Metrology challenges for infrastructure

Carlos Huggins

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EXECUTIVE SUMMARY

Measurement Network has interviewed a range of players in the Infrastructure sector to understand where there are challenges and opportunities presented by improvements in metrology (the application and science of measurement). Four high impact applications have been explored in depth and the underlying common themes summarised.

The key messages are that there are opportunities for improvement of existing infrastructure, and better design of future infrastructure, but that often there is a need for metrology action in terms of identification of signatures of the state of the system and the implementation of convenient and common processes, frameworks and standards for the whole supply and value chain to use. The benefits to the UK economy could be many hundreds of millions of pounds. There is the prospect of the 'Internet of Things' supporting new business and technical opportunities in a Digital Economy.

The barriers to progress, apart from the cost of R&D and implementation, include a need for the industry to continue further in collaborative working and the building of collaborative value-chains.

The sector has access to support mechanisms, via Measurement Network and the Special Interest Groups within the TSB’s Knowledge Transfer Networks, to mediate and bring together the community and help gain traction with all of these opportunities.
ABOUT MEASUREMENT NETWORK

Measurement Network connects business with measurement knowledge. It is the UK’s network that supports businesses to improve, innovate and grow through facilitating the access to and adoption of measurement expertise, training, facilities, standards and good practice.

With a vibrant community of over 2000 businesses, the network is a place for the academic and business community to engage, interact and find solutions to current and future challenges in measurement. We focus on increasing the spread and access of measurement knowledge and expertise to businesses that will benefit from learning and adopting good practices in measurements.

APPROACH

To facilitate innovative growth, the network focuses on a challenge-led approach, where each of these challenges represents a key industrial issue for which measurement interventions can add significant value.

Our focus is to connect businesses with measurement knowledge and help them solve their measurement needs through knowledge transfer and technology brokerage.

We create opportunities for the business community to network and engage through events, workshops, roadshows and seminars.

Our newsletter focuses on innovations in measurement, information on networking events, funding and partnering opportunities.

We also focus on supporting small and medium sized companies to access facilities and expertise, as well as the NPL Technology Innovation Fund.

“The trouble with measurement is its seeming simplicity” (Anon)

The network provides a window to organisations to access free resources to help improve and innovate. These include Good Practice Guides, Event Reports, Educational Videos, Event Podcasts, Posters and Case Studies.

To know more about the current focus areas and activities of the network, please visit: www.npl.co.uk/measurement-network

To join the online discussions, please visit our groups on: LinkedIn and _connect

If you have questions or comments about this report or would like to engage in discussions please contact Carlos Huggins: carlos.huggins@npl.co.uk
INTRODUCTION

IS THERE A METROLOGY GAP?

Large infrastructure projects, for example bridges, tunnels, railways, canals, flood defences or large buildings, have traditionally been designed on the basis of large margins, to allow for the incomplete knowledge of the actual structural performance limits and of the evolution of these complex systems during the construction phase and subsequently. In the operational phase, the desire to minimise costs and environmental impacts, and to monitor stability and degradation, are both important drivers, which contribute to the need to introduce measurement systems. This lack of understanding extends to maintenance, repair and overhaul, and even clearance of such structures, as there is often uncertainty of what is a complete, efficient and sustainable intervention.

All of these sensing and measurement challenges are recognised as high priority, with the opportunity to make significant changes in efficiency and open up opportunities for new business activities.

To give some context:

- The UK government has taken a lead by launching a Construction Strategy, which requires 3D Building Information Management systems to be in place on all its projects by 2016, encompassing both measurement and reporting systems, and communications between stakeholders at all stages of the project lifecycle. This has implications for the application of sensing and measurement, as the opportunity exists for feedback from existing structures to those designing, or establishing design rules, for the next generation.

