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REthinking Future Infrastructure NETworks

REFINET

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Catalogue of technologies for multi-modal transport infrastructures

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Project Coordinator: Alain Zarli (CSTB)
Tel: +33 493 956 736
E mail: alain.zarli@cstb.fr
Project website address: http://www.refinet.eu/

Revision History

Date	Version	Author/Contributor[1]	Revision By[2]	Comments
18.04.2016	V01	Arup, B Kidd, REFINET Partners		First draft upon request of the P.O
13.05.2016	V02	Arup, B Kidd, REFINET Partners		Final draft
03.07.2017	V03	ARUP		Final version submited to EC/INEA with changes linked to publication on CORDIS (EU emblem, disclaimer).

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[1] Partner, Name Surname
[2] Partner, Name Surname

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ABBREVIATIONS

Acronym	Full name
CSA	Coordination and Support Action
ECTP	European Construction Technology Platform
RMMTI	REFINET multi-modal transport infrastructure

DEFINITIONS

Term	Full name
Taxonomy	Taxonomy is the science or the technique used to make a classification. It is also used to refer to a classification and especially a classification in a hierarchical system.

Executive Summary

Currently, many of the technologies that are needed to allow evolving the European transport infrastructures toward the REFINET multi-modal transport infrastructure (RMMTI) model are already available in the market or will be available in the next few years, but the sector is not aware about their availability and potential. In order to overcome the gap between "common practices" in design, construction and maintenance of transport infrastructures and the "most sustainable practices" that could be deployed, examples of different technologies being developed and trialled by transport infrastructure clients, and the main engineering companies, contractors and maintenance services providers have been collected and categorised.

For each technology, the following information has been collected:

- Short description of the technology
- Main advantages in relation to competitor technologies
- Maturity: TRL (Technology Readiness Level), examples of application of this technology…
- Links for further information: who offers this technology

It must be understood that the compilation of technologies included in this deliverable cannot be comprehensive given the wide scope of transport infrastructure systems covered in the REFINET project and the wide array of technologies available on the market. A framework for the taxonomy of technologies in transport infrastructure, adapted from deliverable D3.2 (best practices collection) and with relevant examples of technologies classification is provided instead. The taxonomy scheme is needed as it is the intention of the Infrastructure and Mobility Committee of ECTP and of the Working Group in Infrastructure of ENCORD to continue after REFINET the work started in this deliverable and thus the taxonomy provides a future means for technology capture and classification (and best practices in deliverable D3.2). The main difference between the content of both deliverables is that D3.2 applies to best practices which are widely used whereas D3.3 reviews practices which are available but not widely used yet bear a potential to increase performance and sustainability.

Relevant examples have been compiled from different sources; by the REFINET partners themselves, by members of the different networks of organisations represented by the partners and by other organizations external to the project partners or their networks such as National Technologies Platforms, and through a review of the main sectorial conferences to detect the most innovative technologies. In practice, the source organisations for the technologies introduced in this deliverable cover several of the most innovative transport infrastructure clients, infrastructure designers, constructors, operators, manufacturers and suppliers globally as well as notable academia and research centers in the fields of expertise.

1. INTRODUCTION

This document provides and non-exhaustive compilation of technologies applicable to the design, construction, operation, maintenance and refurbishment of transport infrastructures. The document is necessarily non-exhaustive given the field of expertise that it is intended to cover. However, the distinguishing characteristic of the example technologies that have been highlighted is that they have to some extent been researched, trialled or deployed in practice in most cases, characterised by Technology Readiness Levels (TRLs). This means that the technologies provide a baseline for the preparation of roadmapping activities as they represent both a snapshot of current technology use in transport infrastructure and a picture of where the sector could be heading. This also provides a baseline for improvement of current practice, as the constraints for the application of the technologies are also recorded in this document.

The document has taken the practical taxonomy approach developed in deliverable 3.3 Best Practices, as it reflects real-world objects and processes and can therefore be easily applied and extended to the collection of additional technologies. The contents of the different sections of this deliverable are as follows:

- *Chapter 1: Introduction*. This chapter
- *Chapter 2: How the technologies have been compiled* explains the process that was followed for cataloguing technologies included in this document.
- *Chapter 3: Taxonomy* defines the classification system defined in this document for the cataloguing of technologies.
- *Chapter 4: Summary of technologies* introduces the catalogue of technologies provided by the desk study research and contributors as well as some statistics in relation to their spread across the lifecycle stages and spread across the different types of infrastructure.
- *Chapter 5: Technologies for design* brings together and provides detail on the technologies related to design of infrastructure systems, components or elements.
- *Chapter 6: Technologies for construction* brings together and provides detail on the technologies related to the construction of transport infrastructure
- *Chapter 7: Technologies for maintenance* brings together and provides detail on the technologies related to the operation, maintenance, and refurbishment of infrastructure systems, components or elements.
- *Chapter 8: Next steps* provides help and tips on how to use the information of this document for subsequent roadmapping exercises of the REFINET CSA
- *Chapter 9: Conclusions* summarises the main findings of this task.

It is noted that a number of the technologies identified apply to several lifecycle stages. The technologies are only presented once in this document in the lifecycle chapter where they appear first, however for completeness a reference to the first appearance of the technologies is provided where it belongs to more than one lifecycle stage, and this is captured in the catalogue itself.

2. HOW THE TECHNOLOGIES HAVE BEEN COMPILED

There have been a number of sources for the capturing technologies relevant to transport infrastructure including:

- *relevant past and current European funded research and development*, including the two other CSAs FOX and USE-it and transport mode-specific research such as captured through the RSSB/UIC SPARK database, the SHIFT2Rail programme and highways research funded by CEDR.
- *the network of National Technology Platforms* (NTPs)
- *innovation and knowledge transfer networks*, such as the Enterprise Europe Network (EEN), and the KTN

- *websites of transport infrastructure operators and their supply chains,* for example Highways England's Knowledge Compendium and Transport Infrastructure Ireland research and innovation linked to CEDR.
- *Industry conferences* such as TRA2016, TRB Annual General Meeting and CITE
- *Other technology scanning reports*, such as the Arup Future of Rail and Future of Highways reports
- *REFINET workshops*

3. Taxonomy (Classification) of technologies

The REFINET taxonomy for the collection of best practices (D3.2) and for the catalogue of technologies for multi-modal transport infrastructure (D3.3) is defined in this section. The taxonomy follows mainly a hierarchical taxonomic scheme as it has been found out that the hierarchical approach provides a good decomposition of how transport infrastructure systems are organised (see Figure 1). Nevertheless, other forms of relationship are not precluded by the taxonomic scheme.

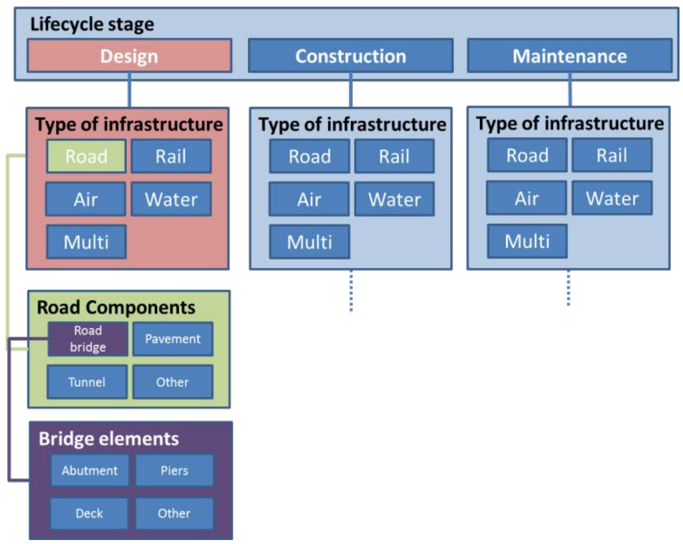


Figure 1: Hierarchical taxonomic scheme for the REFINET taxonomy

This document needs to follow a pragmatic approach, in which practitioners (with a main focus in the industry that designs-builds-maintains the infrastructure) can easily search for information and advice on specific practices. This is the other reason why the classification is organised hierarchically in this way, because industry experts are familiar with the proposed structure.

Other forms of classification of the transport infrastructure are possible and equally valid. For instance, it could have been decided to use a classification based on Processes (design, construction and maintenance processes) and Operations (governance or others). However, the fact that the proposed taxonomy directly links the best practices to the physical tangible assets of the infrastructure gives added value in the view of the authors as it provides a framework that can be easily understood by a majority of readers.

Notice that as explained in the executive summary, the compilation of technologies included in this deliverable cannot be comprehensive given the wide scope of transport infrastructure systems covered in the REFINET project and also because of the hierarchical structure of the taxonomic scheme proposed. However, for the purpose of the future work after REFINET, the template fits the need of the Infrastructure and Mobility Committee of the ECTP and that of the Working Group in Infrastructure of ENCORD.

In deciding the format of the template for the collection of best practices and catalogue of technologies, there has been a discussion with the other two CSAs running in parallel to REFINET, FOX and USE-IT, on the fields and format of the template. The template proposed by REFINET in the paragraphs below has also been discussed at Project Meeting #3 in Madrid on December 3rd 2015 and it was agreed that it will be used for REFINET. It does not however exclude cooperation, collaboration or comparison with the information on best practices generated by the other CSAs as in our view the REFINET template includes the information of the USE-IT and FOX template. The REFINET template contains the following fields of data (see Table 1).

Best Practice / Catalogue of Technologies template	
Field	**Description**
Title and Keywords.	Title of the best practice or technology and main keywords
Source of best practice / technology	Organization providing the best practice or technology or other reference to the source (e.g. conference, etc.).
Lifecycle stage	Design, Construction or Maintenance.
Type of infrastructure	Road, Rail, Air, Water, Multi-modal.
Component of infrastructure	Bridge, tunnel, pavement, etc.
Short Description	scenario for application, technology and how is applied, geographical coverage
Success factors	For example, what are the conditions for successful replication.
Constraints	Which are the factors that restrain the application of the best practice (e.g. environmental or weather conditions).
Main impacts	For instance economic or environmental benefits, advantages to users, increased safety, reduction of disturbance, etc.
Maturity and degree of implementation	For example technically feasible, replicable, adaptable.
Key Performance Indicators	Indicators according to the definition of the RMMTI model that help to assess the efficiency of the described practice.
Further information	Links, references and / or contact details for further information.

Table 1: Template and field description for the REFINET best practices and catalogue and of technologies collection

4. Summary of technologies

The technologies identified from the sources listed in Section 2 have been collated and categorised into a catalogue of technologies (See Appendix A). The technologies that have been identified cover a broad range of the Technology Readiness Level (TRL) spectrum, and broadly fall into the following categories:

- ***Digital engineering for design and construction***, encompassing next generation Building Information Modelling, remote sensing, virtual reality and augmented reality for more efficient and effective construction.

- ***Digital infrastructure condition monitoring***, encompassing smart monitoring and data analytics techniques that are particularly prevalent in the case of renovation and management of existing transport infrastructure assets.

- ***Immersive & augmented reality,*** including technologies for enhanced visual and audio engagement in both concept design and asset management. Also used in crowd-sourcing design feedback and stakeholder engagement for major projects.

- ***Internet of Things (IoT) technologies***, including vehicle to infrastructure (V2I) technologies

- ***Nanotechnologies and composites,*** including paints and other surface coatings as well as Fibre Reinforced Polymers (FPRs)

- ***Self-healing materials***, such as biologically enhanced concrete.

- ***Drones and satellite applications,*** which are already widely used currently and the technologies are fast developing – providing ever greater resolution and accuracy of data, for use in design, construction and ongoing monitoring and maintenance.

- ***3D printing****,* including a full scale test of robotic-led 3D printing of a bridge in Amsterdam.

Figure 2 shows the proportion of technologies identified across lifecycle stages, while Figure 3 shows the proportion across different transport modes.

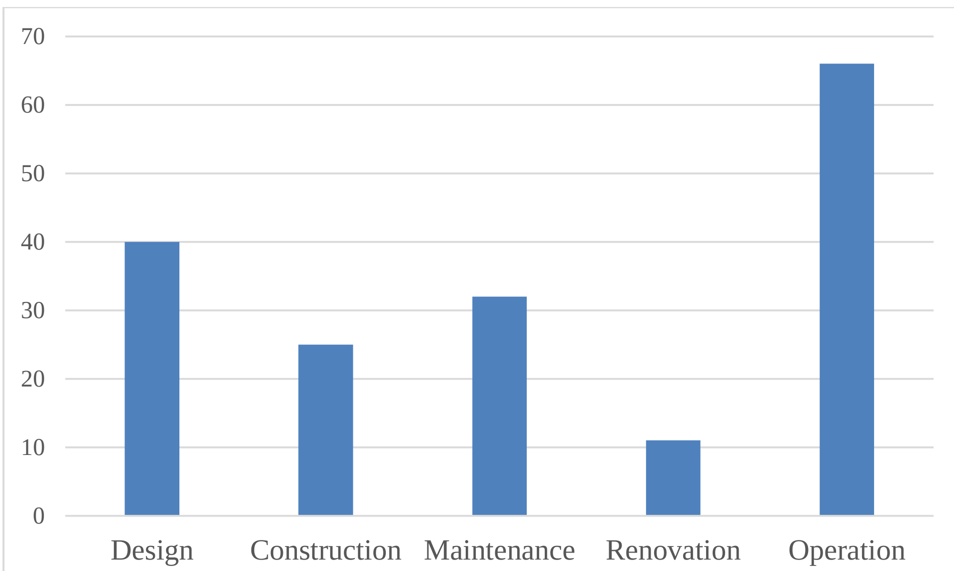


Figure 2. Proportion of technologies attributed to different life cycle stages

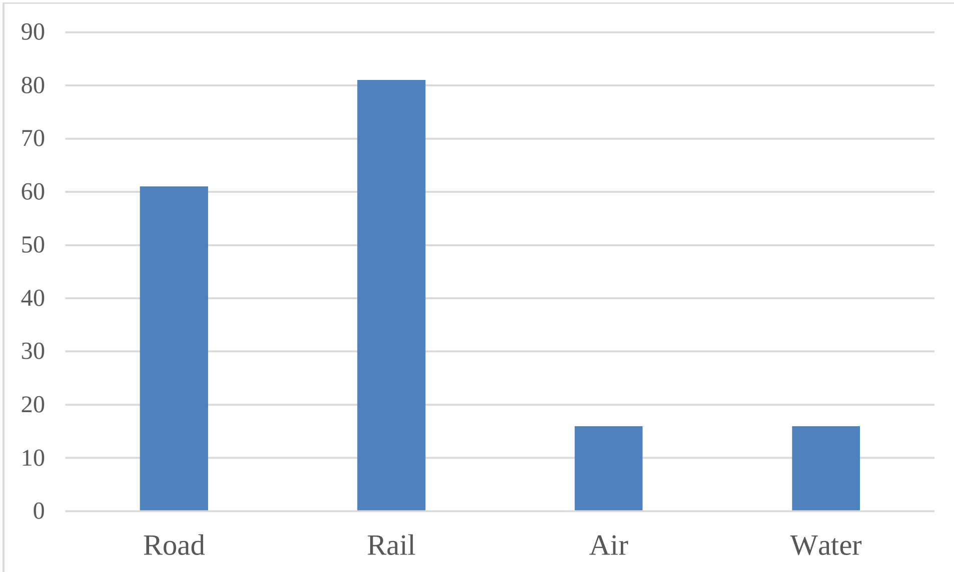


Figure 3. Proportion of technologies attributed to different transport modes

Figure 4 shows that the technologies identified to date are predominantly those that are near-to-market and being trialled by transport operators, contractors and designers across Europe and internationally. It also shows that there is a good spread of more emerging technologies, from both within the sector and outside, including those being developed as a result of European funded research and development through FP7 and Horizon 2020.

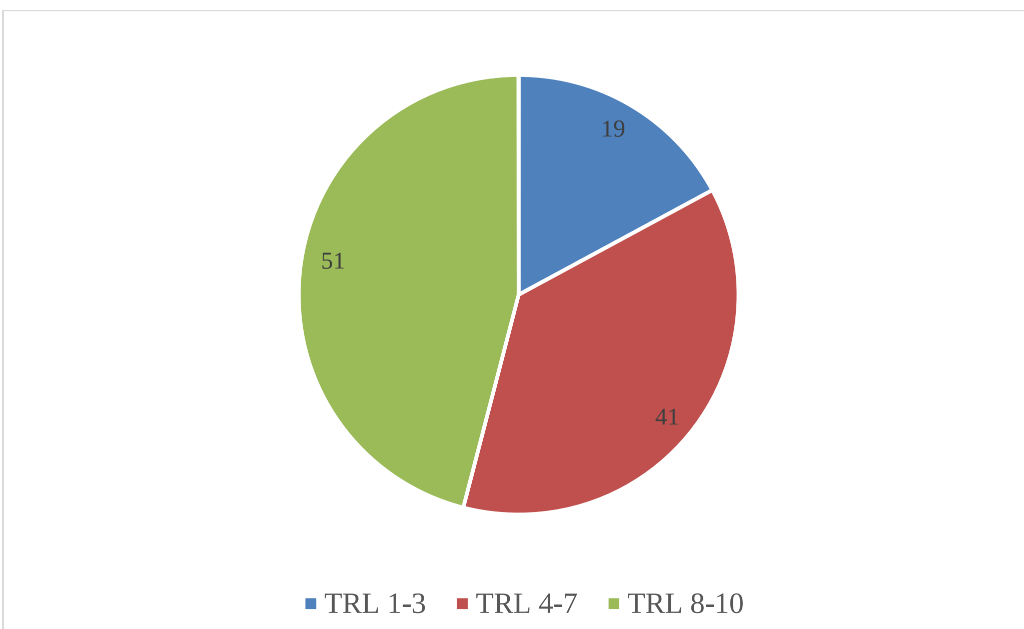


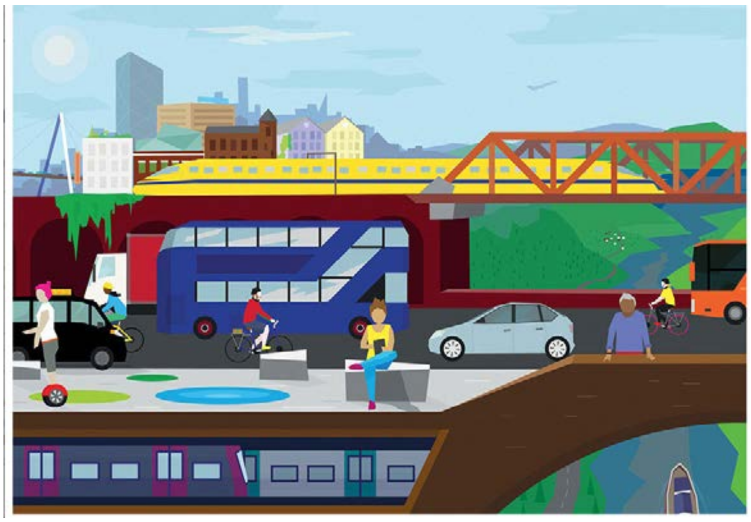
Figure 4. Proportion of technologies attributed to different TRL levels

The subsequent sections of this report capture a selection of the technologies identified in the catalogue (Appendix A), and structured using the taxonomy previously identified.

5. Technologies for Design

5.1 Type of infrastructure: Multi-modal

Best Practice / Technology REF: T001



Field	Description
Title and Keywords	Title: **oneTRANSPORT - harnessing V2I data and Internet of Things technologies**
Source of best practice / technology	Innovate UK-funded oneTRANSPORT project with Arup-led consortium, plus Interdigital Europe, Buckinghamshire County Council, Clearview Traffic Group, Hertfordshire County Council, Highways England, Imperial College London, Northamptonshire County Council, Oxfordshire County Council, Traak Systems, World Sensing
Lifecycle stage	Design and operation
Type of infrastructure	Multi-modal
Component of infrastructure	ITS infrastructure
Element of the infrastructure	
Short Description	The oneTRANSPORT project, in part funded by Innovate UK, aims to enable the smart application of data by addressing the existing challenges in transportation systems by using Internet of Things (IoT) technology in an open and transparent manner. As part of the consortium behind the project, Arup is providing smart mobility advice as well as industry promotion and facilitation. It is a framework that ensures transport and travel services are integral with the 'smart cities' agenda. Uses IoT technology to share existing transport data to enable expert

	developers and analytics communities to develop new public information services and tools. The result are advanced, new travel apps, developed and delivered by the market similar to TfL Journey Planner or CityMapper, but at a fraction of the cost. The project aims to enable multimodal transport information, such as live information about rail delays, traffic jams, or disruption to be easily published by data owners (e.g. transport authorities and third parties) through personalised services. Once published this data can be accessed nationally by transport authorities, application developers and others to develop new services to create better journeys for passengers.
Success factors	The business model has shown payback in 2-3 years, and the 'publish once, license to many' approach for sharing transport operators' premium data overcomes the lack of local authority staff experienced with data licensing, and economies of scale drives reduced costs over time.
Constraints	Standardisation across national and international authorities
Main impacts	The project will bring about improved travel experiences for customers and generate new revenues for local authorities on a truly nationwide basis. Further benefits will include reduced vehicle emissions, fuel usage and traveller frustration through decreased congestion and avoidance of unnecessary journeys. Ultimately delivering a better transport experience for users and a better digital built environment for everyone affected by transport networks.
Maturity and degree of implementation	TRL 5-6
Key Performance Indicators	Improved travel experiences, reduced vehicle emissions, fuel usage and decreased congestion.
Further information	http://www.interdigital.com/data_sheets/oneTRANSPORT

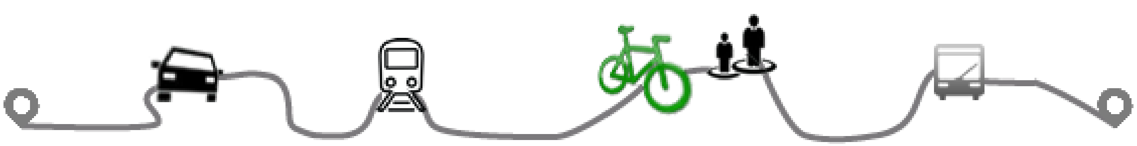
Best Practice / Technology REF: T023

Field	Description
Title and Keywords	Title: **UAV for site mapping to inform design and construction**
Source of best practice /	DJI, Pix4D, Arup, Hong Kong Polytechnic University

technology	
Lifecycle stage	Design
Type of infrastructure	Road / Multi-modal
Component of infrastructure	All
Element of the infrastructure	
Short Description	This project developed unmanned aerial vehicles (UAVs) and digital mapping systems that enable engineering teams to accurately obtain site information. This includes 3D modelling, site surveys, and environmental conditions such as solar and thermal mapping. This is an innovative method of capturing photos and data using high-quality cameras and sensors launched from drones. The drones can fly above and below difficult sites such as tall buildings, bridges, chimneys, disaster zones, and steep hills. The drones can quickly scan a project site, obtain 3D terrain point data, and translate this into digital models for 3D printing. Collected image data improves the quality of a project in the early stages, and also helps to monitor progress during construction and maintenance. There are profound implications for project quality and business development opportunities. This approach is widely applicable to planning, architecture, traffic, structure, environmental, geotechnical, building physics, and façade teams. UAVs bypass traditional CAD models, and project staff no longer have to rely on limited GIS data or outdated satellite images. Instead, a myriad of data can be obtained and processed within a week. Projects using UAVs have more efficient onsite inspection procedures and building operations, reduced construction safety risks, and save time on procedures such as labour-intensive documentation and surveys. The research team also developed a web-based platform to record UAV 3D models, environmental data and 4D construction sequence models.
Success factors	A UAV can be used on several projects as a cost-effective alternative to aerial photos. It can reduce mistakes and redundancies by providing construction site information to all collaborators. UAVs can fly through and inspect unreachable locations, such as tall chimneys and the undersides of bridges. DJI's iPad ground station enables us to quickly set up a waypoint system for smooth control and fly safely in a predefined path, showcasing UAV flexible data capture.
Constraints	
Main impacts	The UAV is a multidisciplinary tool, providing engineers and designers with state-of-the-art data. UAVs are versatile, and can be integrated into disciplines such as construction monitoring, smart city data capture, environmental survey, traffic monitoring, and creating GIS data for planners. In turn, this helps to enhance and validate Arup's work. With UAVs, less reliance is placed on incomplete or outdated data. UAV and the digital mapping system enables us to obtain digital terrain models at a very early stage and deliver relevant studies such as 3D modelling and site environmental

	studies such as CFD, solar, and thermal. The UAV can be also used for environmental measurements such as terrain analysis, temperature, humidity, CO2, and PM2.5 levels, as well as CFD modelling and simulation.
Maturity and degree of implementation	TRL 8-10 The research team is continuing their collaboration with DJI and Pix4D, testing and integrating the next series of developer-based drones. Working with Hong Kong Polytechnic University, the team is measuring the accuracy of our environmental sensors mounted on both propeller-based drones and aerodynamic drones. The team is also documenting detailed historic monuments as the next stage of enhanced 3D modelling with BIM.
Key Performance Indicators	Reduced time for site mapping
Further information	http://v.youku.com/v_show/id_XOTUwMDA5NDg4_type_99.html?from=s1.8-1-2.999&f=442199813&sf=10202

Best Practice / Technology REF: T026



Field	Description
Title and Keywords	Title: **Efficient Urban Interchangers – The City-Hub Model**
Source of best practice / technology	Technical University of Madrid – Transport Research Centre (UPM/TRANSyT), acting as project coordinator, the Institute for Transport Sciences – Non profit Ltd. (KTI), the Institute of Transport Economics (TOI), the Centre for Research and Technology

	Hellas (CERTH) – Institute of Transport, Panteia/NEA, the Transport Research Laboratory (TRL), the Technical Research Centre of Finland (VTT), the Institut français des sciences et technologies des tran, Arup
Lifecycle stage	Design
Type of infrastructure	Multi-modal
Component of infrastructure	
Element of the infrastructure	
Short Description	Urban transport interchanges play a key role as part of public transport networks, facilitating the links between public transportation modes, such as the connection between bus and subway or metropolitan railway. Time saving, urban integration, better use of waiting time and improvement of operational business models are some of the benefits that result from the development of efficient urban interchanges, which aim at: • Facilitating the users' transfer between two or more public transport modes. • Coordinating public transport services through the provision of information services at the interchange facilities. • Using urban space in an efficient way. However, although urban transport interchanges are crucial for the improvement of accessibility, there are still problems, gaps or bottlenecks, which are mainly indicated in the coordination among different modes and the use of information systems and management models. Towards this direction, the City-HUB project, bringing together leading experts of design and urban integration, transport operation and business, local and regional authorities and end-users organizations, aims at contributing to the design and operation of seamless, smart, clean and safe intermodal public transport systems. At the same time, the project investigates how these interchanges should be designed in order to ensure that "vulnerable" target groups, i.e. the elderly, youth, physically and mentally handicapped people can adequately benefit from these interchanges. The objectives of the project are: • To test and validate the City-HUB model for the improvement of integrated management approaches to intermodality, monitoring and operations across European countries. • To achieve efficient urban interchanges, reducing their carbon footprint, maximizing the value of new technologies for mobility, communications and virtual travel, reducing accidents and encouraging healthier lifestyles. • To achieve the widespread implementation of integrated mobility policies for all – providing more opportunities for citizens to access jobs, healthcare, education and training, retail opportunities as well as leisure facilities. • To achieve widespread acceptance of public transport planning that meets social, environmental and mobility efficiency criteria in the most economical and effective way. • To make a full contribution to the development of intermodality standards,

	minimum requirements, quality management, benchmark examples and public transport service level in Europe
Success factors	Five pilot case studies have been selected and will be studied in order to identify best practices, barriers and areas of improvement related with ITS solutions, efficient design and planning, and integrated management: • Moncloa interchange, Madrid, Spain • Ilford railway station, Redbridge, London, United Kingdom • New railway station, Thessaloniki, Greece • Kamppi terminal, Helsinki, Finland • Kőbánya-Kispest, Hungary The solutions that the project will propose for effective and smart design and integrated management will then be validated through six case studies. The City-HUB model will also be simulated in the specific case studies: • Paseo de Gracia, Barcelona, Spain • Prague terminus Dejvicka, Prague, Czech Republic • Utrecht Central, Utrecht, The Netherlands • Gare Lille Flandres-Europe, Lille, France • Vaterland bus station, Oslo, Norway • Intermodal terminal of Miskolc, Hungary
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Faster journey time, reduced carbon footprint
Further information	http://www.cityhub-project.eu/

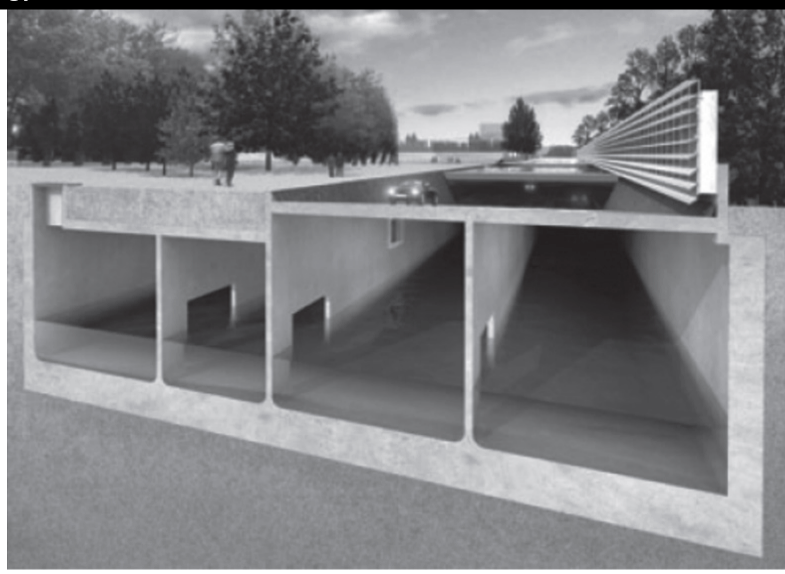
Best Practice / Technology REF: T032

Field	Description
Title and Keywords	Title: **Crowd-sourced design of multi-modal hubs using digital models and**

	augmented reality
Source of best practice / technology	Arup, MTR
Lifecycle stage	Design
Type of infrastructure	Multi-modal
Component of infrastructure	Railway stations, Bus depots, Airports, Ports
Element of the infrastructure	
Short Description	Changing a sign in a major transport hub can incur substantial financial costs, but the human cost of not getting it right is far greater. From passengers at stations looking for the 'exit' signs in an emergency; to travellers at airport terminals finding their gate, signs should lead us from A to B quickly, safely and easily. Planning, modelling then testing journeys in complex virtual environments gives us a better understanding of how people navigate spaces, where they look for signs, and which signs work best. A good wayfinding system is intuitive and acts as a visual and cognitive reassurance of the user's needs. This wayfinding is brought to life through real-time synthetic environments, a 3D gaming technology. Designs and signage can be explored and tested at an early stage of the project lifecycle, ensuring the correct level of information is available to the user throughout their journey. Architects and developers are able to review proposed designs in greater detail, viewing surface texture, changes in lighting and integration with other technologies. For example, SoundLab has been used to enhance this experience further, showing how tannoy systems will work in different areas of the design. The technology allows us to take a holistic and user-centric approach to the design. Once a building has been created in 3D, users sit in front of a bank of monitors and use a joystick to navigate the space. They are encouraged to test out a simulated route with only virtual signs to guide them. It allows hundreds or thousands of real people to have input into the design. The technology captures huge amounts of data, including user journeys and points of view from different eye levels. Crowdsourcing this data, ultimately helps clients ensure their buildings and public spaces will be easily navigable and helps identify where wayfinding solutions should be improved, well before a single sign is put in place.
Success factors	Real-time synthetic environments is fundamental to changes at Hong Kong's Admiralty Underground Station. With more than 800,000 passengers passing through every day, it is one of the busiest stations in the world. In 2009, Arup was commissioned to work on an extension doubling its size from four to eight platforms. Synthetic environment technology was used to test 970 signs at various phases of the project's development, to minimise costly and disruptive changes to wayfinding and CCTV installations at a later date. In total, 235 potential issues were identified and 145 signs were changed.

