AGENDA SETTING SCOPING STUDIES

RESILIENT FOUNDATION THROUGH SYSTEMS THINKING

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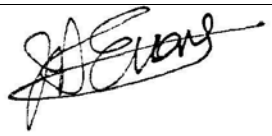
1 16/06/17				First formal issue for Client review
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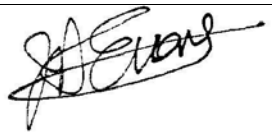
2 13/10/17				For publication
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EXECUTIVE SUMMARY

Context

We are 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 aging 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 and 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 government's 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.

Flooding events, accidents, organisational failures are frequently followed by calls for increased resilience; however, it is not clear how these calls should be interpreted. There is a very significant body of work defining and applying resilience principles to a range of contexts including work by the United Nations International Strategy for Disaster Risk Reduction, the Rockefeller Foundation with the 100 Resilience Cities programme.

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 as the "shift left", from response to prevention and then opportunity.

Purpose

This study provides outline suggestions on what a framework should look like 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. The outline for the framework will:

- Allow requirements to be articulated in such a way which provides clear objectives and enables innovative solutions
- Enable an organisation to establish its risk tolerance in such a manner that can be used to develop a platform for change
- Maintains line of sight back to the organisational values (golden thread)

The study was focused on infrastructure in the UK and predominantly England.

Methodology

A simple methodology was adopted focused on engaging stakeholders from selected infrastructure organisations via interviews driven by a consistent set of questions. Through this engagement an understanding of cross cutting industry issues was developed and system maps were developed to provide clarity.

These infrastructure systems were also assessed against a consistent 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;
- No 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);
- The total 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.

A New Approach

Systems thinking has a powerful role to play in understanding and diagnosing the resilience of complex systems. The starting point and key to unlocking this understanding is the concept of value and how organisations and stakeholders need to work together within a value chain in order to be resilient. 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.

The resilience principles defined proved to be a very useful means of diagnosing those systems that were underperforming in comparative terms with other types of infrastructure. An example used was that of highways which has a very fragmented value chain with limited strategic oversight and limited governance controls over the whole system.

A key area for resilience improvement was based around the principle of adaptive capacity especially when underpinned by effective information management systems and horizontal and vertical integration of value chains allowing investments in resilience to be made even in areas that may not experience direct benefit.

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.

CONTENTS

INTRODUCTION

This research was performed as part of the Resilience Shift, a Lloyd's Register Foundation[1] initiative delivered by Arup. 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. The purpose of the programme is to achieve a paradigm shift in the following ways:

- From preventing failure (at a pre-defined threshold) to ensuring functionality in diverse conditions;
- From considering risk to individual assets to also understanding the contribution of sociotechnical systems to the safety and well-being of society;
- From describing critical infrastructure predominantly in terms of physical parameters to instead, focusing on the critical functions and services from the infrastructure;

More specifically, the paradigm shift is likely to be taking place once the following outcomes have been witnessed:

- Adoption of dynamic, performance-based design approaches in broad practice;
- Tools and processes to value resilience and ensure that value is realized through the project life cycle by project owners, developers, financiers and insurers;
- Use of integrated systems approaches as context for major engineering projects;
- Integration of systems-thinking and resilience into existing engineering education and new course focused on "resilience engineering";
- Emergence of transformative technologies that facilitate critical system functionality.

Project Overview

This scoping study was funded as part of the JPRE, "The Resilience Shift" program and seeks to use Systems Thinking to articulate resilience requirements at a corporate level, and to establish a good practice framework for translating this to implementable solutions.

[1] Lloyd's Register Foundation is a charitable foundation, helping to protect life and property by supporting engineering-related education, public engagement and the application of research.

Scope

Principally, systems-thinking seeks to take a strategic perspective, understand the whole, and define the requirements. A systems-based understanding at the corporate level will enable a coherent, logical, measurable, auditable and repeatable approach to building resilience capacity. It will promote the evolution from an issue - response model to a more comprehensive anticipate – avoid/exploit – adapt model and will also foster innovation through dynamic performance-based design and use of transformative technologies.

Systems thinking has been proven to reduce risk, cost, and project slippage as well as foster innovation on a range of project scales from large, international research programmes, delivery of major critical infrastructure down to small scale project delivery.

This study provides outline suggestions on what a framework should look like for developing resilience based requirements and management structures. This will be based on current best practice in Systems Engineering, and applicable to a range of sectors and technologies. It is envisaged that the outline for the framework will:

- Allow requirements to be articulated in such a way to provide clear objectives and enable innovative solutions;
- Enable organisations to establish risk tolerance criteria that can be used to develop a platform for change;
- Maintain line of sight back to the organisational values (golden thread).

METHODOLOGY

The methodology followed for this study is shown in Figure 1and described in more detail below.

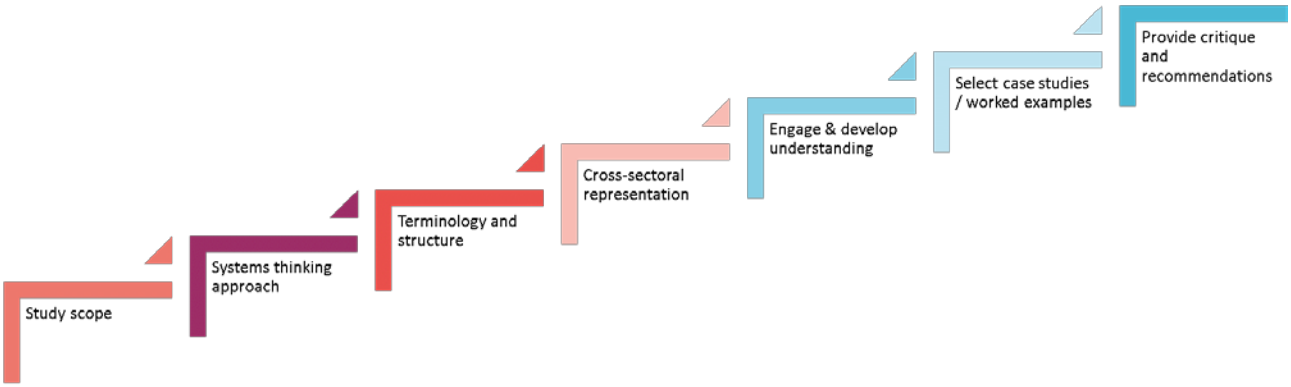

Figure 1 Methodology

1 ESTABLISH THE STUDY CONTEXT

An initial review of the study context, stakeholders, literature and scope was followed by establishing a project plan.

2. ESTABLISH THE SYSTEMS THINKING APPROACH

Outlining the systems thinking approach provided formative guidance and a platform for further defining the activities and interactions required to provide the technological and emotive changes required to develop a resilience based framework. It provided the basis for the development of a universal framework system to better understand and manage resilience across different sector groups.

3. ESTABLISH FIRST PASS AT COMMON GLOBALLY ACCEPTABLE TERMINOLOGY AND STRUCTURE

As different sectors have specific terminology a structured approach to the gathering of information ensured that relevant information is provided. The development of metrics to provide a level of quantification on the approaches used in different sectors provided additional insight. In addition, this provided a consistent approach in the information gathering and development of case studies phase of the work.

4. IDENTIFY REPRESENTATION FROM GIVEN SECTORS

The wide basis of our industry interactions enabled the consideration of a variety of sectors and prevented tunnel vision driven from established behaviours in specific industry sectors. Further, this allowed us to challenge the paradigm and foster innovation. Representation and input from several sectors pertinent to critical infrastructure was achieved. Identification of relevant companies and personnel within these sectors was important to provide information on cross sector dependencies, and identify suitable industry bodies such as INCOSE.

5. ENGAGE WITH REPRESENTATIVE INFORMALLY TO UNDERSTAND HOW RESILIENCE WAS DEFINED AND UNDERSTAND CROSS SECTOR INTERDEPENDENCIES

Representatives from a selection of sectors were interviewed to understand initially how they define resilience to: (i) provide a comparison with other sectors; (ii) to understand how they manage, future-proof and value resilience pertinent to critical infrastructure for their business; and (iii) to better understand the tools and processes they use.

6. SELECT CASE STUDIES / WORKED EXAMPLES

Several case studies, were developed from the engagement with the different sectors representatives detailing their current activities pertinent to resilience of their critical infrastructure, how they assure these activities and the tools they used and the relative strengths, weaknesses, opportunities and threats as they see them.

7. PROVIDE CRITIQUE AND RECOMMENDATIONS, INCLUDING A COMMENTARY ON GLOBAL SCALING OF THE FRAMEWORK

This final report has been prepared summarising the scope of this project, findings from engagements with different industries including the metrics, models and processes developed and used in different sectors. A key outcome was the outline for the framework, conceptual, value definitions, systems structure and process. The outline for the framework has taken into account the comprehension and understanding of the concepts and benefits of Systems Thinking; key to getting buy in and promoting collaboration within cross-sector inter-dependences.

BACKGROUND

What is resilience?

We are living in an increasingly VUCA environment (Volatile, Uncertain, Complex and Ambiguous), exposed to an unprecedented level of shock and stress factors. Shock factors are those one-off events that cause disruption, harm or damage on such a scale that specific action needs to be taken to respond and resources need to be diverted. The shock factors that are most commonly considered include accidents, flooding, disease or utility failure but can include terrorist attacks, land movement and seismic events, cyber-attack and many others.

The UK has a finite budget to spend on National Infrastructure and the effectiveness of that spending directly impacts our nation's 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 government's 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.

Stresses are factors that continually change our environment and systems over time, they may exacerbate existing shocks or become shocks themselves. The current environment is forming into a perfect storm of stress factors with an ever-increasing demand for resources from a growing and aging population; an increased scarcity of supply in a wide range of key resources including fresh water and energy; and a rapidly changing environment because of climate change.

Coupled to these severe strategic challenges are other pervasive stress factors that will impact every level of society such as growing obesity and diabetes levels, rapidly changing technology, a widening gap between rich and poor, a rise in international terrorism, and increased globalisation where greater reliance is placed on elongated supply chains. This requires a joined-up, comprehensive approach to managing disruption and change. We define resilience as:

> *"The will and ability to anticipate, prepare, respond, learn, adapt to and thrive within a disruptive and changing environment".*

The above differs from many definitions which, at present, tend to focus on response and recovery from a specific event. The above definition is more encompassing of the "shift left", meaning a move to prevention rather than response. It breaks down into three critical parts; the characteristics of the subject system; the resilience process outcomes; and the environment within which the system operates.

As resilience is built within and around a system, it becomes more able to prevent or mitigate stresses and shocks that can be identified and is therefore better able to respond to those that cannot be predicted or avoided. Greater capacity to "bounce back better" from a crisis, by learning, adapting and capitalising on opportunities is also developed.

UK INFRASTRUCTURE CONTEXT

What is infrastructure

In the most literal terms, Infrastructure is the physical, technical and organisational structures, facilities and technologies (e.g. buildings, roads, power supplies, broadband) needed for the maintenance of our way of life.

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). These are both relatively newly created bodies, showing that the government is thinking about the future and infrastructure. *"The IPA brings together Infrastructure UK and the Major Projects Authority into a single organisation that will report to and carry the combined weight of HM Treasury and Cabinet Office ministers. It will have a renewed mandate to ensure timely and cost-effective delivery of the government's infrastructure priorities alongside other major government projects and programmes."* The NIC was set up *"to produce a clear picture of the future infrastructure the country needs and provide expert, independent, analysis and advice on pressing infrastructure issues."* The NIC has produced a National Infrastructure Delivery Plan (NIDP) which defines the priorities for investment over the next 5 years (2016-2021).

Priority investments in infrastructure are selected based on the following criteria:

- They are nationally significant and deliver substantial new or replacement infrastructure of enhanced quality, sustainability and capacity;
- They have the potential to drive economic growth or unlock significant private investment;
- They make a significant contribution to the government's strategic objectives.

Infrastructure here is split into two groups:

- Economic infrastructure

  - 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 IPA exists to provide *"earlier project initiation support and more robust assurance processes."* It aims to improve the information gathered on major projects from an early stage to assess and test plans before firm costs have been defined and measure performance and outcomes against defined costs and timescales. With guidance from the NIC the IPA will prioritise the most effective infrastructure projects.

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."* This can happen at any level of infrastructure. At a high level, there may be interdependence between entire infrastructure networks; such as the additional demands placed upon the energy network as electrification of the rail network is expanded. At a local level a failure in flood defences could lead to local loss of power and access by transport.

Sector Resilience

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. The sector resilience planning process provides the opportunity for government, regulators and infrastructure owners to work together to produce a mix of resilience components that are:

- Proportionate to the risks identified in National Risk Assessment products;
- Enabled by improved sharing of information;
- In keeping with legal and regulatory frameworks, industry standards, licence agreements and business models.

The government departments that should be leading resilience in a particular sector are shown in Table 1 below. It can be seen that the Department for Business, Energy and Industrial Strategy has a large role to play in leading resilience.

Table 1 Critical Sectors, Associated Sectors and Lead Government

Sector	Sub –Sector(s)	Sector Resilience Lead
Chemicals		Department for Business, Energy and Industrial Strategy
Civil Nuclear		Department for Business, Energy and Industrial Strategy
Communications	Broadcast	Department for Culture, Media and Sport
	Telecommunications	
	Internet	
	Postal	Department for Business, Energy and Industrial Strategy
Defence		Ministry of Defence
Emergency Services	Ambulance	Department of Health
	HM Coastguard	Department for Transport
	Fire & Rescue	Home Office
	Police	Home Office
Energy	Electricity	Department for Business, Energy and Industrial Strategy
	Gas	
	Oil	
Finance		HM Treasury
Food		Department for Environment, Food and Rural Affairs
Government		Cabinet Office
Health		Department of Health
Space		Department for Business, Energy and Industrial Strategy
Transport	Aviation	Department for Transport
	Ports	
	Rail	
	Road	
Water		Department for Environment, Food and Rural Affairs

For instance, the current priorities to build resilience in the energy sector include:

- Electricity: Implementing a three-digit emergency phone number for reporting power disruption;
- Energy Networks: Assessment of the risk posed by severe space weather and cyber-attack;
- Downstream oil: working on maintaining capability to make fuel deliveries in the event of a serious disruption;
- Energy Sector Flood Resilience: Continuing assessment of flood risks to energy assets and flood protection enhancement programmes.

As can be seen all these resilience measures have interdependencies with other sectors and therefore other government departments and infrastructure owners.

Control of the energy sector from a governmental point of view is very complicated (see Figure 2– noting that "security & resilience" here is largely limited to meeting future demand). Therefore, when the multitude of energy infrastructure suppliers are added, the number of stakeholders and required interactions to implement resilience in the sector are numerous.

It should be noted that different sectors and sub-sectors of sectors have varying amounts of government control, and therefore so does their infrastructure. To illustrate this point, the nuclear sector is currently highly regulated, but future projects may see that generation moves into private hands. In the wider energy sector electricity generation is again highly regulated by the National Grid, but oil and gas supplies are largely driven by market supply and demand with some oversight and regulation from Ofgem.

Transport infrastructure has similar variations in government control. Network Rail owns and maintains the rail infrastructure with private businesses running the services. Motorways and trunk roads are the responsibility of Highways England in England (this responsibility is devolved to the devolved governments in Northern Ireland, Scotland and Wales), however all other highways are the responsibility of the highways authority within local governments. Ports and Airports however are largely private owned.