In the European Union the construction industry accounts for a total turnover of €1305 billion and 13.2 million employees. This represents 10% of GDP and 7.3% of the total employment. The residential sector represents 46% of the total EU production, the non-residential sector 31% and civil engineering 23%. [source: FP7 BuildingUp project]

The UK construction industry consists of over 300,000 firms employing over 2 million people in a multitude of roles, contributing 8.3% of the nation’s GVA (Gross Value Added) in 2008 [source: UK Contractors Group]

- EPSRC and TSB have funded the creation of the Centre for Smart Infrastructure and Construction (CSIC)\(^n\), which will, over five years, research innovative use of emerging technologies in sensor and data management, coupled with emerging best practice in the form of the latest manufacturing and supply chain management approaches applied to construction and infrastructure. This project has attracted the support of several major construction and asset operating companies, and those involved in sensing and measurement instrumentation and service delivery. This is, in itself, highly significant as such commercial groups do not have a history of collaborative working, so this initiative offers the prospect of the rapid promotion of advances across the industry to deliver 'game-changers'.

[90x280 to 100x294]
[Image 334x460 to 344x473]
[Image 337x495 to 546x768]
[72x51]4
• The importance of the Asset Maintenance sector may be measured by the strength and standing of the Institute of Asset Management, which has over 2000 members internationally.

• The issues related to retrofit are especially important, as buildings contribute around 45% of UK carbon emissions, and the majority of UK building-stock will need to be retrofitted to meet UK carbon emission targets. Measurements are key to deciding on the interventions and assessing success.

• Measurement Network has identified via workshops and dialogues with stakeholders that, although there is demand for significant changes in sensing and measurement, there is often not a clear appreciation of the gaps in the underpinning measurement science, known as ‘metrology’, without which many sensing or measurement tools will not be fit for purpose. This situation can be summarised in the following challenge question:

“Do I believe the numbers generated by my sensor system and can I convince someone else of their reliability?”

Furthermore, there is often no clear view of the importance to the different stakeholder groups of these sensing and metrology gaps, or of the opportunity that these present to UK business or science. This study is a response to these gaps.

Bond Street station in London is undergoing a £300m major redevelopment, increasing capacity, improving accessibility and creating interchange with Crossrail. In the design phase of works to fill lining cavities, a need was identified for a highly flexible, safe and reliable system to monitor the tunnel lining whilst grouting. The monitoring solution used Senceive’s high resolution wireless tilt meters mounted on tunnel lining segments, showing their individual rotational and linear equivalent movements on Senceive’s Webmonitor software. The innovative powerful magnetic sensor fixings designed by Halcrow and Senceive, allowed fast and simple deployment as well as relocation during shifts, and the design ensured that sensors could also be left in situ during running hours.

“We looked at other possible technologies and alternatives and initially asked some of the big players in the monitoring space if they could provide a potential solution. Wired monitoring would not have been feasible, and there was simply no credible solution other than that developed with Senceive. The system made significant savings to the cost of the works, which would have been significantly more labour intensive, time consuming and slower if a mechanically-fixed wired solution had been used”

Peter Wright – Associate Director Tunnels, Halcrow

Halcrow and Senceive, in collaboration with the Costain/Laing O’Rourke JV and London Underground, have won the prestigious International Tunnelling Award for Product/Equipment Innovation of the year.
WHAT IS METROLOGY?

Metrology is defined as the science of measurement and covers three main activities:

- **Definition**: The definition of internationally accepted units of measurement, e.g. the metre.
- **Realisation**: The realisation of units of measurement by scientific methods, e.g. the realisation of a metre through the use of lasers.
- **Traceability**: The establishment of traceability chains by determining and documenting the value and accuracy of a measurement and disseminating that knowledge, e.g. the documented relationship between the micrometre screw in a precision engineering workshop and a primary laboratory for optical length metrology.

This rigorous framework allows science and business to have the mutual confidence that supports measurements and trade.

AIMS AND OBJECTIVES

To highlight the importance of sensing, measurement and the underpinning metrology issues for the infrastructure sector, by performing a landscape-survey of some of case studies; summarising the key drivers and stakeholders, the gaps, and the potential benefits to the various players; and extracting any cross-cutting messages.