	Real-time synthetic environments harnesses the power of countless simulations and virtual explorations to optimise journeys of the future before a single brick has been laid or sign installed.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced cost for design and operation
Further information	http://www.arup.com/synthetic_environments

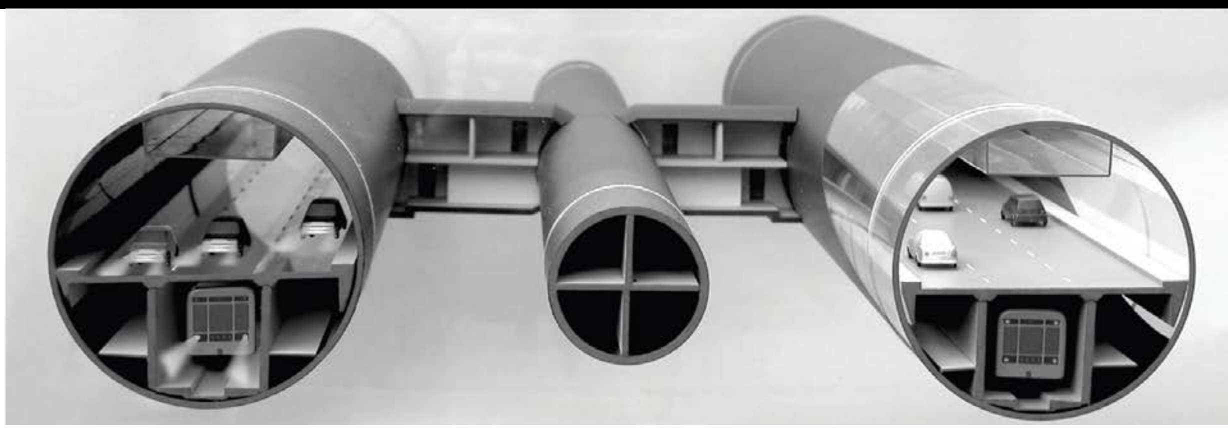
Best Practice / Technology REF: T066



Field	Description
Title and Keywords	Sustainable urbanization through underground development: towards an urban underground future
Source of best practice / technology	ITACUS & Amberg Engineering AG ITACUS & Enprodes Management Consultance BV
Lifecycle stage	Design
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	More and more cities are looking to their underground spaces for relief as the resource land is being used up at alarming rates. Efforts are made to contain the sprawl of cities and to densify further in already built-up areas. Underground space suddenly becomes an interesting alternative leading to often very positive developments.
Success factors	
Constraints	
Main impacts	

Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

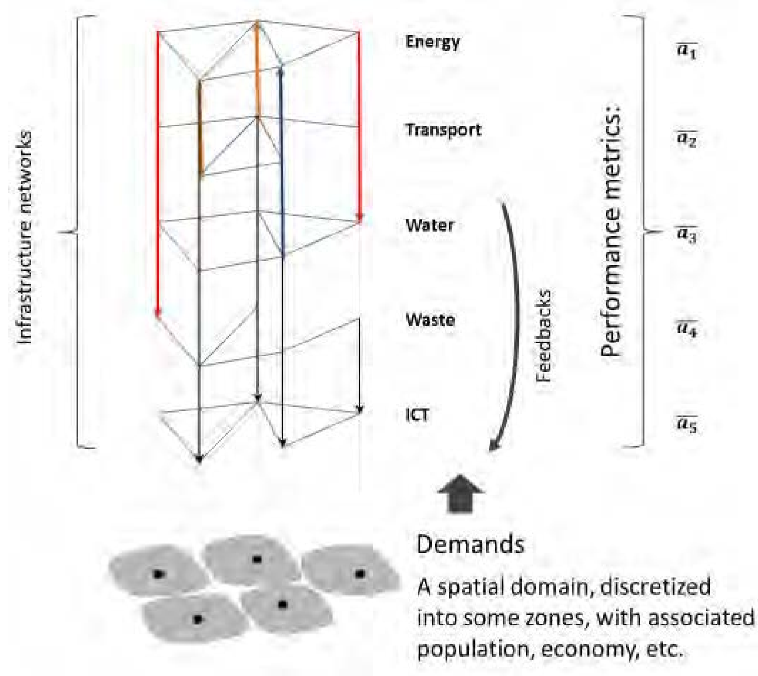
Best Practice / Technology REF: T067



Field	Description
Title and Keywords	Design of tunnels for combined traffic motor transport and metro KEYWORDS: tunnel, metro, automobile transport, service adits.
Source of best practice / technology	Design Institute “Metrogiprotrans”
Lifecycle stage	Design
Type of infrastructure	Road / Rail / multimodal
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	A new layout and arrangement decision required development of the innovative systems of ventilation, water and smoke removal. For this purpose, a service tunnel, 6 m in diameter, was constructed between the transport tunnels, connected with the transport tunnels by five cross adits which provided all necessary support systems (see Figure 1). Construction of the connecting adits was carried out by the rock tunneling method either with ground freezing or ground stabilization by means of injection of cement – bentonite solutions. For division of the traffic flows, a roadway slab was constructed inside the tunnel. The uniqueness of the frame required a detailed research including mathematical modeling and in place testing.
Success factors	
Constraints	
Main impacts	Construction of tunnels with two level traffic for automobile transport and metro trains provides high traffic capacity due to more effective use of the internal space. At the same time the costs related with construction of the two double level tunnels and a service tunnel are considerably lower than of the four one-level tunnels: for automobile and for metro rail traffic. Developed for the combined traffic effective ventilation systems, water and smoke

	removal systems as well as other systems ensure safe and reliable operation and quick evacuation of passengers in case of emergency.
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	High traffic capacity, effective use of internal space, reduced costs,
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T087



Field	Description
Title and Keywords	MISTRAL: Multi-scale Infrastructure Systems Analytics
Source of best practice / technology	Acciona Analysys Mason Limited (UK) ARCC Arup Group Ltd Atkins Black & Veatch BP Broadband Stakeholder Group CH2M HILL Committee on Climate Change Costain Department for Transport Department of Energy and Climate Change Energy Research Partnership ERP Environment Agency (Grouped) European Investment Bank Future Cities Catapult Greater London Authority GTE Carbon Improbable Worlds Ltd Infrastructure Ops Adaptation Forum Infrastructure UK Institution of Civil Engineers Institution of Mechanical Engineers JBA Trust KPMG Lloyd's Register Microsoft Mohammed Bin Rashid al Maktoum Foundatio National Grid Network Rail Newcastle City Council Northumbrian Water Ltd OECD Ofcom Ordnance Survey RWE Power International Satellite Applications Catapult Shell Siemens SITA TechUK Thames Water Plc The Core Cities group Transport for Greater Manchester

	Transport for London Transport Systems Catapult UK Power Networks United Nations Office for Project Servic University of Oxford Volterra Partners LLP Willis Group Ltd Zurich Global Corporate UK
Lifecycle stage	Design, Operation & Maintenance
Type of infrastructure	Multimodal
Component of infrastructure	
Element of the infrastructure	
Short Description	The UK Infrastructure Transitions Research Consortium (ITRC) is a consortium of seven UK universities, led by the University of Oxford, which has developed unique capability in infrastructure systems analysis, modelling and decision making. Thanks to an EPSRC Programme Grant (2011-2015) the ITRC has developed and demonstrated the world's first family of national infrastructure system models (NISMOD) for analysis and long-term planning of interdependent infrastructure systems. The research is already beng used by utility companies, engineering consultants, the Institution of Civil Engineers and many parts of the UK government, to analyse risks and inform billions of pounds worth of better infrastructure decisions. Infrastructure UK is now using NISMOD to analyse the National Infrastructure Plan.
Success factors	The aim of MISTRAL is to develop and demonstrate a highly integrated analytics capability to inform strategic infrastructure decision making across scales, from local to global. MISTRAL will thereby radically extend infrastructure systems analysis capability: - Downscale: from ITRC's pioneering representation of national networks to the UK's 25.7 million households and 5.2 million businesses, representing the infrastructure services they demand and the multi-scale networks through which these services are delivered. - Upscale: from the national perspective to incorporate global interconnections via telecommunications, transport and energy networks. - Across-scale: to other national settings outside the UK, where infrastructure needs are greatest and where systems analysis represents a huge business opportunity for UK engineering firms.
Constraints	
Main impacts	These research challenges urgently need to be tackled because infrastructure systems are interconnected across scales and prolific technological innovation is now occurring that will exploit, or may threaten, that interconnectedness. MISTRAL will push the frontiers of system research in order to quantify these opportunities and risks, providing the evidence needed to plan, invest in and design modern, sustainable and resilient infrastructure services.
Maturity and degree of implementation	1-3 (Research level) 3-7 (Technology development & demonstration) *"Five years ago, proposing theory, methodology and network models that stretched from the household to the globe, and from the UK to different national contexts would not have been credible. Now the opportunity for multi-scale modelling is coming into sight, and ITRC, perhaps uniquely, has the capacity and ambition to take on that challenge in the MISTRAL programme."*
Key Performance Indicators	Cost savings
Further information	*http://www.itrc.org.uk/about-itrc/itrc-awarded-funding-for-major-new-programme-mistral/*

	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N017064/1

5.2 Type of infrastructure: Road

Best Practice / Technology REF: T002

Field	Description
Title and Keywords	Title: **Wireless induction charging for buses**
Source of best practice / technology	The trial will be managed by Mitsui-Arup joint venture MBK Arup Sustainable Projects (MASP). Other collaborators are eFleet Integrated Service Ltd (eFIS), Milton Keynes Borough Council, Arriva, The University of Cambridge, Scottish & Southern Energy, Wrightbus Limited, IPT-Technology, Western Power Distribution, Chargemaster Plc
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Wireless electric charging
Short Description	The buses will run for five years in a carefully monitored demonstration programme, which will objectively assess their technical and commercial viability. The trial has been planned and will be managed by Mitsui-Arup joint venture MBK Arup Sustainable Projects (MASP). Eight electric buses will take over a route that even diesel buses find demanding: running 17 hours a day, seven days a week, with each bus covering over 56,000 miles per year. However, the Milton Keynes buses have a special technological advantage to help them meet the rigours of their route: wireless charging. Instead of plugging into the mains, the new buses will be able to recharge their batteries wirelessly during their working day. This means they can run a continuous service for a whole 17 hours, just like a diesel bus. The concept is simple: wireless

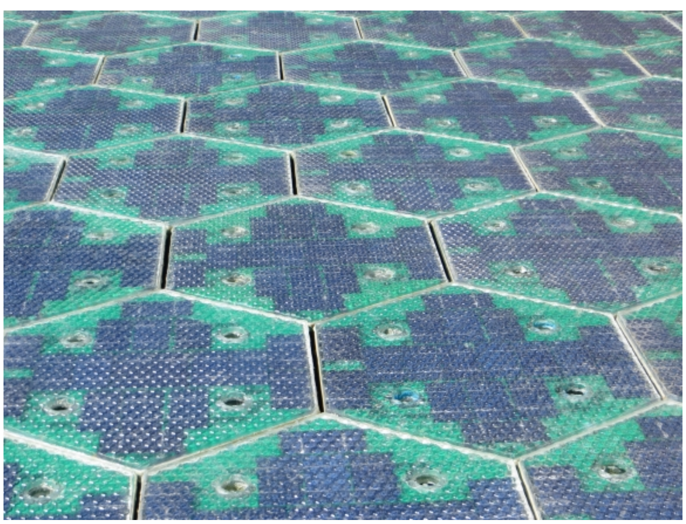
	charging plates set into the road transfer power directly to receiving plates underneath the bus, using a technique based on the principles of electrical induction. In just 10 minutes, a bus parked over a charging point will replenish two-thirds of the energy consumed on its 15-mile route. Only two wireless charging points are needed to service all eight buses, which will charge in the time scheduled for driver breaks.
Success factors	The eight electric buses have important environmental benefits: they will remove approximately five tonnes of particulates and noxious tailpipe emissions from the city's streets each year and approximately 270 tonnes of CO2 per year from the atmosphere. As the UK electricity supply becomes greener in future years, the CO2 savings from the continuing operation of electric buses on this route could increase to more than 680 tonnes per year.
Constraints	Snow and other loading on the induction pads. Overheating of the induction pads.
Main impacts	The ultimate aim of eFIS is to use the data collected by the Milton Keynes trial to demonstrate the technical and economic viability of low-carbon public transport. This data could be used to kick-start electric bus projects in other towns and cities worldwide.
Maturity and degree of implementation	TRL 5-6
Key Performance Indicators	Carbon emission savings, and reduction in air pollutants.
Further information	http://www.arup.com/News/2014_01_January/09_January_Worlds_most_demanding_electric_bus_route_launched.aspx

Best Practice / Technology REF: T004

Field	Description
Title and Keywords	Title: **Energy harvesting road surface prototype**
Source of best practice / technology	Energy Intelligence, Greentown Labs Incubator, USA.
Lifecycle stage	Design
Type of infrastructure	Road

Component of infrastructure	Pavement
Element of the infrastructure	Motion-pad
Short Description	Energy Intelligence have developed technology that generates clean energy at high-traffic locations from the motion of vehicles. It's an ultra-compact system that lays flat on top of the road where vehicles are required to slow down. When cars drive over, they compress embedded hydraulic channels, generating electricity to power nearby equipment such as traffic signals and other devices that require relatively low levels of power.
Success factors	Each system generates 250W - 2kW and takes equipment 'off the grid'. The modular design means multiple systems can be connected in series to form larger units and scale the output. Embedded sensors collect data for customer dashboards and reporting through data analytics, and each system is WiFi enabled for remote monitoring and data collection. The company website claims payback of upfront capital expenditures in as little as 6 months.
Constraints	Need for integration with pavement design and ongoing asset management to ensure adequate drainage and skid resistance of equipment and to avoid potholing around system.
Main impacts	Energy generation to power nearby equipment
Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	kJ of energy generated
Further information	http://www.energyintel.us/#/

Best Practice / Technology REF: T020



Field	**Description**
Title and Keywords	Title: **Solar roadways**
Source of best practice / technology	Solar roadways

Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	
Short Description	Solar Roadways® (SR) is a modular system of specially engineered solar panels that can be walked and driven upon. The panels contain LED lights to create lines and signage without paint. They contain heating elements to prevent snow and ice accumulation. The panels have microprocessors, which makes them intelligent. This allows the panels to communicate with each other, a central control station, and vehicles. The panels are made of specifically formulated tempered glass, which can support the weight of semi-trucks. The glass has a tractioned surface which is equivalent to asphalt. Eventually the SR panels will be available for highways, but first will come non-critical applications such as driveways and parking lots. Two funding contracts have been completed with the U.S. Department of Transportation, and a new contract was awarded in November 2015. Then people from all over the world decided to help speed the development progress via an Indiegogo crowdfunding campaign.
Success factors	The goal of Solar Roadways is to modernise infrastructure with modular, intelligent panels, while producing clean renewable energy for homes and businesses.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	kJ energy generation
Further information	http://www.solarroadways.com/

Best Practice / Technology REF: T021

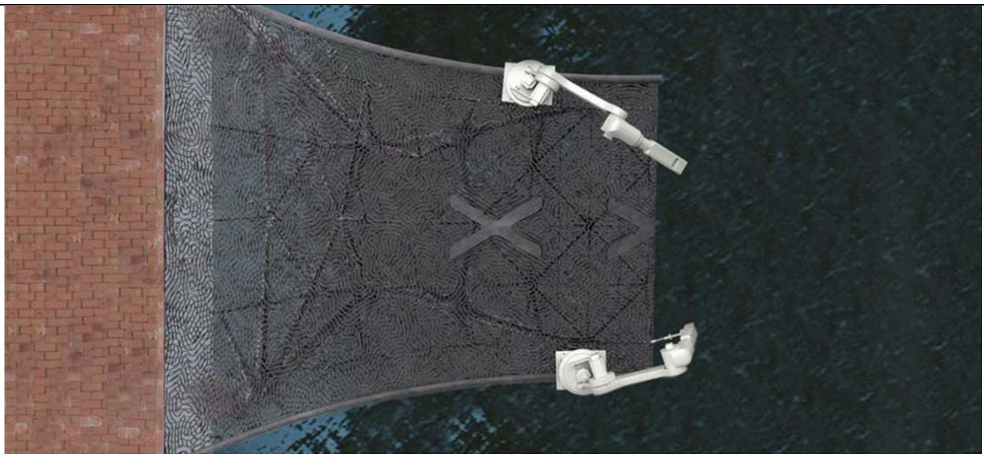
Field	Description
Title and Keywords	Title: **Automated underground bicycle storage**
Source of best practice / technology	Giken
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Sub-surface
Element of the infrastructure	
Short Description	Eco-cycle is an anti-seismic mechanical underground parking lot. Giken, based in Japan, aggregated their own long term experience of press-in technologies and developed the Eco-cycle with the design concept of "Culture Aboveground, Function Underground". If bicycle parking is available near final destination, people use the facility more often. It eventually eliminates nuisance parking at footpath. Such space at footpath can be utilised for cultural activities. One ECO Cycle unit was Installed in "Mikawadai Park", which is a city park in Roppongi, Minato-ku, Tokyo. High expectations are placed on this to be a mechanical underground bicycle parking space that suits the internationally recognised district of Roppongi. This is the second case for ECO Cycle being operated as a public bicycle parking space in Minato-ku, the first being the bicycle parking space in Konan Star Park in front of Shinagawa Station.
Success factors	• Land-saving and compact design • Indispesable items for aesthetic urban development • user-friendly and high security system • fast operation • low running cost • simple design for short construction duration
Constraints	
Main impacts	

Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduction in congestion and opening up of surface space for other uses.
Further information	https://www.giken.com/en/developments/eco_cycle/

Best Practice / Technology REF: T022	
	
Field	**Description**
Title and Keywords	Title: **Self-healing concrete surfaces for highway pavement refurbishment**
Source of best practice / technology	Cardiff University-led Materials 4 Life (MFL) project with Costain, University of Bath and University of Cambridge
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	
Short Description	A University-led project is testing ways of automatically repairing concrete without human intervention. The first major trial of self-healing concrete in the UK, led by a team of researchers from Cardiff University, is being undertaken at a site in the South Wales Valleys. The project, entitled Materials for Life (M4L), is piloting three separate concrete-healing technologies for the first time in real-world settings, with a view to incorporating them into a single system that could be used to automatically repair concrete in the built environment. At present, billions of pounds are spent every year maintaining, fixing and restoring structures such as bridges, buildings, tunnels and roads. It is estimated that around £40 billion a year is spent in the UK on the repair and maintenance of structures, the majority of which are made from concrete. The overall aim of the Cardiff-led project is to develop a single system that can be embedded into concrete when it is initially set, and then automatically sense when damage occurs. Once damage is detected, the system will be able to repair itself autonomously without the need for human intervention.

	The trial is being undertaken in collaboration with one of the major industrial partners on the project, Costain, and is taking place at one of their construction sites on the Heads of the Valleys road improvement scheme in South Wales – the A465. The research team, which also includes academics from the University of Bath and the University of Cambridge, is trialling three separate technologies at the site. The first technique uses shape-shifting materials, known as shape-memory polymers, to repair large cracks in concrete. When these materials are heated with a small current, they can transform into a different shape that the material has 'memorised'. The researchers believe that these materials can be embedded into concrete and used to close cracks or make them smaller. In the second technique, researchers will pump both organic and inorganic healing agents through a network of thin tunnels in the concrete to help repair damage. In the third technique, the team will embed tiny capsules, or lightweight aggregates, containing both bacteria and healing agents into the concrete. It is anticipated that once cracks occur, these capsules will release their cargos and, in the case of the bacteria, the nutrients that will enable them to function and produce calcium carbonate, which the researchers envisage will heal the cracks in the concrete. The researchers have cast six concrete walls at the test site, each containing the different technologies. Over time the team will load the concrete at specific angles to induce cracks, and then monitor how effective each of the self-healing techniques is.
Success factors	These self-healing materials and intelligent structures will significantly enhance durability, improve safety and reduce the extremely high maintenance costs that are spent each year.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	Improved safety, reduced costs
Further information	http://www.cardiff.ac.uk/news/view/152733-uks-first-trial-of-self-healing-concrete

Best Practice / Technology REF: T027



Field	Description
Title and Keywords	Title: **3D printing bridges**
Source of best practice / technology	MX3D, Autodesk, Heijmans, Arcelor Mittal, Air Liquide sponsors, ABB robotics, STV, Delcam, Within, Lenovo, TU Delft, AMS, Amsterdam City Council
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Bridge
Element of the infrastructure	Bridge deck
Short Description	MX3D and their partners are are going to 3D print a fully functional, intricate steel bridge over water in the center of Amsterdam to showcase their revolutionary technology. MX3D equips industrial multi-axis robots with 3D tools and develops the software to control them. This allows us to 3D print strong, complex and gracious structures out of sustainable material – from large bridges to small parts. MX3D research and develop groundbreaking, cost-effective robotic technology with which can be produced 3D print beautiful, functional objects in almost any form. Since October 2015 this project officially kicked off by opening our workspace by Alderman and Deputy of Amsterdam, Mayor Kajsa Ollongren. She also and announced that the printed bridge will be installed across the Oudezijds Achterburgwal canal.
Success factors	
Constraints	Structural integrity and meeting structural design codes
Main impacts	Flexibility in design
Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	
Further information	http://mx3d.com/projects/bridge/

Best Practice / Technology REF: T037

Field	Description
Title and Keywords	Title: **Innovative highway intersection and interchange geometrics**
Source of best practice / technology	Federal Highway Administration, USA
Lifecycle stage	Design
Type of infrastructure	Road / Rail
Component of infrastructure	Pavement / Track alignment
Element of the infrastructure	
Short Description	Intersections and interchanges are planned points of conflict where motorists, pedestrians and bicyclists cross paths or change direction. This inherently creates conditions that could result in a crash. The Federal Highway Administration reports that over 20 percent of the 33,808 roadway fatalities in 2009 were intersection or intersection-related, and that that relationship of total fatalities to intersection or intersection-related ones has not changed greatly in the last 25 years. As part of the ongoing effort to improve the safety performance of all roads, the Federal Highway Administration (FHWA) encourages State Departments of Transportation (DOTs) to consider alternative geometric intersection and interchange designs, which are specifically designed to reduce or alter conflict points, allowing for safer travel for motorists, pedestrians and bicyclists. Past and ongoing FHWA studies of various alternative intersection and interchange designs implemented within the last few years document the magnitude of both safety and operational improvements. Roundabouts, diverging diamond interchanges (DDIs) and intersections with displaced left-turns or variations on U-turns are proving to be a few of the effective alternatives to traditional designs. The DDI enhances and simplifies the operation of the intersections at a diamond-style interchange by removing from the signalized intersection the turns on to and off of the ramps. This is accomplished by moving traffic to the left side of the roadway between the ramp terminals. The DDI design reduces the number of perpendicular conflict points as compared to an equivalent conventional diamond layout.
Success factors	The geometric patterns of these alternative forms may appear to be complex

	designs; however, evaluation and observation show that users do find them easy to navigate. The primary benefit to these designs are enhanced safety performance through fewer or less severe crashes, but operational improvements have also been found, through overall reduced delay and less time spent stopped at red lights. The benefits associated with alternative intersections and interchanges are not limited only to the agencies that construct them. Improved safety and reduced congestion can provide direct and indirect economic benefits to businesses and communities. The economic benefits combined with improved safety, mobility and maintained access to properties near intersections and interchanges will contribute to an enhanced quality of life in communities where the alternative designs are implemented.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Improved safety, increased mobility
Further information	https://www.fhwa.dot.gov/innovation/everydaycounts/edc-2/geometrics.cfm

Best Practice / Technology REF: T068	
Field	**Description**
Title and Keywords	A case study of Virtual Design and Construction and BIM in the Stockholm bypass, Europe's largest road tunnel project KEYWORDS: tunnel, VDC, BIM, models, requirements, review.
Source of best practice / technology	Trafikverket
Lifecycle stage	Design / Construction
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	The Stockholm bypass is founded on different types of specific requirements such as functional, economical, environmental requirements and Swedish standards. A database has been set up at the start of the detailed design phase to provide the designers with a consolidated list of requirements. The requirement database is used in combination with Virtual Design and Construction (VDC). Traditional drawings have been replaced as much as possible with building information models (BIMs). Prior to the detailed design, the tunnel system has been broken down into parts that are designed as BIMs. Integrated Concurrent Engineering (ICE) methods enable multiple stakeholders to work collaboratively using models. All design work is hosted by the project's common design platform that is accessible to all project stakeholders. The fulfillment of the design requirements is constantly verified during the design.
Success factors	The advantages of using BIMs in the detailed design are numerous. The quality of

	the produced BIMs and documents is noticeably higher than for a traditional 2D-CAD based design. Models are also used to estimate the quantities. The collaboration between stakeholders during the design has been strongly improved with better and quicker communication.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Time saving, reduced risk, quality assurance
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T073

Field	**Description**
Title and Keywords	Fibre reinforced precast concrete segments: design and applications
Source of best practice / technology	World Tunnel Congress 2014 proceedings
Lifecycle stage	Design / Construction
Type of infrastructure	Road / Rail
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	The use of structural fibre as replacement of the traditional reinforcement in precast concrete segmental linings is a widespread practice. As a matter of fact, more than forty examples of application in tunnels and vertical shafts can be cited. The success of using fibres in this structural elements lies in the mechanical improvements (reduction of the crack width, increasing of the toughness, among others) as well as in economic reasons (reduction of the labour force as well as of the production periods, increasing the efficiency, among others) that could be achieved. In this sense, the main goals of this scientific contribution consist of, on the one hand, presenting and analysing some of the more relevant applications of fibre reinforced precast concrete segmental linings existing up to date and, on the other hand,

	presenting a numeral strategy to optimize the reinforcement in this sort of elements as well as its application to recent real examples already constructed or under construction in the metropolitan area of Barcelona
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

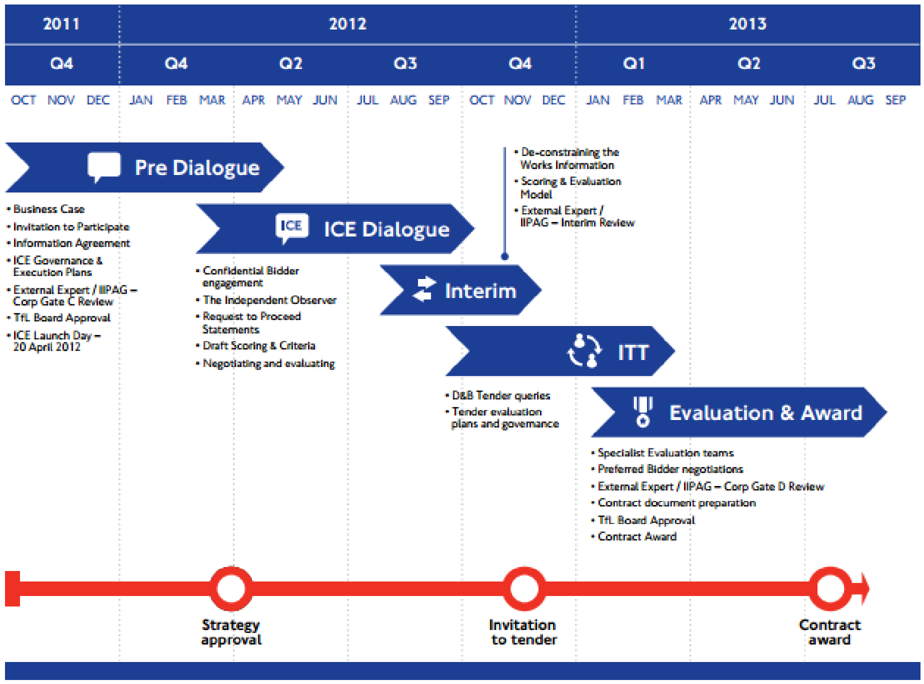
Best Practice / Technology REF: T084

Field	Description
Title and Keywords	Materials for Life (M4L): Biomimetic multi-scale damage immunity for construction materials Keywords: materials, concrete, grouts, mortarts, soil systems
Source of best practice / technology	Cardiff University, United Kingdom (Lead Research Organisation) Alun Griffiths (Contractors) Limited, United Kingdom (Project Partner) URS Infrastructure & Environment UK Ltd (Project Partner) Schlumberger Group, France (Project Partner) Costain Ltd, United Kingdom (Project Partner) Laing O'Rourke plc, United Kingdom (Project Partner) Parsons Brinckerhoff, United States (Project Partner) Arup Group Ltd, United Kingdom (Project Partner) Transport Research Laboratory Ltd, United Kingdom (Project Partner) National Grid PLC, United Kingdom (Project Partner) Atkins UK, United Kingdom (Project Partner) Shell Global Solutions UK, United Kingdom (Project Partner) Mott Macdonald UK Ltd, United Kingdom (Project Partner) BRE Trust, United Kingdom (Project Partner)
Lifecycle stage	Design
Type of infrastructure	Road
Component of infrastructure	Pavement, bridges
Element of the infrastructure	
Short Description	Inspired by nature, the intention of this project is to develop an interdisciplinary, multiscale system utilising a range of technologies to promote and enable self-healing of construction materials over various timescales; in particular, there is a focus on conglomerate materials such as concrete, grouts, mortars, hydraulically bound materials and grouted soil systems. One of the primary outputs of the project will be the

	formation and establishment of a UK Virtual Centre of Excellence in Intelligent Construction Materials that will provide a national and international platform for facilitating dialogue and collaboration to enhance the global knowledge economy. The technologies that are proposed are microbioloical and chemical healing at the micro- and meso-scale and crack control and prevention at the macro scale. This will be achieved through 4 work packages, three of which target the healing at the individual scales (micro/meso/macro) and the fourth which addresses the integration of the individual systems, their compatibility and methods of achieving healing of recurrent damage. This will then culminate in a number of field-trials in partnership with the project industrial collaborators to take this innovation closer to commercialisation.
Success factors	This proposal seeks to develop a multi-faceted self-healing approach that will be applicable to a wide range of conglomerates and their respective damage mechanisms.
Constraints	
Main impacts	The proposed developments are expected to achieve significant reductions in whole-life costings of projects, by significantly reducing maintenance and repair costs; a 15% reduction could amount to over £5 billion/annum. The development of such resilient materials which will significantly enhance and extend the life of structures will lead to significant reductions in the production and use of cements and aggregates and hence will significantly reduce their impacts (~8% of global anthropogenic CO2 emissions from the ~2.8 billion tonnes/year and ~100 million tonnes/year extraction of natural resources for cement and aggregates respectively which also constitute a large proportion of construction and demolition waste of ~20 million tonnes/year).
Maturity and degree of implementation	(1-3) Research Level
Key Performance Indicators	Carbon saving, cost saving,
Further information	*http://gtr.rcuk.ac.uk/project/A3D71EDF-824E-4ECE-9B12-D5DD2A579512* *https://www.youtube.com/watch?v=v0LD5E6QgTo* *http://www.bath.ac.uk/ace/research/cicm/concrete-cements/materials-for-life.html* *http://m4l.engineering.cf.ac.uk/*

5.3 Type of infrastructure: Rail

Best Practice / Technology REF: T016



Field	Description
Title and Keywords	Title: **New approaches in procurement through innovative contractor engagement**
Source of best practice / technology	London Underground (Bank Station upgrade), Dragados
Lifecycle stage	Design / Renovation
Type of infrastructure	Rail / Multi-modal
Component of infrastructure	Tunnel (connection design for urban mobility)
Element of the infrastructure	
Short Description	Infrastructure UK is a unit within the UK Treasury that works on long term infrastructure priorities. Its 2011 Implementation Plan identified components of work including changing the behaviours of industry and clients, using smarter procurement and improving infrastructure data as part of a drive towards an industry which is better placed to invest in developing solutions, skill and capability that can deliver better value. London Underground (LU) is a major owner and operator of public infrastructure and is fully committed to the objectives championed by Infrastructure UK. LU's Tube network is the world's oldest metro, and carries more than one billion passengers a year, on 11 lines serving 270 stations. Passenger demand for the use of its infrastructure has never been higher, and the population of London continues to grow apace. LU has embarked on a major programme to deliver the extra capacity needed to keep pace with rising demand, a £1.3bn a year investment programme which will deliver a 30% upgrade in Tube capacity. It is an ambitious plan to update, upgrade and expand the Tube while maintaining the vital flow of close to four million customers through the network every day.

