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Challenges in infrastructure asset management

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Abstract: Infrastructure owners are facing a number of challenges in an increasingly difficult economic and political setting, and are seeking novel approaches to are required to meet the demands of operators, shareholders and other stakeholders. Owners are demanding greater value, for less overall cost, from their assets. New technologies enable higher performance and greater safety, but at a price. Initial purchase costs are rising, leading to longer periods in service. Maintenance requires a more highly skilled, and so more expensive, workforce. This paper summarises the outputs of two industrial workshops carried out in the UK and USA targeted at identifying the major challenges faced by infrastructure owners and operators. These challenges provide guidance to the academic community for directing research activities to address the needs of industry, thus delivering maximum impact.

Keywords: Asset management; whole-life cost, infrastructure management, maintenance, investment.

1 INTRODUCTION

Asset owners and managers face complex challenges in maintaining a state of good repair for transportation infrastructure assets. Most developed nations undertook an enormous investment in construction of infrastructure such as highway networks in the second half of the 20th century. This investment has helped catapult the countries' economic growth – but maintaining this huge infrastructure is now proving to be an enormous financial strain. In the US, 57% of total spending on infrastructure in 2014 has been towards operation and maintenance of existing infrastructure assets and this has been rising by about 6% over 2003-14 (Congress, 2014). However, there is general consensus that the level of investment is not increasing in line with the requirement, leading to worsening state of infrastructure assets. Figure 1 shows the transport infrastructure spending as a share of GDP, clearly showing a decline in most countries. In the UK, there are rising concerns about the low level of spending on infrastructure compared to its OECD peers (OECD, 2015).

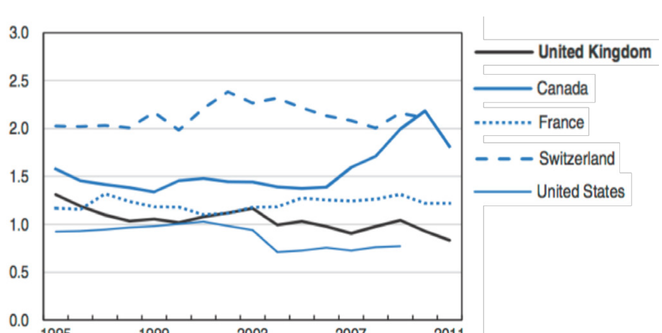

Fig. 1: Transport infrastructure spending as a percent of GDP (adapted from OECD (2015))

New regulations, such as MAP-21 (Congress, 2012) and (Congress, 2015), have created new requirements that further challenge managers in forecasting deterioration to prioritize preservation. There is impetus to develop new guidelines and innovative approaches for reducing the total cost and increasing the whole-life value of building and maintaining assets. For example, new standards such as ISO 55000 (ISO, 2014) provide guidance on how to deliver the best cradle-to-grave value, optimized for a range of stakeholders over a long period. Extracting the maximum value from an asset requires a broad range of expertise, whether that is business and financial know-how, or engineering and operations capabilities (IAM, 2008; Zuashkiani *et al.*, 2014). These skills may be required at different stages of an asset's life, when acquiring, utilising and maintaining the asset, for example. They are also needed to make decisions about how to best combine factors such as costs, risks, and performance.

On the other hand, cutting edge research in the field of asset management in the world's leading universities is delivering innovative solutions, tools and methodologies aimed at reducing the lifecycle cost and enhancing the performance of infrastructure assets and systems (e.g., CSIC (2016); CAIT, (2016)). It is essential that current and future research activities are informed by and directed at addressing the pressing challenges faced by industry to ensure that the research outcomes deliver maximum impact.

1.1 Paper objective

In order to identify the current and future challenges faced by industry, we organised two industrial workshops – one at the University of Cambridge, UK and another at Rutgers

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University, USA. The workshops brought together practitioners (asset owners, operators, designers, consultants, etc.) across different infrastructure sectors such as transportation (rail, road, air), utilities (water, energy), housing in addition to the academics with a range of related expertise. The objective of this paper is to summarise the outputs of these workshops, which can then be used as a basis for developing research roadmaps.

1.2 Paper structure

The paper is structured as follows. The next section outlines the key influencing factors that impact on the way in which infrastructure assets are managed. This section will help in understanding the relative differences between the infrastructure and manufacturing sectors. Following this, in section 3, we discuss the challenges faced by infrastructure owners and operators, as identified through the workshops. Further, in section 4, we briefly outline the solutions to the challenges as suggested by the workshop delegates. Finally, in section 5, we provide some concluding remarks.

