CEDR

Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

INFRACOMS

Innovative and Future-proof Road Asset Condition Monitoring Systems

# Case study report

Deliverable D4.1

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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 D4.1

# Case study report

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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. 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 to better 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.

The Work Packages (WP1-3) of INFRACOMS have developed an understanding of the current priorities and needs of NRAs for the management of carriageway and bridge assets, identified the gaps in the data, and the technologies with the potential to address those gaps. An INFRACOMS Technology Database has listed potential remote condition monitoring technologies and mapped them against current and future asset management needs / use cases.  An overall methodology has also been developed for appraising these technologies.

The work in this report has been carried out under WP4. It has focussed on selecting emerging technologies from the work carried out in WP1-3, to identify case studies that have demonstrated success in the use of these technologies to bridge the gaps between current practice and future needs identified in WP1. The work has developed a semi-formalised approach to undertake assessment of the technologies at the level of "case study" - which can provide further detail on the technologies, including information on the costs associated with their implementation. The report presents specific case studies applying new technologies to assess pavement and bridge condition including: mobile imaging; aerial satellite spectroscopy; a virtual bridge inspection platform; a wireless acoustic emission measurement system; and bridge weigh-In-motion technology. Each study is summarised in the report, but a separate INFRACOMS Case study catalogue has been provided that presents the studies in full detail.

The report presents the approach taken to undertake the case study, with the expectation that NRAs could apply this approach in the future. The approach/outcomes will be taken forward for integration into WP2's Tier 3 Technology Appraisal, which will be included in the INFRACOMS database.

For the examples considered in this report WP4 has demonstrated the practical implementation of emerging technologies to address the gap between the current situation and the future needs of NRAs for infrastructure condition monitoring identified in WP1. The case studies also show that, despite various challenges being encountered - such as implementation delays, difficulties determining damage levels for specific defects, or resistance from staff - the overall experience has been positive. The technologies have shown promise by bridging data gaps, enhancing decision-making processes, maintaining updated asset registers, and improving budgeting.

# Glossary

Table 1 summarises the terminology used throughout this document, and the INFRACOMS project.

*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) |
| 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] |
| 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) |
| 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. [COST TU 1406 WG3 report, 2018] |
| 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). Remote Sensing/Monitoring can be defined as ”any surveying method which does not require physical contact with the road surface or subsurface” (Schnebele et al, 2015) |
| 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. |
| Technology Readiness Level (TRL) | 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. |

## Abbreviations

*Table 2. List of abbreviations.*

| Abbreviation | Definition |
|---|---|
| ADP | Advanced data processing |
| AE | Acoustic Emission |
| AI | Artificial intelligence |
| CEDR | Conference of European Directors of Roads |
| DRD | Danish Road Directorate |
| CS | Crowd sourcing |
| CVI | COWI Virtual Inspection |
| GIS | Geographic Information System |
| GNS | Global Navigation Satellite system |
| INFRACOMS | Innovative & Future-proof Road Asset Condition Monitoring Systems |
| INS | Inertial Navigation System |
| InSAR | Interferometric Synthetic Aperture Radar |
| IoT | Internet of Things |
| LiDAR | Light Distance and Ranging |
| LOS | Line of Sight |
| NH | National Highways |
| (N)RA | National Road Authority or other road authority |
| PIARC | World Road Association (Permanent International Association of Road Congresses) |
| RA | Road Authority |
| RCM | Reality Capture Model |
| RS | Remote Sensing |
| RTK | Real-time kinematic |
| SAR | Synthetic Aperture Radar |
| TRL | Technology Readiness Level |
| 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. In this report they are collectively referred to as 'Remote Monitoring Technologies', which is defined in the Glossary. However, National Road Authorities ((N)RAs) in Europe 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.

