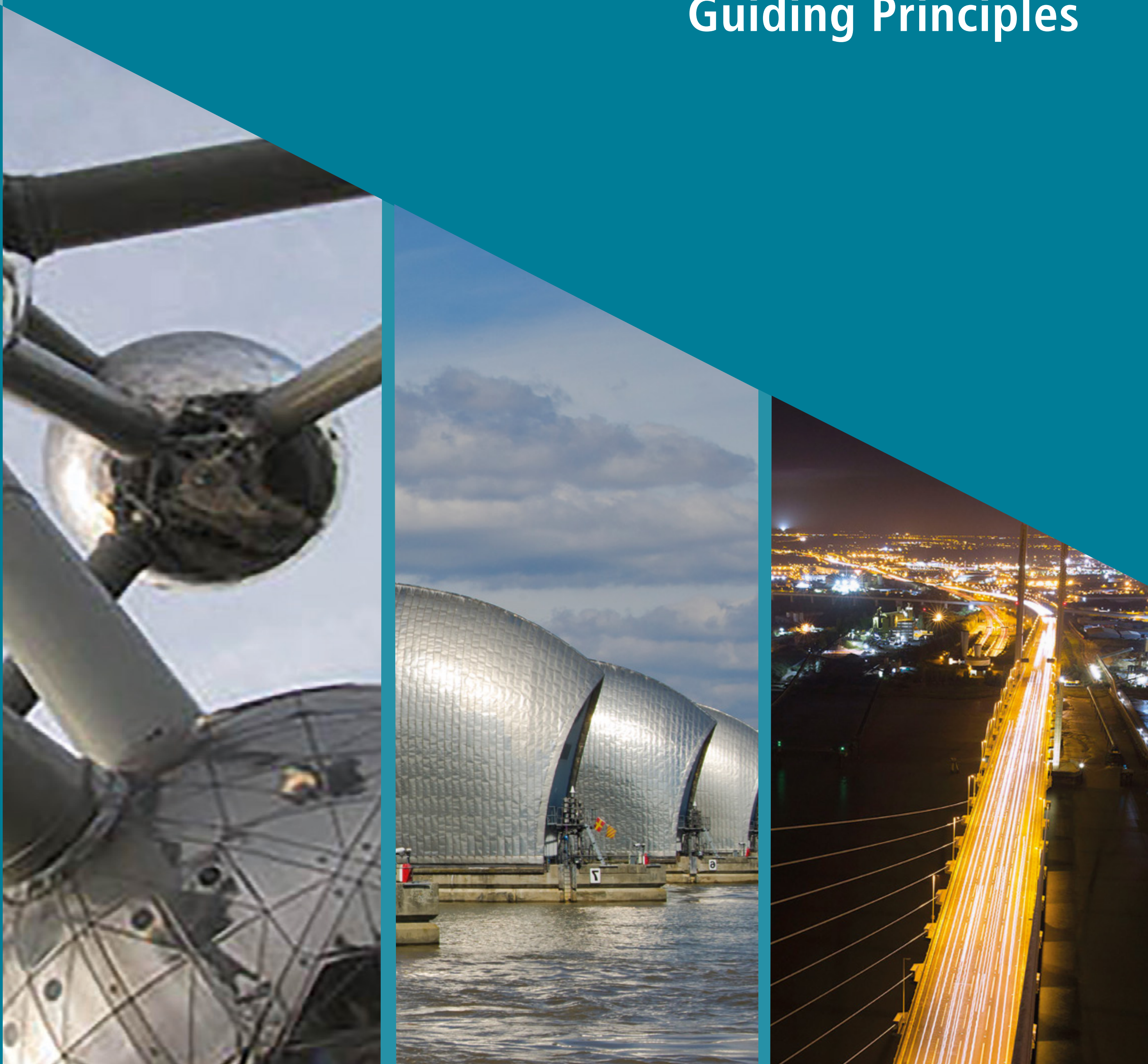
CSIC Cambridge Centre for Smart Infrastructure & Construction

ice Institution of Civil Engineers

ICE Guidance Paper

Intelligent Assets for Tomorrow's Infrastructure:

Guiding Principles



ICE Guidance Paper

Intelligent Assets for Tomorrow's Infrastructure

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1. Foreword

We all know that when it comes to delivering and maintaining infrastructure assets, better information leads to better decision making. This, in turn, leads to smarter infrastructure.

ICE's Guidance Paper is an introduction to smart infrastructure and in particular how civil engineers can enable its underlying assets. It follows a series of recent ICE publications on infrastructure sensing, modelling and whole-life valuing — ranging in application from single assets to even entire cities.

Infrastructure sensing is becoming simpler, cheaper and more versatile. Data can now be readily collected, analysed in real time and compared across assets, companies and countries. The fast pace of technological change mean that the cost of developments such as sensors and data storage is decreasing rapidly. This enables better decisions on the construction of future assets, better running of today's existing assets, and far better avoidance of failure, not to mention long term financial benefits such as significantly reducing whole-life costs.

Even though such benefits of smart infrastructure are only just beginning to emerge, as an industry we can continue to encourage its development in the future. As a sector, we are still relatively new to using digital engineering, but ICE is committed to encouraging more innovation in the industry, for the benefit of the whole of society.

Today the new technology headlines tend to be grabbed in other industries such as healthcare and telecommunications. When it comes to the building and civil engineering sectors, big changes are less obvious and certainly less obvious to the public. We live in a world brimming with new ideas in other sectors. It is time to make ours every bit as vital!

This Paper is one of many examples of how ICE has strived to do this throughout my Presidential year and will continue to do so under Tim Broyd, ICE President.

I would like to thank all those who have contributed, particularly the members of the ICE Asset Management Group and the Cambridge Centre for Smart Infrastructure and Construction (CSIC). The hard work and expertise of our members — and our ability to collaborate with other professional groups across the country — are vital to ensuring the ICE remains a powerful voice for infrastructure and that we deepen our collective pool of knowledge.

Sir John Armitt

ICE Past-President

Member, National Infrastructure Commission

2. Introduction to smart infrastructure and intelligent assets

Imagine an underground rail network that can detect its own degradations: trains that automatically communicate with a tunnel on a regular basis to record condition monitoring information and to advise the tunnel operator about maintenance schedules for its lining. Train operations may also be adapted accordingly.

