

Towards the Futureproofing of UK Infrastructure

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Abstract

Ensuring long-term performance from key infrastructure is essential to enable it to serve society and to maintain a sustainable economy. The futureproofing of key infrastructure involves addressing two broad issues:

- (i) Resilience to unexpected or uncontrollable events e.g. extreme weather events; and
- (ii) Adaptability to required changes in structure and / or operations of the infrastructure in the future.

Increasingly, in their respective roles, infrastructure owners, designers, builders, governments and operators are being required to consider possible future challenges as part of the life cycle planning for assets and systems that make up key infrastructure.

In this paper, we report on a preliminary study aimed at exploring the following questions related to infrastructure and infrastructure systems:

- What does 'futureproofing' of infrastructural assets mean?
- Why and when to futureproof critical infrastructure?
- How can infrastructure assets and systems be prepared for uncertain future events?
- How can futureproofing considerations be incorporated into infrastructure asset management practices?

In order to seek answers to the above questions, we conducted two industrial workshops bringing together leading practitioners in the UK infrastructure and construction sectors, along with government policy makers. This paper captures lessons learnt from the workshops, and proposes a simple framework for linking futureproofing into broader asset management considerations. Case studies of Dawlish Railway and Heathrow Airport are also presented.

Keywords chosen from ICE Publishing list

Infrastructure planning; whole life management.

1. Introduction

Infrastructure assets have long service lifetimes, and are therefore subject to a range of changes over time, including extreme weather events, changes of use, and ageing.

Climate and weather are changing globally and UK has recently faced a range of extreme weather events e.g. flooding, wind and snow storms and drought. Such natural hazards account for 10-35% of all delays or service interruptions to electricity, road and rail infrastructure (IPCC 2001; IPCC 2014; Committee on Climate Change 2014; DfT Transport Resilience Review 2014). The Intergovernmental Panel on Climate Change (IPCC) has predicted increasingly dramatic weather changes in the future, which highlights the need for infrastructure to be designed and maintained keeping future climate variations in mind.

The UK's national infrastructure assets generally have long operational lifetimes and much of the UK's existing infrastructure was originally built in the 19th century (DEFRA 2011). The national infrastructure has been recently assessed in The State of National Infrastructure Report (ICE 2014), and most infrastructure was found to be 'in need of attention' or 'at risk'. Only strategic transport (e.g. rail) and water infrastructure were considered to be 'adequate for now' and no major infrastructure category was graded as 'fit for the future'.

Anticipated or unanticipated user driven changes to the loading of infrastructure and infrastructure systems are also expected to occur over long infrastructure life cycles, necessitating significant modifications to assets. Typical examples include the conversion of residential buildings to office space, addition of lanes to a motorway or addition of a runway to an airport due to increase in commuters. The consequences of such disruptions and changing requirements are significant over long infrastructure life cycles.

HM Treasury has recently identified planned investment needs in excess of £375 billion to replace ageing assets and those assets that don't comply with EU regulations, to help meet policy commitments e.g. climate change targets, support economic growth and to meet the future needs of a growing population (House of Commons 2014; Waller 2014). In order to achieve the investment goals, national infrastructure plan was first published in 2010 and is regularly updated every year since then (HM Treasury 2014; Waller 2014; HM Treasury 2013; HM Treasury 2010).

The aim of this paper is to discuss the 'what, why and how' of infrastructure futureproofing. The issues explored include bouncing back to the original functionality of an infrastructure system following exposure to a major environmental event e.g. UK national rail network following heavy flooding, wind storm or snow events. Other issues are related to change management due to anticipated or unanticipated changes in the infrastructure or its systems in future e.g. a capacity upgrade of an underground train station.

To begin, this paper presents an overview of infrastructure futureproofing and the need to consider the futureproofing of infrastructure assets. Following this, the paper covers general issues and views on how to futureproof infrastructure; some futureproofing strategies currently in use in the infrastructure sector, and their implications. A framework is proposed for assessing the futureproofing requirements of infrastructure, including a set of criteria for futureproofing assessment. The framework is supported by examples from two case studies. Key barriers to infrastructure futureproofing are presented. Finally, the ISO 55001 Asset Management standard is examined to highlight the interplay between futureproofing and infrastructure asset management, and the value of futureproofing over the life cycle of an asset is discussed. In addressing these key questions, the paper aims to clarify the role of futureproofing in the management of key infrastructure.

2. What is infrastructure futureproofing?

Futureproofing is the process of anticipating future events, changes, needs or uses in order to prepare appropriately, minimise impact and capitalise on opportunities (Atkins, UCL and DFID 2012). Other related terms used in the context of futureproofing are *obsolescence management* (Romero Rojo 2011), *reconfigurability* (Koren et al 2013) and *digital preservation* (CCSDS 2012; Barbau et al 2014)). The term 'futureproofing' has also been used for long-term business continuity (ISO 22301 2012) and long-term information continuity (Masood et al 2013).

We define infrastructure futureproofing as *"the process of making provision for future developments, needs or events that impact on particular infrastructure through its current planning, design, construction or asset management processes"* (Masood et al 2014). Here asset management processes also include operation and maintenance processes. Shetty (2014) defined futureproofing in an asset management context as "the process of anticipating the distant future and taking actions to minimise risks and maximise opportunities for value realisation from assets".

As discussed earlier, there are generally two major dimensions of infrastructure futureproofing: (1) infrastructural resilience - resilience to unexpected / uncontrollable events and circumstances; and (2) change management capability - capability to adapt or respond to changing needs, uses or capacities.

Infrastructural Resilience: In simple terms, this property refers to the ability of the infrastructure to maintain/resume normal operations during/ after an adverse event. This might include ability to withstand climate change variations, flooding events or even terrorist actions. This addresses sustainable asset longevity and asset management for future revenue, i.e. developing resilience to emerging risks and liabilities as well as resilience against disruptions.

Adaptability and Change Management Capability: Flexibility to adapt to an unexpected future means changing the way we build by allowing for future growth and capacity requirements (considering dimensions of capacity, suitability, usability and desirability that contributes towards achieving futureproofing). This also means building or managing a business to avoid / reduce impact of future change events, and taking account of future drivers (climate, carbon, resources, and population) in decision making in advance. Examples of futureproofing in this context include a capacity upgrade of an underground train station, easier reuse of substructure elements and buried structures, and allowing infrastructure life to be extended through capacity changes such as adding extra lanes to a bridge or building more floors on an existing building.

These definitions of infrastructure futureproofing are applicable to a wide scope of infrastructure including transport, energy, water and communication. However, because of the nature of the organisations engaged in this study, this paper is more focussed on transport infrastructure [rail, road and highway networks including structures e.g. bridges and tunnels; mass transit systems; railways; airports, etc].

3. Why consider futureproofing of infrastructure?

It is a significant commitment to consider futureproofing and take appropriate actions which increase the level of futureproofing of key infrastructure. The aim of this section is to provide the motivations for considering futureproofing of infrastructure in the UK by providing an overview of three key issues faced:

- (i) Ageing infrastructure and long operational lifetimes
- (ii) Extreme weather events
- (iii) Capacity enhancements and changing uses of key infrastructure.

These issues capture some of the evolving debates around the need for anticipating and managing future scenarios for critical infrastructure carefully and thoroughly. In resolving these key issues, it also needs to make economic sense to do so by measuring and quantifying value of potential disruption to a company's operation. We will now explore each of these issues in detail.

i) Ageing infrastructure and long operational lifetimes

The UK national infrastructure assets are old and generally have *long operational lifetimes*. Majority of the UK's existing infrastructure was originally built in the 19th century e.g. London's sewerage system and the Royal Albert Bridge over the River Tamar (DEFRA 2011). The national infrastructure has been recently assessed on A (Fit for future) – E (Unfit for future) grades in The State of National Infrastructure Report (ICE 2014). Local transport infrastructure (e.g. roads) is identified as being in the worst condition (Grade D – At Risk) followed by waste, flood management and energy infrastructure (Grade C – Requires Attention) and strategic transport (e.g. rail) and water infrastructure with Grade B – Adequate for Now (ICE 2014). No

infrastructure category was given Grade A – Fit for the Future, and futureproofing was highlighted as a key concern.

(ii) Extreme weather events

There is an increasing trend of extreme weather events that suggest that key national infrastructure needs to be maintained for long term with *future climate changes* in mind (IPCC 2001; IPCC 2014; Royal Academy of Engineering 2011).

Recently in the UK there has been an increase *in disruptive extreme weather events* e.g. floods and storms. During 2009-2014, severe flooding in the UK caused a number of road bridges to collapse as well as disrupting the airports, road, and rail infrastructure (DfT 2014a; HM Government 2011). Well over a thousand major roads and another over a thousand railway assets are located in areas of significant chance of flood risk (Environment Agency 2009) (see Figure 1).

