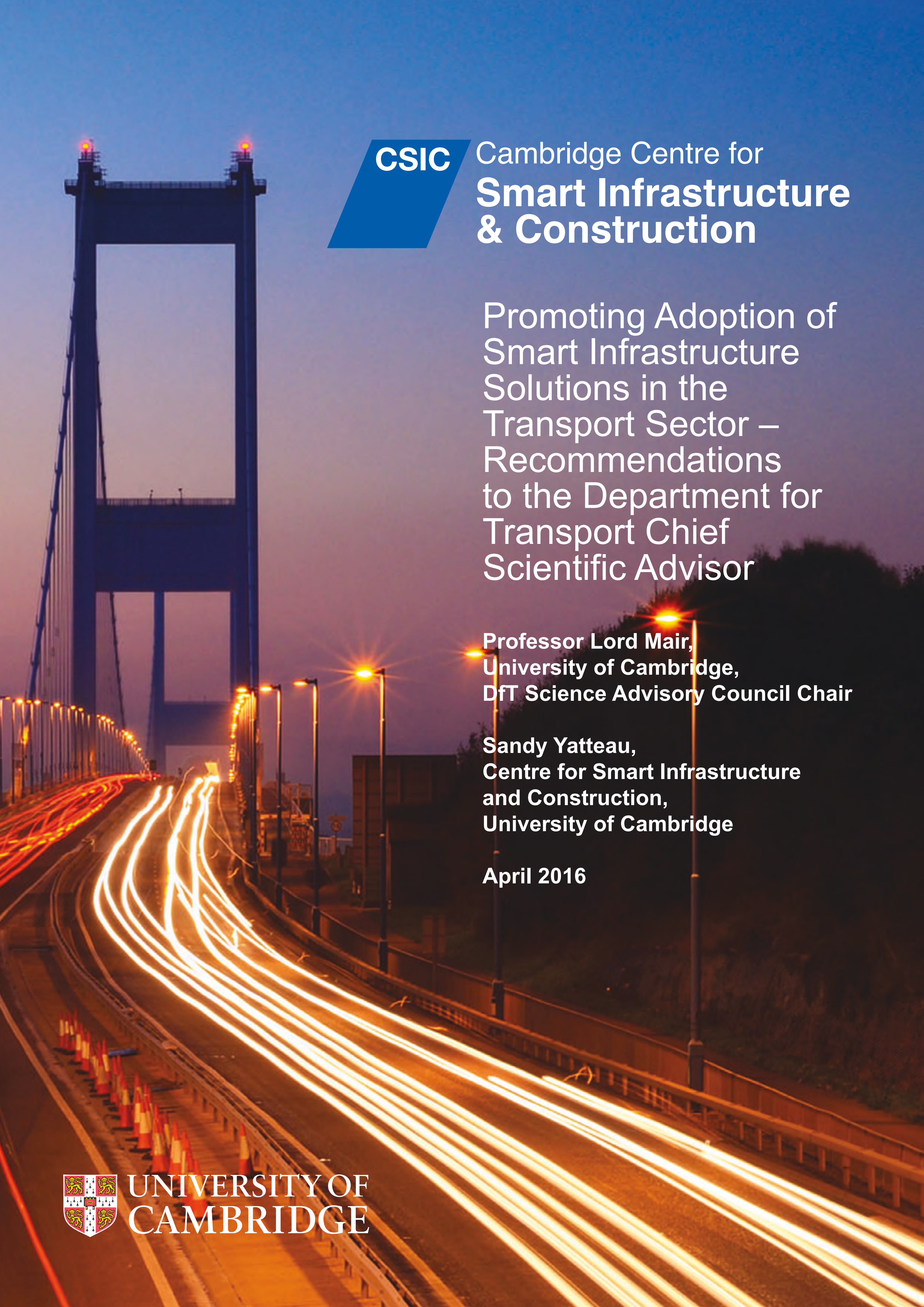

CSIC Cambridge Centre for **Smart Infrastructure & Construction**

Promoting Adoption of Smart Infrastructure Solutions in the Transport Sector – Recommendations to the Department for Transport Chief Scientific Advisor

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April 2016

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Executive Summary

The creation and maintenance of a robust, resilient and affordable transport infrastructure – one that is fit for purpose in a growing economy – is key in enabling our economy to thrive.

In this paper, we consider the role played by our transport infrastructure in the protection and development of our local and national economies, how we might build resilience into our transport networks and how we might use our existing infrastructure more efficiently. It is vital that we prioritise transport infrastructure investment effectively to ensure economic wellbeing, to prepare for a greener, safer and more resource-efficient future for our transportation networks.

Our transport infrastructure consumes both resource and investment, yet the ability of our businesses and communities to function and grow depends on its reliability and fitness for purpose. Without a strategic, government-led, cross-sector approach to caring for a complete network of roads and rail services, we run the risk of over-investing in some areas while neglecting others that are in need of our attention, or indeed risk failing to address economic and societal need. It is the complexity of the landscape in this area that calls for a cohesive strategy and joined-up programme of action.

This paper seeks to identify the key challenge areas, and those that would most benefit from government leadership in providing a framework of action to take our transport infrastructure through the 21st century.

In this paper we seek to outline those challenges, provide a rationale for intervention, and identify specific courses of action, including:

1. Conduct a national audit of assets to mitigate against risk of failure, to plan for the future and to ensure a truly needs-led approach be taken in this area.

2. Develop of a set of defined standards or 'best practice' guidance for smart road and rail technologies.

3. Further develop the shape and practice around the storage and sharing of valuable data and information to enable a truly integrated approach to maintaining our transport networks.