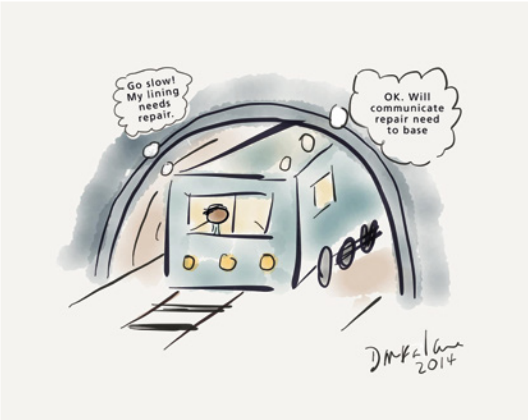

Figure 1
Imagine an underground rail network detecting and communicating its own degradations

Now consider a bridge system that adapts its routine and critical maintenance in such a way that traffic flows are gracefully degraded / minimally interrupted so as to minimise the impact on vehicle throughout and bridge maintenance. The bridge might also communicate with passing vehicles to gather vibration data in strong winds as well as pass on information about driving restrictions to the vehicles and redirecting them if necessary. This is very close to reality. Under the current Smart Motorways programme, the traffic sensing turns on the warning signs, and the manual controller decides when to open the 4th lane (hard-shoulder running). Cathodic Protection systems to control steel reinforcement corrosion monitor their own performance and send out reports.

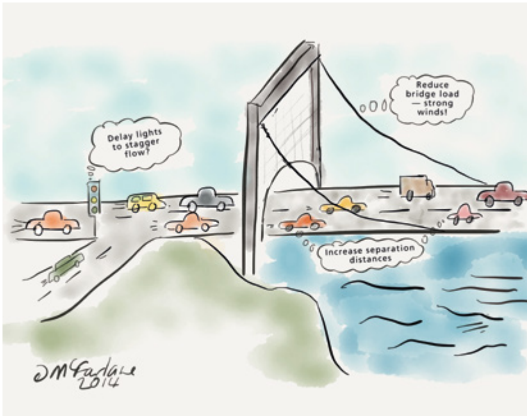

Figure 2
A bridge system adjusting its traffic flow to minimise disruption, and adapt to conditions

Welcome to the world of smart infrastructure, in which embedded sensing capabilities are combined with computer-based decision support to allow each asset to effectively "think for itself"!

This guidance paper sets the scene for the development of the next generation of infrastructure. Infrastructure made smart by developing key assets — intelligent assets — that can monitor, manage and maintain themselves on a daily basis throughout their lifecycle.

While this might seem like a vision from a futuristic sci-fi movie, this paper will make the case that a) the development of such capabilities is critical if we are going to be able to manage key assets effectively in the future, and b) that the technologies to enable such a vision are not as far away as might be imagined — in fact many of the necessary components are already available today.

The notion of an "intelligent" infrastructure asset — effectively the building blocks for forming smart infrastructure — is drawn from the Artificial Intelligence literature, where the concept of intelligence in machines and other inanimate objects refers to the ability to analyse information to deduce, reason and solve problems. We define an intelligent infrastructural asset or intelligent asset as below:

Intelligent (Infrastructure) Asset Definition

An infrastructure asset that

- is linked to information and rules governing the way it is intended to be constructed, maintained, used, refurbished and demolished and
- enables the asset to support or influence its own use.

The notion of intelligence is linked here with concepts such as self-sufficiency, ownership, virtual and physical representations of an asset — many of these terms are used already today in the construction domain in discussions around Building Information Management (BIM). This guidance paper can therefore be viewed as one way in which BIM data can be exploited to improve the interacting operations and functions of key assets. Beyond this is the implication that assets can — for example — automatically collaborate to share maintenance data or make joint energy management decisions.

Figure 3
Optimised operation of buildings

In this document, we propose the need for an alternative view on the management of infrastructure assets — pointing to some of the shortcomings in today's approaches as motivation. We describe in more detail what we mean by an intelligent asset and provide a pathway to developing such capabilities in which key technological constituents are described. We then note some of the current developments in sensing and data management that provide a basis for our vision, and in doing so demonstrate that the "sci-fi" vision is rather closer to becoming a reality than might be imagined.

The intention of this paper is to provide the reader with a sense of the need for change in the way we manage our infrastructure and to give a clear notion of what the monitoring and management of key assets will be like in the future. The paper also provides a justified route to achieving a smarter infrastructure environment, and the incremental steps to follow.

We begin, however, by examining some of the challenges we face today.

3. Challenges for today's infrastructure

The reason for considering an "alternative" approach to asset management is that there are currently numerous challenges in managing infrastructure assets such that they continue to provide value to owners and the community at large. In this section, we highlight some key areas for concern which motivate the need for a significant change to the current practice:

Financial Limitations:

In today's economic climate, infrastructure owners and operators are coming under immense pressure to maintain an adequate (and often improved) level of service and performance within an ever-shrinking budget. Success in this climate is determined by an operator's ability to strike the right balance of expenditure without taking inappropriate risks and adversely affecting performance over the life of the infrastructure. Better asset information, generated throughout the life of the asset, is critical to developing a good understanding of through-life risks and performance, and to enable proposed levels and timings of expenditure to be justified.

Tighter Regulations:

Most key infrastructure sectors (e.g. transport, energy, water, communications) are heavily regulated in the UK. These regulators (e.g. CAA, ORR, OFGEM, OFWAT, OFCOM,) increasingly require greater accountability and justification from operators for capital and operational expenditures, as well as performance data. The fact that infrastructure assets have a very long life makes it difficult to estimate long-term costs and risks, thus providing the impetus for 'smarter' ways of monitoring those assets and capturing data so as to improve whole-life cost modelling.

Large Numbers of Ageing Assets:

UK infrastructure is ageing, and requires an ever-increasing amount of investment in maintenance and upgrade in order to maintain existing — or even increasing — performance levels. Infrastructure assets are characterised by long life and complex deterioration modes: knowledge about the way these assets deteriorate over time and how the deterioration affects the costs, risks, and performance is patchy. The age of UK infrastructure assets also mean that crucial information about the assets is often lost, or is expensive to retrieve or regenerate. The challenge here in this context is the issue of integration of newer, smarter assets with legacy infrastructure and systems.

Climate Change:

Changing climate, and the new weather conditions that arise as a result, means that some future operating conditions are unknown: appropriate measures need to be in place to detect and respond to these changes.

Three further complicating factors which exacerbate the challenges for managing infrastructure are:

Complex Networks of Interacting Assets:

Individual assets in infrastructure rarely provide value on their own, rather it is the combination of different types of assets in a network that generates value. For example, a bridge on its own does not deliver value, but the associated road network generates value for the users and the owners. However, individual assets have the ability to affect the value generated by the system depending on their criticality to the service. Smart infrastructure management therefore requires us to understand these interactions — data being a key enabler for this.