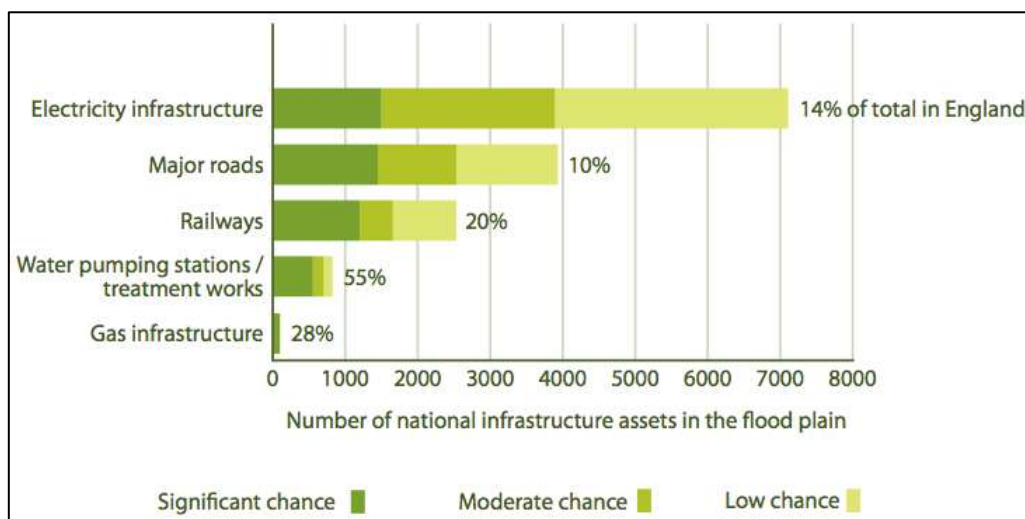


Figure 1: National transport and utilities infrastructure assets in flood risk areas (Environment Agency 2009)

These challenges are increasingly being recognised by transport providers.

Network Rail and the rail industry are keen to learn how climate change will affect their ability to achieve and deliver a safe railway, a highly reliable railway, increased capacity and value for money (Network Rail 2010; DfT 2014a). Incremental changes in the climate as well as increased frequency of extreme weather events will impact on the rail system (i.e. traction, services, subsystems covering track, rolling stock, stations, depots, structures, electrification and signalling and other train control systems) (Network Rail 2010; DfT 2014a). Network Rail's Tomorrow's Railway and Climate Change Adaptation (TRaCCA) programme has identified *heating and floods related impacts on safety, performance and likely negative impact from climate change* (Network Rail 2010; Dora 2014; Avery 2014).

Similarly, London's transport network has a number of areas that have the potential to be affected by weather related events e.g. flooding, overheating, low temperatures and snow (TfL 2011). Transport for London (TfL) has conducted Business Climate Change Risk Assessment exercise in 2011, based on the UK Climate Projections 2009 (TfL 2011). The results suggest that there are many weather-related risks that fall under medium to very high impact but very low likelihood. TfL's Climate Change Risk Maps for London Underground, London Rail, Surface Transport and Crossrail are included in Appendix A (TfL 2011). Crossrail has also identified key *climate change impacts* as increased flooding (fluvial, tidal and pluvial or surface water), high temperatures (extreme weather events) and increased water scarcity (TfL 2011; Paris 2011).

(iii) Capacity enhancements and changing uses of key infrastructure

Problems at Heathrow due to winter snowstorms during winter 2010/11 were compounded by the lack of spare or contingency capacity at the airport as it already operated to its maximum every day (UK Parliament 2011). Now expansion of Heathrow, through reconfiguring its terminals, is being planned. A number of capacity upgrade projects are being undertaken for underground stations in London e.g. Bond Street, Tottenham Court Road, and Bank/Monument underground stations (worth hundreds of millions of pounds) (Transport for London 2015). London's rail capacity is also being enhanced by building Crossrail (Europe's largest infrastructure project worth £14.8 billion) (Crossrail 2015). Widening of M25 will also help cope with increasing capacity requirements of road transport infrastructure in future.

Land use changes and user driven future changes to infrastructure and infrastructure systems also need to be considered. Examples include Canary Wharf redevelopment, changing modes of use of buildings e.g. warehouse to residential conversion or change of a residential block into an office building. The consequences of such disruptions and changes over long infrastructure life cycles are potentially significant, leading to futureproofing considerations.

Wider social, economic and environmental benefits of futureproofing are particularly important for infrastructure with high vulnerability and lower capacity to respond to risks (Atkins, UCL and DFID 2012). Other reasons for futureproofing include risk reduction, and reduced effort in redesign, redevelopment, reconstruction or demolition with diminishing Govt. budgets, reduced life cycle costs, changes in legislation e.g. on carbon footprints and recognising opportunities for future exploitation.

4. How to futureproof infrastructure?

UK Government reports provide significant emerging evidence that consideration of the future needs of infrastructure is a responsible path to follow in the development and maintenance of infrastructure (RSSB 2011; DEFRA 2011; House of Commons 2014; HM Treasury 2014). The growing set of drivers for a more formal and considered approach to managing the future of critical infrastructure, naturally leads to the question of how infrastructure can be futureproofed. In this section, general issues and views on how to futureproof will be discussed. Then the requirement of a framework for considering infrastructure futureproofing will be discussed along with a set of criteria for futureproofing assessment.

4.1 Current approaches to futureproofing

Infrastructure asset systems are composed of various civil and non-civil components e.g. railway station buildings contain elevators. If one component of the system fails, it can potentially have an adverse impact on the operation of the whole infrastructure.

To a certain extent, companies already do futureproof, using a number of strategies for assessing and managing non-civil assets and systems across life cycle stages. These strategies are summarised in Figure 2 which represents the outputs from an industrial futureproofing workshop, literature and a series of industrial interviews in 2014 (see acknowledgements and appendix C for a list of companies involved). The x-axis shows design and management stages of non-civil assets, while y-axis shows whether the strategies (shown as oval shaped boxes) are used for asset level decisions or system level decisions. For example, obsolescence forecasting and management has been investigated primarily in aerospace and defence sectors due to their dealing with long life products and services (Romero Rojo 2011).

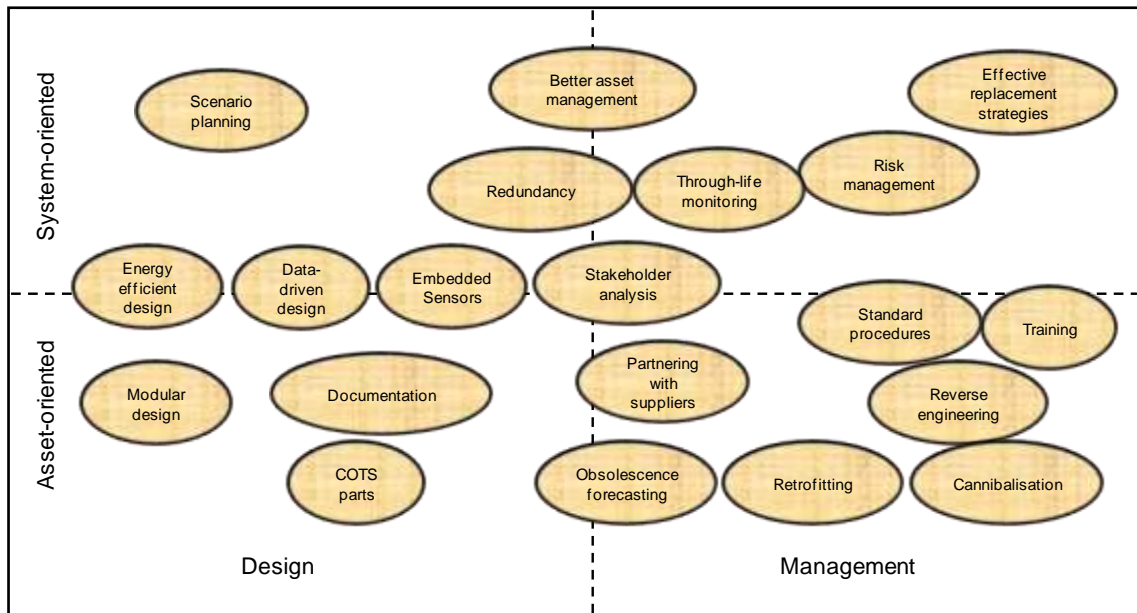


Figure 2: Futureproofing related strategies for industrial assets and systems

Futureproofing-related strategies relevant for civil infrastructural assets and systems partially overlap with those used for non-civil assets and systems. For example, Heathrow considers future issues while conducting its overall master planning exercises in following areas: runway capacity, stand capacity, terminal capacity, surface access and infrastructure like heating, cooling, power, aircraft fuel systems, drainage, communications and IT, and baggage (Ellis 2014). Some organisations carry out long term scenario planning and robust decision-making techniques while also considering strategic growth and resilience of the network capacity, security and climate change views e.g. Atkins' futureproofing cities project (Atkins, UCL and DFID 2012).