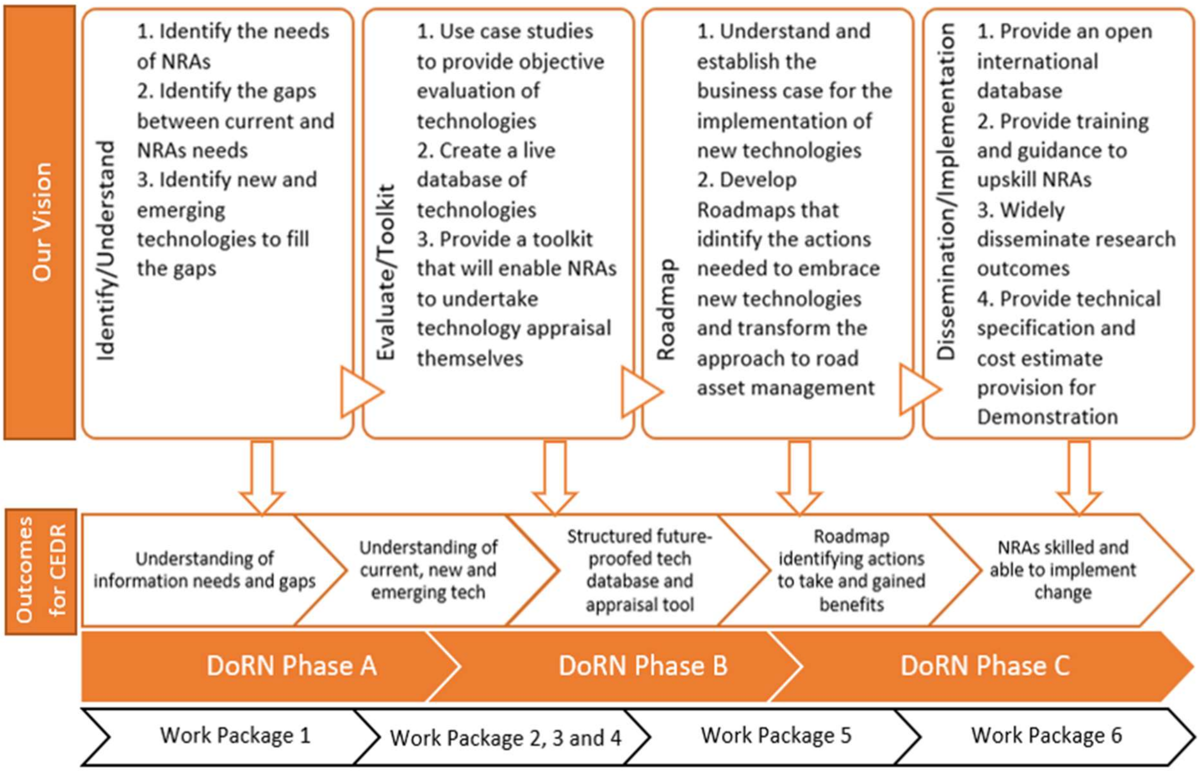


*Figure 1. Vision and outcomes of INFRACOMS.*

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 new technologies for understanding the performance of highway assets. INFRACOMS is establishing a database of these technologies and an Appraisal toolkit to appraise them, to help NRAs assess the costs, benefits and limitations of applying the 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 Overview of INFRACOMS Work Packages

This report (D4.1 – Case study report) has been prepared as a deliverable of Work Package 4 of the INFRACOMS project. Figure 2 shows the relationship of the INFRACOMS work packages, tasks and deliverables with respect to WP4.

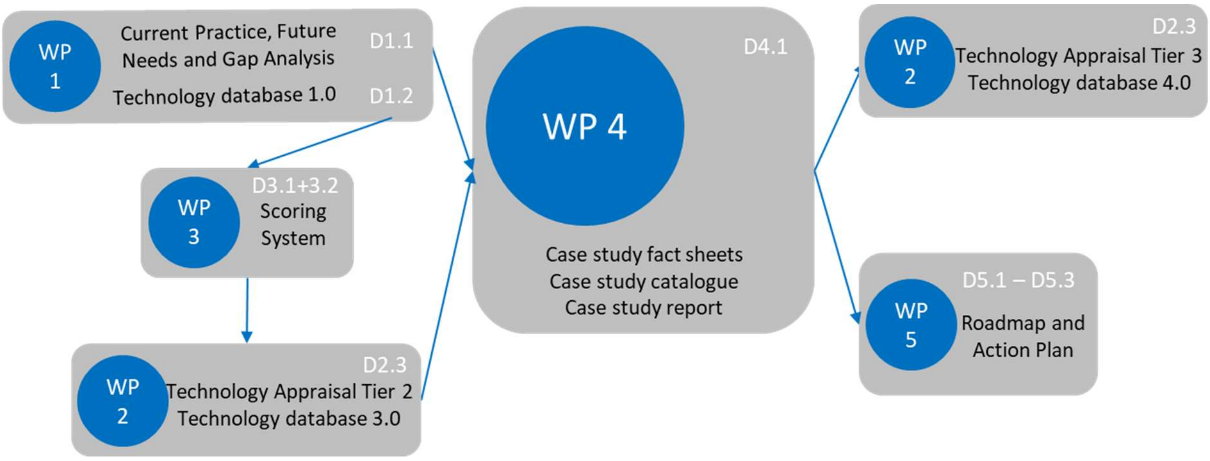


*Figure 2. Relationship of WP4 to other Work Packages, Tasks and Deliverables*

Previous reports delivered by INFRACOMS have developed an understanding of 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 (D1.1). This identified gaps in data, challenges in collecting data, and challenges in application of data that is already collected, and the technologies with the potential to address those gaps. This led to the development of a Technology Database (D1.2) which listed remote condition monitoring technologies and mapped them against the current and future asset management needs / use cases identified in WP1. In WP2 an overall methodology was developed for appraising these technologies, in the context of use cases. WP3 (D3.1, D3.2) considered the data that these technologies provide and how it could be integrated into NRAs' asset management systems.