Multiple and Changing Stakeholders:

Infrastructure assets increasingly involve multiple stakeholders ranging from the asset owners (e.g. UK Government), asset managers (e.g. Highways England), asset operators (e.g. contractors), and asset users (e.g. general public). The longevity of assets may mean that the stakeholders (e.g. the owner) or even the type of usage (e.g. power stations converted to office buildings) may change over time. This poses challenges not only in the way these assets are managed over their life, but specific challenges to the way data and information about them are handled.

Separated Management of Interacting Systems:

There is added complexity due to the fact that the management of key infrastructure is assigned to different silos in organisations, often along the lines of traditional "asset type" disciplines. For example, maintenance of a bridge structure might be the responsibility of one department that is different to that responsible for the maintenance of the pavement on the same bridge, which is again different to that responsible for the signals or for the lighting on the bridge!

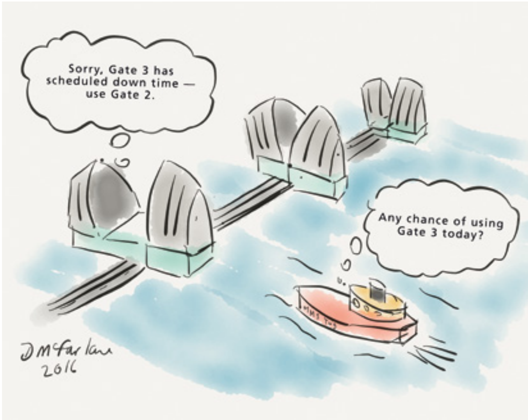

Figure 4
The interaction of systems under differing management (or ownership)

In addition, the maintenance and operation of infrastructure assets is often managed by separate teams, which can lead to difficulties in coordination and decision-making. Alongside this, the silo-based management of labour skills, effort and operating expenditure within distinct operational groups can lead to the inefficient deployment of scarce budget.

So, today's infrastructure is faced with familiar and seemingly insurmountable problems — too little money, too many assets and increasing complexity. As in many other sectors, making better use of information holds a potential key to addressing these issues: better data extraction; more effective information management and sharing; increased quality of decision-making and coordination. These are all key issues in the development of intelligent systems. This is illustrated in the diagram that follows.

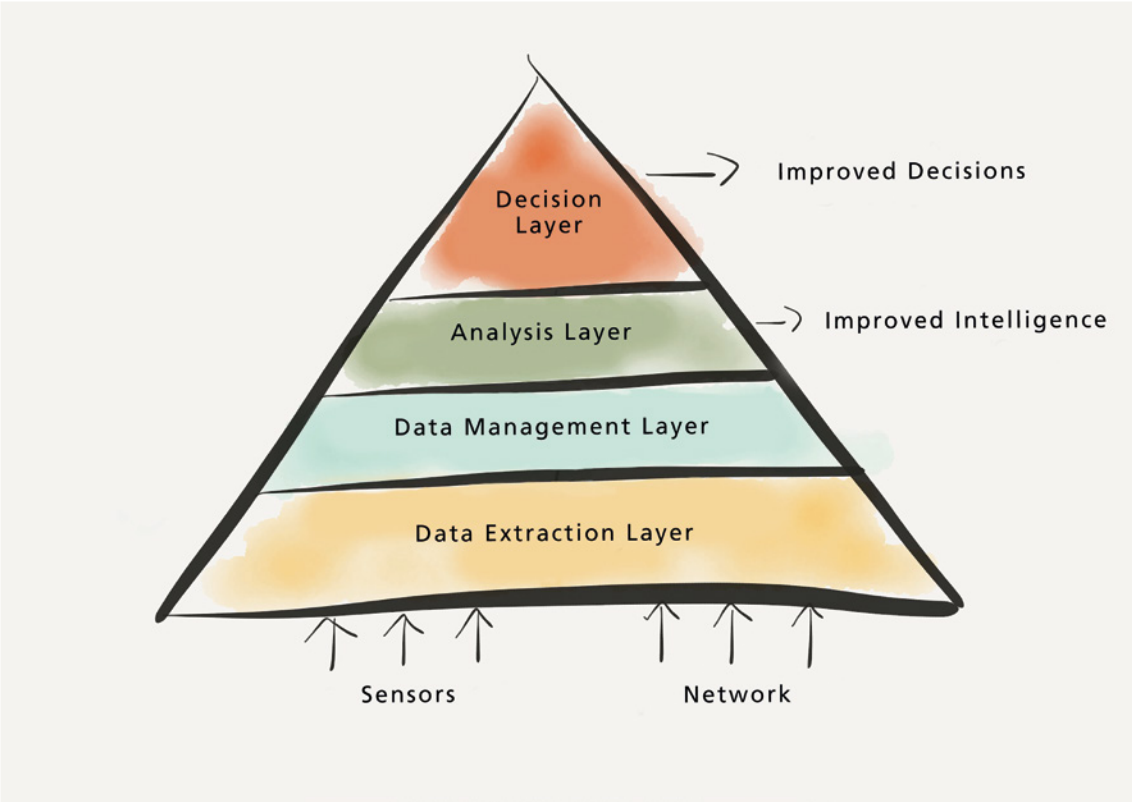

Figure 5
Development of intelligent systems: Hierarchy of decision layers for processing data.

There is huge potential for the introduction of IT systems to support intelligent assets to help greatly with the challenges and complications of infrastructure management identified above. Introducing intelligent asset technology to realise this potential cost-effectively requires a number of physical and operational advances: fortunately, great strides are now being made in each. As a result, the cost of using monitoring to help with infrastructure management is falling significantly, and sufficiently so that old mindsets can begin to change. This opens up the exciting new potential shown in the various illustrations. The main advances are:

- automated sensing: a requirement for automated, low-cost, easy-to-maintain sensing of key asset properties;
- automated data gathering and processing: gathering of sensed and other data relevant to an asset needs to occur in an automated manner and involve processing of the data — filtering, cleaning, correction, structuring etc.;
- asset-oriented data: data organised in an asset-oriented manner — so that all required information relating to one asset or a set of assets can be viewed in a single location;
- data sharing: ability to share data seamlessly as required between organisations;
- information analysis: management and interpretation of information for both predictive and reactive responses;

- decision support: information directly supporting asset management / maintenance planning practices;
- value-oriented data: cost and value of asset management practices understood in the context of the whole-life cost of the asset; and
- robustness to change: asset information and management practices should be robust to ownership changes and adaptable to changes to the operating conditions of the asset.

A common question in IT systems development is whether to use a centrally managed approach to data and decisions or to alternatively take a distributed approach. The former represents most conventional IT solutions but increasingly coordinated 'local information and decision' IT solutions represent a more scalable and cost-effective approach. In the distributed model we are proposing each asset will have an information part which mirrors its physical part (very much in line with BIM thinking) but will also have a decision-making part. Hence the need for an infrastructural asset to "own" its data and be able to "take care of itself" — namely that the asset be effectively empowered to manage much of its own operations, maintenance and repair. For example, the light pole in the sketch (Figure 6) is responsible for its own replacement bulb, or for communicating systematic failure patterns. This observation of local "ownership" is at the heart of the intelligent infrastructural asset pathways that we will introduce in the next section.