TARGET AUDIENCE AND IMPACT

**Infrastructure and sensing businesses and professional organisations** – which may better appreciate some metrology barriers to successfully building products or supply chains, and will gain routes to overcome them, or to turn them to their advantage.

The **Research Councils, TSB, and NMO** – who will gain an overview of the limits of existing measurement science in some specific areas and may take this as an input to their developing strategy.

**Researchers** – engaging in development or transfer of measurement approaches, who may approach new research challenges.
METHODOLOGY

The survey is not intended to be a complete overview of the field, but more an attempt to pick out some tangible and high impact case studies, through wide consultation with academic, business and third sector bodies with a significant involvement in the sector.

Interviewees were asked to outline the “known applications where progress was limited by gaps in the definition of the unit of measurement, in the realisation of this unit, or in the traceability of measurements”, and to comment on the role of metrology frameworks in their organisations. About 20 of these applications were collated by the Measurement Network and a sample was chosen for further detailed study, based on two criteria:

- The applications covered the interests of a wide range of stakeholders.
- There was a tangible route to improved metrology, related to a high impact outcome.

More detailed exploration of this sample led to the creation of four summary Case Studies (presented in the Annexes). Measurement Network then extracted any common or key themes that emerged from the Case Studies and the interviewees' comments, be they gaps, opportunities or UK strengths and weaknesses. Preliminary conclusions were drawn regarding the nature of the metrology landscape.
In the construction and infrastructure management sector, one major issue revealed through conversation with a large number of players is the challenging situation for collaboration that follows from the business models used.

These, even now, tend to be based on a specification-driven model, with earlier players in the supply-chain having little responsibility for the long-term performance of the asset. This leads to there being little incentive to pursue long-term measurement challenges. The UK government’s Building Information Modelling (BIM) initiative has obviously started a process that will bring players together technically – and hopefully operational benefits will also follow. The enduring movement by public bodies towards a Public-Private Partnership model for procurement and operation of major assets will also have an impact on the supply and value chain – but is outside the scope of this report to explore further.

Several players in the construction and monitoring community have indicated that they have specific underpinning metrology needs, but are reluctant to make these public for fear of losing the confidence of their clients.

This situation used to be common in many sectors, for example in automotive and aerospace, however, in these sectors, a regulatory-driven need for high-quality information and frameworks in which it can be used has existed. This need has brought the supply-chain together to launch collaborative activities, underpinning competitiveness, reputation and capability by creating, for example, accepted standards, databases, working methods and training programmes. Measurement Network and partner organisations like the Knowledge Transfer Networks can have a role in bringing the community together and sharing knowledge of technology, best practice and business models across different sectors.

Many metrology needs are associated with detailed characterisation, modelling, and comparison of materials as they are to be used in real-world situations, but there is no business case for any one organisation to do this.

These can best be handled on an industry-wide basis, using the services of the existing strong technical and standards community in the UK to underpin such attempts.

However, such procedures are resource intensive and require support from private and public sources.

The data deluge cannot be managed without automatic means in place.

Most of our interviewees made it clear that they are drowning in data and that they can only occasionally extract value from certain parts of it. There are many centres of expertise in information science and machine learning. However, there is a need for measurement frameworks to provide a basis for the processes for sifting
data, and assigning traceability and value to the ensuing information products.

5. *There is a massive upside in the realisation of new service and product offerings enabled by the Internet of Things and supporting a Connected Digital Economy (CDE).*

The existence of recognisably high-quality data and information products will be key to supporting new added-value business cases. The scope is evolving, and the Internet of Things, and CDE Catapult Special Interest Groups have been implemented as a focus for the UK players.

6. *Several interviewees expressed the apparent conflict between the benefits of regulation and standards, and that of business flexibility.*

Measurement Network can only point at, as a counter-example, the communications industry, which has unlocked massive new business streams despite heavy regulation, through innovation in business models and offerings to consumers of all types.