WP4 has focussed on selecting emerging technologies from the studies carried out in WP1-3, to identify case studies that have demonstrated success in the use of these technologies to bridge the gaps between current practice and future needs identified in WP1.

As noted above WP1 established a Technology Database. Version 1.0 of the database comprises a comprehensive list of remote condition monitoring technologies mapped against current and future asset management needs. This database served as a foundation for Tier 1 Technology Appraisal using the appraisal methodology developed in WP2, which was built on in WP3 to introduce a scoring system for Tier 2 Technology Appraisal. Technologies that successfully pass this tier are included in Technology Database 3.0. In WP4, Technology Database 3.0 has been used as a source for selecting technologies to be featured in the case studies.

WP4 has added a Business Case layer that encompasses the implementation process, benefits, challenges, and costs faced by early adopting NRAs for the selected case studies. The WP4 case studies hence provide valuable information on the costs associated with implementing the technologies, which can then be integrated into WP2's Tier 3 Technology Appraisal. Technologies that pass Tier 3 are incorporated into Technology Database 4.0.

Furthermore, WP4 provides practical examples and information for the technology-specific roadmaps that will be considered in WP5. In WP5, a roadmap will be developed for the implementation of new technologies by NRAs, along with a method for NRAs to assess their readiness for adopting these technologies.

## 1.3 Scope of this report

The work described in this report was carried out under WP4. WP4 includes the deliverable D4.1, which includes a Case Study Catalogue (which is provided separately) and this Case study report. The purpose of this report is to provide an overview of the case studies included in the catalogue, offer guidance on the catalogue content, and provide an outline of the process followed to create the catalogue. This report is structured as follows:

- Section 1 is this introduction.
- Section 2 summarises the work package objectives and approach.
- Section 3 gives an outline of the process followed to create the case study catalogue.
- Section 4 summarises the case studies included in the catalogue.
- Appendix A contains a fact sheet template

# 2. Work Package 4 Objectives and Approach

## 2.1 Objectives

The objectives of WP4 are to:

- Develop a comprehensive rationale for the implementation of new technologies, offering practical insights and justifications.
- Gather cost information from case studies to support the Tier 3 appraisal in WP2, providing data for assessing the economic aspects of the technologies.
- Generate case study reports for promising remote condition monitoring technologies, providing in-depth analysis and findings.

## 2.2 Approach

In order to fulfil the objectives of WP4, INFRACOMS adopted the following approach for gathering details on selected remote condition monitoring technologies implemented by National or other Road Authorities (NRAs and RAs).

- Building on WP1-3, emerging technologies that had demonstrated success in addressing the gaps between current practices and future needs in the road network were identified. The selection prioritised technologies that had already been implemented successfully.
- A search was undertaken for NRAs or other Road Authorities that had applied the selected technologies (hence in this report we use the terms NRA and (N)RA where appropriate). This allowed the project to establish a link between the identified emerging technologies, infrastructure owners, applications, and networks, providing valuable hands-on experience.
- Contacts were established with the identified (N)RAs and ensured they were willing to provide details through a fact sheet and an interview. The fact sheet (Appendix A) captured essential information for each case study including the benefits achieved, the implementation process, associated challenges, limitations, and costs. The fact sheet template served as a robust framework for effectively documenting insights from the case studies. The fact sheet template is found in Appendix A.
- A detailed description was developed of the network on which the technology was applied.
- A comprehensive description of the technology was sought from the technology providers – optimally including insights from the specific case study.
- Based on the fact sheets, the detailed network description, and the comprehensive description of the technology from the technology providers, a catalogue of the case studies was compiled. This catalogue provides an organised overview of the technologies, focussing on the ability to improve asset management, monitoring, and maintenance.

This case study report summarises the key findings and insights derived from the case studies featured in the catalogue. This report not only offers an overview of the case studies, but also provides guidance on the content of the catalogue (which is provided separately), and the process that was followed to create it.

Through this approach, the aim was to deliver a case study catalogue and report to support current and future technology appraisals carried out using the INFRACOMS methodology. The case studies provide practical insights into the benefits, challenges, and costs associated with implementing remote condition monitoring technologies.