4. Further develop and champion a government procurement framework that drives innovation by adopting whole life costing and risk management, such as that set out in its Innovative Contractor Engagement Procurement Model.[1]

5. Apply the lessons learnt from this and other sectors in regard to accommodating innovation within the procurement process for capital infrastructure investment projects.

6. Engage insurers and risk managers at a strategic level in discourse around the way technology can help identify and manage risk.

7. Coordinate multi-stakeholder approaches to calculating the real whole-life cost of our assets, and the modelling of economic impact to help monetise the return on investment in technology.

8. Develop a framework for skills development in the area of smart infrastructure that supports a pipeline of skilled staff and engineers for the sector.

9. Apply strategic thinking to the use of crowd sourced data in planning for and maintaining the nation's infrastructure.

10. Develop a 'business case tool' for the commercialisation of innovative technical solutions in this arena.

11. Enable the sharing of knowledge and lessons learnt in relation to disruptive technology in this traditionally slow-to-change sector.

[1] www.ice.org.uk/disciplines-and-resources/case-studies/bank-station-capacity-upgrade-2015

Promoting Adoption of Smart Infrastructure Solutions in the Transport Sector

On 16th November 2015, the Cambridge Centre for Smart Infrastructure and Construction (CSIC), on behalf of DfT's Scientific Advisory Committee, convened an invited group of business leaders, infrastructure managers, strategists and academics for a Workshop. This Workshop enabled those assembled to discuss the importance of the continued development and deployment of smart technologies in the areas of transport infrastructure and related construction.

The aim was to prepare a paper setting out some of the drivers and imperatives related to smart infrastructure, the challenges faced by the sector in modernising its assets, and to suggest solutions to these challenges.

This paper outlines the key points of discussion at the Workshop.

> 'Smart infrastructure' is infrastructure that responds intelligently to changes in its environment, with the ability to influence and direct its own delivery, use, maintenance and support.
>
> Cambridge Centre for Smart Infrastructure and Construction

Foreword

by Dr Jennifer Schooling, Director of CSIC

Over recent months in the winter of 2015-2016, when unprecedented levels of rainfall brought chaos to parts of the UK's transport and utilities infrastructure, there have been calls for more to be done to predict weakness and avoid catastrophic failure of some of our key structures. Unrelated to the winter storms, the Forth Road Bridge was closed this winter with the cause of the closure identified as a pin that had rusted, preventing slight articulation which over time caused more damage to the bridge's load bearing steelwork. Engineers working on the bridge reportedly said that *"only a hi-tech structural health monitoring system, using a network of sensors to check the bridge, could potentially have revealed the problem"*.[2]

Infrastructure is made 'smart' by mounting or embedding instrumentation within infrastructure and the equipment with which it interacts. It requires a communication backbone that allows real time data aggregation and analysis. Dashboards or interfaces are needed to provide meaningful data integration for faster, better-informed decision making.

Best value is achieved if the data generated can be used to benefit design, construction, operation and asset management. Ideally, it should also be shareable, so that it benefits as wide a group of stakeholders as possible.

There are a number of inherent challenges that relate to the type of data being gathered, the assets that are being monitored, how these assets interrelate within a system, and the cost of the technology, its robustness and its long-term reliability.

The people best-placed to help determine the way forward are the asset owners themselves, and the construction and asset management experts charged with delivering and maintaining them. Therefore key industry players were invited to a Workshop to encourage them to share their experiences and help define a developmental pathway.

The aim of the Workshop was to explore both the benefits and challenges of introducing new approaches to technology and infrastructure, and the reasons why Smart Infrastructure needs to be routinely adopted in the UK. Some current new technologies and models of working were presented, and these presentations, outlining some recent industry case studies looking at the role of new technology in monitoring and protecting key infrastructure, are summarised in Appendix.

Participants were asked to focus on four key questions:
- What opportunities do intelligent infrastructure and condition monitoring offer to better manage and maintain ageing infrastructure, improve performance and policy outcomes?
- What are the essential criteria needed for intelligent condition monitoring to be implemented at scale?
- What are the key challenges to overcome in implementing intelligent infrastructure solutions?
- What should the Department do to help address these challenges?

Responses of the Workshop participants were collated, and outputs were then used to create a series of recommendations for the Department.

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[2] Infrastructure Intelligence, 21 January 2016 www.infrastructure-intelligence.com/article/jan-2016/seized-pin-forced-closure-forth-road-bridge-says-engineer

Setting the Scene – why is Smart Infrastructure important?

The UK has an ageing infrastructure, and we need to get the most out of what we already have in place. In an era of reduced spending and strategic investment, it is advantageous to maximise the traffic flow on the roads and rail systems that already exist. Not only does this control investment in maintenance, it can also mitigate against an acute need for expansion, increase levels of safety by avoiding overcrowding, and maximise capacity by ‘smoothing’ traffic flow.

According to the DfT’s 2014 publication, *Road Investment Strategy: Strategic Vision* (http://bit.ly/1ubKe0w): *“The greater uptake of existing technologies and the likely emergence of new innovations will transform the way we use our roads. More Smart Motorways will increase the capacity of motorways by a third while only slightly increasing their physical footprint.”* Yet only a small percentage of our road network is currently a ‘smart highway’, and the efforts to date to make our transport networks ‘smarter’ have focused on their use, and less on their fabric and condition.

Although great strides have been taken in recent years to up-grade our railway infrastructure and maximise track use by rolling stock, much of the fabric of our existing network continues to be assessed in traditional ways, such as periodic visual inspection of embankments and track.

Technologies have been – and continue to be – developed to make this condition monitoring and reporting more reliable, accessible and consistent, and yet those technologies are slow to be adopted by asset owners and the construction sector. Notable exceptions include recent Crossrail, London Underground and other TfL-related projects which have seen the active incorporation of innovative sensing and monitoring tools in new developments, and the retrofit of sensors on older elements of the network. There has also been innovative use of data by some organisations which serve as an example of good practice for other projects, but this level of innovation has yet to be widely adopted.

