV	Autonomous vehicle
CBA	Cost Benefit Analysis
CDE	Common Data Environment
CEDR	Conference of European Directors of Roads
CO2	Carbon dioxide
CPX	Close-Proximity Method
DT	Digital Twin
eLPV	Enhanced Longitudinal Profile Variance
EPDs	Environmental Product Declarations
FOS	Fibre Optic Sensors
FWD	Falling Weight Deflectometers
GPR	Ground Penetrating Radar
GW	Guided Waves Propagation
ICT	Information and Communications Technology
IE	Impact echo
INFRACOMS	Innovative & Future-proof Road Asset Condition Monitoring Systems
IoT	Internet of Things
IR	Infrared thermography
IRI	International Roughness Index
IRT	Active Thermal Imaging/infrared thermography
ITS	Intelligent Transport System
KPI	Key performance indicator
LCA	Life Cycle Assessment
LCC/LCCA	Life Cycle Cost/Life Cycle Cost Analysis
LCMS	Laser Crack Measurement System
LiDAR	Light Distance and Ranging
LOI	Letter of Intent
LOS	Level of service
LVDT	Linear variable differential transformer
M2M	Machine-to-machine interfaces
MCDA	Multi-Criteria Decision Analysis
MEMS	Micro Electro-Mechanical Systems
ML	Machine Learning
MLS	Mobile Laser Scanning
MPD	Mean Profile Depth

MR	Mixed Reality
NOX	Nitrogen oxides
NRA	National Road Authority
OBSI	On-board Sound Intensity
OWL	Web Ontology Language
PIARC	World Road Association (Permanent International Association of Road Congresses)
PM	Particulate Matter
PMS	Pavement Management System
RDF	Resource Description Framework
RWIS	Road Weather Information System
SA	Smart Aggregate
SF	Sideway Force
SHACL	SHapes And Constraints Language
SHM	Structural Health Monitoring
SKOS	Simple Knowledge Organization System
SPB	Statistical Pass-By method
TARVA	Tool for traffic safety evaluations
TMLS	Terrestrial Mobile Laser Scanning
TRL	Technology Readiness Level
TSD	Traffic Speed Deflectometer
UAV	Unmanned Aerial Vehicle
UPV	Ultrasonic Pulse velocity
V2X	Vehicle to other technologies
VR	Virtual Reality
VRS	Vehicle Restraint System
WIM	Weight in Motion system
WLC	Whole Life Costing
WLP	Weighted Longitudinal Profile
WP	Work Package

1 Introduction

1.1 The INFRACOMS project

The application of consistent, reliable information has been a key component of highway asset management for over 40 years. The information and the tools to help collect, interpret and apply data have continuously evolved during that time. Technologies with the potential to support asset management include remote sensing, intelligent infrastructure monitoring, crowdsourcing, data analytics and visualisation. However, National Road Authorities (NRAs) are not yet fully exploiting their potential in the highway environment to better understand highway assets and to improve both reactive and proactive asset management decisions.

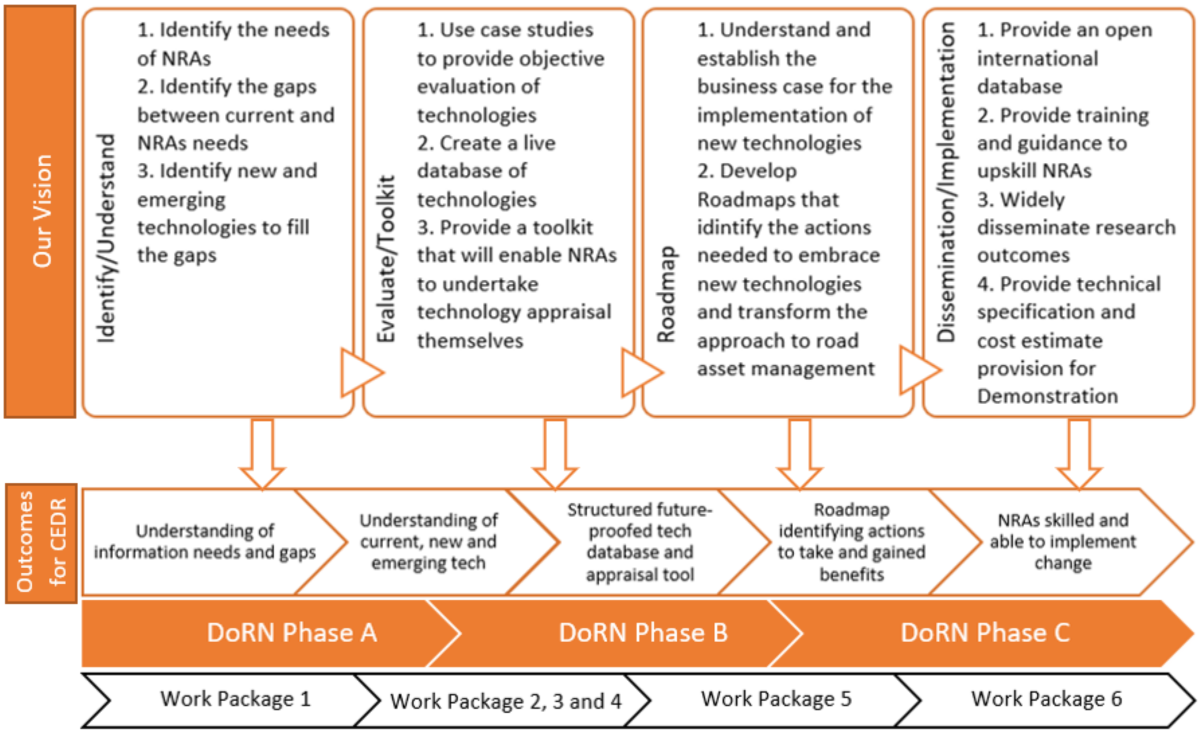

Figure 1. Vision and outcomes of INFRACOMS.

INFRACOMS aims to equip NRAs with the ability to better leverage the technological evolution in data and monitoring. Figure 1 summarises the approach being taken in this project. INFRACOMS is investigating the capabilities and benefits of technologies for understanding the performance of highway assets. INFRACOMS is establishing a database of new technologies and a toolkit to appraise them, to help NRAs assess the costs, benefits and limitations of applying these technologies in their own environments. INFRACOMS will also provide a roadmap to provide strategy and guidance for NRAs to improve their business processes for more effective assessment and implementation of new technologies.

1.2 Scope of this report (INFRACOMS Deliverable D2.1)

The work described in this report was carried out in the Evaluate/Toolkit phase of INFRACOMS. This D2.1 report presents the INFRACOMS Appraisal Methodology as developed under Work Package (WP) 2. A future report D2.2 will describe the INFRACOMS toolkit.

Figure 2 shows the relationship of the various INFRACOMS work packages, tasks and deliverables with respect to WP2.

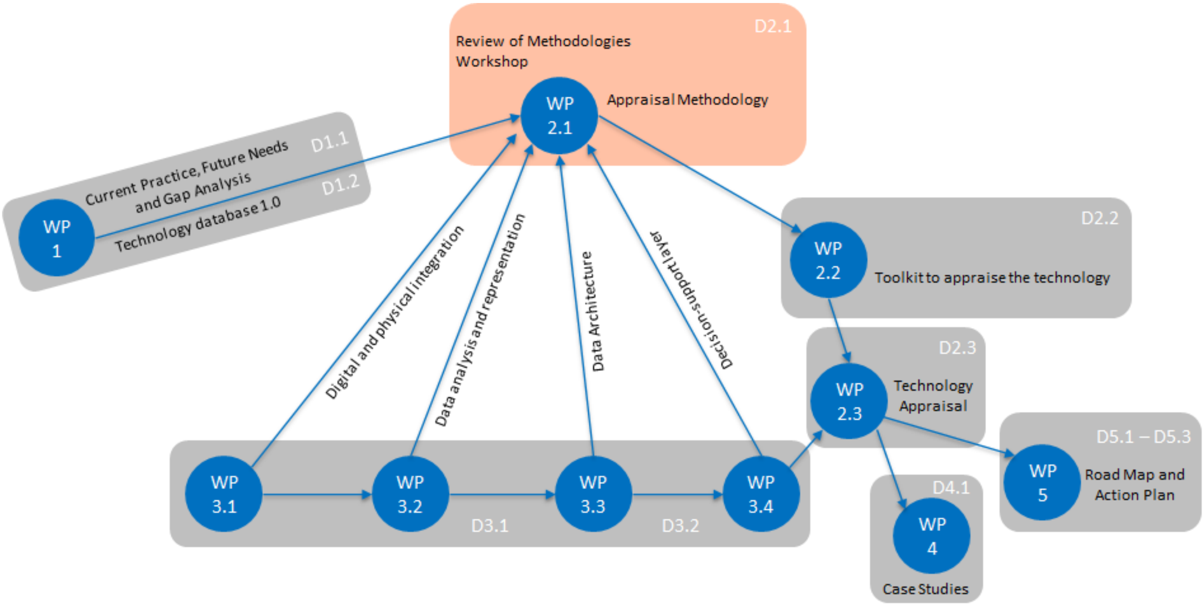

Figure 2. Relationship of WP2 to other Work Packages, Tasks and Deliverables

WP1 D1.1 on Current Practice, Future Needs and Gap Analysis identified the current priorities and needs of NRAs for the management of carriageway and bridge assets in terms of their approach to data collection and monitoring. It identified gaps in data, challenges in collecting data, and challenges in application of data that is already collected. It also identified technologies that can address those gaps and challenges. WP1 also produced D1.2 - Technology Database. This containied a list of remote condition monitoring technologies and mapped them against the current and future asset management needs identified in the consultation carried out in WP1.

WP2.1 brought together the outputs from WP1, the outcomes of a review of methodologies and workshop conducted under WP2, and outputs from WP3. Those outputs from WP3 include methods for describing and assessing which physical characteristics the technology is measuring, what data it provides, how that data can be analysed and represented, how easy it is to integrate that data into asset management systems, and how that data contributes to a NRA's decision-making processes. These outputs have been combined into a methodology for the appraisal of technologies with respect to their application by NRAs to understand the performance of highway assets. This appraisal methodology is the subject of this report.

WP2.2 will develop a toolkit to implement the appraisal methodology. WP2.3 will apply the toolkit to appraise technologies identified in the (WP1) technology database. A separate Deliverable D2.2 will describe the appraisal toolkit and user manual.

WP4 will develop real-world case studies for the most promising technologies identified using the methodology.

WP5 will develop a roadmap for the implementation of new technologies for NRAs, and a method for NRAs to assess their maturity in being able to adopt new technologies.

2 Work Package Objectives and Approach to Developing the Appraisal Methodology

2.1 Objectives

The objectives of WP2 are to:

- Create a methodology that can be used to appraise technologies with respect to their ability to understand the performance of highway assets (O2.1)
- Develop a practical Appraisal Toolkit that implements the methodology (O2.2)
- Apply the toolkit to appraise new and emerging remote condition monitoring technologies O2.3)
- Produce a list of appraised technologies for implementation (O2.4)

2.2 Approach

The review of appraisal methodologies and workshop held under WP2, and the activities in WP3, have helped identify and develop the key components of the overall INFRACOMS methodology.

The activities carried out under WP2.1 as discussed in this report are:

- Review existing appraisal methodologies available in the broad infrastructure landscape, including review of existing approaches applied by NRAs
- Consultation with NRAs on the appraisal streams and imperatives that should be included within a technology appraisal
- Determine the scope and boundaries of a technology appraisal and business case assessment
- Define criteria for technlogy appraisal

Note that the other activities from WP2.1 relating to the design and development of a toolkit to support the methodology will be included under Deliverable D2.2 in September 2023, namely:

- Determine the structure of the appraisal toolkit
- Design and develop the appraisal toolkit to implement the appraisal methodology
- Select an LCCA tool/methodology for integration to the appraisal toolkit

3 Review of Appraisal Methodologies

There are several methodologies that can be used to evaluate the effectiveness, suitability, and potential impact of new technologies for an organisation. We reviewed a range of common evaluation methodologies under WP 2.1, with a view to incorporating best practice into an overall methodology for INFRACOMS. INFRACOMS should evaluate technologies from a broad range of perspectives, and draw upon aspects of commonly accepted methodologies to give a comprehensive assessment of the potential application of technology use case in an NRA.

Technology Readiness Level (TRL) Assessment: TRL assessment is a systematic method for evaluating the maturity of a technology. It involves evaluating a technology against a specific set of criteria to determine its readiness for implementation. Use of TRLs is widespread across many industries. The EU introduced TRLs in 2012 to determine the development or maturity of a research and its readiness for market uptake and potential investments (European Commission, 2020). TRLs can be considered to be subjective, however they can be tailored for sectors or organisations to reduce subjectivity. Transport Infrastructure Ireland (TII) produced 'Guidelines for the Implementation of Innovation' (TII, December 2020) to provide a consistent approach to the assessment of readiness of potentially innovative products and processes. The TII guidelines include TRLs specifically devised for the agency, which is responsible for road and light rail networks (see Annex 1). The guidelines provide a clear path for products or processes to move through the TRLs towards deployment as a pilot or trial. Highways England (now National Highways) in 2016 recognised that it needed technical innovation to meet its performance targets for its next Road Investment Strategy (RIS), and used TRLs to assess the maturity / viability of technologies to reach those targets (Highways England, 2017). We consider TRLs a useful method for assessing technology readiness and informing decision-making as part of INFRACOMS as long as it is clear whether the technology has been assessed from the point of view of the supplier or the roads agency.

Cost-Benefit Analysis (CBA): CBA is a systematic method for evaluating the economic viability of a technology by comparing the costs of implementing the technology with the potential benefits it can generate. It can be used to evaluate whether the benefits of a given technology outweigh the costs of that technology, and to compare the costs and benefits of different technologies. Costs can include the initial investment in the technology, and the ongoing costs over the lifespan of the technology. Benefits can include direct benefits generated by the technology, for example reduced survey or inspection costs, as well as indirect benefits such as improved safety to workers or reduced environmental impact. CBA may include sensitivity analysis to evaluate the impact of different assumptions on the costs and benefits. Most national governments have detailed requirements or guidelines for cost-benefit analysis, for both CBA of infrastructure projects and technologies to ensure that CBAs are conducted in a consistent and transparent manner, and describing the types of economic and non-economic factors that should be included (e.g. UK Treasury Green Book, Irish Public Spending Code, Swedish Guidelines for Economic Analysis). The overall concepts of CBA methodologies are widely applied, but there are distinct differences in the details across national governments. At a high level, INFRACOMS can help to identify the different types of costs and benefits to be considered when conducting a CBA of a technology for a particular use case. Any full CBA for a technology use case for an individual NRA must be conducted according to the guidelines of the NRA.

Life cycle cost analysis (LCCA): LCCA is a type of cost-benefit analysis (CBA). CBA traditionally focuses on the costs and benefits of an investment at a particular point in time, and may be used to evaluate the costs and benefits of implementing a project this year versus implementing the same project in succeeding years. LCCA, on the other hand, explicitly looks to ensure that the total lifespan of the investment, including costs and benefits that may occur over the lifetime of the technology or asset, are included in the evaluation. As with CBA, INFRACOMS can help to identify the different types of costs and benefits that should be considered when conducting an LCCA.