7. *The benefits of better metrology are clear in several here-and-now applications: for instance in underpinning the UK’s carbon emission targets; and in supporting flood avoidance and mitigation.*

It is not straightforward to quantify benefits provided by existing metrology frameworks and programmes, or the opportunities identified in this report. However, it is clear that from only the four applications covered, there is scope for many hundreds of millions of pounds worth of benefits to be realised.

The overall situation is summarised in Table 1.
<table>
<thead>
<tr>
<th>Application</th>
<th>Metrology needs</th>
<th>Potential benefits of improved metrology</th>
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<tbody>
<tr>
<td><strong>Building Performance Evaluation</strong></td>
<td><strong>Unit of measure</strong>&lt;br&gt;Better measurement units for compensation for microclimate (the kW.day is not sufficient)&lt;br&gt;&lt;br&gt;<strong>Realisation</strong>&lt;br&gt;Validation of theory by experiments.&lt;br&gt;Frameworks for measurement of assorted heat loss mechanisms, and for comparison of buildings and management processes.&lt;br&gt;&lt;br&gt;<strong>Traceability</strong>&lt;br&gt;Standards, training and working practices, test facilities.</td>
<td>Unlock investment in upgrades to enable UK carbon reduction objectives.&lt;br&gt;More comfortable buildings with lower carbon impact.</td>
</tr>
<tr>
<td><strong>Corrosion of rebar</strong></td>
<td><strong>Definition of feature 'signatures' associated with specific types of concrete</strong>&lt;br&gt;&lt;br&gt;<strong>Realisation</strong>&lt;br&gt;Automatic detection and classification thereof, especially using several sensor types.&lt;br&gt;&lt;br&gt;<strong>Traceability</strong>&lt;br&gt;Standards, training and working practices, test facilities, availability of 'standard artefacts'</td>
<td>Reduce cost and inconvenience of intervention</td>
</tr>
<tr>
<td><strong>Discovery of underground services</strong></td>
<td><strong>Definition of feature 'signatures' associated with specific services</strong>&lt;br&gt;&lt;br&gt;<strong>Realisation</strong>&lt;br&gt;Means to identify which data streams are critical and sufficient in making decisions.&lt;br&gt;&lt;br&gt;<strong>Traceability</strong>&lt;br&gt;Standards, training and working practices, test facilities, availability of 'standard artefacts'</td>
<td>Reduce cost and inconvenience of intervention (currently c. £7bn pa)</td>
</tr>
<tr>
<td><strong>Defence of critical infrastructure</strong></td>
<td><strong>Definition of feature 'signatures' associated with flood risk and threat identification to assets.</strong>&lt;br&gt;&lt;br&gt;<strong>Realisation</strong>&lt;br&gt;</td>
<td>Unlock insurance availability and cost reduction.&lt;br&gt;Reduce damage costs (leverage of early intervention overall 1:6); guide cost of £3.2bn for the 2007 UK floods.</td>
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</table>
CONCLUSIONS

1. This survey of four applications in the Infrastructure sector has shown several common needs for metrology, namely:
   • definition of signatures for faults or critical states, often calling for painstaking laboratory-based work on a range of materials and manufacturing processes
   • automatic means of identification of these signatures, sometimes using several different sensor or measurement types
   • means of assigning a measure of confidence to any signatures detected
   • establishment of a framework for industry buy-in, particularly standards, training and working practices, accessible databases, and unbiased test facilities.

2. Improvements in metrology, alongside the implementation of some new sensor systems, could have a significant impact in increasing operation efficiency and in reducing the adverse impacts of natural events, as well as unlocking new business opportunities, both traditional and related to a Digital Economy, delivered via the Internet of Things.

3. There are several national initiatives, projects and institutions that contribute to improved metrology. However, the industry is still less advanced than many sectors.

4. Increased cooperation across the industry supply-chain and value-chain will be needed to capitalise on these opportunities, and there seems to be a role for organisations with the experience of mediating and supporting such stakeholder groups, to transfer that experience to the Infrastructure sector.