Other futureproofing related strategies used for infrastructure assets and systems include: improving decision support tools, developing strong governance processes, working with and influencing asset owners and policy makers on ensuring efficient planning and design of interconnected infrastructure assets, preparing climate change adaptation plans via conducting feasibility studies and investing in sustainability and energy monitoring capability enhancement.

However, it emerges from discussions with related organisations that there is a lack of a structured, common approach for considering the changing future needs of infrastructure as part of its asset management plans. Current approaches miss the opportunity to consider and assess infrastructure futureproofing at a system level (McBain 2014; Dora 2014). Typically structural or mechanical assets fail in unexpected ways due to wear, fatigue cracking, damage and corrosion (Romero Rojo 2009; Howard 2002). However, this may also be partly due to a lack of futureproofing criteria and a lack of systematic consideration of future infrastructure scenarios during earlier life cycle stages e.g. planning and design.

4.2 Requirements for a structured framework for considering infrastructure futureproofing

In this section we identify requirements for a systematic approach to infrastructure futureproofing. Based on the outputs of a series of workshops relating to infrastructure futureproofing and a literature gap analysis, it has been identified that a structured framework is required for identifying futureproofing considerations and embedding them into infrastructural management practices. It is proposed that as a minimum the following should be considered while developing an infrastructure futureproofing framework:

1. Conduct requirements analysis
2. Analyse current infrastructure management practice
3. Identify and analyse futureproofing considerations
4. Identify and analyse futureproofing strategies
5. Develop a model for futureproofing-considered infrastructure management

These elements represent a potential pathway to establishing future consideration as part of an overall infrastructure asset management plan (see Figure 3).

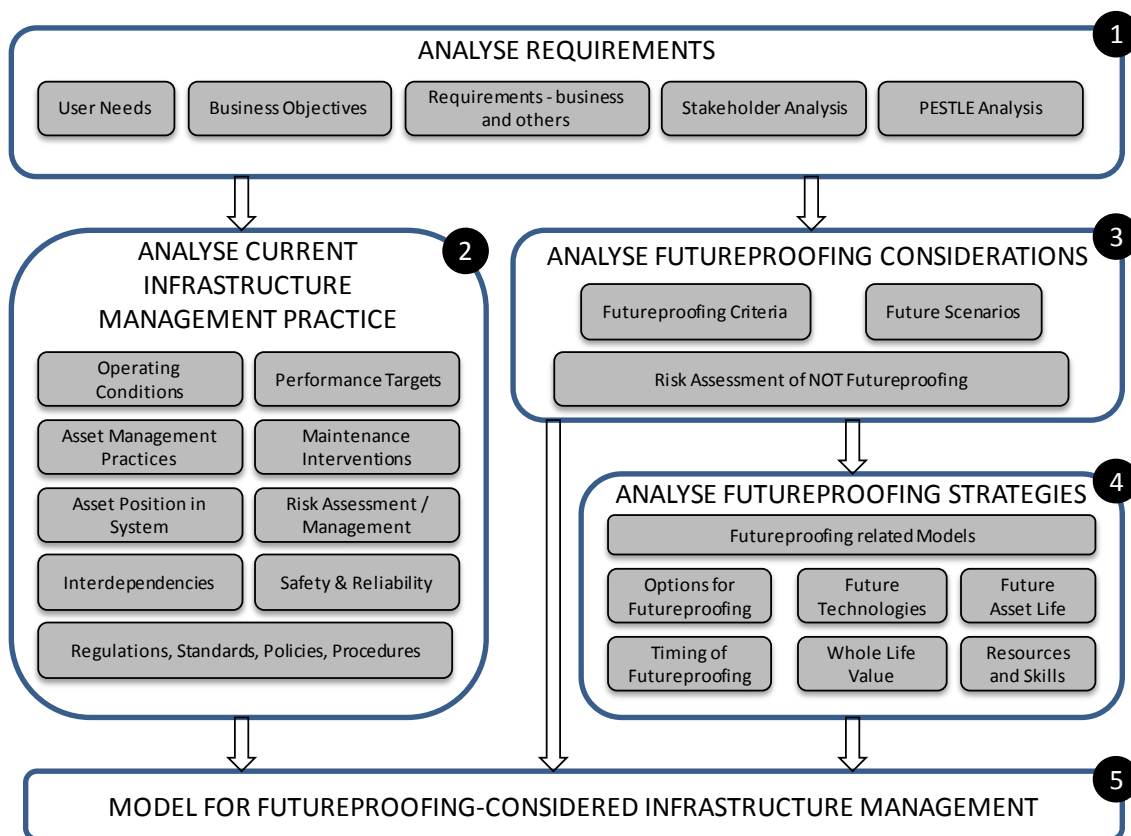


Figure 3: A framework for futureproofing of infrastructure portfolio

For each of the elements of the framework proposed in Figure 3, we will now identify key issues and conclude by identifying key steps remaining to consolidate these requirements into a useable framework.

To illustrate the approach being proposed, two case studies will be used to exemplify the framework where appropriate: Dawlish Railway and Heathrow Airport (see Appendix B for figures related to the case studies). These cases have been selected because of the very different future challenges they face. In the case of Dawlish railway, the key issue is the need for resilience in the face of environmental events, while Heathrow's challenges are more concerned with the rapidly changing needs of its customers and the growth of the industry generally.

Box DR-0 Futureproofing the Dawlish Railway - Introduction

This case study provides an elementary example of what might constitute a starting point for futureproofing the Dawlish railway, using the futureproofing criteria to be detailed later in this section.

Network Rail's four mile long Dawlish sea wall is actually a series of wall sections of different construction forms, running from Teignmouth through Dawlish to Langstone Rock at the western tip of Dawlish Warren (see Appendix B, Figure B1-1). Along this stretch parts of the walls are separated by tunnels. The walls have been maintained on a basically reactive basis for at least the past 30 years with the only recent investment in the early 2000s being around £10M spent on forming a concrete toe along the base of the wall, which has served to increase the wall's resistance to undermining. It has suffered from major failures in the past but none as serious as around 80 metres breach on the 4th February 2014 due to wind and sea's high tide washing away ballast and the foundations on which the track is built (see Appendix B, Figure B1-2) (Department for Transport 2014a).

Taking about eight weeks to repair and accompanied by numerous other failures, damage to the station at Dawlish and serious geotechnical failure of the cliffs above the line near Teignmouth, and the storms over the winter of 2013/14 have brought into question the future of the sea wall and the resilience of this portion of the Great Western Main Line that serves much of Devon and is the only line connecting Cornwall with the rest of the country. These require spending roundly £600K pa maintaining Network rail-owned sea and estuary walls between Exeter, Newton Abbot, and Exmouth (Network Rail 2014b).

Box HA-0 Futureproofing the Heathrow Airport - Introduction

Future proofing at the Heathrow airport (see Appendix B, Figure B2) needs to consider a wide range of variables that will, or might change in the future. Political, economic, environmental,

technological factors all need to be factored into decisions about how to futureproof the on-going development of the airport.

4.2.1 Conduct requirements analysis

Initially, a detailed (future) requirements analysis is needed. During this stage, user needs and requirements (business and external) are identified alongside conducting PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis and stakeholder analysis (e.g. UK Government, Regulators, Public, Investors, Media and Legal bodies).

Box DR-1 Dawlish Railway - Conducting requirements analysis

The requirement to provide a service connecting Exeter with stations between Exeter and Newton Abbot is enshrined in the First Great Western franchise and Network Rail's operating licence, all set out by the Office of Rail Regulation and the Department for Transport via the Railways Act provisions (Network Rail 2009). These provisions are reviewed and confirmed within the five-year regulatory cycle (Department for Transport 2014b).

As such it could be said that there are no long-term strategic drivers for the continued provision of services or sea wall integrity at this part of the Great Western Main Line.

RSSB (2008) showed how climate-change induced sea level rise and increased storminess will impact the Dawlish Railway (see Appendix B for an introduction to Dawlish Railway Case Study). Dawson (2012) reinforced this by examining disruptions, damages, repairs and wider economic consequences for the south west (see Appendix B, Figure B1-3).

Box HA-1 Heathrow Airport – Conducting requirements analysis

The development of utilities infrastructure at the airport requires Heathrow to think about the long term plan and growth of the airport and futureproof to ensure the infrastructure will meet those requirements. An example of this is the management of the airport's high voltage electrical network where there is a long term plan to create a network that offers both improved resilience and increased capacity. This is then being built incrementally as the need for additional electrical demand arises or when there is a need to undertake work on the network in a particular area. Without the future proofing plan the network would be developed in a way that would be unsustainable, with individual projects simply installing infrastructure to meet their needs to reduce cost but not in a way that enables ongoing improvement.