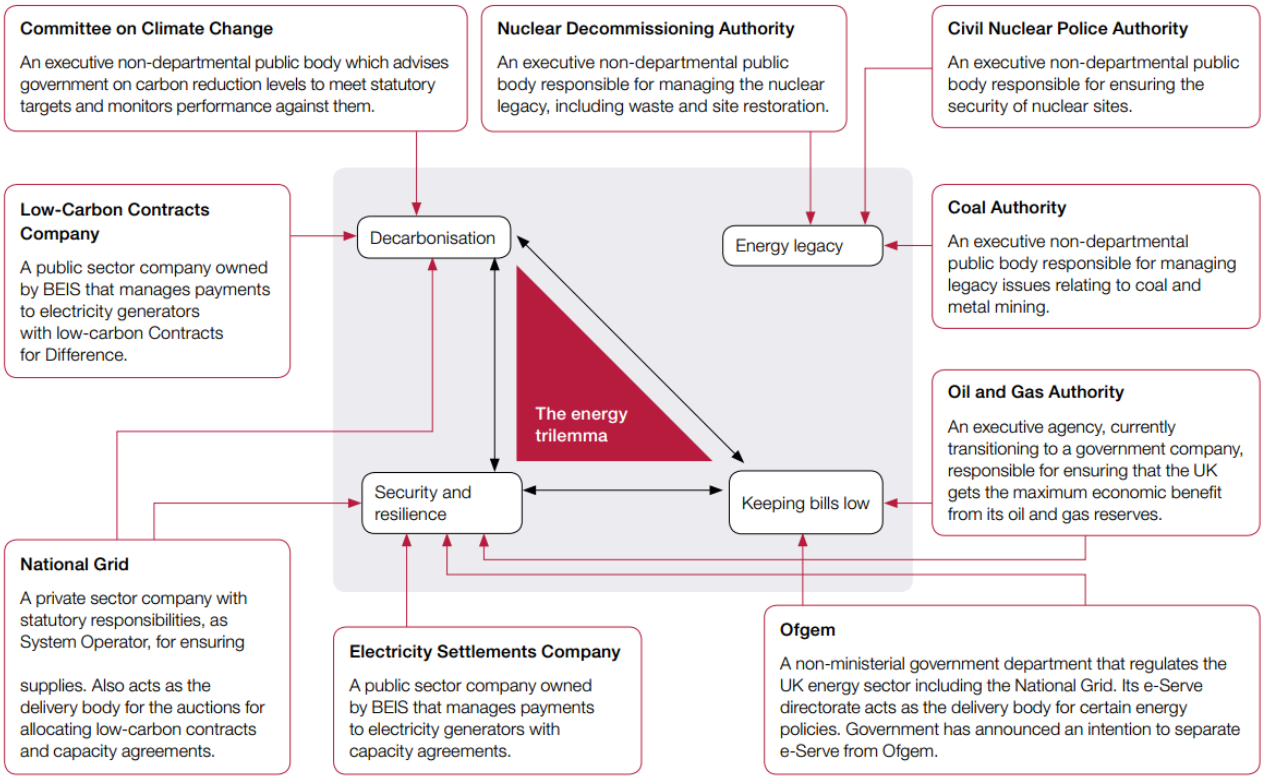

Figure 2 Diagram showing Energy Industry Stakeholders

Flood Resilience Review

One active area of resilience planning is the Flood Resilience Review. This review will "stress test" the UK's resilience to flooding and improve knowledge of the implications of extreme weather events and climate change. This will consider *"the longer-term strategy on flood risk management. It will look at temporary and flexible responses as well as hard flood defences beyond the current 6-year programme. This will include the balance between protection and resilience, an assessment of risk in England's core cities and will consider the role of both government and wider society in reducing flood risk."* Again, the list of stakeholders is a long one: the government's Chief Scientist, Defra (Department for Environment Food & Rural Affairs), DECC (The Department of Energy & Climate Change), DCLG (Department for Communities and Local Government), HM Treasury and the EA (Environment Agency).

Topical Issues from within Infrastructure

At the recent National Infrastructure Forum in London on June 13, 2017, many industry experts from the fields of energy, power and water gave their views on key issues for the 21st century included:

- How to protect consumers?
- How to adapt & allow more innovation (e.g. supply) – more of a system view;
- Where should the boundaries be with other sectors? Responsibility? A need for new frameworks? Cross-sectoral models? To better manage disruption and innovation.

The key organisational challenges were balancing regulation, flexibility, innovation, operability/efficiency and affordability. Key opportunities and threats included the electrification of transport infrastructure, electric cars and autonomous vehicles. It was noted a key barrier to these technologies was the need for a new charging infrastructure.

Some solutions were identified in terms of the need for long term stable policy framework – (NIC) – based on building infrastructure and cross sectoral collaboration. It was suggested regulators need regulations that focus on customer service, innovations, horizontal and vertical integration and meeting the growing skills shortage. It was suggested that at times of uncertainty there is a tendency to over-contemplate when, quick changes are needed to allow private sector to invest rapidly. There is a need for an open framework – a long term view to enable innovation, drive down cost and incentivise investment.

The final remarks focused on the need for stability with evolution and linking systems and value.

UK SHOCKS & STRESSES

There are a range of factors that shock or stress our infrastructure systems. Shock factors are those one-off events that cause disruption, harm or damage on such a scale that specific action needs to be taken to respond and resources need to be diverted. The shock factors that are most commonly considered include accidents, flooding, disease or utility failure but can include terrorist attacks, land movement and seismic events, cyber-attack and many others.

Stress factors continually change our environment and systems over time; they exacerbate existing shocks or become shocks themselves. The current environment is forming into a perfect storm of stress factors with ever increasing demand for resources from a growing and aging population; an increased scarcity of supply in a wide range of key resources including fresh water and energy; and a rapidly changing environment as a result of climate change.

Figure 1 shows how global stress factors influence shock factors which are also influenced by specific structural stress factors. When susceptible city vulnerabilities are exposed to these shock and stress factors they will suffer either disruption, harm, failure or reduced utility. Examples of the types of adverse impacts that could be expected are also outlined. This diagram can be used for designing risk mitigation measures as well as response capabilities. Response capabilities needs to be designed to respond to the impacts whilst mitigation measures can be designed to interrupt each step in the chain leading to adverse impact.

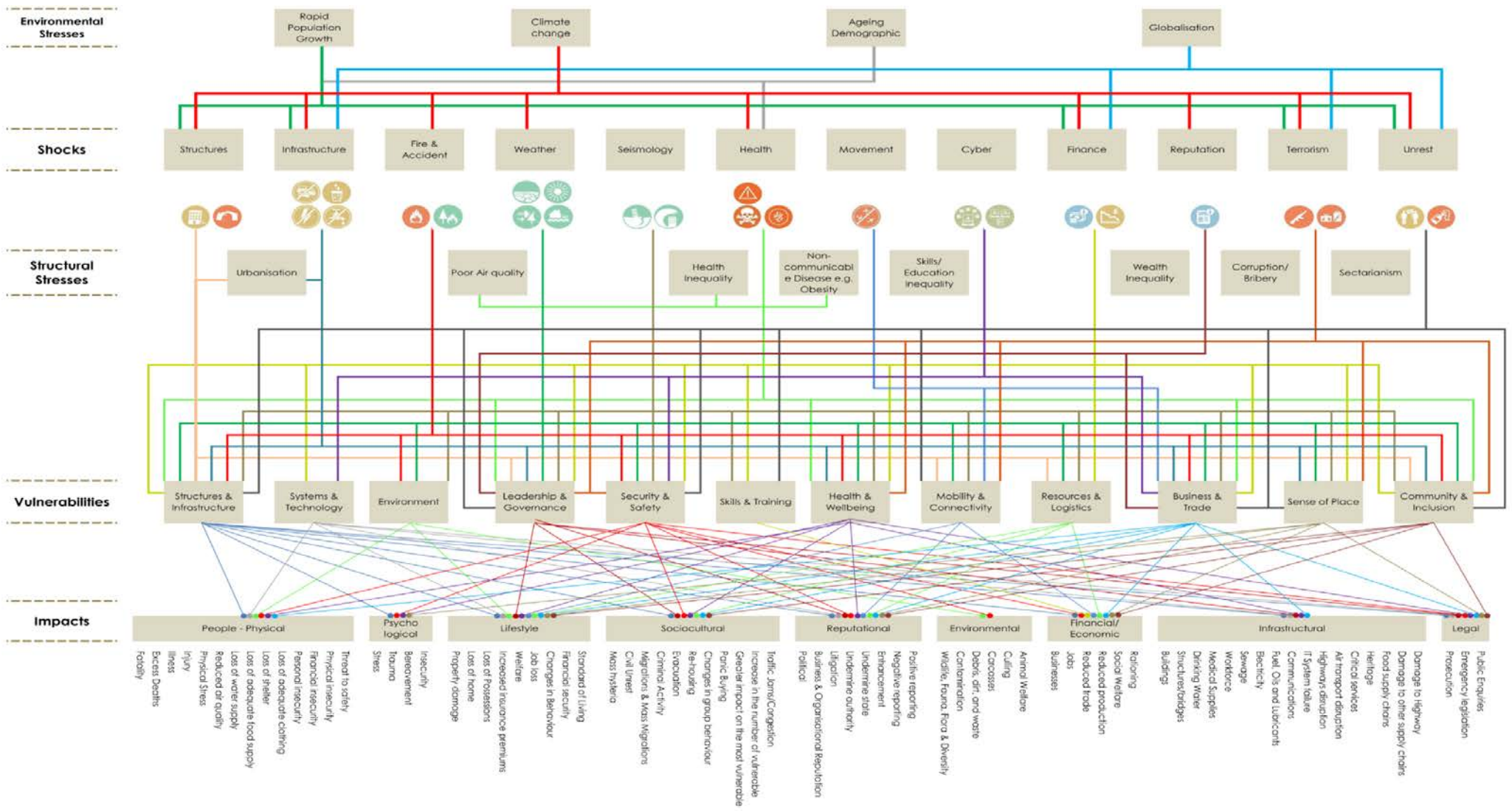

Figure 3 Systems Diagram illustrating inter-relationships between shocks, stresses, vulnerabilities and impacts

SHOCKS

There are a wide range of shock factors that can impact on infrastructure. Shocks and their relative impact and probability are very much context driven.

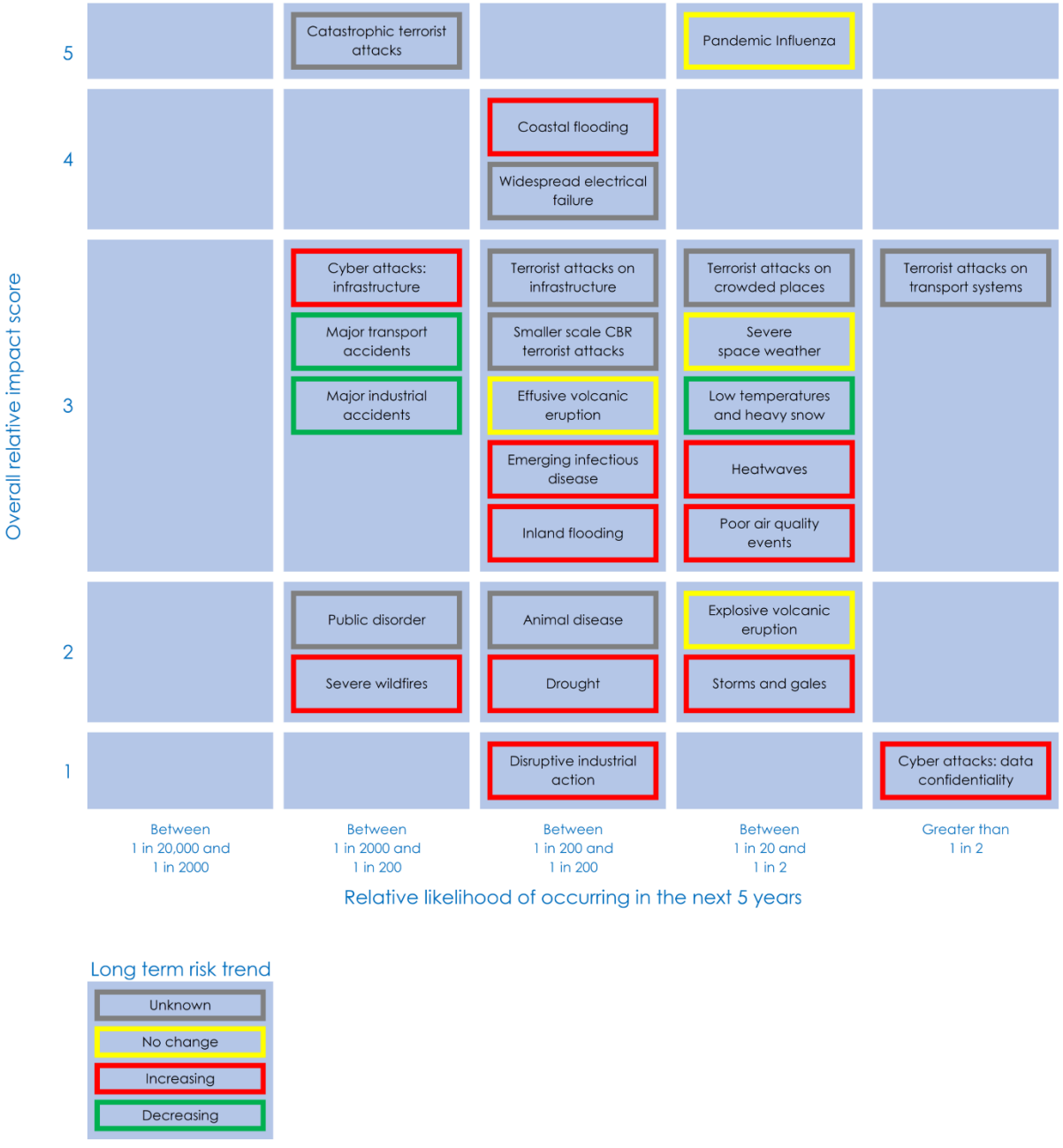

Figure 4 Risk Matrix from the UK National Risk Register (Adapted)

Figure 4 above is taken from the UK National Risk Register 2015 and shows the risk matrix for the UK. The national risk register does not take stress factors into account within its published documentation. To illustrate the effect of stress factors on the risk posed by shocks, a long-term risk trend assessment has been added to the matrix.

It should be noted that nearly every shock factor identified on this matrix is far more likely than the matrix suggests, illustrating the weaknesses of applying logarithmic probability scales to shocks of this type. The evidence does not support these probability ratings and therefore underplays the real risk posed by this range of shock factors. A scale weighted towards the higher frequency shock would prove far more effective in prioritising shock factors and informing policy decisions.

STRESSES

There are a wide range of stress factors influencing the way of life within the UK. However, none of these factors are reflected within the National Risk Register even as influencing factors. It should be noted that overall, stress factors are not risks within the purest definition as they tend to be factors that are exerting an influence now and are therefore issues, not risks. Having said that, although these factors may be exerting an influence now, they are likely to be part way through a maturing process by which they are still to develop into their full potential for influence be that positive or negative. This is true for stress factors such as climate change, automation, aging populations, etc. Stresses are also factors with great potential to deliver opportunity and benefit providing they are identified and managed early.