5. The benefits will exceed many £100m should just four areas be addressed.
ANNEXE 1: BUILDING

COMMERCIAL AND SOCIETAL CONTEXT

If the UK government’s target of reducing carbon emissions by 80% by 2050 is to be met, then the building stock, which produces about 45% of the emissions, must be upgraded. This is especially important for the ‘legacy’ 70% of the existing stock that will still be in use in 2050. Building Performance Evaluation (BPE) as a discipline is essential, in order to assess existing stock, inform renovation and confirm the impact of interventions and new-build practice.

This has particular importance with the launch of the Green Deal initiative, which hinges on the acceptance of predictions of energy savings that should be effected through renovation work, as these will affect the value of government cash support to the involved asset owner.

Such high quality information, applied to ‘estate’ or larger scales, will be needed to inform public and charitable bodies, commercial investors and funding bodies before large investments are made in ‘green (re)-developments’. One valuable comparison can be made with Australia, where the Nationwide House Energy Rating Scheme\textsuperscript{vii} (NatHERS) gives domestic property an energy rating comparable in scope and impact to that applied to domestic white goods in the UK.

Interventions in this area include that of the Modern Built Environment Knowledge Transfer Network (MBE KTN) and Measurement Network, which recently ran a workshop on measurement gaps for \textit{Building Performance Measurement}\textsuperscript{x} and another on \textit{Measurement and Standards to Enable Sustainable Cities}\textsuperscript{x}. These ran alongside several other activities by TSB and professional bodies to bring together the wider community and to focus activities.

DRIVERS OF CHANGE

The UK has a large group of policy drivers related to building renovation, and hence BPE: the Renewables Obligation, Feed In Tariffs, Renewable Heat Incentive, Climate Change Levy, Building Regulations and others.

There is general recognition that the measurement capability is technically unsatisfactory at present – an influential report by Leeds Metropolitan University states that energy consumption often exceeds expectations by 100%\textsuperscript{xii}. There is thus a driver of technical change.

Even with expected mitigation (efficiencies and micro-generation), energy costs have already increased significantly over the last decade and are expected to increase by up to 35% for non-domestic stock, which will drive consumer behaviour.

METROLOGY NEEDS

The recent stakeholder workshop organised by the TSB, MBE KTN and Measurement Network identified a short-list of measurement and sensor system needs, which is summarised below, highlighting whether the need is for a development in metrology or a sensor system.
Table 2: Summary of measurement and sensor needs for BPE

<table>
<thead>
<tr>
<th>Application</th>
<th>Need</th>
<th>Metrology need?</th>
<th>Sensor System need?</th>
</tr>
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<tbody>
<tr>
<td>Thermal performance</td>
<td>Measure subsystems rather than materials, validate modelling at subsystem level.</td>
<td>x</td>
<td></td>
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<tr>
<td>Building Management Systems (BMS)</td>
<td>Use of common frameworks for the necessary inputs and data processing.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Air movement and ventilation</td>
<td>Process standards and training.</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Thermal bridges</td>
<td>Means to both locate thermal bridges, and to quantify their impact.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Thermal performance</td>
<td>Airtightness-type test for system-level, and development of standards etc.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Air quality and comfort</td>
<td>Means to measure ventilation (i.e. air flow/volume) rather than airtightness.</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Thermal performance</td>
<td>Modelling and measurement approaches for compensation of the microclimate- the existing kW.day approach is insufficient.</td>
<td>x</td>
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</tbody>
</table>
IMPACT OF METROLOGY IMPROVEMENTS

The BPE community is at present hampered by the lack of robust measurement tools, frameworks and processes: the confidence of the general and professional population in the national policies will be strengthened if such tools are in place, unlocking private and commercial capital for the massive undertaking.

In principal, the establishment of such public confidence could also contribute to a paradigm shift in the valuation of property, making an explicit link to the lifecycle resource usage and costs.