Workshop findings

1. What are the risks faced by our infrastructure today?

The failure of any element of the UK's critical infrastructure can have significant detrimental impact. One notable example of this is the washout of the sea wall and erosion of the railway at Dawlish, Cornwall, during an extreme storm in February 2014 (a report on the economic costs and socio-economic impact of that event can be found here: (http://bit.ly/1JTK6Sa). Whilst sensing would not have stemmed the storm or prevented damage, early indications of bank and slope erosion may have signalled a need to take earlier action to avoid the loss of the line.

> "As a trial, we installed sensing systems to assets on one of our infrastructure projects and were pleased that the instrumentation quickly offered us, and ultimately the client, certainty and product assurance data, and confirmed for us that our pre-stressing accords with EC2 and aligns with the Laing O'Rourke Design for Manufacture & Assembly strategy. For the wider industry, the data we gather using this technology can provide evidence and a framework for future reassessment of load history and therefore new structural loading, potentially enabling us to engineer-out significant waste. It also allows an inspection programme to be planned around actual need rather than supposition, thereby making efficient use of resources, improving response and reducing down-time. It would be useful, for instance, if key infrastructure assets like our bridges were issued with 'Health Passports' for structures that could be shared and used in reporting. Also, it enables us to monitor these bridges remotely, saving money and keeping staff safe."
>
> Phil Holland, Structures Project Manager, Laing O'Rourke

Transport infrastructure failure has implications beyond safety; there can also be significant economic and societal impacts caused by the subsequent disruption. Therefore it is vital that we protect our assets in order to protect our way of life and economic wellbeing. While there is a cost to implementing an effective monitoring and maintenance programme for our highways and transport systems, the costs of rebuilding and repair following catastrophic loss or failure are inevitably much higher, and the economic costs of disruption are often larger still. The methods used to calculate these costs are complex, but as set out in Devon County Council's impact review following the Dawlish incident (referred to above), they are possible to undertake.

Increased asset loading and longer-term impacts such as climate change are accelerating the degradation of our assets. This means we must be more vigilant in identifying maintenance and protection requirements if we are to maintain the capacity of our existing infrastructure. Sensing and monitoring technology can help to identify and prioritise these interventions, and can be used to design more resilient new structures.

By assessing traffic flow and passenger trends, smart technology can also help us decide what we need to build in future to support our economy, and to optimise design to provide best whole-life value. Intelligent sensing can also enable us to employ 'leaner', 'greener' and more flexible design and construction methods better-suited to combat those conditions made more challenging by climate change. None of this can be achieved without a full understanding of the physical and systemic nature of our transport infrastructure, through deployment of new sensing and monitoring technologies and analysis techniques.

2. What are the key drivers behind investment in smart infrastructure?

In the long-term a thorough understanding of asset value, achieved through concerted efforts in condition monitoring, can have substantial benefits. There is a need to further explore the following questions, and these were the focus of the Workshop: *What is the business case? How do we capture and quantify value? How do we compare different sectors? Are our evaluation methods sufficient? Are we using the right measures? How do we assign value to the data?*

Making the most of what we have – When it comes to our infrastructure, needs outstrip capacity, and the cost of keeping pace with transport infrastructure requirements is huge. According to the DfT's 2013 report, *Action for Roads, A Network for the 21st Century* (http://bit.ly/1WXBUlK) the usage of the UK's roads has quadrupled since 1960, yet the spending on our roads infrastructure is currently not much higher than it was then. Smart Infrastructure that controls the speed and volume of vehicular traffic making use of a particular asset can maximise traffic flow whilst keeping costs down.

Setting investment strategy – During 2015 innovative work conducted by TfL using 'crowd-sourced' travellers' journey data, garnered from Oyster Cards, mapped journeys and traveller behaviour across the network. The use of such data alongside physical infrastructure monitoring data enables modelling of the use of infrastructure that then can inform planning of future investments.

Keeping pace with the competition – As the DfT 2013 report sets out, we have fallen behind our nearest European competitors in terms of the commercial and societal readiness of our transport network, and this has had a significant economic impact on the UK's GDP. The report suggests as many as 100 million working days are lost every year due to congestion and poor transport infrastructure, and that the cost to the freight industry alone is £14bn per annum.

Identifying priorities for maintenance work – In the current financial climate, budgets for maintenance activities are constrained. In 2013/14 the highway maintenance backlog for carriageways alone had escalated to an estimated £767 million. There is a very live need to be able to identify and prioritise those assets that require most immediate remedial work. Condition monitoring using innovative sensing can help us prioritise the most critical interventions. Longer term, better understanding and knowledge of our assets will enable a move from reactive to proactive maintenance programmes, to keep our transport infrastructure fit for purpose and minimise disruption to the network.

Controlling costs and carbon footprint – A better understanding of the structural behaviour of materials and building techniques can help to engineer out waste, and demonstrate the efficacy of leaner – and greener – structural design. Careful assessment and monitoring using the latest sensing tools and techniques would enable structures to be built with a smaller carbon footprint, and at lower cost.

Whole-life costing – The largest proportion of the cost of an asset is often incurred during its operational lifetime rather than at the point of its initial construction. Whole-life value-based decision-making tools, combined with effective condition monitoring and proactive maintenance planning, can provide a better understanding of the whole-life cost and value implications of different design, operational and maintenance decisions.

Making what we do safer and less disruptive – The use of remote monitoring and sensors in hard-to-reach places means fewer manned visits are required to sites that are hard to access. This makes inspection regimes safer for the teams involved, and reduces disruption caused by the need to close assets to enable manned inspection.