4.2.2 Analyse current infrastructure management practice

In order to understand futureproofing problem of an infrastructure, it is important to analyse the current infrastructure management practice (in other words the ability of an infrastructure to respond to the present day let alone future requirements) e.g. the current operating conditions, current performance targets, current asset management practice, asset position in system,

interdependencies, regulations, standards, policies and procedures, safety and reliability, risk assessment, and maintenance interventions..

If a particular infrastructure community has issued a sector-specific or a group-of-infrastructure level guidance, those would be useful at this stage.

Box DR-2 Dawlish Railway – Analyse current infrastructure management practice

Network Rail traditionally maintains its sea defences in Devon on a rolling programme of masonry repainting and a ‘find and fix’ policy where minor defects are repaired before they become hazardous. Whilst the sea wall complex in itself affords protection to the railway, prevents erosion of the soft sandstone cliffs and protects Dawlish town from the full force of the sea, it is not particularly effective at resisting wave overtopping onto the railway tracks or onto trains; after a 2008 study by RSSB into climate change impacts Network Rail planned to design replacement infrastructure for the railway during CP5 (2014 – 2019) with a construction planned for CP6 (2019 – 2024) (RSSB 2008) (Network Rail 2014b).

The RSSB study determined that in the baseline year (2006) the line would be affected by climate change related closures on a 1 in 5 year basis. By the 2080s this would become 1 in 1 year probability (RSSB 2008).

Box HA-2 Heathrow Airport – Analyse current infrastructure management practice

Heathrow has carbon reduction targets and is regularly reviewing ways to minimise its environmental impact. The way Heathrow has chosen to heat and cool their buildings using a district heating and cooling approach with networks fed by centralised boilers or chillers as opposed to individual buildings having their own heating and cooling plant allows Heathrow to plug in alternative greener energy sources and helps future proof opportunities to introduce alternative energy sources more simply.

In terms of economic factors, one of the most significant is trying to future proof against changes in airline ownership e.g. purchase of British Midland by British Airways in 2012. Changes in ownership are far easier to accommodate when operating from large terminal buildings that host a larger number of airlines hence the gradual move to an airport operating with fewer larger terminals.

4.2.3 Identify and analyse futureproofing considerations

It is crucial to identify a number of considerations for infrastructure futureproofing. This can range from possible future scenarios, a set of futureproofing criteria, and risk assessment of NOT futureproofing.

4.2.3.1 Identify and analyse future scenarios of possible disruptions in infrastructure management

Infrastructure operating environments are subject to a range of potential future changes. A number of events might occur in future, therefore it is important to identify possible event scenarios e.g. flood, snow, and wind. Potential usage changes / upgrades also need to be considered early on. Evaluating possible future scenarios in advance will help asset owners to make informed decisions to prepare the infrastructure to cope with disruptions and impacts of future events and changes.

Box DR-3 Dawlish Railway – Identify and analyse future scenarios of possible disruptions in infrastructure management

The future operating environment through climate change was shown to be disruptive to the economy of the south west and for rail operations generally; delays and closures south of Exeter can have impacts across the network. Annual closures and frequent speed restrictions and single-line working procedures would mean an unacceptable level of resilience for the Dawlish railway.

This knowledge of possible future scenarios does help to prepare the owners, operators and Government for likely decisions to futureproof this important part of the railway system. Dawson (2012) has shown a relationship between sea-level change and maintenance activity along the sea defences on the London – Penzance railway line (see Appendix B, Figure B1-4).

Box HA-3 Heathrow Airport – Identify and analyse future scenarios of possible disruptions in infrastructure management

The predictions for how the climate will change have led to Heathrow changing their asset design standards for building services and drainage to reflect predicted increases in temperature and increases in rainfall. New facilities are designed in accordance with the new standards and existing facilities have been reviewed so that they understand where the operation might be at risk.

4.2.3.2 Identify and contextualise futureproofing criteria

It is crucial to understand and assess the fitness for the future of the infrastructure based upon the current infrastructure state, future scenarios (e.g. in the light of environmental change, future events or usage change), performance targets and a set of robust futureproofing criteria. This is in line with identifying and assessing specific risks as well as impacts of NOT futureproofing a particular infrastructure. This will help in identifying gaps and taking further actions to enable futureproofing of infrastructure as well as developing and analysing future business cases.

A set of futureproofing criteria is proposed in the following.

- **(C1) Resilience** is the ability to withstand shocks and recover quickly. The UK Government's approach to building infrastructure resilience is based on its definition as "the ability of assets and networks to anticipate, absorb, adapt to and recover from disruption", where resilience is secured through a combination of principal components i.e. resistance, reliability, redundancy and response & recovery (Cabinet Office 2013a; Cabinet Office 2013b; Cabinet Office 2013c; Cabinet Office 2011).
- **(C2) Adaptability** is the ability of infrastructure to readily adapt or reconfigure if understanding of risks or requirements change over time. Adaptability is often defined as having different dimensions: extension, internal, use, planning (Cowee and Schwehr 2012).
- **(C3) Replace ability** is the ability to be replaced during or at the end of infrastructure life or use, assuming the infrastructure has a finite life.
- **(C4) Reusability** is the ability of the infrastructure to be reused or extended at the end of its life.
- **(C5) System stability** is the ability of infrastructure assets to work for an overall balanced or positive effect, ensuring stability of a system or systems during or after future change(s). This could also mean that systems should work with rather against natural processes (McBain 2014).

Information futureproofing is very important for decision makers, for a 'system of systems' view, for future owners, operators, the environment and society. Hence, it is important to identify through-life information requirements at earlier life cycle stages of infrastructure and ensure availability of information at all stages by planning and taking appropriate actions for its collection, retention and reuse in long term (Masood et al 2013). The principles outlined here deserve a lot more emphasis due to their importance, however are not included in detail as this paper is focussed on futureproofing of physical infrastructure. Masood et al (2013) may be referred for further details on information futureproofing.

To successfully incorporate futureproofing into asset management processes, organisations would need to consider the above elements in their strategies to plan, design, construct, maintain and retire infrastructure. Organisations need to interpret these guiding criteria for a particular infrastructure, assess the current state and then work to achieve required futureproofing goals. The key criteria for futureproofing were allocated weightings during one of the project workshops, where the participants from 17 companies prioritised the criteria in terms of relevance to futureproofing in their organisations. The polling results are presented in Figure 4.

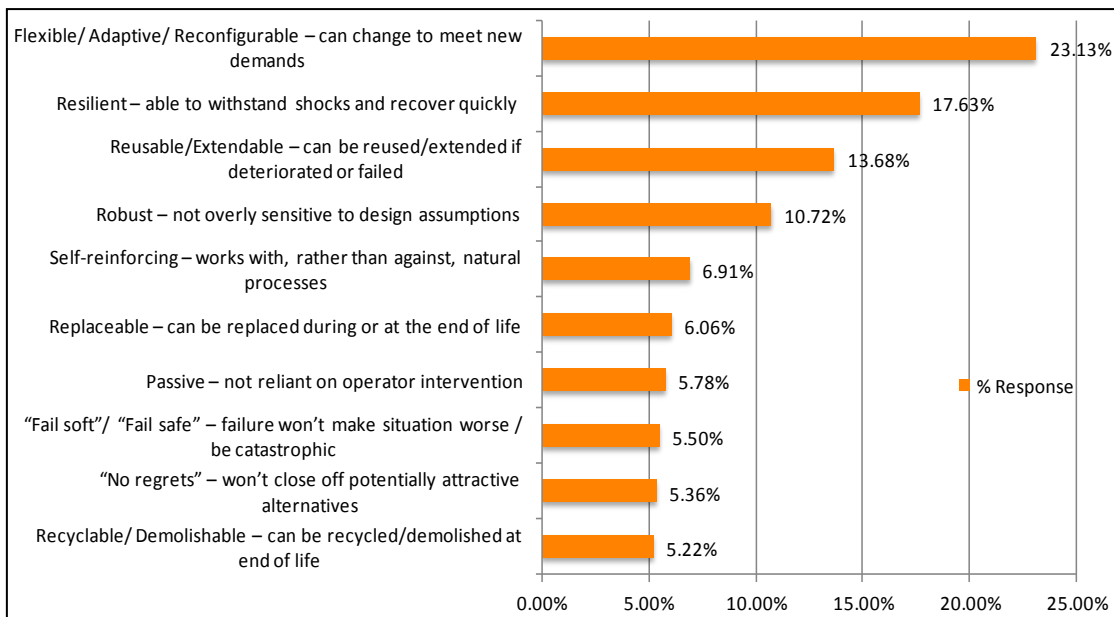


Figure 4: Infrastructure futureproofing criteria – responses of futureproofing project workshop participants

The order of futureproofing criteria elements presented in Figure 4 may change from organisation to organisation. This would serve as a guide as to where it is important for an organisation to focus attention.