SECTOR NEEDS FOR METROLOGY

<table>
<thead>
<tr>
<th>Definition</th>
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<tr>
<td>Realisation</td>
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<td>Traceability chains</td>
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ANNEXE 2: ASSESSMENT OF CORROSION OF REINFORCING RODS IN CONCRETE

COMMERCIAL AND SOCIETAL CONTEXT

Reinforced concrete is the common structural material for much of the infrastructure in the world, normally using carbon-steel reinforcing rods (rebar). This material, and concrete degradation caused by its deterioration, has become a significant financial and logistical issue: according to an article from Concrete International\textsuperscript{xii}, “Concrete bridge decks deteriorate faster than any other bridge components because of direct exposure to the environment, de-icing chemicals, and ever increasing traffic loads”. In the United States, $100 billion pa is expended due to corrosion alone. According to the 'National Bridge Inventory' it was stated that over 28% of bridges [in the USA] are classified as either structurally deficient or functionally obsolete.\textsuperscript{xiii}

METROLOGY NEEDS

The existing and well-established methods for measurement of rebar corrosion include\textsuperscript{xiv}:

1. Open circuit potential (OCP) measurements
2. Surface potential (SP) measurements
3. Concrete resistivity measurement
4. Linear polarization resistance (LPR) measurement
5. Tafel extrapolation
6. Galvanostatic pulse transient method
7. Electrochemical impedance spectroscopy (EIS)
8. Harmonic analysis
9. Noise Analysis
10. Embeddable corrosion monitoring sensor
11. Cover thickness measurements
12. Ultrasonic pulse velocity technique
13. X-ray, Gamma radiography measurement
14. Infrared Thermography
15. Electrochemical
16. Visual inspection

However, it is notable that most of these methods are typically deployed on an intermittent 'campaign' basis, require instrumentation to be fitted to the structure, are highly dependent on the user’s experience, and often require data to be processed and assessed off-line. The use of networked and 'permanently on' embedded or 'surface mount' sensors would allow the use of informatics approaches to generate knowledge of the state and evolution of the structure in real time, and to exploit the opportunities to identify the...
relationships between, for example, loading, local environmental conditions and the degradation process, allowing operators to exert more control and maintenance staff to better design and target interventions.

Certain enabling technologies are needed to unlock these opportunities, particularly reliable wireless communications between sensors (possibly embedded in concrete, or highly obscured by concrete and rebars), battery-free energy sources and, of course, suitable sensors. It must not be forgotten that the combination of disparate datasets is technically challenging, and is largely regarded as a 'black art' with only empirical grounding, leading to a lack of repeatability, buy-in and traceability.

The high impact enabling metrology needs that arise from these include:

- the definition and realisation of thresholds for damage assessment in specific types of concrete structure, which is often related to ambient environmental conditions: rebar degradation is much accelerated by salts, so is worse in the northern latitudes and close to the sea
- standard methods and processes by which the outputs of different sensors and technologies may be combined to give quantified and traceable confidence
- frameworks and institutions to engender acceptance of these thresholds and standard methods in a traceable manner by the widest community possible

The definition of thresholds and standards is currently held back by the lack of sector cooperation within the industry, although a few agencies (e.g. TRL, TWI, BRE, RCNDE) perform underpinning work on behalf of several UK players that make use of Non-Destructive Test and Conditioning Monitoring, and co-operate internationally. However, with the huge variety of structures and building approaches, a more strategic activity would be of value.

To give two examples in another application sector, the International Atomic Energy Agency (IAEA), which regulates the international use of nuclear energy, funded long-term studies into the Non-Destructive Evaluation of research reactors and of operational reactors, highlighting how to apply specific tools to specific systems and materials. This guidance and information has been a common source for the global industrial and academic sector ever since.
POTENTIAL IMPACT OF METROLOGY IMPROVEMENTS

Ultimately, it is expected that such improvements in metrology will reduce the monetary and inconvenience costs of inspection and maintenance, and reduce the consequential risks of failure and downtime.