3. What are the key challenges faced in taking forward smart infrastructure?

A variety of different 'smart infrastructure' tools and technologies are already available, yet up-take of these technologies is traditionally slow in the area of infrastructure construction. Why?

Which of our assets are 'key'? – In the UK, there is no defined, nationally-held list of which of our transport assets are critical to the functioning of our nation and economy, nor a formal audit system in place to inform decision-makers of the ages and condition of the assets; so, no tools to inform the organisations responsible for their up-keep when these assets were last inspected and when maintenance or renewal are due. Because many of our transport assets (roads, bridges, trackway), are managed locally, and contemporary records of them held corporately, it is hard to apply a coherent national strategy to design, construction and maintenance. The National Infrastructure Commission has identified the requirement for a 'National Needs Assessment' to assess the UK's future needs and how they might be met (http://bit.ly/20jtsT9).

Ownership of up-front costs – There is a cost associated with implementing smart infrastructure solutions, and it is often difficult to find this from existing maintenance budgets, which are already stretched by existing inspection and maintenance schedules. Inspection is costly, and current methods are often technically subjective; this can result in inspections of somewhat limited accuracy being carried out less frequently than they should be, thereby increasing the risk of failure and, ultimately, giving rise to a greater cost of repair. The installation of remote sensors might be a cost- and time-efficient solution, but asset owners are reluctant to invest in technology that may only see significant returns at some stage in the future.

For new assets, installing monitoring equipment during construction provides long term benefits in asset condition monitoring. However, typically this is viewed as an up-front cost, as 'Cap-ex' rather than 'Op-ex', even though the benefit is likely to be reduction in operating costs due to reduced need for manned inspection and maintenance. The benefits may take some years to accrue, so innovative monitoring systems are not usually implemented during construction of a new asset, meaning that the risks of increased inspection and maintenance costs are then borne by the asset owners and operators further down the line. There is a need for a longer-term approach to the problem of robustness and longevity in our built environment.

Culture and Practice – Even where sensors could enable less material redundancy to be incorporated in the design from the start (for example, where less concrete could be used in piles, or where a drainage channel could be made narrower or slopes steeper by monitoring these for signs of potential slippage), there is a tendency by designers to revert to standard practice. This relates in part to the skills and experience of project teams and their managers, and in part to the lack of an incentive to innovate. The need to manage contractual risk can sometimes be linked to a reluctance to implement new solutions.

Procurement practice in the sector – Government procurement processes and supply chain management have an important role to play in enabling innovations to be adopted. It is accepted that current procurement practices, for good reason, impose limitations and boundaries by which departments must abide. However, guidelines can often focus more on specific short term outputs when longer term performance outcomes should be preferred.

The focus of asset delivery contracts on minimising the capital cost of delivery and project timescales is often the default approach. However, opportunities to take a whole-life approach to value and incorporate better solutions for asset operation and maintenance have been considered in Infrastructure UK's recent Innovative Contractor Engagement ('ICE') procurement model.[3]

At the present time, there is little impetus for construction firms to innovate because the benefits of that innovation will be felt further down the line, long after the construction has been completed. In addition, it is often other government agencies and stakeholders responsible for operation of roads or railways that procure the vast majority of key assets, and invitations to tender often remain prescriptive. Technology requirements tend to be based on the information available at the start of a major project, rather than employing an outcome-based specification that would allow for implementation of newer, more appropriate emerging technologies as and when they are required or identified; the rigidity and complexity of government procurement frameworks can sometimes serve to prevent innovation by discouraging procurement from smaller, more innovative companies.

In an attempt to tackle these challenges, the 'ICE' model was piloted, resulting in positive outcomes in a number of areas, by London Underground in the contracting and procurement processes for the Bank Station development programme. The model places at its heart the need for suppliers to be selected on their ability to innovate, not merely to deliver to an initial brief. But this approach is still new to many, and ways of promoting this practice more widely should be explored with urgency.

Challenges around cost models – Our assets are usually built to serve us for decades, often for generations, but the imperative for investment is often driven in shorter bursts, often in line with political change. There is little long-term consideration in planning spend and determining how an asset can benefit its users in the future. There may be a need to investigate novel ways of reflecting this in the way contracts are devised so that there is a motivation to consider the whole life cost of an asset.

A need for standards to support innovation – There is a lack of cross-sector collaboration within the infrastructure and construction industry. Different parties use different metrics and language. Currently there are no defined standards set for the outputs of the sensing and monitoring technologies on offer, nor a formalised framework for using the outputs to define ways of assessing asset performance and condition. Data exchange needs to be better facilitated, with data organised in a consistent way, and standardisation introduced to allow benchmarking and calibration to take place. It is also recognised that rigid standards can prevent development by imposing certain specifications and thresholds; thus, there may be a need instead for new guidance and for outcome-based standards.

Constraints around data sharing – There is a need to be able to share data between stakeholders to increase the value that can be derived from them and enable benchmarking of asset performance and degradation models. Where there is sensing data available, there are problems in sharing the information for reasons of security, data protection, and sometimes simply due to lack of standardisation that means the data itself is not comparable. Some work has been undertaken in this area by some organisations (recent work by TfL is an example of good practice in this area), but work is needed to share the lessons learnt, and to encourage other bodies to share the information they gather. The Government's Open Data agenda has helped in this regard, but more work needs to be done in this area (see section 2.6, http://bit.ly/1WYcncf).

Skills deficits – The skill-sets needed to manage infrastructure are changing, and the pace of change is increasing as new technologies and approaches are developed. This needs to be recognised in the development and provision of continuing education programmes. It also needs to be recognised that many of the organisations contracted, for instance, to inspect and check assets such as bridges are small companies with limited access to the latest tools or technological know-how and with limited training budgets. Thought needs to be given to how best to support all areas of the sector in developing its skills base to avoid reverting to the established, and often out-of-date practice that prevents the wide-spread take-up of newer systems and methods of working.