	With the objective of procuring better value whilst delivering projects, Innovative Contractor Engagement (ICE) has been conceived to ensure that the good ideas the market has in response to project requirements can be bought forward and developed with the client as soon as possible for maximum benefit. ICE has been pioneered on a major upgrade upgrade project at Bank Station and the results demonstrate the spectacular increase in value that the industry can achieve when the client (London Underground), designer, Tier 1 contractors and their supply chain – get it right. The winning bid is a clear demonstration that good ideas from the market will deliver better value and win bids.
Success factors	The Bank Station Capacity Upgrade Project Team have led the development of ICE and pioneered its use to procure the design and build Contractor for the project. Four pre-qualified bidders were selected for the ICE and they provided four different schemes with significantly different approaches. Two bidders in particular demonstrated unique and innovative thinking – they were ranked 1st and 2nd in the tender evaluation. The tender winning bid by Dragados SA provides a more "Effective Product", increasing the benefits within the business case, and provides a more "Efficient Method", delivering it faster and cheaper compared to the original LU Base Case. This value is made up from: • An increase of 1.1:1 (45.1%) in the B:CR from 2.4:1 to 3.5:1; • A £148,625,000 (19.2%) increase in Journey Time Social Benefit over the 60 year project life; • A £61,155,000 (9.8%) reduction in the Estimated Final Cost to £563,812,000; • A 5 week (22.7%) reduction in closure duration of the Northern line, to 17 weeks. This equates to a £35,884,000 (52.9%) saving in social dis-benefit ; • A £30,850,000 (15.6%) increase in induced Revenue throughout the life of the project to £228,909,000; • A more effective Step-Free Access solution direct from street to platform on both the Northern & DLR lines; and • A more efficient fire and evacuation strategy throughout the whole station.
Constraints	Concerns over intellectual property during early stages of ICE where BIM models are openly shared
Main impacts	As above
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	https://www.secbe.org.uk/content/panels/Report%20-%20Innovative%20Contractor%20Engagement%20Procurement%20Model%20-%20Bank%20Station%20Capacity%20Upgrade-6d5f2a.pdf

Best Practice / Technology REF: T024

Field	Description
Title and Keywords	Title: **Freight pipelines**
Source of best practice / technology	Mole Solutions, WHG Engineering, Force Engineering
Lifecycle stage	Design
Type of infrastructure	Road / Rail
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Mole Solutions Ltd was formed in 2002 to focus exclusively on the introduction of freight pipelines. The company has carried out a number of DEFRA/Department for Transport and Innovate UK sponsored studies to explore the feasibility and proof of concept of this innovative mode of transportation. The MOLE freight pipeline system concept is to move unitised or bulk goods in customised capsules travelling in dedicated pipelines under full automatic control.The key design principles of the concept are: • Pipelines to be laid beside or under existing or new transport infrastructure to simplify construction, installation and integration with current supply chains and distribution centres. • Highly automated to allow 24×7 unmanned operation. • Simple and mature technology to provide high reliability, availability and maintainability. • Electrically powered to be sustainable and have low environmental impact. • Enclosed to be safe and secure. • Modular construction from factory-built units to ensure quality and minimise installation time and cost Mole Solutions has developed extensive computer based models of the freight pipeline system on which the commercial justification and the technical system design are based. Continuing development tests and trials are conducted to validate, enhance, optimise and extend these models. Mole Solutions has constructed a development test site at Alconbury Weald

	Enterprise Park near Cambridge. The facility is for tests and trials to validate commercial and technical computer models and also to specifically demonstrate the operation of a MOLE BULK system aimed at replacing conveyor systems in quarry and mineral extraction applications. The facility has been part-funded by the Technology Strategy Board. Mole Solutions has led a consortium which includes WGH Engineering (who have supplied the tracks and capsules) and Force Engineering (who have supplied the linear induction motors and propulsion control). The facility was completed in April 2014, three months ahead of schedule. The site has over 100m of track, (some of it in a 1.3m diameter pipe), LIM's, a control system, two 5 tonne capacity capsules and a track position switch. Plans are in place to increase the test site track length to allow extended running trials of both MOLE BULK and MOLE PRIMARY (pallets) capsules and the incorporation of intermodal load / unload stations for both system configurations.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	
Further information	http://www.molesolutions.co.uk/how-it-works/

Best Practice / Technology REF: T025

Field	**Description**
Title and Keywords	Title: **SoundLab for demonstrating acoustic performance**
Source of best practice / technology	Arup
Lifecycle stage	Design

Type of infrastructure	Road / Rail
Component of infrastructure	
Element of the infrastructure	Acoustic performance
Short Description	An extremely powerful tool, SoundLab takes a human-centric view of design to give people objective, quantifiable information in an accessible format. It enables them to make up their own minds about what they hear. For clients, SoundLab clarifies a design by making the intangible tangible. You don't have to interpret decibel charts or acoustic maps; you can simply experience the design for yourself by listening. You can discuss what works and what doesn't during the concept and design phase, and focus from the start on getting the design right. Because SoundLab's auralisations are perfectly matched to real-world conditions, clients and design teams can be sure they're focusing on finding solutions for the real problem areas. The constructive dialogue this enables increases trust between designers, engineers, clients and the general public. SoundLab is open and objective enabling honest and real feedback. SoundLab was used to understand the likely impact of noise from HS2 on the surrounding areas and presenting this to local stakeholders. The technology offered a way to present the information neutrally so that people could decide for themselves what they think and feel about what they hear. SoundLab has been used in HS2 technology demonstrations to articulate how the latest technology can make a high-speed railway a better neighbour. The demonstrations respond to questions from stakeholders, such as: • Are high-speed trains noisier than other trains I am used to hearing? • As trains go much faster, do they become much noisier? • What difference will noise barriers make?
Success factors	
Constraints	
Main impacts	Following the technology demonstrations, HS2 Ltd has committed to procure quieter trains. The demonstrations also showed HS2 Ltd and stakeholders the effect of noise barriers. Like High Speed 1, over 75% of the surface sections of HS2 will include noise barriers such as cuttings, fences and landscaped earthworks.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Influencing design and assisting stakeholder engagement to reduce cost and time
Further information	http://www.arup.com/projects/hs2_soundlab_demonstrations

Best Practice / Technology REF: T036

Field	Description
Title and Keywords	Title: **Innovative embedded rail slabtrack design**
Source of best practice / technology	Balfour Beatty, Charles Penny
Lifecycle stage	Design
Type of infrastructure	Rail
Component of infrastructure	Track
Element of the infrastructure	Balfour Beatty Rail has developed, for supply to railway clients, main contractors and track installers, an embedded rail system, invented by Charles Penny, that provides greater safety, performance and availability, with lower maintenance and reduced whole life costs. The rail is continuously supported in an elastomeric pad and a fibre reinforced plastic shell. The system enables an efficient, low profile reinforced concrete track slab. Initial installation using either slipform or pre-cast concrete is both fast and economical. A high performance affordable embedded rail slab track system for high speed and heavy freight traffic, also suitable for light-rail applications, delivering: • Integral broken rail containment • Integral derailment prevention • Buckle-proof rail containment at all temperatures • Lowest system height for improved clearances (370mm) • Configurable to reduce airborne noise and ground borne vibration • Environmental drainage control and easier cleaning • Unique rail head stability Compared to traditional track forms: • Up to 90 % reduction in the number of components required • An installed cost approaching that of ballasted track • Up to 50% increase in rail life • A 70% reduction in the use of quarried aggregates • An 80% reduction in inspection and maintenance costs • A 50% reduction in risk of track related fatalities • Increased operational availability and capacity

Short Description	
Success factors	Development work, including dynamic testing at Munich Technical University, confirmed the unique performance of the system. Trial installation tests were then carried out at Beeston in the UK, followed by installation in a high speed test track at Medina del Campo in Spain. The first scheduled traffic installation took place at Crewe in the UK in August 2003 where a section of the system is now carrying passenger and freight traffic for Network Rail. The system received Network Rail Acceptance in February 2006.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced capital and whole-life cost, increased safety
Further information	http://www.balfourbeatty.com/media/29022/embedded-rail-system-datasheet.pdf

Best Practice / Technology REF: T039

Field	**Description**
Title and Keywords	Title: **FRP (Fibre Reinforced Polymer) composites in bridge design**
Source of best practice / technology	Composites UK, South Gloucestershire Council, University of Bristol
Lifecycle stage	Design
Type of infrastructure	Road /Rail
Component of infrastructure	Bridge
Element of the infrastructure	Bridge deck
Short Description	South Gloucestershire Council undertook a bridge deck replacement using glass- and carbon-fibre reinforced polymer pultrusions for an 8.5m span bridge. Church Bridge spans a local river which dissects the community of Frampton Cotterell. No short diversions were possible hence one of the key objectives of this deck replacement was to minimise disruption and reduce impact on local residents.

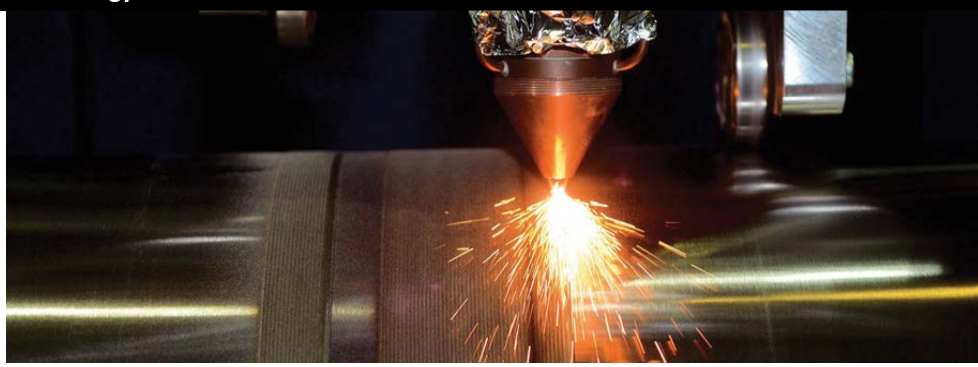
	Fiberline Composites FBD600 Asset Sections were used in combination with Square GFRP Pultrusion and CFRP pultrusion (plate). The GFRP used consisted of E-glass fibre and isophthalic polyester resin and carbon fibre pultruded plates in epoxy resin. The structure has numerous embedded sensors. In collaboration with Dr Wendel Sebastian at the University of Bristol, the bridge was load tested and the data is being interpreted to inform future designs.
Success factors	The ability to fabricate this structure off site was a key advantage which reduced programme and the lightweight nature of the structure aided installation. Within 48hrs vehicles were using the bridge.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost, time and improved safety for installation
Further information	https://compositesuk.co.uk/system/files/documents/Case%20Study%20-%20Church%20Road%20Bridge.pdf

Best Practice / Technology REF: T048

Field	Description
Title and Keywords	Generator Set Enclosure acoustic barrier for rail generators
Source of best practice / technology	Echo Barrier
Lifecycle stage	Design
Type of infrastructure	Road / rail / water / air
Component of infrastructure	
Element of the infrastructure	
Short Description	Echo Barrier, well known and respected for the 'H' series of noise reduction barriers, has designed, created and manufactured the Generator Set Enclosure, which can be quickly and easily installed around generators to dramatically reduce unwanted and

	excessive noise.
Success factors	Generatore enclosure reduces noise up to 90%
Constraints	
Main impacts	Echo Barrier offers high tech, market leading solutions for controlling excessive noise. Their systems make noise management simple, fast and highly effective. Barriers are flexible, provide exceptional acoustic performance, are easy to store, transport and fit. They were recently recognised by the Noise Abatement Society and were a finalist in the London Construction awards.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Noise absorption, waterproof,
Further information	http://www.echobarrier.co.uk/news-articles/echobarrier-acoustic-enclosure-product-launched/

Best Practice / Technology REF: T086



Field	**Description**
Title and Keywords	Rail-energy knowledge exchange on emerging materials (ALCHEMy)
Source of best practice / technology	L. B. Foster Rail Technologies Laser Cladding Technology Ltd (LCT) Network Rail SKF Group Tata Steel
Lifecycle stage	Design, Operation & Maintenance
Type of infrastructure	Rail
Component of infrastructure	Raiways
Element of the infrastructure	Track
Short Description	In order to improve the management of railway networks and provide the timetables that passengers demand throughout the week, track components with greater durability that are easier to maintain are essential. With these in place less access will be needed to the track, keeping it free for trains.
Success factors	
Constraints	
Main impacts	The aim of this project is, through the use of process modelling and full-scale testing and

	modelling, to enable the effective design of a laser clad layer of premium material for application to a range of track components to reduce wear and the likelihood of rolling contact fatigue occurring. These are the two most prolific damage mechanisms in railway track. A major goal of the project is to comprehensively study the behaviour of cladded components on a test track to validate the modelling and laboratory work. The project, while focussed on railway track applications will also consider vehicle components in parallel activity and ensure that the knowledge and fundamental knowledge gained on the integrity of cladded components through multi-scale modelling of different geometries and cladding parameters is transferred to other sectors where cladding is used, such as energy, oil and gas and aerospace.
Maturity and degree of implementation	1-3 (Research Level)
Key Performance Indicators	The technique, as well as improving component life and reducing maintenance needs, will reduce costs by allowing lower grade rail material to be used and also in-situ repairs could be facilitated eventually, negating the need for components to be removed from track when they reach the end of their life.
Further information	*http://www.sheffield.ac.uk/* *http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M023044/1*

Best Practice / Technology REF: T088	
Field	**Description**
Title and Keywords	LOCORPS: Lowering the Costs of Railways using Preformed Systems
Source of best practice / technology	Heriot-Watt University, United Kingdom (Lead Research Organisation) High Speed Two HS2 Ltd, United Kingdom (Project Partner) Network Rail Ltd, United Kingdom (Project Partner) Tarmac Ltd, United Kingdom (Project Partner) Laing O'Rourke plc, United Kingdom (Project Partner) Atkins Global (Project Partner)
Lifecycle stage	Design, Construction
Type of infrastructure	Rail
Component of infrastructure	Rail
Element of the infrastructure	Embankment
Short Description	High-speed rail lines, at ever increasing speeds and distances, are in development both in the UK and world-wide, but up-front capital expenditure can potentially be a major inhibiting factor both to the client and also in the eyes of the public. Cost reductions for these lines could be achievable if the initial costs of the physical construction, the duration of construction and the land take could be reduced. All three of these costs can potentially be reduced for embankments if the industry were to move towards a novel embankment replacement system. In addition embankment replacement systems could significantly improve the performance of the track structure as the dynamic properties of the contained material can be better controlled. However, such technology requires significant performance evaluation and the development of appropriate design guidance before UK industry can justifiably implement it in a project. This project therefore aims

	to evaluate and produce design guidance for two novel embankment replacement systems as a means to potentially reduce the cost of constructing new high-speed railway lines (particularly in urban environments) and improve the overall track behaviour and hence passenger experience.
Success factors	The project will result in the training of two PDRAs in high-speed railway track design and application which will have a positive effect on increasing the specialist knowledge in the UK for high-speed railways. This research application therefore has an extremely high impact factor and the findings of the project will lead to significant cost savings for new high-speed lines and push UK technology on the international market.
Constraints	
Main impacts	The ability to extend the speed range and/or develop new infrastructure techniques that can potentially reduce the capital expenditure of new lines will have a significant impact on the railway industry both nationally and internationally.
Maturity and degree of implementation	1-3 (Research level)
Key Performance Indicators	Reduce capital expenditure, improve the operation expenditure, reduce life cycle costs,
Further information	*http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N009207/1* *http://gtr.rcuk.ac.uk/projects?ref=EP/N009207/1*

5.4 Type of infrastructure: Air

Best Practice / Technology REF: T035

Field	Description
Title and Keywords	Title: **Jet fan deflectors for road tunnel longitudinal ventilation**
Source of best practice / technology	Atkins
Lifecycle stage	Design / Renovation
Type of infrastructure	Road / Air
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	On behalf of Heathrow Airport Ltd, Atkins assessed options for the upgrade of fire &

	life safety systems in two major road tunnels at Heathrow Airport, adopting a performance-based design approach with detailed risk analysis to determine the optimum tunnel safety upgrade provisions for fire protection, evacuation and ventilation systems. Passive fire protection can offer cost benefits due to reduced structural damage and repair time in the case of vehicle fires. The potential benefits of sprayed and board linings were quantified for a variety of fire scenarios in the Heathrow tunnels. Active fire suppression systems are a relatively new technology for road tunnels, with no tunnel-specific design standards. Atkins engaged with specialist suppliers and manufacturers; analysed data from recent full scale fire test programmes; conducted independent analysis and developed design and performance specification for an effective, reliable fixed fire fighting system (FFFS). Atkins developed the design for a longitudinal ventilation system in one tunnel and a semi-transverse system in a second tunnel to provide effective improvements to ventilation systems to direct smoke and hot gases away from tunnel users in the event of a fire. For the longitudinal system, Atkins developed a unique and innovative aerodynamic jet fan deflector system which was trialed in the tunnel.
Success factors	Results demonstrated significant improvements in ventilation efficiency with simple deflector technology, intelligently applied on site; enabling significant cost savings in the final solution for ventilation upgrade.
Constraints	Access to operational demonstration sites (which has been provided)
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost and improved safety
Further information	http://www.atkinsglobal.co.uk/en-GB/projects/heathrow-airport-tunnels-fire-and-life-safety-system-upgrade

5.5 Type of infrastructure: Water

Best Practice / Technology REF: T008

Myanmar.
UK-DMC2 satellite image© [2011] SSTL,
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Field	Description
Title and Keywords	Title: **Application of Earth Observations to hydrological surveys for maritime transport infrastructure**
Source of best practice / technology	Surrey Satellite Technology Ltd.
Lifecycle stage	Design / Operation
Type of infrastructure	Water
Component of infrastructure	Port walls
Element of the infrastructure	
Short Description	Hydrological survey is critical to the understanding of a territory's coastal zones and inland waterways. The use, consumption and distribution of water resources can be monitored through the use of imagery. Manual surveys are labour intensive and rarely offer a complete overview of the resource in question. Automated sensors are important to monitor single points in waterways, levels at gauges and points of critical concern. However, they don't provide data elsewhere and can suffer in remote areas from a lack of connectivity and power. There is therefore a role for Earth observation from space. Additionally, it is possible to monitor agricultural water use and wastage and take accurate measurements of soil moisture from space.
Success factors	The surveys that can be undertaken from space give a regular accurate overview.
Constraints	
Main impacts	Coastal and tidal zones subject to regular changes due to meteorological influences can be of concern. Utilising the technical capabilities of satellites, information may be derived such as shallow water depths, topology of mudflats or presence or absence of outflow or sediments. In coastal zones, satellite imagery provides information on the changing bathymetry, which can be particularly useful around ports and busy shipping areas.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Cost and time savings
Further information	http://www.sstl.co.uk/Downloads/Brochures/SSTL-Applications-Brochure-Web

Best Practice / Technology REF: T041


Field	Description
Title and Keywords	Title: **Modular manufacturing for construction of new container port and logistics terminal**
Source of best practice / technology	Laing O'Rourke, DP World London Gateway
Lifecycle stage	Design / Construction
Type of infrastructure	Water
Component of infrastructure	Port terminal
Element of the infrastructure	Cranes and other logistics facilities
Short Description	Laing O'Rourke was principal contractor, working alongside Dredging International, to deliver the unique London Gateway container port and logistics terminal, located just 25 miles from central London. Using world-leading technology to increase productivity and reduce costs, the largest deep-sea container ships in the world will dock and unload using streamlined automated systems. From the outset, world-leading technology has proved invaluable, not only from an engineering perspective, but also environmentally. Laing O'Rourke used a specialist quay wall technique which stretches 50m through the existing river bed into the London Clay beyond, and dredged 30 million cubic metres to increase the depth of the channel and reclaim land crucial to the development. The project has used the most sophisticated system in the world to preserve water quality throughout the dredging process. Multi-instrument buoys surrounded the area and transmitted environmental data in 'real time' back to base station, where it was monitored around the clock and used to manage and avoid any negative impact. Design for Manufacture and Assembly (DfMA) encourages precise and innovative design and engineering. Laing O'Rourke used this method to pass a major structural milestone – the tie rod installation for the 1.3km quay. Laing O'Rourke worked closely with the manufacturer to design and produce the largest coupler anchors in the UK, and then installed 1,300 of these to tie the quay wall to the anchor wall.
Success factors	Following a number of trials, Laing O'Rourke assembled the tie rods at the top of the quay wall before craning them into position. Once perfected, the team championed

	this consistent, reliable approach throughout the remainder of the work – 10,000 elements were flawlessly jointed, lubricated and fettled. An extensive network of sensors were installed to monitor ground conditions and much work was undertaken to determine how the data would be collected, recorded and presented.
Constraints	
Main impacts	Reduced time and cost, plus improved safety, for construction. Input to improved whole-life performance through inclusion of condition monitoring sensors.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced time and cost, plus improved safety, for construction.
Further information	http://www.laingorourke.com/our-work/all-projects/london-gateway-port.aspx

6. Technologies for Construction

6.1 Type of infrastructure: Roads

Best Practice / Technology REF: T042

Field	Description
Title and Keywords	Title: **Closed loop recycling for plastic infrastructure and utility products**
Source of best practice / technology	Balfour Beatty Utility Solutions, Centriforce, V10 Polymers
Lifecycle stage	Construction
Type of infrastructure	Road /Rail
Component of infrastructure	Utility products
Element of the infrastructure	
Short Description	Balfour Beatty Utility Solutions formed a closed loop recycling scheme with Centriforce and V10 Polymers. Believed to be a first for waste management in the utilities industry, the scheme allows for waste plastic collected from up to 100 of

	Balfour Beatty's sites throughout the UK to be recycled into cable protection covers for use during the company's essential work in replacing and maintaining vital utility assets. The waste management scheme sets an important example of environmental best practice by achieving a true 'closed loop' in which Balfour Beatty Utility Solutions keeps complete control of its plastics waste stream and accepts it back as a usable product. The project was co-ordinated by the company's materials and equipment buying team, who set out to investigate recycling waste plastic into products for re-use in the business. A key objective was also to identify opportunities to eliminate disposal costs and generate revenue by selling plastic waste to specialist collection firms. Centriforce's innovation team then worked with Balfour Beatty to advise on the establishment of the national closed loop scheme. Balfour Beatty Utility Solutions site personnel alert V10 to collect mixed plastic waste from site within a maximum of 48 hours. It is then transported to V10's Blackburn reprocessing centre, where it is sorted, cleaned and granulated. The resulting HDPE/LDPE waste plastic feedstock is delivered to Centriforce's Liverpool manufacturing centre. From this feedstock, Centriforce manufactures Stokbord® heavy-duty protection tiles which are used widely throughout the world to protect underground utilities such as high-voltage power lines, fibre optic cables, and gas and water pipes.
Success factors	It is estimated that between 150 and 200 tonnes of waste plastic could be collected annually and turned into a range of products for Balfour Beatty Utility Solutions. This amounts to an estimated carbon saving of between 2,000 and 2,500 tonnes across the process of manufacturing new products, through landfill avoidance and the reduced need for virgin raw materials.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced carbon and resource use.
Further information	http://www.centriforce.com/files/4613/6567/6032/CaseStudy1-BalbourBeatty.pdf

Best Practice / Technology REF: T049

Field	Description
Title and Keywords	Temporary Sound Control solutions on transport construction projects
Source of best practice / technology	SOUNDEX Solutions
Lifecycle stage	Construction
Type of infrastructure	Road / Rail
Component of infrastructure	
Element of the infrastructure	
Short Description	Close proximity to residential areas in conjunction with the 24 hour working schedules that are common in this industry often result in temporary noise control being required to meet section 61 parameters that have been requested by local councils. The SOUNDEX® systems have proved to be very successful in reducing the noise that is created during track and platform works allowing critical travel and safety announcements to be perfectly audible despite live maintenance and construction projects.
Success factors	The acoustic quilts/curtains performed extremely well and were easy to install which was noted by our ability to complete works without further nuisance to neighbours and complete the works for our client on time.
Constraints	
Main impacts	Reduction of the nuisanse to neighbours when working nearby.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	http://www.soundexsolutions.com/industry-specific-noise-solutions/rail

Best Practice / Technology REF: T054

Field	Description
Title and Keywords	Design for Manufacture Assembly (DfMA) for efficient on-site construction and reduction in wastes and risks to the environment
Source of best practice / technology	Highways England, White Young Green, Laing O'Rourke
Lifecycle stage	Design / Construction
Type of infrastructure	Road
Component of infrastructure	
Element of the infrastructure	
Short Description	The A453 is one of three major routes that connect the M1 Motorway to the City of Nottingham. It provides the principal route between Nottingham and the South, South-West of the country and East Midlands Airport. The 9km long section between M1 Junction 24 and a roundabout junction at Mill Hill, southwest of Clifton, has been improved from a single two lane (S2) carriageway with some at grade junctions to a dual two lane all purpose (D2AP) standard with two grade separated junctions. The alignment of the new dual carriageway follows the alignment of the existing road from the M1 to Thrumpton, and the widening achieved by the construction of a westbound (W/B) carriageway on the south side of and adjacent to the existing road. The earthworks balance along the scheme was revisited several times to alter design where possible to negate the need for importation/exportation of material. This reduced construction traffic on the road and surrounding area and carbon impacts. Energy and waste saving opportunities were trialled on the A453 one of which included the use of Concrete Socks to eliminate concrete washout within the urban areas as space for on-site concrete washout systems was not available. This eliminated the risk to the environment from concrete wash water and minimised waste. Design for Manufacturing Assembly (DfMA) was utilised on structures along the

	scheme allowing for greater and more efficient on-site construction therefore reducing wastage and risk to the environment. This was particularly beneficial when working on structures over the canal and the River Soar.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced time and waste during construction, improved safety
Further information	http://www.ceequal.com/awards_209.html

Best Practice / Technology REF: T055

Field	Description
Title and Keywords	Collaborative construction to deliver commitment to social sustainability which ensures that all passengers have access to and from both buses/trams and platforms
Source of best practice / technology	Trafikförvaltningen (the Transport Administration, Stockholm County Council), Skanska
Lifecycle stage	Design / Construction
Type of infrastructure	Road
Component of infrastructure	
Element of the infrastructure	
Short Description	Tram Line 7 is currently in regular service between Kungsträdgården in Stockholm city and Waldemarsudde in South Djurgården. The (Spårväg City) tram system is planned to be expanded and link Lidingö with Stockholm city via Stockholm Royal Seaport, the new sustainable urban development in Frihamn and Värtahamn. The first stage of this expansion, assessed in accordance with CEEQUAL, is the accessibility upgrade of Tram Line 7 and the tram stops in South Djurgården. 12,000 new homes and 35,000 new workplaces are under construction in Stockholm Royal Seaport, and Spårväg City will supply most of the public transport services. In addition, South Djurgården is the world's seventh largest entertainment centre with more than 14 million visitors annually. Visitor statistics for South Djurgården indicate that this number will continue to rise; hence Tram Line 7 is an important

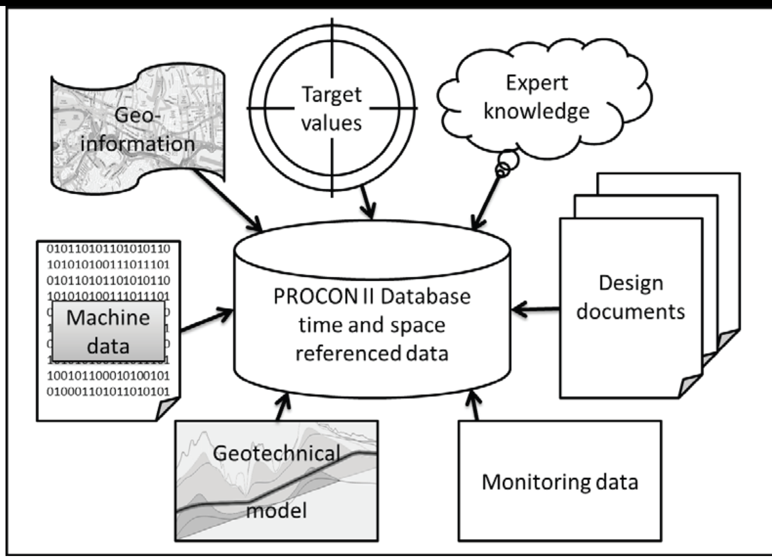
	connection for Stockholm's economy
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Improved accessibility
Further information	http://www.ceequal.com/awards_208.html