2 FACTORS INFLUENCING INFRASTRUCTURE MANAGEMENT

A nation's infrastructure supports the development of the society as well as provides essential services necessary to sustain a vibrant economy. A number of factors influence the way in which infrastructure assets are managed in a way that they continue to provide value to its owners and to the community at large.

2.1 Financial climate

In todays economic climate, infrastructure owners and operators are coming under immense pressure to maintain an adequate (and often improved) level of service and performance within an ever-shrinking budget. Success in this climate is determined by an operator's ability to strike the right balance of expenditure without taking additional risks and adversely affecting performance over the life of the infrastructure. When developing capital investment and maintenance plans, decision-makers need to consider options that may require higher initial investment, but yield lower costs and risks, and higher performance over the life of the assets.

2.2 Regulations

Every infrastructure sector (e.g., transport, energy, water, communications) is heavily regulated in the UK. These regulators (e.g., OFGEM, OFWAT, ORR, OFCOM) increasingly demand more accountability and justification from the operators for capital and operational expenditures. The ability to generate efficient investment plans is key to satisfy the regulatory demands. Regulators (e.g., OFWAT) have now begun to emphasise more on `outcomes' rather than `outputs' by asking infrastructure owners to focus on TOTEX when submitting their investment plans.

2.3 Ageing infrastructure

UK infrastructure is ageing, and requires ever-increasing amount of investment in maintenance and upgrade in order to maintain existing performance levels. Infrastructure assets are characterised by long life and complex deterioration, and knowledge about the way these assets deteriorate over time and how the deterioration affects the costs, risks, and performance is patchy.

2.4 Network effect

Individual assets in an infrastructure network/system does not provide value on their own. It is the combination of different types of assets in the network/system that generates value. For example, a bridge on its own need not deliver value, but the bridge along with the associated road network generates value for the users and the owners. However, individual assets have the ability to affect the value generated by the network/system depending on their criticality to the service. The disparate nature of these assets (e.g., civil, electrical, mechanical at the highest level) means that effective management of an infrastructure network requires multi-disciplinary and systems-based approaches. Adding to the complexity is the sheer scale of infrastructure networks and the number of assets that need to be managed and maintained for effective service provision.

2.5 Multi-stakeholder perspective

Infrastructure assets involve multiple stakeholders ranging from the asset owners (e.g., UK Government/Public), asset operators (e.g., Highways England), asset managers (e.g., contractors), and asset users (e.g., general public). Meeting the requirements and expectations of the different stakeholders is often the biggest challenge. Furthermore, the longevity of the assets may mean that the stakeholders (e.g., the owner) or even the type of usage (e.g., power stations converted to office buildings) may change over time. This poses great challenges to the way these assets are managed over their life.

2.6 Silo mentality

There is added complexity due to the fact that infrastructure organisations are often structured in siloes along traditional disciplines. For example, maintenance of a bridge structure might be the responsibility of one department that is different to that responsible for the maintenance of the pavement on the same bridge, which is again different to that responsible for the signals/lighting on the bridge! This makes cross-asset prioritisation a challenging prospect, with each department competing for higher budgets from a shrinking pot. Effective communication, sharing of information between departments, and a clear understanding of network value is critical for effective asset management.

3 CHALLENGES

Prior to the workshops, the delegates were requested to provide the following input:

1. Identify three pressing challenges for reducing life cycle costs of infrastructure systems.
2. Identify three innovative capabilities (tools, methods, models) that can optimize the costs invested in infrastructure systems.

The challenges and solutions were categorised and further explored during the workshops. In the following sub-sections, we will discuss the key challenges faced by industry. The challenges are categorised under:

1. Asset performance monitoring and prediction
2. Data management
3. Optimising investment/expenditure
4. Organisational culture change

3.1 Asset performance monitoring and prediction.

The large volumes of ageing infrastructure presents an ever-increasing challenge in terms of understanding their current condition and performance, and affects the ability to predict how these might evolve in the future. Regular inspections enforced by regulations are infrequent, and are often affected by subjectivity. In fact, the large scale nature of infrastructure makes it difficult even to identify and locate all the assets, affecting the integrity and completeness of the asset register.

Compounding this challenge are the uncertainties in the nature and intensity of usage of these assets over their long lifetimes. It is difficult (but increasingly made possible with novel technologies) to perform real-time monitoring of users, their use of assets, the assets themselves and the operating environment of the assets. Due to the unique nature of design and construction of many infrastructure assets, traditional techniques of deterioration and risk modelling based on historical patterns might not be suitable. Moreover, infrastructure owners are expected to understand the performance of the assets from perspectives that were no considered previously, e.g., How can asset managers best evaluate embodied carbon of materials and mitigate any correlation with the carbon footprint and the environmental impact of those material choices and processes? How can smart systems be used to monitor changing external influences (demand, climate) on infrastructure? Are there specific items of data, or monitoring strategies, that will support long term planning? What is the timescale for such strategies; can limited and non-contiguous historic data sets be integrated to provide a head start?

