The Royal Academy of Engineering

Smart infrastructure: the future

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Smart infrastructure provides the evidence for informed decision-making.

1 Foreword

'Smart infrastructure' and 'smart' systems are currently hot topics under discussion by government, the media and others. 'Smart' meters are about to be rolled out across the UK and 'smart' cars are already on sale. In the future 'smart' technologies and systems will reduce journey-times, remotely monitor the sick, and help in the fight against man-made climate change. 'Smart' appears to be a panacea that will improve society in a multiplicity of ways. However, although there is a universal thread to the way in which 'smart' is used, there is no common definition in usage. What is 'smart infrastructure'?

In October 2011, The Royal Academy of Engineering held a roundtable meeting to investigate the use and meaning of 'smart' and 'smart infrastructure'. This report provides a summary of what was discussed. A working definition of 'smartness' was agreed, applications of smartness that have benefited different industries were identified and discussion held on whether there were principles that could be shared between sectors. Potential barriers to a smarter future were also examined. The sectors specifically discussed at the meeting were energy, water, land and maritime transport, communications and the built environment.

'Smart infrastructure' responds intelligently to changes in its environment, including user demands and other infrastructure, to achieve an improved performance.

2 Definition of smart infrastructure

A smart system uses a feedback loop of data, which provides evidence for informed decision-making. The system can monitor, measure, analyse, communicate and act, based on information captured from sensors. Different levels of smart systems exist. A system may:

- collect usage and performance data to help future designers to produce the next, more efficient version;
- collect data, process them and present information to help a human operator to take decisions (for example, traffic systems that detect congestion and inform drivers);
- use collected data to take action without human intervention

There are examples of each level of smartness already operating, but the same principles can be applied far more widely across interconnected and complex infrastructures.

Data are turned into information, into knowledge and then into value.

3 Principles of smart infrastructure

3.1 Data

Data are at the heart of all smart technology. As smart infrastructure is rolled out into different areas of our society, there will be a vast explosion of data generated and data ownership will become increasingly important.

Systems that are able to process these data and then make appropriate decisions will have to be developed and put in place.

3.2 Analysis

Selective sampling of this information, careful fusion of data and interpretation through robust mathematical modelling will provide highly reliable decision-making tools to benefit individuals, organisations and governments alike.

Feedback within a smart system provides opportunities to increase its performance.

3.3 Feedback

Smartness is about gathering information on the way an asset is used and using that information to improve the way that system operates. The data feedback loop is fundamental to any smart system.

Smart systems and infrastructure need to be adaptable to varying demands and conditions, including developing technology.

3.4 Adaptability

There will be huge gains from making smart systems that can meet future needs and absorb future technologies with much less replacement and expensive re-engineering. Redundancy is currently built into systems because assumptions about what may go wrong have to be made. If data can be collected to enable a system to be well maintained, designs that are more efficient can be developed.

4 Applications of smart infrastructure

4.1 Utilities

Utilities, including power and water, apply smartness to their grids. Smart grids are:

- adaptive – they adapt and reconfigure in response to changes of supply and demand (as in renewable energy sources);
- predictive – models of the grids can be created and used to plan and operate systems;
- integrated – no longer a hierarchy from generator through distribution network to consumer. Supply, consumption and control can occur at many locations on the grid;
- reactive – engaging with customers through smart meters, rather than expecting customers to take what they are given;
- optimised – grids control themselves to maximise efficiency in operation.

For the National Grid, smartness is all about the timely use of information – getting that information at the right time and place so that informed decisions can be made.

4.1.1 Energy

Monitoring, remote control and automation are increasingly being implemented across the industry, which, coupled with the energy market and regulatory framework, make the networks relatively advanced in world terms. Smartness is key to facilitating a high level of cooperation and interaction between consumers, generators and networks.

