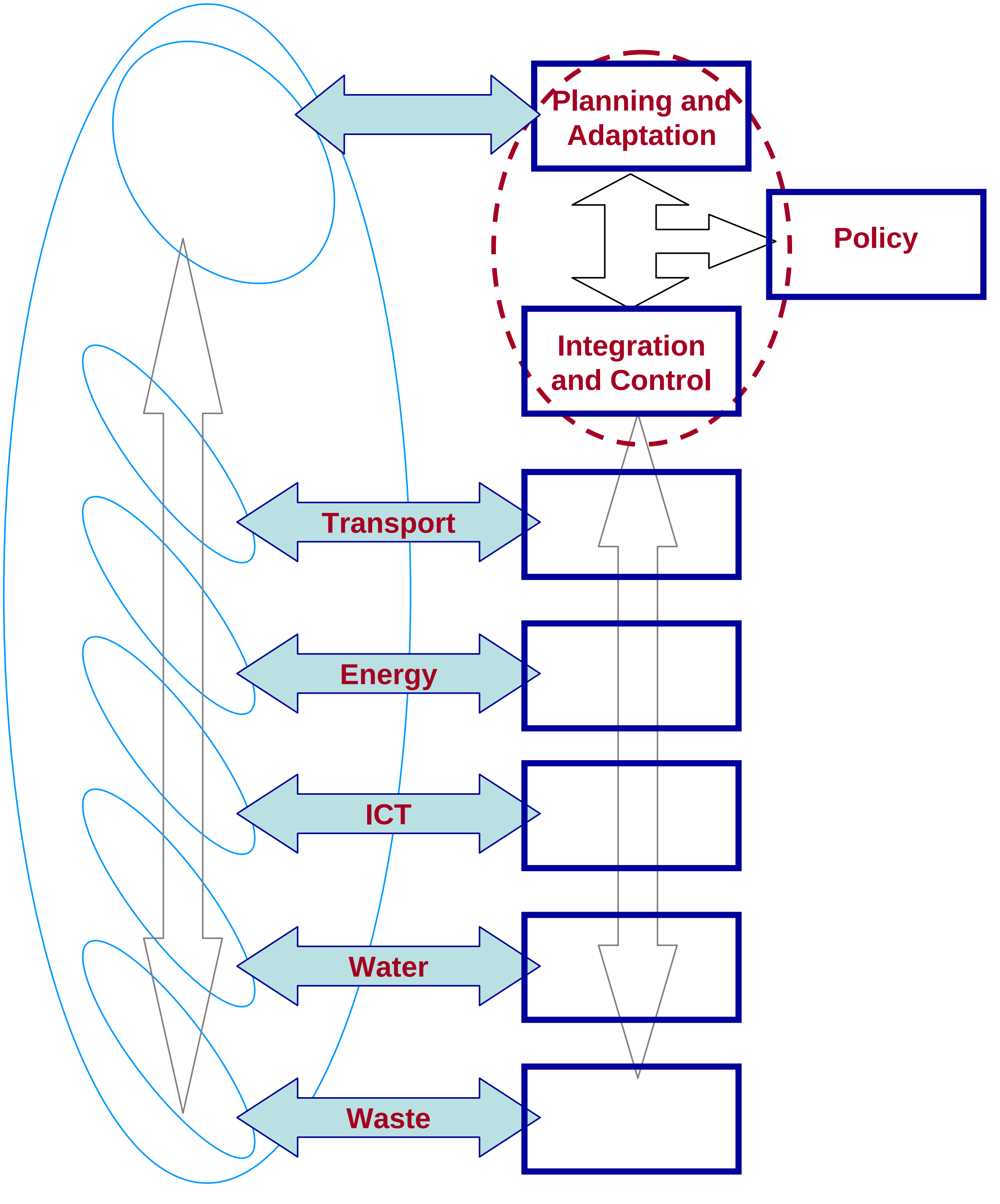

Infrastructure Resilience Matters

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Interviews: Volume Three (Confidential)

1: Executive Summary

This research project was established to test and validate assertions made in prior work concerned with systemic interactions and resilience of the UK National Infrastructure in the light of UKCP09.

Commissioned by Professor Brian Collins, Chief Scientific Adviser to DfT and BIS, the research, conducted by Professor John Beckford, extends across Water, Waste, Transport Energy and ICT, coupling interviews to brief case studies and numerous published reports as well as a review of the operation of Infrastructure Australia and other infrastructure research occurring in that country.

This report recommends:

Resilience Assessment for all new/upgrade infrastructure projects
Golden Resilience Share investment by Government
Systemic Modelling of the National Infrastructure
Review of the Infrastructure Supply Chain
Development of critical skills in Systemic Thinking
Development of critical skills in information utilisation
Review of the definition and operation of critical communications.

It is proposed that while the actions above are stimulated and co-ordinated by Central Government, the responsibility for action and engagement of stakeholders should be as widely distributed as possible.

The report is supported by accompanying appendices which provide case studies, evidence and background material. A further confidential appendix is held by Professor Brian Collins which contains interview notes and sensitive material.

It is acknowledged that this research has benefitted from the contributions of a wide variety of people internationally.

2: Introduction

2.1: Background

In December 2009, Professor Brian Collins, Chief Scientific Adviser to DfT and BIS, commissioned Beckford Consulting to develop the 'Initial Insights' section of the 2009 Report by AEA on 'Systemic Interactions of the UK National Infrastructure'. Section 4 of this report provides an overview of that project with key findings included as Appendix 1.

The need for this project is rooted in the conscious lack of elaboration and substance in the initial work and in the light of developments such as Infrastructure UK. Extreme weather events happening at the time, leading to the bridge failure at Cockermouth and the Eurostar failures provided further impetus to the work.