Risk Assessment: Risk assessment is concerned with the documentation, collation and analysis of risks associated with implementation of a technology. Potential risks can be identified and then assessed in terms of their likelihood and consequences. Implementation of any new system or technology carries with it both direct and incidental risks. General risks for any organisation include financial risks or environmental risks. Specific risks typically assessed by a roads agency include safety risks to road users, safety risks to road workers, travel disruption, and failure of the infrastructure or asset. As with CBA, each NRA has its own risk assessment guidelines or procedures, and INFRACOMS should enable capture of the potential risks of a technology for feeding into an NRA's procedures.

Multi-Criteria Decision Analysis (MCDA): MCDA is a method for evaluating technologies based on multiple criteria, such as economic, environmental, and social factors, and weighting each criterion based on its importance. MCDA can provide a structured and transparent approach to decision-making to help ensure that decision-making is aligned with an organisation's objectives. Elements of an MCDA approach are useful to score a technology and to filter those technologies that are capable of addressing the key imperatives or technical priorities of NRAs. Multiple types of scoring can be applied in a MCDA, for example scoring can be based on a simple appraisal method (such as on a scale of 1 – 5 with 1 representing low importance and 5 representing high importance), or it can be based on a more complex numerical approach such as entropy weighting which involves measurement of each criterion in different units and scales, normalisation of those, and inclusion of uncertainty in each of the measurements. Elements of a MCDA approach are useful in INFRACOMS to allow appraisal of multiple technologies according to the needs of each NRA. As seen later in this document, we suggest a simple appraisal method to score the characteristics of different technologies.

Political Economic Social Technological Legal Environmental (PESTLE) method: PESTLE is a high-level analytical tool used to identify and analyze external factors that may affect an organization or a project. The method involves conducting a thorough analysis of each of these factors to assess the impact they may have on an organisation or a project. This analysis can be used to identify opportunities and threats that may arise from changes in the external environment, as well as to inform strategic decision-making and risk management. Some aspects of the PESTLE framework (e.g. government policies, laws or regulations, or social impacts) are not normally relevant to evaluation of specific technologies, and if they are present, could be identified under a general Risk Assessment. Therefore in our view they do not need to be explicitly analysed for each technology. Economic factors, on the other hand, are covered in more detail under a cost-benefit analysis as discussed above.

4 Workshop

An on-line workshop was held on January 26th 2023 with representatives from nine NRAs. The workshop was split into a morning and afternoon session. The first session concentrated on the evaluation of moinitoring technologies for carriageways, the second on evaluation of technologies for bridges. Writeups of both sessions are given in Annex 5.

Key highlights from the workshop included:

- Discussions around the definitions and priorities for the key imperatives. The key imperatives of availability, environment, socio-economic, and safety, for both carriageway and bridges, were presented in the WP1 report D1.1 ‘Current practice, future need and gap analysis’. NRAs at the workshop identified availability and safety as being the most important imperatives for carriageways although socio-economic and environment also featured; while for bridges safety was clearly the most important imperative, with availability and reliability returning slightly lower priorities.
- The need for involvement in the evaluation process from different departments within NRAs, including asset management (roads and structures are often managed separately), also those involved from different managerial or technical perspectives.
- The need for consideration of different uses of the same data within the NRA.
- The frustration of NRAs being told by vendors or suppliers of the benefits and readiness of their technologies without the supplier understanding the process of evaluation.
- The need for some NRAs to report against historical KPIs for continuity and long-term analysis of the performance of their assets.
- NRAs often need to know exactly how data is defined, how it is collected, to what standards it is collected, and what post-processing is done. KPIs can be very sensitive to small changes in data, so any change to a data collection methodology can have a profound impact. Use of data from crowd-sourcing or from AI may be problematic because it may not be possible to determine how it was produced, and it may not be exactly repeatable.
- In some NRAs there is little appetite to conduct research or trialling into new technologies unless they have been demonstrated to be useful to other NRAs.
- Knowledge sharing should be an important component of the methodology and toolkit, current knowledge sharing is done on a ‘who you know’ basis.
- Some NRAs have sophisticated asset management systems and data architectures and want data to be integrated into their systems; while other NRAs have less sophisticated systems and/or do not require ‘raw’ data to be integrated into their systems.
- Although the DoRN had a focus on carriageways and structures, if technologies for other structures (e.g. retaining walls) can also be considered then that would also be useful.

The takeaways from the workshop have helped feed into the recommendations for the appraisal methodology, and will also feed into the design of the toolkit to implement that appraisal process.

5 Key Recommendations for Appraisal Methodology

Based on the technologies identified in WP1, and on the review of common appraisal methodologies and discussions in the workshop in WP2.1, we make the following recommendations for the INFRACOMS Appraisal Methodology.

- The methodology should be built around the **technology use case,** that is, a particular application of a technology by a NRA. Some technologies identified in WP1 may have more than one technology use case within a NRA. Each technology use case should be subject to a separate appraisal, as the costs and benefits, risks and limitations will be different for each technology use case.
- The methodology should provide a consistent and objective appraisal method for new technologies, with clear guidance on how to evaluate a technology. The methodology should be designed and described so that any evaluator with a good technical background and understanding of the technology and its anticipated use case should be able to conduct a consistent and objective evaluation of the technology use case. However, a detailed evaluation of some technologies may require expert input when applying to a particular use case in a given NRA.
- There are several evaluation methodologies already in use in many NRAs. The most common methodologies in use include technology readiness levels (TRLs), cost-benefit analysis (CBA), life cycle cost analysis (LCCA) (which is a subset of CBA), and risk assessments. The high-level concepts in these methods are well-understood and are similar across NRAs. Together they provide a wide-ranging assessment of different aspects of a technology use case, and should be included as part of an overall INFRACOMS methodology.
- TRLs have been considered by some to be subjective. However they can be tailored for sectors or organisations to reduce subjectivity, and so their definiitions must be made clear. It is also important to understand from whose point of view a technology is being assessed (e.g. the supplier, the NRA, or other). We consider TRLs a useful method for assessing technology readiness and informing decision-making as part of INFRACOMS at different levels.
- CBA, LCCA and Risk Assessments are complex subjects in their own right. INFRACOMS should not attempt to replace or somehow implement common definitions and methods across NRAs, however at a high level it should provide guidance to NRAs on the types of costs, benefits, risks etc. that should be considered when assessing a technology. This can be used to guide detailed evaluations at a case study level.
- Multi-Critera Decision Analysis (MCDA) is another common method that is used to compare multiple options based on a set of decision criteria or attributes. With regards to technology evaluations, it provides the ability to score different criteria of a technology (such as technical performance, ease of data collection, ease of data analytics etc.) according to the requirements of the NRA. Multiple types of scoring can be applied in MCDA, ranging from simple appraisal to complex mathematical functions. We recommend using MCDA, with simple appraisal approaches based on scales of 1 – 5 (where 1 might represent a 'difficult' data collection process, and 5 might represent an 'easy' data colleciton process). We recommend a simple appraisal approach to reflect the nature of the scoring being performed.

We have incorporated these recommendations into the INFRACOMS Appraisal Methodology as described in section 6.

6 INFRACOMS Appraisal Methodology

6.1 Introduction

This section presents the appraisal methodology designed by INFRACOMS in the light of the review presented in section 3, the workshop described in section 4, and the recommendations described in section 5.

To describe the methodology, we present process diagrams based loosely on IDEF (Integrated DEFinition) process models. Under this representation, each process is represented by a box, with inputs (on the left), outputs (on the right), mechanisms (such as organisations or units (at the bottom), and constraints (such as laws, policies or regulations) at the top. See Figure 3.

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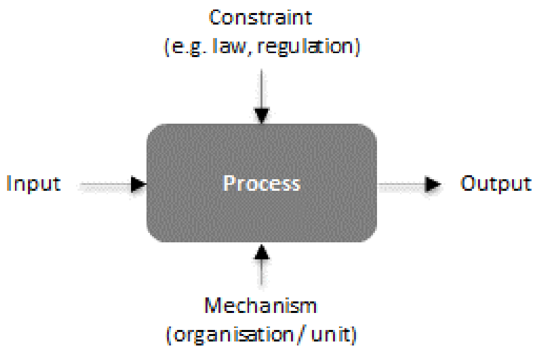

Figure 3: Introduction to process models

6.2 The Apprasial Methodology

Figure 4 shows the proposed INFRACOMS Appraisal Methodology. The processes shown in orange boxes represent the core components of an INFRACOMS appraisal. The blue boxes are filtering and prioritisation processes, representing the ways in which the methodology can be tailored to individual NRAs.

An INFRACOMS appraisal has three (3) core processes, with increasing levels of detail and complexity. These core processes apply at the level of the technology use case.

- **Pre-Evaluation**: A high-level analysis of the anticipated benefits, limitations and costs, and an assesssment of the readiness level of the technology for a particular use case from the *supplier's* perspective. It also scores the technology for the particualr use case against the key imperatives (availability, reliability, economy and safety as defined in WP1). Pre-evaluation should be accomplished quite quickly (in perhaps 2 – 3 hours). It would require general knowledge of technologies and their applications, and an understanding of the potential applications by the NRA.
- **Evaluation**: This is a more detailed breakdown of the, benefits, limitations and cost factors of the technology within the proposed use case, including a more in-depth technical evaluation and an assessment of the steps needed that would be required to implement it in an NRA. It provides an assessment of the readiness level of the technlogy from the NRA's perspective. Evaluation would take longer to accomplish (perhaps 2 – 3 days of inputs). It would require inputs from a specialist or expert in the field, and discussion with the supplier of the technlogy, to gain a full understanding of the technology and its potential application for a NRA.
- **Case Study**: This is an in-depth analysis of the potential implementation of the technology in a given NRA. The inputs required will depend very much on the individual technlogy and use case being assesssed, and could take several weeks to complete depending on the availability of

information and complexity of the technology use case. It will require discussion and cooperation between the technology provider and the NRA to define the exact scope of the implementation, the CBA and LCCA methodology to be used, the cost and benefit factors to be applied, and any risk assessment to be conducted. Information from a completed case study, such as additional cost factors or benefit categories, would be used to update the pre-evaluation and evaluation.

Although the appraisal focusses on a specific technology use case, the Pre-Evaluation and Evaluation stages are still considered generic, and would be useful to any NRA considering applying that technology in a broadly similar use case. Case Studies are normally conducted with an individual NRA and more focused, and which use the CBA, LCCA and Risk Assessment criteria for that specific NRA. The completed Case Studies will also provide valuable insights for other NRAs interested in evaluating that (or similar) technology.

It can also be seen from Figure 4 that both the pre-evaluation and evaluation processes also consider the strategic and technical priorities of the NRA.

- **Strategic Priorities**: These are established by the NRA with respect to the key imperatives that the NRA wishes to address using technology. For example, if the NRA wishes only to identify or appraise technologies that improve safety, then they can filter technologies that support safety as a key imperative.
- **Technical Priorities**: These define the technical priorities of the NRA with respect to its capabilities for use and integration of technology. For example, if the NRA places a high priority on ease of data collection, then technologies which make data collection easier can be identified and filtered; on the other hand, if an NRA does not place a high priority on integrating data provided by the technology into its existing systems, then a technology which enables such ease of integration would have lower significance to that NRA and can be filtered accordingly.

The following sections describe the different processes within the overall methodology. Examples of Pre-Evaluation and Evaluation stages are shown for one technology use cases: 'Tyre Grip Indicator (TGI) by NIRA as potential replacement for network-wide Sideways Force skid resistance measurement'. The pre-evaluation and evaluation for that use case is shown in Annex 2. Evaluation of a separate technology use case, 'Acoustic Emissions to detect wire break in steel cables in bridges' is given in Annex 3.

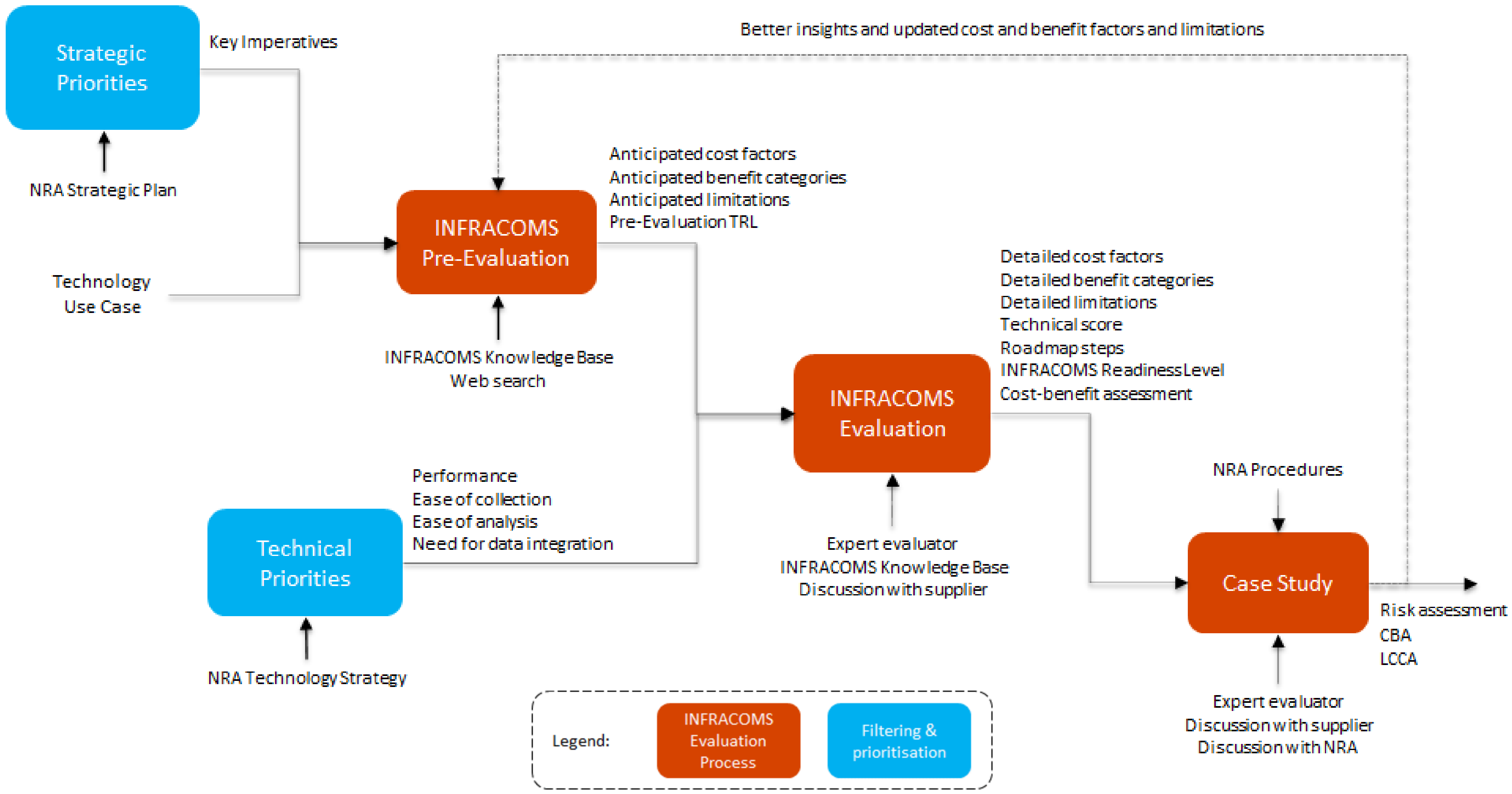

Figure 4: INFRACOMS Overall Methodology

6.3 Strategic Priorities

Strategic Priorities are established by the NRA with respect to the key imperatives that the NRA wishes to address using technology. The strategic imperatives are used to support filtering and prioritisation of a technology use cases during Pre-Evaluation (see example in Figure 5). Multiple strategic imperatives can be defined if necessary.