In the UK, it is the responsibility of National Grid, among others, to ensure that energy is delivered securely, efficiently and reliably. However, the move towards low carbon and renewable forms of generation present issues for consumers and the National Grid alike. Consumers may see energy bills rise, unless they choose to start using off-peak energy or use energy in more innovative ways. Much more uncertainty in terms of generation profile will exist for the National Grid. To respond to this, data from smart metering and monitoring will be fed into models to help balance demand and generation. The grid will have to become more automated and distributed, rather than central and manual, to be responsive to the wealth of data generated and participants involved. Being smarter will also release the latent capacity within the network and, where possible, minimise the need for additional infrastructure.

At the consumer level, there is an increasing ability of individual consuming devices to negotiate for power usage. A home may have a fridge, washing machine and heat pump which could be synchronised so they never overlap in their consumption cycle. This scales to offices and industrial sectors.

Smart meter roll-out

DECC and Ofgem have recently consulted the energy industry on technical and regulatory requirements for smart meter technology, installation, communications and data management to support the roll-out of over 50 million electricity and gas smart meter units. The consultation sought stakeholder opinion to inform future policy, legislation and commercial frameworks[1].

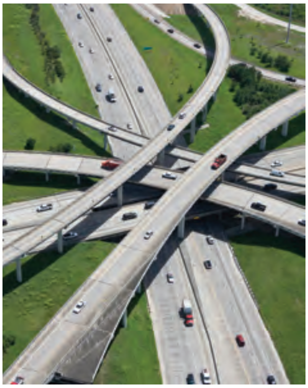
Smart water systems are important in delivering more integrated and resilient water, wastewater and flood protection infrastructure to meet the current and emerging global sustainability and climate change challenges.

4.1.2 Water

Water infrastructure has historically been 'dumb', relying on the operation of the laws of gravity, assisted by human or animal labour. Motor driven pumps have adapted such systems to unhelpful topography. The integration of such traditional systems with automated and remote instrumentation, control, feedback and communications systems has changed and is changing this picture. Consumers will be exposed to smart meters which will allow them to monitor and manage their own water use, as with smart electricity and gas metering. This will lead them to become active players in water operations through more predictable and reduced demand as well as potentially reduced bills. Smart metering is particularly helpful for industrial and commercial users, giving them easier and simplified access to the information they need to control their water consumption. Future water infrastructure will be designed to adapt flexibly to changes in demand and supply patterns, which will also cut the energy needed to pump water and wastewater.

New strategies currently being implemented or considered around the world include; smart closed-loop wastewater systems with energy recovery, both small and large-scale (UK); water resource and flood information and management response systems (Netherlands, China); and holistic catchment management integrated with water supply and wastewater systems (USA).

Future smart water systems will commonly utilise automated meter reading with walk by, drive by, fly by or fixed network intelligent meters. There will be remote water quality control and remote water quality adjustment, as well as remote control of water supply systems by satellite. Smartphones will include water 'apps' for water bill monitoring and payment via the internet. Leaks in the water grid will be detected automatically by live water



Transport being smart does not necessarily solve all problems because the infrastructure operators have no control over when people want to use the network – smartness needs to reach user level.

consumption analysis using data from smart meters. Water and wastewater treatment plants will be telemetrically operated by satellite (as is under consideration by Scottish Water for use on remote islands).

4.2 Transport

Twenty years ago, aviation, shipping and land transport each had its own navigation technologies. Ships did not use landing systems deployed by aviation; aircraft did not use zebra crossings and traffic lights. But increasingly, the same satellite navigation is serving them all.

4.2.1 Land transport

Land transport includes motorways, roads, trains and trams. The road system is an open system; the rail system is substantially a closed system. Those are fundamental differences in the transport equation and therefore have different requirements and challenges when it comes to smarter infrastructure.

Transport infrastructure is already smart in many ways. For example, rail is currently managed with automatic sensors and automatic route setting. In the future, the smart system will have to communicate with an individual the level of reliability of the journey they are undertaking and help people find alternative transport options if things go wrong. Much more could be done within the overall integration of road and rail passenger transport networks to make these kinds of interactions possible.