The purpose of the research was to test and verify or refute the assertions about interdependence made in the prior work by identifying cases, examples and incidents across a range of sectors which provide evidence. It was also desired that examples of systems would be found which, while interdependent are also resilient under conditions of change or stress.

2.2: Acknowledgments

The following people contributed to this research and their contributions are greatly appreciated:

Peter Allen	Professor of Complex Systems' Cranfield University
Anna-Maria Arabia	Executive Director, FASTS (Federation of Australian Scientific and Technological Societies)
Matt Beeton	Area Director, Northern Rail
Jim Betts	Secretary, Department of Transport, Victoria.
Ian Bevan	Finance Director, Northern Rail
Tim Broyd	Director, Halcrow, London
Jasmine Cernovs	Assistant Director, CIPMA, Canberra (Critical Infrastructure Protection Modelling and Analysis)
Peter Colacino	National Policy Manager, Infrastructure Partnerships Australia
Shaun Cronin	National Policing Improvement Agency
Michael Deegan	CEO, Infrastructure Australia
Rod Eddington	Chair, Infrastructure Australia Advisory Board

Richard Farmer	General Manager, Dept of Infrastructure, Transport, Regional Development and Local Government, Canberra
Christopher Garnett	Non-Executive Director, ODA, TfL and Anglian Water
Allen Kearns	Deputy Chief, CSIRO, Canberra Australia
Richard Kell	Chair New Division, ATSE (Australian Academy of Technological Sciences and Engineering)
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Carolyn McNally	Executive Director, Dept of Infrastructure, Transport, Regional Development and Local Government, Canberra
Jonathan Metcalfe	CEO, Veolia Australia, Melbourne
Lindsay Morgan	FCO, British High Commission, Canberra
David Murphy	Civil Contingencies Secretariat, Whitehall
John Nutt	Vice-President, ATSE (Australian Academy of Technological Sciences and Engineering)
Tom Ramsay	Head of IT, East Coast Main Line Limited
Susan Vale	Policy Director, Committee for Melbourne
Denis Waters	Chief Economist, CIPMA, Canberra (Critical Infrastructure Protection Modelling and Analysis)

2.3: Independence and Warranty

This is an independent research report commissioned by Professor Brian Collins. Its findings, conclusions and recommendations are not endorsed by Government but will be considered by Professor Collins as part of his deliberations on the issues of Adaptation and Climate Change.

Beckford Consulting has prepared this report in accordance with the agreed specification and agreement under which the services were performed. No other warranty, expressed or implied, is made as to the professional advice included in this report or any other services provided by us. The Report may not be relied upon by any other party without the prior and express written agreement of the commissioning party and Beckford Consulting. The conclusions and recommendations contained herein are based upon information provided by others and upon the assumption that all relevant information has been provided by those parties from whom it was requested. Information so provided has not been verified except where it is so stated.

3: Brief Recommendations

3.1: Resilience Assessment

It is recommended that all infrastructure projects should be subject to a systemic ‘Resilience Assessment’. This will determine the extent to which any project will contribute to or detract from the existing resilience of the interdependent system of which it will form a part. Planning consent and funding should be linked to projects which mitigate risks to or from other assets and act to increase overall resilience of the system. It may be appropriate to develop national standards for system resilience.

It is apparent from the research undertaken that, in general, while project designs necessarily consider ‘inbound’ interconnectivity, they do not adequately consider the dependencies which are, or may be generated, as a consequence.

3.2: The Resilience Share

It is recommended that Infrastructure UK, funded by Government, should act as an ‘equity investor’ in infrastructure projects, working with private organisations to define the ‘just-in-case’ resilience element of any infrastructure project and invest in that element (or proportion) on a ‘shared risk’ basis – probably 50:50.

This will serve to increase the resilience of new or upgraded UK infrastructure. Infrastructure UK will then be a significant influencer of investment decisions and start to close the gap between the ‘just-in-time’ investments of, largely, private infrastructure operators and the ‘just-in-case’ investments necessary to meet the national interest and protect infrastructure against the predicted effects of climate change. The evidence (apocryphal, case study and analytical) suggests that the ‘just-in-case’ investment is not being made – and is not likely to be.

3.3: Modelling for Resilience

It is recommended that the UK develop a robust systemic model of the National Infrastructure bringing together all of the key assets and interaction points in a single view. This model will enable situation analysis, risk assessment, resilience analysis and asset investment prioritisation. It is recognised that models may exist for other purposes from which this proposed model could be derived.

It is currently the case that neither Central nor Local Government, nor individual infrastructure providers have a meaningful view of the total national infrastructure, its interactions and vulnerabilities and the consequences of any failure or damage.

3.4: Infrastructure Supply Chain Ownership

It is recommended that a full strategic review is undertaken of the total supply chains for all elements of the national infrastructure including artefacts, skills and intellectual property.

A significant weakness is emerging in the ability of the UK to sustain its national infrastructure. This weakness rests in the dependence of the UK systems on international sourcing of design, development expertise and of the components and sub-assemblies of infrastructure artefacts.

3.5: Critical Skills – Systemic Thinking

It is recommended that systemic thinking and systemic modelling be adopted and encouraged by learned societies, professional bodies, academic institutions and funding councils and organisations working with or affected by the National Infrastructure.

Systemic thinking, modelling and synthesis is a small and usually optional part of many educational programmes – but is clearly absent in the mainstream thinking that drives much decision making. The consequence is that infrastructure project proposals and plans are developed with an absence of understanding of their systemic consequences. This is seen to lead to underperformance and failure.

3.6: Managing Resilience - Exploiting Information Technology

It is recommended that the capability inherent in much contemporary information technology to capture and store data about the performance and behaviour of infrastructure artefacts and their control systems should be properly explored and exploited.