Parameter	Assessment
Asset type	Carriageway
Strategic imperative	Safety

Figure 5: Identification of the strategic imperative of a technology use case during pre-evaluation

6.4 Technical Priorities

Technical priorirites define the priorities of the NRA from a technical point of view when it is appraising a technology use case. These technical priorirites are used to support filtering and prioritisation of technology use cases. Each technology use case undergoes an appraisal of various technical elements during the Evaluation stage (see Figure 6).

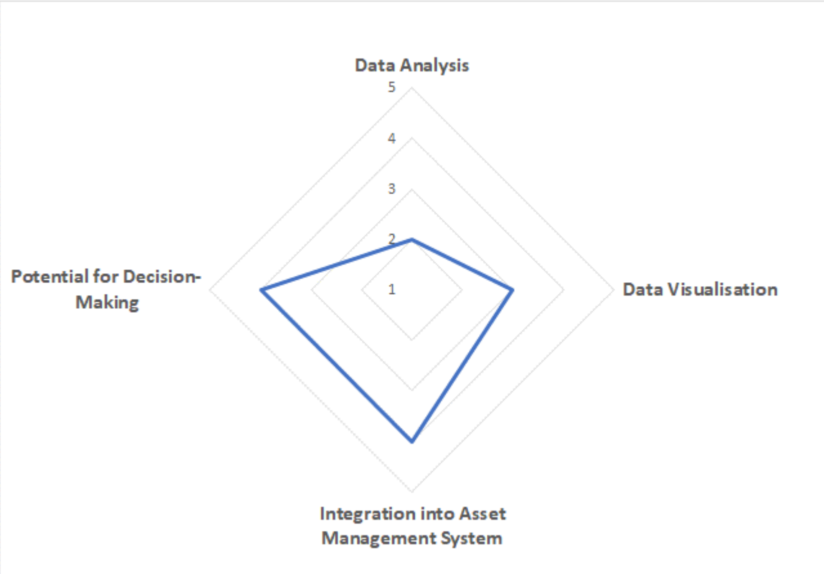

Figure 6: Identifcation of technical scoring of a technology use case during evaluation

Figure 6 shows the four key components that are scored in a technical evaluation – potential for improvement in decision-making, ease of data analysis, ease of data visualisation, and ease of data integration. These are further elaborated on page 26. If an NRA is concened with ease of integrating data into its existing asset management systems, then a technology which enables easy integration into existing systems becomes of higher significance to that agency and should be able to be identified.

6.5 Pre-Evaluation

6.5.1 Pre-Evaluation Appraisal

Pre-Evaluation provides a high-level description of the technology, analysis of the anticipated cost factors, benefits and limitations of the technology use case. This can be accomplished quite quickly (with perhaps 2 – 3 hours of inputs) based on research from the INFRACOMS knowledge base and/or web searches. It needs good general knowledge of technologies and their applications, and an understanding of potential road agency applications.

Figure 7 shows a sample overview of the Tyre Grip Indicator (TGI) technology from NIRA Dynamics. The overview includes descriptive text of the overall system from collection to delivery, with diagrams if possible; describes the underlying technologies; and the potential use case in a roads agency. The use case being considered in this instance is as a potential replacement for current methods of network-wide Sideways Force skid resistance measurement. Note that this is a sample evaluation for illustrative purposes only. It is still subject to technical review.

Technology	**Use case**
The Tyre Grip Indicator (TGI) from NIRA Dynamics continually monitors the friction between the tyre and the road by analysing wheel speed signals and other automotive grade sensors. TGI can be made available through telemetry.	Potential replacement for current methods of network-wide Sideways Force skid resistance measurement.

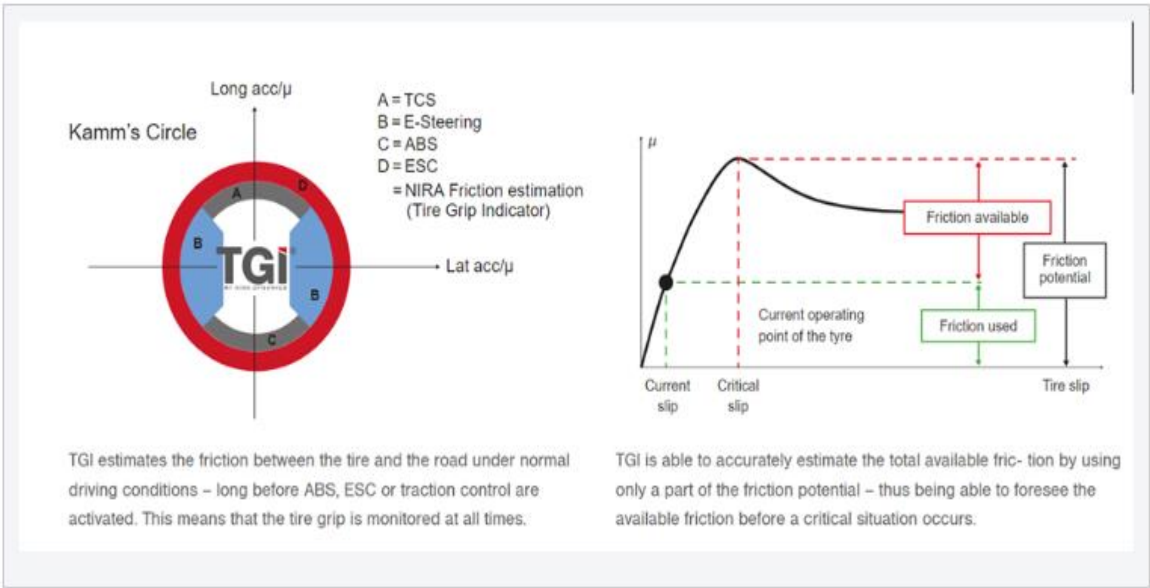

Figure 7: Sample technology use case overview

Note that the Pre-Evaluation also identifies the asset type and strategic imperative of the Technology Use Case (as seen in Figure 5).

Anticipated cost factors	€ Data purchase € Data storage € Data processing and aggregation
Anticipated benefits	Cost savings over traditional Sideways Force (SF) skid resistance surveys Higher frequency of data provision gives opportunity to improve road user safety through more timely interventions and hence reduced Killed or Seriously Injured (KSIs) Improved worker safety as a result of crowd-sourcing instead of dedicated survey Improved assessment of road user skidding risk Characterisation of skid resistance performance aligning with the experience of vehicles Reactive to changes in the vehicle fleet
Anticipated limitations	Current Sideways Force - Texture Depth (SF-TEX) methodologies are well-established internationally SF-TEX methodologies characterise the 'worst-case' scenario while TGI does not necessarily Current SF-TEX data is collected in a very controlled environment while there is less control with crowd-sourced methods May not get full network coverage leading to potential 'blind-spots' No consistency with historical SF-TEX data No relationship to current network Key Performance Indicators (KPIs) No integration with road owner's condition databases Lack of standardisation

Figure 8: Sample technology cost factors, anticipated benefits and anticipated limitations

Figure 8 gives sample anticipated cost factors, benefits and limitations for the technology when applied in the proposed technology use case. These are quite high-level, and would expanded as part of a full evaluation.

- **Anticipated cost factors**: These are not limited to the purchase of the technology or the data, but include wider factors that would incur costs to the NRA. It can be anticipated that for any particular technology the costs will vary by the type of data purchased, storage of that data, and costs for additional processing and aggregation of data. It is not necessary at this pre-evaluation stage to break down those costs beyond those likely high-level categories.

- **Anticipated benefits**: the likely benefits are high-level. In this example they include potential cost savings over traditional methods, better granularity of data, more timely data etc. These categories of benefit would be couched in terms of the key imperatives which the technology use case is designed to address.

- **Anticipated limitations**: the anticipated limitations are similarly high-level. These include barriers or constraints to implementation of the technology in the technology use case, such as for example calibration against the technology/data which it is looking to replace. In the case of a technology which provides brand new data that has not been available to date, this could include the establishment of new decision-making policies and processes.

6.5.2 Pre-Evaluation Readiness Level

Pre-evaluation includes an assesssment of the readiness level of the technology for the proposed technology case *from the supplier's perspective*. At the Pre-Evaluation stage, INFRACOMS uses the TRLs adopted by the European Commission. This is a generic TRL scale which was introduced in EU funded projects in 2020 and is the point of reference for determining the development or maturity of a research and its readiness for market uptake and potential investment. See Table 3.

Table 3: Pre-Evaluation TRLs (as defined by European Commission)

TRL level	Description
9	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
8	system complete and qualified
7	system prototype demonstration in operational environment
6	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
5	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
4	technology validated in lab
3	experimental proof of concept
2	technology concept formulated
1	basic principles observed
Unknown	TRL level can not be estimated due to the lack of information

In this example in Figure 9 for tyre grip indicator data, the supplier claims that the data could be made available 'today'. Hence, while the technology may not have been used in an NRA for the tecyhnology use case being considered, from the supplier's point of view the TRL is level 7.

Pre-Evaluation TRL	7 - system prototype demonstration in operational environment

Figure 9: Sample pre-evaluation TRL, by supplier

6.6 Evaluation

6.6.1 Appraisal of the technology use case

Evaluation carries out a more in-depth appraisal than the pre-evaluation. It builds on the expectation that the proposed technology use case is associated with an existing decision-making process in the NRA, and this new technology is being evaluated as a potential replacement for (or improvement to) the technology or data that supports this decision-making process. See Figure 10. Hence this directly associates the technology (and the evaluation of it) with specific business/operational activities of the NRA, to focus on the objectivity and value of the appraisal process. If the new technology/data is expected to be associated with the provision of new types of data that are not directly replacing/enhancing an existing process, then the Existing Process entry should describe where/how this technology could contribute to improved operation of the network.

Existing process	Current Sideways Force (SF) process is to conduct an annual network survey to identify locations on the network at which there is a risk of wet-road skidding. Skid policies based on annual surveys identify locations on the network on which high skid-resistant aggregates should be used. Investigation of deficient sites can be undertaken to help reduce accidents. SF survey data is also used as part of road authority annual network performance indicators.

Figure 10: Sample description of existing process

Evaluation also describes the new data collection method. See Figure 11, and any opportunities for enhancement of the existing process, as shown in Figure 12.

Potential new data collection method	TGI data requires no additional sensors. It is a software solution that can provide continuous, network-level summary data from the NIRA fleet, collected and summarised at varying road locations and at varying time periods according to the needs of the client.

Figure 11: Sample description of potential new data collection method

Opportunities for enhancement of existing processes	**Improved skid resistance policies** There have been recent suggestions that the changing vehicle fleet and the opportunities allowed by anti-lock braking systems (ABS) should prompt review of the way in which skid resistance policies are generated and monitored. There may be opportunities to devise more effective skid-resistance policies based on data other than that provided by SF-TEX methods. **Higher frequency of data** Currently, SF-TEX assessments are carried out at different frequencies depending on the policy of different NRAs. As far as the evaluator is aware, the highest frequency of network level assessment is annually. TGI may provide data with a greater temporal resolution as data are collected constantly from the vehicle fleet directly.

Figure 12: Sample description of opportunities for enhancement of the existing process

Evaluation also provides a more detailed analysis of the cost factors, benefit categories and limitations of the technology use case than those included in Pre-evaluation. With regards to the cost factors, whereas Pre-evaluation identified very high-level cost factors, Evaluation breaks these down into more detail. Thus, as shown in Figure 13, whereas Pre-evaluation simply identifies data purchase as one of the cost factors, discussion with the supplier identifies the unit prices of those data – in this case, depending on the number of vehicles 'activated' in the supplier's fleet (i.e. the number of vehicles from which data will be obtained), the number of km for which data can be provided (which may be able to be differentiated by lane), the frequency of supply (for example weekly, monthly, annually) etc. Cost factors for data storage, processing etc. are similarly expanded.

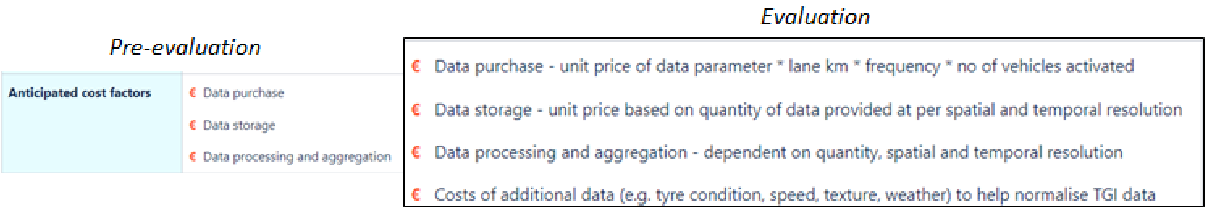

Figure 13: Sample pre-evaluation and evaluation cost factors

6.6.2 Scoring of the technology use case

In addition to the in-depth evaluation of the technology use case, INFRACOMS includes a simple scoring mechanism to enable easy visualisation using radar diagrams to interpret the strengths or weaknesses of a particular technology for its use case. This is an instance of the MCDA method as described in section 2.

The key aspsects of the technology scoring are given in Table 4. These are further elaborated under WP3 Deliverables 3.1 and 3.2.

Table 4: Key aspects of INFRACOMS technology scoring

Components	Criteria
Assessment of associated data analysis	○ Need for raw data interpretation ○ Does the technology come with an analysis engine? ○ Uncertainty of analysis results ○ Complexity of analysis ○ Compliance with client data requirements ○ Data processing ○ Data anomalies
Data Visualisation	○ Does the technology come with a visualisation platform? ○ Can visualisation data be extracted? ○ Current state and prognosis ○ Compliance with client visualisation requirements for decision-support
Potential for practical decision-making	○ Is data quality sufficient for decision-making? ○ Is data acquisition frequency sufficient for decision-making? ○ Can (processed) measurements be directly used in the decision-making process? ○ Advantages/disadvantages for decision-making
Ease of data integration	○ Data organisation ○ Data formats ○ Data interface mechanisms

The technical scores for each component can be presented for each 'spoke' in a radar diagram as shown in the example in Figure 14. When plotted on a radar diagram, it provides a concise interpretation of the strengths and weaknesses of the technology in each of the technical evaluation areas.

Technical scores of 1 – 5 are assigned to the four key components (potential for practical decision-making, data visualisation, ease of data integration, and assessment of associated data analysis). The detailed criteria for each component are shown in Figure 15, Figure 16,

Figure 17 and Figure 18 respectively. These are further elaborated in WP3 Deliverables 3.1 and 3.2.

