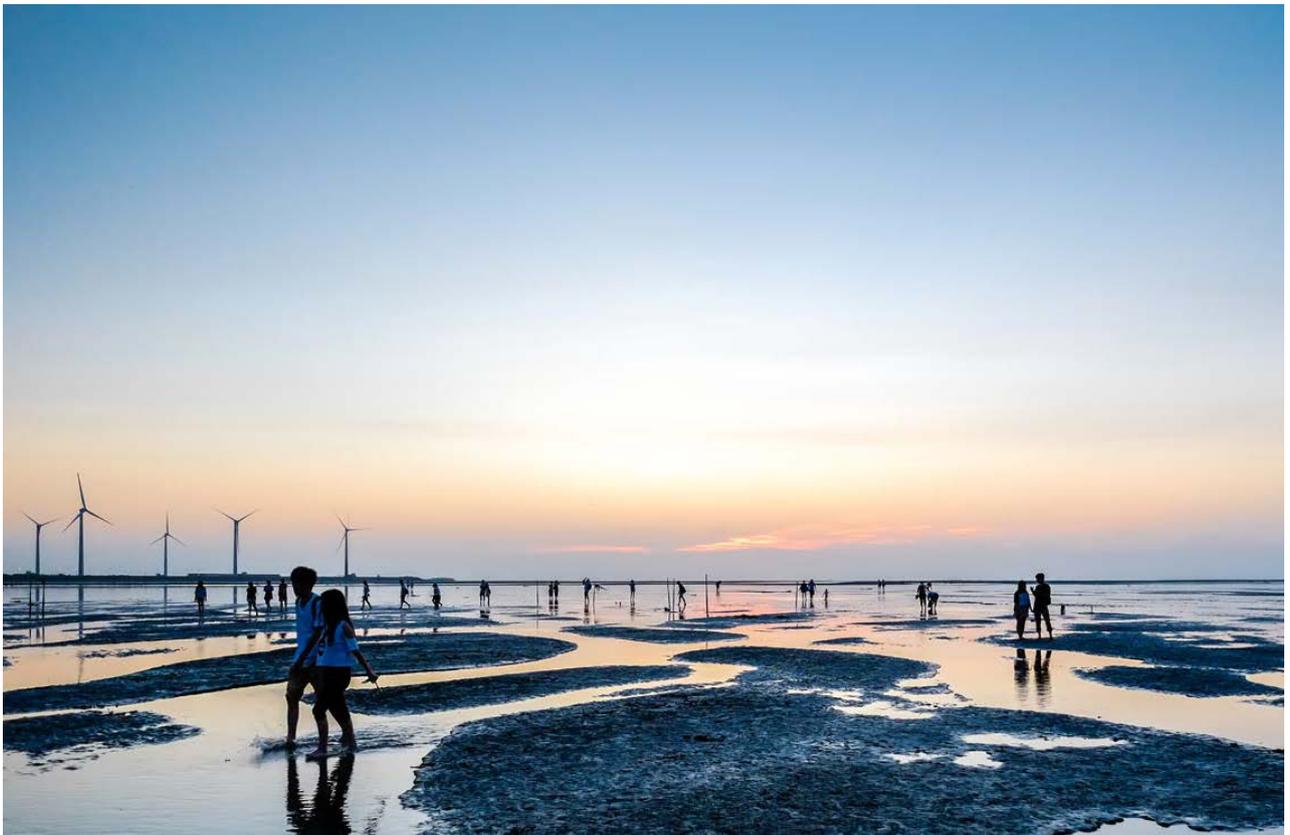


Resilient Foundation Through Systems Thinking

Agenda Setting Scoping Studies
Summary Report



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Introduction

Lloyds Register Foundation (LRF) has funded a Joint Programme for Resilience Engineering (JPRE) also known as “the Resilience Shift” which aims to improve resilience within and between critical infrastructure sectors globally. This is an opportunity to accelerate the Resilience Shift by promoting resilience engineering as a new approach that challenges old paradigms. The programme will contribute to influencing the education of engineers; creating change in practice through tools, technologies and piloting, as well as influencing standards and regulations; and catalysing a global network of resilience change leaders.

Context

The World is entering what has been termed a VUCA (Volatile, Uncertain, Complex and Ambiguous) future. There is a “perfect storm” of stress factors such as climate change, resource scarcity, wealth inequality, an ageing population, increasing non-communicable disease, housing shortages, congestion, poor air quality, the automation of more and more of the economy, but to name a few. Many of these stress factors increase the impact and frequency of shock incidents such as flooding or heatwaves or make the systems that support our way of life more susceptible to them.