Figure 6
Local "ownership": Assets empowered to manage most of its own operations, maintenance and repair

4. Towards intelligent infrastructure assets: A Pathway

The idea of an asset taking care of itself is one that has been discussed in other sectors for some time as sensing, internet and artificial intelligence technologies have become more mainstream. For example, in work with Boeing in the 2000s (Brintrup et al, 2011), the notion of a self-aware asset was introduced while developing software environments to enable aircraft parts to schedule their own repair and replacement.

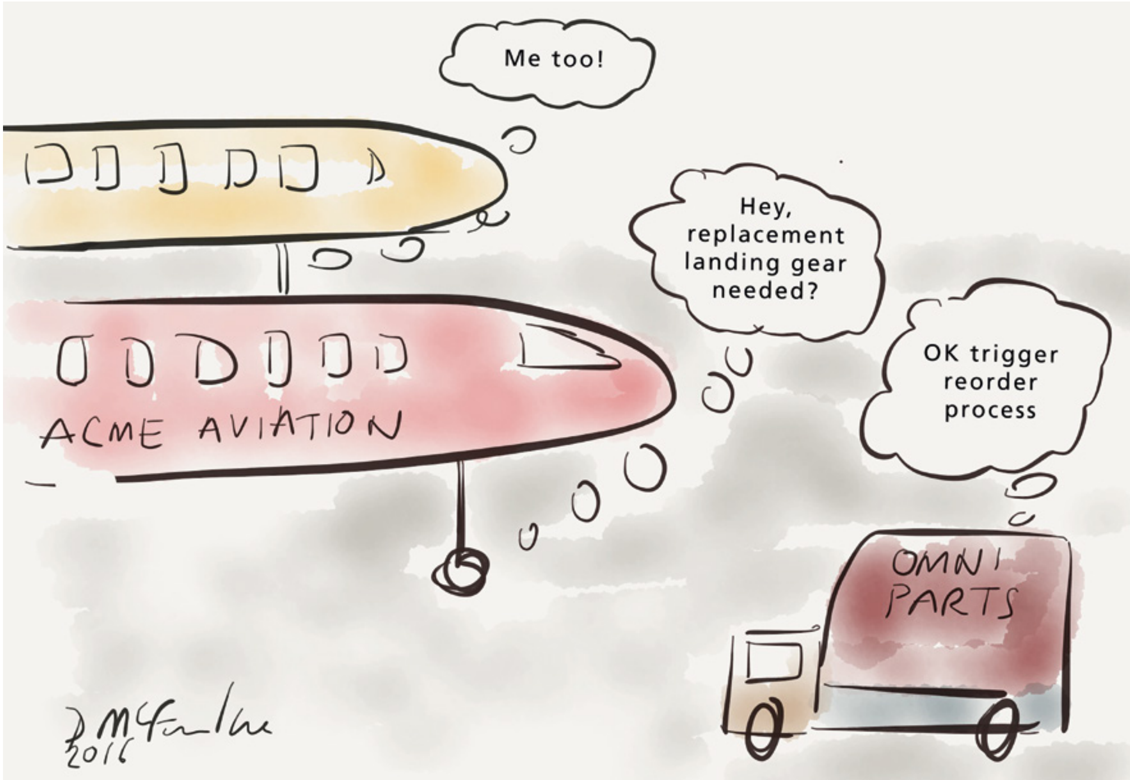

Figure 7
Self-aware asset: In the 2000s, Boeing developed software environments to enable aircraft parts to schedule their own repair (Brintrup et al. 2011).

The rationale behind this development was to seek ways to simplify and automate the complex "maintain-repair-upgrade-replace" processes associated with aerospace components, while also seeking to achieve efficiencies and cost savings, while maintaining high standards of safety. In that work and previous research, it was proposed that the evolution towards this automated, self-management environment might be achieved in stages. Here we propose a similar process for infrastructure assets, in which the migration from conventional to intelligent infrastructure might also be achieved through a series of maturity stages, as outlined in the table below (Table 1). There is a very good alignment between these suggested stages and the BIM Levels 1,2,3 currently being adopted in the infrastructure industry. We also therefore propose a BIM Level 4 alignment here to capture some of the decision support capabilities.

Maturity Stage	Description
Unaware	Base Case (non-sensored, non-inventoried asset)
Identifiable	Asset is identifiable and on the asset register; and design data is linked to asset identity. (BIM Level 1 compatible)
Aware	Appropriate sensors integrated to monitor condition and other state parameters to enhance lifecycle asset management.
Communicative	Asset is able to share its data in a standardised format
Interactive	Asset is able to share its data and to retrieve necessary external information. (BIM Level 2 compatible)
Instructive	Asset is able to convey instructions to enable or support its own lifecycle. (BIM Level 3 compatible)
Intelligent	Self-managing asset, making decisions on its own and instigating actions. (potentially BIM Level 4 compatible)

Table 1
Asset Information Maturity Scale

In simple terms this means that any information associated with an asset is tightly 'bound' to the asset it represents and not to the owner / user / operator. There are often potential procurement-related issues with data ownership in operation and maintenance arrangements, which committing to this would help address. In this way the asset has a virtual counterpart which not only holds data, as prescribed in today's BIM developments, but is also linked to operating rules and guidelines via this virtual counterpart which can (automatically) trigger new decisions and actions as required. Directly and automatically associating the actions with the asset itself reduces the risk that operators might miss key indicators or that maintenance tasks might be neglected due to altered priorities or reduced budgets, or due to the sheer numbers of assets.

It is possibly not practical, nor useful, for every single asset or component of an asset to be "intelligent". When making infrastructure "smart", the core principle of "appropriateness" needs to be applied, depending on the criticality of the assets. The purpose is to make the "infrastructure system" smart, and not necessarily the individual assets! For example, in the case of a railway and waterway crossing, the intention might be that the main bridge sections be rendered "intelligent" while the railway sleepers enabled with simple load sensors just be specified to achieve "awareness" on the maturity scale.