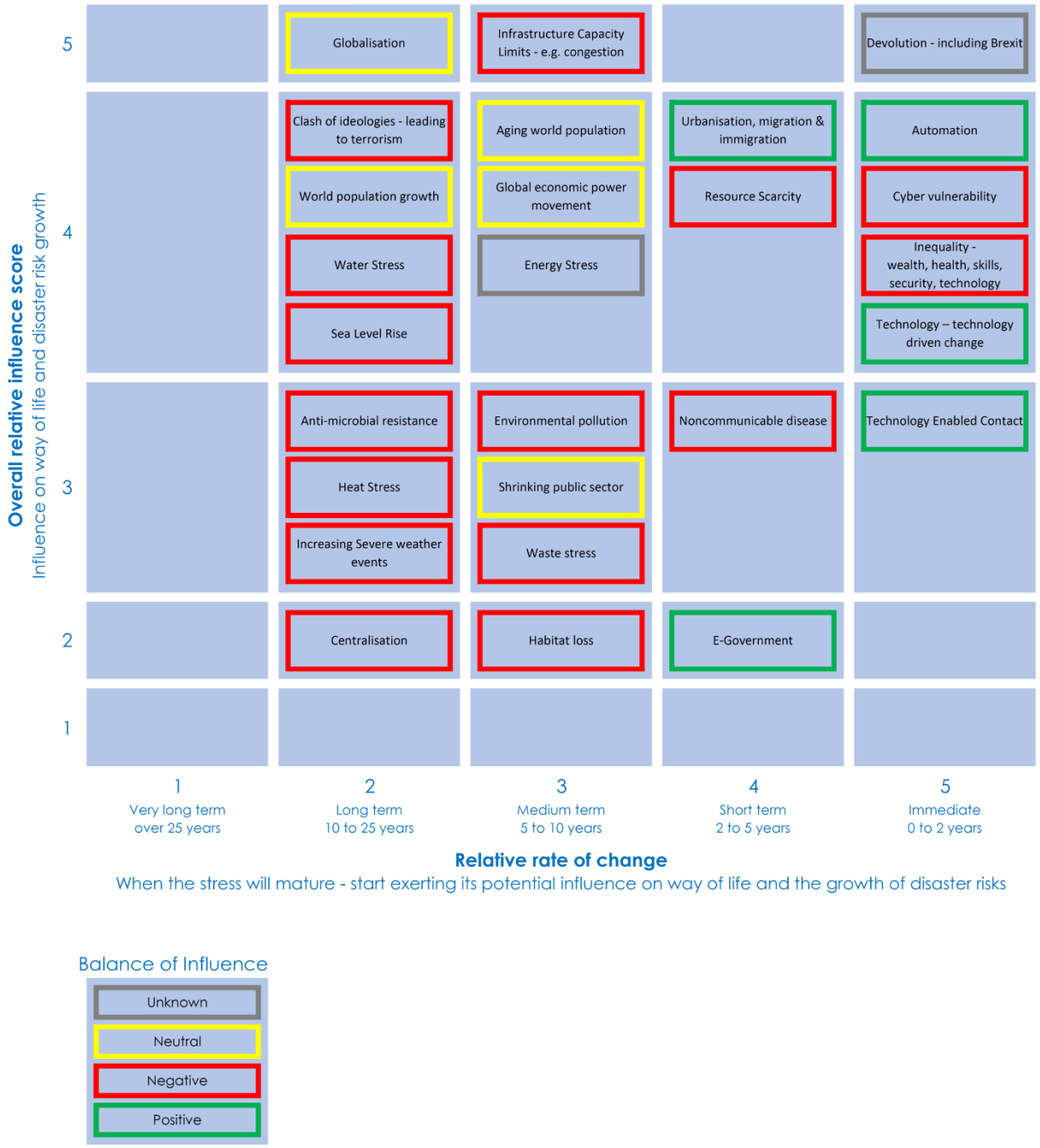

Figure 5 Stress Factors Affecting the UK

Figure 5 places a range of stress factors on the stress equivalent of a Heatmap. It should be noted that climate change has not been stated as a stress in its own right, rather its key outcomes have been stated such as sea level rise, water stress and heat stress. Also, as stresses are not risks, they cannot be assessed in terms of "impact" and "likelihood". "Influence" and "rate of change" have been used instead.

Each stress has been assessed in terms of its overall negative or positive effect on the UK's way of life, economy and hazard profile. It should be noted that in many cases, stresses

represent both threats and opportunities and it is an assessment of the balance that is represented here.

In summary, the stress analysis suggests increasing overall pressure on the UK's systems and structures as a result of the stress factors identified. Climate change and its outcomes represents the greatest of these pressures however resource scarcity, limited infrastructure capacity, the health of the population, an aging population, cyber vulnerability and inequalities are likely to be very significant negative features affecting the nation's future health and prosperity. This is balanced against advancements in technology such as increased automation, driverless cars, etc. that although they may have some negative side effects, will represent the greatest advances in productivity and improvements in quality of life for the nation. This analysis places the devolution of power including Brexit as the greatest single stress factor on the UK at the moment (accepting that if climate change were treated as a single factor is would also achieve a maximum score); however, it is not known if this will ultimately be a positive or negative influence.

SYSTEMS ENGINEERING

What is systems thinking?

In his seminal work "the Fifth Discipline" the American systems scientist who is a senior lecturer at the MIT Sloan School of Management defines systems thinking as "*a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots"*." (P Senge, 2006)

This ability to see the whole in its dynamic environment is an essential requirement when trying to understand resilience. Resilience by its nature looks from the large scale to the small and seeks to understand how large-scale factors can cascade to impact the small and how small factors can compound to effect large scale change.

Fundamentally the principle is to take a strategic view of the issue and understand what the function/purpose of the given system is and how it interacts with adjacent systems, without being constrained by the methodologies or how the system may be solved. The purpose of which is to define the constraints in which a solution is required, enabling onward innovation and simplifying programme delivery.

The benefits of bringing systems thinking approach into resilience include:

- Ability to articulate the user need, such that organisational objectives can include resilience, and therefore provide line of sight for projects;
- Visibility of decisions against a clear requirement stated in terms of outcome;
- Analyse complex problems and elevate through to the "big picture" rather than focus on individual elements;
- Analyse the impact of changes to the constraints (e.g. through shocks and stresses) from adjacent systems or from the environment;
- Articulate a platform for innovation where solutions are not obvious, or wide ranging.

Systems model

If systems methods are to be used to view infrastructure as a whole (value chain) it is necessary to view components as black boxes i.e. through understanding inputs and outputs without the need to understand internal processes. The complexity of infrastructure systems means there will always be a level of detail beyond further analysis is not worthwhile. Considering a systems or functions as black boxes, enables clarity of thought and simplification, as follows:

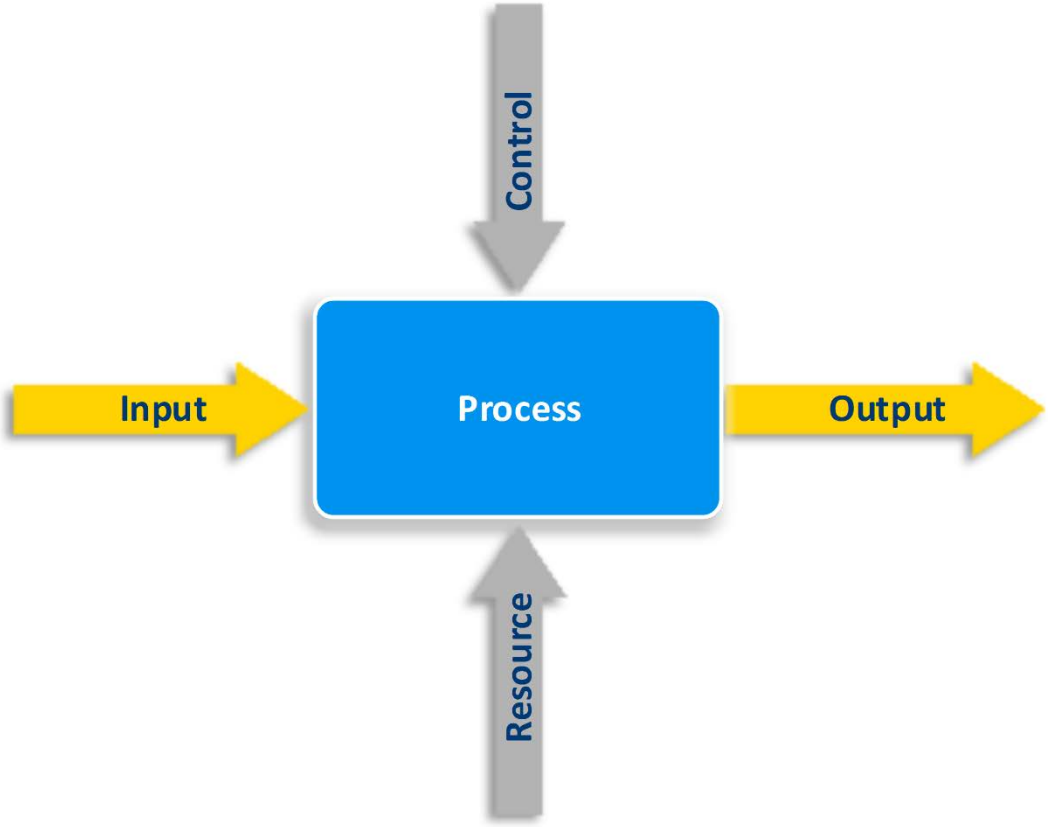

Figure 6 A Simple System within its Environment

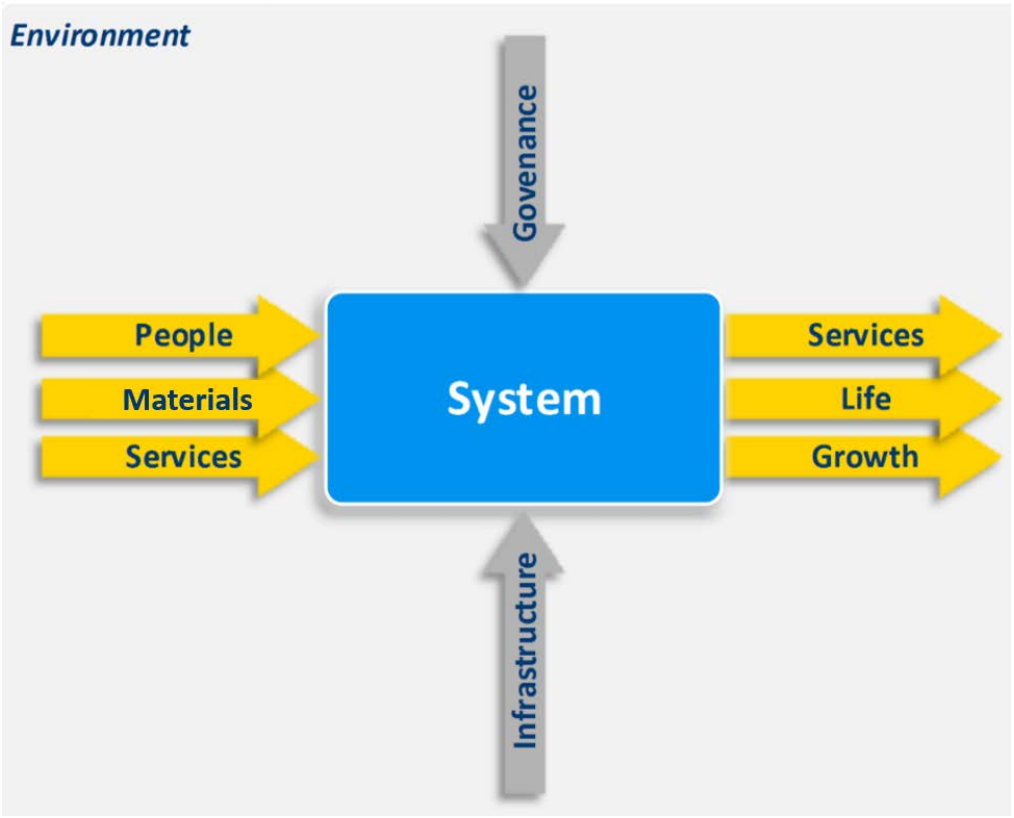

Figure 7 Example system diagram

The interactions and inputs can then be assessed in the context of shocks and stresses, and provide a structure for articulating requirements to/from shocks and stresses.

Each type of infrastructure is built of a consistent set of components. System models can be used as the basis for breaking each infrastructure industry down into its component parts to allow infrastructure to be viewed consistently across infrastructure types.

Such a simplistic view can be connected as part of a nested system of systems approach as shown in Figure 8.

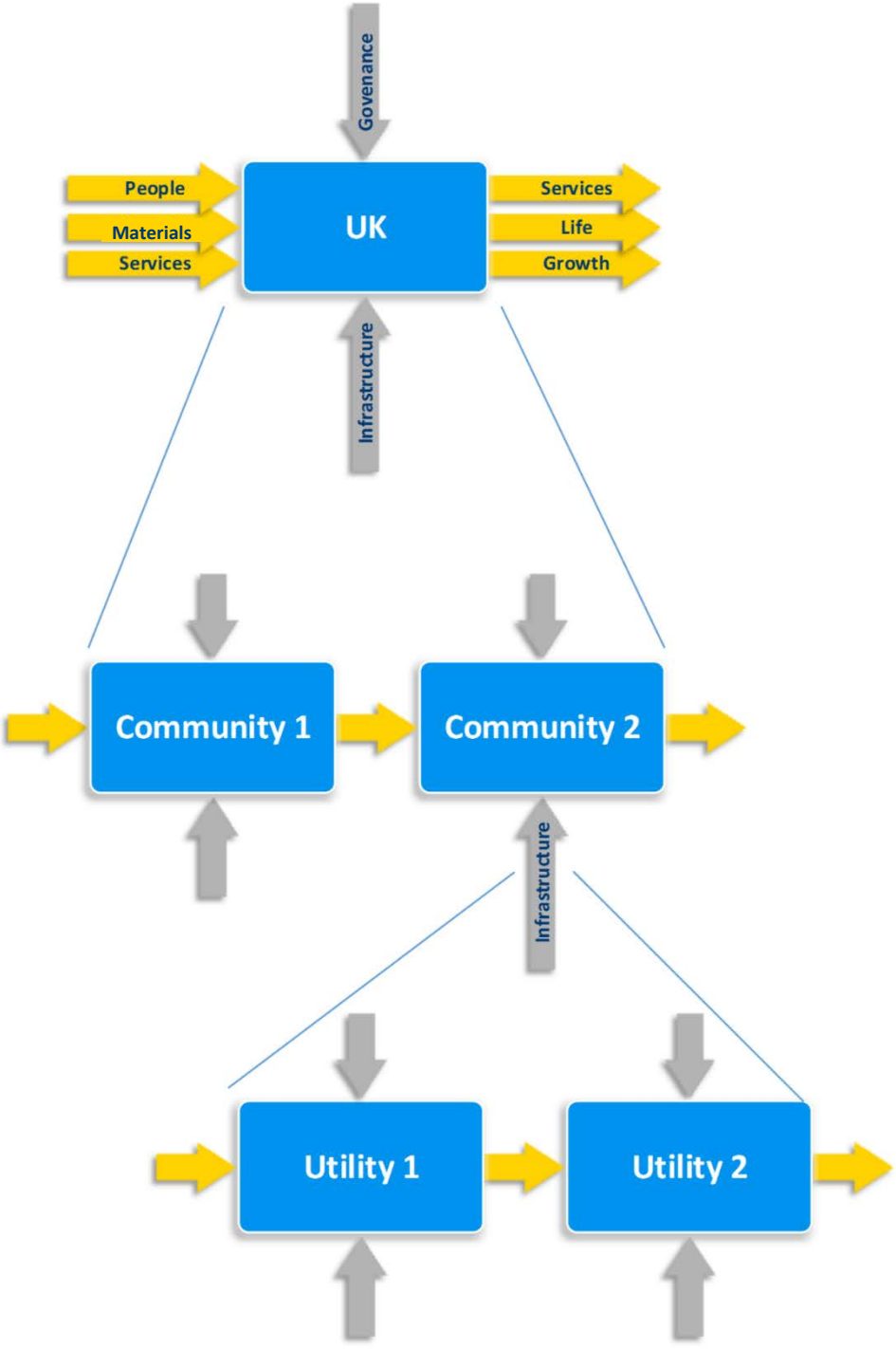

Figure 8 Simple Nested System of Systems Model

The Importance of Understanding and Protecting Value

Central to understanding complex systems, their resilience and how to grow them, is the concept of value; how value is created, changed, lost and protected. Value is the relative importance, worth or usefulness of a subject; and therefore, value is subjective. It is each persons' balanced judgement of what is important or worth caring about. Value is also the key to unlocking one of the most difficult resilience problems; what is a vulnerability and how do you prioritise vulnerabilities?