This is happening at a time of continuing public-sector cuts, potentially reducing the capacity of the state to respond to shocks or adapt to meet the challenges posed by stresses. The UK has a finite budget to spend on National Infrastructure and the effectiveness of that spending directly impacts our nations productivity and therefore competitiveness. In light of Brexit, making sure we maximise our resource spend ensuring every pound delivers the maximum productivity gains in the long term is even more important and must be governments number one priority. It is not acceptable to invest our finite resources in large infrastructure projects that we know will not deliver the long-term benefits needed. The money could be much more effectively invested where there is a definite future need.

For many, resilience holds the key to meeting these challenges in the long term. Moving our society away from a reactive response focused strategy for these shock and stress factors and moving instead to a proactive, preventative strategy and through to a foresight model where resilience is seen as a means of exploiting opportunities in the future. Within risk management circles this is referred to the shift left, from response to prevention and then opportunity.

UK infrastructure

Within the UK government, infrastructure strategy is steered by the National Infrastructure Commission (NIC) and implementation is overseen by the Infrastructure and Projects Authority (IPA). The NIC has produced a National Infrastructure Delivery Plan (NIDP) which defines the priorities for investment over the next 5 years (2016-2021). Infrastructure here is split into two groups:

- Economic infrastructure

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- Transport – Road, rail, airports and ports
- Energy
- Communications – Mainly focussed on digital communications
- Flood & Coastal Erosion
- Science & Research
- Waste
- Water
- Social Infrastructure
 - Education – Schools
 - Health – Hospitals and laboratories
 - Justice - Prisons
 - Housing & Regeneration

The NIDP explicitly cites resilience in its Improving Delivery and Performance section. Therefore, in theory, resilience is being built in to any new infrastructure projects. Resilience is defined as “*the ability of infrastructure to withstand, prevent, adapt to or rapidly recover from disruptive challenges. This includes 4 characteristics to improving systemic resilience:*

- Resistance: preventing damage or disruption by strengthening or protecting assets, for example building flood defences to protect transport networks
- Reliability: designing assets to operate under a range of conditions, for example designing electrical cables to operate in extreme temperatures
- Redundancy: making backup installations or spare capacity available in networks and systems to enable operations to be switched or diverted, for example installing back-up data centres
- Response and recovery: understanding the weaknesses in networks and systems and have arrangements in place to respond quickly to restore services, for example ensuring an organisation is prepared to rapidly respond to disruptions”

The NIDP also highlights the fact that infrastructure projects may be interdependent, i.e. there could be “*mutual dependence between 2 or more assets or networks, which impacts their efficient and effective functioning.*”

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The same 4 approaches to improving systemic resilience are cited within the government's Sector Security and Resilience Plans. These set out the resilience of the UK's most important infrastructure to the relevant risks identified in the National Risk Assessment. The plans are produced annually and are placed before ministers to alert them to any perceived vulnerabilities, with a programme of measures to improve resilience where necessary. in keeping with legal and regulatory frameworks, industry standards, license agreements and business models.

Purpose

This study provides outline suggestions for a framework for developing resilience based requirements and management structures. This is based on current best practice in Systems Engineering, and applicable to a range of sectors and technologies.

A series of interviews were undertaken with stakeholders from various infrastructure organisations. From these interviews, common themes and perspectives were synthesised in order to provide a framework of metrics against which an individual organisations resilience performance could be assessed.

These infrastructure systems were also assessed against a proposed resilience based set of metrics to assess comparative performance. The learning from the interviews was also synthesised into a clear set of resilience principles useful for diagnosing resilience issues or pointing towards potential solutions. The final part was to devise a consistent and comprehensive framework for implementing this learning to all types of infrastructure.

Findings

Key findings included a lack of incentives for providers to work proactively with other providers and sectors; not incentives to deliver cross-sectoral resilience; a focus on response and recovery rather than proactive mitigation measures; current structure and fragmentation (particularly in power generation) means that resilience is not joined up (no golden thread). Additionally, the impact of disruption on the UK was not being measured (e.g. loss of productivity) – better understanding of losses assists with building a business case for investment. Additionally, a review of the National Risk Register identified a number of areas for improvement.

A new approach

Defining and measuring value

A resilient organisation has a clear vision that understands value, its dynamic nature and brings each part of the business together to sustainably and coherently create and protect that value within a disruptive and changing environment. Coupled to this, a resilient organisation is far sighted, coherent and has high adaptive capacity, allowing opportunities to be exploited and threats to be avoided.

The core value creation process runs through the centre of the model with strategic direction functions above and verification functions below.