The management and control systems themselves should be developed to provide the capability to model and simulate the performance of the infrastructure artefact under consideration. The skills required to do this are addressed in the section 3.5.

Increasing use of information technology based control systems while reducing operating costs, because control can be exercised at a distance, is also reducing resilience since the skills and knowledge required become increasingly centralised – and in some cases may be held completely outside the UK.

3.7: Critical Communications

It is recommended that the resilience of the critical communications systems used by 1st and 2nd responders, particularly under emergency conditions, should be re-examined.

It is apparent that, whilst offering ‘bandwidth’ and ‘cell overlap’ resilience through the ability to sequester frequency ranges, cell sites and density of masts, there are points of weakness in these communications systems. These weaknesses arise through the sharing of elements of the infrastructure with civil communications and the, understandable, desire of the operators to improve the cost-efficiency of their operations.

It is also recommended that the definition of critical communications should be widened to include the delivery, control and management systems that enable the operation of the various artefacts of the national infrastructure.

The research shows that such delivery, control and management systems are of increasing importance in maintaining the operation of the connected artefacts but are managed by the owners within the economic limits of their interest in sustaining business continuity. There is considered to be a gap between that limit and the national requirement to sustain the provision of services which provide or rely upon the national infrastructure.

3.8: Implementation

It is recommended that this systemic approach to infrastructure resilience is sponsored by central government with specific involvement through Infrastructure UK. However, delivery of much of the improved resilience should be devolved to Local Authorities and infrastructure owners and operators. They should respectively adopt regional and functional perspectives and synthesise them into maps or models of local resilience.

Resilience on the scale of the UK infrastructure is not something that can be addressed through central planning and control. The infrastructure is spread too widely across the landscape and its interactions and inter-dependencies are hugely diverse at the level of the specific artefacts. It is clear however that resilience in the UK needs to be addressed and resolved over time.

4: Research Methodology

This investigation extends and develops the 'Initial Insights' contained in the AEA report already cited. Its purpose was to test and verify or challenge the assertions made therein.

4.1: Methodology

The approach taken was:

To enrich the existing insights with further evidence where obtainable;

To engage with key individuals in both government and industry to obtain their insights and evidence;

To determine what further insights could be obtained by exploring the experience of the Australian Government and Infrastructure Australia which has been working in this area for some time.

Specific actions included:

Desktop/Internet research on the five sectors plus government policy, legislation and published research;

Interviews with senior figures and thought leaders in each sector;

Evaluation of the previously developed 'systemic interaction' diagrams;

Interviews with senior figures involved in the Australian work.

Extensive notes of the interviews which often contain sensitive information are held by Professor Brian Collins. A list of public sources identified and used are included as appendices to this report.

The examples given vary in length and substance reflecting the range of circumstances and insight.

4.2: Definitions

The following terms used in this report have the following meanings:

Co-functional: A system that ONLY works when other connected systems also work. For example, a rail vehicle only functions when the power supply system (energy) and the signalling system (ICT) also work.

Dependency: Where the functioning of one sector relies on the effective functioning of another. For example, water transmission depends on electrical supply to power pumps and control systems.

Interaction: This exists when there is some element of cross-over between two or more systems which are, in some way, connected. This might be a dependency as specified above or interaction through a shared network, conduit, pipeline or other facility.

Systemic: A systemic relationship exists where the interaction of two or more systems generates 'emergent' properties which belong to neither system individually but only to their interaction. For example, flight is an emergent property of the interaction of an airframe, propulsion system and control system – it belongs to none of those things individually, only to the whole interacting system. Data or voice transmission relies on the interaction of a power supply system, transmission and receipt systems and encoding/decoding applications.

Resilience: An infrastructure element is resilient when, although dependent on other systems, it can continue to function effectively when one or more of those dependencies are broken. It can do this because there are multiple paths to enable its operation such that no single dependency failure can prevent its operation.

4.3: Prior Work

In early 2009, the Chief Scientific Advisor to DfT, BERR and DECC (Now DfT and BIS) engaged AEA to develop a systems map of the major infrastructure components and sub-components. The resulting report is entitled **"An Overview of Systemic Interactions of the UK National Infrastructure"** (AEA ED45432v4.8) and elements of the report were included in The Council on Science and Technology Report **"A National Infrastructure for the 21st Century"** published in June 2009. The work also informed the **Engineering and Climate Change Adaptation Conference** held by DeFRA at the Royal Society on 1st December 2009.

The initial project with AEA considered five elements of the UK national infrastructure - Energy, ICT, Transport, Waste and Water.

That project was based on iterative systems mapping in which sector experts worked with John Beckford to identify and document the basic structural components for each sector. Higher-level maps were then developed to reveal key interactions and identify points of strength and resilience and potential single points of individual or cascade failure. The potential effects of climate change on the interdependencies were considered as were possible future trends in resilience and the necessity for improvement. In all, at least 67 inter-dependencies were identified with all sectors having multiple dependencies on other sectors for their effective operation.