# 3. Creating the Case Study Catalogue, and Catalogue structure

## 3.1 Selection of relevant technologies

The technologies for the case studies were selected from Technology Database 3.0 based on the following criteria:

- The inclusion of both carriageway and bridge specific technologies. Both of these asset types are considered in the INFRACOMS project.
- The technologies chosen should be directly related to the imperatives that hold the highest importance for NRAs. During workshop 1, NRAs expressed that their top priority for bridges to be safety, followed closely by reliability. For carriageways, availability was identified as the primary imperative, followed by safety.
- The selected technologies should address the gaps identified in WP1 (Report D1.1 section B).
- Preferably, the chosen technologies should demonstrate benefits and provide insight into the challenges related to delivery, integration, and visualization (as these components are specifically considered in the INFRACOMS appraisal methodology). As it is more likely that these insights would derive from experience of technologies that have been applied in practice, technologies with a Technology Readiness Level (TRL) exceeding 7 were given preference.
- Given that different groups/types of technologies may present unique implementation challenges, the work attempted to include case studies that encompassed various groups/types of technologies - such as crowd sourcing, remote sensing, Internet of Things (IoT), and advanced data processing.

By considering these criteria, WP4 ensured that the case studies would reflect relevant technologies to support delivery of the aims of INFRACOMS, whilst also meeting the imperatives of NRAs and closing the identified gaps in the D1.1 report. Table 3 presents an overview of the technologies chosen for case studies. The technologies are categorized by their asset type, NRA imperative, and solution group. Additionally, the Technology Readiness Level (TRL) is indicated to demonstrate the maturity of each technology.

*Table 3. Overview of technologies chosen for case studies.*

| Technology | Asset | Imperative | TRL | Solution type | | | |
|---|---|---|---|---|---|---|---|
| | | | | CS | RS | IoT | ADP |
| **EyeVi Platform - point cloud generation** | Carriageway | Safety | 8 | | | | x |
| **Aerial Satellite Spectroscopy** | Carriageway | Availability | 8 | | x | | |
| **Virtual inspection platform** | Bridge | Reliability | 9 | | | | x |
| **Wireless Acoustic emission** | Bridge | Reliability | 7 | | x | x | x |
| **Bridge Wrigh-In-Motion** | Bridge | Reliability | 9 | | | x | x |

Key: **CS = Crowdsourcing, RS = Remote sensing, IoT = Internet of things, ADP = Advanced data processing**

## 3.2 Identification of cases

To establish a practical connection between the selected technologies and their real-world application, we sought case studies where (N)RAs had implemented these technologies. The case studies demonstrate how early adopters have successfully integrated remote condition monitoring technologies into their infrastructure management practice. In Section 4, a curated selection of case studies will be presented, showcasing the adoption and utilization of these technologies.

Please refer to Table 4 for the coupling between selected technologies and the associated (N)RAs and specific applications.

*Table 4. Coupling between selected technologies, (N)Ras, and specific applications.*

| Technology | (N)RA | Application |
|---|---|---|
| **EyeVi Platform - point cloud generation** | City of Oslo | Defect detection |
| **Aerial Satellite Spectroscopy** | National Highways | M25 Carriageway movements |
| **Virtual inspection platform** | Danish Road Directorate | SHM of Farø Bridges |
| **Wireless Acoustic emission** | Rijkswaterstaat | Possible crack detection on bridge |
| **Bridge Weigh-In-Motion** | Slovenian Motorway Company (DARS) | Monitoring of traffic loads and bridge responses |

## 3.3 Design of case study catalogue

The design of the case study catalogue was carefully considered. It was decided that greater benefit would be provided if the catalogue included comprehensive levels, rather than summary/superficial levels, of information. As a result, the decision was made not to utilize a systematic colour code to indicate solution type, TRL level, or other features. Instead, the primary focus was on providing in-depth information about each case study, ensuring a thorough understanding of its context, implementation, and outcomes.

To facilitate easy navigation and readability, the case study catalogue was structured as a collection of multiple A4 pages. Each case study was given dedicated space to present its key details, including data on the network, technology, (N)RA experience, and contact information. The layout was designed to ensure clarity and coherence, enabling readers to quickly locate and absorb the relevant information.

In addition to the physical case study catalogue, an online format was established for inclusion in the INFRACOMS database (which is provided using the Confluence platform) to provide convenient access to the case studies. This digital extension allows users to explore the case studies under the corresponding technologies, providing a user-friendly interface for browsing and searching for specific information. The online platform complements the physical catalogue by offering additional features such as hyperlinks to related resources, and the ability to leave comments or ask questions, fostering collaboration and knowledge sharing among NRAs.

## 3.4 The sections contained in the catalogue, and the collection of information

The catalogue is divided into the following key sections:

1. **Introduction**: This section describe the criteria for the selection of case studies presented in the catalogue as well as a brief overview of the selected case studies.
2. **Case Studies**: This section constitutes the main content. Each case study sub-section begins with a general overview and is further broken down into the following subheadings:
    a. The Network: Describes the infrastructure involved in the case study.

   b. The Technology: Discusses the technology used in each case.
   c. (N)RA Experiences: Shares the experiences, challenges, benefits, and limitations encountered by (N)RA.
   d. Contact Persons: Provides contact details of relevant persons related to each case study.
3. **Final Thoughts**: Summarises the various technologies addressed in the catalogue and discusses their implications for the future of infrastructure management.