Best Practice / Technology REF: T062


Field	Description
Title and Keywords	Unbonded strand post-tensioning systems using monostrand
Source of best practice / technology	VSL Structural Technologies DYWIDAG-Systems
Lifecycle stage	Design / Construction
Type of infrastructure	Road / Rail
Component of infrastructure	
Element of the infrastructure	
Short Description	Adaptable to a variety of structures, unbonded monostrand can be easily, rapidly, and economically installed. Applications for monostrand systems include elevated slabs, slab-on-grade, beams and transfer girders, joists, shear walls and mat foundations.
Success factors	Our unbonded systems feature 0.5" and 0.6" diameter strands coated with a layer of specially formulated grease. The outer layer is seamless plastic extruded in one continuous operation to provide protection against corrosion. Each tendon is precisely coiled, cut, labeled, color-coded and delivered to the construction site. A wide variety of anchorage systems are available to meet design specifications.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7

Key Performance Indicators	Continous operation, prevents corrosion
Further information	

Best Practice / Technology REF: T065



Field	**Description**
Title and Keywords	Real-time process controlling of TBM production (PROCON II)
Source of best practice / technology	MTC Maidl Tunnelconsultants
Lifecycle stage	Construction
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Shield tunneling is characterized by a degree of mechanization that is usually uncommon in the construction sector. The construction process is governed by the shield machine with its manifold technical devices that need to be carefully controlled to achieve an optimal performance. Taking advantage of the high degree of mechanization, tunnel boring machines (TBMs) are equipped with a large amount of sensors that provide the opportunity to evaluate, optimize and control the construction process at any time. Along with automatically acquired machine data (200 to 1000 sensor readings every 2 to 10 seconds), a large number of heterogeneous external data sources exists from geodetic monitoring via geotechnical information to maintenance and shift reports that are closely related to the excavation works. These external data are increasingly often available in terms of computer-readable information rather than being captured manually and allow for integrated storage and evaluation. In this software, all project information is shown along with the actual process data such that the maximum advantage is taken from the available data. The knowledge acquired from the project is transferred to all participants of the project worldwide and in real-time. This way, critical situations can be recognized timely and

	preventive measures can be taken immediately
Success factors	A specific feature of the PROCON II database is the capability to handle real-time data. In a special mode of the visualization client of PROCON II, it is possible to monitor the data on-the-fly such that the supervising engineer obtains online access not only to machine data but also to preconfigured analyses (e.g. target/actual analysis) in real-time.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Increased safety, cost saving,
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

6.2 Type of infrastructure: Rail

Best Practice / Technology REF: T013

Field	Description
Title and Keywords	Title: **Smart monitoring of Bond Street to Baker Street Tunnel Lining Replacement**
Source of best practice / technology	Senceive, CH2M Hill, London Underground, Bentley
Lifecycle stage	Construction
Type of infrastructure	Rail
Component of infrastructure	Tunnel
Element of the infrastructure	Tunnel lining
Short Description	A stretch of London Underground’s Jubilee line between Bond St and Baker St required the concrete lining to be replaced with cast steel (SGI) segments. This extremely ambitious project involved two special engineering trains replacing the lining shift by shift during engineering hours. Monitoring was required ahead of the

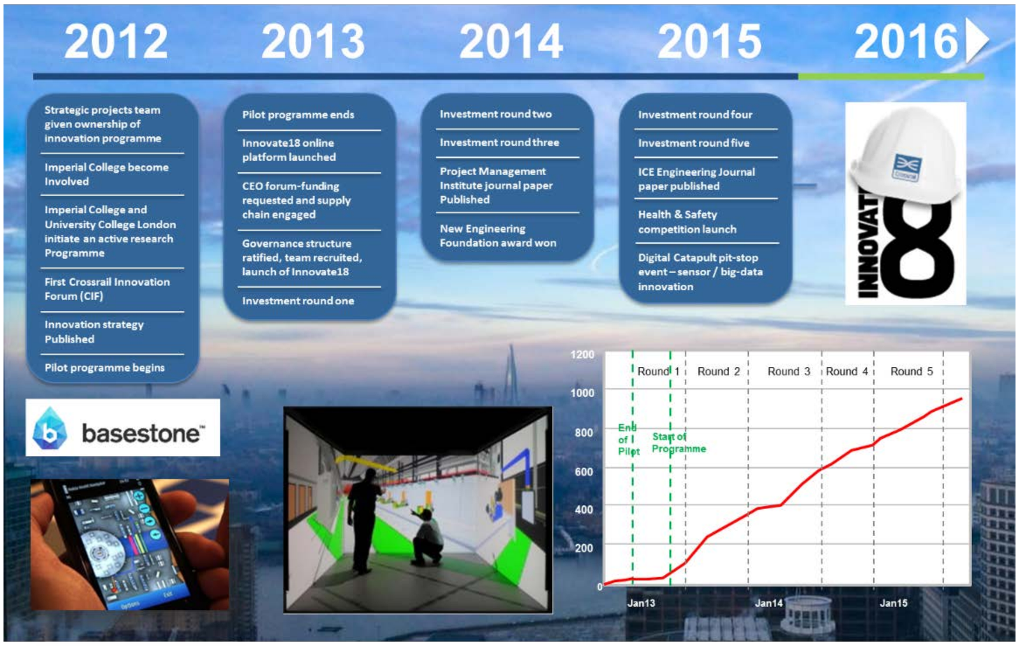
	works on temporary restraining rings, so needed to be flexible and easy to both deploy and re-deploy. Monitoring was also required immediately behind as the work progressed, as well as on the completed tunnel segments long term. Senceive's wireless tiltmeters were deployed ahead and immediately behind, leapfrogging ring by ring as the work progressed. Further rings of sensors were left behind to monitor long term stability. The system was further developed for this project, not only enabling the data to be accessed from the nearest platform at any time, as was originally required, but additionally as identified during the trials, by the engineers on the train, using a locally wireless connected portable device.
Success factors	
Constraints	
Main impacts	This project ran until late 2015 i.e. almost 3 years. It has been extremely successful and has won several engineering awards. The FlatMesh system has proven itself as a stable platform for monitoring in highly demanding environments and can be used tactically for short term deployment or equally in long term deployment and stable monitoring. Further awards and deployments have followed as a result of its success.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost and time to construction process
Further information	http://www.senceive.com/

Best Practice / Technology REF: T014

Field	**Description**
Title and Keywords	Title: **Track Movement monitoring - robust, reliable and repeatable for total confidence, using Flat Mesh bi-axial tilt sensor system for monitoring cant and twist**
Source of best practice / technology	KOREC Group, Morgan Sindall, Senceive, Docklands Light Railway
Lifecycle stage	Construction

Type of infrastructure	Rail
Component of infrastructure	Track
Element of the infrastructure	Rails
Short Description	The Docklands Light Railway (DLR) station at Pudding Mill Lane has been demolished and both the track and station are being moved to make way for the Crossrail tunnel that surfaces next to it. Morgan Sindall are responsible for the works, and are required to monitor the multiple rail tracks belonging to Network Rail (NR), as well as the DLR tracks, to ensure that there is no significant movement whilst the works are in progress – for a period of some two years. Following issues with the use of optical monitoring, they sought an alternative solution for measuring track cant and twist with high precision, reliability and stability. Working in close cooperation with the Morgan Sindall team, Senceive installed over 700 standard wireless high precision tilt meters attached directly to the track on five DLR and NR lines. All the sensors communicate with a solar powered GPRS gateway. This means there is a totally mains power and wire free solution for the whole system. Data is sent back to a cloud server Webmonitor software and shows cant and twist in real time. There is no lag or delay in the data being available instantaneously.
Success factors	The data is showing unprecedented stability and accuracy at below 0.1mm on a 1.435m track beam length (see Figure 1). Furthermore there were no spikes or false alerts or alarms. The response to the system and its ability to pick up tiny movements whilst providing stable and repeatable data with high precision has been outstanding. This has enabled it to pick up real movement at a very early stage and allowed the surveying team to respond rapidly. The fact that installation time was minimal and there is no need to go out on the track to clean prisms has improved safety and reduced on-going cost. It has led already to several other large track bed deployments with NR.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost and time to construction process; improved safety
Further information	http://www.senceive.com/

Best Practice / Technology REF: T029



Field	Description
Title and Keywords	Title: **Crossrail Innovate18 open platform for Innovation**
Source of best practice / technology	Crossrail and supply chain contractors, plus Imperial College London
Lifecycle stage	Construction
Type of infrastructure	Rail
Component of infrastructure	Tunnels, Stations, Track
Element of the infrastructure	
Short Description	The Crossrail Innovate18 programme, transitioning in Autumn 2016 to a dissemination phase, was an innovative R&D procurement method that was open to all Crossrail employees and colleagues from participating Tier 1 contractors, or nominated supply chain / stakeholder organisations. The intention was to stimulate and incentivise innovation on the major Crossrail project, by requiring that all Tier 1 contractors contribute funding, together with central Crossrail funding, and then making the outputs from the innovation available to all parties / members. The benefits that were put forward from innovate18 included: • Know-how: through innovate18, members have access to a team of innovation experts who can help develop and share ideas. Members can also use the system to identify people across the programme with the right skills and experience to help. • Funding: if an idea was accepted for development, Crossrail provided development capital and other resources to make it happen. • Sharing: awareness of innovations from around the Crossrail programme to use on individual projects.

	• Recognition: everyone who shares an idea or helps to develop an idea becomes part of the Crossrail innovation story and legacy to the industry.
Success factors	Over 1000 innovations have been developed and shared through the programme.
Constraints	
Main impacts	Crossrail are now working with the Major Projects Authority, KTN Ltd, professional institutions, CIRIA and other major project organsiations such as HS2 and Thames Tideway, to develop a subscription-based platform to share the innovations from major construction projects in the UK.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	https://www.innovate18.co.uk/connect.ti

Best Practice / Technology REF: T034


Field	**Description**
Title and Keywords	Title: **Big data analytics for urban infrastructure**
Source of best practice / technology	QuantumBlack
Lifecycle stage	Design / Contruction / Operation
Type of infrastructure	Road /Rail
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Technology borne out of Formula 1, the data analytics technology has been applied to transport infrastructure projects including Crossrail in the UK. Leadership and engineers found making sense of the volume of data produced from 250,000 sensors extremely difficult. QuantumBlack developed an analytics and data visualisation platform for monitoring a range of instrument and sensor data more efficiently. Traditional Gaussian models were extended with spatio-temporal correlation derived from machine learning techniques to improve risk management on the £15bn Crossrail urban infrastructure project.

	QuantumBlack's proprietary analytics are designed to help understand the relationship between observed movements and external factors in order to spot anomalies, forecast events and optimise the monitoring regime to improve risk management while minimising the cost. These analytics are embedded within a web interface that supports simple reporting and interpretation across the whole project organisation. This ability to hunt for patterns between sensors is changing the industry by enabling real time anomaly detection, event forecasting and optimisation of the monitoring regime. The analytics tool was successfully deployed operationally at two stations to reduce monitoring costs by 20% whilst improving risk management capability. It enabled real time anomaly detection across the whole area rather than just within a limited 'zone-of-influence'.
Success factors	Enhanced the historical process with a predictive capability to forecast construction and monitoring events within a seven day window, enabling faster and better interventions. This automation of the basic analysis enabled asset protection engineers to focus on value-add interpretation rather than spotting issues.
Constraints	Quality of data captured from sensors
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced time and cost in design and construction, plus increased safety
Further information	http://www.quantumblack.com/work/urban-infrastructure-sensor-monitoring.html

Best Practice / Technology REF: T046

Field	Description
Title and Keywords	New innovation in sleeper design for more efficient construction
Source of best practice /	CEMEX Rail Solutions, Track Partnership (London Underground & Balfour Beatty)

technology	
Lifecycle stage	Construction
Type of infrastructure	Rail
Component of infrastructure	
Element of the infrastructure	
Short Description	The new 1502 concrete sleeper represents a major innovation offering a preassembled sleeper incorporating the Pandrol Fastclip 'FE' fastening system, which allows for automated installation. The sleeper is also fitted with the required insulators and pads in place, reducing five installation steps down to one. The final step requires the rail to be threaded on to the sleepers and the clips to be driven automatically on to the rails. The 1502 has been developed in partnership with Pandrol, Balfour Beatty Rail and London Underground in response to a growing need to construct track faster, more safely and at a lower cost with reduced maintenance requirements. It is estimated that the new sleeper system can be laid in half the time needed to lay traditional sleepers.
Success factors	THE first new sleeper design in more than 30 years has recently been laid on the London Underground. Produced by CEMEX Rail Solutions, the bespoke sleeper solution offers faster installation of new track with improved reliability and greater longevity.
Constraints	
Main impacts	
Maturity and degree of implementation	http://www.agg-net.com/news/new-innovation-in-sleeper-design
Key Performance Indicators	
Further information	

Best Practice / Technology REF: T053

Field	Description
Title and Keywords	Crossrail - Connaught Tunnel and Surface Railway
Source of best practice / technology	Atkins, VINCI Construction, Crossrail Ltd
Lifecycle stage	Design / Construction
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	The Connaught Tunnel Refurbishment Project transformed an abandoned 1878 Victorian tunnel and disused railway and re-engineered it to receive the Crossrail track and trains for the next 120 years. The project was technically challenging and very unusual for a major new transport scheme such as Crossrail. The principal elements of the Project comprised: • Refurbishment and modification to the existing Connaught Tunnel and approach ramps, including converting the twin binocular tunnels into one large-bore tunnel, requiring the central section to be removed and rebuilt by 'cut and cover' method enabled by two cofferdams in the dock allowing dewatering. • Construction of the surface rail between Custom House Station and North Woolwich portal. • Upgrading drainage systems. • Micro tunnelling / SCL works in pump house and vent shafts. • Demolition of buildings which included Grade Listed Buildings. • Marine Works / Diving Operations. CEEQUAL was used to influence and in turn assess the sustainability of the Project. The Project achieved an 'Excellent' CEEQUAL Whole Project Award. There were a number of key areas where the Project scored particularly highly.
Success factors	

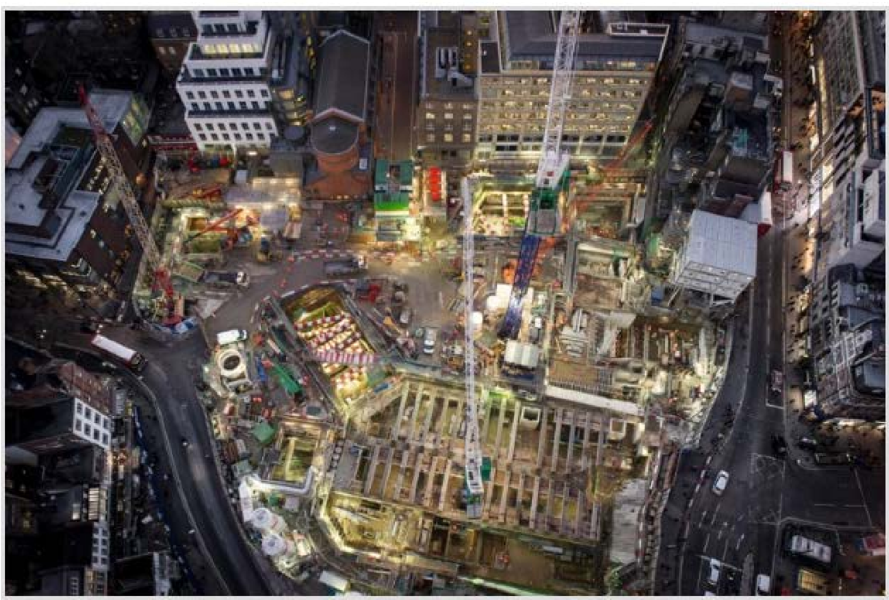
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Cost Saving
Further information	http://www.ceequal.com/awards_235.html

Best Practice / Technology REF: T070	
Field	**Description**
Title and Keywords	Cutting Edge Sprayed Concrete Design to Upgrade an Existing London Underground Station KEYWORDS: SCL; urban tunnelling; soft ground
Source of best practice / technology	World Tunnel Congress 2014 proceedings Atkins Ltd, Dr Sauer & Partner Ltd, Constain Laing O'Rourke JV
Lifecycle stage	Construction / Renovation
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Sprayed waterproofing membrane is an advantageous alternative to pre-fabricated waterproofing sheet membranes under typical tunneling conditions, especially in geometrically complex areas, such as in lay-by niches, cross passages and crossover caverns, where installation of conventional waterproofing membranes is inherently difficult and locating of leaks is challenging.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Minimised construction risks, optimised design, minimal impact on the surrounding infraestructure.
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T071	
Field	**Description**
Title and Keywords	Sprayable waterproofing membranes KEYWORDS: spray applied membrane, waterproofing, composite shell lining, MasterSeal 345
Source of best practice / technology	World Tunnel Congress 2014 proceedings BASF
Lifecycle stage	Construction / Renovation
Type of infrastructure	Rail / Road

Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Sprayed waterproofing membrane is an advantageous alternative to pre-fabricated waterproofing sheet membranes under typical tunneling conditions, especially in geometrically complex areas, such as in lay-by niches, cross passages and crossover caverns, where installation of conventional waterproofing membranes is inherently difficult and locating of leaks is challenging.
Success factors	This membrane has been successfully used in underground projects with different waterproofing design concepts and under diverse hydro-geological and environmental conditions since more than a decade. It has provided tunnel designers with different options and optimization for the design of tunnel concrete linings. It provides a durable waterproofing concept matching the design life of the tunnel structure.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Increased productivity, flexibility in design, flexibility in working and programming, improved logistics, cost saving, reduced long-term maintenance costs.
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T072



Field	Description
Title and Keywords	An innovative application of sprayed concrete linings for the London Underground transport network upgrade (TfL - Tottenham Court Road)
Source of best practice / technology	World Tunnel Congress 2014 proceedings Transport for London

Lifecycle stage	Construction / Renovation
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Moving away from the traditional 3-stage hand mined solution, the tunneling operations created two caverns above the existing platform tunnels into which the permanent works were installed. Significant work was completed in order to ensure there was adequate ground support, to minimize ground movements and damage to the platform tunnel linings.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

6.3 Type of infrastructure: Air

6.4 Type of infrastructure: Water

Best Practice / Technology REF: T056	
 	
Field	**Description**
Title and Keywords	Carbon reduction through use of environmentally-friendly material for filler in backfill for culvert refurbishment
Source of best practice / technology	Trafikverket, Skanska Sweden
Lifecycle stage	Construction / Renovation
Type of infrastructure	Road / Water
Component of infrastructure	
Element of the infrastructure	

Short Description	The highway E18 connects the cities Västerås and Stockholm. The purpose of the project was to widen and upgrade a section of the existing E18. The 10 km road section only had 1 + 2 lanes in each direction, but now has 2+2 lanes as result of the project. In addition, the project has built a new interchange with a bridge over a local road, a new traffic control area for the police, as well as complementary work on existing culverts and bridges. Some of the bigger sustainability aspects were carbon and energy, both imbedded in materials as well as emissions from machines and vehicles, waste, local ecological values, and protection of water bodies. The area surrounding E18 consist of fields, woods and a couple of small streams, one of them called Sagån. The lake Mälaren, a fresh water source for about 1 million people, is located 5 km west of the project area.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	http://www.ceequal.com/awards_204.html

Best Practice / Technology REF: T057

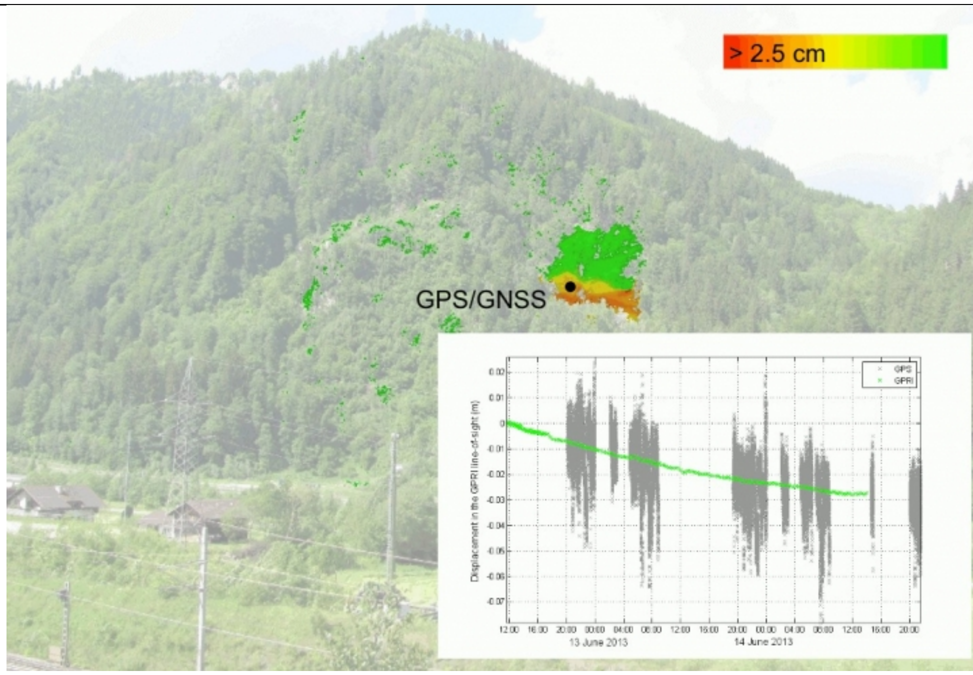

Field	Description
Title and Keywords	Refurbishment of historic quay infrastructure
Source of best practice / technology	Cornwall Council, Parsons Brinkerhoff, Carillion Civil Engineering
Lifecycle stage	Construction / Renovation
Type of infrastructure	Water
Component of infrastructure	
Element of the infrastructure	
Short Description	Necessary infrastructure works included: a new vehicular bridge over Copperhouse Pool a Special Site of Scientific Interest (SSSI); repair works to listed harbour walls on the North, East and Merchant Curnow Quays; the creation of a promenade along North Quay and flood protection works.

	The project has had a direct economic impact, not only for Hayle and West Cornwall, but also the region as a whole through opening up the area for further economic development and augmenting Cornwall's and South West Marine Energy Park's marine renewables and employment agenda. With existing Public Rights of Way across North Quay, one of the key challenges to the delivery of the project was to maintain these Rights and ensure that local residents and the community as a whole were considered and consulted with as part of the delivery process. This also included close collaboration and the subsequent relocation of operational businesses within the area of construction activity.
Success factors	With phase one of the project completed and the new adopted highway and bridge opening up access to Cornwall Council's Marine Renewables Business Park, an additional £6m of capital investment has been released to enable work to commence on the first phase of development on North Quay in February 2014 which is, as previously stated, the first significant capital investment in Hayle Harbour since 1939! The public sector urban regeneration investment in North Quay (DBIS, DECC, ERDF and Cornwall Council) will also shortly unlock private sector development on North Quay and also, arguably on viability grounds, has expedited development on Hayle Harbour's South Quay where redevelopment commenced in October 2013. Furthermore, as was the case with North Quay, a number of historic features on South Quay will be enhanced to preserve links with Hayle's historic past. The total cost of the first phase of development on the Hayle North Quay infrastructure project was £17million, including detailed design and project management costs. In what proved to be an exceptionally challenging project, the scheme initially achieved a "Very Good interim Client and Design Award" in December 2010 which, with committed and dedicated work by the wider team and in spite of personnel changes, elevated the outcome to an "Excellent" Whole Project Award in May 2013.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	http://www.ceequal.com/awards_162.html

7. Technologies for Maintenance, Operation, & Renovation

7.1 Type of infrastructure: Roads

Best Practice / Technology REF: T006



Field	Description
Title and Keywords	Title: **Monitoring Alpine Transportation Infrastructures Using Space Techniques (MATIST)**
Source of best practice / technology	European Space Agency, Swiss Federal Railways, Austrian Federal Railways, Austrian Motorway Operator (ASFINAG), Gamma Remote Sensing AG, Institute of Navigation, Graz University of Technology
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail / Water
Component of infrastructure	Earthworks
Element of the infrastructure	
Short Description	The MATIST services provide ground motion information using the integration of satellite and terrestrial radar interferometry and space-based navigation. The Swiss Federal Railways lines are frequently exposed to natural hazards, which cause around 33% of the insured damages. Of a network of around 3,000 km, 500 km are potentially endangered by natural hazards and costs are estimated of 30 million Swiss Francs per year. Also, the Austrian railway system is vulnerable to numerous natural hazards at several sections and in order to provide a high level of reliability, a super-regional database for all segments of endangerment has to be elaborated. Gravitative natural hazards such as avalanches, rock fall, debris flow and floods and landslides are a constant threat as well as for sections of alpine road networks in Switzerland and Austria. The space assets mobilized for this project are: • Earth Observation: satellite SAR interferometry for surface displacement mapping and monitoring

	• Satellite Positioning: to accurately measure surface displacement.
Success factors	The foreseen added value of using different space assets along to terrestrial assets (terrestrial radar interferometry) is: • Large area mapping from space; • Improved completeness and consistency of the results; • Reduced costs.
Constraints	The key issues addressed by this project include: • Acceptance of the space technologies in the user's practices and operation solutions; • Validation of critical elements of the system implementation and performance in the proof-of-concept; • Detailed description of a prototype system; • Technical definition and evaluation of low-cost satellite navigation receivers; • Definition of service provision chain; • Viability analysis focused on the economic elements of the system
Main impacts	The set of expected benefits are the following: • Improved hazard mapping and monitoring user's system based on the integration of space and terrestrial monitoring techniques; • Increased spatial coverage of ground motion information; • Improved performance of satellite navigation receivers for cost-effective and accurate landslide monitoring; • Increased user's access to information; • Increased user's interest for the services.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost and time for asset condition monitoring
Further information	https://artes-apps.esa.int/projects/matist

Best Practice / Technology REF: T007

©TRL 2013

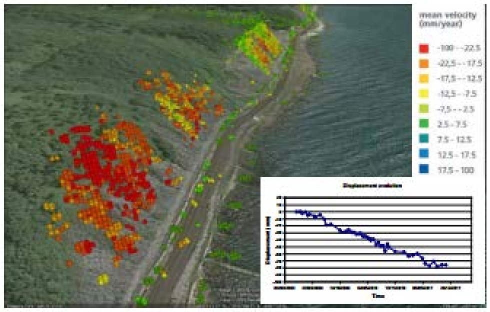
Image collecting survey vehicle

©Airbus DS / Spot Image 2013

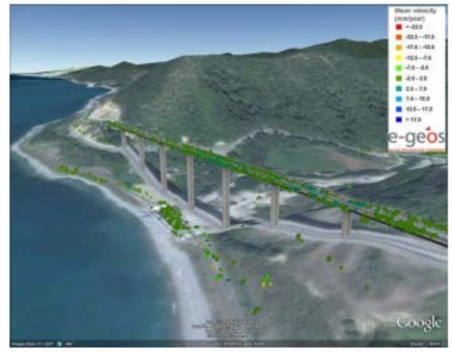
Field	Description

Title and Keywords	Title: **Transportation Infrastructure Monitoring Project (TranMon)**
Source of best practice / technology	The Satellite Applications Catapult, Defence & Space, TRL, Nigerian Federal State and urban roads outside city of Kano
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	
Short Description	The Satellite Applications Catapult, in partnership with Airbus (formerly Astrium Geo Information Services) - a provider of geoinformation and geospatial services - and TRL (the UK's Transport Research Laboratory – an independent research and technical consultancy in the transport sector, with over 50 years' experience of working in Africa) set up the Transport Infrastructure Monitoring Project (TranMon) to investigate the potential for existing and near future satellite capability to assist in the management of road assets. An initial scoping study concluded that satellite data would be particularly useful in the following areas: • Remote areas, that are difficult or expensive to access on the ground • Areas affected by security and safety issues • Areas of disaster; both man-made (human displacement) and natural (hurricanes, floods, earthquakes) The aim of the TranMon Project was to demonstrate that the capability to perform semi-automatic road detection using satellites exists, and that road information, extracted from satellite imagery, can be incorporated and exploited in an existing road asset management system (the TRL Road Asset Management System, iROADS
Success factors	Due to the global coverage and temporal frequency of satellite data, significant savings can potentially be made with regard to cost and time required to collect information on infrastructure assets, as well as reduced risk to life. These savings can be made through the ability of satellite data to provide the information required to map, monitor and assess road infrastructure condition and distribution as an alternative to the deployment of surveying teams on the ground.
Constraints	Granularity of datasets
Main impacts	Reduced cost and time for highway asset monitoring
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	https://sa.catapult.org.uk/documents/10625/53676/C222722+TranMon+CS+Stg5.pdf/d10eba88-e3c7-4d0a-bf3c-2d73881075d8

Best Practice / Technology REF: T010



Landslides along the Tuapse-Adler railway, Russia. PSP-IFSAR analysis from COSMO-SkyMed HIMAGE SAR data.

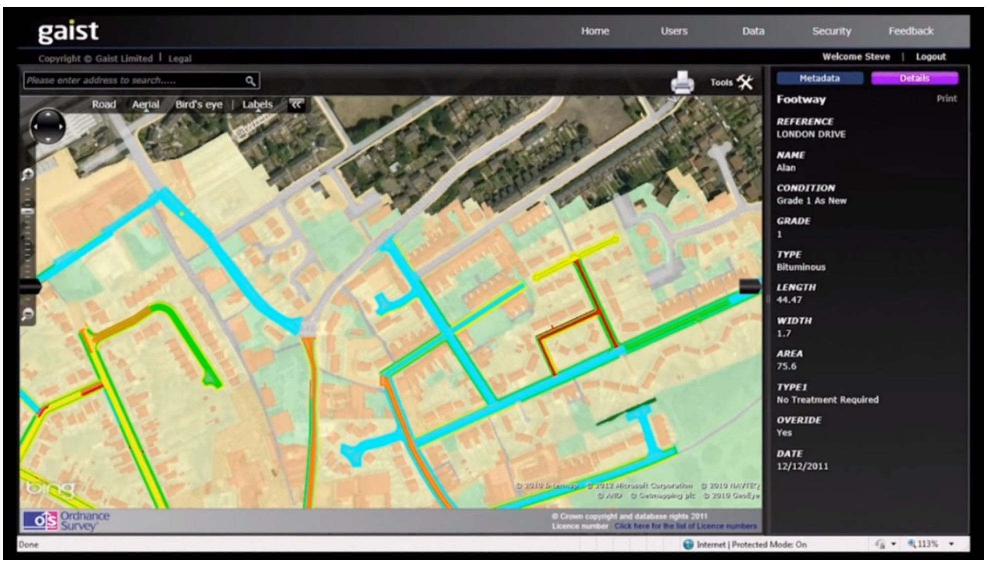


Zubov bridge, Black Sea coast, Russia. PSP-IFSAR analysis from COSMO-SkyMed HIMAGE SAR data.