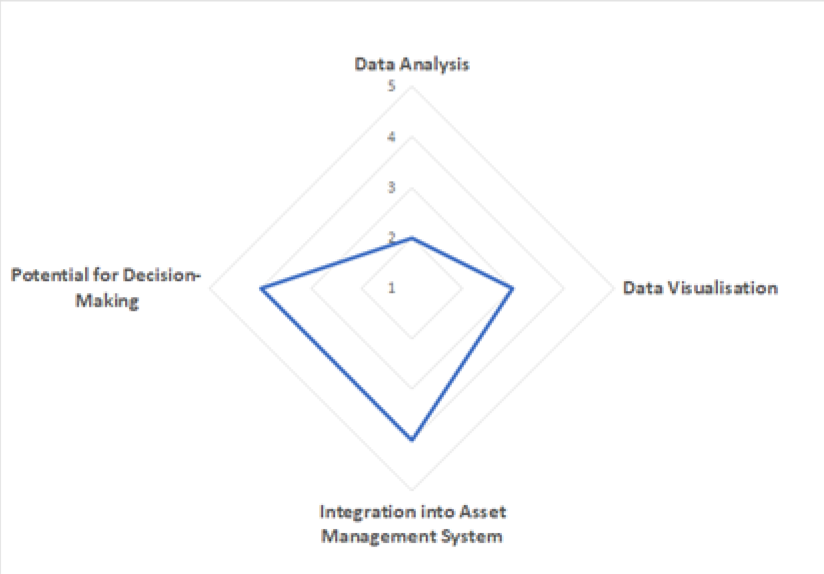

Figure 14: Sample technical scoring for a given technology use case

DESCRIPTION OF ANALYSIS:							
FINAL SCORING	NEED FOR RAW DATA INTERPRETATION	DOES THE TECHNOLOGY COME WITH A DATA ANALYSIS ENGINE?	UNCERTAINTY OF ANALYSIS RESULTS	COMPLEXITY OF ANALYSIS	COMPLIANCE WITH CLIENT DATA REQUIREMENTS	DATA PROCESSING	DATA ANOMALIES
5 – well established and reliable, no additional analysis is required	No need	Yes, and it does not require expert staff to perform the analysis only basic training of final users	Reliable: Good quality of data	Not difficult: Technology allows reasonably straightforward analysis	The data provided is overqualified for the client's requirements and open for future developments	No data processing is needed	Technology reports about the data anomalies and gives informations of possible reasons to detected anomalies
4 –generally reliable, may have some limitations	Basic training of final users is need to understand the origin of signals and classify them into relevant information	Yes and but it requires some basic training of final users staff with occasional expert checking or QA the performed analysis	Reliable: Good quality of data	Difficult: Calibration of analysis needed to account for field conditions	The data provided is in line with the client's requirements	No data processing is needed	Technology reports about the data anomalies and gives informations of possible reasons to detected anomalies
3 –significant limitations, data analysis is advisable to improve accuracy	Experts are needed to locate and understand the origin of signals and classify them into relevant information	Yes, but it requires expert staff to perform the analysis	Predictable: Low degree of uncertainty due to quality assurance procedures in place	Complex: Calibration of analysis needed to account for field conditions and/or automatically detected events need manual interpretation as part of the data analysis process.	The data provided is in line with the client's requirements	No data processing is needed	Technology reports about the data anomalies
2 – limited, additional data analysis is required	Advanced analytics and experts are needed to locate the origin of signals and classify signals into relevant information	Yes, but it requires senior expert staff to perform the analysis	Uncertain: A degree of uncertainty arising from signal signatures specific to the application case. Complex site trials are needed to calibrate the analysis.	Very complex: specialist companies are needed for data interpretation. Calibration of analysis needed to account for field conditions. Automatically detected events need manual interpretation as part of the data analysis process.	Data fits the client's requirements only partially; there is a need for additional data sources to provide useful information	Data, when initially obtained, must be processed or organised for analysis	Specialised staff is required to analyse data for anomalies
1 – complex and uncertain, extensive additional data analysis is required	Advanced analytics and senior experts are needed to locate the origin of signals and classify signals into relevant information	No, therefore senior expert staff and consultants are need to be engaged to perform the analysis	Questionable: A higher degree of uncertainty arising from signal signatures specific to the application case. Complex site trials to calibrate the analysis.	Very complex: specialist companies are needed for installation and especially for data interpretation. Calibration of analysis is needed to account for field conditions. Automatically detected events need manual interpretation as part of the data analysis process.	Data fits the client's requirements only partially; there is a need for additional data sources to provide useful information	When initially obtained, data must be processed or organised for analysis and cleaned of duplicates, etc.	Specialised staff is required to analyse data for anomalies

Figure 15: Technical scoring criteria for assessment of associated data analysis

DESCRIPTION OF ANALYSIS:

FINAL SCORING	DOES THE TECHNOLOGY COME WITH A VISUALISATION PLATFORM?	CAN VISUALIZATION DATA BE EXTRACTED?	CURRENT STATE AND PROGNOSIS	COMPLIANCE WITH CLIENT VISUALIZATION REQUIREMENTS FOR DECISION SUPPORT/ GAP CLOSURE
5 – Visualization provides complete information for decision support / gap closure	Yes, Technology comes with clear and useful visualisation platform. The platform requires some basic training.	Yes, The visualized data can easily be extracted and used for further analysis	The visualization provides information of current state and prognosis can be easily visualised within the platform	The visualization provided gives sufficient and clear information for decision support and open for future developments
4 – Visualization provides complete information for decision support, but some traning are required to interpretate visualization	Yes, Technology comes with clear and useful visualisation platform but the visualization requires detailed technical training to interpret results	Yes, The visualized data can easily be extracted and used for further analysis	The visualization provides information of current state. Prognosis and trends needs to be done manually but this does not require expert staff.	The visualization provided gives sufficient and clear information for decision support
3 –A visualization will provide information for decision support but work is required to develop this	No, But proper visualization/interpretation can be made using simple plotting tools which can generate 2D/3D plots. No specialized staff needs to develop the visualisation platform	Yes, Data can be extracted and used for further analysis but some work are needed to extract the data	The visualization provides information of current state. Prognosis and trends needs to be done manual but this work do not require expert staff.	If the data are visualized it provides sufficient and clear information for decision support
2 – Visualization provides information for decision support, but expert staff are required to interpret visualization	Yes, Technology comes with clear and useful visualisation platform but the visualization requires expert to interpret results	Yes, The visualized data can be extracted and used for further analysis but work from expert staff are needed to extract the data	The visualization provides information of current state. Prognosis and trends needs to be done manual by expert staff.	The visualisation provides information for decision support.
1 – Visualisation only provides partial information for decision support and expert staff are needed to interpret	No,In order to make proper visualisation complex programming are required (e.g. 3D-'as-is'-model based on photogrammetry, possibly paired with AI for automated identification of defects). Expert staff needs to develop the visualisation platform	Yes, The visualized data can be extracted and used for further analysis but work from expert staff are needed to extract the data	The visualization provides information of current state. Prognosis and trends needs to be done manual by expert staff.	The visualisation only provides partial information for decision support; there is a need for additional information

Figure 16: Technical scoring criteria for visualisation

DESCRIPTION OF ANALYSIS:				
FINAL SCORING	IS DATA QUALITY SUFFICIENT FOR DECISION-MAKING?*	IS DATA ACQUISITION FREQUENCY SUFFICIENT FOR DECISION-MAKING?	CAN (PROCESSED) MEASUREMENT BE DIRECTLY USED IN DECISION MAKING PROCESS?	ADVANTAGE / DISADVANTAGE
5 – High potential for direct use for practical decision making	Yes, the quality of the data is sufficient, considering also the frequency with which the data are collected	Yes, the data acquisition frequency is sufficient for decision making, given the quality of the data	Yes, the data can easily be used in the decision making process	The technology does not present any significant disadvantage. The technology does present an advantage for the decision-making process.
4 – Useful data for practical decision making but some adaptation is needed	Yes, the quality of the data can be made sufficiently high, considering also the frequency with which the data are collected	Yes, the data acquisition frequency can be made sufficiently high for decision making, given the quality of the data	Yes, after some processing, the data can easily be used in the decision making process	The technology needs some minor adaptations in order to make it fully operational for practical decision-making
3 –Only in combination of other (existing) data, this technology has potential for practical decision-making	No, the quality of the data is not sufficiently high for the data to be sufficient on their own for decision-making	No, the data acquisition frequency is not sufficiently high for the data to be sufficient on their own for decision-making	No, only in combination with other (existing) data, the technology can contribute to the decision-making process	Advantage: the technology provides additional, useful information Disadvantage: other data must also be available
2 – There is a need for development before this technology can be used for practical decision making	No, the data quality must be improved by further development but potential for improvement exists	No, the data acquisition frequency is not high enough but further development has the potential for a sufficient frequency increase	No, there is a need for further development of data processing in order to make the input useful for decision-making	Advantage: high potential for improvement of the technology Disadvantage: not yet ready for direct use in the decision-making process
1 – The technology does not provide useful input for practical decision making	No, the data quality is not sufficient for decision-making	No, the data acquisition frequency is not high enough for decision-making	No, the data do not provide input that can be used directly for decision-making and it cannot be expected that data processing that would make the data useful for decision-making will be developed soon	Disadvantage: the technology is not ready for practical use.

Figure 17: Technical scoring criteria for potential for practical decision-making

DESCRIPTION OF ANALYSIS

FINAL SCORING	DATA ORGANIZATION	DATA FIDELITY	DATA FORMAT	DATA FREQUENCY	DATA INTERFACE
5 – Data integration is easy, direct, reliable and automatic.	The data are well organized in a specific, pre-defined format, such as columns and rows in a spreadsheet or fields in a database. The data are easily searchable and analysable.	The complete data are reliable.	The pre-defined data format can be directly integrated into the data architecture.	The pre-defined data frequency meets the required data integration frequency for decision making.	The data are automatically integrated into the data architecture, for example through API. A software is available.
4 – Data integration needs some help from experts, but generally is easy and reliable.	The data are sufficiently organized for the specific need. For other implementation, more organization is needed.	The useful part of data is reliable.	The data need to be exported to a certain format to be integrated. The data exportation is easy.	The pre-defined data frequency is higher than the required data integration frequency. Data can be stored and batched. Complete data are available.	The automated data integration is possible. Internal experts can easily develop the interface.
3 –Data integration needs experts and is sufficiently easy and reliable.	The data are not organized, but have metadata containing enough information for organizing.	The data can be validated easily.	The data need to be exported to a certain format to be integrated. The data exportation needs experts.	The pre-defined data frequency is higher than the required data integration frequency. Data are too large to be stored and batched. Only scheduled data can be used. The data not on schedule will be lost.	The automated data integration is possible. External experts are needed to develop the interface.
2 – Data integration needs eperts heavily and can be reliable.	The data are not organized, but the metadata are achievable.	The data can be validated by the experts.	The data need to be processed and only the results in a certain format can be integrated. The data processing is easy.	The pre-defined data frequency is lower than the required data integration frequency, but useful for decision making.	The automated data integration is hard. Data need to be transmitted manually.
1 – Data integration needs experts heavily and requires more cost and labour to achieve reliable integration.	The data are not organized, and the metadata are not easily achieved.	The data are hard to be validated.	The data need to be processed an only the results in a certain format can be integrated. The data processing needs experts.	The pre-defined data frequency is lower than the required data integration frequency. Critical information is missing for decision making.	The automated data integration is hard. Data need to be transmitted manually by experts.

Figure 18: Technical scoring criteria for ease of data integration

6.6.3 Roadmap

Evaluation also includes an assessment of the steps needed that would be required to implement the technology (for the identified technology use case) in an NRA. These can include significant amount of detail depending on the technology being evaluated, the maturity level of the technology, and the technology use case. See Figure 19.

Roadmap to implementation	The following activities are required to address the system limitations: • Demonstrate that using the TGI creates no increase in risk to road users • Determine the minimum amount of data required to accurately characterise skid resistance. • Demonstrate that the TGI has a network coverage not worse than that of SF-TEX methods, or have contingency to operate SF-TEX methods in parallel to fill in gaps • Develop national / international standards for the performance of data driven approaches to the characterisation of SR. • Develop or update national policies to use TGI data for the management of skidding risk • Develop an equivalent network performance KPI based on TGI data and demonstrate backward compatibility with historical metrics • Develop data integration procedures to allow NRA's asset management system to ingest data • Demonstrate, through independent testing (i.e. by comparing TGI results with SR measurements such as those collected using the PFT), and/or a detailed demonstration of the system, that the TGI can indeed "accurately estimate the total available friction" and "estimates the friction between the tyre and the road". • Research into TGI data considering issues of speed and road surface texture. Whilst not addressed directly in the limitations section, it would also be beneficial to repeat some of the research supporting SF-TEX methods using the TGI system. These may include: • Collision studies comparing STATS 19 data with TGI data, these studies could be used in the development of policy • An assessment of the relationships between material properties (PSV, AAV, Material types, etc.) and SR as determined using TGI

Figure 19: Sample roadmap to implementation

6.6.4 Summary Evaluation - INFRACOMS Readiness Levels

Finally, a summary evaluation is made of the readiness level of the technlogy from an NRA perspective (as opposed to the supplier perspective in the pre-evaluation) for the proposed technology use case. This is called the INFRACOMS Readiness Level (to distinguish it from Technology Readiness Level as this is a level of readiness specifically focussed on this technology use case). These have been based on the Readiness Levels defined by Transport Infrastructure Ireland (TII) 'Guidelines for the Implementation of Innovation' (GE-GEN-01006) (TII, December 2020), see Figure 20.

One key feature of the INFRACOMS Readiness Levels is that they emphasize the use and deployment for an infrastructure authority *and for the use case under consideration*. At all levels, the technology must have been evaluated or implemented for an infrastructure authority (preferably a roads authority) and for the particular use case. The summary evaluation and IRL for our example technology are shown in Figure 21.

INFRACOMS Readiness Level	Description of evaluation or implementation for an infrastructure authority for the use case under consideration
9	Proven Solution Deployment
8	System Level Production Verfication
7	Pre-Production Controlled demonstration
6	System Based Representative Testing
5	Isolated Representative Testing
4	Laboratory Testing
3	Research and Validation
2	Applied Research
1	Concept Exploration / Fundamental Research

Figure 20: INFRACOMS Readiness Levels

Summary evaluation	So far as the evaluator can ascertain, the technology has not demonstrated that it provides the data claimed i.e. total available friction and the friction between the tyre and the road. Independent testing, or further explanation, will be required to substantiate the technology claims. Once the claims of the technology have been verified, the technology cannot be used by NRAs without substantial further research as indicated in the roadmap.
INFRACOMS Readiness Level	3 - Research and Validation

Figure 21: Sample summary evaluation and INFRACOMS Readiness Level

6.7 Case Study

A Case Study is an in-depth analysis of a completed implementation of the technology for a given NRA. The inputs required will depend very much on the individual technlogy and use case being assesssed, and could take several weeks to complete depending on the availability of information. It will require discussion and cooperation between the technology provider and the NRA to define the exact scope of the implementation, the CBA and LCCA methodology to be used, the cost and benefit factors to be applied, and any risk assessment to be conducted. Information from the case study, such as additional cost factors or benefit categories, would be used to update the pre-evaluation and evaluation.

With regards to CBA and LCCA, these should be conducted according to the detailed policies and procedures of the NRA. Most CBA and LCCA analyses employ similar steps as outlined in such as ISO 15686-5 and EN 16627 guidelines:

- Establish alternatives
- Determine the analysis period and activity timing including maintenance and rehabilitation
- Determine the cost factors and estimate the cost values
- Compute life-cycle costs

The alternatives are the range of potential technologies that can fill a gap or meet a strategic priority. These are the technologies that are identified for evaluation under INFRACOMS.