SECTOR NEEDS FOR METROLOGY

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<td>Traceability chains</td>
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ANNEXE 3: DISCOVERY OF UNDERGROUND SERVICES

COMMERCIAL AND SOCIETAL CONTEXT

It is estimated that up to 4 million holes are cut into the UK road network each year in order to install or repair buried service pipes and cables, with a good fraction of these failing to deliver or damaging existing infrastructure. This arises from both a lack of accurate mapping and of processes by which location and type information can readily be archived and accessed. The location of existing buried assets results in numerous practical problems, costs, inconveniences and dangers for utility owners, contractors and road users. The impact has been assessed as £7 billion in direct and indirect costs, and 30-40 serious injuries per year.

This challenge is just as applicable to new build and renovation of large assets as it is to road maintenance, because it is important to locate existing services, which are often poorly mapped and unlabelled when uncovered, so that they may be preserved or re-routed. Interruption will often lead to consequential costs.

DRIVERS OF CHANGE

Apart from the simple costs and health and safety considerations, the situation is worsening, with the major cities and population centres becoming more congested and increased use of 'brown-field' sites or retrofits to existing infrastructure. There is increasing public and commercial discontent with road-works, which has led to cities announcing that utilities or their contractors will be charged for lane access, in so-called 'lane-rental' schemes.

The on-going need for renovation of irreplaceable or defunct assets often leads to work close to dense concentrations of existing services, which may include any or all of:

- Communications
- Gas
- Oil/Petroleum
- Sewerage
- Road drainage
- Power
- Steam
- Water
- District heating
- Street lighting
- Traffic management

Finally, there is quantitative recognition that the state of the art is not good enough: a trial funded by the UK water industry on a road at Langley Mere had only a 50% success rate in accurately locating and classifying buried services.

All of these issues have led to the establishment, under EPSRC funding, of a series of major research projects collectively entitled 'Mapping the Underworld'.

Image source: Jo Parker

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There are a variety of issues that are being tackled, but that are often regarded as 'impossible':

- Development of sensor systems (using Ground Penetrating Radar, Acoustics, Low-Frequency Electromagnetic Fields, and Passive Magnetic Fields), and the associated metrology task of definition of standard 'signatures' to locate and identify buried services.

- Placing these assets in their macroscopic location using GPS-mapping approaches. This necessitates new measurement approaches that exploit existing hardware.

- Agreement of a language and syntax for communication of this location and type information between disparate stakeholders.

- It has been recognised that the success of sensors is dependent on the properties of the soil itself, and that there would be a benefit in the establishment of a measurement campaign and online database of the soil parameters.

**POTENTIAL IMPACT OF METROLOGY IMPROVEMENTS**

- Reduction of inconvenience to the public
- Reduction of consequential damage
- Acceleration of work
- Reduction of costs
- Generation of new business sectors and businesses exploiting 'high quality location and type data'

**SECTORS NEEDS FOR METROLOGY**

| Definition | x |
| Realisation | x |
| Traceability chains | x |
ANNEXE 4: DEFENCE OF CRITICAL INFRASTRUCTURE

COMMERCIAL AND SOCIETAL CONTEXT

It has become increasingly obvious that in today’s densely populated, highly interconnected world, there are many risks to critical infrastructure. These have become apparent after, for example, the terrorist attack on the London transport system in 2005, the effects of the floods of summer 2007, and the heavy snow in early 2009.xxvi

To give just one example, a total of five water treatment works and 322 sewage treatment works were put out of action by the 2007 floods. Many electricity transmission and distribution assets were also affected, with 40,000 people in Gloucestershire left without power for up to 24 hours and 9,000 customers spending several days on rota disconnection in South Yorkshire and Humberside.xxvii

Such events have led the UK government to establish the Centre for the Protection of National Infrastructure (CPNI), which defines critical infrastructure as: "specific assets which if destroyed or seriously disrupted would cause major disruption to the service being provided".

The CPNI focuses on deliberately-generated threats, but the Cabinet Office has established a cross sector Critical Infrastructure Resilience Programme (CIRP)xxix to lead response to natural hazards, and a particular priority at present is on Flood Awareness and Defence.