Field	Description
Title and Keywords	Title: **Ground Deformation Analysis by PSP SAR Interferometry**
Source of best practice / technology	Telespazio Vega UK/ e-GEOS. Trials at Zubov bridge, Black Sea coast, Russia; Landslides along the Tuapse-Adler railway, Russia.
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road
Component of infrastructure	Earthworks
Element of the infrastructure	
Short Description	Telespazio Vega UK provide a portal to all the Telespazio Geo-Information group services, including e-GEOS ground deformation monitoring products, and to data from most other commercial suppliers. Vega adds further value through integration of in-situ data, (of particular benefit for some ground deformation applications), delivery to remote locations via reduced bandwidth and the option of access via tablet and smart phone applications. Repeat-pass satellite synthetic aperture radar (SAR) interferometry (IFSAR) is a very effective technology for the measurement with millimetric accuracy of ground deformation due to subsidence, landslides, earthquakes and volcanic phenomena. The technology relies on the fact that the phase difference between two SAR images acquired at different times and with slightly different view angles is related to the topography and also to the changes in the observed scene and the transmission medium on the different dates. The measurements are made over objects on the ground with stable radar backscatter properties. These persistent scatterers (PS) are usually found in areas with light vegetation cover, and especially corresponding to structures – artificial or natural – such as buildings,rocks, etc. Vega's sister company e-GEOS has developed an advanced persistent scatterer interferometry approach, named Persistent Scatterer Pairs (PSP) – IFSAR, an original solution to the main limitations of classical techniques in the accurate determination of terrain displacement.
Success factors	Key elements of the system are: • High quality ground deformation measurements, both in terms of accuracy and density, even in areas where radiometrically stable structures are very

	sparse, or with displacements that evolve non- linearly over time. • Robustness: the algorithm exploits redundant information to obtain very reliable results. • Automation: the robustness of the algorithm and processing chain minimize the need for human intervention. • Parallel software running on a high-performance system reduces processing time.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost and time for monitoring
Further information	http://www.telespazio-vega.com/~/media/Files/T/Telespazio-Vega/pdfs/2811ground-deformation.pdf

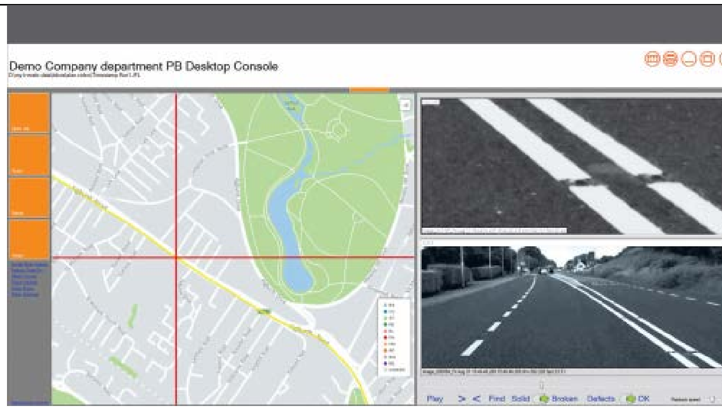
Best Practice / Technology REF: T011



Field	Description
Title and Keywords	Title: **Using real-time updates and high accuracy level technology to combine highway condition and maintenance data from a wide range of sources**
Source of best practice / technology	Gaist Solutions, University of York, Blackpool City Council Highway Authority
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	
Short Description	The partnership between Gaist and the University of York involves researchers from the University's York Centre for Complex Systems Analysis (YCCSA) working with

	specialists from Gaist Solutions to combine condition and maintenance data from a wide range of sources. Using an unprecedented level of accuracy and a real-time update mechanism, they are able to ensure the effective targeting of ever scarcer resources. GRP-2 is a web based shared information platform for all functional levels - management, external stakeholders and the public, if required. Now everyone can understand and gain the value of corporate asset information without programming skills, technical knowledge or an understanding of the underlying data sources or structures. GRP-2 provides very intuitive interfaces and easy to use tools which empower users to unlock the value of the information available to them. Gaist designed the GRP-2 system to maximise collaboration between all information stakeholders offering the capability to publish and circulate geospatial information creating a high level of situational awareness. Operational tasks can be captured electronically and managed centrally in real time to ensure compliance with health and safety regulations, procedures and policies etc. The GRP-2 system is designed to work as a hosted service or be deployed within any corporate IT infrastructure. Workflow routines can be configured providing efficient and transparent works management. The system allows the storage of many different types of data providing organisations with a highly innovative repository for their valuable data with the ability to access it instantly and from anywhere at anytime.
Success factors	The sucess of the partnership was highlighted in Blackpool's performance in the annual national public satisfaction survey carried out by MORI on behalf of the National Highways and Transportation Network. While the survey, which involved 116 local authorities, found that overall views about the condition of highways in the UK are still at near record low levels, Blackpool Council bucked the trend. It gained the largest improvement for overall satisfaction, tackling congestion and road safety while also gaining the best overall score for road safety. The authority was also rated in the top five for improvements in public transport, walking and cycling, and highway maintenance.
Constraints	
Main impacts	Features include centralised tracking of assets, ability to import and management of CAD plans and maps, uploading/storage of images and other media, inventory and workflow management, mobile working and online collaboration with clients, integration with environmental data, and live links to traffic data.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Safety and reduced congestion
Further information	http://www.gaist.co.uk

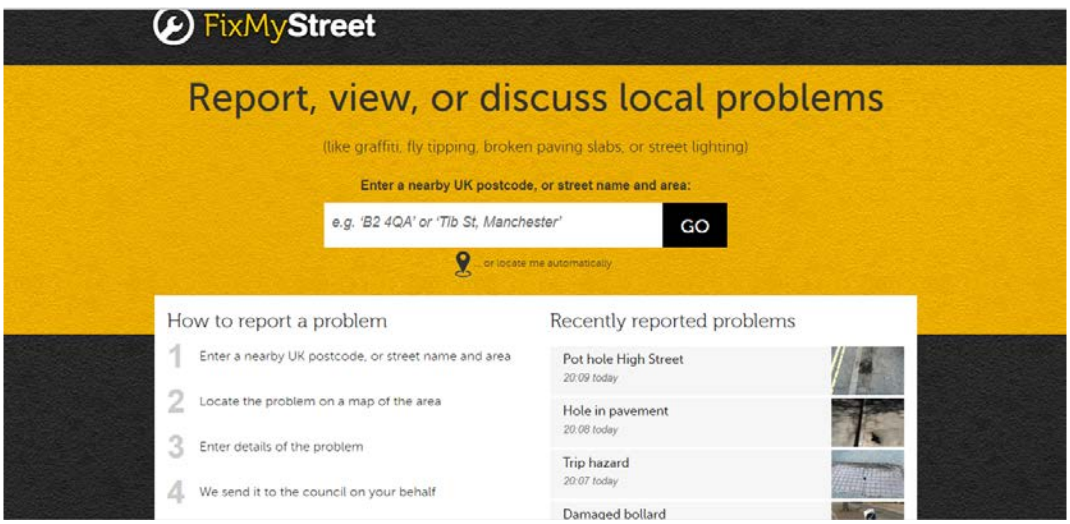
Best Practice / Technology REF: T012



Field	**Description**
Title and Keywords	Title: **Development of road stud survey solution**
Source of best practice / technology	KOREC Group, Kelly Bros, MILESTONE Pavement Technologies, Trimble Technology, Transport Infrastructure Ireland (formerly National Roads Authority)
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	Road studs
Short Description	In tackling a very specific challenge - the streamlining of road stud reflectivity and condition surveys - an Irish company has created a video/GPS based system and workflow, streamlining the survey process by integrating a state of the art reflectivity camera, a sub-metre GPS and customised software to turn a manual data collection task, that could take 2 weeks of field work, into one that takes less than 2 hours. In Ireland, these monitoring surveys are carried out directly by the National Roads Authority (NRA) or by roads contractors through Motorway Maintenance and Renewals contracts (MMaRC). One company tendering for these MMaRC contracts is Kelly Bros, a leading road marking contractor in Ireland and manufacturer of high-quality road-marking materials and associated products. Kelly Bros were convinced that the existing workflow for these surveys could be greatly improved through the introduction of a more integrated approach. Each MMaRC requires three different types of information to be recorded; firstly the reflectivity of each road stud which demands a night time survey, secondly, information on the physical condition of the stud including details such as stability, rubber condition and physical appearance which requires a daylight survey and thirdly, the road marking reflectivity which can be done at any time. Additionally, the position of each stud has to be logged by GPS or referenced to the nearest road marker. The collected data, mostly recorded manually, would then be transcribed into a report format as specified by the MMaRC. A final major drawback to this manual method was that despite needing extensive traffic management, the surveys could still only be undertaken at walking pace or at the speed of a slow moving quad bike. Work began with a third party to develop the specialised camera central to the

	system's success. The result was a highly sophisticated light sensitive camera that could pick up both the reflectivity of each road stud at night and its physical condition during the day and yet also compensate for any shake or vibration due to vehicle movement. Consequently the camera was capable of producing the flawless still images that Kelly Bros required. This camera was mounted on the inside of the vehicle windscreen, next to the rear view mirror, using a suction cup. Meanwhile, Kelly Bros had approached UK and Irish Trimble distributor KOREC to produce the customised software that would link the camera with the dashboard mounted GPS. In this case a Trimble GeoExplorer handheld unit offering sub-metre accuracy was selected for its reliability and ease of use. Working in partnership with Kelly Bros, K-MATIC, KOREC's in-house software division, customised its K-Mobile field data capture and office software which in turn was to complete the system's missing link.
Success factors	With data collected at normal driving speeds, by technology rather than the naked eye, there is no need for traffic management, no need for transcribing information back at the office and the whole process can be completed in hours rather than days.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced time for data collection and reporting
Further information	http://www.korecgroup.com/media/KOREC-%20Kelly%20Bros.pdf

Best Practice / Technology REF: T015



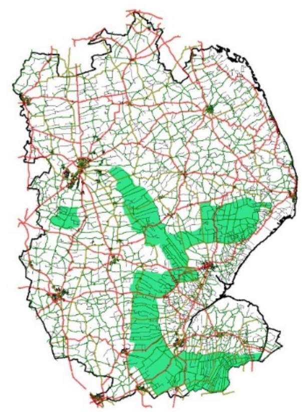
Field	Description
Title and Keywords	Title: **FixMyStreet GIS online tool and mobile app**

Source of best practice / technology	FixMyStreet
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	
Short Description	FixMyStreet is an independent website, built by the charity mySociety. It is intended to make it easier to report problems in local communities, even if residents do not know who those reports should go to. All the user has to do is type in a postcode – or let the site locate the user automatically – and then describe the problem. Then FixMyStreet send a report to the people whose job it is to fix it at the relevant local authority. FixMyStreet covers the whole of the UK. Some local highway authorities integrate their asset management systems directly, so that FixMyStreet can place report details directly into their systems, saving them time and money.
Success factors	Time and cost savings from infrastructure surveys
Constraints	Accuracy of data provided by public
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Improved safety
Further information	https://www.fixmystreet.com/

Best Practice / Technology REF: T018	
Field	**Description**
Title and Keywords	Title: **Leveraging Vehicle Infrastructure Integration (VII) Data for Pavement Condition Monitoring**
Source of best practice / technology	Transportation Research Board
Lifecycle stage	Design / Operation
Type of infrastructure	Road
Component of infrastructure	Pavement
Element of the infrastructure	
Short Description	The TRB paper from the 87th Annual Meeting, 2008, outlines a method to monitor pavement conditions using the emerging Vehicle Infrastructure Integration (VII) programme to leverage vehicle accelerometer and position data. GPS and body mounted accelerometers are used to collect data.
Success factors	Accelerometers are effective at detecting potholes and other pavement distress
Constraints	Spatial uncertainty of GPS data precludes the simple averaging of data. Post-processing accelerometer data with correlation algorithms required to effectively identify pavement distress.

Main impacts	
Maturity and degree of implementation	TRL 1-3
Key Performance Indicators	
Further information	https://trid.trb.org/view.aspx?id=847537

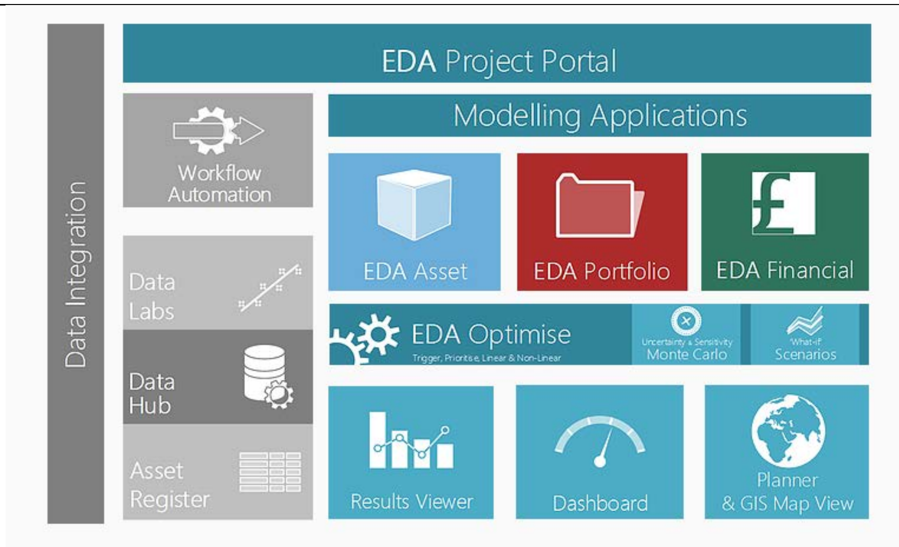
Best Practice / Technology REF: T028

Field	Description
Title and Keywords	Title: **Soil geohazard mapping for improved asset management of UK local roads**
Source of best practice / technology	Cranfield University (Infrastructure Transitions Research Consortium), Lincolnshire County Council Highway Authority.
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road
Component of infrastructure	Earthworks
Element of the infrastructure	
Short Description	Unclassified roads comprise 60 % of the road network in the United Kingdom (UK). The resilience of this locally important network is declining. It is considered by the Institution of Civil Engineers to be “at risk” and is ranked 26th in the world. Many factors contribute to the degradation and ultimate failure of particular road sections. However, several UK local authorities have identified that in drought conditions, road sections founded upon shrink/swell susceptible clay soils undergo significant deterioration compared with sections on non-susceptible soils. This arises from the local road network having little, if any structural foundations. Consequently, droughts in East Anglia have resulted in millions of pounds of damage, leading authorities to seek emergency governmental funding. The Infrastructure Transitions Research Consortium (ITRC) assessed the use of soil-related geohazard assessments in providing soil- informed maintenance strategies for the asset management of the locally important road network of the UK. A case study draws upon the UK administrative county of Lincolnshire, where road

	assessment data have been analysed against mapped clay-subsidence risk. This reveals a statistically significant relationship between road condition and susceptible clay soils. Furthermore, incorporation of UKCP09 future climate projections within the geohazard models has highlighted roads likely to be at future risk of clay-related subsidence.
Success factors	The mapping was successful in informing an improved asset management strategy for Lincolnshire County Council. The approach is now also being adopted for work on the UK major trunk road network managed by Highways England.
Constraints	Resolution and accuracy of datasets.
Main impacts	Using Cranfield University's geohazard datasets and Lincolnshire County Council's road network and condition surveys, the ITRC assessed soil-related geohazards for Lincolnshire's highways department. ITRC concluded that areas prone to clay-related subsidence, which is intensified in drought conditions, have a detrimental impact on road surface quality. Lincolnshire Highways Alliance has since used the research to allocate £600k of road maintenance fund. EPSRC feature the work in a 'Big data' case study to demonstrate the practical impacts of funded research. The research has not only supported Lincolnshire County Council's latest road maintenance funding bid to the Department for Transport, but also helped them further understand the soil-related risks which they have and are likely to face in the future, helping the Council plan appropriate mitigation strategies.
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Improved asset management strategy and access to financing for renewal
Further information	http://www.itrc.org.uk/soil-geohazard-mapping-for-improved-asset-management-of-uk-local-roads/ http://www.geolsoc.org.uk/Geoscientist/Archive/March-2014/Cracking-up-in-Lincolnshire https://www.epsrc.ac.uk/newsevents/casestudies/bigdata1/

Best Practice / Technology REF: T043



Field	Description
Title and Keywords	Title: **Data analytics to inform investment and asset management strategies for local highway lighting assets**
Source of best practice / technology	SEAMS Ltd, London Borough of Bromley
Lifecycle stage	Maintenance / Operation
Type of infrastructure	Road
Component of infrastructure	Street lighting
Element of the infrastructure	
Short Description	With £1.6 billion in assets to manage, London Borough of Bromley initiated the ‘invest to save’ programme in 2011 which identifies areas where the borough can realise cost savings by investing in capital assets earlier. Projects are put forward for the ‘invest to save’ scheme and considered on cost savings, benefits and impact on services. The Transport & Highways division wanted to investigate whether investing in street lighting assets earlier than planned would return future cost savings. They approached SEAMS to investigate three potential strategies against the current plan from a ‘Do Nothing’ scenario to replacing all street lighting assets within a 12 month period. SEAMS’ consultants worked with LBB staff to analyse the different scenarios and SEAMS’ Enterprise Decision Analytics software was used to calculate future costs for each asset. The analysis took into consideration electricity, carbon dioxide, maintenance, structural testing and emergency replacement costs and considered 28% of the total asset stock of 27,624.
Success factors	SEAMS’ analysis showed that significant savings could be realised by increasing investment in columns replacement, and that these strategies would begin to

	deliver return on investment between six and eight years.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced whole-life costs
Further information	http://media.wix.com/ugd/6f225a_d823dd3fad7945e0813a4eeb3c771589.pdf

Best Practice / Technology REF: T047	
 	
Field	**Description**
Title and Keywords	Birmingham Highways Maintenance and Management Service upgrading traffic signals and traffic management systems
Source of best practice / technology	Siemens, Amey, Birmingham City Council
Lifecycle stage	Operation
Type of infrastructure	Road
Component of infrastructure	
Element of the infrastructure	
Short Description	Leading UK infrastructure services provider Amey, which works in partnership with Birmingham City Council to run the highways maintenance service in the city, has placed an order with Siemens for an upgrade to the latest PC SCOOT Urban Traffic Control (UTC) system. The existing analogue data transmission system will be replaced with the latest UTMC compliant UG405 outstations installed in tandem with a new Internet Protocol (IP) communications network on behalf of Amey as part of their UTMC upgrade project in Birmingham.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Energy-saving, cost-saving
Further information	http://www.npl.co.uk/upload/pdf/20121204_street_lighting_scragg.pdf

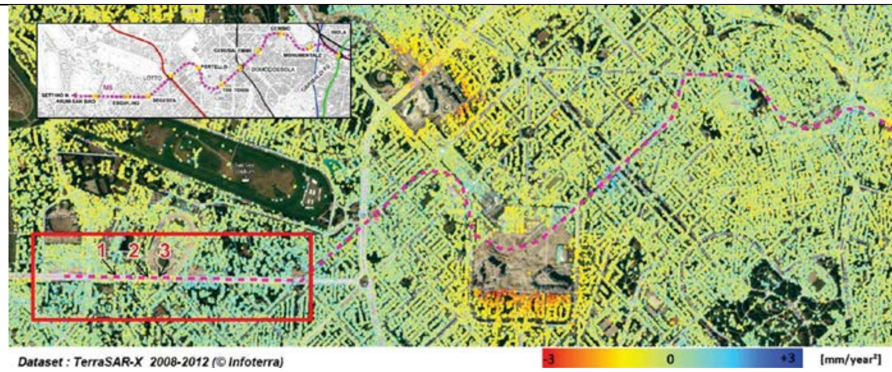
Best Practice / Technology REF: T058	
	
Field	**Description**
Title and Keywords	Managed Motorways Calibration and Optimisation (MMCALO)
Source of best practice / technology	Highways Agency Transport Research Laboratory
Lifecycle stage	Operation
Type of infrastructure	Road
Component of infrastructure	
Element of the infrastructure	
Short Description	In 2011 it was recognised by the Highways Agency (HA) that to ensure the on-going optimisation of MM schemes, the HA itself should have the knowledge, skills and tools to be able to visualise and assess system performance, as well as calculate and calibrate MM operational parameters. As a consequence, TRL was asked to develop a process (including roles and responsibilities), a set of guidance documents, a training course, and a web-based software tool - the MMCALO Toolkit. Now, as a result of this work, the HA's Delivery Partners have trained Optimisation Engineers, whose role is to fulfil the requirements as set out in the guidance document, and work in conjunction with a Highways Agency Scheme Representative and Central Client Side Specialist. Operating within this framework, the MMCALO Toolkit is a useful tool in improving the efficiency, quality and consistency of the Optimisation Engineer's tasks.
Success factors	This work has enabled the Highways Agency to bring about more optimised Managed Motorways schemes, meaning that the information and instruction presented to customers using the schemes is as appropriate as possible. This in turn enables customers to trust the accuracy and usefulness of the information.
Constraints	
Main impacts	On-going optimisation reduces the risk of the performance of MM schemes not keeping pace with changing traffic patterns or conditions, hence sustaining the effectiveness of schemes and the return on the capital investment.
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced risk, more effective schemes
Further information	http://www.trl.co.uk/case-studies/intelligent-transport-systems/

Best Practice / Technology REF: T061	
	
Field	**Description**
Title and Keywords	Airborne remote sensing using LiDAR
Source of best practice / technology	Neon Science
Lifecycle stage	Operation
Type of infrastructure	Road / Rail / Water / Air
Component of infrastructure	
Element of the infrastructure	
Short Description	The NEON airborne observation platform (AOP) collects annual remote sensing data over NEON field sites using sensors mounted on an airplane. The AOP consists of a hyperspectral imaging spectrometer, a full waveform and discrete return LiDAR, and a high-resolution Red, Blue Green (RGB) camera. Data from the AOP build a robust time series of landscape-scale changes in numerous physical, biological and biochemical metrics, such as vegetation cover and density, canopy chemistry, and topography, including elevation, slope and aspect.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	http://www.neonscience.org/data-resources/papers-publications

Best Practice / Technology REF: T063	
Field	**Description**
Title and Keywords	Automatic Monitoring System for Continuous Structural Assessment of Tunnels (SYSTUNNEL) KEYWORDS: monitoring, fiber optics, alarms, data analysis

Source of best practice / technology	TRE – Tele-Rilevamento Europa TRE Canada
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	The system – SysTunnel - is an automatic tunnel monitoring system for continuous structural assessment of tunnels using only fiber optic sensors. It results from the joined work of FiberSensing and EPOS. The SysTunnel consists on several strain and temperature sensors installed along the contour of the tunnel's structure. The sensors are based on Fiber Bragg Grating (FBG) technology. Tunnel convergences are calculated using the MEMCOT method to estimate convergences which is most suited for tunnels in operation since it does not need the traffic to be interrupted to take measurements and has a marginal impact on the clearance gauge.
Success factors	The first example of application of the SysTunnel refers to the Rossio Tunnel in Lisbon. The Rossio Tunnel is a centenary structure that was rehabilitated in early 2000's for safety reasons. The system has been successfully operating since its installation in 2008. The importance of the structure dictated the installation of a long term monitoring system. The automation and continuous data saving creates a large amount of data that needs to be checked and evaluated. The definition of alarms for emergency values or for regular evolution has been deeply studied. With data collected over the last 5 years, seasonal behavior of the structure has been identified and tendencies out of this behavior are the values that should be cautiously been look for. In a different approach the SysTunnel system was also installed by Moretti Engenharia in a short length of one of the Metrô de São Paulo tunnel, in Av. Paulista, for a limited period. An anchored diaphragm wall at a short 11 m distance from the metro tunnel needed to be constructed for the erection of a tall building with several underground floors. The regular operation of the metro train while the excavation was taking place dictated the need for an intensive and redundant monitoring plan that would include a continuous remote system to control the structure's behavior. It was the speed of deformation measured by the SysTunnel together with the conventional convergence measurements on the tunnel that allowed a proper and timing reaction to the effects of the excavation on the operating tunnel.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Easy monitoring, alarm generation, decision making support, alarm generation
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T064



Field	Description
Title and Keywords	Satellite radar data to monitor tunneling-related surface displacements in sensitive urban areas KEYWORDS: Tunneling Monitoring, SqueeSAR™, satellite, surface displacement
Source of best practice / technology	TRE – Tele-Rilevamento Europa TRE Canada
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail
Component of infrastructure	
Element of the infrastructure	
Short Description	Satellite radar data have been used in recent decades to monitor ground displacements, thanks to a technique known as advanced satellite InSAR. The latest development of this technique is SqueeSAR™, which allows the identification of ground points and their displacement in time with millimetric accuracy. The high density of measurement points coupled with the possibility to cover large areas (up to 10.000 km2) allows site characterization at a fraction of the cost of conventional surveys. Furthermore, SqueeSAR™ data are complementary to in-situ measurements and does not require the installation of any ground instrumentation.
Success factors	SqueeSAR™ has been already applied in several projects related to underground tunneling (mainly TAV railway tunnels) and resulted to be a useful tool in all stages of a tunneling project, from design to construction and management. In this paper 3 case studies (Rome, Milan, Vancouver) of metro lines tunneling monitoring with SqueeSAR™ will be presented, in different urban context.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Cost saving
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T069

Field	Description
Title and Keywords	Multiple Gas Detection (MGD) technology for early fire detection in tunnel environments
Source of best practice / technology	SENTIO by Firefly Firefly RST
Lifecycle stage	Operation
Type of infrastructure	Rail / Road
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Multiple Gas Detection (MGD) technology, originally developed for aerospace, is based on the detection of gases and specifically fire related gases. The principle is to identify the 'smell' (composition of gases) in the air in an early stage of a fire (see chapter 4.1). Each 'smell' will form a unique 'fingerprint'. Registered gas patterns (fingerprints) will be classified as a 'permitted' (non-dangerous) or 'not permitted' (dangerous) pattern. An example of a 'non-dangerous' combustion gas is diesel fume from a truck. With MGD technology, these types of 'known disturbances' can be suppressed.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Early detection of accidents and other related incidents
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T074

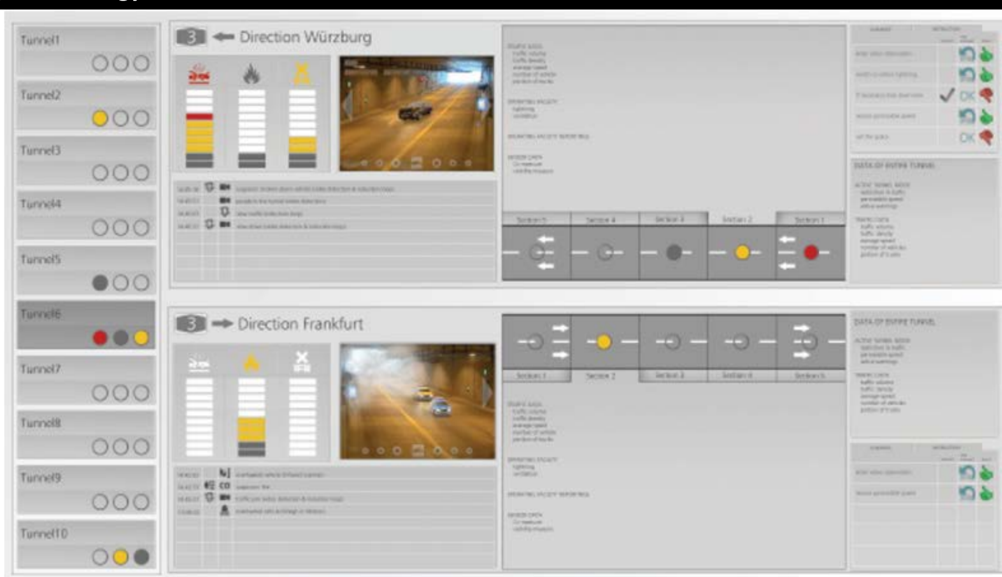
Figure 1 - LCMS/LFOD/LTSS Sensors and Controller

Figure 2 - Laser Profiling of Pavement

Figure 3 - LTSS Mounted on an All-terrain Vehicle

Field	Description
Title and Keywords	Use of 3D Scanning Technology for Automated Inspection of Tunnels
Source of best practice / technology	World Tunnel Congress 2014 proceedings
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail
Component of infrastructure	
Element of the infrastructure	
Short Description	Significant advances in high-speed 3D imaging technology have been made in the last decade and there are now commercial, off-the-shelf, solutions for automatically evaluating infrastructure condition at high-speed.
Success factors	Pavemetrics Systems Inc., Quebec City RFI Consulting Services, Euroconsult Group
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	http://www.pavemetrics.com/wp-content/uploads/2016/04/Tunnel-Scanning_Pavemetrics_Euro.pdf

Best Practice / Technology REF: T075



Field	Description
Title and Keywords	Real-time visualization of road tunnel safety status
Source of best practice / technology	World Tunnel Congress 2014 proceedings Research Association for Underground Transportation Facilities – STUVA Ilmenau University of Technology Federal Highway Research Institute PTV Transport Consult GmbH

	OSMO-Anlagenbau GmbH & Co
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	Tunnel operators are often responsible for a large number of tunnels within an entire region. Hence, it is necessary for them to assess the safety status of individual tunnels in a reliable way and to identify possible risk and incident situations at an early stage. For this purpose, the operator has separate monitoring screens for each tunnel as well as additional screens for operational and traffic data. Furthermore, the traffic can visually be observed via video cameras. Often, individual tunnels are monitored and controlled via different control systems. Thereby, frequent changes between heterogeneous user interfaces are necessary. Hence, the main disadvantage is that in risk or incident situations precious time is sometimes lost due to the readaptation to different user interfaces. As a result, in case of an event and intensive event management, the overview of other tunnels may get lost. Therefore, a superordinated user interface for tunnel control centers is desirable which can be used for monitoring the safety status of a large number of tunnels simultaneously.
Success factors	Enable the required event management to be executed properly. However, not only the early detection of risk or incident situations is in focus but also, in particular, the possibility to minimize the extent of damage by early intervention in the course of an event.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Improve safety and reliability, reduces human inspection, reduces costs
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

7.2 Type of infrastructure: Rail

Best Practice / Technology REF: T003

Field	Description
Title and Keywords	Title: **CSIC Instrumenting the Staffordshire Alliance new Rail bridges for smart infrastructure condition monitoring**
Source of best practice / technology	Cambridge Centre for Smart Infrastructure & Construction (CSIC), Staffordshire Alliance (a partnership of Atkins, Laing O'Rourke, Network Rail and VolkerRail)
Lifecycle stage	Construction / Maintenance / Operation
Type of infrastructure	Rail
Component of infrastructure	Bridge
Element of the infrastructure	Bridge deck
Short Description	The £250m Stafford Area Improvements Programme will increase capacity on the West Coast Main Line near Crewe, allow for train speeds up to 100 mph (160 kph), and aims to both reduce congestion and improve maintainability. The main project works are scheduled for completion by winter 2016. For this project, CSIC is implementing monitoring systems in two of the 11 new bridges being constructed as part of this major improvement programme. The first bridge is a pre-stressed concrete girder bridge and the other a steel composite girder bridge. The aim is to develop a robust, highly distributed and real-time fibre optic based bridge monitoring and data collection system. CSIC has deployed two types of fibre optic monitoring systems, one distributed system based on Brillouin Optical Time Domain Reflectometry (BOTDR) and the other a point-based system using fibre Bragg gratings (FBG) capable of measuring changes in strain in real time. At present, more than 400 FBG sensors and over 600 metres of BOTDR sensor cables have been installed. These sensors have already provided some fundamental data that has been useful in determining static and dynamic load response, and will continue to feed analysis of the performance of the structures once the bridges are in use.