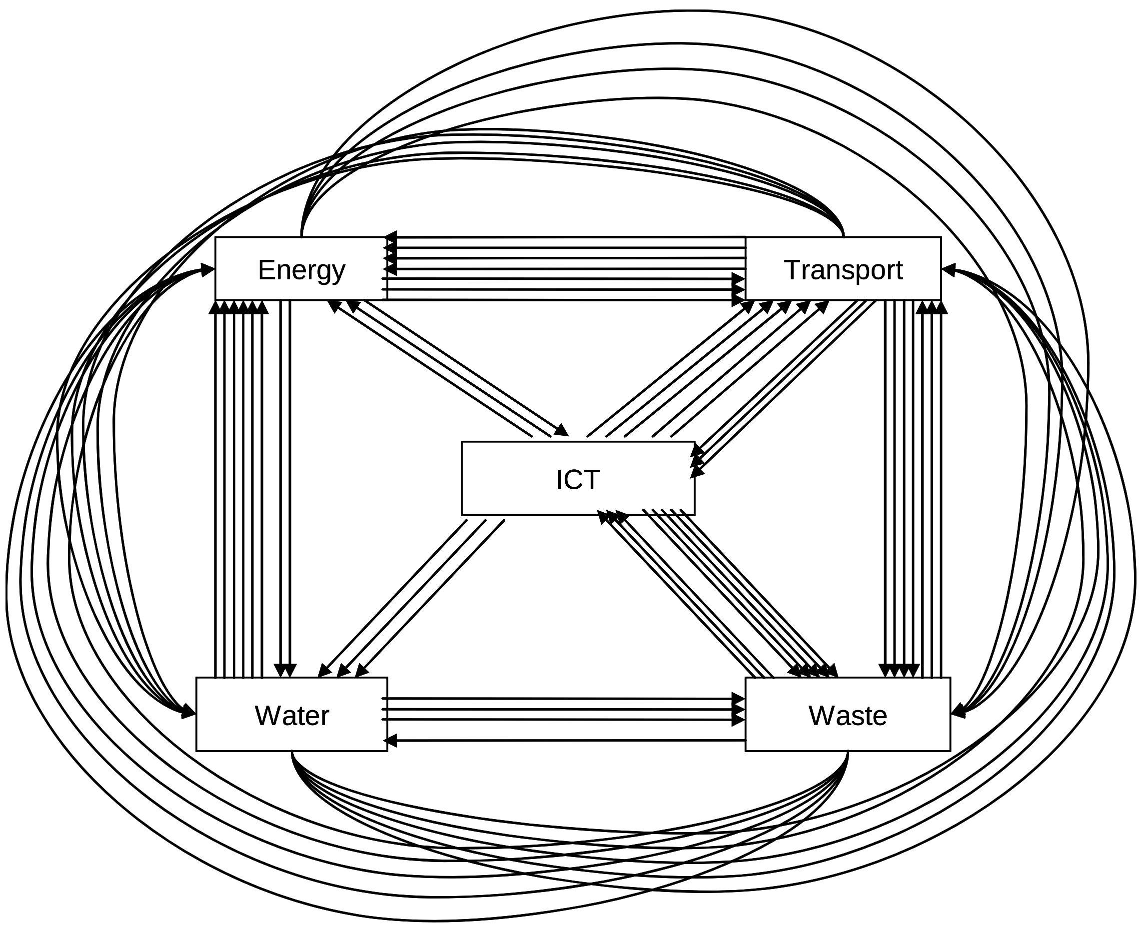

Figure 1: Systemic Interactions of the UK National Infrastructure

In addition to risks, the project reviewed opportunities presented by the potential renewal of infrastructure. This included improvements for better operational efficiencies, for example through better use of ICT, as well as opportunities to adapt to climate change and support the provision of ‘green jobs’.

The process was necessarily qualitative but provided useful initial insights and revealed richer complexity in the interdependencies than is widely acknowledged. Initial key findings are included in appendix 1 to this report.

5: Analysis and Recommendations

This section extends and develops the brief recommendations provided in section 3 of the report.

5.1: Overview of Findings:

The UK Infrastructure for Water, Waste, Energy, Transport and ICT (and others outside the scope of this inquiry) is undoubtedly systemically interdependent although this interdependence and its consequences are not well or widely understood.

Infrastructure investment decisions have been made (and continue to be made) in isolation from each other and the infrastructure has largely co-evolved with the population and political dynamics with little evidence of systemic awareness and design in the overall interdependency (appendices sections 6.3.1, 6.3.2). While each individual artefact of the infrastructure is usually built with its own resilience considered, the resilience of the infrastructure as a whole is not so considered. The critical element in the performance of any system – including the infrastructure - is the interaction between the parts which generates emergent characteristics that belong to the whole system, not to any of its parts. Nobody is responsible for managing the whole system.

The level of interaction renders the entire operation of the infrastructure vulnerable through disruption to either of two elements in particular, energy supply and ICT. The energy system powers all of the ICT and the ICT provides the data transmission and control systems to manage the energy system - these systems are co-functional – neither works without the (relevant parts of) the other.

The regulatory regimes are not systemic since they only operate within the boundaries of their own industry and neither academic nor professional education is developing, as a matter of course, engineers and managers who approach their subject systemically. At the same time some aspects of current regulation may be inhibiting effective investment, for example, the franchise cycle for the rail industry of 7-9 years is not consistent with the capital cycle for investment of 15-20 years.

Overall system resilience is probably lower than is necessary to deal with the adaptation and climate change challenges of the future – as evidenced by the wider consequences of events such as the bridge failure at Cockermouth (appendices section 6.1 and 6.2). Investment has been declining for many years with much of the infrastructure either near capacity and/or reaching the end of its useful working life. Meanwhile owners and operators are ‘sweating the asset’, maximising return and minimising new investment, especially in the current economic climate.

There are potential ‘single points of failure’ and ‘cascade failure’ triggers in the system – but the absence of coherent mapping of the whole infrastructure means their whereabouts and vulnerability are largely unknown. If the UK Infrastructure for Water, Waste, Energy, Transport and ICT (and other sectors outside the scope of this inquiry) is to be fit for purpose for the future predicted by UKCP09, the weaknesses identified will need to be addressed urgently.

The substantial investments which are likely to be required to mitigate current vulnerabilities and to respond to the likely impacts of climate change will need to be made in the context of a systemic understanding of their interaction and interdependency in order to increase resilience.