Various methods were employed to gather the information required for section 2 (case studies), as described below.

### 3.4.1 The network

Several sources (such as the internet, (N)RAs, and technology providers) were used to obtain information about the network where the technology was implemented. Depending on the case, relevant data was accessed through these channels to gain insights into the network's characteristics and infrastructure.

### 3.4.2 The technology

Initially, basic information was obtained about the selected technologies from previous work packages. However, to enhance our understanding and acquire more detailed and case-specific information, the project directly engaged with technology providers, who were asked to provide comprehensive details about their technologies, focusing on aspects directly relevant to the chosen cases.

### 3.4.3 NRA experiences

A key objective of the study was to facilitate knowledge sharing among NRAs within CEDR. To achieve this, substantial efforts were made to gather information from the (N)RAs who had implemented the technologies. This was achieved though in-depth interviews with the (N)RAs who had implemented the identified technologies. Prior to the interviews, the (N)RAs were provided with a fact sheet template as found in Appendix A, allowing them to familiarize themselves with the format and prepare for the discussions. These interviews provided valuable insights into their experience and practical application of the technologies. In addition to pre-determined questions based on the fact sheet template, additional inquiries were made to explore specific aspects of their implementation in greater detail.

### 3.4.4 Contact persons

This subsection includes a list of contact persons from the (N)RA, technology provider, and the INFRACOMS partner who conducted the case study. These individuals can be contacted for further information or clarification regarding the respective case studies. (N)RA and technology provider contact persons were found by various means such as through homepages, press releases, personal referral and already established connections with INFRACOMS partners.

# 4. Summary of case studies

In addition to this report D4.1, the case study catalogue is provided as a separate document. Table 5 gives an overview of the case studies. The following subsections gives a summary of the case studies included in the catalogue.

*Table 5: Overview of case studies showing the selected technology, Vendor, RA and network on which it was applied.*

| Technology | Vendor | RA | Network |
|---|---|---|---|
| **EyeVi Platform – point cloud generation** | EyeVI Technologies + Triona | City of Oslo | Oslo city |
| **Aerial Satellite Spectroscopy** | Satsense | Connect Plus Services, operating for National Highways UK | M25 Motorway, London |
| **Virtual inspection platform** | COWI | Danish road directorate | Farø Bridges |
| **Wireless Acoustic emission** | SHMnext | Rijkswaterstaat | Steel bridge |
| **Bridge Weigh-In-Motion** | Cestel | Slovenian Motorway Company (DARS) | Bridge |

## 4.1 EyeVi technology platform

The City of Oslo, Norway, successfully implemented the EyeVi technology platform to manage the condition of its 1300 km urban road network. EyeVi uses vehicle-mounted equipment to capture, process, analyse, and visualize road condition, utilizing a 360° panoramic camera, a LIDAR scanner, and a GNSS/INS sensor.

The technology collects data every 3 meters while operating between -10 to +50°C with speeds of 50-70 km/h. Through EyeVi Data Capture and fieldwork software, data such as GNSS/INS, LIDAR, and raw panoramic camera imagery are harvested. Data Processing Software enhances the raw sensor input to produce 360° panoramic images, orthophotos with a resolution of 0.5 cm, and full-coverage 3D point clouds covering the environment. Data is analysed by AI processing that uses ortho imagery to identify defects in roads and footways, panoramic images for recognizing and establishing the position of traffic signs, and differentiates between various ground and structural features in the point clouds. A Web Application is provided to visualise the data, which enables representation in an orthophoto/map view, a panoramic view, and a point cloud view to assist understanding and communication with third parties. The system offers the potential for detailed and frequent monitoring, for objective condition assessment and up to date asset registries.

The case study project had a budget of 2.8 million NOK in 2021 (approx. 236 000 EUR). A tender named "17-BYM-2021 – Kartlegging og planlegging av vedlikehold av gater og veier" inviting consultants to leverage technology of their to gather condition and asset data on the city network. The EyeVi system was selected to collect the data.

The project built on collaboration between the consultants and the city to configuring the technological solution, in particular how condition (damage levels) would be rated, building on existing standards. The project successfully collected anonymized panoramic image data (to address privacy regulations), and undertook data processing to enable objective condition data to be successfully incorporated into Oslo's existing road databank. The compatibility with the client's existing systems was ensured by agreeing compatible data formats. Quality assurance was built into the contract, with checkpoints at each stage to validate accuracy and performance.

However, the project did experience challenges including delivery delays and difficulties in determining he damage levels for specific damage groups during data analysis. Technological limitations included gaps in data collection relating to elements like curb stones and storm drains and differentiating private and public objects. Nevertheless the study found that the use of EyeVi is considered to have enhanced Oslo's decision-making process by providing objective, data-backed insights, bridging data gaps that previously existed, and revolutionizing the budget allocation process.

