ROYAL ACADEMY OF ENGINEERING

National Infrastructure Commission Technology Study - call for evidence

Response to the National Infrastructure Commission, 15 March 2017

National Infrastructure Commission: Technology study call for evidence

The Royal Academy of Engineering welcomes this opportunity to submit evidence to the National Infrastructure Commission (NIC). 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.

Through its Fellowship, the Academy has access to highly qualified individuals in infrastructure, systems engineering, construction, digital systems, civil and structural engineering, energy, transport, flooding and water supply. Their expertise spans research, policy making, regulation and practice including the management of major projects. This response is based on the views of Fellows and on policy studies that the Academy has undertaken.

Introduction

1. New technologies could potentially underpin improvements in infrastructure productivity by helping in the delivery of new infrastructure, and in the reuse or repurposing of existing infrastructure. Reuse or repurposing of existing assets will in many cases carry lower financial and environmental costs than provision of new. In its response to the NIC's National Infrastructure Assessment call for evidence[1], the Academy stressed that maintaining and operating existing infrastructure at highly resilient levels is vital, and new technologies can play an important role in enabling this.

2. The focus of this response is digital technologies such as big data, the internet of things and artificial intelligence; it does not consider other technologies that could potentially have a large impact on infrastructure such as Hyperloop, or the battery technologies that could impact on electric vehicles and drones.

Benefits to infrastructure users and providers

3. Digital technologies will provide many benefits to both infrastructure users and providers. Pervasive monitoring and sensing strategies will enable the use of preventative maintenance strategies so that maintenance interventions are carried out when needed, rather than after a set number of hours of operation. Reliability will also be improved, as weaknesses can be detected prior to failure occurring. Technologies can also enable better utilisation of existing infrastructure by means of peak demand spreading, such as through differential pricing. Alternative ways of increasing capacity exist too, which could improve the productivity of existing structures and systems beyond original design intentions. For example, the development of an innovative tool, iFACTS[2], has enabled NATS to increase the traffic densities in UK controlled airspace. Technologies can also be used to allow users and providers to respond to unexpected congestion with real-time information. Better design of new infrastructure facilities will in future be achieved through the active feedback of real operating conditions. There will be services in future that as yet have not been thought of, that will be of value both to users and providers.

[1] Royal Academy of Engineering, February 2017, *National Infrastructure Assessment: response to the National Infrastructure Commission's call for evidence*.

[2] iFACTS is a predictive tool for air traffic controllers that helps to increase capacity and improve safety. See for example: http://www.altran.co.uk/pressandnews/in-the-uk/newsarchives/2013/ifacts-wins-ihs-janes-enabling-technology-award-for-2013.html#.WL_yeNPcu70

Futureproofing smart infrastructure

4. Smart infrastructure will need to be futureproofed so that it is resilient, adaptive and flexible in response to unforeseeable changes – for example, in demographics, climate and technologies – that will occur in the lifetime of the infrastructure. For example:

   - There is uncertainty about how autonomous vehicles will change transport usage and requirements for existing and future infrastructure. Autonomous vehicles could transform the amount of road space needed, while autonomous truck convoys would change the loading on bridges designed in a very different context. This will have an impact on future infrastructure spending.

   - Smart infrastructure needs to be designed in order to remain relevant in the face of relentless digital disruption. One possible solution is the creation of 'vanilla' or plain infrastructure – for example, roads just as flat surfaces - with disruption managed via updates to devices using the infrastructure.

5. Infrastructure that is built over the next decade needs to start taking advantage of the growing opportunities to utilise innovative technologies that are emerging. Digital strategies should accompany all major infrastructure projects.

6. If the approach to defining the value of infrastructure is too narrow[3], there is a risk that benefits may be overlooked and systemic interactions ignored. For example, wider social, economic or environmental benefits could accrue from the Oxford-Cambridge Expressway which connects four key hubs for autonomous vehicles: Oxford, Cranfield, Milton Keynes and Cambridge, if broader benefits are considered beyond just improved physical connectivity.