The process of creating value is the core operation of the organisation. Functions such as systems engineering ensure the operation delivers value coherently and within pre-determined tolerances. These processes are enhanced when delivered within the principles of "Lean" and "Learning" organisations. When organisations are developing an understanding of their value delivery systems (which in essence is the whole organisation within its environment) it is useful to think in terms of Porter's value chains as shown in *Figure 9*, rather than just focusing on the internal organisation and its supply chain. The concept of a value chain is founded in systems thinking; looking at the organisation as a whole system with multiple sub systems. The value chain view sets the organisation within a chain that creates value for the customer or end user and is therefore a more holistic view rather than simply focusing on those parts of the value chain for which the organisation is responsible or owns. Both upstream and downstream are essential areas of understanding and therefore, determining the ownership of each element of value creation also becomes critical. This view provides a much greater awareness of those factors that can affect value creation in the short, medium and long term and supports concepts such as relationship marketing.

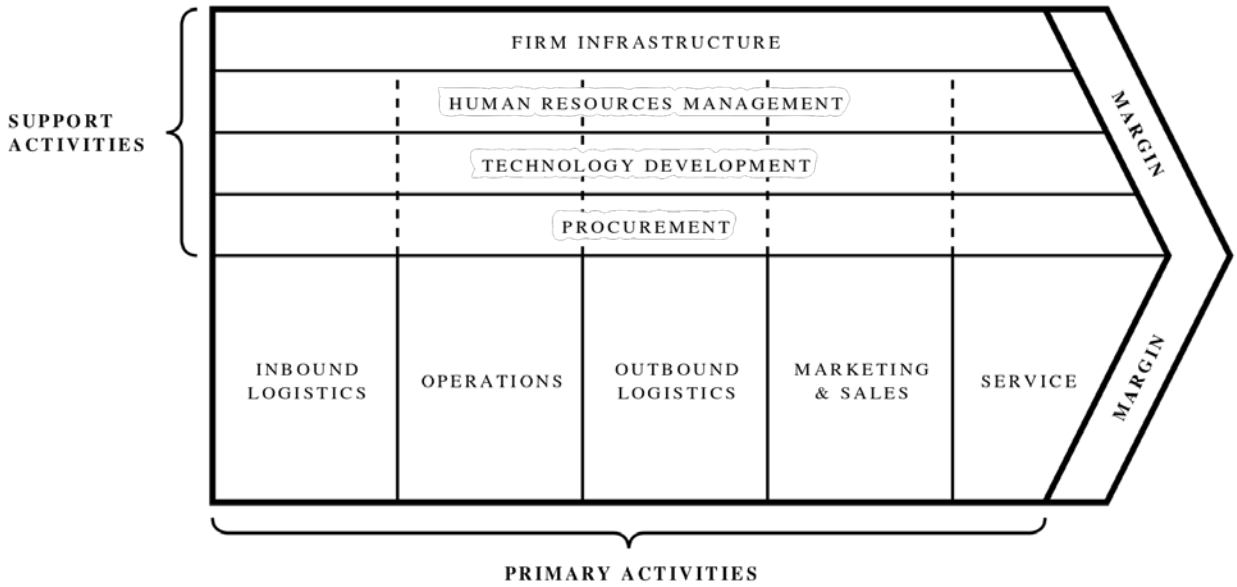

Figure 9 Michael Porter's Value Chain

Organisations protect value through functions such as business continuity, health & safety, legal, commercial, audit, quality assurance, compliance, et al. These functions need to understand value and relative value in order to prioritise and plan.

In this way value and ownership of value creation become key to understanding the organisation within its environment and its overall resilience. It puts the customer, investors and staff at the centre of organisational objectives and all performance indicators. Risk assessment criteria need to be aligned to creating and protecting this value, informing all decision making and governance systems.

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.

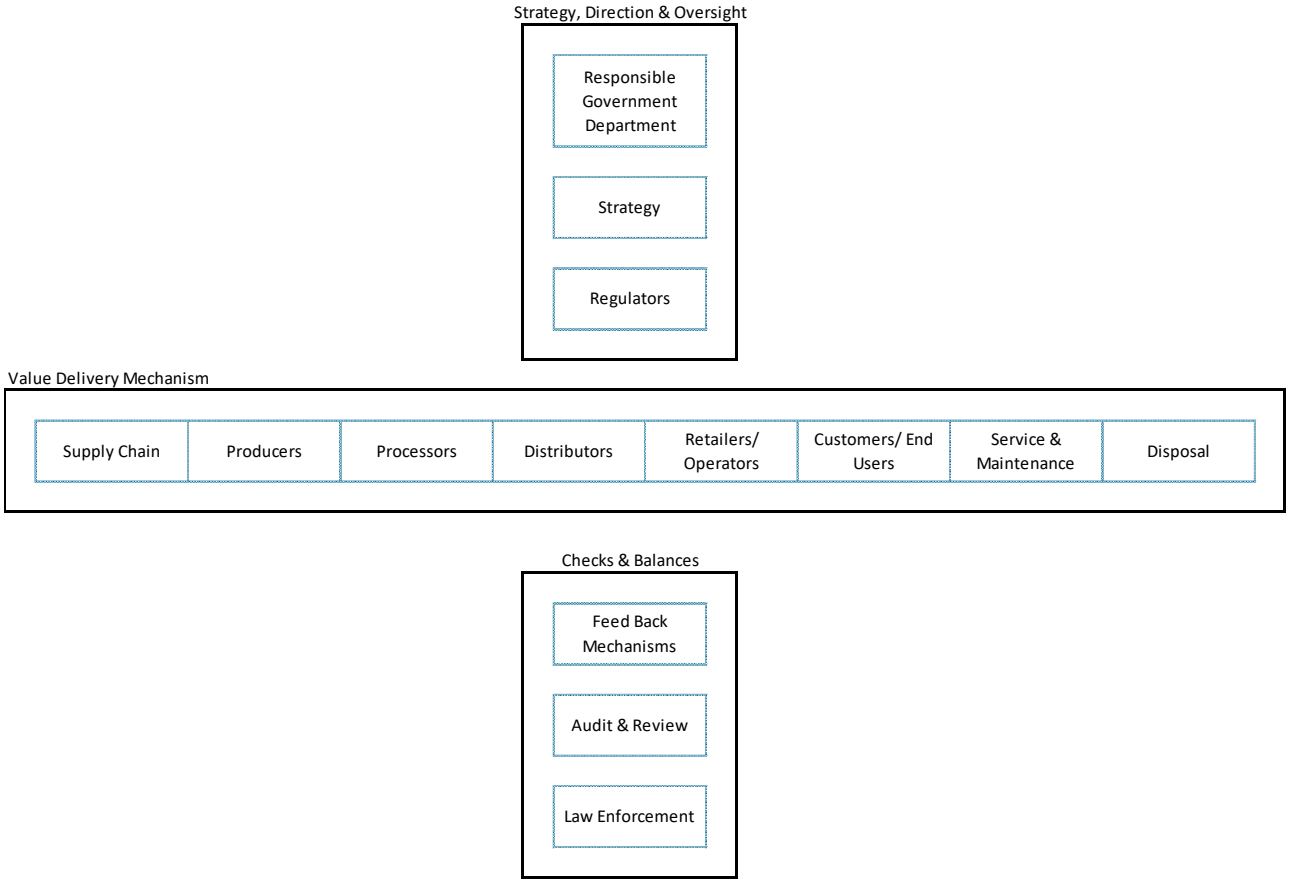

Figure 10 Generic Infrastructure Industry Structure

As Figure 10 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, therefore the work of the National Infrastructure Commission and Infrastructure & Projects Authority is so critical and must be consistent across all infrastructure and consider a wide array of shock and stress factors.

INDUSTRY INSIGHTS

As part of this study a number of critical utility providers were interviewed to understand their organisation's approach to resilience.

Industry Stakeholder Questions

- How does the organisation manage disruption and change?
    - Who is responsible?
    - Is there board representation?
    - Is it part of culture?
    - IS disruption managed separately from change?
    - Is the term resilience used and understood?
    - Does resilience include risk reduction as well as response and recovery?
- How far ahead do you look when you consider risks to your business?
    - Do you consider future trends? Stresses?
- How have you identified the critical parts of your business? What measures have been taken to protect these?
- How do you communicate and coordinate resilience within your organisation?
- Do you communicate and share lessons learned with other providers?
    - Within your sector
    - Cross-sector?
- Where does the demand for resilience come from?
- Do you have resilience based requirements that you must meet?
- How do you measure resilience within your organisation? What KPIs do you use?
- Give an example of an implemented resilience measure and how that investment was justified?
    - How do you build the business case for investment in resilience?

- How effective do you think your organisation is at anticipating disruption and change? What methods do you use to manage this?
- How do you spread good practise and ensure consistency across the organisation?
- How do you maintain and enhance awareness of changing risk factors to your organisation? How is this used to inform decision making?
- Do you have response plans? Are these regularly exercised and updated? How is learning captured?
- Are those responsible for resilience empowered to work across boundaries and communicate freely with top management?
- Describe how you adapt products, services and processes to better fit the new conditions brought about by long term strategic change factors e.g. climate change, automation, AI?
- What improvements need to be made?
- What are your biggest challenges?
- Does being resilient positively impact the company bottom line?

The following is a summary of the findings. The section is structured by infrastructure type with an overview of each industry, followed by a summary of the interviews and a SWOT analysis.

Within the following section, text highlighted in *this manner* has been used within the common factors analysis.

Water

BACKGROUND

The provision of water treatment and distribution, sanitation and sewage services in England and Wales are provided by the private sector. The government sets the strategic policy framework for the industry to ensure resilient, sustainable and affordable water and sewerage services. Ofwat, the economic regulator, sets the framework within which companies are licensed and regulated to ensure consumers receive a safe, reliable service at a fair price. The Drinking Water Inspectorate ensures water supplies in England and Wales are safe and drinking water quality meets acceptable standards. The Environment Agency also regulates the industry to protect the environment and promote sustainable development.

The provision of solid waste collection, disposal and/or recycling: Private companies build and run waste infrastructure to treat and divert Municipal Solid Waste (MSW) from landfill. To meet its landfill diversion target, the Government provides financial support through PFI to local authorities and this has helped fund waste infrastructure contracts with private sector suppliers.

The provision of waste water and sewage removal and treatment: Water, sanitation and sewage services in England and Wales are provided by the private sector. The government sets the strategic policy framework for the industry to ensure resilient, sustainable and affordable water and sewerage services. Ofwat, the economic regulator, sets the framework within which companies are licensed and regulated to ensure consumers receive a safe, reliable service at a fair price. The Environment Agency also regulates the industry to protect the environment and promote sustainable development.

There is industry collaboration around this issue, specifically Water UK, a membership organisation which represents and works with the major water and wastewater service providers in England, Scotland, Wales and Northern Ireland. Their priorities are to help water and wastewater companies work with others to:

- Increase levels of customer and stakeholder trust in the sector;
- Address short and long-term pressures on UK water and wastewater networks posed by growing demand and climate change;
- Inform the operation and development of markets, and their regulation, in the long-term interests of customers;
- Make the case for smart design and enforcement of legislation/regulation governing water quality and wastewater in delivering public health and environmental improvements.

KEY DRIVERS

Climate change is bringing more volatile and extreme weather patterns. In just the past few years we have seen severe droughts, floods, and extremes of rainfall and cold weather. This has led to shortages and to too much water, sometimes both at once.

At the same time, environmental standards are getting tougher, particularly around the quality of our rivers and bathing waters. This requires, for example, the highest standards of water treatment and well-maintained sewer networks.

Another big challenge facing many water companies is dealing with growth in population and housing. The UK's population is expected to rise by 10 million by the 2030s and another 10 million by around 2050.

SWOT ANALYSIS

Based on interviews with industry providers, the following SWOT analysis was constructed.

Strengths

- *Strong in adaptive capacity* (situational awareness, response etc) and moving towards a more *proactive stance;*
- *Horizon scanning and future proofing* for > 25 years ahead;
- *Understanding of consumer requirements* - Most customers happy with level of service – water quality important, protection of environment important;
- Some organisations are forward looking – implementing *organisational resilience standard* (BS 65000);
- Industry forum (Water UK) to determine appropriate metrics around resilience;
- Broad understanding of resilience (governance, environmental, social aspects), *consider future trends*;
- Some are *pro-active and doing more* than required.

Weaknesses

- *Consequential loss not captured for consumers* and region as a whole therefore difficult to justify business case for investing in proactive resilience measures e.g. measuring down time, loss of productivity etc.;
- OFWAT provides no return on investment for proactively investing in resilience capacity building;

- *No prioritisation of consumer based on needs/value;*
- *Lack of collaboration with other utility providers*;
- *Lack of' joined-up-ness'* to solve broader flood management issues. E.g. working with DEFRA and EA – reservoir levels a factor in flooding;
- *Regulations are one size fits all;*
- *Drainage system not fit for future.*

Opportunities

- Drinking *water inspectorate change in stance and guidance*. Water quality should not be compromised to maintain supply. i.e. will *punish company that takes a risk*. Need ability to shut water treatment down for more than 24 hours. That will expose a huge requirement for resilience investment;
- *Greater knowledge sharing with other critical utility providers would be beneficial*. As would joining up stakeholders regarding flood resilience;
- *Join up departments* dealing with resilience (asset management, risk management, crisis response, incident response etc);
- *Adopt BS 65000 organisational resilience model;*
- Need national discussion and agenda on *what level of resilience is needed;*
- Ofwat revising metrics therefore opportunity to influence and improve;
- Future consumers seem willing to accept short term outages if benefits environment (i.e. care more about environment);
- *Engagement with consumers helps to understand value and expectations* and drive through industry changes.

Threats

- Seeing increased power outages that are affecting plants - increased reliance on automation will make this a big issue - not currently getting any answers from power providers;
- *Lack of integrated national approach*;
- Ofwat under pressure to perform. Concern that revised metrics rushed through and will *not deliver intended benefit* and will be unfair to water providers and customers.

SUMMARY

Water seems to lead the utility field in terms of resilience. We found some very innovative thinking. One company is using BS 65000 Organisational; Resilience Standard as a basis for understanding its organisation's resilience. This is currently being driven by Ofwat's requirement for resilience as one of its four factors for the 2019 Price Review.

In general, this sector is familiar with the broader resilience definition and are in various stages of maturity in transitioning to this more holistic approach. Still more focus is given to quick response and recovery over upfront mitigation and little incentives exist for investing in proactive resilience building measures. Losses due to disruption are not currently measured financially in terms of loss of revenue/productivity. The number and extent of outages are captured.

Power

BACKGROUND

Gas and oil is moved from source and refineries as necessary by private pipeline and distribution companies to local access points such as home gas networks (provided by the regional transmission companies) or petrol stations. The energy regulator is Ofgem under the supervision of the Department for Business, Energy and Industrial Strategy.

Electricity is generated by various large and small producers. The electricity system is made up of high voltage electricity wires that extend across Britain and nearby offshore waters. It is owned and maintained by regional transmission companies (such as Scottish Power), while the system as a whole is operated by National Grid Electricity Transmission plc (NGET). The sector is rather fragmented with not one provider responsible from the start to end of the value chain. This is illustrated in Figure 11 below, with separate providers for power generation, power transmission, power distribution and power supply. There appears to be limited communication between these entitles and only the suppliers have sight or contact with the consumer.