Effective use of enterprise wide systems to provide near/real time information on asset failure (i.e. deriving asset failure data from a work order management system) is a major challenge. This could allow businesses to update operational risks through the automation of reliability type modelling (using Business Impact Matrix and other data), which could triggers the optimal intervention against business constraints

A related challenge is also to develop an accurate estimate of the impact/effect of intervention actions on the performance of the asset, e.g., "what does refurbishment do to an asset's likelihood of failure?". Replacement will result in a like-new asset, but what does refurbish result in? – one could say that it extends asset life but to what extent?

3.2 Data management

Emerging technologies enable the capture of data from a variety of sources. This comes with an associated challenge: How do we actually connect data from multiple electronic sources (e.g., LIDAR, phones, embedded sensors)?

Sharing of data and information in an open semantic form across industry stakeholders to deliver enhanced customer experience is a major challenge. Data capture, data sharing and data standards have a part to play in driving improvement in the overall performance of an asset. In turn this should increase the overall value available to the stakeholders involved in delivering a service that involves that asset. The effective use of data can inform decisions that then improve asset performance. For example, good use of data allows organisations to understand risk and criticality better, and to avoid surprises and failures. It enables organisations to understand the performance of assets, assess whether performance meets expectations, and take action to improve the asset lifecycle cost. This not only benefits organisations participating in the value creation network, but also society in general, in many cases.

The adoption of dating sharing standards would, theoretically, enable organisations to share data more willingly and more effectively. It is possible, for example, that an organisation in one part of the asset related value creation network may own data, but an organisation in another part of the value creation network is able to use that data to create value. There may be no apparent incentive for the organisation that owns the data to share it, or even to collect it. Data sharing standards may enforce sharing of that data. If information sharing standards are to be implemented, it must be done in a way that does not comprise commercial standing.

In the infrastructure sectors, standards such as the PAS 1192 series and the development of BIM-compliant solutions offer industry the capability to manage asset data efficiently. The concept of Smart Infrastructure extends the developments in the field of Internet of Things (IoT) to infrastructure assets. For instance, the EU-funded IoT-A project created an architectural reference model together with the definition of an initial set of key building blocks for managing data about smart, connected assets. The IEEE IoT architecture (IEEE, 2016) is another example of a key development in this area.

Emerging predictive analytic techniques allow organisations to predict events, or the cause of events, that affect the creation of value by the Asset Management systems, using historical and real time data, and change practice to reduce costs and risks of failure.

Traditionally, attention might focus on maintenance only after the warranty period has expired. The owner would then take a view on the maintenance approach, such as adopting a time based, condition based approach for maintenance, or just repair when the equipment fails.

Predictive analysis goes a step further. It harnesses cutting-edge technology to enable informed decision making based on facts, on data, on information that is going to mitigate risk. So, for example, when a component fails unexpectedly it has a negative impact on the performance of an asset, and thus value creation. The ability to anticipate the failure of that component, to a high degree of probability, allows action to be taken in advance, reducing costs, and potentially increasing performance. Running things to fail is usually not the most efficient strategy, particularly when human safety is compromised.

3.3 Optimising investment

Gathering data is only a means to an end. Unless the data helps in managing our assets differently, delivering reduction in costs and risks, the data does not have any value. In order to extract this value from the data, industry requires novel approaches, methodologies, and tools for making asset management decisions. These decisions range from strategic (e.g., determining the levels of investment required across our infrastructure) to tactical (e.g., which repair option to choose when a crack appears on a tunnel?). However, regardless of advances in data collection technologies and management techniques, industry need decision support tools.

Many organisations struggle with developing and applying qualitative risk management. This partly because of the complexities of assessing the possible multiple impacts from the risk and the costs of those impacts. Simple quantitative risk management tools to understand risk quantitatively and the value risk mitigations are providing is a key requirement for asset managers.

The long-term life and nature of infrastructure assets brings with it a set of decision-making challenges. In particular, very long-term investment planning is a key challenge – some asset owners develop 100+ year investment plans, however, most of what is in there is based on assumptions and is not in any way ‘real’. Infrastructure organisations generally lack very long term strategic planning, going beyond whole-life of individual assets. Much of this is also because of uncertainty in demand.

Infrastructure owners such as government agencies and councils are responsible for managing a mixed portfolio of different types of assets. Optimising the annual maintenance plan for a portfolio of diverse assets (e.g., a county council needs to determine the optimal maintenance plan for their roads, bridges, lights etc) with an aim to deliver maximum value to the stakeholders over a time-horizon is a challenging proposition. . How much money to spent on which assets of what type under ever-decreasing budgets is an issue that needs to be addressed. At present, this is done in an unscientific and ad-hoc manner, which means that the users and taxpayers are potentially not getting the best value-for-money from the infrastructure.