7. The UK could gain competitive advantage by developing expertise and creating export opportunities around the technologies and processes that will underpin improvements in infrastructure performance, building on existing strengths in infrastructure, data analytics, sensors, artificial intelligence, the internet of things and cybersecurity.

Connecting data: the potential for data analytics, the internet of things and advanced connectivity to improve infrastructure productivity

8. A joint study by the Royal Academy of Engineering and the IET, *Connecting data: driving productivity and innovation*[4], investigated the future opportunities for organisations and sectors to improve products and processes and to innovate using data analytics and advanced data connectivity, and outlined known barriers to success. Stakeholder workshops were held for infrastructure sectors including transport, energy and the built environment. The scope of the study extended to the internet of things – the networks of sensors and devices that will generate, communicate and respond to data – and the systems that will be created by integrating previously separate networks.

9. The study found that the area is still immature, but that there are early pockets of excellent practice in data analytics. The challenge will be to spread these examples of best practice to sectors – including those that design, deliver and operate infrastructure – that are only now

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[3] A more detailed discussion on value is in: Royal Academy of Engineering, February 2017, *National Infrastructure Assessment: response to the National Infrastructure Commission's call for evidence*.

[4] Royal Academy of Engineering and the IET, November 2015, *Connecting data: driving productivity and innovation*, http://www.raeng.org.uk/publications/reports/connecting-data-driving-productivity

recognising the opportunities around data that will allow them to create new business activities with potentially strong economic and employment implications.

10. Data analytics, supported by data science and advanced data connectivity, has the potential to improve the UK's productivity – including infrastructure productivity – in myriad ways, including optimising design, construction, operation, maintenance, efficiency and resilience. This opportunity is arising as a result of new sources of data – from sensing, digitisation, and imaging technologies, data from social media and crowdsourced data – and more powerful computing, and hence analytics, capability.

11. Advanced analytics will increasingly exploit artificial intelligence technologies since the volume of data generated will require analytics that have the ability to learn patterns and highlight results autonomously – a key role for artificial intelligence.

12. Data analytics will benefit infrastructure in a number of ways[5] which are set out below.

    Built environment: Data has the potential to improve the design and performance of buildings and cities, leading to greater sustainability, more efficient use of space and a higher quality environment. For example:
    - *Procurement*: data feeds from smart cities could in future drive the performance required from an asset. Visualisation of data could assist clients in developing specifications
    - *Design*: behavioural data from social media and sensors could be used to understand how built environment influences behaviour and to inform evidence-based design that results in a sustainable, productive and healthy built environment[6]
    - *Operations*: better energy data will allow the energy performance of an asset to be linked to its original construction contract.
    - *Maintenance*: predictive asset maintenance will be possible based on information about component and sub-system degradation. Autonomous technologies could be used in inspection and maintenance.

    Energy: Data from smart meters and other sources will enable an energy system capable of more integrated, flexible and complex transmission, distribution and trading. For example:
    - *Planning*: local strategic energy system planning will be improved if data from the energy system is combined with other types of data such as on building typologies, construction types and potential energy resources.
    - *Operations*:
        - convergence across different energy networks will be possible, so that the energy system may be considered as delivering services to its end-users rather than as separate electricity, gas or heat networks.
        - the operation of new types of energy generation, distribution and local storage will improve, including community energy systems and heat networks.
        - optimal decision-making will be enabled including day/hour ahead forecasting and immediate operational management.
        - better data will aid in setting tariffs and managing system carbon intensity.

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[5] The application of data analytics to the built environment, energy and transport sectors is discussed in more detail in Sections 3.2, 3.3 and 3.4 respectively of *Connecting data: driving productivity and innovation.*
[6] Royal Academy of Engineering (2015), Built for living: understanding behaviour and the built environment through engineering and design, http://www.raeng.org.uk/publications/reports/built-for-living-understanding-behaviour

Water and smart cities: Similarly to the energy system, better management of water distribution in cities in future will rely heavily on data. This will help reduce the risk of flooding in cities and enable more efficient use of water.