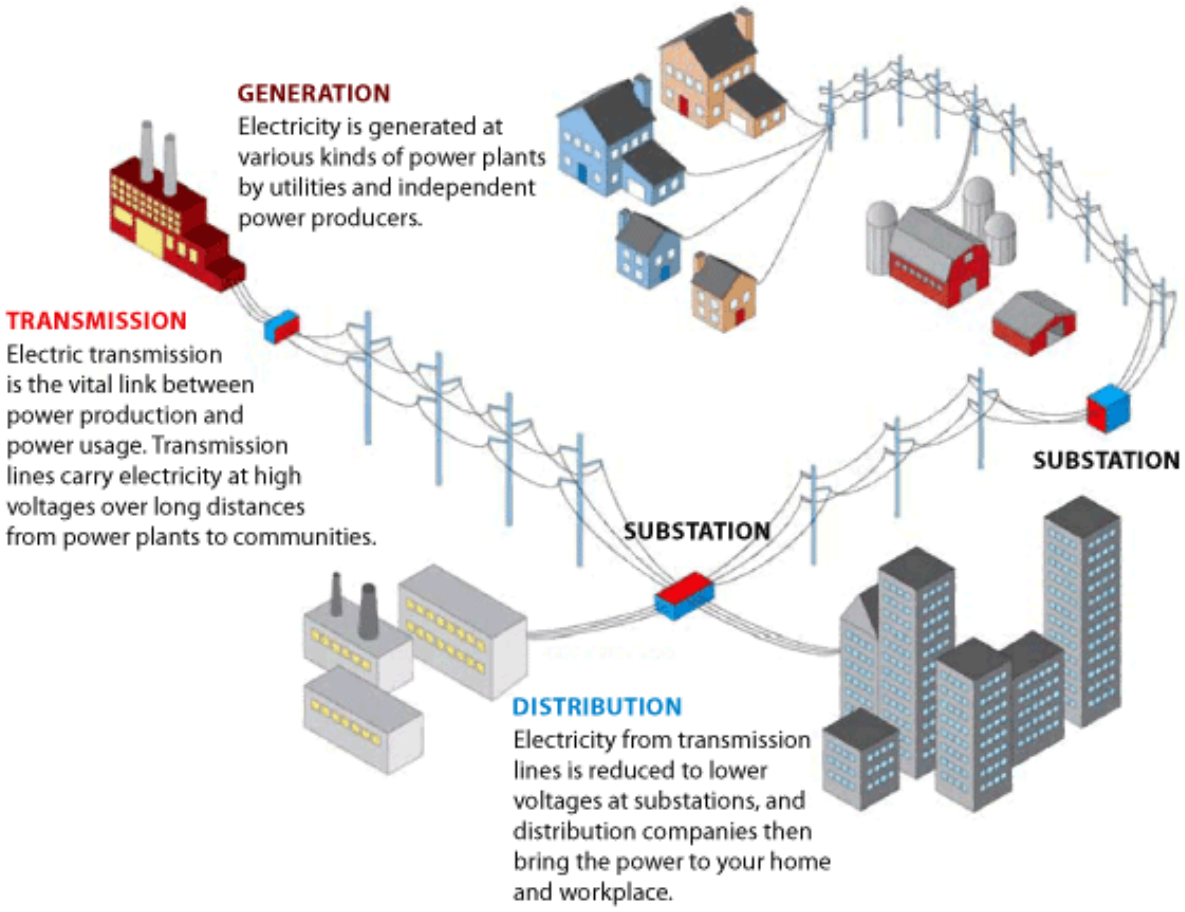

Figure 11 Schematic of UK Power System

SWOT ANALYSIS

Strengths

- They look at future trends – challenges and opportunity, but this tends to be separate team from day-to-day resilience;
- Good level of redundancy within the system;
- Impact of climate change is considered;
- Approach changing from "keep the lights on" to more consumer-focused requirements.

Weaknesses

- Rigid, old infrastructure – expensive to replace and not very adaptable;
- Customer not aware of risk they are bearing;
- No prioritisation of consumer based on needs/value;
- No incentives to work proactively with other providers;
- Business as usual vs all bets are off approach too binary and does not incentivise improving resilience;
- Incentives generate response focus and no cross-sector collaboration;
- Does not foster innovation;
- No return on investment for proactively investing in resilience capacity building;
- Performance judged on number of people brought back on. Not based on value or importance of facility. No prioritisation;
- Company is paid based on how much power they move. Model should be capacity and availability based;
- Consequential loss not captured for consumers and region as whole.

Opportunities

- SMART devices being utilised to automate existing networks;
- Ofgem has opportunity to revise incentives to promote good resilience behaviour;

- Re-structure of industry to provide better linkage of various parts to enable a golden thread through industry;
- Better understanding of what consumer values;
- Ability to control and prioritise service delivery;
- Better understanding of losses that consumer suffers – hence data for building business case for investing in resilience.

Threats

- Structure is fragmented and siloed with no joined-up mechanism to prioritise resilience delivery;
- No golden thread through industry;
- Performance metrics do not incentivise resilience – promotes big response (being seen to show up in force and response quickly);
- Lack of information sharing during delivery process – power generation through to consumer;
- Micro-generation and linking diverse power generation sources to the networks – also creating flows of power and levels of power for which the network was not designed;
- Electrification of rail, and more electric vehicles. Current infrastructure inadequate to meet this future demand.

TRANSPORTATION

HIGHWAYS

Highways England

BACKGROUND

The provision of a road network for use by private and public motor vehicles. Responsibility for the road network differs between trunk and non-trunk routes. Trunk roads, which are the most important roads, are administered by Highways England in England, Transport Scotland in Scotland and the North and Mid Wales Trunk Road Agency and South Wales Trunk Road Agent. These agencies fall under the Department for Transport. Non-trunk routes are the responsibility of the relevant county council or unitary authority. The roads are regulated by the Office for Road and Rail, part of the Department for Transport.

Highways England's roads make up just 2% of the wider road network. They carry one third of all traffic, and two thirds of all freight. The nation's economy - and its people - depend on the network for which Highways England are responsible.

£15 billion will be invested by 2020 to make Highways England's roads safer and smarter. Highways England is a skilled organisation with engineers, project managers, analysts, planners, and more. They claim to be skilled professionals, experts in risk, finance, efficiency, technology and more.

Highways England put safety first: for everyone who uses or works on their roads.

Since 2015, Highways England added more than 100 miles of capacity to England's motorways. 1,471 miles of motorway/trunk road have been resurfaced in two years. They are:

- Improving the capacity of roads while upgrading them to cut journey times;
- Making roads safer with improved junctions and signage;
- Aiming to reduce deaths and injuries by 40% by 2020;
- Cutting congestion with innovative smart motorways;
- Delivering an invested £100 million to keep cyclists safe;
- Reducing noise pollution with noise barriers and low-noise road surfacing.

SWOT ANALYSIS

Strengths

- Government owned, communally operated;
- *Significant skills, expertise and knowledge* especially when sub-contractors considered;
- Significant roads *information management infrastructure.*

Weaknesses

- Limited resources;
- *No holistic strategy* for all highways in the UK;
- *Projects regularly over run*, has been subject to significant criticism from the Public Accounts Committee;
- Highways England implies a direct supplier/customer transaction relationship, however, no such relationship exists and in fact Highways England are somewhat removed from direct network user transactions. This *remoteness from the network user* could be a source of long term problems in terms of *understanding what their value is*, how it needs to be delivered and what are the resilience priorities.

Opportunities

- *Growing need for highways.*

Threats

- *Speed of change – can Highways England keep up with the rate of change needed for highways?*
- *Population increases;*
- *High car ownership;*
- *People spending longer in cars;*
- *Devolution.*

Local Authorities

BACKGROUND

2% of English roads are managed by Highways England; the vast majority of the rest of the highways in England are managed and maintained by Local Authorities. There are 353 Local Authorities in England with highways network management responsibilities. There are no information management systems or accountable governance systems in place for the coordination of these highways network management functions.

SWOT ANALYSIS

Strengths

- *Significant skills, expertise and knowledge* especially when sub-contractors considered;
- Significant roads information management infrastructure.

Weaknesses

- Limited resources – the Highways Network Management Department is one of the largest departments in the Local Authority with significant capital and revenue budgets. Unfortunately, this means it is often seen as an area form which cuts can be made. Highways budgets are not protected and there are *no means to measuring the effectiveness* of these operations. Cuts can be made and the impact of those *cuts will not be immediately felt, understood or directly attributable*;
- Local Authorities have to balance a range of *competing agendas* but *have little budget to invest* in information management systems that will help them prioritise. Local Authorities are also political organisations and in some areas experience a *change in political leadership* every 2 years with a subsequent change in priorities and a learning curve for the incoming administration. The impact of decisions is often not felt immediately and those who make *decisions are not easily held accountable* for them;
- *No holistic strategy* for all highways in the UK.

Opportunities

- *Growing need for highways.*
- Devolution (also a threat).

Threats

- *Speed of change – can Highways England keep up with the rate of change needed for highways?.*
- *Population increases;*
- *High car ownership;*
- *People spending longer in cars.*

Aviation

BACKGROUND

The provision of passenger and freight transport services by air. The UK air industry is largely privately owned. A variety of airlines aimed at different market shares run passenger and freight services. Airports with substantial market power are regulated by the Civil Aviation Authority (CAA). In practice this means that the CAA licences both Heathrow and Gatwick. In addition, it also manages the NATS licence which the government awarded to NATS for the provision of the UK's en-route air traffic services in 2001.

SWOT ANALYSIS

Strengths

- Future thinking is incorporated into risk assessments to some extent.

Weaknesses

- Responsibility for resilience fragmented between various departments. Air traffic control is subcontracted;
- No one individual is responsible for resilience, it is an extra part of everyone's job;
- Siloed within various departments;
- Difficult to articulate business case;
- Understanding of value of comprehensive resilience approach not uniformly held at board level;
- Resilience focused on risk and response rather than mitigations.

Opportunities

- To implement a more joined up, comprehensive approach;
- UK PLC define disruption limits since aviation disruption has large effect on productivity;
- To quantify the benefits (business case) for investing in resilience.

Threats

- Smaller airports are reactive and not proactive, making them more vulnerable to disruption. Mainly due to under investment in resilience resourcing and no dedicated resilience person or team.

Emergency Services

Interviews were conducted covering three of the organisations within this structure, one Fire and Rescue Service, one Local Resilience Forum and one Local Authority.

FIRE & RESCUE SERVICE SWOT ANALYSIS

Strengths

- Fire and Rescue Services (FRS) *core value* is delivered through improving public safety through *preventing, protecting and responding* – this is clear and robust;
- *Resilience is at the core of the FRS value system* with the principles of risk reduction as the preferred option compared to emergency response, although the response still being very important;
- The FRS is very *adept at managing disruption* in the community and with others;
- The fire services nationally look at *developing for the future* through the Fire Chief Council which has an R&D department looking at new technologies;
- The FRS is structured along military lines with clear hierarchies and duplication with the hierarchy to *ensure succession* of command;
- They are also *strong advocates of health & safety practices with a robust culture* of risk minimisation, controls and appropriate reporting including near miss reporting;
- The *strong health and safety culture* puts a strong *emphasis on protecting* the firefighter and command & control structure;
- All FRS' are also obliged to have *business continuity* procedures under the civil contingencies act 2004;
- Resilience as a concept is *culturally accepted* within the FRS as well as being mandated through various legislative instruments;
- Resilience based requirements are not articulated in terms of resilience but through related language;
- The service has *proven to learn quickly* and has *adapted to the new operating environment* following budget cuts of circa 17%;
- FRS' have *formal debriefs following incidents* and share good practice through the Fire Chief Council;
- Response is this organisation's main function;

- The *resilience of the organisation* is such that the strike action in 2014 did not result in identified loss of life.

Weaknesses

- The *time horizon for strategic planning* would appear to be no more than 3 years;
- Long term planning is significantly hampered by the fact the FRS is publicly funded and it is *strongly effected by political change*;
- Its *internal processes to look at its overall resilience are not a mature* as could be expected;
- There would appear to be no formal *vulnerability mapping* for the organisation as a whole.

Opportunities

- The FRS could *improve its horizon scanning* so that it could *better anticipate events* such as the *financial crash* and its subsequent *impacts on public spending*;
- There is a growing realisation that all agencies need *to pool their information and resources* in the future and *work more closely together* like a single entity;
- An *improved Civil Contingencies Act* could significantly improve the current situation for all emergency responders.

Threats

- *Budget cuts* have significantly changed all FRS' across the UK. The challenge has been to deliver the same or *more with less;*
- FRS' were subject to significant strike action in 2014 as a result of staff cuts. Further strike action is a *threat*.

LOCAL RESILIENCE FORUM (LRF) SWOT ANALYSIS

Strengths

- The LRF's main function is response planning which it delivers well within resource limitations.

Weaknesses

- LRFs are mainly constituted by discretionary support by relevant agencies and has a *weak mandate* in the Civil Contingencies Act 2004;
- The *amount of support required* from partner agencies to meet the minimum set out by law is *very little*;
- LRFs have very little power or *capacity to effect change* or *improve performance*. LRFs have no *centrally funded capacity*, with all capacity provided at the *discretion of partner agencies* with *very few governance controls*;
- Resilience is not the *remit* of LRFs – LRFs are focused and only have a *remit* for multi-agency response planning rather than the *whole disaster management cycle;*
- LRFs have very *little capacity* to *assess and manage their own risks* or to support the organisational risks to their partner agencies. It has a very basic community risk register but there is no *link between risk, planning assumptions, capability assessment, plans and strategy.*

Opportunities

- There is an opportunity to building community resilience within the area. The Deputy Chair of the LRF has been *driving this agenda* forward. He has also been driving the need to improved catastrophe planning.;
- The CCA 2004 should be revised to *strengthen* the role of LRFs and improve their *mandate*, *resourcing* and partner agency *commitments*;
- There is a growing realisation that all agencies need to *pool their information and resources* in the future and *work more closely together* like a single entity;
- The LRF is undergoing a programme of *change* driven by the Chair and Deputy Chair to increase the *value added* by this forum.

Threats

- The LRF challenges include the limited *commitment* by some partner agencies largely due to continuing *public sector cuts* that result in some agencies *prioritising* other work.

Summary of Industry Insights

The above reviews of various national infrastructure found the following common themes:

Governance	
	Where horizon scanning was done well it was valued, other stakeholders saw they were deficient
	Effective governance controls helped drive good performance
	Good governance included holding people accountable for decisions
	Most stakeholders acknowledged they had Immature internal processes to look at resilience
	Cultural acceptance of resilience was an important factor for maintaining resilient systems
	Integration of governance structures also improved resilience and performance
Prioritising	
	Assess and manage risks was essential as it allowed effective prioritisation and linking risk to action
Understanding	
	Organisations needed to understand their vulnerabilities and mapping these within a system was seen as a powerful tool
	Having a holistic strategy linking the golden thread of the organisation was seen as important
	Having a means of measuring effectiveness
	The Impact of cuts on organisational resilience was not understood
	Some organisations didn't understand their value and their position within their value chain
	Information management infrastructure is critical to developing situational awareness
	There was a general inability to understanding the impact of losses that consumer suffers
	It was also noted that customer not aware of risk they are bearing despite this being understood by organisations planning to deliver infrastructure

Learning & Adapting	
	Formal debriefs following incidents are essential to learning
	The ability to learn quickly and adapt has saved some organisations
	Adapting to new operating environment
	Some organisations are adept at managing disruption externally but less able to manage disruption internally
	A proactive stance that fosters innovation
	Strong in adaptive capacity
Productivity	
	A key to productivity was a continuous drive to do more with less
	Productivity can be improved by working more closely together
	Pooling information and resources
	Developing for the future
	Clear and coherent performance metrics
Change	
	Change includes opportunities as well as threats
	Threats for the future included:
	Financial crash Public sector cuts
	Political change, both structure (Brexit) and policy (controlling party)
	Speed of change – can infrastructure keep up with the rate of change needed e.g. highways?
	Population increases
	High car ownership and people spending longer in cars
	SMART devices being utilised to automate existing networks
	Climate change

Value	
	Being able to add value, protect value and improve performance
	Core value of preventing, protecting and responding
	Resilience is at the core of some organisations value system
	Creating and protecting value is at the heart of the business case for investing in resilience
	Capital projects must deliver intended benefit
	Engagement with consumers helps to understand value and expectations
Mandate	
	A clear mandate or commitment, remit or case is essential
	Weak mandates hinder performance and produce weak organisations
	Need to improve the Civil Contingencies Act 2004
	Regulations are one size fits all and not always supporting innovation and resilience
Strengthen	
	Resilience needs to view the whole disaster cycle
	Emphasis on protecting and ensure succession
	Good level of redundancy
	Rigid, old infrastructure is a barrier – expensive to replace and not very adaptable
	Organisational resilience standard is very useful, some organisations are adopting the BS 65000 organisational resilience model
	What level of resilience is needed?
Will	
	Will is driving the agenda
	Current incentives need to be revised as they generate response focus
	Regulators tend to punish companies that takes a risk thus dissolving the will for innovation

Capacity	
	Emergency services need centrally funded capacity for multi-agency planning and organisation.
	Adaptive capacity can be seen as the capacity to effect change
	Limitations of resources, skills and expertise undermine the ability to be proactive and effect change
Effectiveness	
	Joined up departments increase effectiveness

These are all quotes directly lifted from interviews with industry experts.