5.2: Resilience Assessment

Drawn on a relatively wide information base, this work has explored a sufficient cross-section of infrastructure organisations and events to suggest that an audit of UK infrastructure in terms of its resilience under changing and stressed conditions is required. Put simply – ‘we don’t know what we don’t know’ - neither the strengths nor the weaknesses of the current infrastructure resilience are sufficiently well understood for any strategic priorities to be determined and mistakes are made (appendices section 6.5). Clearly a separate full audit of infrastructure would be a costly exercise and difficult to justify in cost-benefit terms for either the government or the private owners/operators of that infrastructure. It is suggested therefore that this audit be dealt with as an integral part of future planning and development.

It may be appropriate for National Standards for Infrastructure Resilience to be developed and adopted, perhaps under the auspices of Infrastructure UK. This would make the resilience demands explicit and provide the basis for modified business planning and ‘Return on Investment’ calculations – especially if a ‘triple bottom line’ is to be used – economic, social and environmental. Under current regulation a building project, typically, will link to the water, telecoms, power supply, waste and transport systems but will not of necessity make any contribution to them other than that which is required for connectivity. It is not the concern of the private developer, except under certain circumstances, to make a contribution to upgrading the wider infrastructure on which the particular project relies. National Infrastructure standards would require that projects be designed to accommodate the extreme weather events projected in UKCP09 and its successors. Hollnagel et al have considered resilience engineering from a risk perspective.

The creation of a resilient infrastructure means that we must develop a system which is homeostatic under conditions of perturbation. Able to stabilise itself – it will be sufficiently (and deliberately) inter-connected that even when one route to effective operation is disrupted there are alternative operable pathways or, where this is not possible, there is back-up capability able to support the continued independent operation of the element for a period of time (sufficiently long for repair or implementation of an alternative solution). Although designed for efficiency and optimum use of bandwidth rather than resilience, the decentralised architecture of telecommunications uses a web-like network which can act as a model for a resilient structure. These use 'many to many' networks to ensure the complete and effective transmission of data to a recipient. Similar thinking could underpin other, non ICT, networks. A good example of resilience by design is provided by National Air Traffic Services (appendices section 6.11).

A resilience assessment (a draft framework is included in appendix 2) should be completed for any project affecting the national infrastructure considering:

The systems on which the project depends;
The capability/capacity of each system to meet the specified need;
The contribution to the capacity of connected systems from the project;
Contribution verification;
The business model;
The overall resilience of this system.

In essence, only projects which reach a given threshold of resilience should be given planning consent to proceed. This will ensure that resilience is built in to all future projects.

5.3: The Resilience Share

There is a significant gap between the 'just-in-time' investment of private infrastructure operators (intended to meet the needs of particular groups of consumers and operable under 'business as usual' conditions) and the 'just-in-case' investment necessary to meet the national interest and protect infrastructure against the predicted effects of climate change.

The evidence (apocryphal, case study and analytical) all suggests that the 'just-in-case' investment is not being made – and is not likely to be. Individual operators seek to achieve an economic balance of service or system availability and the cost of guaranteed continuity of service outweighs the income. The market will not bear this cost.

Whilst short term loss of service on a telephone or power line may be tolerable for the individual consumer, the continuity risk increases massively when the loss affects whole communities. The consequences run not just to minor disruptions and loss of income but, as was seen with New Orleans and more recently in Haiti and Chile, reversion of a community to a basic survival mode with consequences for social cohesion and maintenance of civil order.

It is recommended therefore that Infrastructure UK, funded by Government, should act as an 'equity investor' in Infrastructure Projects, working with private organisations to define the 'just-in-case' resilience element of any infrastructure project and invest in that element (or proportion) on a 'shared risk' basis – probably 50:50.This will serve to increase the resilience of new or upgraded UK infrastructure.

Infrastructure UK will then be a significant influencer of investment decisions and act as a supervising regulator, taking an interest in inter-sector resilience, encouraging co-location and co-functionality of infrastructure and dealing with matters outside the scope of the various existing regulators.

Infrastructure UK would earn a return on its equity investment in the same way as any other investor and should:

Become self-funding from investment returns;
Invest a proportion of its earnings in sponsoring resilient infrastructure research;
Pay the balance of earnings to the Treasury;
Be constrained to continuously improve its cost/income ratio.

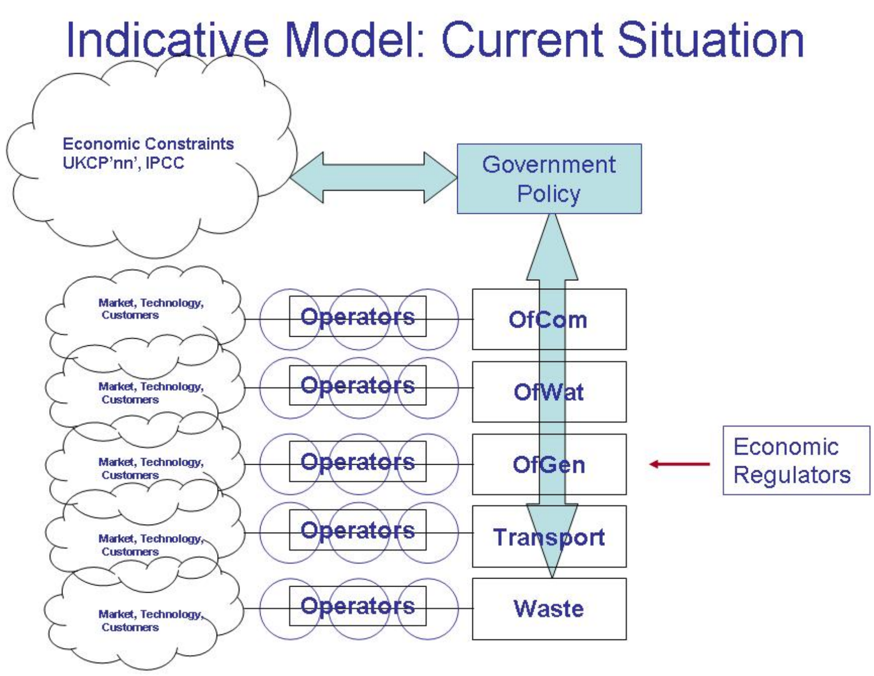

Figure 2

Infrastructure UK is suggested as the integrating device. Independent of the individual sectors, I-UK can tackle the combined issues of inter-dependency, resilience and public investment in infrastructure projects.