The second step is to determine the analysis period and monitoring timing. The analysis period refers to the time from the the introduction of the technology until the end of life of the asset which it is monitoring. The end of asset life can be identified from the asset's design documents. If the technology under consideration can improve the life of the asset, then the analysis period should include the extended life. This lifetime extension needs to be estimated by experts. The monitoring timing is often planned by NRAs according to the asset condition, budget and maintenance plan. If, on the other hand, a technology service time is less than the (extended) lifetime of an asset, if NRAs keep using that technology, the cost of replacement of the technology (or, annual costs of procuding the data) must be included. For example, assuming a bridge that will remain for 50 years and a sensor technology lasts 5 years, then the costs of replacing the sensors every 5 years needs to be calculated. The analysis period and monitoring timing will be parameters that are identified in the evaluation phase.

The third step is to determine the cost factors and cost values. The INFRACOMS pre-evaluation and evaluation stages identify the cost factors that should be included in a CBA and LCCA. Relevant cost factors could be cost of data purchase, data storage, data processing and aggregation. If NRAs perform monitoring internally, the cost should also include the labour cost and equipment cost. There may be many other types of cost factor. If, for example, data collection impacts traffic flows, costs should also include the user cost e.g. cost due to travel delay. Some of this information will be provided by the technology providers, other will be estimated by the NRA.

Once the total costs and benefits of a technology have been calculated, a Net Present Value (NPV) can be calculated. This is a key output of any CBA / LCCA assessment, and should be recorded in the INFRACOMS methodology.

Figure 22 illustrates the INFRACOMS LCCA guidance.

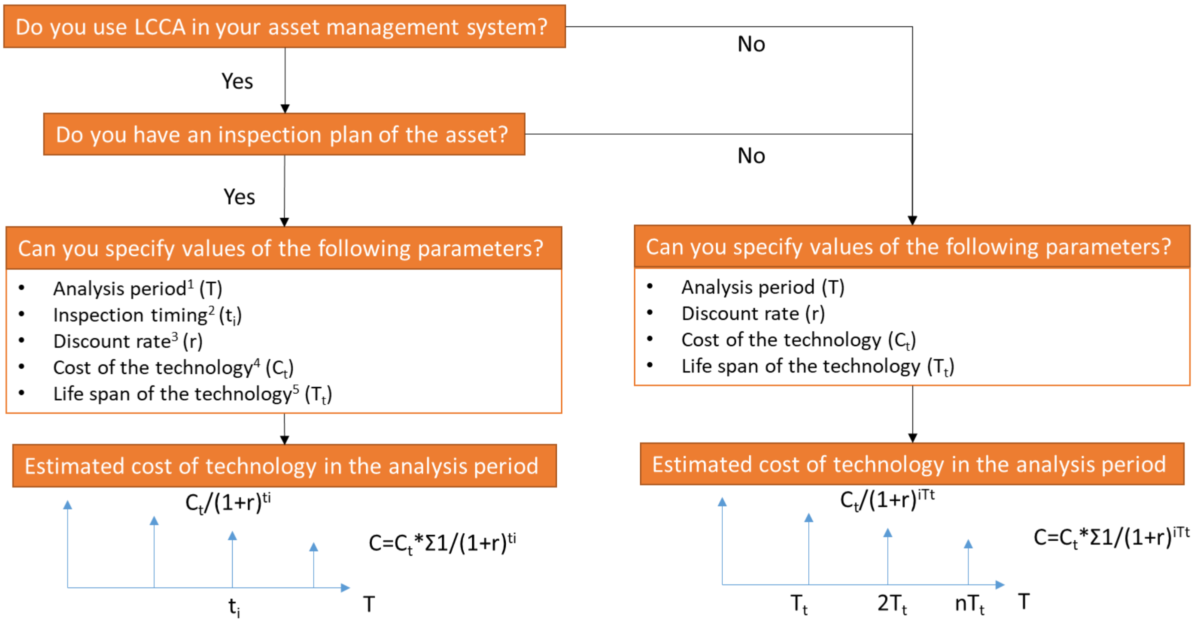

Figure 22: INFRACOMS LCCA guidance

7 Summary

This draft report has presented the work carried out in INFRACOMS Work Package 2.1 to develop an Appraisal Methodology for technology.

It builds upon the deliverables of INFRACOMS Work Package 1 which identified the key imperatives of NRAs for technologies to monitor their carriageway and bridge assets. It also used sample technologies from the Technology Database to help identify the types of questions to be asked when appraising a technology.

It presents a review of several appraisal commonly-used appraisal methodologies that can be used to evaluate the effectiveness, suitability and potential impact of new technologies for an organisation. These appraisal methods include Technology Readiness Levels (TRLs), Cost Benefit Analysis (CBA), Life Cycle Cost Analysis (LCCA), Risk Assessment, and Multi-Criteria Decision Analysis (MCDA). The report makes recommendations for elements of those common methodologies for inclusion in the INFRACOMS Appraisal Methodology.

It also presents key highlights from a workshop held in January 2023 with representatives from nine NRAs, on evaluation of monitotring technologies for carriageways and bridges. The takeaways from that workshop helped feed into the Appraisal Methodology which is the subject of this report. They included NRAs' needs for the methodology not just to score a technology, but also to record the reasons that scoring. Any guidance must be as clear and objective as possible. The workshop also highlighted differences in priorities among some NRAs in terms of their willingness to invest in technologies at different states of maturity, and the requirements of different NRAs to integrate data from monitoring technologies into their asset management systems.

The report then presents the INFRACOMS Appraisal Methodology. The methodology is designed around the technology use case, that is, a particular application of a technology by a NRA. The methodology contains three core processes for Pre-Evaluation, Evaluation and Case Studies of technology use cases. It also includes processes for NRAs to define their strategic and technical priorities so that the appraisal process can be tailored to addressing their individual requirements.

WP2.2 will develop a toolkit to implement the appraisal methodology. That will be the subject of a future deliverable under INFRACOMS.

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Annex 1 TRLs in NRAs

Transport Infrastructure Ireland (TII)

Transport Infrastructure Ireland (TII) produced 'Guidelines for the Implementation of Innovation' (GE-GEN-01006) (TII, December 2020) to provide a consistent approach to the assessment of readiness of potentially innovative products and processes. The guidelines include Technology Readiness Levels (TRLs) specifically devised for the agency, which is responsible for road and light rail networks. The guidelines provide a clear path for products or processes to move through the TRLs towards deployment as a pilot or trial. See Figure 23.

TRL	Solution Function Defined	KPIs for solution provisionally defined	Component Specification	Laboratory Testing	CRS and CBS	System Testing	Prototype Testing	Monitored Deployment	Risk Acceptable Deployment	Evidence required for moving between TRLs
1										N/A
2										Further contextual evidence and solution description are provided; KPIs are provisionally defined, and possible development trajectories are provided, including funding
3										Breakdown of system components is provided; functional specification is defined; laboratory testing is being designed; more detailed risk assessment
4										Laboratory testing is taking place; KPIs for the solution are verified and validated; conformance to relevant Standards is demonstrated; route to market is summarised, and preparations are being made for production
5										CRB and CRS are defined; technical specification is developed; system-level integration is being defined; performance is being tested; and production methods are validated
6										Testing is performed in operations-representative environment; financial risk management procedures are developed
7										Prototypes are developed; testing is taking place in a live environment to verify its functionality; deployment parameters are being developed; and solution performance is approved
8										The solution is being deployed under control to exclude anomalies and capture any situational performance issues; the system is ready and qualified for live deployment
9										The solution is proven and fit for purpose

Figure 23: TII Evidence Required to Move Between TRLs

The TRLs are considered by TII across all of TII's future technological or innovation deployments. They create a standardised approach to the management of risk (see Table 5). At each TRL stage, a risk assessment is carried out, which is updated as the technology moves through subsequent stages. Hence they reduce the risk of applying technologies that are not at an appropriate stage of readiness. They also brings the benefit of ensuring transparency in engagement with suppliers, and streamlining TII's own procedures (TRLs are also grouped into four categories to help suppliers understand the various levels of evaluation and testing that are conducted at each level, as shown in Table 6).

Table 5: TII Operational Risk Categories

Operational	The functions being performed by the verified and validated solution, and the deployment of the solution itself i.e. the operation, outcomes it achieves, and maintenance requirements.
Political	The risk to the business through the introduction of the new solution, from the perspective of its national and international policy support for the solution, as well as legal implications of this new solution.
Financial	Cost-benefit analysis of the implementation of the solution, together with limiting the financial risk of exposure to elevated costs due to lifecycle issues.
Reputational	Reputational risk to TII using the solution, either through performance uncertainty, testing procedures, environmental, political values etc. Risk to TII reputation through inaction in the area that the solution addresses.
Digital	Consideration of the integration of the solution with current systems, practices, etc. and the levels of data produced as a result of the solution and its system.
Safety	Is the solution safe by design and will its introduction improve safety in any particular manner?

Table 6: TII TRLs (supplier guide)

TRL Level 1: Concept Exploration / Fundamental Research	Concept
TRL Level 2: Applied Research	
TRL Level 3: Research and Validation	
TRL Level 4: Laboratory Testing	Standalone Validation and Verification
TRL Level 5: Isolated Representative Testing	
TRL Level 6: System Based Representative Testing	Arrangement of Systems
TRL Level 7: Pre-Production Controlled demonstration	
TRL Level 8: System Level Production Verfication	Design Standards
TRL Level 9: Proven Solution Deployment	

Highways England (now National Highways)

Highways England (HE). Assessment Procedure for 'Innovative' techniques and materials

Table 7: Highways England TRLs (2017)

Technology Readiness Level (TRL)	Description	TRL assessment implication & futher work recommendation	Responsibility
1	Basic principles observed and reported	(Further) Laboratory investigation and validation	Innovator
2	Technology concept and/or application formulated		
3	Analytical and experimental critical function and/or characteristic proof-of-concept		
4	Technology validation in a laboratory environment	Demonstration / validation of concept trial (off HE network)	Innovator
5	Technology basic validation in a relevant environment	Trafficked demonstration / validation of concept trial (off HE network)	Innovator (+ HE or other sponsor)
6	Technology model or prototype demonstration in a relevant environment	Demonstration / validation of concept trial (on HE network)	Innovator / HE sponsor
7	Technology prototype demonstration in an operational environment	If acceptable, authorise for DfS on project basis	HE
8	Actual technology completed and qualified through test and demonstration	Develop standard/specification	HE
9	Actual technology qualified through successful mission operations	Authorise duplicate / related technologies for Generic Network Approval. Publish new standard/specification in DMRB/MCHW	HE

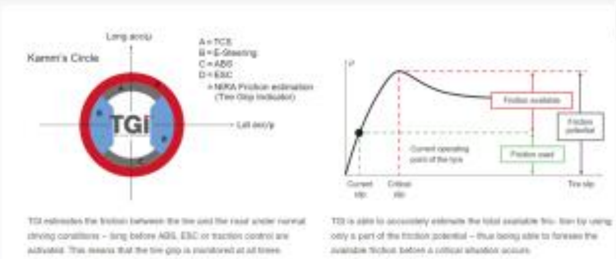
Annex 2 Sample Use Case Tyre Grip Indicator (TGI) by NIRA as potential replacement for network-wide Sideways Force skid resistance measurement

Tyre Grip Indicator (TGI) by NIRA as potential replacement for network-wide Sideways Force skid resistance measurement

Status	[illegible]
Organisation	INFRACOMS
On this page	• Overview • Pre-Evaluation • Evaluation

Overview

The Tyre Grip Indicator (TGI) by NIRA continuously monitors the friction between the tyre and the road. By analysing wheel speed signals and other automotive grade sensors, TGI provides friction values, taking both road and tyre properties into account.



Technology

The Tyre Grip Indicator (TGI) from NIRA Dynamics continually monitors the friction between the tyre and the road by analysing wheel speed signals and other automotive grade sensors. TGI can be made available through telemetry.

Use case

Potential replacement for current methods of network-wide Sideways Force skid resistance measurement.

Pre-Evaluation

Parameter	Assessment
Asset type	Carriageway
Strategic imperative	Safety
Solution group	Crowdsourcing
References	https://niradynamics.se/tire-grip-indicator/
Anticipated cost factors	€ Data purchase € Data storage € Data processing and aggregation
Anticipated benefits	⊕ Cost savings over traditional Sideways Force (SF) skid resistance surveys ⊕ Higher frequency of data provision gives opportunity to improve road user safety through more timely interventions and hence reduced Killed or Seriously Injured (KSIs) ⊕ Improved worker safety as a result of crowd-sourcing instead of dedicated survey ⊕ Improved assessment of road user skidding risk ⊕ Characterisation of skid resistance performance aligning with the experience of vehicles ⊕ Reactive to changes in the vehicle fleet
Anticipated limitations	⊖ Current Sideways Force - Texture Depth (SF-TEX) methodologies are well-established internationally ⊖ SF-TEX methodologies characterise the 'worst-case' scenario while TGI does not necessarily ⊖ Current SF-TEX data is collected in a very controlled environment while there is less control with crowd-sourced methods ⊖ May not get full network coverage leading to potential 'blind-spots' ⊖ No consistency with historical SF-TEX data ⊖ No relationship to current network Key Performance Indicators (KPIs) ⊖ No integration with road owner's condition databases ⊖ Lack of standardisation
Pre-Evaluation TRL	7 - system prototype demonstration in operational environment

Evaluation

Parameter	Assessment
Existing process	Current Sideways Force (SF) process is to conduct an annual network survey to identify locations on the network at which there is a risk of wet-road skidding. Skid policies based on annual surveys identify locations on the network on which high skid-resistant aggregates should be used. Investigation of deficient sites can be undertaken to help reduce accidents. SF survey data is also used as part of road authority annual network performance indicators.
Potential new data collection method	TGI data requires no additional sensors. It is a software solution that can provide continuous, network-level summary data from the NIRA fleet, collected and summarised at varying road locations and at varying time periods according to the needs of the client.
Opportunities for enhancement of existing processes	**Improved skid resistance policies** There have been recent suggestions that the changing vehicle fleet and the opportunities allowed by anti-lock braking systems (ABS) should prompt review of the way in which skid resistance policies are generated and monitored. There may be opportunities to devise more effective skid-resistance policies based on data other than that provided by SF-TEX methods. **Higher frequency of data** Currently, SF-TEX assessments are carried out at different frequencies depending on the policy of different NRAs. As far as the evaluator is aware, the highest frequency of network level assessment is annually. TGI may provide data with a greater temporal resolution as data are collected constantly from the vehicle fleet directly.
Cost factors	€ Data purchase - unit price of data parameter * lane km * frequency * no of vehicles activated € Data storage - unit price based on quantity of data provided at per spatial and temporal resolution € Data processing and aggregation - dependent on quantity, spatial and temporal resolution € Costs of additional data (e.g. tyre condition, speed, texture, weather) to help normalise TGI data
Benefits	⊕Costs of SF-TEX surveys reduced (potentially to zero if completely replaced, although some SF-TEX surveys may need to proceed in parallel for calibration and for filling in 'blind-spots') ⊕Potential reduction in costs of annual accreditation of SF-TEX devices ⊕In comparison to the SF-TEX methodology, risks to road workers are reduced to zero ⊕Improved assessment of road user skidding risk. The ND TGI could close the gap between skid resistance characterisation and skid resistance demand. A SR policy based on this technology would be immune to changes in the characteristics of vehicles.