ANALYSIS & RECOMMENDATIONS

Defining and measuring Value

As discussed earlier, value acts as the golden thread joining up a system and sub-systems. Given that resilience is about protecting value, this makes value definition and measuring value a critical aspect of resilience building. Value can be measured in many ways, most commonly in terms of money/finance e.g. cost, insurance value, profit, investment. Indeed, money was developed to convert subjective value to comparative value facilitating the trade of unrelated goods and services. This is also a central role of economics; to study comparative value determined by supply and demand within an environment of scarcity.

However, as *Figure 12* shows, value has been defined in the following ways, (although should be tailored to each organisation); **financial** value (profit, meeting shareholder requirements, affordability for customers etc); 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); reputation and **social** value (culture, integrity, trust, aspiration, meaning, belonging, desire, security, public perception, social good); and finally **environment** (enhancing natural environment, reducing emissions, environmental stewardship, etc.) It is important to note that reputational valuations are the most complex and colour all others. They are a mixture of perception and emotion.

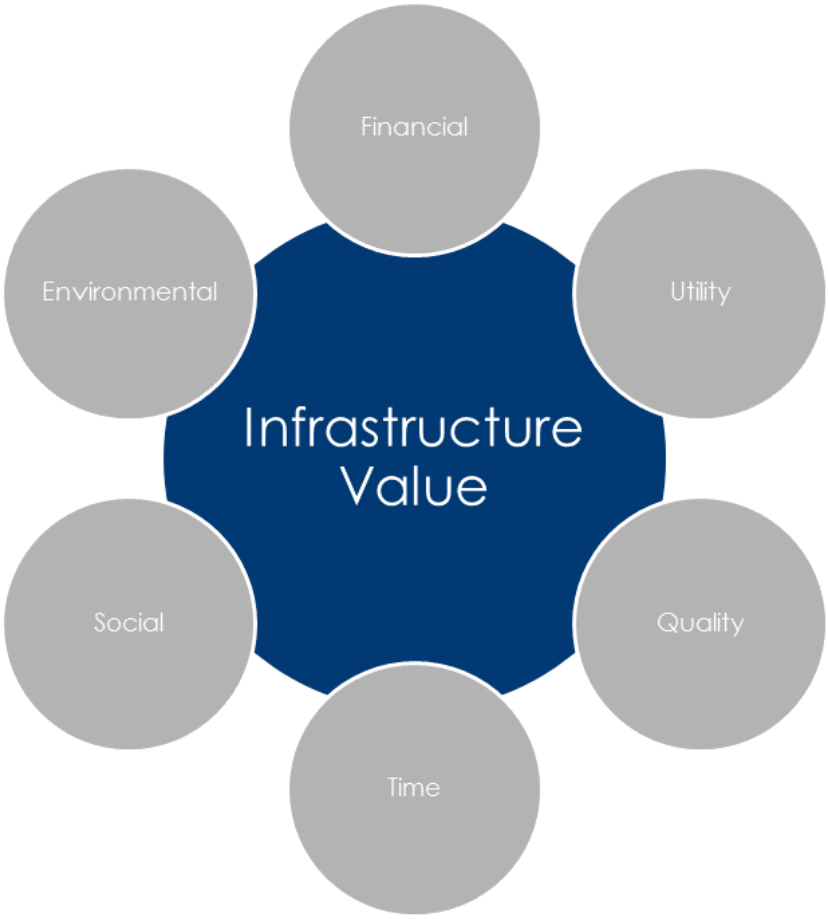

Figure 12 Understanding Value

Value is also dynamic not static. It is not in one time or place and does not belong to one person, although it is felt by everyone individually. We make value judgements constantly about everything. Financial value is determined by the ability of a product or service to satisfy a human want, not what it costs to produce or deliver. These wants are constantly changing.

According to ISO 31000 Risk Management, the first principle of risk management is to create and protect value; and risk management is a key component of governance for this reason. Within organisations value is predominantly determined by customers, investors and employees with a wide range of other stakeholders having influence. In these terms the parts of the organisation that have the best understanding of value should be, marketing, governance and human resources. If these departments do not understand the organisation's value, they are unable to create and protect it and inform how the organisation needs to be developed to ensure it is fit for the future.

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.

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. 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

Customers want good quality service at what is a perceived low cost. Infrastructure that is perceived to be poor value for money can be seen as profiteering.

RETURN ON INVESTMENT

Investors want a return on their investment that is competitive.

STABLE AND LOW RISK OR HIGH RISK HIGH REWARD

Investors want to minimise risk for their investments or to take risks but have a high reward as a result.

PROFITABLE

Investors and all parts of the value chain, excepting customers (although many customers may also see they have an interest in the organisation's profitability), have an interest in the organisation remaining profitable. This allows suppliers and investors to be paid.

EFFICIENCY

Investors and the organisation are interested in efficiency and reducing waste as this increases working capital and profitability. This is also strongly linked to productivity.

APPRECIATION

Investors are particularly interested in their investment gaining market value i.e. increasing share price. This is also useful to the organisation as it protects against take over.

REVENUE

Suppliers are interested in the revenue they can receive from the organisation. The profitability of this revenue is key.

CREDIT RATING

Suppliers often need assurance of the credit worthiness of an organisation, especially if there is no existing relationship, as they want to minimise the risk of not being paid.

WIN-WIN RELATIONSHIPS

A win-win relationship is where the organisation and suppliers all make a reasonable profit within a stable business relationship.

Utility

DELIVERY OF BASIC SERVICE/SUPPLY

A service user/customer wants the delivery of basic services or supply.

FACILITATE PRODUCTION

Business customers need services and supplies to facilitate their operations.

PREDICTABLE

All service users/ customers need their services and supplies to be predictable.

ON DEMAND

All service user/ customers expect their infrastructure to be available on demand.

Quality

WITHIN RECOGNISED STANDARDS

All service users/ customers expect infrastructure to operate within recognised standards e.g. healthy, safe, clean, etc.

MEETING SERVICE EXPECTATIONS

All service users/ customers have unspecified expectations of infrastructure that need to be met e.g. standards of behaviour, corporate responsibility.

EASY COMMUNICATION & ISSUE RESOLUTION WHEN NECESSARY

Service users/ customers value infrastructure organisations with whom it is easy to communicate and resolve issues.

OPEN & TRANSPARENT

Service users/ customers value organisations that provide a perception of openness and transparency – these help engender trust.

UNOBTRUSIVE

Service users/ customers expect infrastructure to be unobtrusive i.e. they just want it to happen and not be concerned about how.

SAFE & SECURE

Users/customers expect all infrastructure to be safe and secure, this include the information provided to and generated from the infrastructure.

MINIMAL DISRUPTION

Service users/customers expect to suffer no disruption to their infrastructure.

LEARNING & IMPROVING

Service users/ customers expect to see investment and improvement in the infrastructure over time.

CONSISTENCY

Service users/ customers expect infrastructure to be delivered consistently across the country; between cities and rural areas; between rich and poor areas; etc.

Time

IMPROVE PRODUCTIVITY

Efficient and effective infrastructure improves productivity e.g. the less traffic congestion there is on the roads, the more time people can spend productively working or consuming other goods and services within the economy.

MINIMAL WAITING

Service users/customers value time and do not want to waste time waiting.

24/7

Service users/customers expect 24 hour, seven days a week utility of infrastructure.

Social

CUSTOMER SATISFACTION

Service users/customers will devalue their perception of any infrastructure that fails to meet their expectations. The more frequently those expectations are failed, the greater the devaluing of the infrastructure.

DEPENDABLE

Service user/customers expect infrastructure to be dependable. They can be understanding regarding one off major events but regular failures/disruption due to identified hazards is not acceptable; this also applied to gradually worsening service due to stress factors such as climate change or population growth. Resilience is expected as is planning for future events and stress factors.

TRUSTWORTHY

Service users/ customers and investors value trust. Failures, poor performance or poor behaviour undermine that trust and devalue the organisation. In this way, a trusted organisation is also a reduced risk organisation. E.g. a company that fails to secure customer data can expect significant devaluation.

ENVIRONMENTALLY FRIENDLY

Although the relative value placed on environmental issues varies between service users/ customers; poor environmental credentials will ultimately devalue the organisation.

NOT PROFITEERING

Linked to value for money, a company perceived as delivering poor value for money within a limited market arrangement can be seen as using the market to generate excessive profits. This perception can exist regardless of the reality.

FAIR

Service users/ customers expect to be treated fairly.

RESPONSIBLE

Service users/ customers expect organisations to behave reasonably, and indeed this is often the legal test set within disputes.

FUTURE READY

Linked to resilience, service users/customers expect infrastructure to develop to meet future needs, such as electric car and rail, automation and deregulated micro-power generation.

REPUTATION ENHANCING

Suppliers value business with an organisation that will enhance their reputation through that business relationship.

Environmental

ENVIRONMENTALLY FRIENDLY

Suppliers and customers value a business that does not harm and has a positive influence on the environment. Some suppliers and customers will avoid organisations that are seen as harming the environment.

REDUCED IMPACT

The value of organisations will be partially judged on the negative or positive impact they have on the environment.

REDUCED EMISSIONS

Organisations seen as overtly emitting harmful fumes and particulates will have value judgements made about them.

SUSTAINABLE

Customers and investors value organisations that are sustainable both in terms of operating in a manner that can be sustained by the environment, but that also have a business model and management regime that can stand the test of time; providing a level of certainty.

OPTIMISING ECO-SYSTEM SERVICES

Eco-system services are the multitude of ways that all kinds of ecosystems benefit society. Benefits regularly include the provisioning of clean drinking water and the decomposition of wastes. Benefits fall into four broad categories: provisioning, regulating, supporting and cultural. Optimising eco-system service delivers real value in other categories, but also

organisations seen as optimising eco-system services will also receive an improved value perception.

ENVIRONMENTAL STEWARDSHIP

Suppliers, investors and customers value organisations that are seen to be environmentally sustainable; operating in an environmentally responsible manner to protect the environment for future generations.

SUSTAINABLE LAND MANAGEMENT

There is a market value for organisations that are seen to integrate the management of land, water, biodiversity, and other environmental resources to meet human needs while ensuring the long-term sustainability of ecosystem services and livelihoods.

ADAPTING TO CLIMATE CHANGE

Organisations that are seen to enhance their resilience through specific measures to adapt to the impacts of climate change can receive a better market valuation.

The Comparative Value Assessment

The above value assessment criteria were weighted in terms of relative importance and then each type of infrastructure (this report if 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 complied and an overall assessment score produced. These scores are shown in Table 2.

Table 2 Results of Comparative Value Delivery Assessment

Transport	
Road	56%
Rail	62%
Air	71%
Sea	74%
Public	62%
Power	77%
Communications	69%
Flood & Coastal Erosion	82%
Science & Research	81%
Waste	
Solid	81%
Water/Sewage	83%
Water	88%
Education	69%
Health	67%
Justice - Prisons	72%
Housing & Regeneration	73%
Cyberspace	88%
Emergency Services	76%
Finance	66%
Defence	84%
Civil Nuclear	80%
Chemicals	82%

There does appear to be a link between state ownership, strength of regulation and value rating.

To illustrate how value and infrastructure systems inter-relate, and following interviews with stakeholders from within selected infrastructure types, a number of simple systems diagrams have been created as shown in Figure 13, Figure 14, Figure 15, and Figure 16:

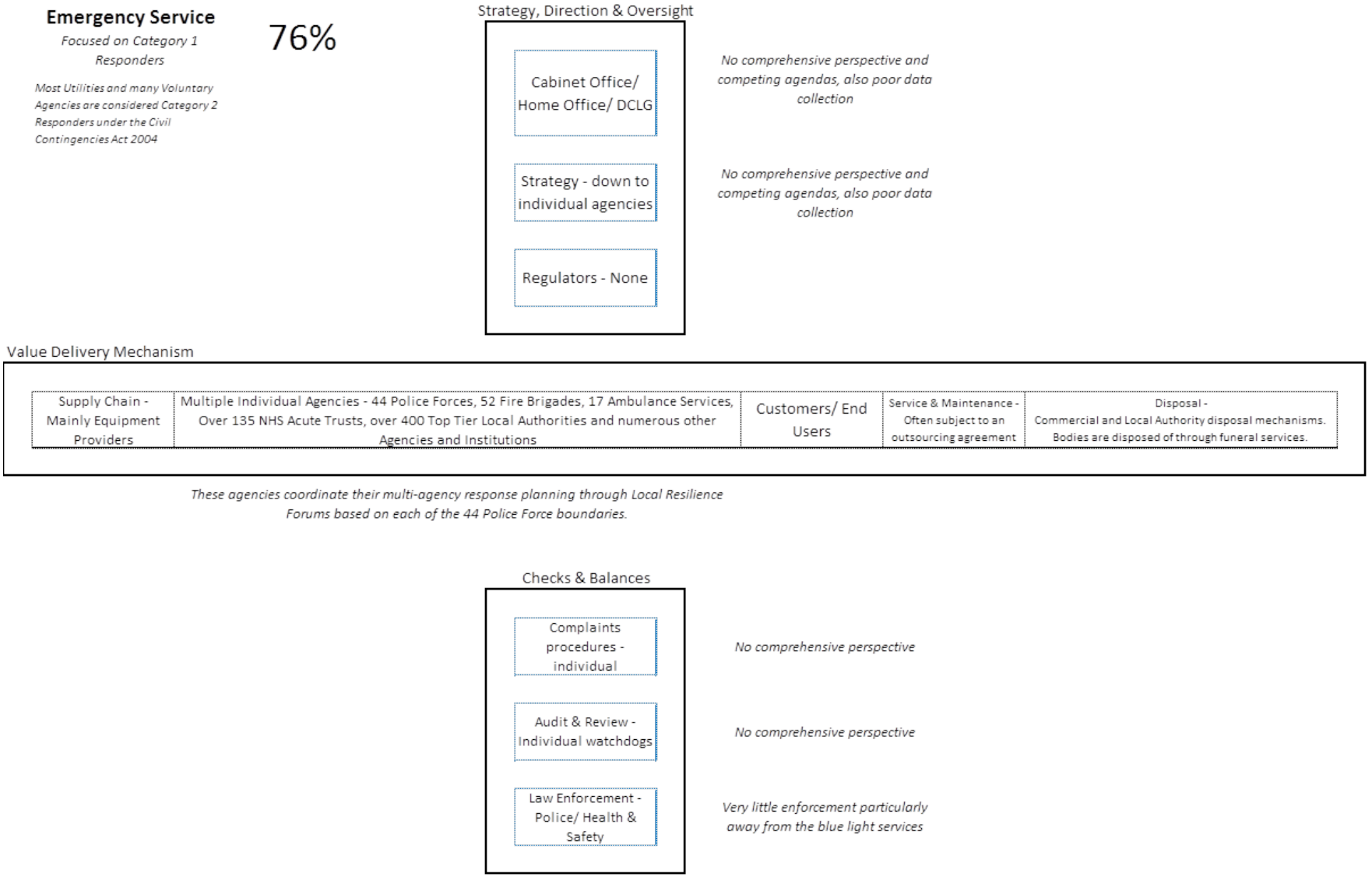

Figure 13 Simple Systems Diagram of Emergency Services

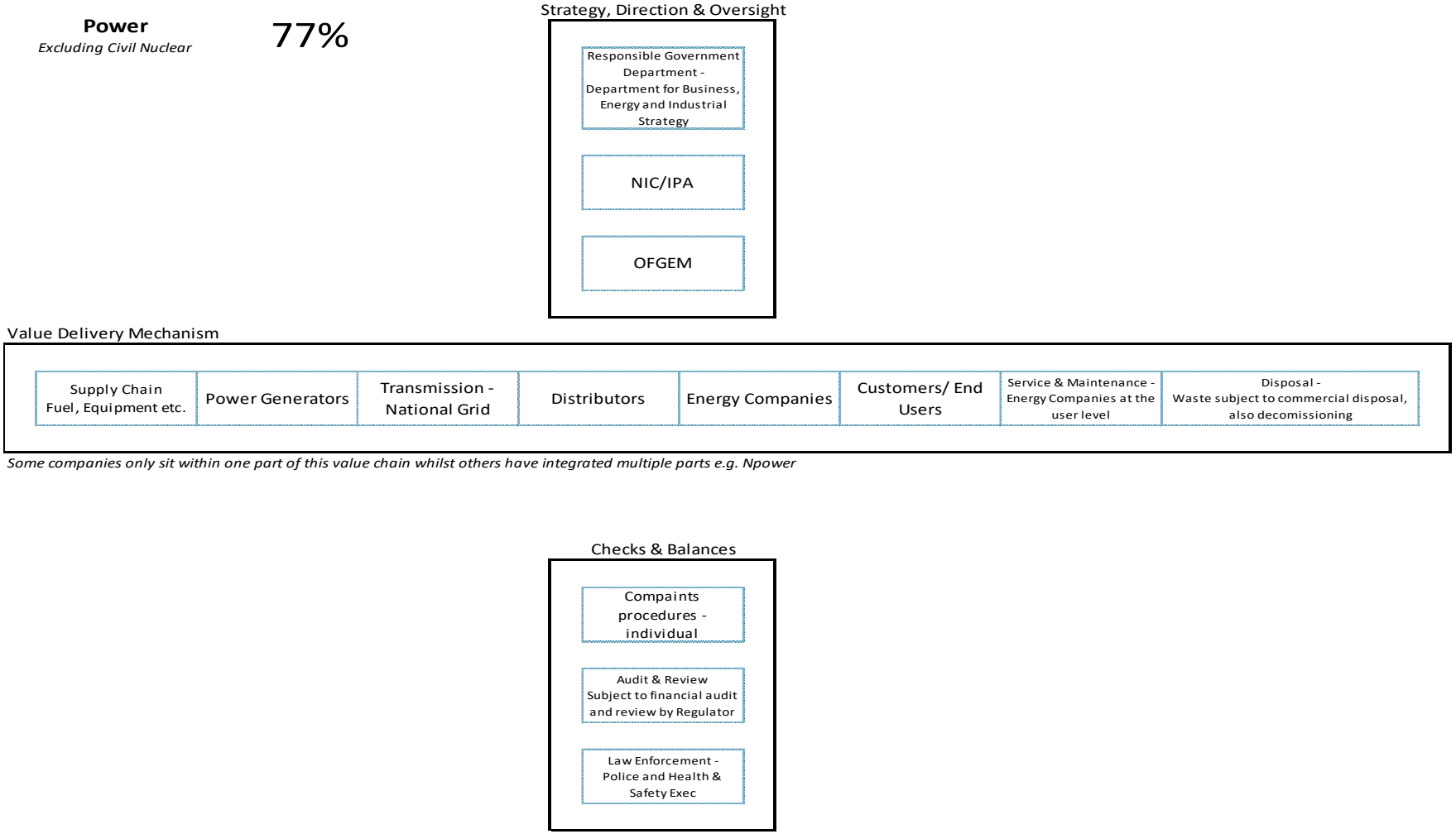

Figure 14 Simple Systems Diagram of Power Infrastructure

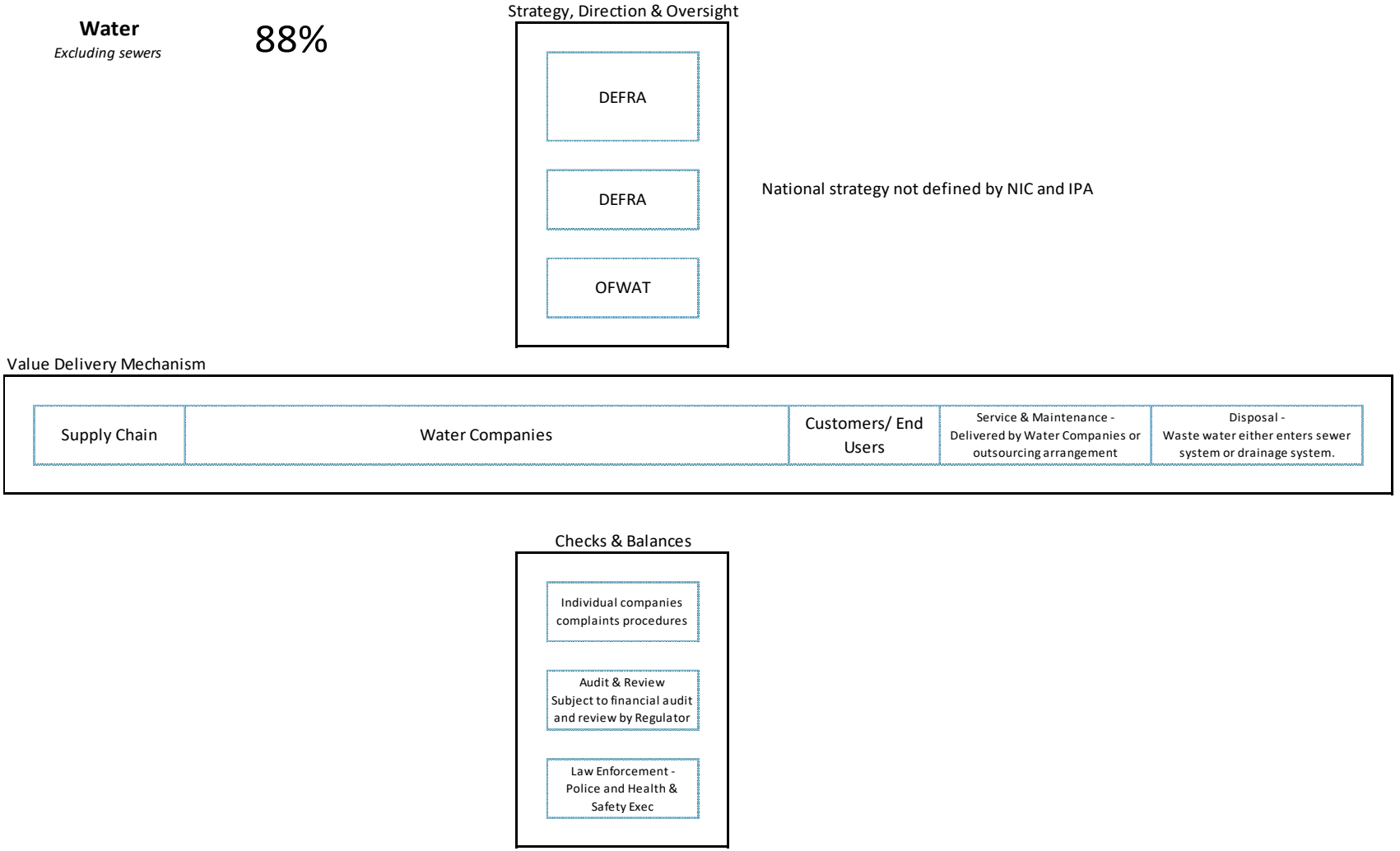

Figure 15 Simple Systems Diagram of Water Infrastructure

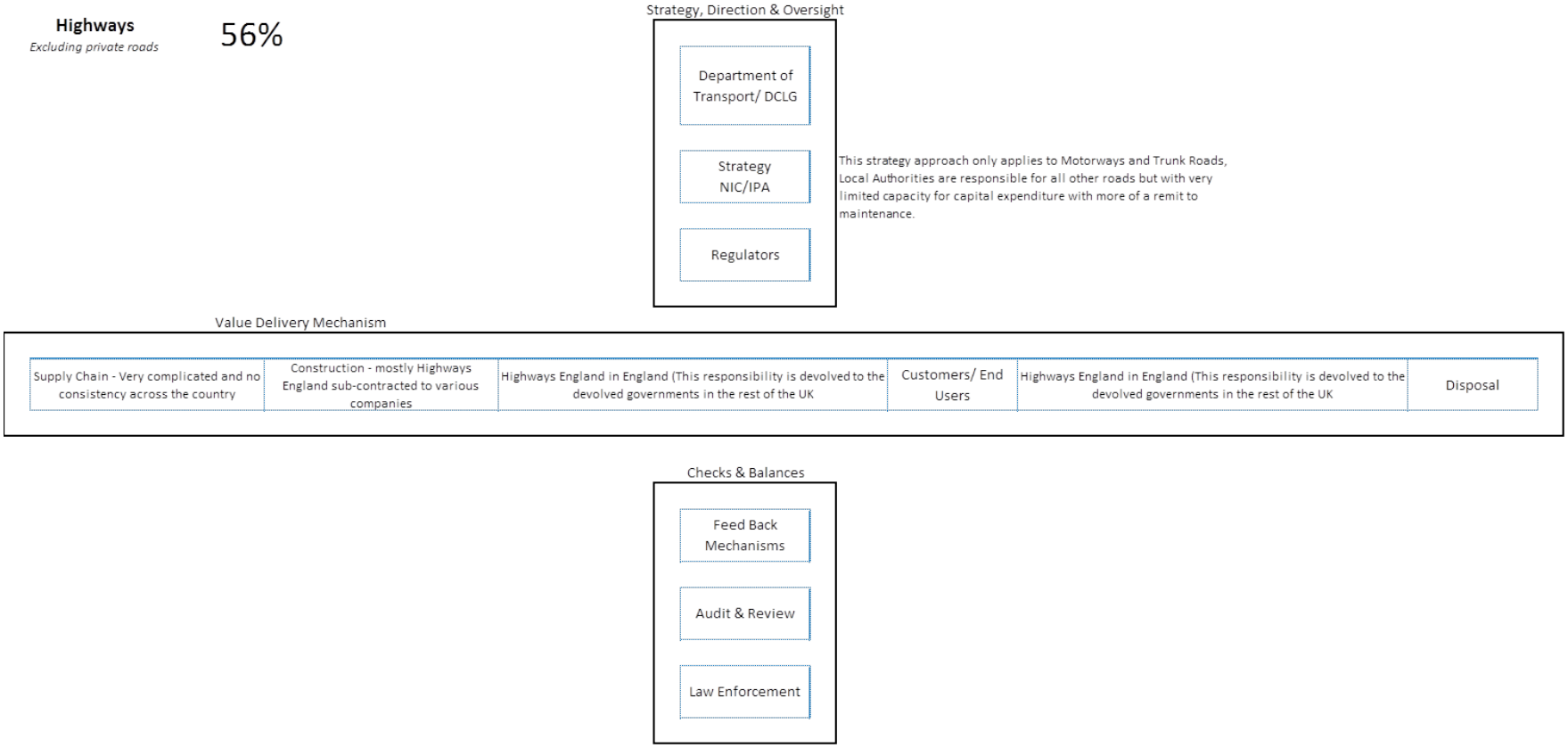

Figure 16 Simple Systems Diagram of Highways Infrastructure

The above figures show their respective value assessment scores (on a scale of 0 through 5, with 0 meeting expectations). To illustrate the usefulness of this diagnostic, there is a further breakdown of the value assessment shown in Table 3:

Table 3 Individual Infrastructure Value Assessment Results

Description of value	Highways	Power	Water	Emergency Services
Value for Money	2	1		3
Return on Investment	3	1	1	3
Risk Reward Balance		2		
Efficiency	3	2	2	3
Appreciation	1	2		
Revenue	4	2	2	1
Win Win Relationship	1	1	1	1
Delivery of basic supply/ service	2			
Facilitate production	2			
Predictable	3		1	
Within recognised standards	2		1	

Description of value	Highways	Power	Water	Emergency Services
Meeting Service expectations	3	2		
Easy communication & issue resolution when necessary	3	3	1	2
Open & transparent	2	3	3	2
Unobtrusive	3	1	2	
Safe & Secure	2	1		
Minimal disruption	4			
Learning & Improving	3	1	2	1
Consistency	4	1		
Improve productivity	4			
Minimal waiting	2			
Customer satisfaction	4	1		2
Dependable	1			
Trustworthy	2	2		

Description of value	Highways	Power	Water	Emergency Services
Not profiteering	2	2		
Responsible		1		
Future proofing	3	1		2
Future ready	3	1		2
Reputation Enhancing (to do business with)	1	1	1	
Environmentally Friendly	3	2	1	4
Reduced Impact	4	2	2	4
Reduced Emissions	4	2	2	4
Sustainable	3	2	1	4
Optimising eco-system services	3	3	1	4
Environmental Stewardship	3	3	1	4
Sustainable Land Use	3	3	1	4
Adapting to Climate Change	2	2	1	4
Percentage of Available Score	56%	77%	88%	76%

Table 3 shows how each infrastructure type was assessed in terms of delivering against the value metrics. The higher the number, the greater the room for improvement. Most of the assessment was subjective although evidence from interviews and other data was used to determine relevant ratings to offset inevitable biases. The subjective nature of this assessment would be strengthened through a broader survey based study on public and industry value perceptions; until such a study is undertaken, there is low confidence in the repeatability of these results. From this assessment, it is quick to see why road infrastructure appears to rate the lowest, followed by Power, then the emergency service and finally water.

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 no 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, but 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 prepare 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 are 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.

A Framework for Delivering & Protecting Value

Based on the findings of this study there are a number of functions that are essential for delivering resilience. Suggested grouping terms are provided below:

- Understanding the operating environment
- Forward strategic View
- Good governance
- Risk Management
    - strategic,
    - enterprise
- 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 17 alongside the underlying value metrics against which value can be defined.