Figure 2 (previous page) provides an indicative overview of the current situation in which Government Policy, which is formed in an appreciation of the prevailing social situation, informed by a political perspective, is translated through the Departments of State into the activity of regulators. The brief of the regulators is primarily economic but there are also a number of agencies with specific responsibility, for example the Environment Agency, Office of Rail Regulation and so on.

Whilst informed by a single view, the requirements emerging from Government are disaggregated through the departments in such a manner that each industry is informed and controlled by a view which is disconnected from the activities of the other sectors, that is, Water is managed and regulated separately to Energy – even though they are closely inter-dependent. It may be that the individual regulation of each is in conflict with another.

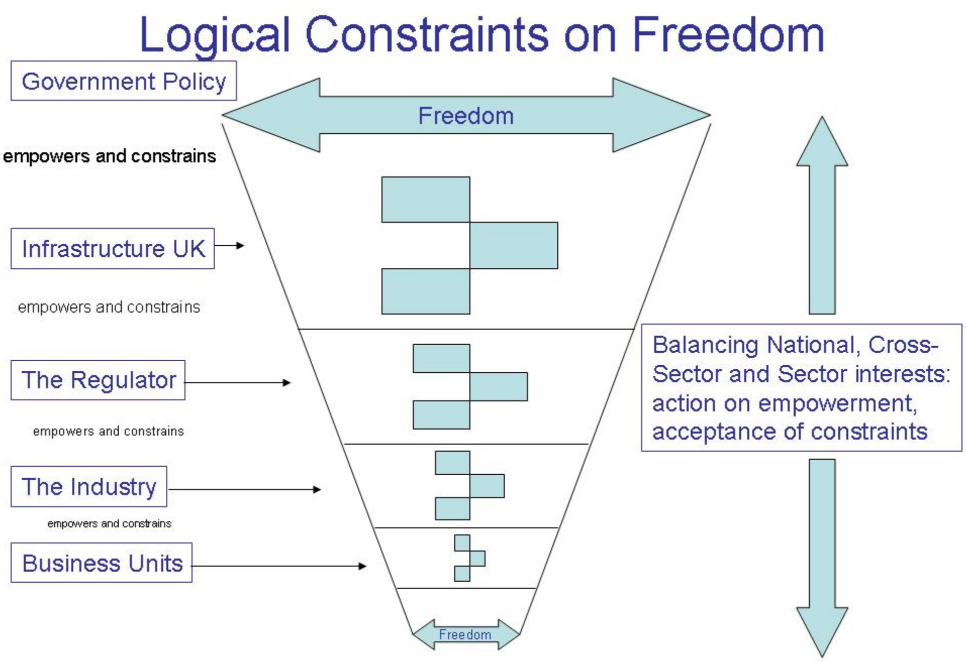

Figure 3

Government policy determines the boundaries within which each of the regulators must operate. It is proposed that Infrastructure UK is positioned as a meta-regulator with regard only to the resilience dimension of infrastructure interdependencies. As such it sits, logically, (figure 3) between Government Policy and the individual industry Regulators, interpreting policy and translating that to operational requirements – complementing but not constraining the existing regulatory activity.

Figure 4 brings this argument together into a viable architecture which integrates Infrastructure UK into the whole system of regulation. This shows the sharp distinction between the 'just-in-time' regulation of business as usual and the 'just-in-case' involvement designed to address infrastructure resilience without compromising the existing regimes.

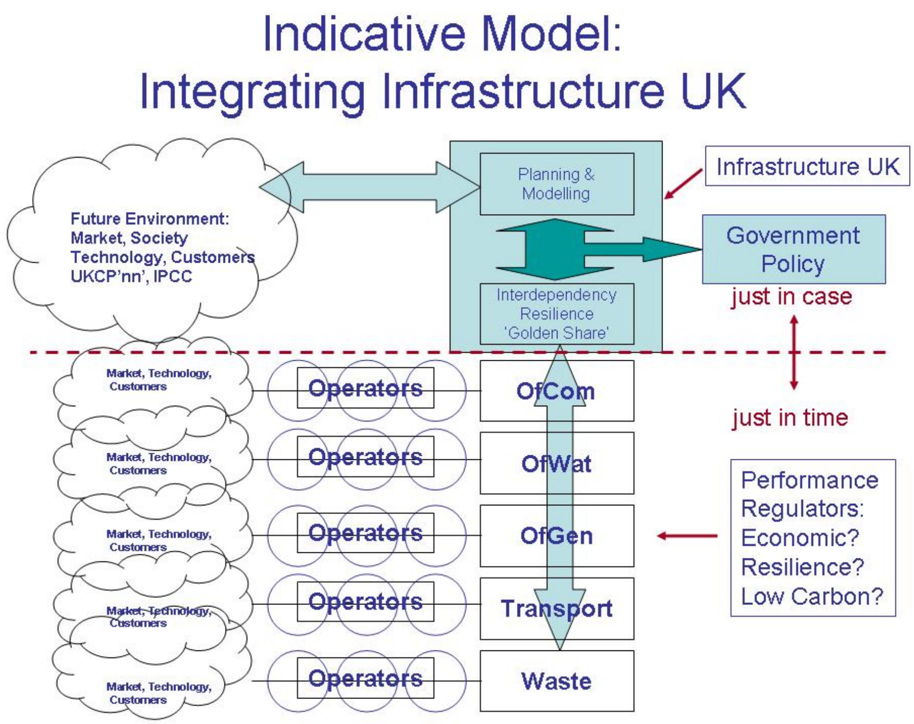

Figure 4

5.4: Modelling for Resilience

The UK Infrastructure has been evolving for well over 100 years and there is no integrated national mapping of the whole set of artefacts, inter-relationships and interactions. For example, much of the utilities networks are, as of right, buried under the strategic road network but the precise whereabouts are often not known and vulnerability to damage through flooding or other extreme weather events is necessarily not known. There may be either single points of failure or cascade failure triggers within this network which are not currently identified and cannot be identified.