Managed networks will be increasingly important as eventually drivers start to concede control to a network. There will be monitoring of energy consumption and mapping of energy access. Electric vehicles and car clubs are starting to push a different view of vehicle ownership and maintenance, with managed maintenance and maximum utilisation starting to come to the fore.

The European Rail Traffic Management System (ERTMS)

In its advanced forms, ERTMS will eliminate trackside signalling. It will increase passenger flow or train flow along routes. It will have moving block signalling, so that trains are spaced not at their maximum braking distance plus an extra margin, but at their actual braking distance. To implement this in the UK, expensive new equipment would need to be fitted onto old and not standardised rolling stock. Large numbers of train operators lease their trains from other companies, so ERTMS would be complicated and expensive to install.

Running convoy operation

In the future, there is the potential to have convoys of automated road vehicles running immediately behind each other, with just one metre between vehicles. This could greatly increase the capacity of the road network. However, issues around governance, personal choice and liability for accidents mean this is unlikely to be deployed in the shorter term.

The strongest benefit smartness has brought marine transportation systems is the deep integration of vessels at sea into transportation systems ashore.

4.2.2 Maritime transport

The maritime sector has been the fastest of the regulated areas of transportation to adopt the new tools of intelligent satellite navigation and communications. A commercial shipping vessel will have half a dozen GPS receivers embedded in multiple systems. Systems can control a 100,000 tonne vessel at 25 knots through complex seaways in low visibility on autopilot; they can synchronise the communications systems that show shore control and other ships the identity of the vessel, where it is headed and what it is carrying; in an emergency they can transmit

alarms and guide rescuers. Container systems are so highly automated that the location of every item being transported by the vessel is known from factory to consumer.

However, the dependence of shipping on one system of satellite navigation and timing has exposed it to considerable risk through the potential loss of that system. Interruptions have been experienced caused by satellite malfunctions, solar events, radio interference and intentional jamming. These can cause all on-board systems to fail at once.

The Enhanced Loran system (eLoran)

The shipping industry is currently pioneering a backup navigation system. The eLoran system operates independently of GPS and so can take over seamlessly when the satellite system malfunctions. The system will use low frequencies and high powers to complement the high frequencies and low powers of satellites, removing single points of failure. It will also be able to be used for land and air navigation.

Most communications devices and networks are relatively smart already, however other smart infrastructure depends upon communications.

4.3 Communications

Operators and other organisations are providing smarter service. Smart billing has been introduced, which can be orientated towards different customer needs, such as itemised billing per second, per cost centre or per location. Online customer care and mobile 'apps' are being provided, serving the customer when they want, by time or day or location. Data can be converted to voice, and voice to data, or from language A to language B.

By 2020, the number of connected devices on the planet will be anything from 20 to 50 billion. Smarter networks will be there to serve those machines, not just the people who

use them. A smart network could be a multiband or a multimode network (an example of a multimode network would be one that would work with both cellular and wifi systems/networks).

Crossover with other sectors

Smart metering and smart grid will be served in many countries by wireless as well as ethernet technology. The communications industry envisages a large crossover with transport and banking among others. Consumers and industry will see this in the form of 'smart money' or paperless transactions, along with near field communications inside a mobile device, such as a Transport for London Oyster card built into a smart phone.

One of the big impacts will be in healthcare where, with an ageing society, systems will involve measurement of vital signs at home, notification to the clinician and then an analysis and diagnosis at a distance. Knowing what medicines pharmacies have in stock will also benefit patients, particularly those who have to travel further.

Smartness is increasingly seen as the ability of buildings and systems within buildings to talk to each other.

4.4 The built environment

Built environments and many of the world's societies do not function or even exist unless they are actually plugged into infrastructure. Architects understand the potential of joining up with smart infrastructure. However, design tools, although smart in themselves, are not currently able to link into and release the potential of the wider infrastructure. Increasingly architects are working with innovators to understand how that smart technology should be deployed and to keep informed of what exists and what technologies are on the horizon.