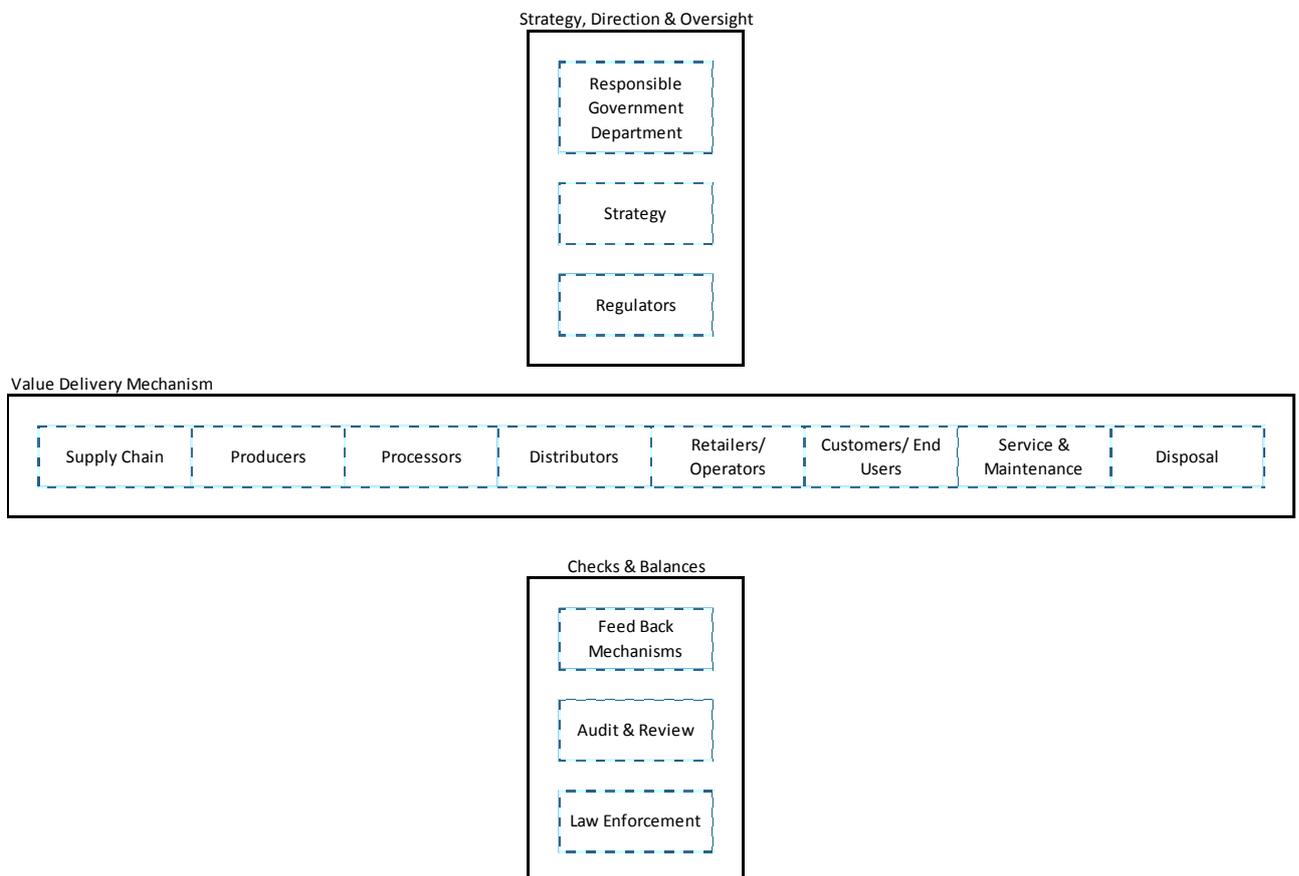


Figure 1 Generic Infrastructure Industry Structure

As *Figure 1* shows, each type of infrastructure has a responsible government department which is specific to the type of infrastructure and the main stakeholder groups concerned. There is usually a body responsible for the long-term strategy and governance of each infrastructure type. In most cases this is the National Infrastructure Commission and the Infrastructure & Projects Authority, with notable exceptions. Most infrastructure also has a regulator exercising autonomous authority to ensure competitiveness and fairness. All infrastructure has a core value chain through which services and supplies are delivered. In many areas, there has been significant integration of the value chain which can help or hinder overall resilience depending on how it is managed. All infrastructure types also have checks and balances such as law enforcement, complaints procedures and audit requirements. It is the function of strategic leadership to view infrastructure as a whole, understanding the inter-dependencies, this is why the work of the National Infrastructure Commission and Infrastructure & Projects Authority is so critical and must be consistent across all infrastructure and take into account a wide array of shock and stress factors.