However, each Local Authority holds a 'constraints map' reflecting much of what is known about local infrastructure which is used for the development and evaluation of planning applications. These maps might provide the basis for development of a national systemic interaction and interdependency mapping which could be used to:

Support the 'audit' proposed in 5.2;
Identify physical points of interaction and interdependency;
Identify potential for low-cost short term improvement of resilience;
Identify critical infrastructure capability;
Identify points of low resilience or weakness;
Model and assess the impacts of anticipated climate change;
Optimise the long-term investment in infrastructure;
Develop guidelines for the development of resilient future infrastructure.

Focused on the resilience of the whole infrastructure rather than only those parts which might be subject to concerns of national security, the analytical capability and outputs would feed into planning processes and, after initial development, could be funded on a 'user pays' basis. This activity could be integrated with Infrastructure UK as a value-adding activity or operated separately within one of the Universities.

CIPMA in Australia (appendices section 4) provides an analysis and modelling service to infrastructure owners on a cost-recovery basis and that model might provide a useful starting point for development of a UK version.

5.5: Infrastructure Value Chain Ownership

There are at least two major vulnerabilities emerging for the UK in relation to infrastructure. The first is the sourcing of both the physical and intellectual content of much of the infrastructure. Simply put – whilst the 'service provider' for a mobile phone may be UK based, for example Vodafone and BT,, the handset was likely to have been designed and assembled in Taiwan, the battery in Korea. It is highly likely that the transmission network switches, antennae and servers are similarly overseas sourced. NATS operates using software and hardware sourced in the USA and Spain.

The supply chain itself is neither resilient nor carbon friendly, rather it is driven towards a 'single-source of supply, lowest short term cost' model. Whilst driven towards economic efficiency by commercial interests, with a changing climate and changing demographics this may not be a sustainable model. Already there is concern in the food supply chain about 'food miles' – the same thinking must in turn apply to other products.

The second key issue is the absolute dependency of all other sectors on ICT. The web of communications technologies and devices on which modern business and the operation of society rely is startling in range, complexity and the vulnerability of individual elements. These include everything from Automated

Teller Machines to Traffic Lights to CCTV and automated control systems that switch pumps on and off at remote sites. The web of data-transmission reliant automated control systems that 'run' the UK infrastructure is mind-numbing and largely invisible.

It is suggested that the UK needs to review the value chains for each element of the national infrastructure (both intellectual and physical) and consider how to develop and sustain the critical capacities to support the anticipated population under predicted conditions. It is suggested that either political or economic instability internationally could damage or inhibit the current value chains and render the UK vulnerable to significant loss of infrastructure performance.

5.6: Critical Skills – Systemic Thinking

A high level review (appendices section 7) of 56 programmes across 16 Universities was undertaken. This showed that systemic thinking and problem solving is not taught systematically in any profession and in few academic programmes. It is most often included as an optional module within a programme – an approach which, in itself, demonstrates a lack of understanding of the fundamental notion of systems thinking. There was until recently a 'Bachelors in Information Systems' at Liverpool, John Moores University which was consciously systemic in content, structure and delivery, but this has been closed due to declining student numbers and financial pressure on the institution

Systems approaches to problem solving began to emerge in the 1920s, coming to the fore early in the 1940s with the emergence of 'Operational Research' as a powerful approach to the resolution of complex inter-disciplinary problems and challenges – mainly of an engineering nature.

Operational Research (OR) brought together a wide range of mathematicians and physical scientists and developed a range of new tools and techniques which broadly might be thought of now as 'Management Science'. This early work was extended by later entrants as approaches to the resolution of social and socio-technical problems and this spawned a further range of approaches ranging from the 'solution-focused' (hard) tools of Managerial Cybernetics (Beer), closely aligned to traditional Management Science, to the 'process-focused' (soft) tools such as Soft Systems Methodology (Checkland).

Partly as a product of the 'socio-political' philosophy brought to bear on these approaches, partly perhaps because of battles over personal fiefdoms, research funding and increasing specialisation, the 'systemic' nature of these enquiries has become largely lost. There has been a fragmentation into separate strands of enquiry or reductionist-systems approaches which are necessarily reductionist in their thinking because they adopt only a partial perspective. The philosophies and tools have become rooted in a false ‘either/or’ dichotomy rather than accommodating the ‘and’ of a truly systemic approach.

In consequence, much of ‘systems thinking’ has become associated with a social-change agenda and has failed to break through to the mainstream of academic or professional education.

Unsurprisingly, given this approach in education, awareness of systems thinking, systems approaches to problem solving, inter-dependencies and inter-actions between elements of the infrastructure is very weak. Where it is recognised, it is also often recognised as being ‘their’ problem – ‘their’ being variously the other sectors and/or the government.

Systemic approaches to problem solving which have been marginalised for a variety of reasons need to be rehabilitated. Systemic problem solving and systems engineering need to become the dominant way of thinking about these issues. Systems thinking needs to become a mainstream approach in both academic and professional education. The size of the paradigm shift involved in this aspect must not be understated as this requires a substantial re-examination of many aspects of both teaching and testing.