The built environment industry already creates some very smart systems, but the people who then operate the buildings very often do not have the benefit of any training, access, or explanation as to what the data might mean and how they could operate the buildings more efficiently. This is where smartness falls down. Bringing the end user, the engineer and the architect together to make use of these systems more intuitive will maximise the value that the smartness delivers. It will also be easier for major technology companies to articulate the value and explain why an item needs to be provided, so that the customer understands and accepts it. Ultimately, for the lifetime of the building it will be about ensuring that customers understand how to get the best from their smart systems.

No overarching governmental structure exists currently to manage multi-modal, multi-agency changes that are currently proposed and underway.

5 Barriers to smart infrastructure

5.1 Smart government

Government is the best place to start with managing issues surrounding smart infrastructure and creating the right environment for investment in smarter technologies. Government needs to be sensitive in its procurement decisions and recognise that smarter infrastructure, although possibly more expensive in the short term, will deliver more for the nation in the future. Government could, for example, mandate that major infrastructure projects should include a data capture element. Without this kind of procurement approval criterion, there is a chance that providers will continue to overlook the importance of data capture. In return for investment, the UK will get better infrastructure and skills that can be exported to boost economic growth.

With the increasing need to share information, it is important to come up with standards to assess data quality, and to do this in ways that meet privacy concerns.

5.2 Data quality and management

The quality of data from a source has to be known before it can be used by a smart system. This allows assessment of the extent to which a system could reasonably base its actions upon the data, as well as where any liability lies if those actions do harm. The government already operates in this area and proposes to make more government data open to organisations, for the economic benefit of the UK.

There are many different ways in which people give up information in order to get some value back.

5.3 Privacy

An abundance of information already exists out in the world but it is unavailable to most smart systems. Its relative lack of availability derives from security and privacy concerns as well as commercial considerations. In Dilemmas of Privacy and Surveillance2, The Royal Academy of Engineering highlighted that there are genuine dilemmas in this area. The report argued that the collection, storage and processing of personal data can be of great benefit to citizens, but that users' privacy concerns must be identified and addressed.

Greater smartness inevitably involves greater integration, which inevitably means changes to the industry structure.

5.4 Investment

It is not always clear that the investments that need to be made in order to improve smartness will provide payback to the companies that make the investment. Traditional methods of proving return on investment fail to take into account the full complexity of a 'system of systems'. Organisations need to work together to develop new ways of measuring value.

The price of connectedness may be vulnerability to new kinds of attack, so security and resilience needs to be built into systems.

5.5 Vulnerability

Interconnected systems introduce more vulnerabilities, particularly in IT systems, potentially leading to a cascade of system failures. The Stuxnet computer worm, for example was developed to target Siemens industrial software and equipment. The impact of the weather on national infrastructure can also be significant and complex, particularly when the weather turns bad. Quantifying the collective effect between more integrated smarter national infrastructure could expose some interesting relationships around disaster recovery.

Electronic sensors embedded into the physical environment can start to limit the lifetime of infrastructure.

5.6 Lifetime

Infrastructure can be designed to last 20, 40 or even 100 years. If sensors start to be physically embedded into this infrastructure, will their lifetime match that of the infrastructure itself? Designers need to be prudent about sensor placement to gather basic data in the field and leave the clever analysis to be carried out remotely. When procuring smart technology, this is one of the things that should to be taken into consideration.

6 Conclusion

The infrastructure found within the UK is becoming smarter. Smartness presents many economic and societal benefits; however there are barriers preventing further integration and further smartening of systems. To ensure that this smartening and integration continues smoothly, organisations need to develop better communication with each other, with users and with government. Government also needs to ensure that the UK keeps growing its skills base in order that smarter infrastructure can be developed in the UK, exported overseas and then continue to be well serviced.