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[3] www.secbe.org.uk/content/panels/Report%20-%20Innovative%20Contractor%20Engagement%20Procurement%20Model%20-%20Bank%20Station%20Capacity%20Upgrade-6d5f2a.pdf

4. What needs to be done to support the sector in driving up-take of new technologies?

A shift in attitude is required from the ‘spend what I can afford now’ position to one where we ‘invest to save in the future’. There is a need to future-proof assets from their initial construction to include considerations around future capacity. But it can be a challenge to ‘sell’ the efficacy and advantages of smart infrastructure because, whilst the data generated provides useful information on the condition of an asset, its rate of degradation and when repairs are needed, it might take a number of years before the true value of that investment is realised.

The challenge we now face is how best to develop a robust business case for innovation that will kick-start the wider adoption of new technologies and practice; one which will provide the best platform for future development and growth. There are several ways in which this needs to be tackled:

a) Conduct a national audit of assets to understand what there is currently in place, what needs to be done to protect our infrastructure, and use that information alongside sensing and monitoring data to determine what new infrastructure planning needs to be considered. This should be used to feed high level modelling of our most complex infrastructure assets to mitigate against risk of failure, and to plan for the future.

b) Consider the development of a set of defined standards for sensing and monitoring technologies that can be widely distributed, accessed and adopted. It may be that, rather than definitive standards in this area, a set of ‘best practice’ guides may be better suited in encouraging innovation.

c) Consider the development and dissemination of guidelines for the shape and storage of the data gathered so that there is common understanding and more widespread applicability to the use and management of that data.

d) Continually review government procurement guidelines to identify ways of providing longer-term contracting that takes account of whole life / whole-economy costs, and attributes responsibilities and inclusive procurement to avoid ‘engineering out’ innovative suppliers. The further roll-out of the Innovative Contractor Engagement Procurement Model as piloted by LUL would be of help, but also there is a need to view the construction of new assets as part of a whole-life cost and value framework and link output requirements to this long life-span. Training and guidance to the sector and its professional bodies should focus on outcome-driven rather than an output-driven procedures. These might include incremental performance modifications and improvements in each phase to maintain the overall performance further down the line. The broader adoption of the ICE model would ‘free up’ procurement to embrace innovative technologies, and encourage a ‘whole life’ approach to planning and implementation that would benefit future generations.

e) Apply the lessons learnt from this and other sectors in regard to accommodating innovation within the procurement process. London Underground already systematically reserves the right to purchase innovations from unsuccessful bidders as part of their procurement process. The healthcare and drug / treatment development sector employs AGILE project management [https://en.wikipedia.org/wiki/Agile_management] in its development cycle, which supports a responsive procurement process.

f) Engage insurers and risk managers at a strategic level in discourse around the way technology can help identify and manage risk, with a view to adopting practice within the insurance sector and professional risk management; this would lead to the creation of incentives to embrace smart infrastructure and monitoring systems.

g) Find ways of calculating the real whole-life cost of an asset to help monetise the return on investment in technology. To be meaningful, this requires a broader modelling of economic impact that can then be used to identify priorities, but this is a complex process and requires cooperation between many stakeholders to achieve a meaningful outcome.

h) Enable widespread access to training and development in this area, and in support of the DfT’s Transport Infrastructure Skills Strategy, to actively promote uptake of this policy in order to support a pipeline of skilled staff and engineers for the sector. Explore how to make basic training more widely available by providing more apprenticeship places, and encourage take-up of related training and study at higher levels. The skills deficit relates equally to new sensor technologies, software development, data analysis and management. Managers need to keep their knowledge current, too, in what is a fast-moving environment.

i) Define and apply strategic, joined-up thinking around the use of crowd sourced data, such as that gathered via vehicle-mounted sensors to detect road condition, to add to our knowledge of the condition of the nation’s infrastructure.

j) Create a ‘business case tool’ and commercial framework that acts as an exemplar for use across all transport sectors to allow for organisations to work together to achieve maximum benefit from the systems they have in place, and to be able to plan for the installation of new technologies that serve more than one purpose.

k) Collate, publish and make widely available existing case studies to illustrate the effective use of new condition monitoring tools, and to continue to encourage further additions, to give confidence to industry and avoid early problems. This would require a targeted approach to garner facts and recommendations from a defined programme of pilot projects.

5. Future steps in the development of a cohesive strategy

The DfT is best-placed to act as convenor for the work in this area, and would be able to both access past and current information, expertise in business cost and Return On Investment (ROI) modelling, and would have a strategic overview of the transport infrastructure networks that are required to suit a growing Britain.

The Workshop panel groups suggested that Government could fund pilot projects and support 'discovery phases', in particular in sectors where market uptake is less likely to happen, for instance the rail sector. It is acknowledged that the DfT acts through other agencies, stakeholders, partners and transport operators. Many of these bodies should support near-market solutions and pilot projects, providing they are going to be beneficial for society as a whole, and therefore should work more closely in collaboration with researchers in the field of intelligent infrastructure and condition monitoring. Because of the disparate nature of the types of organisations involved with delivering the UK's infrastructure, Government does have a role to play in coordinating discussion to ensure all of the appropriate agencies and stakeholders are included, and in issuing core guidance that underpins further development of practice in a variety of allied areas, such as Transport, Environment, Agriculture and Economic Regeneration.

All of the activities and approaches set out in this paper would actively encourage the adoption of innovative tools and techniques for intelligent infrastructure and condition monitoring, and would benefit our nation's infrastructure. But each of these is complex and will require multi agency and stakeholder support.