	Now, even more advanced data analysis and visualisation techniques are being developed to provide engineers and researchers with an invaluable tool for understanding the actual structural behavior of bridges. Investigation is also underway into the load deformation response of railway track beds utilising fibre optic sensing, dynamic laboratory testing and finite element modelling.
Success factors	The monitoring system is a resilient, easy-to-installand cost-effective alternative to more conventional systems. Fibre optic sensors present a number of advantages over more traditional instrumentation, including their size, non-ferrous non-corroding nature, longer life span and immunity to electromagnetic radiation. This project represents the first time new bridges have been instrumented in such detail to understand their structural behaviour from the moment they are created. The evaluation of actual short-term pre-stress losses, the onset of composite action, and the realtime tracking of live train forces as they are transmitted through the various structural components will all be made possible using this sensor system. CSIC's installed fibre-optic bridge monitoring systems will serve as long term demonstrators for this technology, showcasing the UK as a world-leading innovator in civil infrastructure sensing.
Constraints	Short time available for instrumentation during construction process
Main impacts	It is anticipated that the findings of this work will provide valuable feedback for the design of future large scale infrastructure projects such as HS2 and could lead to more economic designs and more efficient asset management strategies.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Accurate real-time measurements reducing the need for visual inspections and providing the evidence for more efficient asset management strategies
Further information	http://www-smartinfrastructure.eng.cam.ac.uk/what-we-do-and-why/focus-areas/data-analysis-interpretation/projects-and-deployment-case-studies/rail-bridge-monitoring-case-study

Best Practice / Technology REF: T009	
Field	**Description**
Title and Keywords	Title: **Infrastructure Monitoring Using Passive Remote Imagery**
Source of best practice / technology	Highways England, Network Rail, SelexES, University of Birmingham
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail
Component of infrastructure	Earthworks
Element of the infrastructure	
Short Description	The use of satellite imagery offers the potential for cost-effective measurement of surface variations. Spaceborne Interferometric Synthetic Aperture Radars (InSAR)

	make use of orbiting satellites to image a given area. Images from successive passes of the satellite can be used to calculate ground displacements. Recent advances have enabled the development of a subclass of InSAR using ground surface mounted receivers, the Passive Interferometric Space-Surface Bistatic Synthetic Aperture Radar (PInSS-BSAR). The PInSS-BSAR topology has a stationary receiver fixed on the ground, with the imaging antennae pointed towards the area of interest. A satellite moving relative to the surface generates an electromagnetic ranging signal illuminating the observation area. The signal is reflected by the earth's surface, and received by the radar antennae. By using two antennae, one fixed above the other, it will be possible to calculate the change in displacement in the vertical direction. PInSS-BSAR is best utilised using non-cooperative transmitters, i.e. satellites being used for other purposes. Global Navigation Satellite Systems, such as GPS and Galileo provide large numbers of non-geostationary, simultaneously operating satellites above the horizon, which illuminate a particular region at different angles. At any time, the satellites should cover the entire surface of the planet without any points in electromagnetic shadow. This University of Birmingham led research project sought to develop a cost-effective monitoring system using PInSS-BSAR to measure surface variations, with specific application to linear infrastructure such as roads and railways, and their associated embankment and cutting slopes. The prototype device will be verified against existing conventional surface displacement instrumentation already installed to monitor two large failing infrastructure slopes.
Success factors	The study undertaken so far has proven the feasibility in using navigation satellites to provide RF imagery for remote sensing applications. This is a major breakthrough in the RF remote sensing community, which had not considered this possibility before. The proposed system has to some extent provided a new remote sensing tool, which is cheap and persistent and therefore can augment or in some occasion replace current technologies.
Constraints	
Main impacts	Reduced cost in monitoring
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	
Further information	http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/G056838/1

Best Practice / Technology REF: T017


Field	Description
Title and Keywords	Title: **Network Rail viaduct degradation monitoring**
Source of best practice / technology	Senceive, Amey, Network Rail
Lifecycle stage	Renovation / Operation
Type of infrastructure	Rail
Component of infrastructure	Viaduct
Element of the infrastructure	Soffit
Short Description	The Network Rail structures team were concerned about the overall movement of a very old viaduct and were most particularly concerned about the potential propagation of a crack on the underside of one of its main arches. Weekly visual inspections were both expensive and not able to provide sufficiently accurate data on movement over time. Setting up wired sensor solutions were regarded as too expensive and difficult to install given the demands of the location. Senceive were commissioned to deploy a range of sensors across the bridge including a) crack potentiometers along the length of the crack b) a draw wire to assess movement across the full width of the arch and c) integrated tilt meters to assess movement on the sides of the spandrel wall. Temperature was also measured, which is standard in all nodes. Deployment was challenging due to the height of the arch, and the very limited accessibility from beneath. Full track possession was required, and limited to engineering hours at night. Specialist abseiling contractors were used to belay off the rails and access the underside of the arch. Standard FlatMesh sensors were supplemented by several repeater nodes to ensure data was relayed to the solar powered GPRS gateway which was situated a little way from the end of the bridge on top of the approach embankment. Data was monitored and viewed remotely using the Senceive Webmonitor software.
Success factors	The availability of web based data every 15 minutes provided a key level of critical information which informed the decision to carry out timely remedial work to repair the area in and around the crack. Selected nodes were left in place to ensure continued monitoring following the repair work. In all this was a very successful 18 month installation.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10

Key Performance Indicators	Reduced risks and improved safety; reduced cost and time.
Further information	http://www.senceive.com/wp-content/uploads/2015/12/Senceive_ViaductMonitoring_NetworkRail.pdf

Best Practice / Technology REF: T019

Field	Description
Title and Keywords	Title: **Smart monitoring of Brunel's box tunnel**
Source of best practice / technology	Senceive, AECOM, Network Rail (Great Western Mainline)
Lifecycle stage	Renovation
Type of infrastructure	Rail
Component of infrastructure	Tunnel
Element of the infrastructure	Soffit
Short Description	The Great Western Mainline is being electrified. It passes through Brunel's 3km Box Tunnel, bored through four distinct strata and two geological fault zones. It was completed in 1841 and subsequently lined due to structural instability. There is a complex and irregular geometry with 2km of brick lined sections, 350m of unlined sections and 464m of free standing brick arches. In order to achieve clearances for overhead lines, the track was lowered by up to 350mm. The key challenge was to implement an economical, industrially resilient and precise, wire free monitoring solution over 3km within a fully operational and congested construction site. Senceive, using its third generation FlatMesh and working in close co-operation with AECOM, implemented a novel and innovative totally wire and mains power free monitoring system of 250 sensors with a few gateways. Precise and stable data sent every 20 minutes helped verify predicted structural movements, identifying trends before instability occurred over the 3km. Senceive's innovative, user friendly and easy to install FlatMesh monitoring system was chosen to achieve this.
Success factors	
Constraints	
Main impacts	A highly successful and innovative project. Despite extremely limited and constrained access, the system operated throughout the engineering works. Data was collated by a small number of customised battery powered GPRS gateways,

	giving remote access in real time with triggers and text/ email alerts for users in/outside of the tunnel, free of wires and power.
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	
Further information	www.senceive.com

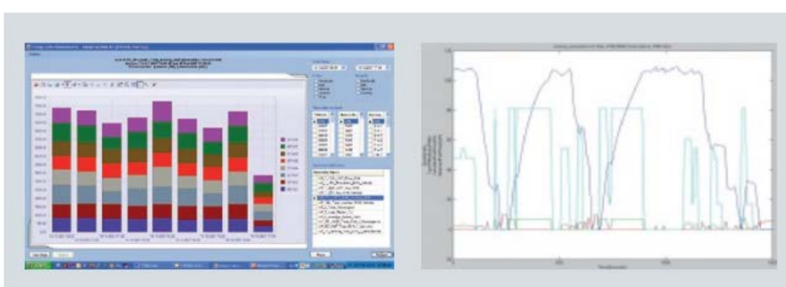
Best Practice / Technology REF: T030



Field	**Description**
Title and Keywords	Title: **The Proactive Infrastructure Monitoring and Evaluation (PRIME) System: Technology Demonstrator for Remote Monitoring of Transportation Earthworks.**
Source of best practice / technology	NERC British Geological Survey, Highways England, Network Rail, Scottish Canals, Canal & Rivers Trust, CIRIA
Lifecycle stage	Maintenance / Operation
Type of infrastructure	Road /Rail / Water
Component of infrastructure	Earthworks
Element of the infrastructure	
Short Description	With the help of funding from the Natural Environment Research Council (NERC) and Innovate UK, together with support via the UK Geotechnical Asset Owners Forum (GAOF) – with membership of a number of transport authorities in the UK - the project team have sought to change current asset management practice with an economically viable monitoring and early warning system, PRIME, that produces near-real-time information to provide decision support and 'solutions' for a range of infrastructure earthwork instability problems. In particular, the project aims to demonstrate and validate newly developed geophysical monitoring technology as a means of improving the resilience of vulnerable rail and water transportation earthworks infrastructure to environmental risks, such as extreme weather and flooding. The new technology could stream near-real-time information on the internal condition of earthworks direct to geotechnical asset owners - thereby allowing slope failure processes to be identified at an early stage so low cost preventative intervention can be planned with minimal disruption to infrastructure (rather than high-cost renewal and remediation of catastrophic earthwork failures, which can be highly disruptive - particularly for the rail industry due to financial penalties associated with delays).

	In response to guidance by the industrial partners, the project team aim to further demonstrate and validate the PRIME concept by testing the approach in a greater range of operational settings, including an operational Network Rail railway embankment (Old Dalby test track) and a water retaining structure on the canal network. These trials are allowing the project team (asset owners, managers and research providers) to consider a range of practical deployment options, demonstrate an adaptive intelligent monitoring approach, undertake a cost benefit analysis, and formally assess the Technology Readiness Level of PRIME by drawing upon the outcomes of the case studies developed under this project and the study undertaken during the related Innovation B project.
Success factors	The overarching aim of the project is to provide the necessary evidence to the stakeholders that PRIME is applicable as an economically viable monitoring, early warning and decision support system (i.e. a 'solution') for a range of infrastructure earthwork instability problems.
Constraints	Access to operational demonstration sites (which has been provided)
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced time and cost for maintenance
Further information	http://gtr.rcuk.ac.uk/projects?ref=NE/M008479/1 http://www.ciria.org/Memberships/Knowledge_hub/Blog_The_Geotechnical_Asset_Owners_Forum_a_site_visit_to_the_British_Geological_Survey.aspx?WebsiteKey=3f18c87a-d62b-4eca-8ef4-9b09309c1c91

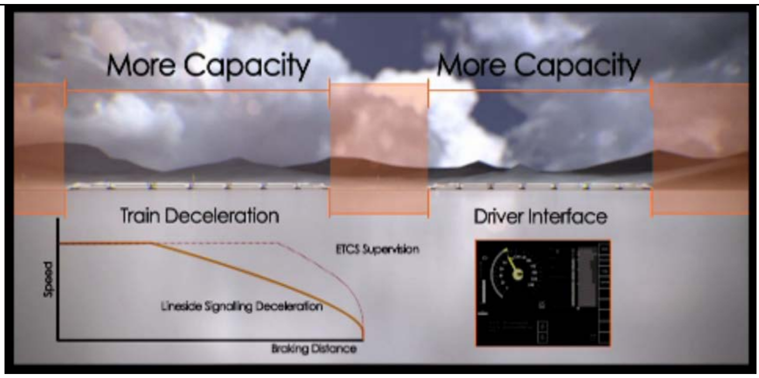
Best Practice / Technology REF: T031

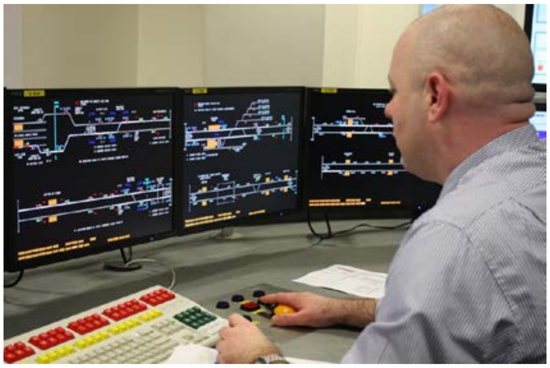


Field	Description
Title and Keywords	Title: **Energy Management Control System for Rail**
Source of best practice / technology	Bombardier
Lifecycle stage	Maintenance / Operation

Type of infrastructure	Rail
Component of infrastructure	Rolling Stock, Track
Element of the infrastructure	
Short Description	Bombardier's Energy Management Control System is designed to integrate energy awareness, efficiency and carbon control into an operator's business where it may be applied to both new and existing fleets. The system provides customers with an accurate and affordable fleet energy management solution, using data gathered from the trains and flexible and intuitive visualisation tools based on methods proven in the BOMBARDIER* ORBITA* system. The objective is to provide useful information to train the operator's management team for them to proactively manage their energy spend. The system is suitable for retrofit to existing vehicles, both diesel and electric. Combined with Bombardier's data collection and analytical tools, designed for reducing energy consumption, customers are provided with easy to-understand consumption information and advice. The ability to overlay this data with, for example, driver input and route characteristics, gives the operator a much clearer view of how and when their vehicles consume energy. Bombardier participated in a joint study by ATOC (UK Association of Train Operating Companies) and National Express, which identified that one of the largest variable factors in energy management is driving technique. The study demonstrated that there is up to 11% difference in energy used between flat-out drivers (those who use full brake and throttle) and drivers who are sympathetic to conditions.
Success factors	
Constraints	Open sharing of data on energy performance with other rail stakeholder who could benefit
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced energy for operation
Further information	http://www.bombardier.com/content/dam/Websites/bombardiercom/supporting-documents/BT/Bombardier-Transportation-ECO4-Energy_Management-EN.pdf

Best Practice / Technology REF: T040





Field	Description
Title and Keywords	Title: **European Rail Traffic Management System (ERTMS) trials**
Source of best practice / technology	Network Rail
Lifecycle stage	Renovation / Operation
Type of infrastructure	Rail
Component of infrastructure	Signalling
Element of the infrastructure	
Short Description	This tried and tested system will replace traditional railway signals with a computer display inside every train cab, reducing the costs of maintaining the railway, improving performance and enhancing safety. Instead of lineside signals, a computer in the driver's cab controls the speed and movement of the train, whilst taking account of other trains on the railway. Installing ERTMS across Great Britain as signalling becomes life-expired will save an estimated 40 per cent over conventional systems. Each train will run at an appropriate safe speed, allowing more trains onto the tracks. ERTMS will improve train performance and reduce energy consumption. Although still operating under the umbrella term of ERTMS, Network Rail are creating their own traffic management system to optimise performance. By bringing the control system inside each individual train, ERTMS allows specific customised

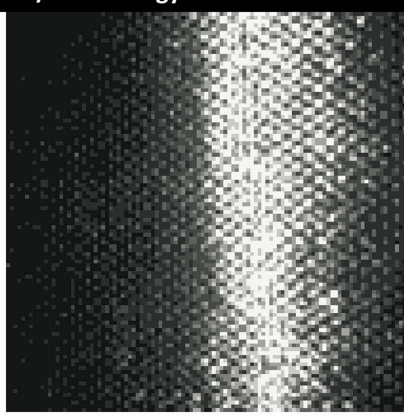
	control. This allows the drivers to always run at the optimum safe speed helping more trains run faster and recover from delays quicker. Network Rail are carrying out testing on part of the Hertford Loop, north of London, using a converted former passenger train. This will trial four suppliers' technology and will help to decide which contractor is best suited to undertake work to install ERTMS on the Great Western and East Coast Main Lines in Control Period 5 (2014-19).
Success factors	Improved mobility, better data.
Constraints	Upgrading existing legacy infrastructure
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Improved mobility, better data.
Further information	http://www.networkrail.co.uk/aspx/12275.aspx

Best Practice / Technology REF: T050

Field	Description
Title and Keywords	PLANTO biodegradable track management lubrication products
Source of best practice / technology	FUCHS
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	
Element of the infrastructure	Tracks
Short Description	Since the 1970s, FUCHS has been pioneering research in developing lubricants from sustainable and renewable resources, with the aim of limiting environmental impact. FUCHS is now respected as a world leader in biodegradable lubricant technology and has developed the technically advanced PLANTO range of products. PLANTO oils are high performance lubricants based on renewable raw materials, such as rapeseed and sunflowers, combined with downstream esters and specially selected additives. All of the products are rapidly biodegradable. Using them minimises environmental damage and reduces clean-up and disposal costs in the event of leaks or equipment defects.

	Performance is not compromised either: the unique combination of raw materials ensures optimum performance, surpassing that of the traditional mineral oils mainly used by the rail industry today.
Success factors	Test results obtained during the construction of the Eden Project in Cornwall showed wear rates of hydraulic system components were 10 times lower when using PLANTOSYN 46 HVI than with conventional mineral hydraulic oil. Furthermore, many PLANTO products carry approval to the 'Euro-Marguerite', the official eco-label of the European Commission.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Environmentally friendly, low aquatic toxicity, reduce CO2 Emisions, meets requiremenets to ISO 15380, free of organic halogen or nitrite compounds
Further information	

Best Practice / Technology REF: T051



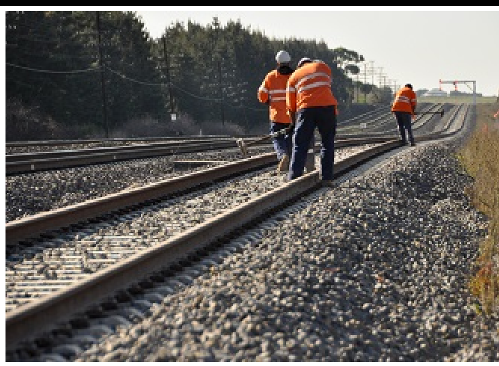

Field	**Description**
Title and Keywords	Strengthening structural elements using carbon fibre strengthening materials
Source of best practice / technology	Fibrwrap Construction UK, Concrete Solutions
Lifecycle stage	Construction / Renovation
Type of infrastructure	Road / Rail / Air / Water
Component of infrastructure	Structures
Element of the infrastructure	
Short Description	The Ryfo Fiberwrap systems are externally bonded fiber reinforced polymer (FRP(systems applied to normal-weight concrete and masonry substrates. The systems consists of carbon, glass, aramid and hybdif fabrics combined with resins which in combination, create the FRP composite material.
Success factors	In-plane shear strengthening In-plane flexural enhancement Out-of-Plane flexural enhancement

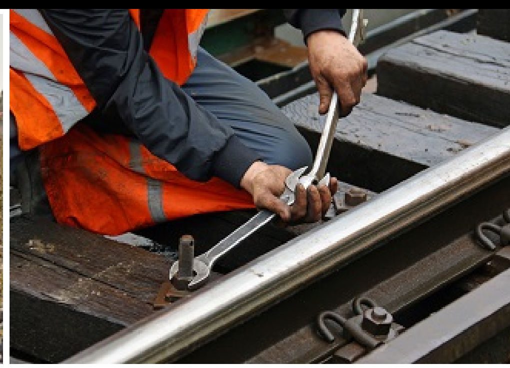
	Shear transfer between wall panels
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Structural enhancement of beams, columns, walls and slabs
Further information	http://concretesolutions.co.nz/services/composite-strengthening

Best Practice / Technology REF: T052	
	
Field	**Description**
Title and Keywords	Derby London Road Overbridge Replacement
Source of best practice / technology	HBPW Consulting Ltd, Morgan Sindall Plc, Network Rail
Lifecycle stage	Renovation / Construction / Design
Type of infrastructure	Road / Rail
Component of infrastructure	Bridge
Element of the infrastructure	
Short Description	In June 2013, Morgan Sindall was awarded the contract to construct a single span replacement for an existing three span structure, replacement of a further single span over sidings and associated road remodelling works. The replacement work included: temporary footbridge, temporary stats diversions, Spans 1-3 bridge demolition, Span 4 bridge replacement, piled and pad foundations, pressure relieving trough and parapets, new BOW arch span, approach parapets and slabs, stats permanent diversion, and approach roadworks and footways. The work was completed in February 2015. It has opened up one of the main radial routes into the city providing a gateway for the significant redevelopment / regeneration sites. It also provides opportunity for the alterations to track layout and electrification in the future.
Success factors	Safe – Zero Accident Frequency Rate

	On Time – Road opening achieved ahead of Contract Programme. No environmental incidents and no noise complaints over the 18-month construction period.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Increased safety, cost-saving
Further information	http://www.ceequal.com/awards_236.html

Best Practice / Technology REF: T059

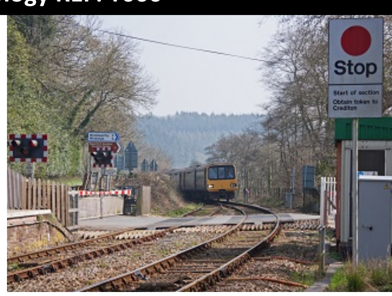




Field	Description
Title and Keywords	Sensors for track-side safety and lone works
Source of best practice / technology	Digital Barriers
Lifecycle stage	Maintenance / Operation
Type of infrastructure	Rail
Component of infrastructure	
Element of the infrastructure	
Short Description	Protecting staff is a primary concern in the rail industry, and it is a particular worry in remote and vulnerable locations. EdgeVis Body Worn, Digital Barriers' unique video-transmitting technology, enhances worker safety. It combines GPS location with a real-time video stream of what a worker is seeing and doing, allowing supervisors to spot and address any potential dangers or causes for alarm. Live video from remote working locations enables rapid identification of issues when trackside workers or lone staff find themselves in difficulties. Obtaining usable video from remote locations is problematic as conventional video codecs aren't designed for poor transmission over low bandwidth or constrained networks. Typically image break-up or delay renders video feeds unusable. EdgeVis BodyWorn cameras on a tunic or helmet will send images back to a central control room with none of these issues.

	The technology was specifically developed to overcome the problems of streaming over congested and low bandwidth wireless networks, and will reliably deliver usable and continuous video and audio even over GPRS/2G/Satellite at bandwidths as low as 9kbps.
Success factors	The technology was specifically developed to overcome the problems of streaming over congested and low bandwidth wireless networks, and will reliably deliver usable and continuous video and audio even over GPRS/2G/Satellite at bandwidths as low as 9kbps. The technology uses around 60% less bandwidth than standard video transmission systems so there are significant savings in data too, making video feeds from rail workers cost effective as well as viable. The video stream is distributed to central command and other rail workers as required. It can be integrated into existing video management systems, while secure local recording allows accurate evidence of events to be kept for forensic and evidential use. The solution also has an on-board panic button and can be used alongside Push4Help and Heartbeat safety services.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Less bandwith compared to standard video transmission, easy integration
Further information	https://www.digitalbarriers.com/rail-road

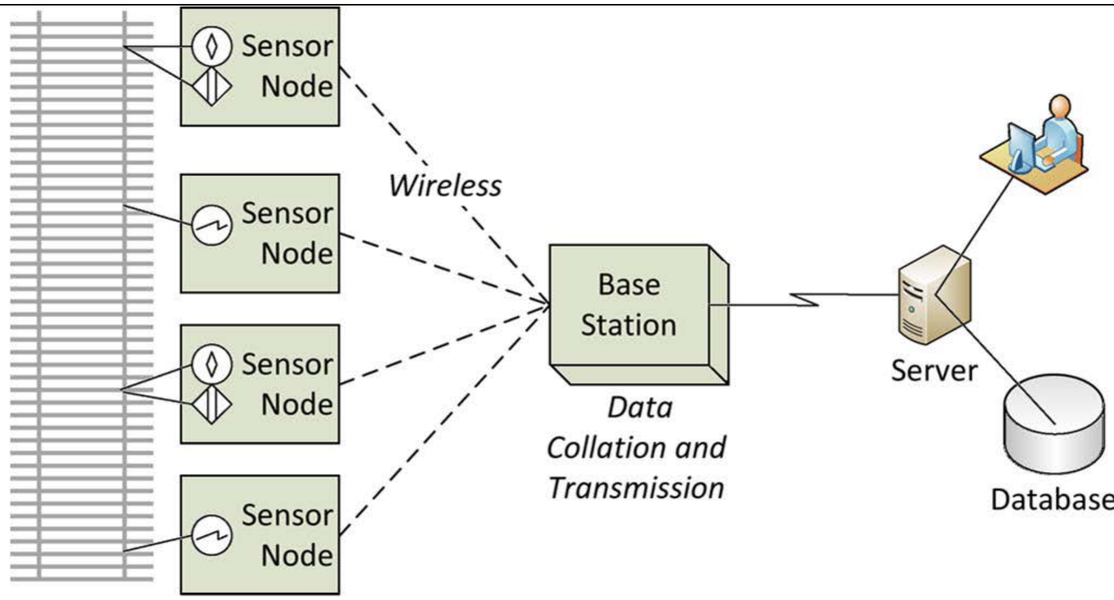
Best Practice / Technology REF: T060



Field	**Description**
Title and Keywords	Level crossing monitoring sensors
Source of best practice / technology	Digital Barriers website
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Level Crossing
Element of the infrastructure	
Short Description	Failing to spot a breakdown in video transmission from a level crossing could have

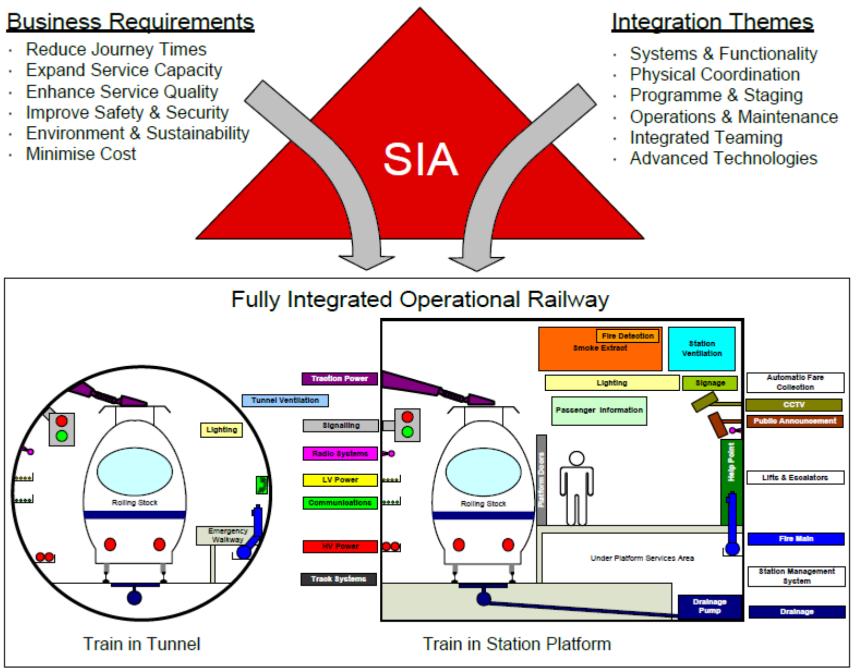
	potentially catastrophic results. High levels of activity will provide visual confirmation that video is streaming. However, during long periods with little or no movement in a scene, video can freeze without an operator being aware. Digital Barriers' world-leading technology, though, provides assurance that equipment is operational by embedding safety alarms and visual indicators into its video encoding solutions to confirm images are live. There are in excess of 4,500 recorded incidents of misuse or error involving rail level crossings each year in the UK alone. According to Network Rail safety statistics, this includes more than 400 near misses with vehicles, pedestrians and other road users - and a number of fatalities. Rail and metro systems with safety-critical applications require surveillance solutions that are engineered for reliable long-term performance. Our safety features also include alarms if any attempt is made to cut a cable or sabotage a camera.
Success factors	The COE range of surveillance equipment from Digital Barriers has been proven in the rail sector over the past 20 years. Video transmission solutions are certified for level-crossing monitoring in the UK, with equipment deployed to more than 200 locations. The latest certification of COE equipment for use by Network Rail in the UK rail network is used for transmitting video over a digital network using Ethernet and IP protocol. Specific applications include level-crossing surveillance and signalling applications requiring video transmission over a digital network (FTN, Ethernet LAN/WAN).
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Safer solution for monitoring level crossings.
Further information	https://www.digitalbarriers.com/rail-road

Best Practice / Technology REF: T076



Field	Description
Title and Keywords	Monitoring System of Railway Tunnels with Wireless Sensor Network
Source of best practice / technology	World Tunnel Congress 2014 proceedings
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Road / Rail
Component of infrastructure	Tunnel
Element of the infrastructure	
Short Description	In recent years, the range of sensing technologies has expanded rapidly, whereas sensor devices have become cheaper. This has led to a rapid expansion in condition monitoring of systems, structures, vehicles, and machinery using sensors. Key factors are the recent advances in networking technologies such as wireless communication and mobile ad hoc networking coupled with the technology to integrate devices. Wireless sensor networks (WSNs) can be used for monitoring the railway infrastructure such as bridges, rail tracks, track beds, and track equipment along with vehicle health monitoring such as chassis, bogies, wheels, and wagons.
Success factors	Condition monitoring reduces human inspection requirements through automated monitoring, reduces maintenance through detecting faults before they escalate, and improves safety and reliability.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Improve safety and reliability, reduces human inspection, reduces costs
Further information	http://www.wtc2014.com.br/bookabstracts.pdf

Best Practice / Technology REF: T077



Field	Description
Title and Keywords	Advanced systems integration in major rail projects
Source of best practice / technology	Bechtel, Crossrail
Lifecycle stage	Operation
Type of infrastructure	
Component of infrastructure	
Element of the infrastructure	
Short Description	In major railway projects where there is considerable level of systems integration complexity, a dedicated SIA needs to be actively considered from the early stages of the project. The SIA will consolidate the business needs and the integration requirements and ensure that the risk to successful project completion and delivery of a robust operational railway is carefully mitigated through each stage of the project life-cycle.
Success factors	
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Safety, cost-effective, enhance of output
Further information	http://events.imeche.org/docs/default-source/rail-events/c1408-stephenson-conference-brochure_z_web_update_1

	http://www.bechtel.com/getmedia/f73ea008-363f-4594-9ec1-f21eb473fe40/S-Bhamra-et-al,-2015-Adv-System-Integ-in-Major-Rail-Projects/