7 People who took part in the meeting:

Chair

Dr Martyn Thomas CBE FREng	Martyn Thomas Associates

Participants

Julian Anderson	Virgin Media
Dr Paul Ashley	Mott MacDonald
Stephen Bagge	IBM
Prof Tim Broyd FREng	Halcrow
Andrew Burrows	i20 Water
Chris Cooper	IBM
Heather Dunlop-Jones	IBM
Philip Greenish CBE	The Royal Academy of Engineering
Steve Hormsby	IBM
Dr Stephen Huntington	HR Wallingford
Prof Roger Kemp FREng	Lancaster University
Prof David Last	Consultant to the General Lighthouse Authorities
Peter Lee	Department for Transport
Alistair Lenczner	Foster and Partners Architects
Andy McVey	BG Group
Prof Campbell Middleton	University of Cambridge
Mark Osborne	National Grid
Phil Pettitt	innovITS
Neil Ridley	Transport KTN
Dr Mike Short FREng	O2
Dr Scott Steedman CBE FREng	BRE Global
Prof William Stewart FREng	Consultant
Huw Thomas	Foster and Partners Architects
Derek Turner FREng	Highways Agency
John Wright	Department for Business, Innovation and Skills
Kirsten Xanthippe	Independent consultant

8 References

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2 www.raeng.org.uk/news/publications/list/reports/dilemmas_of_privacy_and_surveillance_report.pdf

The Royal Academy of Engineering

As the UK's national academy for engineering, we bring together the most successful and talented engineers from across the engineering sectors for a shared purpose: to advance and promote excellence in engineering. We provide analysis and policy support to promote the UK's role as a great place from which to do business. We take a lead on engineering education and we invest in the UK's world class research base to underpin innovation. We work to improve public awareness and understanding of engineering. We are a national academy with a global outlook and use our international partnerships to ensure that the UK benefits from international networks, expertise and investment.

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The strategic challenge is to create a system of engineering education and training that satisfies the aspirations of young people while delivering the high calibre engineers and technicians that businesses need.

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The strategic challenge is to improve public understanding of engineering, increase awareness of how engineering impacts on lives and increase public recognition for our most talented engineers.

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Utilities, including power and water, apply smartness to their grids. Smart grids are:

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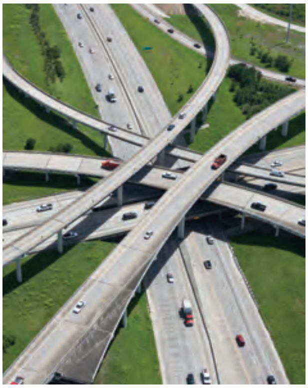

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Smartness is increasingly seen as the ability of buildings and systems within buildings to talk to each other.

4.4 The built environment

Built environments and many of the world's societies do not function or even exist unless they are actually plugged into infrastructure. Architects understand the potential of joining up with smart infrastructure. However, design tools, although smart in themselves, are not currently able to link into and release the potential of the wider infrastructure. Increasingly architects are working with innovators to understand how that smart technology should be deployed and to keep informed of what exists and what technologies are on the horizon.

The built environment industry already creates some very smart systems, but the people who then operate the buildings very often do not have the benefit of any training, access, or explanation as to what the data might mean and how they could operate the buildings more efficiently. This is where smartness falls down. Bringing the end user, the engineer and the architect together to make use of these systems more intuitive will maximise the value that the smartness delivers. It will also be easier for major technology companies to articulate the value and explain why an item needs to be provided, so that the customer understands and accepts it. Ultimately, for the lifetime of the building it will be about ensuring that customers understand how to get the best from their smart systems.

No overarching governmental structure exists currently to manage multi-modal, multi-agency changes that are currently proposed and underway.

5 Barriers to smart infrastructure

5.1 Smart government

Government is the best place to start with managing issues surrounding smart infrastructure and creating the right environment for investment in smarter technologies. Government needs to be sensitive in its procurement decisions and recognise that smarter infrastructure, although possibly more expensive in the short term, will deliver more for the nation in the future. Government could, for example, mandate that major infrastructure projects should include a data capture element. Without this kind of procurement approval criterion, there is a chance that providers will continue to overlook the importance of data capture. In return for investment, the UK will get better infrastructure and skills that can be exported to boost economic growth.