Increasing acceptance of the concept of value-based decision-making requires the development of appropriate tools for decision-support. It is important to realise that investment/expenditure is often made at the asset level (e.g., a bridge), but value is realised through effective system performance (e.g., road network). Tools that will help analyse the system-wide effect of asset-level investment, in particular those that consider and model the interdependencies between various assets in a system (and even interdependencies between systems, e.g., between the transport network and the energy network) are required.

As mentioned earlier, the raw data generated by data collection and sensor systems is of little use and value. It needs to be processed and put into a geometric context within an infrastructure asset, which facilitates the interpretation and analysis of the data. This supports informed decision making that leads to effective actions. However, BIM provisions that support structural performance monitoring tasks are not yet sufficient. A new approach that enables to model structural performance monitoring systems in a BIM environment and hence permits visualizing sensor data directly on BIM models is a challenge that needs to be addressed.

3.4 Organisational culture change

Implementing a good asset management system is a major organisational and cultural shift – requiring a change in processes, methods, techniques, and in some cases, even organisational structures. Breaking down of organisational silos that have been created over long periods of time require top management support and motivation. Coupled with this “inertia”, organisations often struggle to justify the need for this change. Although many organisations have used the “status quo is not good enough” rationale, increasingly business leaders are demanding stronger justification for asset management. Across the board, practitioners are demanding methodologies and tools for developing a business case for asset management.

One of the major shifts in thinking that effective asset management brings about is whole-life considerations instead of just immediate expenditure. For instance, how can Design and Build tenders for construction projects be evaluated on a Whole-life cost/value basis? The problem here is that conventional evaluation encourages lowest-price mentality, and WLC-based design often encourages build-it-to-last and hence higher initial cost. In addition to the tools, techniques and methodologies required for whole-life cost/value calculation, organisations need to embrace the fact that myopic views that dominate investment decision-making must be disposed of, and long-term thinking needs to prevail.

Table 1. Solutions to industrial asset management challenges

	Organisational culture	Optimising investment	Effective management of asset information/technologies
Models and tools		• Long-term investment planning • Linking degradation to performance • Infrastructure performance simulation platform • Modeling risks before and after sensor deployment or change of AM strategy • Diverse asset portfolio management	• Hadoop-based asset information model
Integrated Solutions		• Integration of enterprise IS for real-time risk analysis • Integrating OM, IM, and AM decisions • Integrating data and physics-based deterioration models	• Solutions for futureproofing building foundation data • HW/SW for Mobile working • Integrating data from multiple data sources
Guidance	• AM Benefits • Idiot's guide to ISO 55000 • Integrating ISO 55000 with other quality management frameworks	• How to use sensory data for managing slow processes • Simplify risk management and risk-based DM for AM	• Generic whole life asset information requirements register • Generic asset information resources • Integrating BIM and digital technology with asset management • Horizon scanning and assessment of digital technologies
Methodologies	• Methodology to quantify AM Benefits (Maturity vs. Performance)	• WLC-based evaluation of D&B tenders • Incorporating sustainability • Very (100+ yr) long-term investment planning	• Economic data gathering and processing to reveal clear priorities for future (long term) action • Effective sensing strategy

This involves – among others – educating engineers, asset managers, and business leaders. Reduction of whole-life costs and maximising whole-life value requires novel approaches, and acceptance of such new approaches across the organisation.

4 SOLUTIONS

In addition to identifying the key challenges, delegates at the workshops were asked to identify potential solutions that would begin to address the challenges. Table 1 provides an outline of the solutions recommended by the delegates. The solutions were classified into: (1) models and tools; (2) integrated solutions; (3) guidance documents; and (4) methodologies. Most of the solutions are self-explanatory, and hence we refrain from discussing them in detail.

5 CONCLUSIONS

The asset management research community needs to work closely with practitioners in order to understand the real challenges they face, and the solutions they are looking for. In our experience, structured workshops that bring together industry professionals from different infrastructure sectors help identify the problems that must be focussed on for near and long-term impact of research. The challenges and solutions outlined in this paper is intended to be a guidance, and by no means an exhaustive list. The challenges tend to vary between sectors and between countries. Regulatory and government roles play an important factor in the way industries in different sectors and countries approach asset management and whole-life thinking. It was however clear that the industry will benefit from working closely with academia and by sharing best practices and lessons learnt between organisations and sectors. This is also another area where the convening power of major research institutions can play an important role.

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