Best Practice / Technology REF: T078

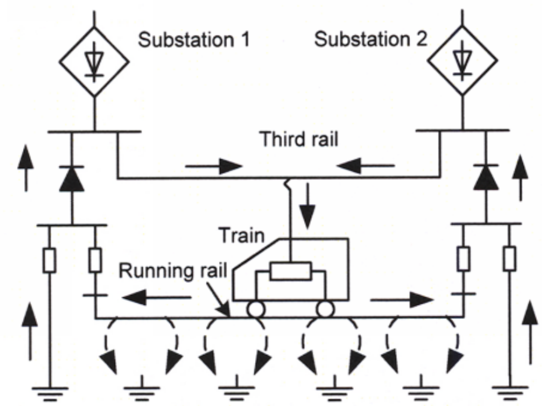


Figure 1. DC electrified railway system

Field	Description
Title and Keywords	Stray of Current Control in DC Railway Systems Keywords: DC elecrified railways, stray current control, corrosion control, earthing system
Source of best practice / technology	Transportation Research Board, Arup
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	
Element of the infrastructure	Tracks
Short Description	In DC rail transit systems, the running rails are usually used as the return conductor for traction current. This arrangement mainly focuses on economic considerations, since it does not require the installation of an additional return conductor. Low resistance between the traction return rails and the ground allows a significant part of the return current to leak into the ground. This is normally referred to as leakage current or stray current. The amount of leaking current depends on the conductance of the return tracks

	compared to the soil; and on the quality of the insulation between the tracks and soil. The stray currents represent serious problems for any electrified rail transit system. The project team: • Collected existing data from both national and international transit agencies (around 30 in total) • Interviewed six corrosion consultants • Field tested three real-life transit systems (two national and one international transit agency) • Authored four conference papers/magazine papers • Gave several presentations, lunch-time talks at Arup, and presented at conferences. The PM is working on advancing computer modelling techniques to calculate the total stray current leakage and the potential metal loss for neighbouring utilities.
Success factors	The research team found that there is a need for uniform design guidelines for stray current isolation, along with track maintenance and testing program in the US transit community. As a result, the team is compiling guidelines including measures for pre-construction, design phasing, and post-construction, followed by design maintenance measures during the revenue service of the transit system. These recommendations, if followed, will achieve uniform stray current isolation and QC for a DC-powered transit system. These guidelines, complemented by a track maintenance and testing plan will help transit agencies keep stray current leakage to a minimum and help in the implementation of QC measures. By implementing the recommendations and best management practices found in these guidelines, coupled with a pre-planned maintenance regime, it's possible to reduce the unpredictable and repetitive cost of repair and breakdown resulting from stray currents.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Reduced cost, improved safety.
Further information	http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3087

Best Practice / Technology REF: T079	
Field	**Description**
Title and Keywords	Title: 'Smart repair' strategies using advanced metrology for enhanced structural health monitoring Keywords: Optics, photonics & lasers, optical devices, subsystems
Source of best practice /	City University London, United Kingdom (Lead Research Organisation)

technology	National Physical Laboratory NPL, United Kingdom (Co-funder) Sengenia Ltd, United Kingdom (Project Partner)
Lifecycle stage	Design, Maintenance & Operation
Type of infrastructure	Road or rail
Component of infrastructure	Pavement, tunnel, bridges and others
Element of the infrastructure	Abutments, decks, beams, columns, pavement
Short Description	Serviceability and enhanced whole life performance are critical to effective use and the long-term monitoring of such structures is invaluable to ensure full structural capability, to minimize risk to the public and give value for money. The sort of system proposed in this project will provide early warning of potential problems and help in the better planning of maintenance and repair: the proposal herein will allow the repair strategies to be determined, monitored and evaluated. The overall aim is thus for better information to predict the likely potential for failure, the need for repair, the efficacy of the repair and thus the likely lifetime of a structure such as a bridge. This recognizes the wide industrial need for predictive systems that can monitor structures and inform the asset holder on its state of health, both in terms of its physical structure and chemical changes, where the type of structure could include bridges, buildings, power plant, aircraft, chemical plant etc.
Success factors	Gives a simple clear indication of the structure's health will provide substantial economic benefits since there are over 10,000 bridges worth more than 1M each in the UK alone - offering effective repair and thus cheaper maintenance and lower running costs would thus be of significant benefit.
Constraints	
Main impacts	A major aim of the work is to make a real impact on the industry and thus on the public at large. There are likely to be significant beneficiaries of the research outputs within the 'user communities', both immediately and in the longer term. For example, in the commercial private sector it is likely that the collaborating SME will be a beneficiary in being able to broaden its experience in the field and being able to bid to licence the exploitation of the 'know how' and explicitly the sensor systems which are developed in the course of the work. Other companies, such as sensor manufacturers will also be given the opportunity to bid for such a licence if necessary and this aspect will be led by the Technology Transfer Office (TTO) at City University. In addition, working with the Structural Health Industrial Advisory Group at NPL, which provides an industry-academic forum for the dissemination of work in the structural health monitoring field, other industries, academics and policy-makers would be exposed to the potential benefits from this research.
Maturity and degree of implementation	1-3 (Research level)
Key Performance Indicators	Cost savings,
Further information	*http://gtr.rcuk.ac.uk/project/5D64C5DF-BF13-4A8D-BBEE-0CDEAC9619B9*

Best Practice / Technology REF: T080

Field	Description
Title and Keywords	Assessment of Landslides using Acoustic Real-time Monitoring Systems (ALARMS): Sensor Technical Development Key Words: slopes, ground engineering, acoustic sensors,
Source of best practice / technology	NERC British Geological Survey, United Kingdom (Lead Research Organisation) Geotechnical Observations Ltd, United Kingdom (Project Partner)
Lifecycle stage	Maintenance & Operation
Type of infrastructure	Road and rail
Component of infrastructure	Geotechnical assets
Element of the infrastructure	Slopes
Short Description	The detection system consists of one or more sensors installed across the slope that presents a risk of collapse. The sensors record the acoustic activity of the soil and rock as it deforms. Monitoring detects only high frequency sound so that background noise is not considered and hence false alarms are avoided. Acoustic emission rates, created by inter-particle friction in soil and crack propagation and displacement on discontinuities in rock, are proportional to rates of movement and so increased acoustic emissions mean a slope is closer to failure. Once a certain emission rate is recorded, the system can send a warning, via a text message, to the authorities responsible for safety in the area.
Success factors	This project aims to design and assess field performance of a prototype acoustic slope displacement rate sensor. Sensors developed through research will be re-engineered and these new sensors will be installed at problem road and rail slopes to investigate how they perform compared to traditional more costly instrumentation.
Constraints	Only for movement detection. Not high level of assessment. Only early warnings
Main impacts	It is essential to have an early warning of slope instability to enable evacuation of vulnerable peoplel, repair and maintenance. Protect critical infraestructre. As well as the life-saving implications for countries prone to disastrous landslides, the technique can also be used in monitoring the condition of potentially unstable slopes built to support transport infrastructure.
Maturity and degree of implementation	*4-7 (technology development & demonstration)*

Key Performance Indicators	Cost Saving, safety,
Further information	http://gtr.rcuk.ac.uk/project/EDE4358A-DD57-4EE8-8530-628FB9995E09 http://www.slopealarms.com/

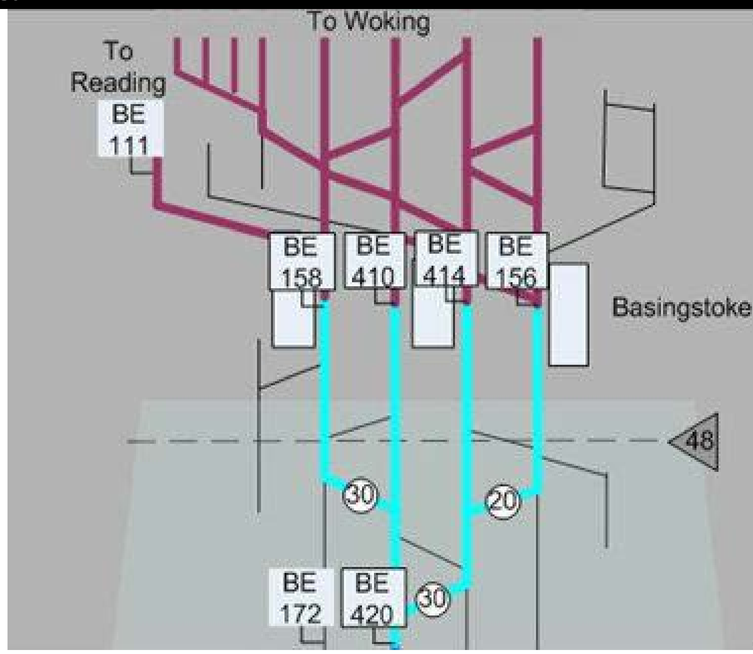
Best Practice / Technology REF: T082	
Field	**Description**
Title and Keywords	Long-term performance of geotechnical transport infrastructure Keywords: Earthworks, Specifications, Sustainability, Field testing,
Source of best practice / technology	University of Southampton, United Kingdom (Lead Research Organisation) Mott Macdonald UK Ltd, United Kingdom (Project Partner) Whitby Bird and Partners, United Kingdom (Project Partner)
Lifecycle stage	Design, Maintenance & Operation
Type of infrastructure	Roads and Rail
Component of infrastructure	Geotechnical Assets
Element of the infrastructure	Slopes, retaining walls
Short Description	Field monitoring has provided many important insights into the real behaviour of geotechnical transport infrastructure such as embankments, tunnels and retained or battered cuts, resolving uncertainties for research, design, construction control or economic purposes. Where such monitoring is carried out, it is usually over a relatively short period of time for example during construction or in connection with a specific maintenance or remediation requirement. Professor Robert Mair's March 2006 Rankine lecture demonstrated the value of longer term field measurements, which may indicate unexpected and unforeseen continuing changes in the behaviour and condition of the infrastructure and the state of the surrounding ground. As the owners and custodians of our transport infrastructure seek to extend its economical life through sometimes extensive in-service maintenance and refurbishment, an understanding of the factors governing its long-term behaviour and state will become increasingly important.In recent years, the Geomechanics Research Group at the University of Southampton has installed loggable instrumentation in connection with a number of research projects to investigate the performance during and for a short period after construction of geotechnical structures such as slopes and retaining walls for transport infrastructure. In some cases, this instrumentation is still in place and working, offering a unique opportunity to continue monitoring to gain an insight into the long-term performance of the structures as equilibrium conditions are gradually reached, perhaps in response to new or unforeseen boundary conditions such as changing climate patterns and groundwater conditions or further construction nearby.
Success factors	The opportunity to answer some questions concerning the long-term performance of geotechnical transportation infrastructure whose answers have remained elusive for decades. These are the potential for the re-establishment of in situ lateral stresses on retaining structures in overconsolidated deposits; the interpretation of strain gauge readings in underground concrete structures as the concrete ages; the impact of cyclic seasonal variations on the stability of unreinforced and remediated cutting and embankment slopes; and the interactions between buried structures and the

	groundwater regime.
Constraints	
Main impacts	Major benefits in terms of the design of new infrastructure and predicting the service life and impacts of climate change on existing structures.
Maturity and degree of implementation	TRL 1-4
Key Performance Indicators	Cost savings, safety,
Further information	http://gtr.rcuk.ac.uk/project/9AB755C9-B44C-4AB4-97AE-EABE46D7D2A2

Best Practice / Technology REF: T083	
Field	**Description**
Title and Keywords	Infrastructure monitoring using passive remote imagery Keywords: monitoring, remote imagery
Source of best practice / technology	University of Southampton, United Kingdom (Lead Research Organisation) Network Rail Ltd (Project Partner) Selex-Galileo, United Kingdom (Project Partner) Highways Agency, United Kingdom (Project Partner)
Lifecycle stage	Maintenance & Operation
Type of infrastructure	Road and Rail
Component of infrastructure	Earthworks, bridges, pipelines, dams, tunnels
Element of the infrastructure	
Short Description	New infrastructure construction projects, particularly large basements and tunnels in urban areas, may require extensive monitoring systems to enable the resulting ground displacements to be measured and compensated for where necessary. The cost of such monitoring, especially over large geographical areas which may be remote or inaccessible, is significant. One of the most effective ways of assessing the performance of infrastructure is to measure surface variation (displacement) and relate instability or loss of performance to the rate of change of this variation..The use of satellite imagery offers the potential for cost-effective measurement of surface variations. Spaceborne Interferometric Synthetic Aperture Radars (InSAR) make use of orbiting satellites to image a given area. Images from successive passes of the satellite can be used to calculate ground displacements. The prototype device will be verified against existing conventional surface displacement instrumentation already installed to monitor two large failing infrastructure slopes.
Success factors	
Constraints	InSAR surface change detectors is that they were developed for global, rather than local, area monitoring purposes and have a long satellite revisit time. Another potential problem is that using only one or two satellites, an area of interest could be in an electromagnetic shadow (i.e., the satellite cannot illuminate the area due to an obstacle blocking the satellite signal). This can occur especially in urban areas or hilly terrain.
Main impacts	The proposed research seeks to develop a cost-effective monitoring system using PInSS-BSAR to measure surface variations, with specific application to linear infrastructure such as roads and railways, and their associated embankment and cutting slopes.

Maturity and degree of implementation	1-3 (Research level)
Key Performance Indicators	More efficient monitoring and early warning systems have the potential to save large sums of money, and even human life.
Further information	http://gtr.rcuk.ac.uk/project/4C1C59C3-1791-416A-AA54-2A48DB6F4413

Best Practice / Technology REF: T090



Field	**Description**
Title and Keywords	Future Traffic Regulation and Optimisation (FuTRO)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Future Traffic Regulation and Optimisation (FuTRO) programme aims to deliver the capabilities and technologies required for the next generation of railway traffic management system. The core FuTRO operational philosophy was published in 2014.
Success factors	Initial projects within the programme include the development of algorithms to control traffic through junctions and across routes, as well as targeted innovation projects in the areas of big data and train location and mapping solutions, and driver information systems.
Constraints	
Main impacts	
Maturity and degree of	TRL 3-7 (Demonstration)

implementation	
Key Performance Indicators	An optimised, efficient traffic management system
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T091

Field	**Description**
Title and Keywords	Closer Running programme
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Closer Running programme aims to show how capacity can be increased by running trains closer together. This programme will look at technical and regulatory issues around closer running and how they may be overcome and potential solutions implemented on the network It will aim to develop early stage technical and commercial solutions to the problem of closer running, going beyond the current envisaged train control and traffic management systems.
Success factors	

Constraints	
Main impacts	
Maturity and degree of implementation	TRL 3-7 (Feasibility)
Key Performance Indicators	Increase in capacity with minimal change to existing infrastructure
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T092

Field	Description
Title and Keywords	COMPASS
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The COMPASS system will provide signallers with a tactical picture of the railway, identifying the position of trains at any given point. This will allow for improved operations during times of perturbation, resulting in reduced disruption to the travelling public and a reduction in delay payments for Network Rail.
Success factors	Phase 1 (assessment and understanding of the system) has been completed. Phase 2, developing a backup traffic management system, which undertakes trials in a representative system, is now underway.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 3-7 (Feasibility)
Key Performance Indicators	Increased resilience to control system failures
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T093

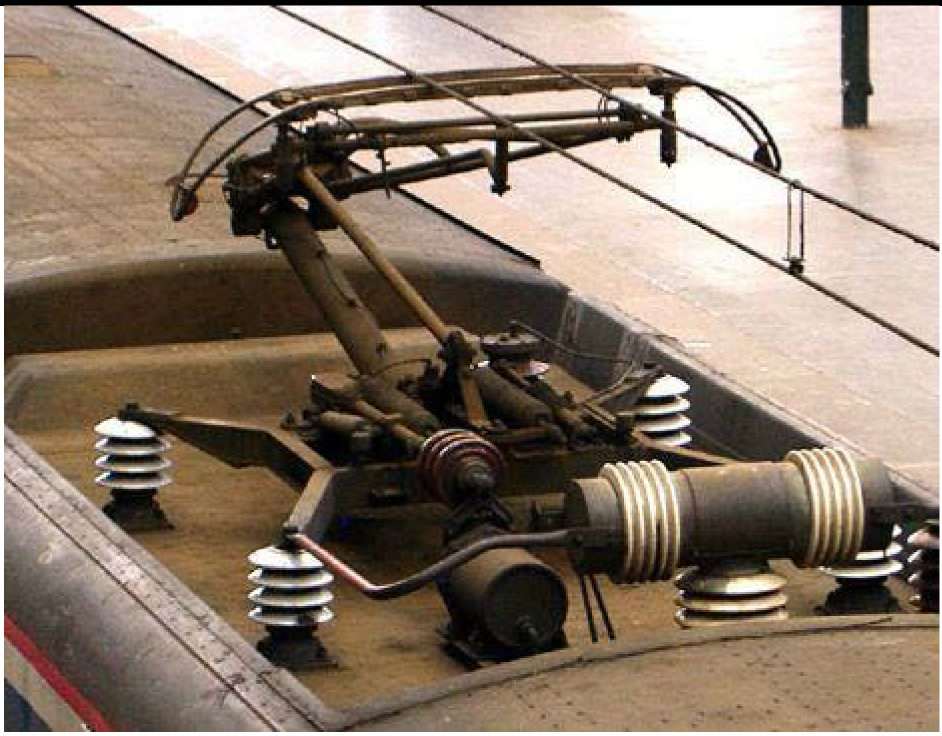
Field	Description
Title and Keywords	Telecoms Capacity Enhancement (Cyber Security Test facility)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Telecoms Capacity Enhancement (Cyber Security Test facility) programme will develop a system level test facility to enable product development and early trials to be conducted in a safe but realistic railway environment. This will aid in evaluating how emerging communications industry products can be applied to the railway while supporting traffic management and critical corporate systems.
Success factors	Existing cyber threat detection is based around identifying and blocking known behaviours. This is a reactive approach, where the core capability is never up-to-date with emerging threats. The core need, and problem statement, is to evaluate an approach which is capable of detecting and describing, in near real-time, emerging threats.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 3-7 (Feasibility)
Key Performance Indicators	Security and safety risk reduction
Further information	http://www.rssb.co.uk/future-railway-programme

Best Practice / Technology REF: T094

Field	Description
Title and Keywords	OnTimeOptimal Networks (Europe-wide)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The OnTimeOptimal Networks (Europe-wide) portfolio of R&D programmes aims to explore European solutions to a range of operational capacity related challenges. The areas studied include the development of robust and resilient timetables, methods for real-time management of operations, driver advisory systems, process and information architecture and the development of standardised definitions and methods.
Success factors	Results are ready and available to inform follow-on work, including standardised definitions, information architectures, interoperability, and perturbation management.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10 (Implementation)
Key Performance Indicators	Research to support solution development

Further information	http://www.rssb.co.uk/future-railway-programme

Best Practice / Technology REF: T095



Field	**Description**
Title and Keywords	Dynamic Pantograph programme
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Dynamic Pantograph programme aims to improve the interface between the pantograph and overhead lines. This will improve energy efficiency; increase capacity through enabling longer trains; and reduce maintenance costs and instances of pantograph failure, which can bring down the overhead lines.
Success factors	There are currently two projects underway for this challenge: improved pantograph maintenance techniques, and a new pantograph design.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 3-7 (Demonstration)
Key Performance Indicators	Improved network reliability, capacity and energy efficiency

Further information	http://www.rssb.co.uk/future-railway-programme

Best Practice / Technology REF: T096

Field	Description
Title and Keywords	Aesthetic Overhead Line Electrification (OLE)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Aesthetic Overhead Line Electrification (OLE) programme is demonstrating new sustainable designs which are less visually obtrusive. These designs are low cost, simple to manufacture, quick to deploy, and have high durability and low maintenance compared to existing designs.
Success factors	Scale models of each of the six designs have been created and exhibited at the National Rail Museum. The best three designs were chosen to be built at full scale for testing. The designs will have particular relevance to routes that pass through areas of natural beauty.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 3-7 (DemonstratioN)

Key Performance Indicators	Reduced environmental impact and lower costs
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T097

Field	Description
Title and Keywords	Remote Condition Monitoring (Network Rail)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Remote Condition Monitoring programme aims to address significant challenges in the monitoring and management of railway infrastructure. The challenges include flood warning, slope instability, control of railway property access and data analytics. New technologies will be demonstrated by the Network Rail/Southwest Trains Wessex Alliance.
Success factors	There are currently 26 project teams undertaking feasibility studies in nine different challenge areas. From these, the most promising solutions to each of the challenges will be progressed to demonstration.
Constraints	

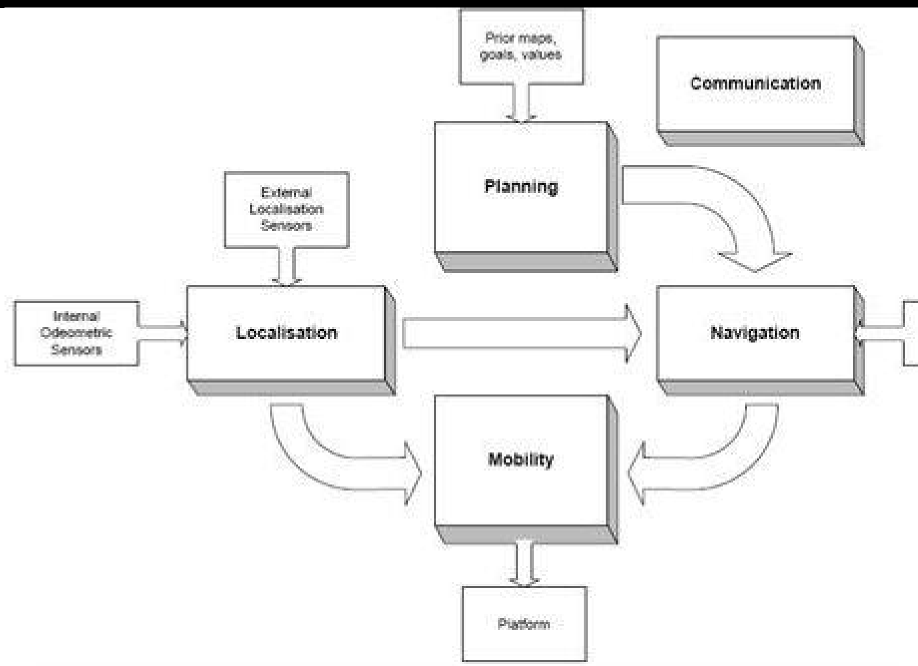
Main impacts	
Maturity and degree of implementation	TRL 3-7 (Feasibility)
Key Performance Indicators	Reduced maintenance costs and increased network availability
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T098

Field	**Description**
Title and Keywords	Track 21 Programme
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Track 21 programme is an academic-led research project investigating railway track behaviour with the objective of developing a better understanding of the behaviour and degradation of ballasted track. The areas considered include piling, vegetation management, soil rotation and stability, ballast grading and fibre reinforcement of ballast.
Success factors	A website, www.track21.org.uk, has been populated with all completed papers and work. The key outcomes of this programme will be safety and cost efficiency.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 1-3 (Research)

Key Performance Indicators	Reduction in whole-life track cost
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T099	



Field	Description
Title and Keywords	Autonomous Intelligent Systems (AIS) Programme
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Autonomous Intelligent Systems (AIS) programme is a 5-year scheme that gives a good introduction to automated decision support tools. These tools will ultimately take the railway in the direction of autonomous inspection and maintenance machines, and decision support tools for infrastructure monitoring and data analysis.
Success factors	AIS consists of nine projects, across 15 universities with total funding of around £8.4m. A further seven projects, worth £8m, have been funded directly by the Engineering and Physical Sciences Research Council (EPSRC).
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10 (Commercialisation)
Key Performance Indicators	Maintenance cost reduction and safety benefit

Further information	http://www.rssb.co.uk/future-railway-programme

Best Practice / Technology REF: T100

Field	Description
Title and Keywords	Tomorrow's Railway and Climate Change Adaptation (TRaCCA)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	This will produce a knowledge base, assessing the likely impact of climate change and increased frequency of extreme weather events on the UK railway.
Success factors	The system-wide approach will inform investment priorities from CP6, forming the foundation for a 20 year investment strategy. Phase 1 has provided a comprehensive knowledge review and knowledge gap analysis. Phase 2 is investigating knowledge of climate change vulnerabilities and support tools to increase resilience of the GB railway.
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 4-7 (Feasibility)

Key Performance Indicators	Measurable improvement to railway resilience
Further information	http://www.rssb.co.uk/future-railway-programme

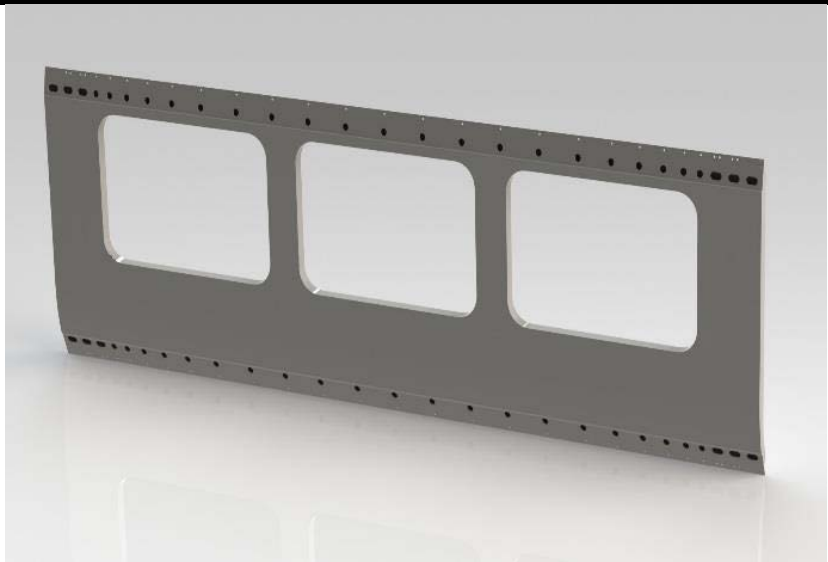
Best Practice / Technology REF: T101

Field	**Description**
Title and Keywords	Indepently Powered EMU (IPEMU)
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The IPEMU is an alternative to conventionally electrified railway. The solution uses existing, but leading edge, battery technologies in a railway environment to operate trains. Energy can be stored on trains to enable a discontinuous energy supply from the infrastructure. This could enable using electric trains on non-electrified lines, converting third rail DC to more efficient operation, and increasing freight electric traction.
Success factors	The solution was successfully demonstrated on a live track under various scenarios, carrying members of the public.
Constraints	
Main impacts	Battery technology offers an alternative or supplementary way to achieve electric powered train services to the conventionally electrified railway.
Maturity and degree of implementation	TRL 4-7 (Feasibility)
Key Performance Indicators	Reduced fuelcosts and emissions, alternative regional solutions
Further information	http://www.rssb.co.uk/future-railway-programme

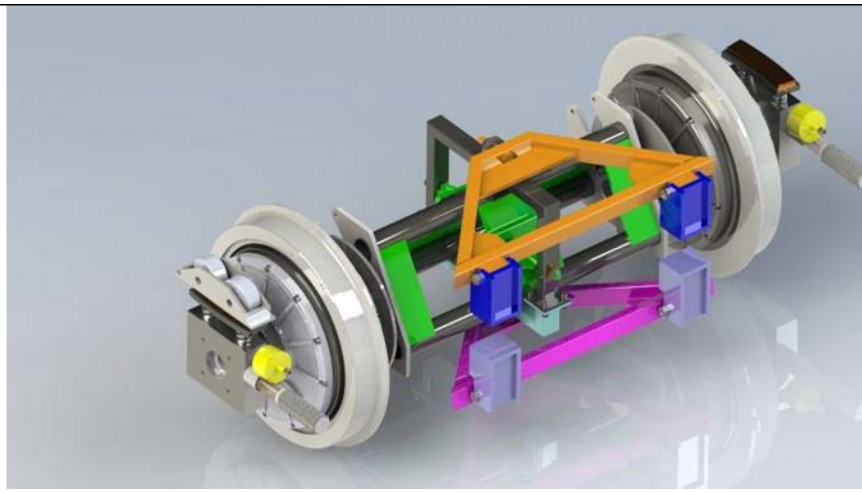
Best Practice / Technology REF: T102	
	
Field	**Description**
Title and Keywords	An optimised braking control system
Source of best practice / technology	Tomorrows Train Design Today
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The proposed Optimised Brake System will create an advanced braking system which optimises the performance of the existing friction braking systems, and supplements this with the latest developments in permanent braking techniques (magnetic eddy current braking).
Success factors	The optimised and integrated software and hardware approach will ensure that the deceleration of the train stays within the required corridor in degraded adhesion conditions whilst optimising energy usage. This allows significant benefits to be achieved.
Constraints	
Main impacts	A new braking control system that improves the utilisation, blending and ultimate performance of the existing friction and dynamic braking systems.
Maturity and degree of implementation	TRL 4-7 (Feasibility)
Key Performance Indicators	Reduced emissions, reduced fuel costs, health benefits
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T103

Field	Description
Title and Keywords	Using hydrogen to raise diesel performance (H2GoGo Hydrogen)
Source of best practice / technology	Tomorrows Train Design Today
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The H2gogo project looks at adding hydrogen to fuel to enable engines to burn efficiently, producing significantly reduced emissions and the potential for fuel reduction. The consortium plans to design and develop a rail vehicle demonstrator which will be tested on a Class 66 loco for a period of 3 months. This will quantify the benefits H2gogo's electrolytic hydrogen gas generator can deliver by assessing, via independent verification, the emissions reduction and potential fuel efficiency.
Success factors	H2gogo's technology has been proven to dramatically reduce emissions on road vehicles, plant machinery and generators.
Constraints	Fault assessment and industry entry barriers for qualification
Main impacts	
Maturity and degree of implementation	TRL 4-7 (Feasibility) To TRL 8-9 by 2016-17
Key Performance Indicators	Reduced emissions, reduced fuel costs, health benefits
Further information	*http://www.rssb.co.uk/future-railway-programme/delivering-solutions/rolling-stock/radical-train*

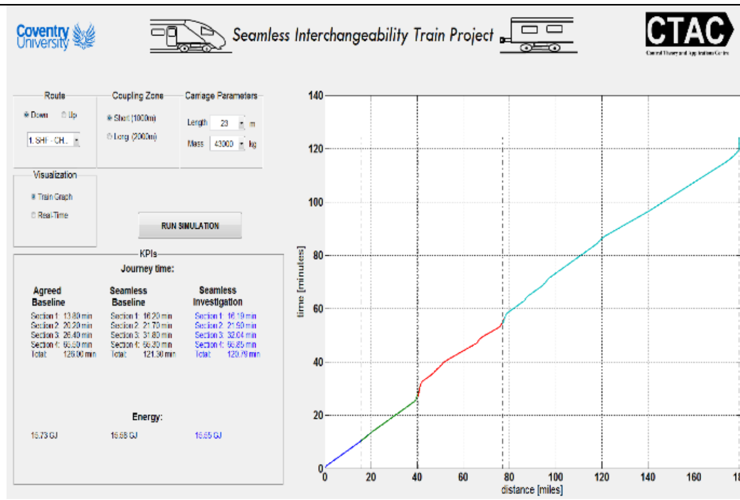
Best Practice / Technology REF: T104	
	
Field	**Description**
Title and Keywords	ACIS (Advanced Composite Integrated Structure)
Source of best practice / technology	Bombardies Transportation
Lifecycle stage	Design / Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The ACIS (Advanced Composite Integrated Structure) Project will develop composite components for train carriages. The use of composite materials in the manufacture of rail vehicle structures can provide significant mass savings. Lighter rail vehicles can lead to a reduction in both energy usage and track damage, as well as increases in acceleration and braking performance
Success factors	Phase One is to understand the current use of the technology, identify the commercially viable opportunities in rail vehicles, and develop an industry roadmap. The use of composite materials for the manufacture of structural parts, and consideration of life cycle costs, are novel within the rail industry
Constraints	Technical and economic challenges of composite materials
Main impacts	Lighter trains lead to better reliability and improved customer experience
Maturity and degree of implementation	TRL 3-7
Key Performance Indicators	
Further information	http://www.rssb.co.uk/future-railway-programme/delivering-solutions/rolling-stock/radical-train