With the increasing need to share information, it is important to come up with standards to assess data quality, and to do this in ways that meet privacy concerns.

5.2 Data quality and management

The quality of data from a source has to be known before it can be used by a smart system. This allows assessment of the extent to which a system could reasonably base its actions upon the data, as well as where any liability lies if those actions do harm. The government already operates in this area and proposes to make more government data open to organisations, for the economic benefit of the UK.

There are many different ways in which people give up information in order to get some value back.

5.3 Privacy

An abundance of information already exists out in the world but it is unavailable to most smart systems. Its relative lack of availability derives from security and privacy concerns as well as commercial considerations. In Dilemmas of Privacy and Surveillance2, The Royal Academy of Engineering highlighted that there are genuine dilemmas in this area. The report argued that the collection, storage and processing of personal data can be of great benefit to citizens, but that users' privacy concerns must be identified and addressed.

Greater smartness inevitably involves greater integration, which inevitably means changes to the industry structure.

5.4 Investment

It is not always clear that the investments that need to be made in order to improve smartness will provide payback to the companies that make the investment. Traditional methods of proving return on investment fail to take into account the full complexity of a 'system of systems'. Organisations need to work together to develop new ways of measuring value.

The price of connectedness may be vulnerability to new kinds of attack, so security and resilience needs to be built into systems.

5.5 Vulnerability

Interconnected systems introduce more vulnerabilities, particularly in IT systems, potentially leading to a cascade of system failures. The Stuxnet computer worm, for example was developed to target Siemens industrial software and equipment. The impact of the weather on national infrastructure can also be significant and complex, particularly when the weather turns bad. Quantifying the collective effect between more integrated smarter national infrastructure could expose some interesting relationships around disaster recovery.

Electronic sensors embedded into the physical environment can start to limit the lifetime of infrastructure.

5.6 Lifetime

Infrastructure can be designed to last 20, 40 or even 100 years. If sensors start to be physically embedded into this infrastructure, will their lifetime match that of the infrastructure itself? Designers need to be prudent about sensor placement to gather basic data in the field and leave the clever analysis to be carried out remotely. When procuring smart technology, this is one of the things that should to be taken into consideration.

6 Conclusion

The infrastructure found within the UK is becoming smarter. Smartness presents many economic and societal benefits; however there are barriers preventing further integration and further smartening of systems. To ensure that this smartening and integration continues smoothly, organisations need to develop better communication with each other, with users and with government. Government also needs to ensure that the UK keeps growing its skills base in order that smarter infrastructure can be developed in the UK, exported overseas and then continue to be well serviced.

7 People who took part in the meeting:

Chair

Dr Martyn Thomas CBE FREng	Martyn Thomas Associates

Participants

Julian Anderson	Virgin Media
Dr Paul Ashley	Mott MacDonald
Stephen Bagge	IBM
Prof Tim Broyd FREng	Halcrow
Andrew Burrows	i20 Water
Chris Cooper	IBM
Heather Dunlop-Jones	IBM
Philip Greenish CBE	The Royal Academy of Engineering
Steve Hormsby	IBM
Dr Stephen Huntington	HR Wallingford
Prof Roger Kemp FREng	Lancaster University
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Peter Lee	Department for Transport
Alistair Lenczner	Foster and Partners Architects
Andy McVey	BG Group
Prof Campbell Middleton	University of Cambridge
Mark Osborne	National Grid
Phil Pettitt	innovITS
Neil Ridley	Transport KTN
Dr Mike Short FREng	O2
Dr Scott Steedman CBE FREng	BRE Global
Prof William Stewart FREng	Consultant
Huw Thomas	Foster and Partners Architects
Derek Turner FREng	Highways Agency
John Wright	Department for Business, Innovation and Skills
Kirsten Xanthippe	Independent consultant

8 References

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