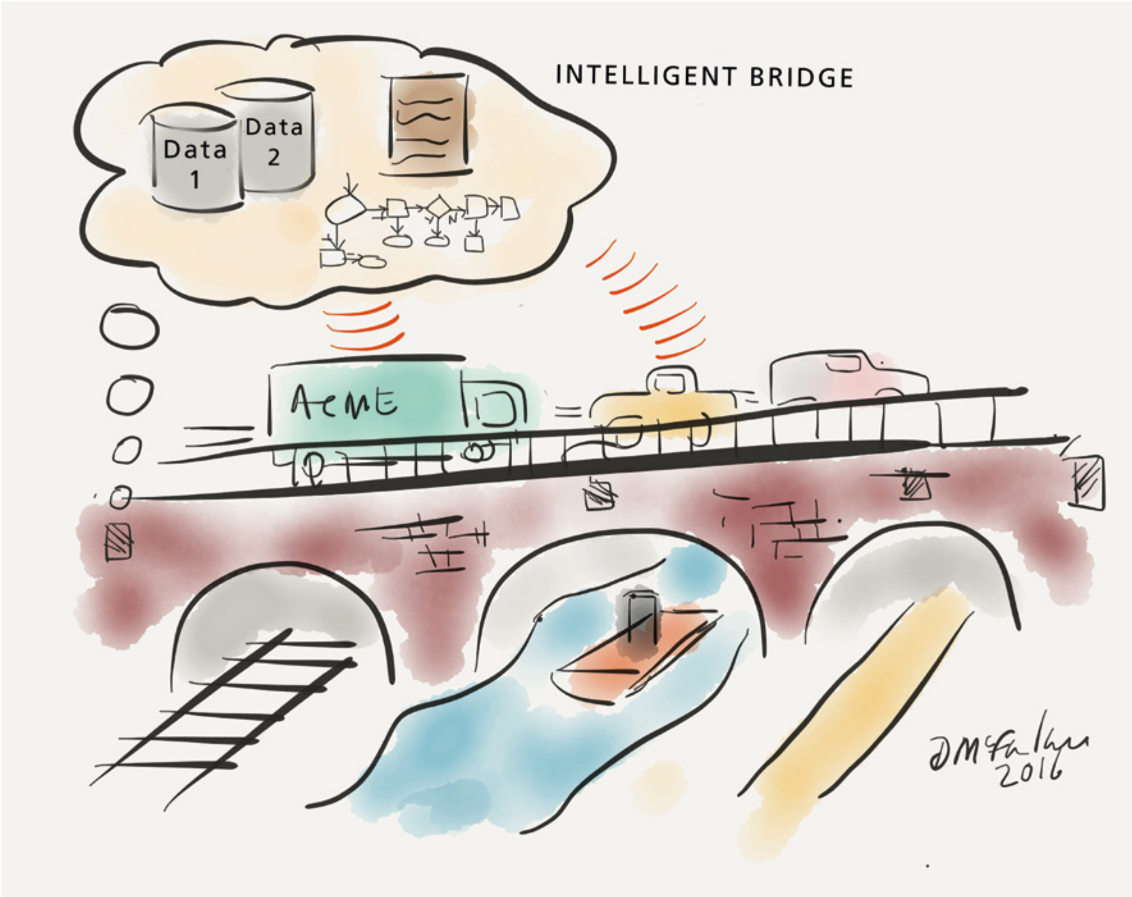

Figure 8
Different assets or components should have differing levels of smartness, ranging from 'aware' to 'intelligent'

The balancing factor might be sheer overall quantity of data, since even today, the largest asset systems are creating so much data that existing databases may struggle. Smart infrastructure technology which reduces the amount of data created, and holds some of that data locally at the asset, can potentially help with the challenge of data quantities at the centre.

Following the multi-stage requirements for intelligent assets and the supporting definition, we now begin to specify the IT building blocks that need to put in place to construct an intelligent infrastructure asset:

1. **Identity:**
   An independently constructed or fabricated element of known properties and unique identity.

2. **State Awareness:**
   An awareness through sensing or inspection of its own state (location, degradation, strain etc.)

3. **Communication:**
   An ability to communicate information relating to identity and state when integrated into larger systems.

4. **Data Management:**
   An ability to collect, store or retrieve data associated with the elements' identity, properties and state as required.

5. **Value system:**
   A means of evaluating cost and benefit in terms of service provided by the asset and services received.

6. **Language:**
   An ability to interpret and communicate information relating to rules, instructions and preferences associated with the use of the element in its environment.

7. **Decision (support):**
   An ability to influence decisions that are made with regard to the assets or collection of the assets.

These building blocks closely align themselves with the maturity stages discussed previously, as indicated below.

Maturity Stage	Identity	State Awareness	Communications	Data Management	Value System	Language	Decision Support
Unaware	N	N	N	N	N	N	N
Identifiable	Y	N	N	N	N	N	N
Aware	Y	Y	N	N	N	N	N
Communicative	Y	Y	Y	N	N	N	N
Interactive	Y	Y	Y	Y	Y	N	N
Instructive	Y	Y	Y	Y	Y	Y	N
Intelligent	Y	Y	Y	Y	Y	Y	Y

Table 2
Asset Information Maturity and IT Building Blocks
(Y= Yes, N=No)

In many ways, these building blocks are similar to characteristics that we associate with people. Again this is in line with the aims of the Artificial Intelligence (AI) community which focuses on the replication of human-like behaviour in inanimate objects and machines. In the next section, we will examine the ability to develop these building blocks, outlining areas of current research and practice that relate to each.

5. Current developments related to asset intelligence

We now look at some state-of-the-art developments to demonstrate that intelligent assets are in fact within reach of current research in the infrastructure domain. Within the Centre for Smart Infrastructure and Construction (CSIC) at the University of Cambridge, a significant amount of groundwork for developing more intelligent infrastructure assets is underway, and we will use some examples from CSIC research to illustrate developments. We point out further that much of this work supports the UK Government's focus on BIM, and Infrastructure UK's (now the Infrastructure and Projects Authority IPA) initiatives on Resilient Infrastructure.

Identity:

A wide variety of product and asset identification technologies is now available on the market, offering different capabilities in terms of storage capacity, line-of-sight requirements and longevity. Simple barcodes and numeric tags have been in use for asset identification for forty years. Two-dimensional barcodes are increasingly popular due to the increased amounts of data that can be held in a small space. Radio Frequency Identification (RFID) tags have also been in use in recent years due to their advantages in non-line-of-sight accessibility, which is invaluable for infrastructure asset identification. In most deployments, the ID technology simply provides a unique identifier for each asset, which can then be used to retrieve linked information from networked asset management systems.

Figure 9
Asset tagging using QR code

State awareness:

A variety of sensing technologies have been developed to help understand the state or condition of infrastructure assets. These sensors monitor critical parameters that can provide an indication of the rate of progression or the likelihood of development of different failure modes of an element, an asset or the system. CSIC has been instrumental in developing new types of sensing technologies as well as improving the effectiveness of the deployment of such sensors. Distributed fibre optic (FO) sensors, available for some time for the monitoring of civil structures and infrastructure, are also gaining popularity. fibre optic (FO) sensors, available for some time for the monitoring of civil structures and infrastructure, are also gaining popularity.