This paper provides a framework for discussion, and will require further consideration and consultation with policymakers, academics, businesses, investors, transport asset owners and operators.

Appendix 1 – Summary of Workshop Presentations from CSIC (Case Studies)

Presentation Summary 1 – Whole-life Value-based Asset Management

Dr Ajith Kumar Parlikad

As defined in the recently produced standard, BS ISO 55000/1/2, *Asset Management is the coordinated activity of an organization to realise value from assets*.

The standard defines two key themes of asset management; firstly the linkage between the asset itself and the business objectives; and secondly, that asset management looks to the long term. It is concerned with the impact assets have on their operating context.

In practice, effective asset management combines engineering and mathematical analyses with sound business practice and economic theory to create a logical methodology for cradle-to-grave operation and maintenance for assets.

But what does "value" mean for infrastructure? Infrastructure provides value if it continues to perform its function at the required quality, at an acceptable level of risk, and when it incurs an acceptable level of expenditure. But how are these values defined?

Value-based decision making has to be objective if it is to succeed, and a systematic methodology must be adopted that takes into account the needs of stakeholders. CSIC has developed frameworks and methodologies to help with this, and these are based on investigative projects in which it considers the 'futureproofing' of infrastructure, the value of sensing to the business and broader stakeholder economy, and the need for suitable asset management information and data management.

	Cost-based (traditional)	**Cost-based (traditional)**
Core focus	**Cost**	**Cost, Risk Performance**
Management philosophy	Minimize expenditure while maintaining satisfying performance requirements	Maximize performance and minimize risk while satisfying budgetary constraints
Stakeholder focus	Decision maker	All stakeholders of the asset (e.g., owner, operator, user, regulator)
Impact on service	Maintain minimum service levels	Explore innovative approaches to improve service levels
Scope of analysis	Generally focusses on asset specific issues	Includes system level dependencies and focusses on business value
Difficulty	Well established body of knowledge	Concepts not well understood in theory and practice

Presentation Summary 2 – BIM Plus+, Adding Value to Monitoring Data

Dr Manuel Davila

There are arguments to suggest that Building Information Modelling (BIM) has not yet met expectations in terms of its reach and suitability for the task. It does however show promise, and by linking monitoring data to BIM models, we can increase the value and applicability of both data and BIM itself, and thereby drive more meaningful levels of take-up. But first some of the challenges posed by BIM need to be recognised and addressed, and the usefulness of the data we gather needs to be maximised.

Data is the starting point to make decisions, but it must be able to be easily exchanged and put into context. Only then can it be analysed and can serve to make decisions and take actions.

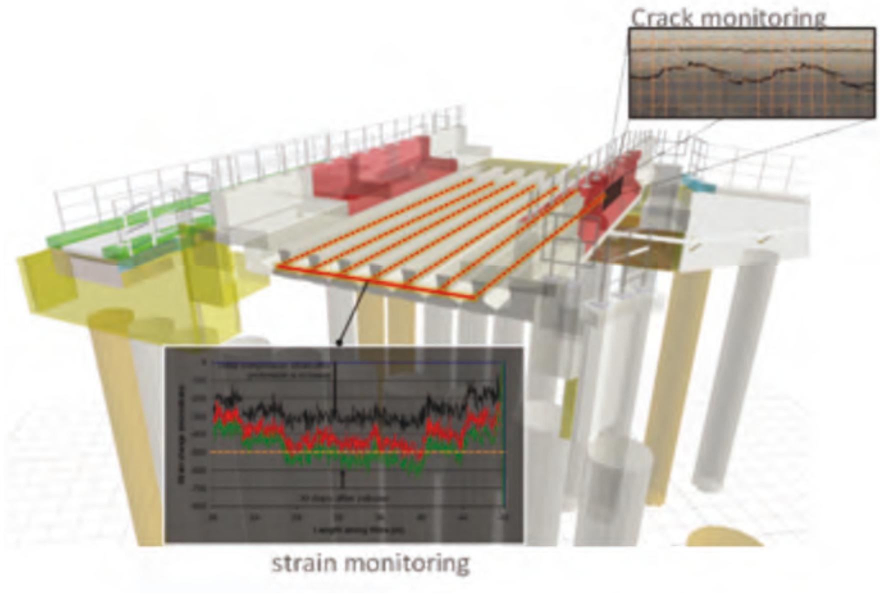
One of the obstacles to robust data exchange is that the existing data model standards are not yet sufficient. BuildingSmart and the Open Geospatial Consortium are the organisations that develop standards for the construction industry. However these standards cannot fully describe infrastructure assets or structural monitoring systems, which are of main interest to the sector. That is why an extension to the Industry Foundation Class (IFC) specification has been developed by CSIC to enable the description of structural performance monitoring systems and to include sensor data in BIM models. This extension will allow the exchange of data irrespective of any authoring tool. The extension is the result of an investigation into capabilities of current standard data models, common practices and requirements.

Another challenge is to visualise data directly in the BIM model. For that, BIM tools are being developed that enable the modelling of monitoring systems and the management and visualisation of sensor data. Case studies to test the capabilities of the extension and the BIM tools are being carried out.

The expected outcome is a BIM tool that enables monitoring systems to be modelled and presents monitoring data directly in the BIM model. The example illustrated shows structural performance data by monitoring strain and condition data by monitoring cracks in concrete elements.

Preliminary results show that files containing the asset, the monitoring system and the sensor data can be exported via IFC and can be used in various authoring tools. A web browser is currently in development which will allow these data to be visualised without an authoring tool. What is unique about this approach, compared with other solutions, is that the monitoring data can be displayed directly in the BIM model. It can be viewed on a web browser and it can be exchanged via IFC. This ‘democratisation’ of access to useful information is vital and is now happening.