This value can be seen as the golden thread that runs through a whole industry. Using this as a starting point, developing an understanding of complex systems was possible, as well as designing a targeted set of assessment metrics. Value is also the key to unlocking one of the most difficult resilience problems; what is a vulnerability and how do you prioritise vulnerabilities?

In **Figure 2** value has been defined in the following ways; the central **utility** (e.g. usefulness, purpose, benefit, scope, criticality to a system), **quality** (specified requirements, reliability, consistency, effectiveness at meeting needs and wants), **time** (improvements in productivity, control and efficiency; the ability to manage and respond to change; the ability to create and save time), and finally reputation and **social** value (culture, integrity, trust, aspiration, meaning, belonging, desire, security, public perception, social good). It is important to note that reputational valuations are the most complex and colour all others. They are a mixture of perception and emotion.



Figure 2 Organisation Resilience Conceptual Framework

In order to protect value, we need to understand where and how it is vulnerable. To do that we need to understand the complete chain that creates value; from supply chain to sales and servicing and market communications. We then need to know the relative importance of each link in the chain in terms of delivering that value and then where the chain is susceptible to disruption/harm/failure or change.

Based on the findings of this study there are a number of functions that are essential for delivering resilience (protecting value). Suggested grouping terms are provided below and shown in:

- Understanding the operating environment
- Forward strategic View
- Good governance

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- Risk Management – strategic, enterprise and PPPM
- Overarching strategy
- Mandates & Incentives
- Leadership, culture & behaviour
- Understanding the organisation and value chains
- Defining Value Capacity
- Vulnerability Mapping and Reduction
- Developing Adaptive Capacity

These themes are shown in Figure 2 alongside the underlying value metrics against which value can be defined.

These are described in more depth below:

1 Understanding the operating environment

- Define Value
- Understand & map value chain
- External threats and opportunities to delivering value
- Risk Assessments
- Cost and Impact of Disruption

2 Forward strategic view

- Take a long view of operating environment (future trends, stress factors)

3 Good governance

- Accountability for decisions,
- The ability to prioritise competing agendas in an open and transparent way.
- Good communications and collaboration.
- Regulations & incentives to build resilience.

4 Risk management – strategic, enterprise and PPPM

Linked to the ability to anticipate and to take forward action is the governance discipline of risk management. The ability to view risk management from a range of perspectives i.e. operational, tactical and strategic and looking outwards rather than just inwards is key to identifying potential threats and opportunities early

5 Overarching strategy

- Joining the dots – cross sectoral approach.
- Clear direction and structure.

6 Mandates

7 Leadership, culture & behaviour

- Resilience should be driven by leadership
- Develop resilient culture & behaviour

8 Understanding the organisation and value chains

- Defining Value Capacity - the tools and techniques at the organisation's disposal used to create value.
- Vulnerability Mapping and Reduction
- Vulnerability mapping
- Prioritisation of needs
- Reducing vulnerability (strengthening, redundancy, diversification and protection, fail-safes)
- Developing Adaptive Capacity
- Effective situational awareness (understanding operating environment)
- Effective information management system
- Effective decision making (leadership)
- Effective response system
- Effective recovery system
- Ability to learn, adapt and improve.

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- Adapt to a changing operating environment in line with or ahead of the speed of change.

Assessment metrics

To illustrate the importance of value as a diagnostic aid to understanding resilience the various infrastructure types were reviewed in terms of their effectiveness at delivering their potential value for stakeholders. In order to produce this assessment each infrastructure type was reviewed in terms of value expectations from its various stakeholder groups; initially focusing on the end user/customer and then including investors, suppliers and constituent organisations. Using the value model discussed above the following value criteria were created against which each infrastructure type was assessed:

Financial	Value for Money
	Return on Investment
	Stable and Low Risk or High Risk High Reward
	Profitable
	Efficiency
	Appreciation
	Revenue
	Credit Rating
	Win-win relationships
Utility	Delivery of basic service/supply
	Facilitate production
	Predictable
	On demand
Quality	Within recognised standards
	Meeting Service expectations
	Easy communication & issue resolution when necessary
	Open & transparent
	Unobtrusive
	Safe & Secure
	Minimal disruption
	Learning & Improving
	Consistency
Time	Improve productivity
	Minimal waiting
	24/7
Social	Customer Satisfaction
	dependable
	Trustworthy
	Environmentally friendly
	Not profiteering

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Fair
Responsible
Future ready
Reputation Enhancing

The Comparative value assessment

The above value assessment criteria were weighted in terms of relative importance and then each type of infrastructure (this report is focused on English infrastructure owing to the stakeholders interviewed) was assessed in terms of maximum relative value and actual relative value. These scores were then compiled and an overall assessment score produced. These scores were as shown in Table 1.