Figure 10
Fibre optic (FO) sensors pads for monitoring a tunnel

Communication:

Data captured by the sensors need to be communicated to data management and analysis systems for making critical decisions. This can be performed either by connecting the sensors physically using wires for data transmission, or (increasingly) through wireless sensor networks. Such networks enable communication between the assets and data management systems, as well as between the assets themselves.

Example:

UtterBerry is a highly-optimised wireless sensor network system with a closed architecture, specifically designed for infrastructure monitoring. It can be easily installed in unsafe or difficult-to-access sites to perform on-board calculations deriving acceleration, inclination and displacement in real-time without human intervention. CSIC has also developed an open-source wireless sensor network (WSN) system, for which the communication software is open source and the hardware information is available to the public.

Figure 11
Wireless sensor network (WSN) system pad on a girder

Data management

Identifying the right data to be collected for effective whole-life management of single or multiple assets is a big challenge. Standards such as the PAS 1192 series and the development of BIM-compliant solutions offer industry the capability to manage asset data efficiently. The intention of the intelligent asset model is that a mechanism be available to enable all asset data to be accessed via a single query, without requiring searches across multiple databases and storage locations in different organisations. Developing this capability will draw on the developments in the field of the Internet of Things (IoT) where, for instance, the EU-funded Internet-of-Things Architecture (IoT-A) project has created an architectural reference model for managing data in smart, connected assets.

Language:

Transmission of asset information in a standardised format is a challenge in a world where different organisations (and in fact different departments within the same organisation) use different types of information systems and databases. One of the major developments towards this in the infrastructure sector is the move towards standard formats for exchanging asset data such as the Construction Operations Building Information Exchange (COBie). COBie is a formal schema that helps organise information about new and existing assets. It helps capture and record important data at the point of origin, including equipment lists, asset data sheets, warranties, spare parts lists and maintenance schedules. Similarly, HyperCat is a format designed for exposing information about smart assets over the web in a standard manner. It is built on the same web standards that are now common for client-server interfaces.

Decision support:

New sensors often produce new engineering datasets (that were not previously available), requiring novel techniques for the interpretation of this new engineering data. For example, some fibre optic technologies provide a continuous set of strain data along the fibre optic cable embedded in or attached to the structures. In addition, advances in the area of predictive analytics help us not only to understand the state of our infrastructure, but also to predict impending failure and create the opportunity to take optimised preventative action. Developments in the area of software agents enable the concept of smart infrastructure to become a reality; for example where every asset is represented by a software program that continuously seeks data from various sources (including sensors), analyses it and takes decisions without the need for human intervention.

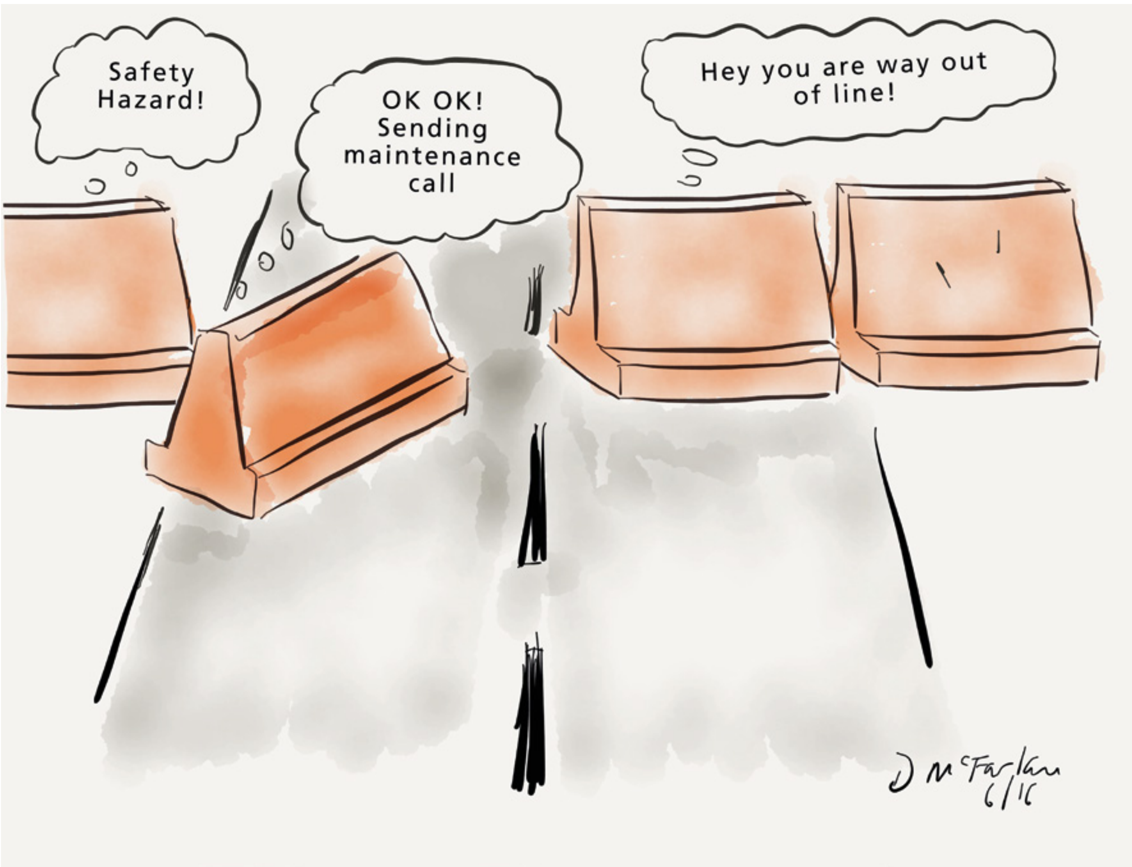

Figure 12
Software agents: Every asset is represented by a software program that continuously seeks data from various sources, analyses it and takes decisions — essentially talking to each other

Value system:

The ISO 55000 family of standards (and PAS-55 before it) has helped shift the emphasis of asset management from minimising cost to realising value. The value of an asset essentially depends on three factors:

(i) the benefits arising from the asset to the stakeholders through effective performance of the system;

(ii) the risks posed by the asset (its operation and its condition) to the system and its stakeholders; and

(iii) the expenditures incurred on the asset. Value-driven Asset Management is therefore the aggregate of activities carried out to realise benefits (and opportunities for further benefits) while minimising both the costs and risks over the lifecycle of the asset. CSIC has developed a structured methodology to determine how an asset contributes to the system's value, how its condition can affect that value, and how value can be managed by making the right decisions. A key element in future smart infrastructure systems is the use of sensory data (condition, environmental, and operational) in combination with other relevant data sources to develop a better understanding of value, including improving the predictability of the effect of asset condition on value. This will enable the right asset management decision to be made with better confidence to maximise asset value.