Once futureproofing criteria are contextualised according to a specific infrastructure, various possible future scenarios for the infrastructure are assessed against the futureproofing criteria, prior to consideration of appropriate futureproofing strategies.

4.2.4 Identify and analyse futureproofing strategies

It is vital to identify and analyse potential futureproofing strategies, changes in future technologies, options and best timing of futureproofing. Following questions will help in identifying and analysing futureproofing strategies:

- What futureproofing models and strategies are relevant for an infrastructure?
- What are the options for futureproofing?
- What future technologies are relevant and going to impact on an infrastructure?
- Why invest in such technologies?
- How can such technologies be used in futureproofing the infrastructure?
- How are asset lives being affected?
- What is the best timing for futureproofing?
- What is the whole life value in futureproofing?
- Would the organisation have right resources and skills in place when futureproofing actions are required?

Box DR-4 Dawlish Railway – Identify and analyse futureproofing strategies

Dawlish Railway had to undertake an extensive work over the last year to restore the south west's rail connection and make the line more resilient for the future. This was accomplished by following (Network Rail 2014a):

- Cliff stabilisation work between Teignmouth and Dawlish;
- Fully restoring signalling and electronic equipment; and
- Restoring and improving the public footpath on the sea wall to enable residents to use it at high tide, which was not possible before.

This work was in response to the severe damage caused by very strong winds and high seas, during February 2014, to the railway line that runs through Dawlish washing away a section of the sea wall, 80 metres of track, platforms at Dawlish station and sections of the coastal path.

Box HA-4 Heathrow Airport – Identify and analyse futureproofing strategies

Where Heathrow can anticipate that there will be changes in types of technology or changes in the amount of demand they can consider futureproofing for this. Two examples of this are firstly Heathrow's hold baggage screening systems, where it is known that the technology will continue to evolve and become more sophisticated, so Heathrow designs its baggage handling facilities with sufficient flexibility in terms of space, access, service capacity to allow upgrades of screening machines easily.

Secondly Heathrow recognised early on that the demand for wireless technology would increase dramatically and that this would impact both airport operational services and the quality of service for passengers if allowed to develop without strict controls. Futureproofing to ensure an efficient use of limited radio spectrum through the use of shared infrastructure for wireless systems such as phones and wireless devices ensures that the spectrum that is available at the airport is used most effectively by all.

Futureproofing at the airport is undertaken in number of ways, responding to diverse factors that shape how the airport will operate and be used by airlines and passengers in the future.

Based upon the foregoing steps, it is important to form a model for futureproofing-considered infrastructure management. This is discussed in the following.

4.2.5 Develop a model for futureproofing-considered infrastructure management

Based upon foregoing process of the futureproofing framework, a model for futureproofing-considered infrastructure management is developed (see Figure 5). Based upon previous steps of the futureproofing framework, assessment of infrastructure futureproofing is conducted via futureproofing criteria. The model reviews possible future scenarios against future proofing

criteria to see if they are adequate or need to be enhanced. This informs as well as helps improve the existing infrastructure management practices.

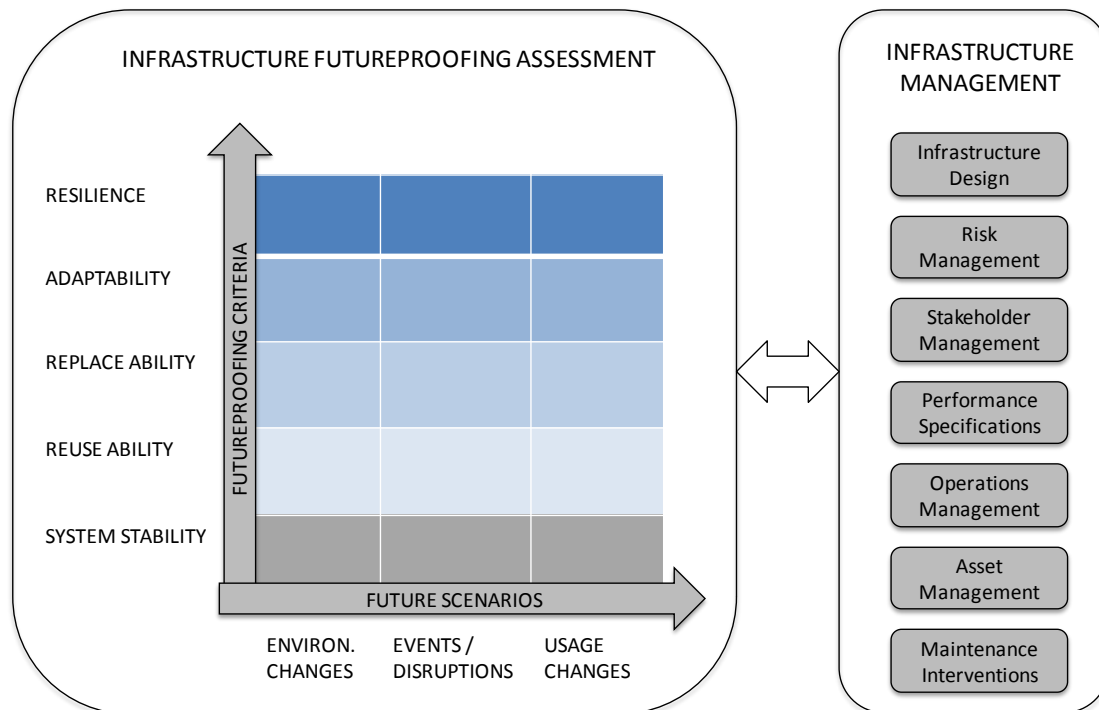


Figure 5: Model for futureproofing-considered infrastructure management

Some examples of what infrastructure futureproofing assessment vs. infrastructure management would contain are included in the following:

- To what extent is the underground railway infrastructure resilient in face of environment changes e.g. increasing heat on tracks?
- To what extent is the rail infrastructure resilient in face of disruptions due to e.g. flood, snow, wind, etc?
- To what extent are underground stations in London adaptable in the face of increasing usage demands?
- To what extent are current (sub) assets replace able in the face of (the pose of) significant failures necessitating such replacements.
- To what extent are piles reusable when converting a large residential building to an office block, in a congested place in London?
- To what extent other transport related systems are going to be affected if changes to underground station systems are made in response to increase in user demands?
- To what extent are current asset management practices applicable in the face of (the pose of) significant disruptions / future scenarios.
- To what extent are current performance targets for key infrastructure applicable in face of environment changes / future scenarios?

Box DR-5 Dawlish Railway – Model for futureproofing-considered infrastructure management

The following are the key criteria to form a model for futureproofing-considered infrastructure management in Dawlish Railway:

- *Resilience* - The Dawlish railway needs to withstand increased stormy weather and sea level rise to afford reliable railway traffic. The damage caused to the Dawlish Railway during February 2014 due to stormy weather and the extensive restoration work in response provides an example of the importance of building resilience in overall futureproofing of this railway section.
- *Adaptability* - If affordability is a concern, the sea wall complex could be rebuilt with a height commensurate with wave heights expected until say the 2050s, and then it could be raised higher. Passive provision could be made economically by constructing foundations large enough to accommodate a higher and / or wider wall.
- *Replace ability* - The wall could be constructed in a modular way allowing extension or replacement with less difficulty than its traditional, masonry construction currently allows. Indeed there is talk in the railway industry long term planning process of widening (triple- or quadruple-tracks) the railway – a modular approach could permit this to happen at a future date.
- *Reusability* - This is the ability of the infrastructure to be reused or extended if deteriorated or failed – again a modular approach can aid reusability.
- *System stability* - A rock-armour protection approach can help this but is likely to be unappealing to the local community wing to its harsh visual impact on an amenity coastline famous for its beaches.

Box HA-5 Heathrow Airport – Model for futureproofing-considered infrastructure management

Heathrow also considers that a model for futureproofing-considered infrastructure management should include key criteria elements of resilience, adaptability, replace ability, reuse ability and system stability. The changes in hold baggage system and wireless technology at the airport in advance provide examples of the role of key futureproofing criteria in Heathrow's model.

Another example is from Heathrow's long-term planning for new terminals incorporating a model that considers key futureproofing elements e.g. adaptability and resilience. How a new airport terminal could affect other transportation networks e.g. road and rail networks is also an important consideration to be made part of a model for futureproofing-considered infrastructure management of an airport organisation.

The model for futureproofing-considered infrastructure management can be further enhanced to map impacts of future scenarios and potential futureproofing strategies against performance, operations, asset management or maintenance of infrastructure assets.

Achieving aims and objectives set out in a futureproofing model for an infrastructure might be challenging due to a number of barriers, which are discussed in the following.

5. Barriers to infrastructure futureproofing

Figure 6 identifies a number of the key barriers to infrastructure futureproofing with key elements noted in each of the categories. These barriers were identified in workshops with futureproofing practitioners and asset managers (see appendix C for workshop details). In the figure the barriers have been categorised into key areas. Clearly if the economic value of futureproofing was clearer, other barriers would be reduced.