Best Practice / Technology REF: T105



Field	Description
Title and Keywords	Wheelmotor demonstrator
Source of best practice / technology	Stored Energy Technology Ltd (SET)
Lifecycle stage	Operation / Maintenance
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The WheelmotorDemonstrator will develop, test and demonstrate a traction system for Light Rail vehicles. This will be based on both SET's Wheelmotortechnology and advanced steering control. This addresses technical issues such as the cost of rail wear on tight radii curves on tramways, nuisance noise generated by wheel slip on these curves, and the restrictions of 25m radii curves in urban areas.
Success factors	The solution delivers multiple benefits including superior dynamic performance afforded by directly acting permanent-magnet synchronous Wheelmotorsand the removal of the need for trackside lubrication systems.
Constraints	Key challenge to find a suitable test and validation site
Main impacts	reduced environmental impact, enhanced performance
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	This solution will free the industry from the fundamental limitations imposed by the traditional solid axle wheelset.
Further information	http://www.rssb.co.uk/future-railway-programme/delivering-solutions/rolling-stock/radical-train

Best Practice / Technology REF: T106



Field	Description
Title and Keywords	Seamless Interchangeability
Source of best practice / technology	Coventry University
Lifecycle stage	Design / Operation / Renovation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The 'Seamless Interchangeability' project is a radical approach to relieving the key capacity constraints of today's railway network, using a network model. This will demonstrate different approaches to relieving these capacity constraints, looking to modify the existing network over the 3-30 year time horizon, to ensure maximum benefit is derived from ERTMS, etc. Seamless interchangeability is a concept for future rail travel, using long trains which can split and join on the move and allows passengers to walk through and 'change' trains without stopping.
Success factors	This project aims to develop a fictitious, yet realistic, train network model to evaluate the potential benefits of radically different ways of running trains.
Constraints	Complexity in modelling
Main impacts	Increased capacity, improved customer experience
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	
Further information	http://www.rssb.co.uk/future-railway-programme/delivering-solutions/rolling-stock/radical-train

Best Practice / Technology REF: T107

Field	Description
Title and Keywords	Revolution VLR (Very Light Rail)
Source of best practice / technology	TDI Ltd Revolution VLR Consortium
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Revolution VLR (Very Light Rail) Consortium will design, test and build a complete low carbon lightweight railcar as a concept demonstrator. This will promote low cost connections to regional and rural areas. It will include a modular design and innovative interior packaging appropriate to shorter distance and relatively low speed operations. It will build on the concept of a 'self-propelled bogie' (previously developed) featuring an integral diesel electric series hybrid drivetrain with regenerative braking and energy storage. This will unlock the wider market for innovative light rail schemes (potentially including tramways in the longer term) in the UK
Success factors	The modular design will enable localised assembly without the need for complex tooling and equipment, and will allow for different railcar configurations.
Constraints	Crashworthiness levels
Main impacts	Increased sustainability, improved regional customer experience
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	
Further information	http://www.rssb.co.uk/future-railway-programme/delivering-solutions/rolling-stock/radical-train

Best Practice / Technology REF: T108

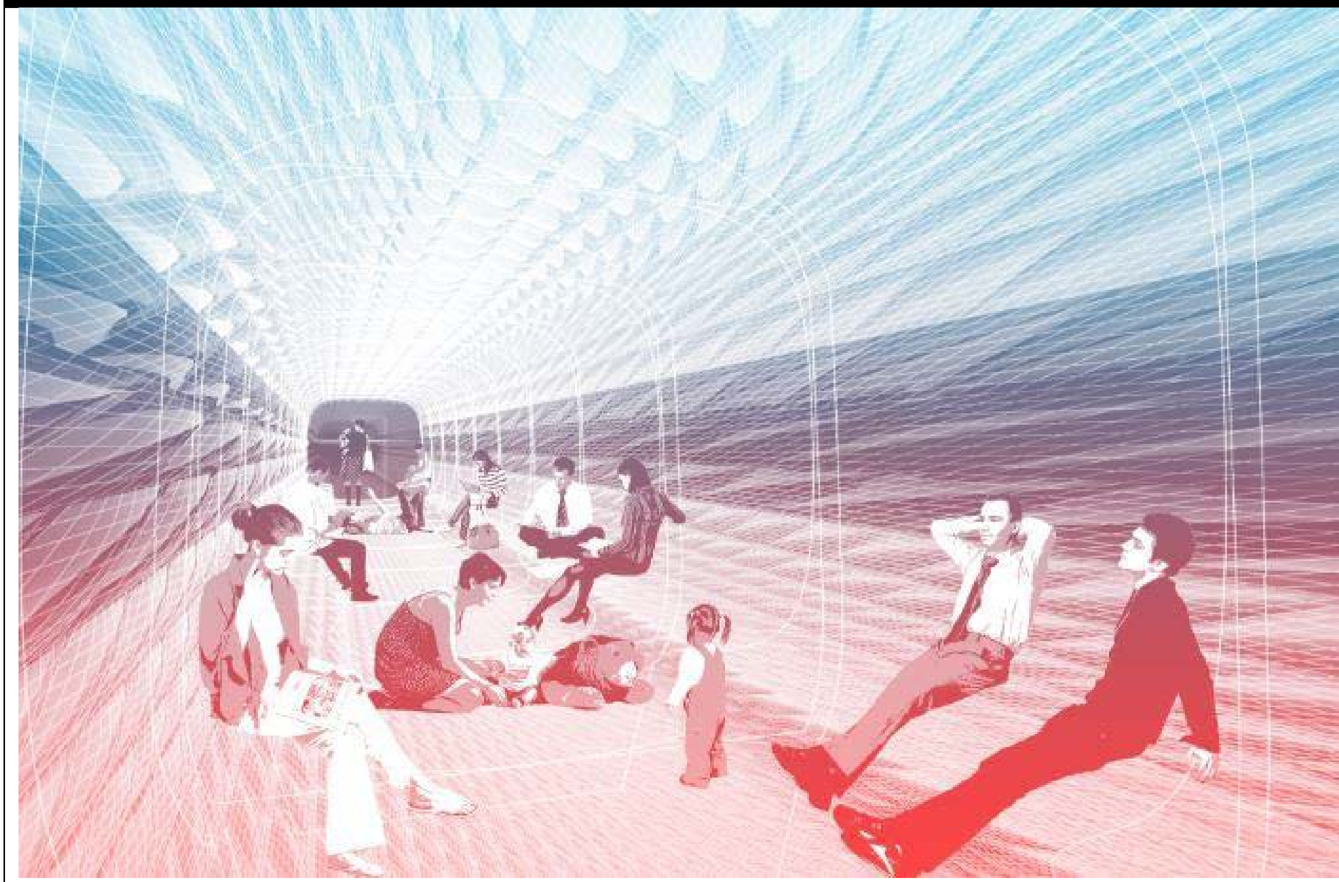
Field	Description
Title and Keywords	Modular interiors and flexible seating
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The 'Connect Me' train concept offers a modular interior with flexible seating zones that help regulate capacity. Complementing the interior flexibility is the Connect Me digital platform and application. This digital tool is used to define the interior layout regulation by communicating capacity data to the operator to provide real time information and journey planning for passengers.
Success factors	It includes Flexible seating that is pneumatically controlled, a modular interior, and more accessible storage.
Constraints	
Main impacts	This flexible interior concept maximises on space, flexibility and convenience for both passenger and train operator alike.
Maturity and degree of implementation	TRL 8-10 (Demonstration)
Key Performance Indicators	Improved customer experience, reduced dwell times
Further information	http://www.rssb.co.uk/future-railway-programme

Best Practice / Technology REF: T109

Field	Description
Title and Keywords	Adaptable Carriage
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The ‘Adaptable Carriage’ concept consists of a flexible-use carriage which can carry passengers during peak hours, and be converted for hauling low-density, high-value goods during off-peak hours. Trains which included Adaptable Carriages could be converted for carrying goods in order to relieve traffic from roads, decongest city centres, create a new revenue stream for TOCs, and stimulate the growth of regional SMEs. It is estimated that each carriage could be converted to carry 20m3.
Success factors	This solution aligns closely with the strategic objectives of many industry bodies, including the TOCs, Network Rail, DfTand RSSB.
Constraints	
Main impacts	Seats which slide along the length of the carriage to create a large amount of space

	for the transport of low-density, high-value goods.
Maturity and degree of implementation	TRL 8-10 (Demonstration)
Key Performance Indicators	Increased freight revenue for TOCs, reduced emissions
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T110



Field	**Description**
Title and Keywords	Air Train
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The Air Train design proposal draws inspiration from clouds floating in the sky and it is intended that passengers should feel this way as they move freely through the carriages. The interior floor, walls, ceiling, windows and seats are formed from a continuous

	'cloud skin', which is designed to house all functions required in the train interior such as seating, lighting and air-conditioning.
Success factors	The Air Train is not restricted by traditional fixed seats. Instead, air bladders manipulate the shape of the 'cloud skin' to deploy or retract seats to accommodate different needs at different times of the day.
Constraints	
Main impacts	Not restricted by traditional fixed seats the 'cloud skin' space transforms itself accordingly to accommodate different needs.
Maturity and degree of implementation	TRL 8-10 (Demonstration)
Key Performance Indicators	Improved customer experience, increased capacity
Further information	*http://www.rssb.co.uk/future-railway-programme*

Best Practice / Technology REF: T111

Field	Description
Title and Keywords	Double decker train withing gauge
Source of best practice / technology	Network Rail
Lifecycle stage	Operation
Type of infrastructure	Rail
Component of infrastructure	Train
Element of the infrastructure	
Short Description	The UK rail network has historically had a limited gauging (physical envelope for trains), which does not easily allow for high capacity double decker or long vehicles.

	AeroLiner3000 is developing a high speed double decker train capable of running on HS2 and also serving other existing routes. The high speed double decker train is based on a systemic approach to the whole train. Bogie and gear design, locomotion, light weight structure and interior geometry and design play hand in hand.
Success factors	It offers the potential to gain significant capacity improvements without neglecting comfort. The solution will be demonstrated as a full scale mock-up coach.
Constraints	
Main impacts	An innovation driven design for double decker coaches within gauge from scratch allows a higher capacity on existing infrastructure.
Maturity and degree of implementation	TRL 8-10 (Demonstration)
Key Performance Indicators	Improved customer experience, increasedcapacity
Further information	*http://www.rssb.co.uk/future-railway-programme*

7.3 Type of infrastructure: Air

Best Practice / Technology REF: T005

Field	Description
Title and Keywords	Title: **HR-MP Magnetic climbing inspection robots**
Source of best practice / technology	Helical Robotics
Lifecycle stage	Maintenance
Type of infrastructure	Road / Rail / Air / Water
Component of infrastructure	Buildings and other vertical infrastructure
Element of the infrastructure	
Short Description	This family of remotely-operated vehicles use magnets to cling to vertical surfaces, enabling safe, thorough inspections of hard-to-reach structures such as wind turbine blades and supertanker hulls.

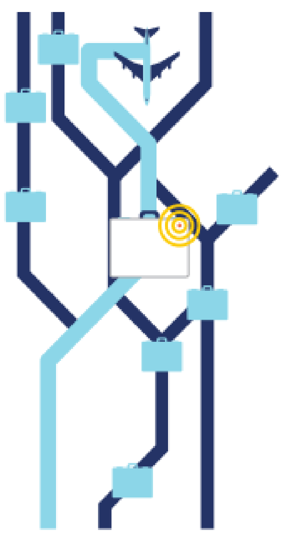
Success factors	Ability to access hard-to-reach structures to gain information on condition
Constraints	Magnetic design not suitable for use on many existing transport infrastructure assets such as brick and concrete structures.
Main impacts	
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	Accessing data on hard-to-reach structures
Further information	http://www.helicalrobotics.com/sites/default/files/Helical%20Robotics%20Q%26A-%205-22-11.pdf

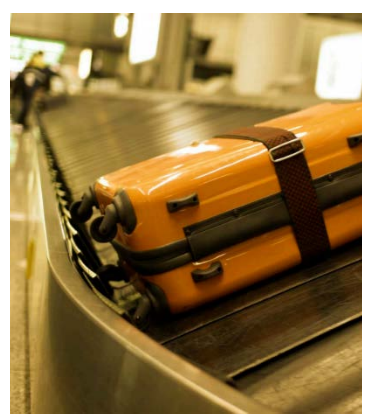
Best Practice / Technology REF: T033

Field	**Description**
Title and Keywords	Title: **Energy harvesting of footfall at multi-modal transport hubs**
Source of best practice / technology	Pavegen
Lifecycle stage	Operation
Type of infrastructure	Multi-modal
Component of infrastructure	Train stations, bus depots, Airports
Element of the infrastructure	
Short Description	The new Pavegen technology known as V3, is sleeker and far more efficient, generating over 200 times more power than the first model manufactured in 2009. The new triangular design maximises both energy output and data capture; whilst its high durability and simple deployability allow Pavegen to seamlessly integrate into any location, as an effective decentralised power solution. Pavegen is shifting to become a permanent and commercial smart-flooring solution. The technology has evolved from a singular tile, which generates electricity from footsteps, to an entire array with three multi-functional component parts. These

	functionalities are called: floor, data and energy. The new interoperable Pavegen System, is poised to power the data-driven smart cities of tomorrow. Pavegen have installed 51 tiles within Terminal 3 of Heathrow Airport, powering LED lights situated along the corridor. The collaboration followed after Heathrow received the Ferrovial Innovation Award for the concept of footfall-powered corridors. Using Pavegen's tiles, the corridor lighting illuminates in correspondence to the tiles, possibly allowing for footfall data analytics and heat mapping in the future. Terminal 3, having received 18.4 million passengers and commuters in 2012, is the busiest terminal at the airport. The high traffic of footfall within the area will help boost CSR initiatives and raise awareness to sustainability.
Success factors	
Constraints	Levels of footfall
Main impacts	Energy generation
Maturity and degree of implementation	TRL 4-7
Key Performance Indicators	
Further information	https://pavegen-systems.squarespace.com/heathrow

Best Practice / Technology REF: T044





Field	**Description**
Title and Keywords	Title: **Smart baggage handling at airports**
Source of best practice / technology	IBM, Schipol Airport, KLM

Lifecycle stage	Design / Operation
Type of infrastructure	Air
Component of infrastructure	Baggage handling infrastructure
Element of the infrastructure	
Short Description	A major source of Schiphol's passenger volume—indeed, the key to its vision of becoming Europe's preferred airport—is the handling of transfer passengers, those making connections to other destinations. Compared with origin/destination baggage (that which has Schiphol as either the origin or final destination), the handling of transfer flight baggage presents a whole new level of complexity. Schiphol and KLM recognized that the systemic nature of the process challenge meant that as passenger volume increased—an important business goal for both parties—the problem of baggage capacity would only be exacerbated. They realized that only a systemic solution would resolve this critical capacity constraint and remove the most significant barrier to their long-term passenger growth from a baggage point of view. Schiphol and KLM worked together to reenvision the baggage management process. Underpinning their efforts was the recognition that the fragmentation of baggage management into separate and discrete process segments. The key was to proactively manage the baggage processing flow to mitigate the effect that peaks and valleys can have on process efficiency. The team realized that for such an orchestration to occur, process integration and collaboration of all the key players—spanning the entire process flow—was absolutely essential. Sensors track the luggage of connecting flights, enabling real-time traceability at all points in the connection pipeline. The solution seamlessly integrates data from Schiphol's own systems as well as from airlines and third-party ground services providers. By comparing a bag's location with underlying routing rules, Schiphol can identify potential problems and keep bags from missing their owners' connecting flights. Schiphol's smart baggage management solution includes IBM® Rational® Software, IBM System p5®, System x® server , IBM GBS® Aviation Competence Center,and IBM Global Technology Services.
Success factors	Reduced cost, increased mobility
Constraints	
Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced cost, increased mobility
Further information	http://insights-on-business.com/travel-and-transportation/wp-content/uploads/sites/14/2015/10/Schiphol-Leadership-Series-Reference.pdf?cm_mc_uid=81862362312614333493301&cm_mc_sid_50200000=14

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Best Practice / Technology REF: T045

Field	Description
Title and Keywords	Title: **Asset management tools enable increase in proactive maintenance**
Source of best practice / technology	IBM, Dubai Airports Co.
Lifecycle stage	Maintenance / Operation
Type of infrastructure	Air
Component of infrastructure	Infrastructure assets
Element of the infrastructure	
Short Description	Dubai Airports deployed IBM WebSphere Application Server V6.1 with IBM Maximo Asset Management V7.1.1.8 and IBM Maximo Mobile Work Manager V7.1.1.0 software. The solution standardizes processes, minimizes resource requirements through process automation and generates job plans with task, duration and resource categories for all planned works. A comprehensive database in the Maximo Asset Management software maps labor types to craft and skill. In addition, the solution automates work assignments by matching employee skills with labor availability, thereby optimizing resource use. Finally, by using the Maximo Mobile Work Manager software, employees can access asset management and maintenance scheduling processes remotely. By deploying IBM WebSphere Application Server, IBM Maximo Asset Management and IBM Maximo Mobile Work Manager software to address its enterprise asset management needs, Dubai Airports automated processes and decreased planning, scheduling and assignment times. In addition, the solution has reduced maintenance costs while improving asset uptime and other key performance indicators. Overall, the company's infrastructure expansion program is balanced between tactical and strategic initiatives, which are on course to save around USD100 million by 2020.
Success factors	In 2014 alone, Dubai Airports estimates that it will save USD10 million through reduced maintenance man hours and other efficiencies.
Constraints	

Main impacts	
Maturity and degree of implementation	TRL 8-10
Key Performance Indicators	Reduced operating costs, improved mobility
Further information	http://www-03.ibm.com/software/businesscasestudies/vn/en/corp?synkey=M428816H46968C14

Best Practice / Technology REF: T081	
Field	**Description**
Title and Keywords	The INtelligent Airport (TINA) Keywords: mobile computing, distributed systems, networks, information & communication.
Source of best practice / technology	University College London, United Kingdom (Lead Research Organisation) Motorola (Project Partner) RED-M, United Kingdom (Project Partner) Laing O'Rourke plc, United Kingdom (Project Partner)
Lifecycle stage	Maintenance & Operation
Type of infrastructure	Air
Component of infrastructure	Airport
Element of the infrastructure	Airport
Short Description	Airport terminals will increasingly require ubiquitous systems with high levels of computational power to provide the necessary intelligent automation; to provide high quality services to passengers; stringent levels of safety and security that are as unobtrusive as possible; efficient processing of commercial goods and luggage; high quality information systems; airport transportation systems and appropriate support for in-house commercial ventures.
Success factors	These requirements will involve both fixed and mobile appliances, and hence an intelligent, adaptive, self-organising and self-managing wired and wireless infrastructure will become an essential asset. This project therefore seeks to develop a new seamless wireless/wired ubiquitous infrastructure able to meet the new requirements.
Constraints	
Main impacts	To develop a next generation advanced wired and wireless network for future airport environments. Radio frequency identification (RFID) tags supported by a transparent optical-RF network can be used to sense, locate and track an array of objects including luggage, mobile assets and commercial goods and can provide additional features such as boarding pass auto-tags and access control tags. The RFID tags will operate at low data rates, typically 64 kbit/s, but an airport environment can be expected to contain a few million of them. Mobile biometric sensors will be widely deployed in this environment providing advanced features. A range of fixed and mobile terminals will provide additional security measures such as chemical detection and analysis, while other terminals, fixed and mobile, will support passenger information and entertainment services on transit. The infrastructure will support an array of personal passenger and

	staff wireless media rich devices. The wired/wireless network envisaged will thus be huge and complex, supporting perhaps 10 million information sources, with an anticipated peak aggregate data rate of order 500 Gbit/s in a relatively local access environment. This is beyond the capability of any current network and research is needed to understand the principles upon which an effective system could be constructed.As this is such an ambitious and multidisciplinary project, a collaborative programme is proposed.
Maturity and degree of implementation	1-3 (Research level)
Key Performance Indicators	
Further information	http://gtr.rcuk.ac.uk/project/D723067F-E1E8-4589-BC26-B5B9D6DFD21E http://intelligentairport.org.uk

Best Practice / Technology REF: T085	
Field	**Description**
Title and Keywords	IMaging and Probabilistic Assessment of Composite damage Threats (IMPACT)
Source of best practice / technology	Airbus Group Limited GKN University of Bristol
Lifecycle stage	Maintenance & Operation
Type of infrastructure	Air
Component of infrastructure	Pavement
Element of the infrastructure	Runway
Short Description	Low velocity impact to Carbon Fibre Reinforced Plastic (CFRP) aerospace structures is common and can create damage that is almost undetectable from the surface yet may reduce compressive strength by up to 60%. Compression After Impact (CAI) strength of aerospace components is currently assessed through expensive and cumbersome experimental studies. The resulting design strategy - conservative thickening of vulnerable components to reduce in-service strains - is likely having a negative effect on airframe weight and fuel efficiency. This strategy is both a consequence of significant uncertainty in the factors that contribute to impact damage and compressive strength reduction, and of a lack of modelling capability for CAI strength that accounts for such uncertainty.
Success factors	A recent project funded by Airbus UK, GKN Aerospace and ESPRC (EP/H025898/1) has led to the development of an analytical Damage Tolerance Model (DTM) that can capture the strain at which impact damage in a CFRP panel will grow under compressive loading. The DTM has computational efficiency that is sufficient to allow uncertainty in factors such as material properties and damage severity to be captured using large scale parallel computations i.e. Monte Carlo Simulations (MCS). However, the DTM

	relies on individual experiments to provide the size and structure of impact damage and this is currently limiting its efficiency and applicability in early stage design.
Constraints	
Main impacts	IMPACT will address the issue of damage structure by developing an empirically based predictive model. X-Ray Computed Tomography (XRCT) and ultrasonic inspection of impacted CFRP laminates, in partnership with generalised laminate design, will underpin the generation of empirically-based, but predictive, scaling laws that describe the structure of impact damage. The resulting model will be combined with the DTM and, exploiting MCS and new aircraft licensing body regulations on probabilistic methods , used to capture the effect of uncertainty in factors affecting the strength of damaged CFRP panels e.g. material properties varying with batch of CFRP. The resulting probability distribution for post-impact compressive panel strength will be linked with probability distributions for the detectability of impact and severity of both damage and compressive loading. The final overall distribution will indicate whether a specific design strain can be reached with an acceptable probability of failure.
Maturity and degree of implementation	1-3 (Research level)
Key Performance Indicators	Cost savings
Further information	*http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M021270/1* *http://www.bath.ac.uk/*

Best Practice / Technology REF: T089

Field	**Description**
Title and Keywords	Mathematical models and algorithms for allocating scarce airport resources (OR-MASTER)
Source of best practice / technology	Adv Syst for Air Traffic Control (SICTA) Air France KLM Airport Services Association Airports Council Intl (ACI) Europe Athens International Airport CRIDA A.I.E Eurocontrol German Aerospace Centre DLR Goldair Handling HALA SESAR Research Network Massachusetts Institute of Technology NATS Ltd NEXTOR-II Consortium Northrop Grumman Park Air Systems SESAR Zurich Airport
Lifecycle stage	Design, Operation
Type of infrastructure	Air
Component of infrastructure	Airports
Element of the infrastructure	Airports
Short Description	Part of the project will be involved in developing and testing new models and solution algorithms that take into account the factors involved in the allocation of flight slots: individual airport operations, networks of airports, airline operations, air traffic management systems, airport authorities, civil aviation authorities, airlines and the travelling public.
Success factors	Mathematical models will be developed and analysed which consider the objectives and requirements of all stakeholders and which take account of a wide range of operational and regulatory constraints. The intrinsic complexity of the proposed programme and its

	large scale (especially for the case of the network-wide slot allocation) will mean that it will provide an excellent test-bed for the development of new heuristics and hyper heuristics for large scale complex scheduling problems more widely. Algorithms that will be developed and tested by this project will provide essential support for the complex large scale capacity allocation problems that arise in other types of transportation networks, including rail networks. In addition, it could extend to other types of networks that share similar problem structures, such as those in energy and telecommunications.
Constraints	
Main impacts	The models and solution techniques developed will underpin the development of novel decision support systems which have the potential to make a major impact on airport operations. The research team has an internationally leading profile in the areas of mathematical modelling, heuristic development, stochastic optimization, airport slot allocation, airport management and performance assessment. It has an excellent track record of research cooperation with all categories of stakeholders. It will cooperate closely with an impressive array of leading industry stakeholders in order to make sure that the work is as cutting edge industrially as it is scientifically.
Maturity and degree of implementation	1-3 (Research level)
Key Performance Indicators	
Further information	http://www.research.lancs.ac.uk/portal/en/projects/mathematical-models-and-algorithms-for-allocating-scarce-airport-resources(a41cfa48-7968-44ee-bc5b-d41491628ba8).html http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M020258/1

7.4 Type of infrastructure: Water

Best Practice / Technology REF: T038

 

Field	Description
Title and Keywords	Title: Intertidal Structures: Engineering for Sustainability and Biodiversity
Source of best practice / technology	University of Southampton/ Arup/ Furgo EMU
Lifecycle stage	Design and maintenance
Type of infrastructure	Maritime
Component of infrastructure	Defence structures – e.g. Groynes, walls, breakwaters
Element of the infrastructure	Rock units, rubble mound, internal space
Short Description	Increased sea levels and storm conditions, resulting in flooding and coastal erosion has led to an increase in coastal protection structures. The proliferation of artificial coastal defence structures is causing removal, replacement and fragmentation of natural coastal habitats and modifying coastal specifies within those areas. Additionally, protective structures are designed with low environmental consideration and made from materials with low environmental value. A 4 year collaborative research project with the University of Southampton, Arup and Fugro EMU Ltd investigated methods of ecological enhancements to intertidal artificial structures to improve the environmental value and sustainability. Methods that were explored included optimisation of structure designs to utilise internal spaces as refuge habitats for biological organisms; complexity of structural designs for increasing habitat opportunities; and use of ecosystem engineers as a sustainable soft engineering method for protection.
Success factors	The results provide evidence of best practice for designing multifunctional maritime defence structures which fulfill engineering needs and enhance ecological value through: 1. Increased kowledge and understanding of successful design features to increase ecological colonisation 2. Identifying and developing a better understanding of the use of intertidal and subtidal species in coastal protection through reduced wave energy, increased sedimentation and habitats, and potentially reduce the use/ size of artificial

	structures. 3. Use of 3D printed rock-type material to create complex structural design that incorporate suitable habitat features for intertidal species and made out of locally sourced sediment. Can be designed to any specification and structural requirement.
Constraints	1. Depending on the design, there may be additional investment cost. 2. Early stages of practical implementation and still limited evidence 3. Implementation of ecosystem engineers for soft engineering protection requires careful research and consideration to determine suitable species for the area and requirements.
Main impacts	Through the 4 years of research, significant advancement in the technical knowledge and understanding of ecologically sensitive structure designs has been achieved. The results help provide informed input for designing structures which not only fulfil engineering functions, but also provide suitable habitats for local marine assemblages, therefore sustaining and supporting important biological organisms and the natural environment. Improvements to the use of materials, surface texture and durability have also been expanded.
Maturity and degree of implementation	Work on environmental design enahncement for maritime structures has been underway for the last 10 years or so. Whilst there is a lot of academic research and evidence, the work is still relatively new and lacks evidence of practical implementations. Therefore, this work is at a moderate to high level of maturity with a TRL level of 7/8.
Key Performance Indicators	• Increased biodiversity • Environmental sustainability • Lower carbon footprints • Reduced maintenance costs and works • Enhanced engineering aesthetics
Further information	https://www.fugro.com/ask/characterising-intertidal-ground-conditions

8. Next steps

In order to make full use of the information contained in this document for the subsequent tasks of the REFINET CSA (e.g. SIP), the next steps need to be taken:

- The collected technologies identified need to be further clustered into groups that represent strategic areas of knowledge for the SIP. For instance the best practices in this document provide information about those which are suitable for the Infrastructure Type "Road", Component type "Pavement", Element type "bituminous mixture".
- The classification can be used for:
    - Identify technologies that are well developed and have the potential to be applied more widely across industry.

  - Detecting gaps, areas of lack of knowledge where research still needs to be developed. With the information contained in this document this item is more difficult to achieve as it was explained the list can't be exhaustive.
- The previous items jointly with the information delivered in D3.4 provide a basis for Strategic Planning in the area of Transport Infrastructure.
- Notice that this work should also be continued by the Infrastructure and Mobility Committee of the ECTP and the ENCORD Work Group on Transport Infrastructure, with a priority activity to create a user-friendly web interface to disseminate the content of this catalogue.
- Finally, the best practice / technologies template provides a field for KPIs to be further completed with the KPIs from the RMMTI model once these are finally consolidated.

9. CONCLUSIONS

Deliverable "D3.3 Catalogue of technologies in design, construction and maintenance of transport infrastructures" due in month 12 compiles a non-exhaustive collection of technologies that are being researched or trialled in design, construction and maintenance of transport infrastructure. The deliverable contributes to the achievement of the project Objective "2) Defining the REFINET vision". So consequently, the deliverable assists in setting the basis to define how the multimodal European transport infrastructure network of the future should be and the R&I demands to evolve the current European transport networks according to this vision of the best practices currently applied in the industry of Transport Infrastructure.

To provide this catalogue a pragmatic (industrial) approach has been taken, basing the work in direct experience of experts from the industry and the academia. Different information sources and organisations have been consulted and workshops organised to identify sources of information in design and construction of new transport infrastructures and maintenance of the existing ones.

For each of the technologies, relevant information regarding scenario defining the context of application, short description of the technology, main impacts, constraints of application, maturity and current level of dissemination have been collected.

10. Appendix A: Catalogue of Technologies Tracker

The Catalogue of Technologies Tracker (Excel file with 2 tabs) is available for download from the REFINET Collaborative Workspace at: http://www.ectp.org/cws/params/ectp/download_files/50D3796v1_REFINET_D3.3_Appendix_.xlsx