Limitations	**SF-TEX methodologies are well established internationally** Current policies utilising SF-TEX methods are based on many decades of research and development (having started in the 1930s). In the evaluator's view the use of alternative data driven methods is an extension of this research. Nonetheless, the weight of research supporting SF-TEX methodologies, necessitates a substantial body of evidence to be provided in support of alternative methods, and/or a substantial body of evidence not supporting SF-TEX methods, in order for NRAs to take an evidence based approach to changing policies to switch to data driven methods. This is discussed in more detail later in this section but a minimal fact of "no increase in risk to motorists" must be established before the TGI becomes a viable replacement of SF-TEX methods. **SF-TEX methodologies characterise the "worst-case-scenario"** TGI characterises SR at the location on the friction profile that does not necessarily overlap with the worst case scenario for motorists. This is exacerbated by the following observations: · Not all vehicles utilise peak friction exploiting driver aids, nor is it likely that 100% of the vehicle fleet ever will (e.g. there is likely to persist a small percentage of the vehicle fleet comprised of classic vehicles which do not utilise such systems). · Peak friction exploiting driver aids are not 100% effective. For example ABS does not function (well) on ice or snow covered roads. Additionally mechanical or systems failures may render driver aids ineffective in some cases. **Less control over external factors** SF-TEX methods have been developed. as far as possible, to isolate the contribution of the road surface to tyre / road friction. This is achieved by specifying key aspects of test devices such as tyres, loads, test wheel angles, water distribution etc. The TGI system cannot control these factors but could potentially normalise them through data validation techniques (e.g. only accepting data that meet strict criteria such as vehicle mass, tyre type, operation in the rain etc.). This limits the ability of the ND TGI to provide comparable data over extended periods of time. For example, changes to the vehicle fleet will affect the friction measurement (a positive from the perspective of risk mitigation) and so it cannot be guaranteed, for example, that measurements made in year 1 are equivalent to those made in year 5. **No way to guarantee full network coverage** It is not possible for the TGI to guarantee full network coverage. There may be some remote locations that are never traversed by vehicles that the TGI has access to and in such instances these locations would not be characterised for SR. Demonstration is required that all locations on the network (especially those considered high risk locations) can provide the required volume of data for valid skid resistance characterisation through the TGI. A technical question arises from the consideration of network coverage; can the ND TGI characterise skid resistance in locations where there is no substantial prevailing wheel slip. This is particularly pertinent for locations such as motorways and dual carriageways where traffic is typically travelling at a constant speed in a straight line. If the answer to this question is 'no' then the ND TGI system may not be able to characterise SR for substantial proportions of NRA networks.

	A final consideration on network coverage is associated with vehicle speed. SF-TEX methods characterise SR directly at 17 km/h operational velocity and modify this characterisation using texture depth measurements to predict skid resistance at higher speeds using empirically derived experimental models. It may be possible for the TGI to characterise SR at all operational velocities directly, but if this is not possible, appropriate models would be required to estimate SR at operational velocities different to those prevailing. ⛔ **No consistency with historical SF-TEX data** Previous research has shown that it is not possible, using current models, to accurately estimate friction values at %wheel slips other than 100% based on SF-TEX data. It is therefore reasonable to infer that it would also not be possible to accurately infer friction values at 100% slip based on characterisations made between 10% and 20% wheel slip (as would be the case for the ND TGI). This leads to the conclusion that it would not be possible to meaningfully compare ND TGI data with SF-TEX data. ⛔ **No relationship to current network KPIs** An extension of the point above is that for those roads authorities using SF data as the basis for their network KPIs, it would not be possible to generate a SR KPI based on TGI data. This would require research to establish an equivalent KPI framework using ND TGI data. ⛔ **Lack of evidence supporting technology claims** The technology provider has published no evidence on their website supporting the claims that the ND TGI system "accurately estimates the total available friction", or that the system "estimates the friction between the tyre and the car". Supporting these claims through independent verification is critical in accepting this system for use. ⛔ **No integration with AMSs** So far as the evaluator is aware, TGI data has not been integrated into any asset management system. The providers of SF-TEX surveys (in the UK) input data directly into the condition databases of the NRA. ⛔ **Lack of standardisation** In the UK and in some European nations, NRAs are required to purchase supplier agnostic products and services, that is, NRAs cannot specify the use of any given supplier, rather the requirements of the product or service will be specified and suppliers will bid against this specification. This is typically handled through standardisation. Standardisation is typically achieved using a technology specification (this is the case for the CEN SCRIM technical specification), or through performance standardisation against some datum (as a hypothetical, any skid resistance testing device can be used so long as its measurements match those made by some reference device). Currently SF devices are specified as part of CEN standards, but no such standard exists for the use of data driven approaches to the characterisation of skid resistance. For those nations which are required to be supplier agnostic, appropriate performance based standards would need to be produced before they could accept data provided by the ND TGI. These standards could be produced by the NRA rather than a standards body such as CEN.

Roadmap to implementation	The following activities are required to address the system limitations: • Demonstrate that using the TGI creates no increase in risk to road users • Determine the minimum amount of data required to accurately characterise skid resistance. • Demonstrate that the TGI has a network coverage not worse than that of SF-TEX methods, or have contingency to operate SF-TEX methods in parallel to fill in gaps • Develop national / international standards for the performance of data driven approaches to the characterisation of SR. • Develop or update national policies to use TGI data for the management of skidding risk • Develop an equivalent network performance KPI based on TGI data and demonstrate backward compatibility with historical metrics • Develop data integration procedures to allow NRA's asset management system to ingest data • Demonstrate, through independent testing (i.e. by comparing TGI results with SR measurements such as those collected using the PFT), and/or a detailed demonstration of the system, that the TGI can indeed "accurately estimate the total available friction" and "estimates the friction between the tyre and the road". • Research into TGI data considering issues of speed and road surface texture. Whilst not addressed directly in the limitations section, it would also be beneficial to repeat some of the research supporting SF-TEX methods using the TGI system. These may include: • Collision studies comparing STATS 19 data with TGI data, these studies could be used in the development of policy • An assessment of the relationships between material properties (PSV, AAV, Material types, etc.) and SR as determined using TGI • An assessment of the between year and inter-year variations in TGI data such that correction factors could be developed to 'correct' for environmental and trafficking effects • An assessment of how TGI data compare with measurements made by traditional SR testing devices. This could include participation in the European Friction Workshop experiments in Nantes.
Summary evaluation	So far as the evaluator can ascertain, the technology has not demonstrated that it provides the data claimed i.e. total available friction and the friction between the tyre and the road. Independent testing, or further explanation, will be required to substantiate the technology claims. Once the claims of the technology have been verified, the technology cannot be used by NRAs without substantial further research as indicated in the roadmap.
INFRACOMS Readiness Level	3 - Research and Validation

Annex 3 Sample Use Case Acoustic Emissions to Detect Wire Break in Steel Cables in Bridges

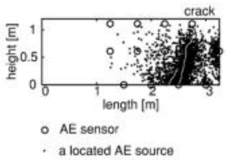
Acoustic Emissions to detect wire break in steel cables in bridges

Status	[illegible]
Organisation	INFRACOMS
On this page	• Overview • Pre-Evaluation • Evaluation

Overview

Acoustic Emissions (AE) is a passive elastic wave-based method which detects damages like cracking and wire breaking. Unlike active methods, AE does not send signals into the medium but only receives signals from the damaged components. The damage process releases energy and generate waves. The waves propagate to the structural surface and are received by sensors. By processing the received waves, AE can identify the damage location, damage type, and determine the structural integrity.

Installation of AE sensor on a concrete bridge and the received signal



Using AE source localization technique to estimate the crack location

Technology

AE can estimate the source location through localization technique, source type through classification technique and determine the structural integrity through statistical analysis of AE signal strength. These algorithms are realized by commercialized software like AEwin from MISTRAS, AMSY-6 from Vallen.

Use case

AE is powerful to detect internal damages, is sensitive to minor damage like microcracking, and can provide real-time monitoring.

Pre-Evaluation

Parameter	Assessment
Asset type	STRUCTURE
Solution group	REMOTE SENSING
References	https://www.mistrasgroup.com/ https://www.vallen.de/ https://doi.org/10.4233/uuid:9220a0c2-f4c1-46e6-a0a9-0069e4662730
Key imperatives	Reliability
Performance indicators	Cracking, delamination, wire break, corrosion
Anticipated cost factors	€ Data purchase € Data storage € Data processing and aggregation
Anticipated benefits	⊕ Internal damage detection ⊕ Real-time monitoring and decision making ⊕ Early-age damage detection for safety and optimized intervention ⊕ Improved worker safety as a result of remote sensing
Anticipated limitations	Data processing and analysis are complex. Even if commercial software processes the data, the analysis of the results and decision-making require expert judgment. Need to correlate results with other assessment methods.
Pre-Evaluation TRL	PRE-EVAL TRL 7

Evaluation

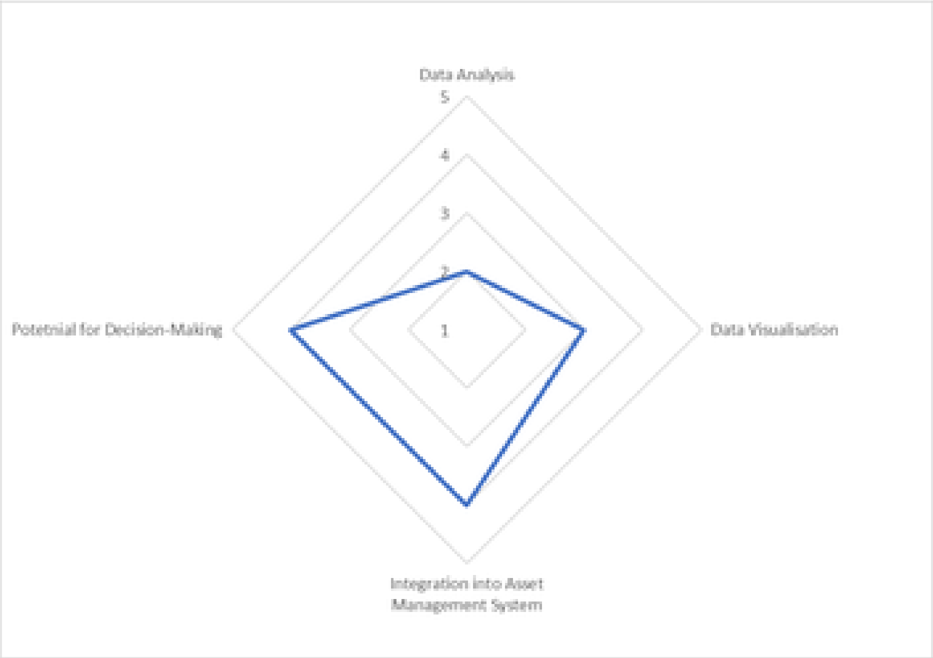
Parameter	Assessment
Existing process	Current inspections mostly detect the damages on the structural surface and at a scheduled timing.
Potential new data collection method	By installing AE sensors on the structural surface, the data can be collected remotely through wires or wirelessly.
Opportunities for enhancement of existing processes	Finer crack detection: AE is sensitive to minor damages like microcracking which can provide an early warning. Higher frequency data: AE can provide real-time monitoring on top of the current inspections at scheduled timing. Together with the ability of finer crack detection, AE results in real-time can facilitate a more accurate decision making.
Spatial coverage of the technology	AE is used to capture the local behaviour. The coverage is determined by the sensor resonant frequency and the noise level. For concrete, by using 60kHz sensors, the sensor spacing is preferred within 1m.
Cost factors	€ Data purchase € Data storage € Data processing and aggregation
Benefits	⊕ Internal damage detection ⊕ Real-time monitoring and decision making ⊕ Early-age damage detection for safety and optimized intervention ⊕ Improved worker safety as a result of remote sensing

Limitations including needs for additional data	**Need for additional data**: Environmental data is beneficial to fine tune data processing algorithms to process acoustic data to distinguish environmental effects form deterioration. For instance, in stay monitoring for wire break detection, precipitation data (e.g. rain and grail) is measured to check their impact do not induce signals that may be interpreted as wire breaks (false positives). **Need for specialists for data processing and analysis**: Some specialist companies have developed their own analysis engine. However, this does not remove the need for very specialized staff to perform the analysis. **Uncertainty of the analysis results**: Analysis are associated with a degree of uncertainty arising from signal signatures, which are specific to the application case (e.g. a given cable of a given bridge subject to a given environment). Therefore, site trials are needed to calibrate the analysis. They may consist of simulating signals to characterize acoustic propagation paths. For some application (e.g. wire break detection), controlled wire ruptures may be induced to characterize actual signature of signals and determine data analysis strategy. **High cost of data storage**: AE data are of high sampling rate therefore large amounts of data will be obtained. The data analysis and storage become computationally costly.
Alternative technologies which may overlap or complement the data to be provided	Depending on the deterioration mechanism under consideration, Non-Destructive-Tests (NDT) may be needed to complement / confirm the outcome from acoustic monitoring (which in general only provides incremental information since system commissioning). Example of such tests are magnetic test, ultrasonic tests, LVDTs, strain gauges and UAV.

Roadmap to implementation	The limitation of AE mainly lies in need for experts to process the data. A more user friendly data processing, analysis and visualization tool is preferred. Due to the uncertainties in the monitoring process, by conducting research on the uncertainties, the tool should also provide the value of the information of the measurement. Another limitation of AE is the large amount of real-time data to be processed and stored. To address the limitation, a careful design of AE setup is needed, including measuring zone, number of sensors to apply, measuring duration and timing. The setup design is based on the preliminary structural analysis (which provides the critical bridge and critical zone to be measured) and the plan of intervention (which decides the time of measurement). Another way of addressing the data storage problem is making use of the cloud space. By uploading the data into the cloud in real time, the data can be integrated into the data management system more easily. To address the processing of large amount of data, machine learning tools can be considered which are powerful in dealing with big data.
Summary evaluation	AE has been widely applied and world-wide technology providers can be found. Successful applications can be found in not only bridges but tunnels, wind mills and etc. Moreover, active researches on AE are undergoing, including using machine learning to process the data, developing wireless and embedded sensors, and developing data analysis algorithms to quantify the damage magnitude and etc. The active ongoing researches show the potential of AE becoming a more powerful tool in the future.
INFRACOMS Readiness Level	IRL 8

Data Integration and Visualisation Overall View

The following radar diagram provides an overall view of the scores for Data Integration and Visualisation. Individual scores are explained in the succeeding sections.



Data Visualisation

Question	Score	Justification
Does the technology come with a Visualisation platform?	3	No, But proper visualisation/interpretation can be made using simple plotting tools which can generate 2D/3D plots. No specialized staff needs to develop the visualisation platform.
Can Visualisation data be extracted?	4	Yes, the visualised data can easily be extracted and used for further analysis.
Current state and prognosis	2	The visualisation provides information of current state. Prognosis and trends needs to be done manual by expert staff.
Compliance with client Visualisation requirements for decision support/gap closure	1	The visualisation only provides partial information for decision support; there is a need for additional information.
Total Score	3	Visualisation will provide information for decision support, but work is required to develop this.