## 4.2 Aerial Satellite Spectroscopy

The case study revolves around the utilization of InSAR technology by the provider Satsense, to determine ground movements on the M25 motorway, operated by Connect Plus Services for National Highways. The particular section of the M25 under investigation was between junctions 26 and 27, Northeast of London. The area is characterized by prevalent London Clay, which is prone to seasonal changes and shifts caused by weather and changes in climate.

To study these geographical shifts, Persistent Scatter processing of the Synthetic Aperture Radar (SAR) data, known as InSAR, was chosen. It's worth noting that InSAR is versatile enough to be used for several geotechnical structures like slopes, retaining gabion walls, embankments, etc.

This investigation used image data captured by the European Space Agency's (ESA) Sentinel 1 polar orbiting satellites from 2015 to 2022. Legacy imaging was referenced to draw immediate insights into historical movements, a dataset that couldn't be acquired from conventional periodic surveys.

The acquired raw imagery posed specific challenges. For one, satellite images aren't always directly overhead, which factors in the Line of Sight (LOS) limitations. Therefore accurate measurements required that the images were of sufficient quality. This meant that a single pixel of the image ranged between 3mx3m down to 1mx1m, leading to measurable areas typically of around 5mx20m.

After receiving the data from ESA secondary processing was applied to identify specific points within certain tiles – this stage presented the largest intellectual challenge. This phase also included data validation, which was conducted both by the satellite vendor technical teams and the Satsense engineers. The outcomes of the revealed substantial ground subsidence of -30 mm since 2015 with increasing seasonal shrink/swell movements at approximately +/-15 mm for 2020. These precise shrink/swell quantifications, and long-term trends, are assisting the network the operator to improve the accuracy of their deterioration models.

Though the study did not immediately integrate the satellite-acquired data into the National Highway systems, it was held for potential future utilization. The data could be presented in widely acceptable formats such as CSV or as a shapefile for GIS systems, making it easy for inclusion in most existing databases.

One of the key benefits of using this technology is that it replaces the need for labour-intensive field work. It allows extensive data acquisition without causing disruption to road users or the risk of operatives dealing with live carriageways. Additionally, InSAR data covered areas beyond the (N)RA land boundaries, negating the necessity for landowner permissions for monitoring and inspection.

Nevertheless, the technology did face certain obstacles. Chief among these was gaining acceptance for the data as a suitable means of measurement. Consistent pilots and repeated reports had to be undertaken to ascertain the improvements in data accuracy and ensure confidence in the results.

In terms of costs, the financial model depended on the area to be surveyed. For an (N)RA, the cost could span £100-£500 per km², where the larger the area, the cheaper the cost per km². However, these costs are reducing as processing is becoming more streamlined and automated. This trend is expected to continue as more providers enter the market.

The case study concluded that the InSAR technology is reaching a stage where it could become a vital part of formal monitoring regimes thanks to its 'scalability' and potential to provide a quantifiable level of resilience to roads networks. The technology aligns well with existing business processes and provides essential detailing, making it suitable for official, consistent use. Drawing from the experience and insights documented from this investigation, National Highways published a Technical Guidance Note on the technology and how to use it.

## 4.3 COWI virtual inspection platform

The Danish Road Directorate (DRD) implemented the COWI Virtual Inspection (CVI) platform for maintaining the Farø bridges, two significant structures in the South-East of Denmark. The CVI system utilizes drone-captured normal daylight and thermal images.

Photogrammetrically processed images were collected by drones operating in predetermined flight paths with a 70% image overlap to provide a detailed 3D mesh of the bridge structure. The drones were flown in cooperation with COWI's external partner, WeFly, which made use of real-time kinematic positioning (RTK) for accurate georeferencing. The captured images and 3D models were processed into the CVI platform, a web-based system. The platform utilized AI algorithms for the automatic detection of defects including cracks, corrosion, and graffiti. The system also allows for RGB and thermal images to be imported and analysed, and defects to be annotated with a confidence level. The AI-algorithms were trained using images from previous structures assessed using the CVI system.

The CVI platform allowed the visualization of bridge condition and defects and provided a tool for inspectors to annotate and report condition. Findings were summarised in an auto-generated report that included descriptions and photographs of the defects found.

The study found that the use of the CVI platform had improved the efficiency of the inspection process e.g., providing the ability to look for recurring damage without revisiting the structure, reducing the operational costs, and optimizing data collection, whilst also providing 100% coverage of documentation for future comparison of condition. Notably, the employment of drones for inspections in challenging-to-access areas not only led to substantial reductions in manual operation costs but also contributed to enhanced workplace safety. Potential challenges included resistance from staff to the new technology, the high initial cost, and limitations in the capability of the AI's defect identification.