Monitoring systems are becoming common practice and more complex. Large amounts of data are being generated. But this data is useless if it cannot be easily exchanged and visualised in context. Only then can it be easily analysed and used as a basis to make decisions and take actions.



Presentation Summary 3 – BIM for Existing Infrastructure

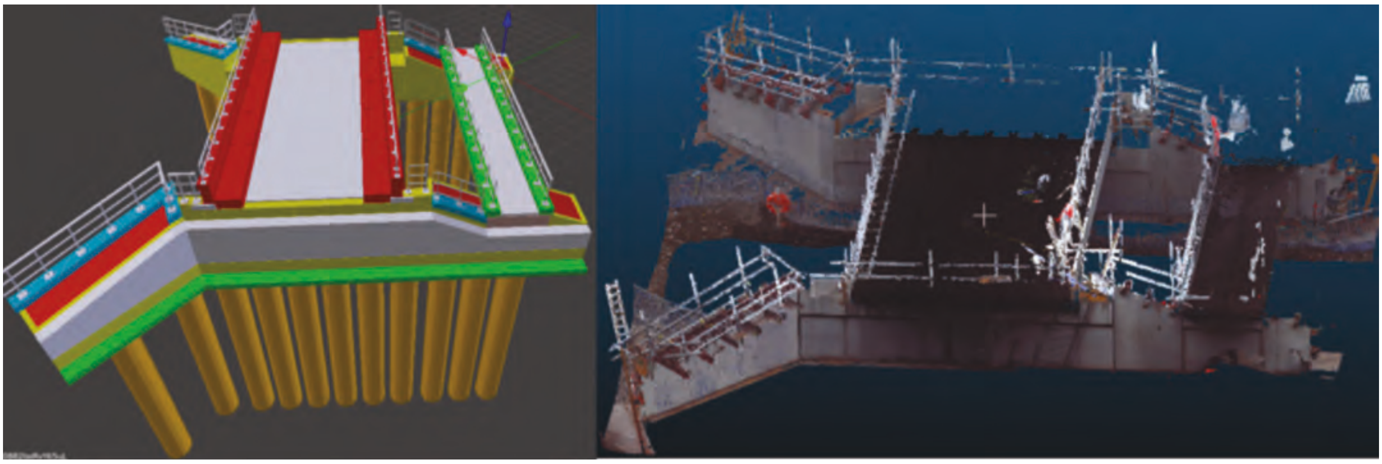
Dr Viorica Pătrăucean

Creating BIM models is not always as easy as one would think it would be. Assets rarely are built entirely to initial design specification, the origins of most BIM diagrams therefore mirror more closely the forms created by the designer, but less so those actually created on site. The as-built reality may differ from the design due to geological, materials-related, or budgetary reasons.

It is also worth noting that existing infrastructure also needs the BIM approach, yet relying on older design specifications (where they exist) is even more a matter of trial and error because assets are often modified over time. Traditional survey and drawing methods are time-consuming and can be costly to undertake. Therefore it has been important to try to find ways in which infrastructure can be re-evaluated, re-measured and accurately visualised.

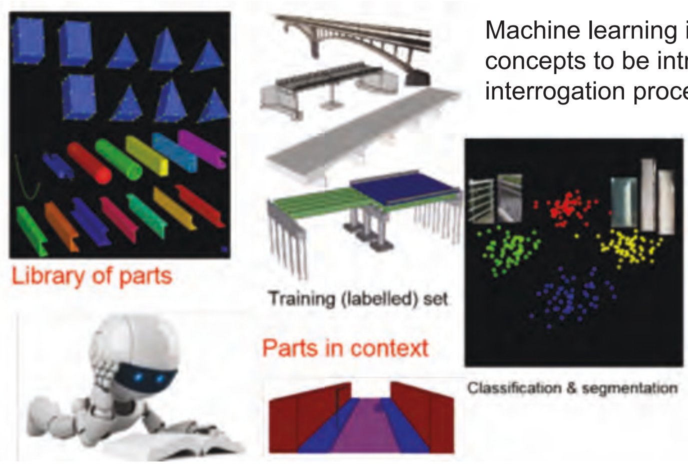
Research undertaken by CSIC has focused on trialling new data gathering and computing methods to reverse-engineer 3-D design of existing infrastructure using photo-imaging which is then used to build a point cloud image of the structure. An example of this, and the difference it can make to identify all of the actual features of a structure is described by the images below.

Note the highly-detailed structural detail included in the point cloud model on the right. But the use of photographic capture to support the construction of a point cloud has had its limitations; not only does the photographic equipment have to be positioned very carefully, the data gathered that relates to odd and sometimes transitory structures such as foliage, passing traffic etc, can make it hard for the system to ‘read’ data correctly. Because the system is largely automated, the next step has been to create a system that can ‘read’ the images gathered correctly, delineating between foliage and the ground surface, birds and the tops of street lighting etc.



Designed IFC model **As-Built Point Cloud**

Thus, we turn to machine learning – and indeed ‘Deep Learning’ based on biological methods of building visual memory – to help the system begin to recognise elements and context.



Machine learning involves some ‘teaching’ at the outset: crude shapes and concepts to be introduced to the system at the beginning of an interrogation process. But once initial lessons are learnt, then the system begins to read elements accurately, and is able to classify and segment elements appropriately.

The advantages of using Advanced Machine Learning to undertake this process are many and varied, but include the fact that the computerised system is simply more accurate than human beings at recognising and remembering detail. It is also very fast and safer to use in the field, and so labour-intensive inspection supervision can often be dispensed with.

The roll-out and adoption of BIM is, arguably, reliant upon this type of automated deep learning system. Without this type of system being widely available, universal BIM applicable to all infrastructure will be impossible to achieve.