Data Integration

Question	Score	Justification
Data organization	5	The data are well organized in a specific, pre-defined format, such as columns and rows in a spreadsheet or fields in a database. The data are easily searchable for analysis.
Data fidelity	4	The useful part of data is reliable.
Data format	4	The data need to be exported to a certain format to be integrated. The data exportation is easy.
Data frequency	5	The pre-defined data frequency meets the required data integration frequency for decision making.
Data interface	2	The automated data integration is hard. Data need to be transmitted manually.
Total Score	4	

Practical Decision-Making

Question	Score	Justification
Is data quality sufficient for decision-making?	4	The reliability of AE data can be enhanced through certain data processing methods, such as employing a threshold to mitigate environmental noise. Therefore, instead of simply being 'sufficient', we consider that its quality can be significantly improved. Yes, the quality of the data is sufficient, considering also the frequency with which the data are collected.
Is data acquisition frequency sufficient for decision-making?	5	The frequency of AE data is exceptionally high, reaching approximately 1 million readings per second. This frequency is more than sufficient for practical decision-making.
Can (processed) measurement be directly used in decision making process?	4	In relation to the use case, the processed details such as number of AE hits, and signal strength, can be used to indicate a wire rupture.
Advantage/disadvantage	4	For the specific use case of wire rupture detection, minor modifications such as establishing an appropriate threshold to filter noise are required. Thus, we assign a score of '4'. However, it is important to note that this might not apply universally. Under certain circumstances, data from other sources may be required to support decision-making. For instance, for long-term monitoring of wire breakages, environmental data (such as rainfall) would be needed to assess its impact. In such a case of long-term monitoring, the score might be assessed as '3'.
Total Score	4	A final score of 4 is given for this use case of supporting decision-making in relation to wire breakage in steel cables.

Data Analysis

Question	Score	Justification
Need for raw data interpretation	2	Advanced analytics and experts are needed to locate the origin of signals and classify signals into relevant information.
Does the technology come with a data analysis engine?	2	Yes, but it requires senior expert staff to perform the analysis.
Uncertainty of analysis results	2	Uncertain: A degree of uncertainty arising from signal signatures specific to the application case. Complex site trials are needed to calibrate the analysis.
Complexity of analysis	1	Very complex: specialist companies are needed for installation and especially for data interpretation. Calibration of analysis is needed to account for field conditions. Automatically detected events need manual interpretation as part of the data analysis process. But some technology providers provide software that can be purchased.
Compliance with client data requirements.	2	Data fits the client's requirements only partially; there is a need for additional data sources to provide useful information.
Data processing	3	No data processing is needed.
Data anomalies	4	Specialised staff is required to analyse data for anomalies.
Total Score	2	Limited, additional data analysis is required.

Annex 4 Notes from Workshop January 26th 2023

INFRACOMS Workshop 1 – Carriageways

26th January 2023, 9am – 12pm (CET)

Held remotely via Teams

Agenda:

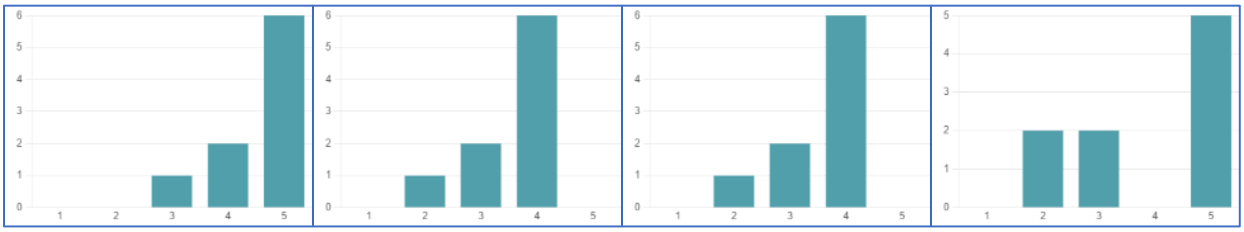
Time (CET)	Session	Lead
09:00	Open: welcome, introductions, workshop structure	RW
09:10	Introduction to the project	RW
09:20	**Work Package 2:** - Appraisal Tiers 0-3 - Databases 1 to 4 - Appraisal Toolkit	RL/KM
09:35	**Example of Appraisal Toolkit:** How it might work, inputs and outputs	RL/KM
09:50	Clarifications / questions	RW/RL/KM
09:55	*Break*	
10:00	**Interactions on Structure of Appraisal Toolkit, Tier 1:** (Groups or Plenary)	All
	Outcomes of workshop: - How gaps in technology are determined - How the value of new technologies is assessed - Understand how to focus on incremental vs revolutionary technologies - Understand the requirements for evidence and validation of new technologies - Challenges faced in assessing new technologies	All
10:50	Conclude and summarise toolkit discussions	RW/RL/KM
11:00	*Break*	
11:10	**Tier 2** and **Tier 3** outline discussions, including: - WP 2: LCCA - WP 3: Data integration, validation and representation - WP 4: Case study evidence of implemented technologies - WP 5: Roadmap and action plan for NRAs	RL/KM/FZ/MS/DK
11:50	Conclude and summarise Tier 2 & 3 discussions	RW
12:00	Close	RW

Present:

No.	NRAs:	Abbr.	No.	INFRACOMS	Abbr.
1	Matteo Pettinari, DRD	MP	1	Robin Workman, TRL	RW
2	Stuart McRobbie, NH	SM	2	Alex Wright, TRL	AW
3	Gerard O'Dea, TII	GO'D	3	Kevin McPherson, TRL	KM
4	Simon Alvey, TII	SA	4	Anna Arvidsson, VTI	AA
5	Dimitrios Papastergiou, FEDRO	DP	5	Darko Kokot, ZAG	DK
6	Gerrit Bartels, ASTRA	GB	6	Mogens Saberi, COWI	MS
7	Niels Skov Dujardin, DRD	NSD	7	Maria Felsgard-Hansen, DTI	MF-H
8	Joakim Fransson, TRV	J	8	Fengqiao Zhang, TUD	FZ
9	Lassila Tero, FTIA	LT	9	Carl Van Geem, BRRC	CVG
10	Mitja Jurgele Slovenia, NRA	MJ	10	Poul Lenneberg, COWI	PL
11	Gerben Van Neyghem, AWV	GVN			
12	Mirella Villani, RWS	MV			

1. Introductions were made and the workshop was recorded
2. RW introduced the project and work package 1
3. **POLL**: A poll was introduced to ask about the relative importance of the key imperatives for carriageways.

Availability Environment Socio-economic Safety



The results shows Availability and Safety as being the most important imperatives, with Environment and Socio-economic returning the same results but with no top scores.

4. **POLL**: Another poll was carried out to ask NRAs if they know of any more new technologies in addition to those in the current technology database, the results were:
   - Embedded sensors for structural integrity of lower layers
   - ESRI Roads & Highways for managing Linear Referencing Systems and associated event data on carriageways such as condition & inventory data
5. KM introduced work package 2 and went on to explain the toolkit development to date, using a worked example of crowdsourcing road friction data from vehicle telemetry versus using skid resistance data.

Feedback and discussion on this session included:

Appraisal tool

a) AW: Clarified the term 'accessibility' for carriageways: It relates to the rating of the performance of your assets and how to classify performance of the asset, not the technology you use to assess it, but the asset itself. Does it perform well in an environmental way, or for safety, and the service it gives to society, focusing on the level of performance of the asset.

b) RW: Clarified the rating system for Poll 1. It is used as a rough guide to rate the relative importance of the Key Imperatives for each NRA. The toolkit may allow setup of individual NRA rankings to help filter or rank the technologies for users of the tool. This exercise confirmed that different NRAs have different priorities for the key imperatives, and the toolkit should allow reflection of those priorities

c) AW: Asked if NRAs feel that they understand what it is whether they have any thoughts about how they might use the toolkit?

d) MP: Understands the principle, finding technologies to fill gaps, understanding more about the technologies, evaluating them, but maybe need to clarify the purpose of the toolkit and how others see the results.

e) AW: TRL (Technology Readiness Level) can be a bit confusing. For example, can we believe TRL levels, and may they be different for different uses?

f) KM: Once an analysis or evaluation of a technology is formalised it will be included in the toolkit/database so that other NRAs could use that experience. They can find out what's already been done elsewhere and this knowledge could be brought together to help NRAs in selecting technologies to use. The demonstration given in the workshop was around the types of questions and evaluation the toolkit would perform at each stage, not how the final toolkit would look in practice. All NRAs should be able to see the results of the evaluations.

g) NSD: Need to consult with other people in NRAs, different departments would be involved in different stages of data use. NSD offered to involve other colleagues to help assess toolkit. INFRACOMS team will follow up.

h) AW: Agreed this is good feedback, we hope that the key imperatives would cover all of the necessary areas.

i) KM: The toolkit should account for different levels of data used in different ways. We may need to separate and conduct different types of analysis for each of the different types of use case for the same technology, which would necessarily involve different types of people and different types of departments within the organisation.

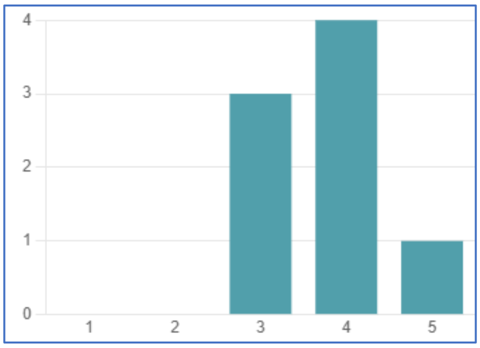
j) SM: SM is in the asset management department, so cares about data for that. But the people in operations and the people in strategy and planning have different uses. We must be careful that we don't just think of texture data purely from a single perspective of rutting or longitudinal profile. Many people come to NRAs, selling them something 'nice and shiny', telling them it will do something, but having no evidence of how well it will actually perform. National Highways is making sure that the quality of data that national surveys provide meets NH needs. SM raised the question what does raw data mean? and what does real-time data mean? We need to use consistent language.

k) SM: Use of the term "real-time data" in general should be avoided, it is important to understand the delays in collection, quality assurance, and post-processing of data for each individual use-case.

l) AW: provided some examples: SCRIM and Fix-my-Street. In theory you could have crowdsourced datasets about accidents and risk that don't actually ever measure friction. It could theoretically give you a very good way of measuring or reducing accident risk and will be used as part of a processes to target accidents, but it wouldn't actually be giving you a friction measurement. The way you measure friction now may not be the way you measure it in the future.

6. **POLL:** Respondents were also asked: Is this toolkit something that would be useful for NRAs to evaluate the performance of new technologies? 1=not useful, 5=very useful

The results are shown below.



7. Respondents were also asked where they think the difficulties would be for NRAs to **implement** the toolkit? Responses were:

a) The level on which each technology needs to be implemented. Some may be very operational, some may more managerial.

b) Include suggestions about possible applications of the technology with more details from NRAs or road manager point of view.

c) We are very resource-constrained currently, cautious of trialling technologies without demonstrated usefulness to other NRAs.

d) If these tools are used as performance indicators, then how to implement those into the system and decision making.

e) I can clearly see the benefit of this toolkit in terms of knowledge sharing of new technologies and to avoid reinventing the wheel among NRAs. I think communicating it with the right people is important. More than happy to share this information among my colleagues in Transport Infrastructure Ireland.

f) I think the real value of the new technologies will emerge when we can compare multiple data sources. e.g. when I have continuous friction I will need information about wetness or iciness of the road surface, travel speed, tire wear, tire pressure, temperature and properly many other factors to assess if it is daily operations, winter maintenance, a campaign to inform the public about how to maintain their vehicles or I should do something about my road surface. Compared to my current focus to have the same friction in the entire network, the new data might give me some focus areas where different departments in collaboration should improve the friction.

g) It was noted that CEDR is the official network for dissemination of information [about technologies], although there are other associations such as the Nordic Road Association for knowledge sharing and dissemination.

LCCA

8. INFRACOMS team will follow up with questions on Life Cycle Cost Analysis (LCCA) after the workshop.

Data Visualisation

9. MS presented some slides and led the discussions on data visualisation and integration. Feedback and discussion on this session included:

a) GO'D: We've been starting to utilise ArcGIS online for visualising our data and we've been using ArcMAP or ArcGIS online dashboards for displaying our condition data on the pavement asset management side. TII found it quite useful for being able to share that among colleagues within the organisation. Sharing that information can be quite difficult internally, so ESRI technology has been introduced to share that kind of data visually more recently. Also trying to bring in other asset groups like bridges and signs, lines and safety barriers, light columns, etc. to be centralised through the likes of ESRI technology. GO'D will share screenshot of the visualisation.

b) NSD: Using PowerBI to visualise data.

c) AW: Is there any link between your bridges and your carriageway visualisation and presentation systems or are they generally separate?

d) NSD: In the Danish Road Directorate, there is a linear representation of our all roads and a centre point on the bridges and the span length.

e) GO'D: Ireland are similar to Denmark. TII are looking at the integration of both pavement and bridges within the same asset management system.

f) MF-H: Do you facilitate or is there some sort of systematic sharing of knowledge and steps forwards in terms of implementing or optimising use of asset management systems?

g) RW: How does that communication work? Could you do it through CEDR or did you just contact directly people you know?

h) NSD: Contact directly people we know.

i) SM: Not aware of any kind of formalised knowledge sharing activities that go on amongst NRAs. It's very much just who you know and who you happen to be talking to. Pavements and bridges are separate in NH. TRL are implementing a pavement asset system for NH.

j) AW: This is a difficult aspect for the project, carriageways and bridges are treated separately but have links!

k) SM: NH tried to implement a joint system, but it didn't work.

l) KM: Is there a process/procedure/policy for implementing new technologies?

m) GVN: Flanders have a PMO unit in innovation to guide NRA through the innovation process, to determine if the technology is strategic or not. The team covers all aspects of the organisation, and searches for new technologies outside the organisation. INFRACOMS team will contact Flanders to discuss their processes and evaluation methods.

Data integration

a) AW: How might the tool work for NRAs?

b) SM: National highways have been very much 'control freaks'. Want to define and provide all the algorithms internally, so that when raw data gets collected NH know exactly what it represents, exactly how it’s being processed, , exactly what that output is, so comparisons can be made for example, between rut depth measurements this year with rut depth measurements 10 years ago, even though it was maybe a different provider, you know that it's been collected, measured and calculated in exactly the same way. There's a variety of different use cases for this data, it's also about the key performance indicator on the condition of the road, valuation of the asset, things that are very, very sensitive to small changes. That's historically how it has always been done, but that doesn't mean that's always how it will be done going forwards, NH expect to have less influence over data provided in future. National Highways is not a fan of black boxes, but at least we should know what the black box does. Use of data produced as a result of AI may be problematic because it may not be possible to determine easily how it was produced.

c) MP: Current data architectures and systems in NRAs tend to be very prescriptive. Need to retain flexibility in data. Need details about data in case it is provided / used in different environments. Will also be necessary for the data architecture to be flexible.