In conclusion, the integration of the CVI platform has shown optimistic results in asset management by providing comprehensive inspection data, increasing decision-making efficacy, and reducing operational costs.

## 4.4 Wireless acoustic emission

The Dutch national infrastructure authority, Rijkswaterstaat, implemented SHM NEXT's UniQ technology for managing a major arch bridge in the Netherlands. The objective was to detect possible internal structural defects that couldn't be identified visually.

UniQ is a wireless sensor node that detects potential cracks via acoustic emission. Installation is simplified by the use of an embedded magnet-based mounting system. Each UniQ measures an area of 20-50 square meters and can operate independently, making it highly scalable for large structures. The implementation process involved collaboration with the vendor (SHM NEXT), pilot testing on a structure with known defects, and multiple modifications to adapt to the specific conditions of the structure.

The comprehensive monitoring covered several two-month periods across a section of 45m of a girder and four riveted connections in the section, using five UniQ nodes for each 15m part. Data analysis and processing included creation of a damage indication map, which presented the location and growth rate of potential cracks. The defect data could be integrated into the existing data architecture of Rijkswaterstaat through APIs.

Operational benefits from adoption of the UniQ technology included: improved detection of internal structural damage; the delivery of more comprehensive data; and enhanced visualization of the condition of the bridge. Limitations of the technology involved the need for validation and integration with the existing 3D model for enhanced structural analysis.

The costs associated with this implementation included the acquisition of the technology and equipment, however specific data about these expenses are not mentioned. It is recommended to confer with the technology provider about implementation costs.

For other national road agencies considering deploying this technology, the advice from Rijkswaterstaat is to understand the technology, consider validation with another technique, and gather as much data as possible across different bridges to gain broader experiences with this approach

## 4.5 Bridge Weigh-In-Motion

This case study focuses on a twin multi-span viaduct located in Slovenia, which is operated and maintained by the Slovenian Motorway Company. This viaduct, a continuous box girder construction stressed with both internal and external tendons, was built using the incremental launching method. The viaduct was equipped with a Bridge Weigh-In-Motion (B-WIM) system, which, along with Soft Load Testing (SLT), allows for the non-intrusive monitoring of traffic loads and bridge responses.

The B-WIM system's key advantage is its ability to gather data without disrupting traffic flow, a significant improvement over traditional load testing methods. It provides critical information like strains, influence lines, load distribution, and dynamic amplification factors, which are crucial for the bridge's structural safety analysis.

The study also considered the practical application of this technology by the Slovenian Motorway Company (DARS), highlighting its effectiveness in assessing structural safety and traffic load capacity. Despite some challenges in calibration and the need for close collaboration among stakeholders ((N)RA, technology provider and bridge assessment expert), the technology demonstrates significant benefits in optimizing safety analysis and operational efficiency.

This case study is a valuable example for other national road agencies, showcasing the benefits of integrating advanced monitoring technologies like B-WIM and SLT in bridge assessment and maintenance strategies.

# 5. Conclusions

To equip NRAs with the ability to better leverage the technological evolution in data and monitoring, INFRACOMS is establishing a database of technologies and a toolkit to help NRAs appraise them. Any assessment of new technology must consider its ability to meet specific technical requirements. Whilst WP1 and WP2 of INFRACOMS have focussed on the identification of gaps in the NRA toolkit for assessing condition, and on the establishment of a database of potential tools that could fill these gaps, the work presented in this report (under INFRACOMS WP4) has focussed on the assessment of specific technologies that could be included in the database, with higher levels of information – i.e. as case studies.

In this work WP4 has developed a semi-formalised approach to undertake assessment of technologies at the level of “case study”, which can provide further detail on the technologies, including information on the costs associated with their implementation. This approach can be applied by NRAs themselves, and will be taken forward for integration into WP2's Tier 3 Technology Appraisal, which will be included in the INFRACOMS database. Technologies that pass Tier 3 will be incorporated into Technology Database 4.0 – which is the final level of technology appraisal applied by INFRACOMS.

For the examples considered in this report WP4 has demonstrated the practical implementation of emerging technologies to address the gap between the current situation and the future needs of NRAs for infrastructure condition monitoring identified in WP1. This case study summary report provides specific examples of the adaption of technology that assists in the assessment of the condition of carriageways and bridges. In particular this report has provided example case studies that involve the use of technologies such as the EyeVi technology platform in Oslo, the Aerial Satellite Spectroscopy for the UK's M25 motorway, the COWI virtual inspection platform for Denmark's Farø bridges, the Wireless Acoustic emission technology for the steel bridge from Rijkswaterstaat and bridge weigh-in-motion for a bridge in Slovenia. Each of these case studies has provided insight into the potential of these technologies and cost information to support Tier 3 appraisals carried out in WP2.