Presentation Summary 4 – Staffordshire Alliance Bridge Monitoring Project

Dr Niamh Gibbons

Between 2002 and 2008 there was a £9bn investment in upgrading the West Coast Main Line (WCML). But one very expensive section just south of Crewe, estimated to cost around £1bn, was omitted from the programme at the time in order to deliver the rest of the upgrade. This last section was the final bottleneck left on the WCML, and it is now that work that is being undertaken.

The aim of the work is to construct a Grade Separated Junction to allow high speed trains to travel straight through without the trains on the other lines having to stop and wait for them to pass, resulting in reduced congestion.

The scheme's aims of enabling trains to travel at higher speeds of around 100 mph (160 kph), were coupled with a need to improve the maintainability and reliability of the network. In terms of actual capacity, renewal of this new section of the network will allow for an additional 2 trains per hour between London Euston and the North West, an extra 1 train per hour Manchester and Birmingham, plus 1 more freight train per hour through Stafford.

historic track alignments

proposed track alignments

This section of the West Coast Main Line is a vital infrastructural element – one which is key to linking the north and south of the country, so it was felt important to futureproof this key asset.

Two new bridges were installed, one concrete bridge, and the other a steel bridge with composite sections, which were instrumented by CSIC's team with two different kinds of innovative fibre optic strain sensing: the BOTDR (Brillouin Optical Time Domain Reflectometry) method and a Fibre Bragg Grating (FBG) system.

Many different elements of the structures have been instrumented. The beams were instrumented while they were being manufactured off-site in a factory, and on-site instrumentation was also carried, with a great deal of data emerging.

This instrumentation has allowed interrogation of each element to determine for example, for the concrete bridge, what pre-stress losses were incurred in the concrete beams; with the steel bridge we were able to assess the effects of composite action and the additional compressive demand on the flanges of the main beams.

In addition to such design-specific questions, element models have been built and validated alongside the different construction stages; parametric and predictive studies for the structures can then be undertaken including the effect of live loads on various elements. Following on from this, once live loads have been fully characterised, this can inform future design of similar bridges, thereby maximising the value derived from what is, initially, a fairly costly monitoring system to install.

As the nature of construction moves from on-site construction, towards more off-site manufacture and prefabrication, the inclusion of integral sensing elements during off-site fabrication is both feasible and cost-effective. The opportunities afforded by off-site incorporation of sensing instrumentation opens up other avenues, too, not least in the drive for standardisation and universality of instrumentation tool-sets.

It is an aspiration to have the core technologies, such as fibre optic cabling, installed in certain build elements as standard, to provide information both on the as-built structure and on the structural health of the component during its lifetime.

Presentation Summary 5 – Laser Scanning Application in Geotechnical Infrastructure

Dr Hyungjoon Seo

Laser Scanning is a very useful tool with which to monitor certain kinds of condition change of infrastructure and has a number of different uses. While not as accurate as conventional strain sensors, it can be applied in three dimensions over large areas. It is therefore appropriate for larger structures that are prone to longer-term deformation and displacement, and for which it is not known where deformation may occur.

A series of investigations have been carried out to refine the use of laser scanning, one of which took place in North Wales where a 22 year old highway retaining wall which had been fitted with traditional strain gauges, needed to be monitored because the strain gauges had stopped working, and there were concerns that some of the blocks were moving. Laser scanning was used to locate the individual displaced or weakened blocks. Two scans were performed around 3 months apart.

Once the scanning areas were identified, and scans undertaken, the data between the first and second scans had to be compared. Data was extracted that sought to compare planes, giving rise to a detailed map highlighting changes to the retaining wall.

One of the key benefits of laser scanning for such applications is that it can be used safely and easily. It is a non-invasive method of tracking movement, so potentially of great use for a wide variety of infrastructure.

A potentially important application is the long term monitoring of highway and railway slopes, embankments and retaining structures, to provide early-indications of movement so that maintenance can be undertaken in a timely, safe and cost-effective way.

Appendix 2 – Workshop Attendees

Name	Organisation
Neil Loudon	Highways England
Chris Newson	Highways England
Kevin Dentith	Devonshire County Council
Andy Bairstow	Nexus
Stephen Pottle	TfL
Keith Bowers	London Underground Limited
Nader Saffari	London Underground Limited
Marie Gilmour	Crossrail
Martin Collett	Docklands Light Railway
Amanda Hall	Network Rail
Smith John	Network Rail
Ian Roche	HS2
Giles Thomas	HS2
Gareth Tucker	Rail Safety and Standards Board (RSSB)
Edwin Barker	Rail Safety and Standards Board (RSSB)
Stephen Hart	Innovate UK
Mike Devriendt	Arup
Ruth Platt	Atkins
Phillip Russell	Costain
Russell Davies	Costain
David Pocock	CH2M Hill
Steve Birdsall	Gaist Solutions
Peter Lee	Road Investment Strategy Futures, DfT
Miles Elsden	DfT Chief Scientist
Neil Ebenezer	Research and Science, DfT
Steve Berry	Head, Local Roads, Light Rail and Cableways Branch, DfT
Nick Bucknall	Rail Accident Investigation Branch, DfT
Manny Chung	DfT
Clemence Cavoli	DfT
Ruth Kennedy	DfT
Robert Mair	CSIC / DfT SAC
Sandy Yatteau	CSIC
Jennifer Whyte	Imperial College
William Powrie	Southampton
Amelia Burnett	CSIC
Jennifer Schooling	CSIC (speaker)
Cam Middleton	CSIC
Kenichi Soga	CSIC
Viorica Patraucean	CSIC (speaker)
Manuel Davila	CSIC (speaker)
Ajith Parlikad	CSIC (speaker)
Niamh Gibbons	CSIC (speaker)

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