Roadmap

10. DK presented slides and led the discussions on the roadmap and action plan. Feedback and discussion on this session included:

a) INFRACOMS team will contact Gerben and the Flanders innovation team.

b) INFRACOMS team will follow up with questions on Roadmap and action plan after the workshop

INFRACOMS Workshop 1 – Bridges

26th January 2023, 1pm – 4pm (CET)

Held remotely via Teams

Agenda:

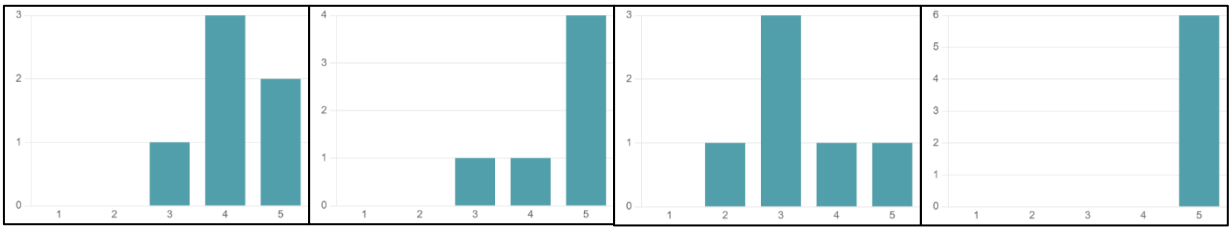
Time (CET)	Session	Lead
13:00	Open: welcome, introductions, workshop structure	RW
13:10	Introduction to the project	RW
13:20	**Work Package 2:** - Appraisal Tiers 0-3 - Databases 1 to 4 - Appraisal Toolkit	RL/KM
13:35	**Example of Appraisal Toolkit:** How it might work, inputs and outputs	RL/KM
13:50	Clarifications / questions	RW/RL/KM
13:55	*Break*	
14:00	**Interactions on Structure of Appraisal Toolkit, Tier 1:** (Groups or Plenary)	All
	Outcomes of workshop: - How gaps in technology are determined - How the value of new technologies is assessed - Understand how to focus on incremental vs revolutionary technologies - Understand the requirements for evidence and validation of new technologies - Challenges faced in assessing new technologies	All
14:50	Conclude and summarise toolkit discussions	RW/RL/KM
15:00	*Break*	
15:10	**Tier 2** and **Tier 3** outline discussions, including: - WP 2: LCCA - WP 3: Data integration, validation and representation - WP 4: Case study evidence of implemented technologies - WP 5: Roadmap and action plan for NRAs	RL/KM/FZ/MS/DK
15:50	Conclude and summarise Tier 2 & 3 discussions	RW
16:00	Close	RW

Present:

No	NRAs:	Abbr.	No	INFRACOMS	Abbr.
1	Bart Mergaerts, AWV	BM	1	Robin Workman, TRL	RW
2	Dimitrios Papastergiou, FEDRO	DP	2	Alex Wright, TRL	AW
3	Said El-Belbol, NH	SE-B	3	Kevin McPherson, TRL	KM
4	Walter Waldis, FEDRO	WW	4	Anna Arvidsson, VTI	AA
5	Fergal Cahill, TII	FC	5	Darko Kokot, ZAG	DK
6	Caroline Besten-van Daalen, RWS	CB-D	6	Mogens Saberi, COWI	MS
7	Gerben Van Neyghem, AWV	GVN	7	Maria Felsgard-Hansen, DTI	MF-H
			8	Fengqiao Zhang, TUD	FZ
			9	Carl Van Geem, BRRC	CVG
			10	Poul Lenneberg, COWI	PL
			11	Maja Kreslin, ZAG	MK

1. Introductions were made and the workshop was recorded.
2. RW introduced the project and work package 1.
3. **POLL**: A poll was introduced to ask about the relative importance of the key imperatives for bridges.

Availability Reliability Economy Safety



This shows Safety as being the most important imperative, with Availability and Reliability being important and Economy returning slightly lower results.

4. POLL: Another poll was carried out to ask NRAs if they know of any more new technologies, the results were:
   - These are not new but I'd list the following: Weigh-In-Motion, Structural Health Monitoring embedded systems for large span bridges - load cells; wind; temp gauges etc.
   - Condition monitoring (tension force) of post-tensioning strands with optical fibres on strands
   - Magnetism sensors and ToFD monitoring. The development of these techniques is now being started in the Netherlands
   - On-board sensors in the axles of heavy vehicles can be an alternative to weigh in motion. Directive (EU) 2015/719.
   - Acoustic emission measurements which can be used to assess the condition of prestressed beams

- Motion Magnification for Optical-Based Structural Health Monitoring https://web.mit.edu/liss/research-sensing.html

5. KM introduced work package 2 and FZ went on to explain the toolkit development to date, using a worked example of smart aggregates.

Feedback and discussion on this session included:

Appraisal tool

a) SE-B: Are you going to collect more available technology that is not widely used?
b) RW: We have about 30 technologies in the database at the moment and we will be doing a search for more new technologies as well.
c) SE-B: We need to look wider than just existing technologies that we're familiar with.
d) AW: Very relevant. We can only review technologies for which we have an awareness of and we are going to look at new technologies. However, if there are experimental technologies that universities haven't published or haven't made communities aware of them, then it is possible we could miss them.
e) FC: Its very rare that we'll have a significant issue with a bridge that we're not aware of, unless its hit by a vehicle. But we also look after structures and a lot of the structures where we could have problems in Ireland are legacy retaining walls with hundreds or thousands of kilometres of them. They can give issues because they can collapse without notice and many are not in the database. There are 3,000 bridges, we control them very well across three regions and each has got a regional manager and each gets a principal inspection every six years. Depending on the condition rating, you revisit it yearly or maybe not for another six years. Retaining walls are a very real issue, as well as utilities under a Masonry Arch bridge that can get scoured out. So, is this project looking at things more than just bridges? Is it looking at things like retaining walls or is it just purely bridges?
f) DP: Since I was also one of the authors of the DoRN, it's mainly focused on bridges, but if technology can also be applied for other relevant civil engineering structures, this is highly appreciated. I think, we should also consider the retaining walls, especially the higher ones for which we don't have particularly design plans or any other relevant information.
g) AW: Are there any other particular non-bridge structures while we're on the subject, any non-bridge structural components that you would be particularly interested in?
h) SE-B: Some work on the pavement, others work on the drainage. We don't have specific things but bridges play a major part in the network. We don't have a fully integrated system to optimise the timing of treatments between pavement and bridges from an operational point of view, but we are working on this at the moment. We work very closely together because, we are in the same division, but we don't have an automatic system.
i) FZ: You said there's no integrated system between bridges and pavements, but is there an integrated system of bridges itself, or when you assess bridges is it more on an individual basis?
j) SE-B: Yes. We basically have a strategy. A bridge assessment strategy and a programme for bridge assessment individually based on our inspection regime and feedback of the data. We have prioritizations, showing which bridge we need to assess first. We have a very good coherent system not only technical but it incorporates everything else, which we call value management. We have also incorporated deterioration modeling so we know exactly when we need to intervene. We do a net present value of the cost, all

these talk to each other and produce an optimum solution. The readings from the remote monitoring systems come into the main structural management system. We have data mostly physically from visual inspection and sometimes remotely, and we integrate them in our central system so we have all the information there. We use this to do deterioration modeling, and we understand our ability reasonably well.

k) SE-B: We are interested in deformation and deflection because this is where serviceability becomes an issue. We have a number of bridges where we are doing remote monitoring. Some data cannot be directly integrated into our main bridge management system.

l) FC: We don't have any remote conditioning monitoring of bridges, we do principal inspections that will dictate what our maintenance regime will be for the following year. We have maintenance contractors on frameworks that undertake that work for us on an annual basis, but we don't have any sort of technology in terms of remote monitoring for our bridges. We only have a very finite set of bridges, 3,000, divided across three regions. They're very well controlled. We're not using the most modern technology, but we'd like to know what's available out there that makes sense and that will make a difference to us. Weigh in motion is something that I'd be very interested in.

m) DP: Simple condition management system. We have analysed WIM data and have traffic loadings for all existing bridges over the past 20 years. So we can do verification based on these loads. It could help find problems that are not visible. This is what we expect from this type of technology.

n) DP: We have a completed project where we analysed data from the last 20 years and now we have values for the traffic load for existing bridges. We can now do verifications according to the type of loads. This allows you to identify hidden problems that are not visible.

o) BM: Yes, in in my organisation, when we try to try out a new technology, we always look if the technology TRL level is high enough (level 7+) because it has to be ready to be implemented. If it's too low on the TRL scale, it probably isn't ready for our use. There are probably new technologies that are ready but a lower TRL level can be promising for the future, maybe it's not ready today, but we want to know what its potential for the future is.

p) DP: Maybe we could replace estimated cost with value for money, as its more general.

q) TII provided a link to Guidelines for Implementation of Innovation for review and consideration by the project. This has been added to the Teams site: TII-guide for implementation of innovation GE-GEN-01006-01.pdf

Overview of crack sensors

6. FZ: Crack sensors, called smart aggregates that are embedded in concrete and can detect cracks at a very early stage or even predict them before they occur. Before going to evaluate this technology, FZ briefly introduced the background. It is very sensitive, so even microcracking at an early stage can be detected and it can also detect strain changes.

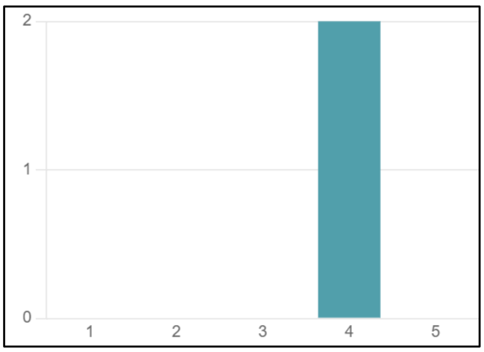
a) SE-B: Raised some questions we need to know; is it being used extensively, has it been verified, can we trust it? Can you install it on a larger scale?

b) AW: It's a very interesting question because we're looking at a technology database about assessing new technologies, so there is a circular question: I might be considering this new technology. Is it going to be good for me? Has it been demonstrated? So I think there's a problem the TRL level won't necessarily answer all of the questions because it might be claimed by the manufacturer that this system is robust and we've used it. But when you ask the question, how many bridges have you actually used it on that are made like this, the answer may be different.

c) SE-B: It is maybe useful for us at tier one to have some indications because, even if it's not verified, it's not necessarily a problem because we may take it further ourselves or take it further in the consortium.
d) RW: It's an interesting example because as mentioned, it's lasted 4 years in a tunnel, but if a bridge is designed for 60 years and the sensor is only going to last 10 years, and it's embedded in the concrete, what do you do after 10 years? We won't know the durability or longevity because it won't be obvious for a while.
e) SE-B: We need to know as much information as possible on the product/technology. There may be some exaggeration of life expectancy for example. Has it been verified extensively? In the field, or in the lab? The toolkit is able to give us the details behind the scoring, not just the scoring itself.
f) AW: Asked how NRAs think of data? How they think an appraisal toolkit might look like and how it might feel if they had to bear in mind the longer-term vision for this is this toolkit? And how information is presented in an appraisal toolkit.
g) DP: It depends also on the resources. In our case we don't have any monitoring apart from very special cases, so we don't have the IT structure to register data in huge quantities. So, in that case if the system provides us too much data, it has medium effectiveness.
h) AW: The wiki type approach that we've talked about this morning I think was mentioned, i.e. this is the information that's available about this technology and this is the capabilities it has in these various areas that we've talked about. Also, this is the evidence about this technology, and various different aspects about what it can do, how it delivers it, what it costs. You can see the evidence that was used to make a decision about its overall rating, but if the evidence is provided in the database it would make it a lot more useful. In terms of data, with a sophisticated system that would be able to absorb the data, this system may be more usable.
i) FC: In TII we don't take particular interest in new technologies because we're really limited in resources. TII Structures has 3 people in the team. From our perspective, the first thing we'd like to know from this project is what NRAs are using globally, that is helping them in their asset management of bridges. We need to know what's tried and tested, e.g. drones, but there may be lots of other technologies that we're not aware of in other countries.

7. **POLL:** Respondents were asked: Is this toolkit something that would be useful for NRAs to evaluate the performance of new technologies? 1=not useful, 5=very useful

The results are shown below with only two responses, both 4 out of 5.



8. In addition respondents were **asked** where they think the difficulties would be for NRAs to implement the toolkit? The only response was:

- Not able to answer now, we have to see how it will be when it is further adapted.

LCCA

9. INFRACOMS team will follow up with questions on LCCA after the workshop

WP3 - Data Visualisation and Integration:

10. MS presented WP3 data visualisation and integration

a) MS: I need to understand your asset management systems. In your general asset management system, do you actually do any visualisation of data you are collecting?
b) AW: Apart from the GIS based visualisations mentioned earlier, there's also wider questions about whether you look at images, LIDAR data, 3D representations, clever plotting, all these things that could be done. You're asking about that in general, I think?
c) MS: Would you want to see individual deflection data in your asset management system? Or would you analyse it in a separate system?
d) SE-B: We don't store, we have to be extremely careful because some of them are acoustic motioning acoustic emission systems. It can be a huge amount of data. We tend to rely on reports. The company providing acoustic emissions is very, very specialist and when there is a wire break they inform us. They manage the data. It’s important to us to consider on a case by case scenario. Would be good to have choices of data, i.e. What technologies are available? How is it working, what they can provide, what data is needed, how you manipulate the data etc. If we have training we'll be able to clearly decide what is useful for us. We have access to the monitoring systems of the contractor if we ever want to view the raw data, but for the most part we use monthly PDF reports.
e) FZ: Is that something you would like to develop in the future, i.e. that you take over the data and manage it and make the decision by yourself based on the data, or you would rather have a specialist or companies doing that and you get the decision or the information from them and make a decision based on that?
f) BM: Yes, I think this depends very much on how well staffed your organisation is. If you have a lot of specialists you can manage data, but with a small team you're more likely to get the reports and use them.
g) AW: The data, the toolkit and the database may not bring value if it's only about scores, it needs to talk about how you achieve the score and that you know what the actual capability is, because different road administrations would score things differently depending on what their end result requirements were. So, it needs to include information that says what the what the technology can do. The basis of assessment is on the scoring, but NRAs need to relook at the information and say, well actually for us we can do this, whereas when it was scored that was done under an assumption. Some administrations will have a different way of using data which might make that technology higher scoring, or otherwise. But we need to make sure we don't remove the information that we provide in the database so that NRAs cannot make their own value judgments if they want to.
h) FC: TII have some specialists but use a lot of third parties as well. For example, providers could manipulate the data and provide dashboards. We have pavement data coming in going to dTIMS. We've got bridge data coming in and going to Aerospan, but they're all disparate systems. They're not one integrated system.

i) WW: We don't have a system that connects all our asset types, so we have difficulties to understand how we would achieve a goal to manage that, but we have ideas how we could deal with that.
j) RW: One the last question was can we get in touch with the relevant people who deal with the data? We'll need to contact NRAs and TPs because everyone has a different setup, and most people will have different data providers for different data.
k) DP: There's also probably different opinions between people being in hierarchy of the NRAs and the people who are operational. Also, important to discuss IT directions with our IT policies staff.

Roadmap

11. There was no time left to present WP5 and the Roadmap. However, DK provided a brief outline.

a) INFRACOMS team will follow up with questions on Roadmap and action plan after the workshop.