The case studies also show that, despite various challenges being encountered - such as implementation delays, difficulties determining damage levels for specific defects, or resistance from staff - the overall experience has been positive. The technologies have shown promise by bridging data gaps, enhancing decision-making processes, maintaining updated asset registers, and improving budgeting.

# Appendix A Fact sheet template

## Fact sheet

The information below can be used when gathering information to prepare a case study for inclusion in the catalogue. A suggestion of where to obtain the information is given in parentheses. E.g., where ((N)RA) is written after a heading, it is suggested that this information be sourced the (N)RA using that technology.

| **Basic description (INFRACOMS/(N)RA)** | |
|---|---|
| Technology (Scoring sheet) | |
| Short solution description (Scoring sheet) | |
| Solution groups (Tech database 3.0) | |
| TRL level (Tech database 3.0) | |
| Related asset type (Tech database 3.0) | |
| Relevant imperatives (Tech database 3.0) | |
| Involved (N)RA, location ((N)RA) | |
| Short description of current state (existing infrastructure, processes and technologies in place ((N)RA)) | |

| **Implementation process ((N)RA)** | |
|---|---|
| Planning and goal setting:<br>- Which objectives and desired outcomes were defined? | |
| Research and vendor selection:<br>- Which potential technological solutions and vendors aligning with the defined objectives were evaluated?<br>- What were the:<br>o Features?<br>o Capabilities?<br>o Costs?<br>o Scalability?<br>o Compatibility with existing systems? | |
| Regulatory compliance:<br>- How was it ensured that the regulatory framework was understood, and any necessary permits obtained? | |
| Pilot testing:<br>- Which potential issues, user feedback and necessary adjustments were identified? | |
| System design and configuration: | |

| Implementation process ((N)RA) | |
|---|---|
| - Please explain the collaboration with the vendor on configuring the technological solution based on your specific requirements. E.g., how was the solution customized, integrated with existing systems and dataflow and interfaces established? | |
| Training and change management:<br>- How was the training conducted?<br>- Which change management strategies were developed to facilitate a smooth transition and address any resistance to change? | |
| Deployment and integration:<br>- How was the new solution integrated with existing systems ensuring compatibility and data interoperability? | |
| Data migration and testing:<br>- How was relevant data from legacy systems transferred to the new solution?<br>- How was data integrity, accuracy and system performance ensured?<br>- How was the new solution validated against predefined acceptance criteria? | |
| Rollout and user support:<br>- How is the new solution implemented (e.g. starting with specific regions, departments, types of structures)?<br>- How are any issues or questions arising addressed? | |
| Evaluation and continuous improvement<br>- How is performance monitored against the predefined goals and performance indicators?<br>- How is the process of gathering feedback from users and stakeholders to identify areas for improvement and implement necessary updates and enhancements? | |
| Which of the above topics were taken care of by:<br>- Vendors (which)<br>- Consultants (which)<br>- Others (what and which) | |
| Other comments on the implementation process | |

| Benefits ((N)RA) | |
|---|---|
| Which gaps did the technology close? | |
| Which benefits are achieved over previous solution related to **data collection?** | |
| Which benefits are achieved over previous solution related to **data analysis?** | |
| Which benefits are achieved over previous solution related to **data representation?** | |
| Which benefits are achieved over previous solution related to **practical decision-making?** | |
| Which benefits are achieved over previous solution related to **data integration into existing architecture?** | |
| Did you achieve any other technical benefits? | |

| Challenges related to implementation ((N)RA) | |
|---|---|
| Which challenges were encountered when implementing this technology related to **delivery,** if any? | |
| Which challenges were encountered when implementing this technology related to **data collection,** if any? | |
| Which challenges were encountered when implementing this technology related to **data analysis,** if any? | |
| Which challenges were encountered when implementing this technology related to **data representation,** if any? | |
| Which challenges were encountered when implementing this technology related to **practical decision-making,** if any? | |
| Which challenges were encountered when implementing this technology related to **data integration into the existing architecture,** if any? | |
| Which challenges are anticipated related to changing consultants (e.g., Ownership of raw and processed data and data sharing)**,** if any? | |
| Did you encounter any other technical challenges? | |

| Limitations ((N)RA/TP/INFRACOMS) | |
|---|---|
| Are there gaps, which are still unresolved? ((N)RA) | |
| Can the technology be improved to close more gaps? (TP/INFRACOMS) | |

| Costs ((N)RA/TP) | |
|---|---|
| Implementation costs: (updated numbers from TP) | |
| - Acquiring technology/equipment | |
| Costs/savings over time: ((N)RA) | |
| - Access, process and use data | |
| - Maintain technology/equipment | |
| - Procure condition surveys | |
| - Financial implications on the asset maintenance (e.g., because of more precise forecasts) | |

| Do you have any advice for implementing this solution at other (N)RAs? ((N)RA) |
|---|
| |