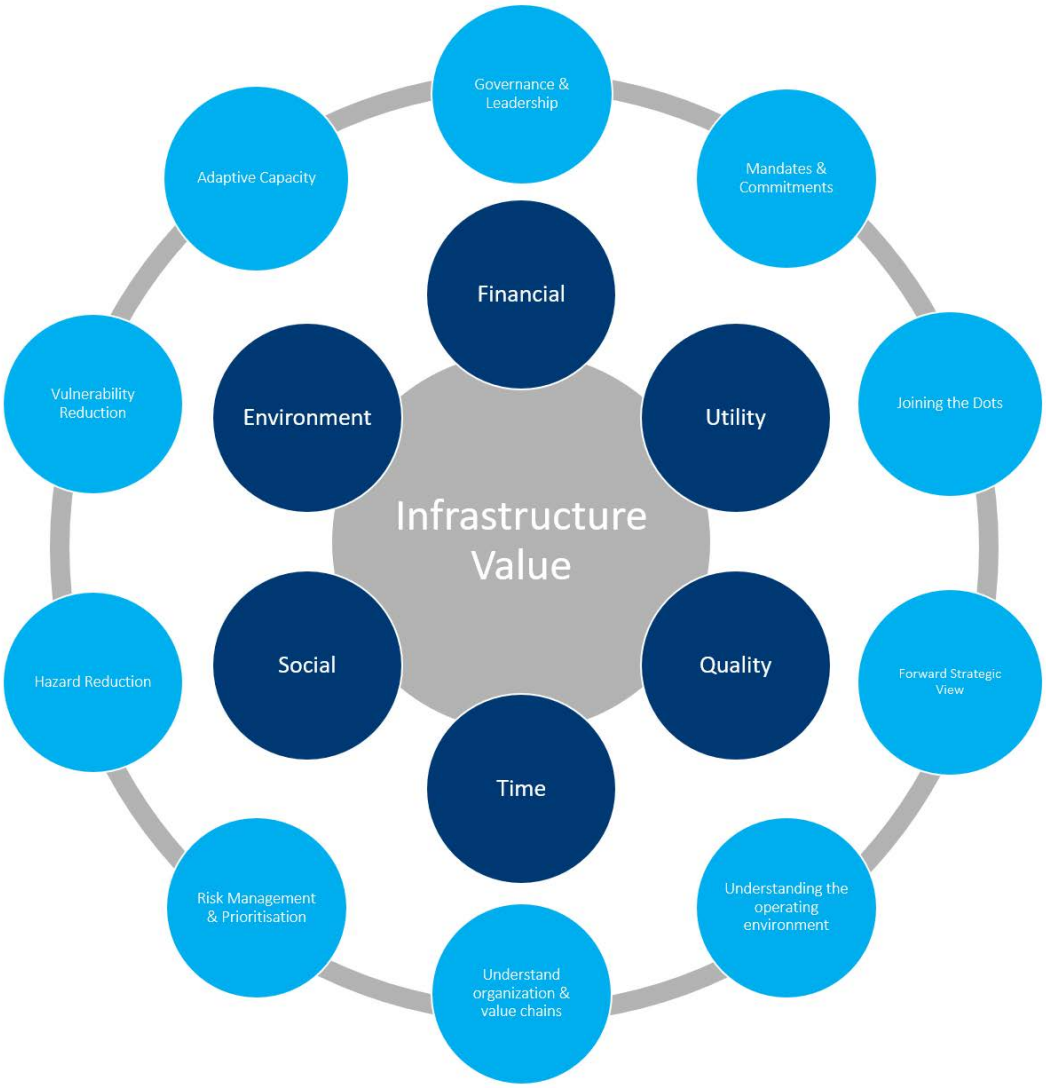

Figure 17 Organisation Resilience Conceptual Framework

PROPOSED PROCESS

Infrastructure comprises complex systems of systems with diverse ownerships and subject to a range of shock and stress factors. Building the resilience capacity of infrastructure must be seen as an ongoing process of defining the core value and how it will change; assessing and analysing the constituent parts within the disruptive and changing environment. Based on a good understanding of the operating environment, clear direction and strategies to build the resilience of infrastructure are required, supported by appropriate leadership and governance. Initiatives to build resilience must be implemented whilst maintaining constant review; allowing for learning and adaptation of plans ensuring resilience capacity building meets the needs of the organisation now and in the future. The following process builds on the principles outlined earlier and provides a mechanism to build resilience over time. Taking the basis of value protection and realisation along with the important components for delivering resilience discussed on page 73, a process has been developed which is shown in *Figure 18* and described below.

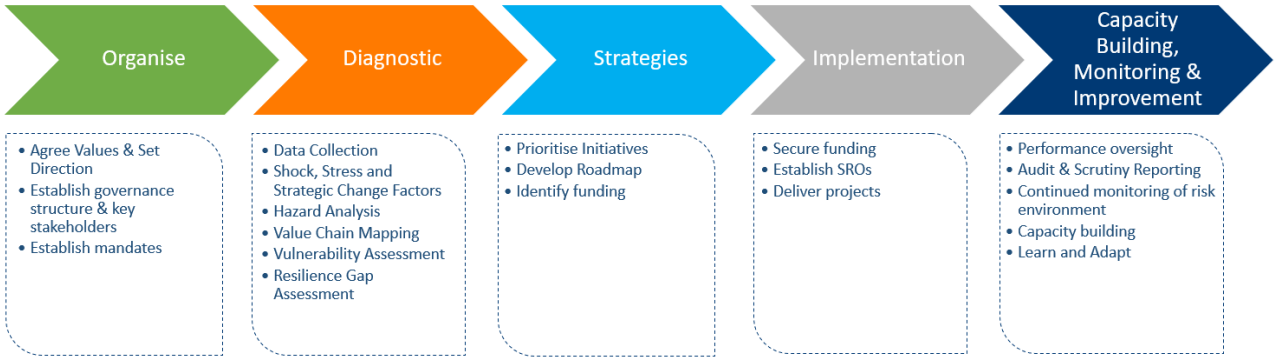

Figure 18 Proposed Infrastructure Resilience Building Process

1 Organise

GOVERNANCE & LEADERSHIP

Good governance and leadership are perhaps the two greatest determinants of success for a holistic resilience capacity building programme.

Themes around governance controls, accountability for decisions, the ability to prioritise competing agendas in an open and transparent way as well as good communications and collaboration came through strongly from stakeholders. What also came through clearly was the pivotal role of government and regulators in setting the conditions for effective infrastructure, resilience capacity building and collaboration to deliver more value through value chains. Regulators and the structure of incentives they put in place have a significant influence on market behaviour and some of that influence has unintended consequences.

Resilience is top down and bottom up; it needs to be driven by leadership but needs to empower employees and stakeholder to develop a resilient culture & behaviours.

MANDATES

At an infrastructure level, leadership needs to be supported by cross-organisational mandate and subject to the checks and balances of an inclusive, accountable, open and transparent governance system to prevent abuse of power or ineffective delivery and waste. This should include:

a) Accountability for decisions

b) The ability to prioritise competing agendas in an open and transparent way

c) Good communications and collaboration

d) Regulations & incentives to build resilience.

Mandates can take the form of statements of commitment, policy, business cases, legislation or regulation and are strengthened with incentives (the carrot and the stick).

COMMITMENT

The governance structures must maintain overall control of the resilience capacity building programmes. They must make a commitment to delivering the vision and improved resilience; agree the roadmap and supporting policies and strategies; assign resources; consult and engage with stakeholders; establish mandates for action; remove barriers and agree business cases for significant projects. The commitment can often be summarised within a short Resilience Policy.

JOINING THE DOTS

Statements such as “joining the dots” and “clear direction and structure” expressed the need for an overarching strategy for each infrastructure value chain that developed the infrastructure to meet future needs. For many types of infrastructure this role is delivered by the National Infrastructure Commission supported by the Infrastructure and Projects Authority; however, this is not true for all infrastructure leaving a significant infrastructure resilience gap. With infrastructure the principle of centralised planning, decentralised execution is essential if the UK’s infrastructure is to be coherent.

Resilience requires breaking down the traditional silos to work together around a common goal. Relevant stakeholder groups need to be engaged, setting clear mandates for action, removing barriers, clarifying priorities, supporting information flows across boundaries and encouraging the right behaviours through example and enforcement. This is often best achieved through a cross sector forum with the right strategic representation. From this frame of reference and through further stakeholder engagement

the long-term vision for infrastructure can be constructed. The vision provides the golden thread that will link all the resilience capacity building initiatives together. It needs to include a well communicated desired end state.

FORWARD STRATEGIC VIEW

A common theme proving to be a strength or weakness for the organisations interviewed was the ability to take the long view of the operating environment. For example, the electricity sector is playing catch-up with technology and will struggle to fulfil the demand from rail electrification and the transition to electric vehicles. Also, there was limited reference made to the critical role infrastructure has regarding the productivity and therefore competitiveness of the nation; this is a fundamental of infrastructure. Those organisations that were better able to take that long view were in a position to anticipate market needs in advance and put effective strategies in place for their organisations to meet that need. Taking the long view must be based on effective data sources that allow projection and scenario hypothesis to be created from which relevant strategies can be developed. This should be seen as a reiterative function for the top level of governance in the organisation based on an ever-greater bank of data/information.

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.

2 Diagnostics

UNDERSTANDING THE OPERATING ENVIRONMENT

The starting point for developing more resilient infrastructure is to understand the operating environment. The key elements to understand are the value the infrastructure delivers, the value chain used to realise that value, threats to that value chain and opportunities represented in the environment. The value chain is in effect the structure of the industry including government and regulators. A key source for such information should be customers, investors and other stakeholders; their needs and expectations. The core value of the value chain acts as the golden thread that should link together strategies, governance controls, performance management metrics, risk management impacts assessment criteria etc. Additionally, data needs to be captured on the cost of disruptions, for example the loss in productivity, so that the business case for investing in resilience can be strongly made.

Additionally, a comprehensive risk assessment should be undertaken that considers shocks and stresses and incorporates horizon scanning for future trends and stress factors.

UNDERSTANDING THE ORGANISATION

The next part is understanding the organisation and the value chains that deliver the organisation's value and their susceptibility to the identified shocks and stresses.

The value chains will include people, processes, suppliers, physical infrastructure, virtual information as well as customers and the environment. These systems first need to be mapped and then the importance and vulnerability understood.

Taking stock of existing resilience capacity and how this will change over time in light of global and structural stress factors is an essential component of developing a resilience diagnostic. The current capability of the infrastructure/organisation to resist or respond to these factors would ideally be through proactive risk reduction measures, but also through the agility of the firm to respond, recover, learn and manoeuvre quickly. The resilience capacity of these value chains can be measured considering the following:

a) Measures taken to reduce vulnerability:

Terms such as strengthening, redundancy, protection and fail-safes are all forms of vulnerability reduction; however, vulnerability reduction cannot be systematically approached or designed until value is properly understood and all the elements needed to create that value. This can be described as vulnerability mapping and when performed in combination with a robust understanding of risk, can provide a prioritised programme of measures needed to reduce vulnerability starting with the areas of greatest need.

b) Measures taken to develop adaptive capacity (agility):

Adaptive capacity is the capacity of people, organisations, cities, regions, nations and trans-national organisations to anticipate, respond, learn and adapt to the changing environment. Measurable strategies for adaptive capacity include an effective response system that provides good preparation, response capability, recovery and the ability to learn, adapt and improve. Adaptive capacity can be seen as the capacity to effect change, adapt to a changing operating environment in line with or ahead of the speed of change. Adaptive capacity is a combination of many of the elements above and is characterised by a proactive and agile stance to identifying and responding to change.

The key enabler of adaptive capacity is data, leading to exploitable information. The more this information can be collected and shared throughout the value chain, the more adaptive that value chain will be, and by means of that, the more resilient each organisation within that value chain can be. Again, this level of integration must be built on a relationship of mutual trust, which is itself underpinned by leadership, culture and behaviours. Technology and cyberspace represent significant threats and opportunities in this area for the future. What is clear is that those organisations that are slow to realise the potential of information sharing, integration and the use of

information technologies to facilitate this, will be the ones that drop by the wayside. Although they may also be joined by organisations that fail to provide sufficient security in this area.

PRIORITIZATION

It is important that resilience building is prioritised to those areas with the greatest risk posed by those shocks and stresses that have the potential to cause the most disruption or realise the most potential opportunity. The gap between the risk and current measures can be determined as a means for prioritising action. This needs to lead to a gap analysis of current and future resilience demands against current and future capacity.

3 Strategies

The complexity of resilience capacity building at a whole infrastructure scale needs to be coordinated through a strategic planning process such as a roadmap or blueprint depending on methodology. There are hundreds of potential initiatives needed to cohesively and comprehensively build resilience. Lots of these strategies already exist, but coherence is needed to realise the co-benefits from joining these up around a common resilience goal focused on delivering value. Metrics need to be devised based on these core values in order to prioritise the various initiatives and form an overall roadmap.

Resilience Capacity Building will include the following types of strategy to achieve the following:

- Hazard reduction or avoidance
- Vulnerability Reduction
- Developing Adaptive Capacity (agility)

Some of the strategies may be legislative, some may be physical and some will be process or people orientated. These strategies needs to be prioritised based on need, benefit and interdependencies.

A robust business case should be developed that incorporates measurements of resilience benefit – e.g. reduction in disruption, increases in productivity.

4 Implementation

The implementation of the roadmap should be left to managers to deliver with control being maintained by leadership and governance structures through periodic or staged reporting. Portfolio, Program and Project Management methodologies promoted by the UK Cabinet Office (AXELOS) are recommended.

Governance arrangements support implementation by establishing Senior Responsible Owners (SROs); maintain executive control; removing barriers; stopping projects where necessary; ensure benefits are realized; publicly showing support and leading by example.

5 Monitor, Validate, Review, Learn and Adapt

Resilience building progress needs to be monitored to ensure outputs are being delivered on schedule and benefits are being realised. Audit, public scrutiny or regulatory oversight should provide assurance of fit and appropriate action. All capabilities delivered as part the of resilience capacity building should be tested individually and exercised as part of wider systems with learning and recommendations feeding back to leadership and governance systems. This also applies to any real incidents or significant near misses that occur from which organisations can learn, adapt and be better prepared.

Leaders and organisations should expect learning to come from all disruptions so that infrastructure advances from disruptive experience, using it to increase adaptive capacity and ultimately increase competitive advantage. The focus needs to be on the realisation of broad resilience benefits rather than the short-term outputs of individual projects.

CONCLUSIONS

Resilience as a perspective and approach has the potential to deliver significant benefits for UK Infrastructure and therefore the UK economy. We are entering what has been referred to as a "perfect storm" of change factors with ever increasing speed of technological change, an aging population, the growing populations, climate change, increases in non-communicable disease and growing wealth inequality to name but a few. This has also been characterised as a VUCA future, a future with every greater volatility, uncertainty, complexity and ambiguity. The health and wealth of the nation is dependent on the UKs infrastructure meeting this challenge and resilience perspectives could hold the key.

This study viewed resilience through a lens of systems thinking as a means of making sense of the complexity and therefore providing the understanding needed to build resilience comprehensively and coherently.

A series of interviews was 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.

Key findings included a lack of incentives to work proactively with other providers and sectors 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.

Risk is a core tool for understanding, prioritising and building infrastructure resilience yet the National Risk Register does not include stress factors within its assessment. The National Risk Register could also review the probability scales it uses as the current assessment, if used as a quantitative scale, is demonstrably inaccurate and underplays the reality; undermining any business case to build resilience.

Central to this understanding was the broad concept of value and infrastructure as a value chain. Using a value model, a generic set of value metrics was created against which each type of infrastructure was comparatively assessed under the hypothesis that infrastructure that performed poorly could also be assessed as least resilient. This hypothesis was based on the principle that resilience is closely linked to survival; and infrastructure that delivers poor value for users/customers is not resilient.

The final part of the study focuses on the development of a comprehensive process through which individual organisations and complete infrastructure value chains could seek to build resilience capacity over time and be prepared for the VUCA future.

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 looking at a larger sample would test many of the assumptions made during this study and provide greater confidence in the results;
- Application of 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;
- Work 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.

REFERENCES

[1] A Comprehensive Approach to City & Building Resilience, C. Field, R. Look and T. Lindsay, AEI Conference 2017.

[2] *The Resilience Engineering: Concepts and Precepts*, E. Hollnagel, D. Woods, N. Leveson, Text Book, 2006

[3] *The Fifth Discipline: The Art and Practice of the Learning Organisation*, P. M. Senge, Book, 2006

[4] *Systems Engineering: Coping with Complexity*, RR Stevens, K. Jackson, P. Brook, S. Arnold, Text Book, 1998

[5] *Resilience: The Governance of Complexity*, D. Chandler, Book, 2014

[6] *Fundamentals of Risk Management: 3rd Edition, P. Hopkins, Text Book, 2014*

[7] *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*, Y. Sheffi, Book, 2005

[8] *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, J. P. Womack, D. T. Jones, Book, 1996

[9] *Exploring Corporate Strategy: Text and Cases*, G. Johnson, K. Scholes, Book, 1997

[10] *Business Continuity Institute Good Practice Guide 2013: Global Edition*, L. Bird, I. Charters, M. Gosling, T. Janes, J. McAlister, C. Maclean-Bristol, Guide, 2013

[11] *Global Strategic Trends – Out to 2045: Fifth Edition*, UK Ministry of Defence, Book, 2015

[12] *Global Risk Assessment and Strategic Planning (GRASP): An introduction and Facilitator's Guide to the GRASP Methodology*, J. McLaughlin, M. Ocock, A. Oldfield, B. Trebes, Guide, 2016

[13] *The Balanced Score Card: Translating Strategy into Action*, R. S. Kaplan, D. P. Norton, Book, 1996