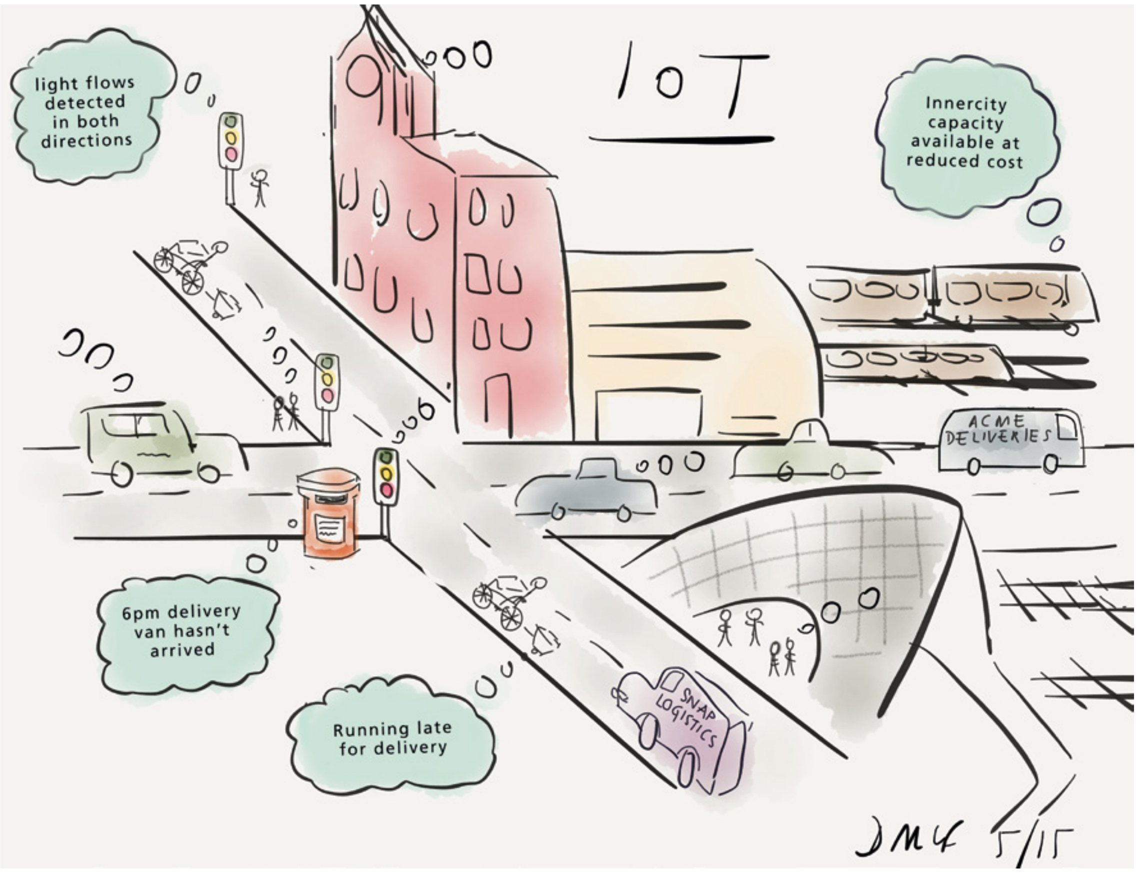

Figure 13
Future smart infrastructure systems using sensory data (condition, environmental, and operational) in combination with other relevant data sources, to create better value, either in performance or condition of the asset

6. Summary and next steps

This guidance paper has provided an image of how many different "intelligent asset" developments might be brought to bear on the challenges of infrastructure asset management. As well as providing a vision, we have outlined a multi-stage maturity model which might be used to guide developments. The intention of this model is to guide the orchestration and integration of technological developments to help improve whole solutions to the challenges in asset management presented by financial pressures, tightening regulations and aging infrastructure. This maturity approach is closely related to developments in BIM levels and hence is a means of selecting sensing and ICT developments to have the most effective impact in a given situation.

The next development steps for this work are to:

- Perform a series of detailed case studies examining the usability and usefulness of the Intelligent Asset Maturity Model as a means of guiding ICT developments for intelligent assets;
- Develop a pilot demonstrator which can establish the feasibility of the benefits of the Intelligent Asset model at different stages in the maturity models, e.g. Level 6 would currently be difficult to deploy in a commercial environment; and
- Identify specific scenarios under which the Intelligent Infrastructure Asset approach would provide the greatest benefit.

An important "take-away" outcome from this paper is the proposition that the "sci-fi" notion of an intelligent, self-managing asset can be broken down into a number of key building blocks and a series of progressive levels of development, which are now progressively turning into reality. This breakdown demonstrates that a more incremental, evolutionary approach is already able to improve infrastructure asset performance, rather than promising an attractive yet unachievable "quantum shift" in the way assets are constructed and maintained.

(iv) The next steps for an interested user to take these developments closer to deployment include:

(v) Recognising or identifying potential applications with a value proposition;

(vi) Assessing needs and opportunities associated with an asset portfolio;

(vii) Reviewing asset portfolios for highest risk assets with the best potential benefits; and

(viii) Determining what a pilot system could look like and how it could be developed

7. Examples of Intelligent Assets

Smart sensing and monitoring of masonry rail infrastructure

(Courtesy: Dr Matt DeJong, CSIC)

Masonry arch bridges are often damaged by differential support movements caused by consolidation or adjacent construction (e.g. bridge expansion, tunnelling, excavation). Dynamic rail loading and environmental effects also increase degradation rates. However, the 3D mechanisms involved in both quasi-static settlement and dynamic response are not well understood, preventing understanding of how degradation progresses. Further, no methods currently exist to predict residual life. CSIC is working with Network Rail to perform dynamic assessment through videogrammetry and dynamic distributed strain measurements to understand 3D mechanisms of motion. Long-term monitoring will be conducted through distributed strain measurements and periodic laser scanning. This will result in a better understanding of the dynamic response of masonry rail infrastructure, and the sources that drive degradation processes. This will also provide essential monitoring techniques for the development of new maintenance and mitigation strategies, and residual life models.