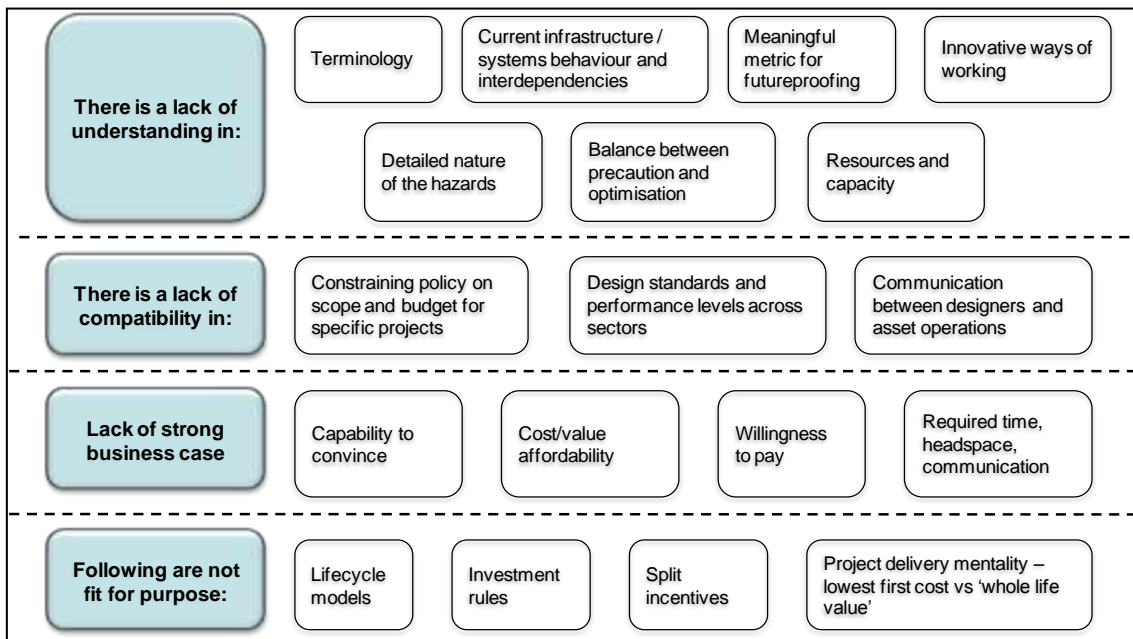


Figure 6: Key barriers to infrastructure futureproofing

The identified barriers to futureproofing highlight the need to take action in this regard. The key actions will be based around enhancing understanding of the concepts e.g. establishing a common terminology and meaningful metrics for futureproofing. Another action will be to enhance communication and introduce effective feedback loops between different stakeholders, for example feeding back knowledge from operators / maintainers to designers to inform futureproof design decisions. Stronger business cases for infrastructure futureproofing are also required. Steps need to be taken to align investment rules with whole life thinking as well as raising awareness levels across industry on futureproofing issues. These actions need to be taken with a shared responsibility amongst Government, Industry and other stakeholders.

An integrated approach to dealing with futureproofing considerations and asset management practice is vital for success. This is further discussed in the following.

6. Integrating futureproofing considerations with asset management practice

This section argues that futureproofing should be integrated with asset management practice to gain the most value. Treating futureproofing as a standalone requirement leads to marginalisation of the issue and ultimately to futureproofing becoming an add-on consideration. Hence, it is important that futureproofing concepts are aligned with asset management practice and standards. Here we identify some steps towards integrating futureproofing into a broader infrastructural asset management agenda.

The following actions will help in integrating futureproofing considerations with asset management practice:

- Addressing stakeholder requirements at an early stage
- Adopting standardised approaches to futureproofing
- Establishing and implementing criteria for futureproofing infrastructural assets across asset life cycle stages to help assess current state of futureproofing and take necessary actions to keep on futureproofing agenda.
- Planning for change earlier on, allowing for future growth across life cycle stages and managing change in operations to help in building resilience and adaptability.
- Keeping futureproofing goals at core of organizational policies, strategies, tactics and operations during whole life cycle of infrastructure.

The integration can also be supported by developing (non-prescriptive) standards, establishing benchmarks and codes of practice, understanding the value of doing futureproofing, defining / identifying impact [benefits for funding and costs for not funding]. Government input can be critical here, through legal and regulatory standards and guidance. Key stakeholders in this process include (but are not limited to) the public, asset owners/operators/maintainers, organisations e.g. utility companies, all industry bodies, interdependent / mutually benefited companies and Infrastructure UK.

There are synergies between futureproofing concepts and asset management standard, ISO 55001:2014 (ISO 2014). The following clauses of ISO 55001 can be extended to include requirements for futureproofing (Shetty 2014):

- *Clause 4.1* (Understanding the organization and its context) can include futureproofing requirements and futureproofing criteria.
- *Clause 4.2* (Understanding the needs and expectations of stakeholders) can also include futureproofing requirements and futureproofing criteria.
- *Clause 6.1* (Actions to address risks and opportunities) can include futureproofing requirements and long term risks and opportunities.

- *Clause 6.2* (Asset management objectives and plans to achieve them) can include futureproofing criteria and a model for futureproofing-considered infrastructure management.

Finally, when considering how futureproofing might be integrated into current asset management practices, it is worth noting that futureproofing will impact differently at different stages in an asset's lifecycle. The greatest value of futureproofing is created at earlier asset lifecycle stages, however that value is usually accrued at later stages in the asset's life. The following describes the value accrued at different asset lifecycle stages and the futureproofing actions which can be taken at each stage:

- *Requirements and plan* - can provide value in terms of greater certainty, answers to more questions, more long-term options, attractive financial proposition and greater rates of return. Actions can include defining asset life and specifying future requirements.
- *Design / Build / Install* - futureproofing provides negligible value gain at this stage in an asset's life cycle. However, actions taken at this stage can provide significant value later on. Actions include adding capacities, functionalities, and redundancies to assets; tailor designing, building and installing to asset life.
- *Operate* - can provide value in terms of reliable performance of infrastructure and cheaper infrastructure operations.
- *Maintain / Renew / Upgrade* - can provide value in terms of less reactive maintenance, safer planning and scheduling. Actions can incorporate predicting and preventing failures; predicting and proposing interventions.
- *Decommission/Reuse* - can provide greater residual value. Actions at this stage include improving ability to decommission safely and in an environmental friendly way; extracting or extending maximum effective life based on evidence.

Figure 7 provides a snapshot indicating how value of futureproofing accrues in the asset management life cycle (Source: futureproofing project workshops 2014).

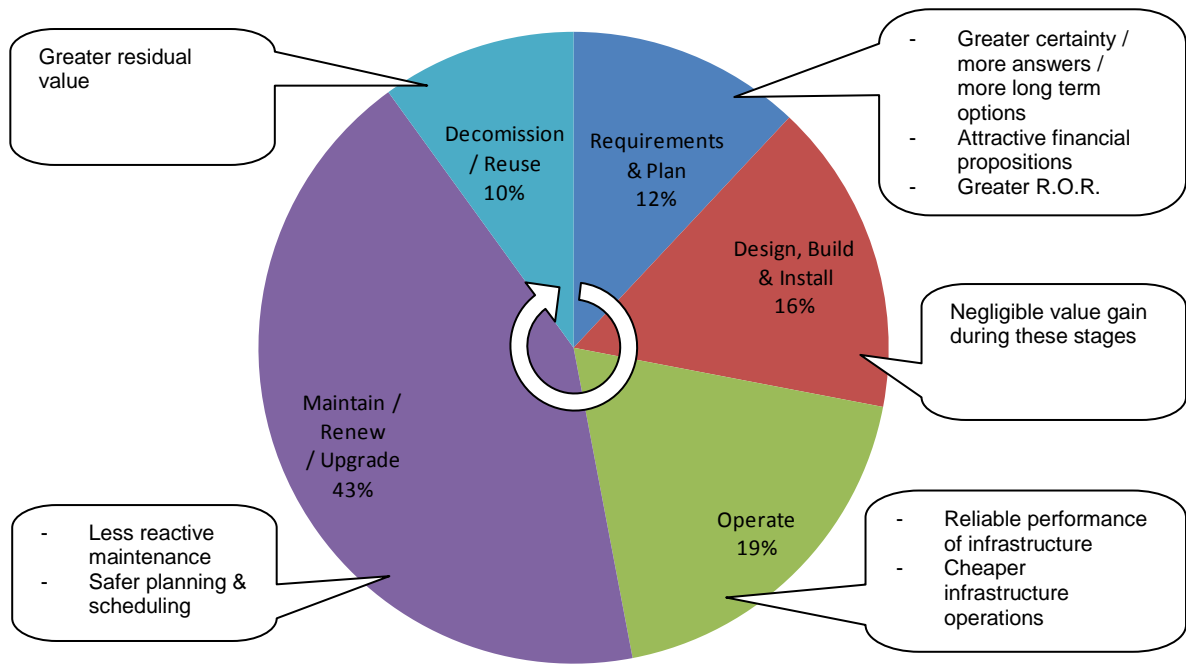


Figure 7: Accruing value of futureproofing in asset life cycle (based on polling results from one of the futureproofing project workshops 2014)

8. Conclusions

The paper has examined the issue of infrastructure futureproofing and associated concepts. It is noted that, to date, a meaningful criteria/metric for futureproofing has not been formally embedded into existing options appraisal and asset management processes. In this paper, infrastructure futureproofing criteria are proposed with key elements of resilience, adaptability, replace ability, reusability and system stability. It is envisaged that incorporating the proposed futureproofing criteria into asset management and other practices could lead to more resilient and adaptable infrastructure future.