Table 1 Results of Comparative Value Delivery Assessment

Transport	
Road	59%
Rail	62%
Air	76%
Sea	81%
Public	62%
Power	82%
Communications	74%
Flood & Coastal Erosion	86%
Science & Research	85%
Waste	
Solid	89%
Water/Sewage	90%
Water	91%
Education	74%
Health	73%
Justice - Prisons	79%
Housing & Regeneration	84%
Cyberspace	86%
Emergency Services	88%
Finance	73%
Defence	88%
Civil Nuclear	85%
Chemicals	91%

There does appear to be a link between state ownership, strength of regulation and value rating. When referencing the systems diagrams for each infrastructure points to some potential reasons for these disparities especially when viewed through the lens of the resilience themes that came through from the interviews.

Highways infrastructure in particular is a very fragmented value chain. No single entity has a **strategic view** of the whole or a **strategy** or **governance controls** to support it; there is no golden thread joining the values of these organisations together. Highways England is only responsible for 2% in term of miles of the network and very much focusing on most of that 2%. Although at project and operational levels **risk management** is said to be very effective, the strategic risk picture is less well considered resulting in less effective planning for long term strategic issues and a focus on technical solutions to what are more often behavioural problems. There is also not sharing of risk understanding between organisations within the value chain – there is no risk golden thread and therefore there is no **enterprise risk** approach for the whole value chain. Many of the organisations appear to have a poor understanding of their **value capacity** and their **vulnerabilities** and how they could be impacted by shocks and stresses within the **operating environment**. Many of the organisations have a very effective response capability for short term disruptive incidents, that appear to have poor **adaptive capacity** when it comes to longer term issues; indeed, some of the long term solutions currently being implemented are taking so long to deliver they run a real risk of being obsolete before they are finished, or at the very least will have severely diminished return on capital investment and return on disruption. The sharing of **information and integration** of information management systems would significantly improve overall situational awareness for all organisations in the value chain and users/customers/suppliers.

Conversely, the water industry scored more highly. This better performance can be attributed to a very well-integrated value chain with a good strategic view that understands the changing environment with broad strategies to prepared for the changed future. The industry seems the be well regulated and close relationships seem to exist between many of those involved.

For systems to be engineered to incorporate higher levels of resilience the systems resilience performance standards need to be defined and then turned into performance based requirements. Without performance based requirements, the system cannot be designed, assured and investment decisions is less likely to be made. Requirements are a series of measurable and defined needs taken from all stakeholders; and form the basis of capabilities/ functions or features to be engineered into the overall system solution. Requirements need to be defined in terms of outcomes not process e.g. not define roles and responsibilities but enable accountability. In this way, having value as the starting point for systems engineering helps focus all requirements on the outcome, the golden thread, which should always be to deliver value.

Once values are agreed and understood, these themselves can be turned into broad user requirements around which a suite of more specific system requirements can be built e.g. “on demand” can be turned into a “SMART” (Specific, Measurable, Attainable, Realisable, Traceable) requirement when directly applied to the relevant context as “on demand” has clear implications on time scales and availability. Setting requirements to meet social values will always prove more difficult as they are hard to measure and any measurement will usually be retrospective. Requirements are often focused on delivering utility, quality and time values and to a lesser extent financial values. This shows a gap in current practice as financial and social factors are more likely to be the final determinants of investment decisions.

Conclusion

There is significant opportunity to improve the resilience of UK Infrastructure. A more joined-up cross-sectoral approach is needed based on protecting the value delivered to the UK and its citizens. A clear method for prioritising investment in resilience building is required based on a comprehensive review of the whole system and its dependencies, a clear understanding of the value chains that deliver this and those areas most vulnerable to future shocks and stresses. The methodologies outlined in this document go some way towards developing this.

Next steps

A further study testing the proposed framework would be useful, to build a robust model and provide greater confidence in the results.

Applying the outcomes from this report to different infrastructure and a different scale would test the transferability and scalability of the studies outcomes.

The subjective nature of the assessments in this study would be strengthened through a broader survey based study on public and industry value perceptions.

Working closely with one industry to prove the value of the outcomes would help prove the business case for taking such a resilience approach and encourage further investment in this area.

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