Figure 14
Smart sensing and monitoring of masonry rail infrastructure

Self-controlling cathodic protection systems

(Courtesy: CH2M)

Cathodic protection has been proven as a cost-effective method for providing life extension to concrete structures which are suffering from deterioration as a result of reinforcement corrosion. Technological developments have allowed impressed current cathodic protection (ICCP) systems to incorporate sophisticated equipment which has allowed for semi-automation, full automation, remote notification and remote system adjustment faculties. Recent software and

Figure 15
Self-controlling cathodic protection systems

hardware developments have enabled owners and operators to receive emailed results following a scheduled task such as performance verification or function checks along with notification of air conditioning failures, equipment intruder alerts or other alarm notifications which may require site attendance and investigation. The semi-automation of these systems presents a number of specific benefits especially for critical high-risk components and or where evidence of risk control and mitigation is required to demonstrate due diligence of the operator. This technology has been installed on several motorway bridges near Newcastle.

Vibration energy harvesting on Forth Crossing

(Courtesy: Ashwin Seshia, Jiu et al. 2015)

A CSIC-developed, patented, low-cost wireless, battery-free energy harvesting device was tested on the Forth Road Bridge in Scotland where, powered only by traffic and wind induced bridge vibrations, it was demonstrated successfully powering a wireless mote (a tiny sensor computer) which transmitted data to a receive mote. The macro-vibration energy harvesting prototype has demonstrated the potential to generate substantially more power than devices based on conventional approaches to vibration energy harvesting and could provide a convenient, self-sustaining on-board power solution to complement emerging wireless sensor technologies, as the smarter "power backbone" to the ever-growing wireless infrastructure.

Intelligent road cones 'Intellicone'

(Courtesy: A-one Integrated Highway Services, 2012)

A-one+ and Highway Resource Solutions researched and developed a unique, low-cost technology that turns ordinary traffic cones into an intelligent wireless network. These new cones activate an alarm and report any perimeter breaches during temporary road maintenance, and thus improve the safety of workers on the road. This innovative technology has been branded Intellicone®.

Figure 16
Intelligent road cones on a motorway

The Intellicone system

Intellicone® is an integrated safety solution for road maintenance contractors. It transforms ordinary temporary road barriers (i.e. cones) into an electronic safety perimeter. The system works by transmitting an alarm signal when an errant vehicle has hit a cone, giving road workers vital seconds to take life-saving evasive action. The patented Intellicone® technology is based on a wireless sensor network that enables automatic detection of a cone barrier breach, which automatically activates an audio-visual site alarm system. Intellicone® is based on a wireless sensor network, with specially designed impact sensors that fit within standard roadside cone lanterns. Sensors are fitted on top of ordinary 6V lantern batteries and when a cone is knocked over it sends an alert signal to the portable central site alarm. The alarm has been designed around an easy to 'use and handle' central site alarm system with one button operation that can be placed on top of a standard one metre cone.

Testing and rollout

The technology has been tried and tested within live traffic management with significant buy-in from operatives who have welcomed this new innovative tool which is improving health and safety in the workplace. The engagement of A-one+ road workers in developing the product enhanced the credibility of the system among staff, making the communications and training during the roll-out much easier.

Improvements from testing and feedback

Feedback from A-one+ road workers has also led to an improved Intellicone® system that can now send text messages, interact with an unlimited number of portable site alarms, and interface directly with client databases. This means multiple crews operating on the same road or lane closure can receive an alarm signalling a cone barrier breach within seconds, regardless of the distance from the breach.

The text message system allows the road workers on site and the patrolling supervisors to receive instant updates when the first and last cone have been installed, but more importantly if any intrusions have occurred. A GPS module allows information including location, time and activated alarms to be logged.

Intellicone in use

An example of a thwarted deliberate intrusion occurred on the A64 where a slip road closure was in place. Here, a taxi driver attempted to move the cones at the top of the slip road to access the closed carriageway, but moving them sounded an alarm and he immediately left the scene rather than driving into the work area and putting lives at risk.

But most importantly of all, the joint venture where it has been used (between Halcrow Group, Colas and Costain) says no road workers were injured on any of its sites in 2012 where Intellicone® was in operation.

Self-Monitoring Drainage Gully 'Gulleyhawk'

(Courtesy: A-one Integrated Highway Services, 2008)

Figure 17
Self-Monitoring Drainage Gully

By not knowing when and where to target gully emptying, maintenance crews can spend numerous shifts on abortive work, carrying out a cyclic maintenance programme that is not only costly and potentially dangerous, but is also not required.

Road gullies are designed to trap any heavy debris from the road surface in the base of the gully pot whilst allowing water to flow freely out from a high level exit pipe. Over a period of time, this debris builds up and if not removed blocks the outlet pipe. An obstruction to this pipe limits the effectiveness of the drainage system, pulling additional load on other gullies and ultimately leading to carriageway flooding. A-one identified a need to develop an alternative method of managing the gully emptying program to move from the traditional cyclic approach to an intelligence led regime.

Identifying the solution

The development of the Gullyhawk solution has been fully supported by the Highways Agency and uses technology proven in the water industry. A-one worked in partnership with IETG to develop a unit suitable for application in a highways environment. Various approaches were considered and it was agreed a 'one size fits all' solution was needed. Other requirements of the system included robustness and a simple user interface. It was also identified that the units would need to be cheap and quick to install.

Implementing the Gullyhawk system

Initially two sites were identified as trial locations. The first units were installed on a grade separate junction on the A99(T). These were trialled for a period of 4 months through various conditions. The trial proved successful. A second trial site was then installed on the A66(T). The major focus of the first site had been proving the theory and the Gullyhawk technology. The focus of the A66(T) trial was to prove the communications between the gulley and the office systems. The Gullyhawk units transmit the readings using a radio signal to a local repeater hub. The data is transmitted from site using GPRS technology which is then automatically added to a database within the A-one IT infrastructure. This automated transfer of data is linked live to a mapping interface, accessible to all A-one staff. The data is displayed using a 'traffic light' type display that is integrated into A-one's existing GIS system so the maintenance teams can immediately see where the gulleys are filling up, and plan their intervention program accordingly. A-one are now developing an area-wide installation of the system.

Performance measures for the Gullyhawk system

Indicative savings based on the trial data show the potential to save up to half of the budget allocated for the full cyclic regime by switching to a targeted intelligence-led regime. This is based on savings in plant, labour and materials as well as a reduction in traffic management. By looking at trends in gullies it is possible to make further savings by integrating gully cleaning work with other programmed works.

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10. Further reading

For further reading, a series of books is being published on this topic:

- Wireless Sensor Networks for Civil Infrastructure Monitoring: A Best Practice Guide
- Distributed Fibre Optic Strain Sensing for Monitoring Civil Infrastructure: A Practical Guide
- Whole-Life Value-Based Decision-Making in Asset Management
- Bridge Monitoring: A Practical Guide
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One Great George Street
Westminster
London
SW1P 3AA

+44 (0)20 7222 7722
ice.org.uk

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