It is also proposed in this paper that there is a requirement for a structured infrastructure futureproofing framework. The paper has proposed key stages and considerations for such a framework including key questions for developing a futureproofing framework are also presented along with case examples from Dawlish Railway and Heathrow Airport. Such a framework would be beneficial for planning and management of infrastructural assets in long-term.

Challenges related to futureproofing include recognizing increased levels of investment in economic infrastructure and demands for value for money, developing and delivering best practice and innovation, identifying appropriate time horizons, identifying key stakeholders and decision makers, balancing 'long term risks' against 'near term need', identifying sponsors, capacity building, and making a business case. The role of key stakeholders including

governments, regulators and standards organisations is vital in addressing most of the challenges and integrating futureproofing in asset management practices.

Based upon the polling results of industrial futureproofing workshops (see appendix C for workshop details), the paper also suggests that the most value of futureproofing is accrued in Maintain/Renew/Upgrade lifecycle stages of the infrastructure, while other lifecycle stages can support accrual of value during these stages.

It is recommended for future work to further test and demonstrate the infrastructure futureproofing criteria and framework in various industries with a particular focus on asset management integration. An actionable tool for considering infrastructure futureproofing is also required.

Acknowledgements

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Appendix A: Climate Change and Future of Infrastructure – A Review

Table A1: Estimates of confidence in observed and projected changes in extreme weather and climate events (IPCC 2001)

Confidence in observed changes (later half of the 20 th century)	Changes in Phenomenon	Confidence in projected changes (during the 21 st century)
Likely ¹	Higher maximum temperature and more hot days over nearly all land areas	Very Likely ¹
Very Likely ¹	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very Likely ¹
Very Likely ¹	Reduced diurnal temperature range over most land areas	Very Likely ¹
Likely ¹ , over many areas	Increase of heat index ² over land areas	Very Likely ¹ , over most areas
Likely ¹ , over many Northern Hemisphere mid- to high latitude areas	More intense precipitation events ³	Very Likely ¹ , over most areas
Likely ¹ , in a few areas	Increased summer continental drying and associated risk of drought	Likely ¹ , over most mid-latitude continental interiors. (Lack of consistent projections in other areas)
Not observed in the few analyses available	Increase in tropical cyclone peak wind intensities ⁴	Likely ¹ , over some areas
Insufficient data for assessment	Increase in tropical cyclone mean and peak precipitation intensities ⁴	Likely ¹ , over some areas

¹ In this Summary for Policymakers and in the Technical Summary, the following words have been used where appropriate to indicate judgmental estimates of confidence: virtually certain (greater than 99% chance that a result is true); very likely (90 – 99% chance); likely (66 – 90% chance); medium likelihood (33 – 66% chance); unlikely (10 – 33% chance); very unlikely (1 – 10% chance); exceptionally unlikely (less than 1% chance). The reader is referred to individual chapters for more details.

² Heat index: A combination of temperature and humidity that measures effects on human comfort.

³ For other areas, there are either insufficient data or conflicting analyses.

⁴ Past and future changes in tropical cyclone location and frequency are uncertain.

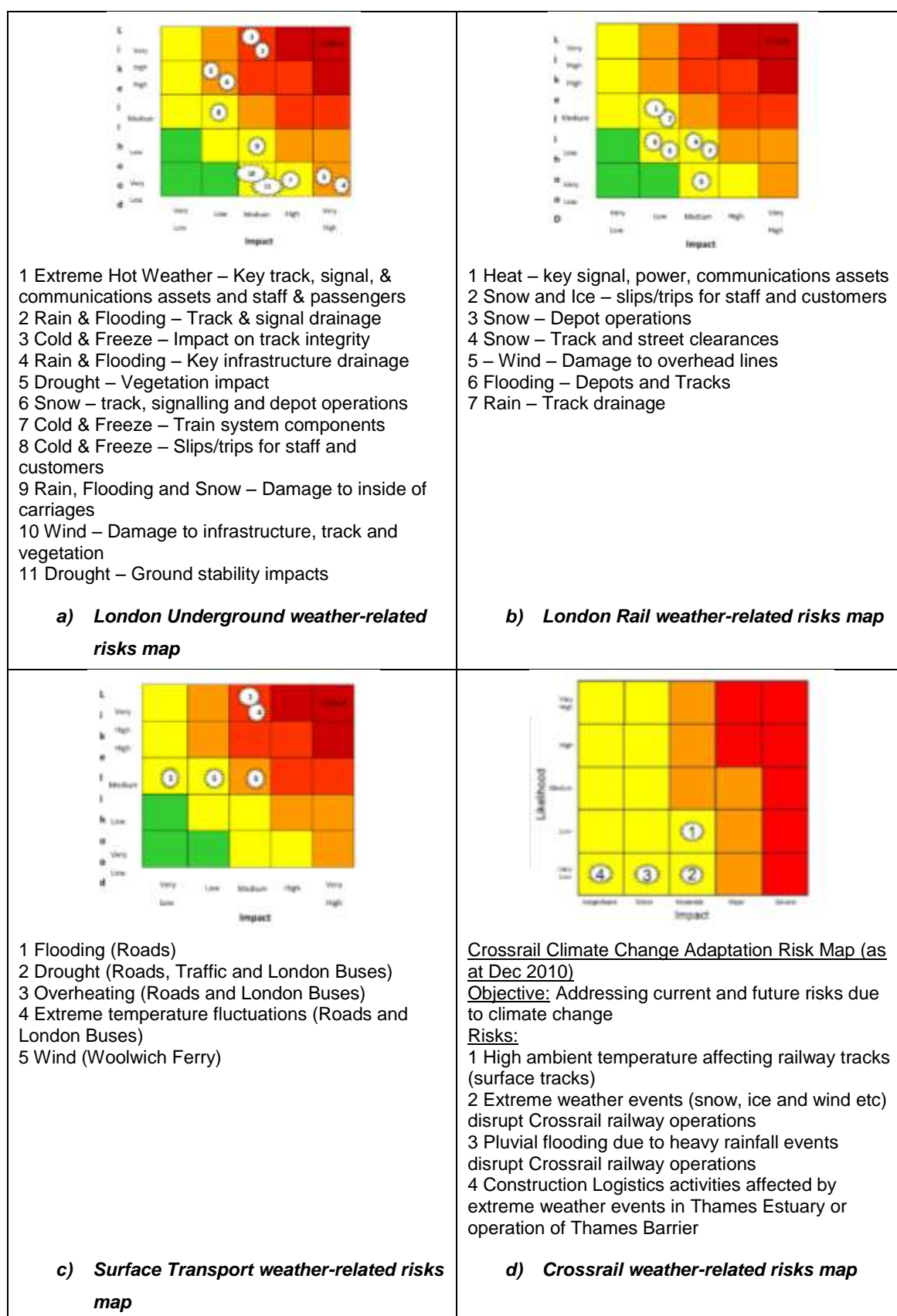


Figure A1: Transport for London Climate Change Risk Maps (TfL 2011)