Transport: Data will support more efficient and smarter transport of people and goods through an integrated system that can optimise capacity, make better use of resources and provide a more customer-focused experience. In particular:

- *Operations*:
  - real-time, multi-modal information provided to passengers via apps[7][8] will help them plan trips using the most appropriate mode and purchase tickets by mobile phone. New business models along with more sophisticated uses of data analytics will enable 'mobility as a service'.
  - vehicle tracking services are already allowing businesses to optimise fuel consumption and reduce running costs for their fleets.
  - digital signalling using on-train sensors will allow trains to be controlled in real time, reducing congestion and allowing the railway to respond to peak demand.
  - *Maintenance*: predictive maintenance will be possible, requiring integration across the supply chain to ensure that spare parts are located and maintenance services are delivered promptly and to vehicle destinations rather than local depots.

13. While many of the emerging applications are from a single sector, new opportunities will arise as the result of combining data across sectors. For example, energy data could be shared with local authorities to provide indicators on fuel poverty, with manufacturers of electrical appliances to improve energy efficiencies, with third parties to develop energy advice products for consumers or with water companies to reduce their significant carbon footprint.

The use of data in improving resilience

14. For increasingly connected systems, there will be a need to focus on the connections between various sub-systems, which can work to good effect in such areas as achieving integrated transport, but can lead to interdependencies between systems that are not always readily apparent and that could make them vulnerable to cascade failure as a result of sub-system or component failure.

15. Data can be used to improve resilience in the following ways[9]:
    - continuous monitoring will enable reactive and timely maintenance across all infrastructure to help avoid component failures and system outages
    - sharing data between sectors will contribute to better scenario planning and infrastructure modelling and operation. This is important for understanding how to ensure that infrastructure is resilient in a changing demographic, environmental and technological context
    - sharing data will enable systems-level planning, and help to ensure vulnerabilities in one sector do not compromise another.

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[7] For example, Citymapper uses real-time data to help users plan trips, www.citymapper.com
[8] For example, Corethree combines data and mobile technologies to provide mobile ticketing services, bridging the gap between consumer and operator, www.corethree.net .
[9] Engineering the Future, February 2011, *Infrastructure, engineering and climate change adaptation – ensuring services in an uncertain future*, www.raeng.org.uk/adaptation

Case studies

16. Detailed case studies from the Academy and IET's *Connecting data* study illustrate how data analytics can improve infrastructure productivity[10]:

    - *Construction of Crossrail:* Data analytics were used to improve the performance of infrastructure delivery during the construction of Crossrail. The application of novel data analytics techniques to data obtained from monitoring equipment helped project managers to manage risk and reduce costs.

    - *Operation of buses in Helsinki*: a Helsinki-based bus company is combining data from its fleet of 400 buses to improve cost-effectiveness and user service, and to reduce carbon emissions. Sensors monitor and analyse fuel usage and other data for each driver, route and vehicle

    - *Modelling the UK's rail network*: Network Rail's ORBIS project seeks to create a detailed digital model of the UK's rail network in order to improve the efficiency, cost-effectiveness and safety of the organisation's asset management capability

    - *Optimising performance in the energy industry*: a global database of well failure data allows operators to benchmark performance and identify where changes in operations or maintenance regimes are beneficial.

Key challenges to be addressed

17. *Improved cyber safety and resilience*: there is a growing awareness of the risks associated with increasingly complex and interdependent systems of systems that are being created as a result of integrating physical and digital systems. Increased dependence on cyberphysical systems will inevitably result in greater consequences if the systems fail, and the software and hardware of these systems must therefore be built to very rigorous engineering standards. It is vital that cybersecurity risks are minimised so that serious incidents are avoided, trust in such systems is maintained and the potential benefits are realised. Specific technical challenges need to be considered around the complexity, size, uncertainty and resilience of such systems.

18. *Enhanced digital infrastructure*: investment in broadband access at least compliant with the EU Digital Agenda for Europe targets of universal fixed access at a minimum of 30 Mbits/sec download by 2020. Similarly, ubiquitous access to high-speed mobile broadband is required. This is crucial for applications requiring the transfer of data in large volumes and at high speeds, or the resilient transfer of data in both urban and rural economies.