The Environmental Agency has reviewed the impact of the 2007 floods in the UK and assigned a direct and indirect cost of £3.2bn. It highlighted that for every £1 spent on protecting homes and businesses and building in resistance and resilience, the cost of clean-up and repairs following a river flood can be reduced by up to £6 on average.

IMAGE source: DEFRA xxxi

DRIVERS OF CHANGE

- Global warming, leading to more erratic and extreme weather systems
- Higher-density urban developments, including use of flood plains
- Land-use patterns leading to faster run-off and less water storage
- Demands for availability of flood insurance

Image source: DEFRA xxxii
METROLOGY NEEDS

The Environment Agency has several specific roles in responding to the floods – and these are often related to the suitable measurement and dissemination of water levels and locations. Specific needs are in making the best use of the data acquired from the network of 10 radar stations, 750 rain gauges, more than 1500 river level and river flow sensors and 100 coastal gauges, all of which transmit information via a Telemetry System. This could include pattern recognition approaches, using computational science approaches, to identify and extract indicators of flood risk.

Of equal importance would be sensor and measurement capabilities for condition-monitoring of the infrastructure itself – for instance, dams, levees, embankments, weirs, tunnels etc., to give early warning of upcoming major problems. This was frequently highlighted by the asset-owner community in the consultation process towards a Sensor Systems Technology Innovation Centre.

POTENTIAL IMPACT OF METROLOGY IMPROVEMENTS

- Greater affordability (or availability) of flood insurance
- Reduced adverse impacts (6:1 leverage overall on preparative measures)
- Greater confidence by business, individuals and authorities in times of weather stress
- Reduced time to respond to damage

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<td>Traceability chains</td>
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REFERENCES

i New Construction Strategy (30 June 2011), MBE KTN.  
https://connect.innovateuk.org/web/modernbuiltktn/articles/-/blogs/new-construction-strategy?ns_33_redirect=%252Fweb%252Fmodernbuiltktn%252Farticles

ii Centre for Smart Infrastructure and Construction http://www.smartinfrastructure.eng.cam.ac.uk/

iii The Institute of Asset Management http://theIAM.org/

iv The retrofit challenge: delivering low carbon buildings, Carbon Trust.  

v Metrology in Short (2011), NPL, p9

vi The Internet of Things Special Interest group https://connect.innovateuk.org/web/internet-of-things

vii The Connected Digital Economy Special Interest Group https://connect.innovateuk.org/web/connected-digital-economy/overview


https://connect.innovateuk.org/c/document_library/get_file?uuid=5f1298ae-0074-448b-ad9c-a7720fd3d032&groupId=2025696

x Measurement and Standards to Enable Sustainable Cities 18 Jul 2012 - event report.  
https://connect.innovateuk.org/c/document_library/get_file?uuid=5f1298ae-0074-448b-ad9c-a7720fd3d032&groupId=2025696


http://transportation.mst.edu/media/research/transportation/documents/R95_CR_2.pdf

xiii A strength degradation modelling approach to life expectancy of FRP strengthened bridges, (2007), A. Sawant, J.J. Myers, University of Missouri-Rolla.  


xvi Application of non-destructive testing and in-service inspection to research reactors: Results of a co-ordinated research project, (2001), IEAE http://www-pub.iaea.org/MTCD/publications/PDF/te_1263_prn.pdf


xviii Briefing: the real cost of street works, Parker J (2008), Proc. Inst. Civil Engineers 161 175–6


http://www.mappingtheunderworld.ac.uk/index.php

xii Jo Parker, Jo Parker Associates Ltd, presentation at Mapping the Underworld workshop, May 2011

xii Jo Parker, op cit.


xxii DEFRA (2009), op.cit. p 6


FURTHER READING

FP7 BuildingUP project website http://www.buildingup-e2b.eu/project-description

Construction in the UK economy, LEK Consulting for UK Contractors Group (Oct 2010 Update)