Appendix B – Case Studies

B1 Dawlish Railway

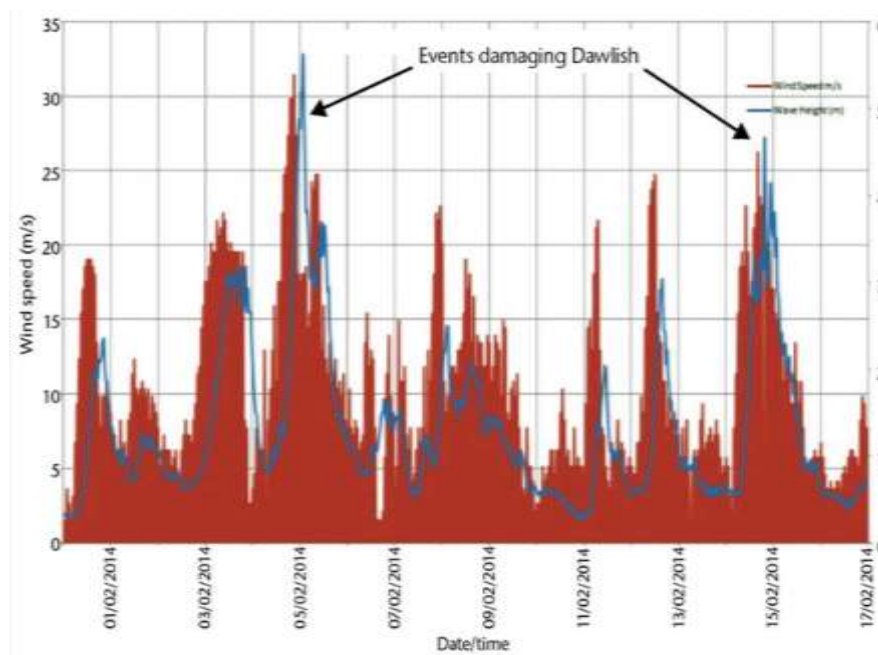


a) Map of Dawlish (Google)



b) Devastating effects of storm – 8 Feb 2014 (Network Rail 2014a)

Figure B1-1: Dawlish Railway



(This shows a comparison between the wave heights recorded at the Dawlish wave buoy against the wind speeds recorded at the Berry Head weather gauge from 31 January 2014 to 17 February 2014. Wind speed is in red, and wave height is the blue line. Berry Head is a headland approx. 10 miles south of Dawlish.)

Figure B1-2: Dawlish Railway - Wave buoy height vs Berry Head wind speed (Department for Transport 2014a)

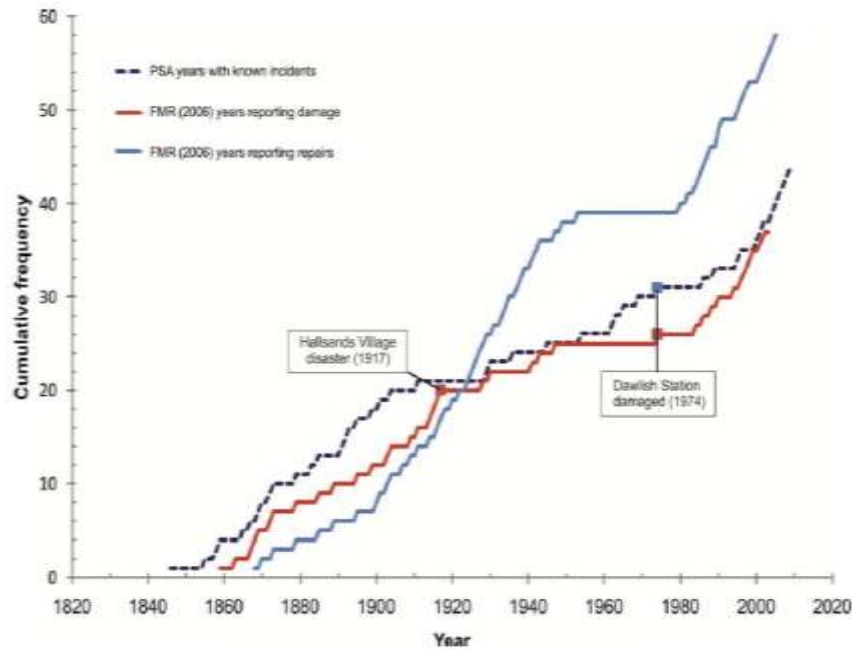


Figure B1-3: Cumulative records of annual disruption/damage/repairs on Dawlish railway line. Taken from Published Sources Archives, and the Frontage Management Records (Dawson 2012).

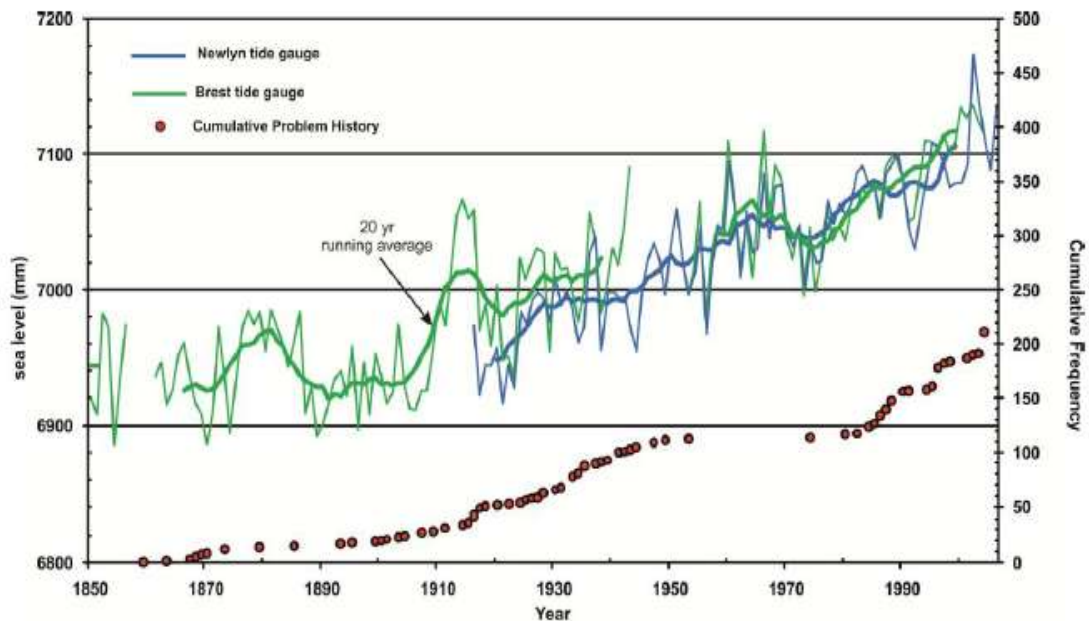


Figure B1-4: Relationship between sea-level change and maintenance activity along the sea defences on the London-Penzance railway line (Dawson 2012).

Periods of frequent repairs correspond with periods of accelerated sea-level rise. Annual tide-gauge data in mm, also showing are 20 year running averages from Newlyn 1916-2007 and Brest 1807-2007 (www.pol.ac.uk). Closed dots show cumulative problem history at Dawlish beginning in 1859 (Rogers and O'Breasail 2006).

B2 Heathrow Airport



a) Heathrow in 2002



b) Heathrow in Oct 2011



c) Heathrow 'Tomorrow' - 2 Runway Heathrow Master Plan

Figure B2: Heathrow (Ellis 2014)

Appendix C – Participants of CSIC Workshops on Infrastructure Futureproofing

1st CSIC Workshop on Infrastructure Futureproofing, held at Institute for Manufacturing, University of Cambridge, Cambridge on 23rd January 2014

Prof Duncan McFarlane*§ (Cambridge, CSIC), Will McBain* (Arup), Dr Kate Avery* (Network Rail), Andrew Ellis* (Heathrow), Jon May* (Lend Lease), Caroline Lowe (Network Rail), Heleni Pantelidou (Arup), John Dora (John Dora Consulting Ltd), Vlad Palan (Highways Agency), Polly Turton (Arup), Tom Lau (Lang O' Rourke), Dr Graham Herries (Lang O' Rourke), Dr Geoff Darch (ATKINS), Lola Vallejo (Committee on Climate Change), Dr Rachel Dick (IBM), Dr Jennifer Schooling§ (CSIC), Dr Tariq Masood§ (CSIC), Dr Raj Srinivasan (CSIC) and Dr Phil Catton (CSIC).

2nd CSIC Workshop on Infrastructure Futureproofing (Futureproofing in Asset Management), held at Institute for Manufacturing, University of Cambridge, Cambridge on 2nd April 2014

Prof Duncan McFarlane*§ (Cambridge, CSIC), John Dora* (John Dora Consulting), Andrew Ellis* (Heathrow), Keith Waller* (Infrastructure UK), Dr Navil Shetty* (Atkins), Dr Ajith Parlikad* (CSIC), Farid Achha (London Underground), Ross Agnew (Costain), Prof Tim Broyd (UCL, ICE), Ross Dentten (Crossrail), John Downes (London Underground), Dr Medina Jordan (Cementation Skanska), Ben Kidd (CIRIA), Tim Kersley (Network Rail), Heleni Pantelidou (Arup), Ben Sadka (Highways Agency), John Turpin (Halcrow/CH2M), Dr Rachel Dick (IBM), Prof Cam Middleton (CSIC), Dr Jennifer Schooling§ (CSIC), Dr Tariq Masood§ (CSIC), Dr Phil Catton (CSIC) and Dr Raj Srinivasan (CSIC).

The contributions of the delegates of both workshops as well as colleagues from CSIC via presentations and discussions are thankfully acknowledged.

* Speaker, § Workshop Organiser