19. *Better access to proprietary data*: much potentially valuable data remains locked away in corporate silos or within sectors. Platforms are needed that allow datasets to be shared or traded within a framework that promotes trust, the assurance of provenance, and practicality.

20. *Better methodologies for the formal valuation of data*: this would improve decision-making around how best to develop, trade, protect and exploit assets.

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[10] IET website, *Connecting data – case studies: where are the success stories?*, http://www.theiet.org/sectors/information-communications/topics/connected-data/articles/connecting-data.cfm. This webpage also includes case studies illustrating the benefits of data from other sectors, that are more broadly applicable across all sectors.

21. *The need for multi-skilled individuals and teams:* this is required to convert data analytics theory into genuine business practice and performance. The necessary combination of skills is challenging, drawing on engineering, computer science, mathematics and statistics as well as specific sector knowledge. Tools will increasingly become available that enable the application of data analytics and interpretation of its findings without requiring specialist data science knowledge.

Future trends over the next few decades

22. The area will continue to evolve as a result of a number of factors that include the following:

- *Innovations in business models* such as 'mobility as a service' that will create value from data in new ways, and may require sharing or trading of data.

- *Improvements in data analytics techniques.* There are challenges around extracting information and generating value from new types, volumes and combinations of data. For example, new techniques are needed to deal with large volumes of sensor data, and from a combination of 'soft' data from social media and 'hard' data from sensors. Improved visualisation tools will also help in extracting information from data.

- *Innovations in artificial intelligence techniques* such as machine learning, so that computers can aid help optimise products and processes based on data.

- *Innovations in sensing and other technologies* used to collect data, that may either be wired or wireless. It is a challenge to take data off the sensors, transfer it securely, and retrofit existing infrastructure with sensors. For example, new quantum sensing technologies could have huge benefit because of improved sensitivity at a fraction of the cost, weight, size and power consumption of existing devices.

- *Increases in the density of sensing* over time, along with more sophisticated data analytics, creating a system-of-systems that could transform how services are provided. There is a view that the internet of things will, in future, itself be a critical, integrated infrastructure, upon which many applications and services can run[11].

- *Better data and metadata standards* for interoperability, that allow data to be shared within and between sectors. Detailed metadata that describe the context in which the data was generated – for example, limits of uncertainty and calibration applied – allow datasets to be curated and used well beyond the applications and sectors for which they were originally collected.

- *Improved toolkits for design and analytics* that should be open, interoperable and cyber-secure. It will be necessary to develop meta language approaches to integrate existing design and run-time tools for data systems design and analytics.

- *Improved connectivity* including broadband access and ubiquitous access to high-speed broadband services to ensure that the transfer of data in large volumes and high speeds, and resilient transfer of data in both urban and rural areas are possible.

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[11] Stankovic, J.A., 2014, *Research directions for the Internet of Things*, IEEE Internet of Things Journal (Vol. 1, Issue 1).

Current Academy studies

23. The following studies are continuing the debate around the use of data analytics, the internet of things and advanced connectivity. The Academy would be very happy to provide more information to the NIC on these studies.

   - *Data as an asset:* the Academy is holding a series of events to explore how value is generated from data, and what factors influence its value, such as its target use, provenance, the processes that the created it, and the ability to reliably link datasets. The events have also explored the benefits of valuing data, both for companies individually and for the UK economy as a whole.

   - *Data sharing and trading:* the Academy will be researching case studies to better understand how to co-create value by sharing or trading data, highlight opportunities and barriers and share best practice. The case studies will include engineering examples, especially those that have involved the supply chain, and examples from other sectors.

   - *Cyber safety and resilience*: the Academy is holding a series of workshops to explore the nature of vulnerabilities created by the interconnection and interdependence of the systems associated with critical infrastructure and the internet of things, and the regulatory and non-regulatory measures that might ensure safety and resilience while promoting innovation. Cyber safety and resilience are key issues in all areas of infrastructure, including autonomous vehicles, the transport system, the energy system and the water supply system.

   - *Regulation of autonomous systems:* the Academy is planning research on the regulation of autonomous systems and its impact on innovation and willingness to invest. It will be published later this year.