Critical skills in the area of infrastructure projects are those of systems dynamics, systems mapping, systems evaluation and operational research. While these in turn draw on a good understanding of mathematics, statistics and sciences, they also rely heavily on a systemic process of inquiry rather than a checklist type reductionist approach. This approach perhaps demands a higher order cognitive capability than is examinable in a conventional, examination paper based manner and necessitates an ‘apprentice’ or ‘guild craftsman’ type approach to development and evaluation.

This will present challenges to both Universities and Professional bodies. It is suggested that these bodies, together with the Funding Councils be encouraged to lead the Country in this regard aiming to:

- capitalise on established systems work;
- embed systems thinking throughout their programmes and qualifications;
- invest in systems thinking research;
- develop the business value logics of systems enquiry.

5.7: Managing Resilience – Exploiting Information Technology

Consideration of the cases (appendices section 6) together with broader experience and research drawn across a wide range of industries suggests that whilst current generation ICT is capable of capturing vast quantities of data about the activity and performance of the artefacts, our total capability to do meaningful things with that data is very limited.

Management systems, data warehouses and reporting systems are, predominantly, concerned with reporting past events. This is necessarily the case for certain things – statutory reporting, incident control, safety management – but is not sufficient. Of even greater importance than knowing what happened is knowing why it happened and either, how to repeat it or prevent it in the future depending whether or not it is an event that might be repeated.

Well developed, integrated performance models of the key elements of the infrastructure, informed by data derived from the embedded control systems would enable the modelling and prediction of future performance and allow anticipatory (feed-forward) management of risks and concerns. This could operate at both the level of the individual plant or business, the industry and at the cross-industry level. The data exists to make this possible and the technology already enables it – it is only the thinking that is limited.

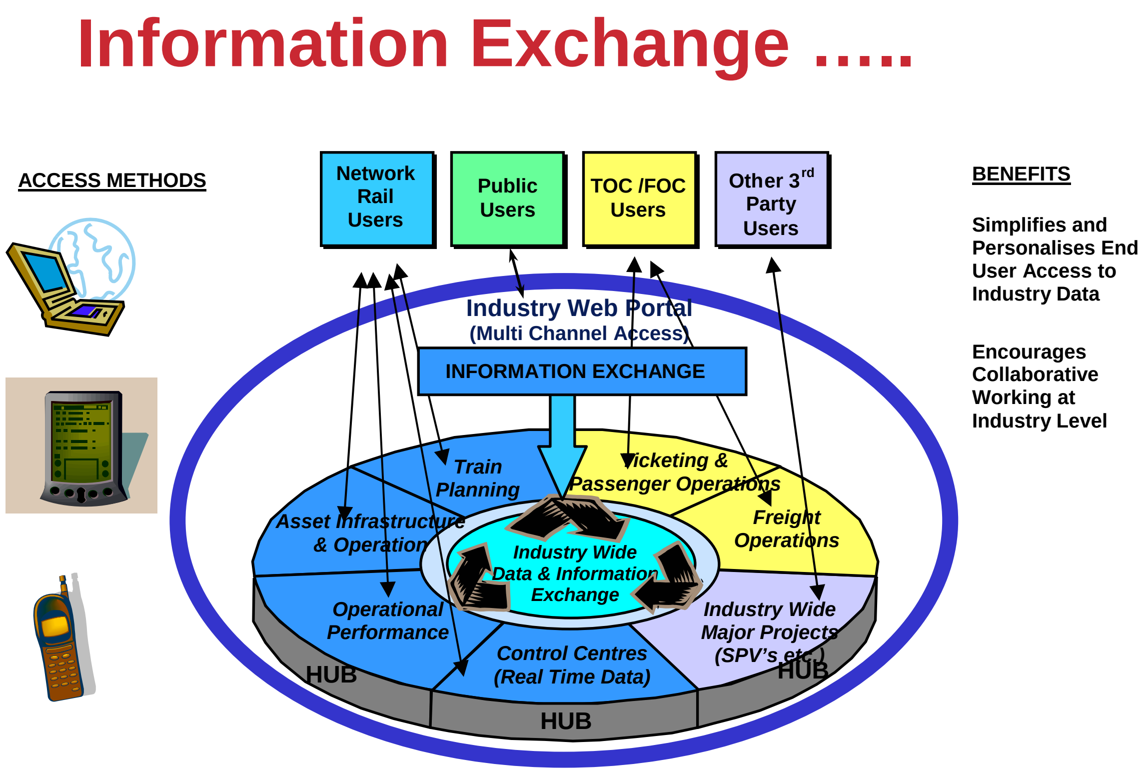

Figure 5 An Information Hub
Courtesy of Tom Ramsay, East Coast Trains

Such an approach would require the development of systemic tools and applications with the emphasis on predictive modelling and synthesis rather than historical analysis which has been the focus of much work in the past. There is arguably a case for an ‘industry’ level model – funded, owned and operated by all organisations in a particular industry perhaps through a trade body – which could then be used to balance the needs and requirements of individual members with the benefit of the industry as a whole.

Aggregated data from one such industry model could be shared with other industries relatively easily – especially if the same modelling methodologies and structures are adopted.

5.8: Critical Communications

The conventional definition of critical communications extends to voice and data systems that support the activities of 1^{st} and 2^{nd} responders in the event of emergencies (e.g. the Cockermouth flooding, the London bombings).

The Airwaves system, a critical element in those communications is vulnerable because although operating on dedicated frequencies and able to sequester bandwidth from civilian communications, the system, at least in part is installed on the same physical infrastructure (masts, antennae, power supplies) as the civil mobile phone network.

During the Cockermouth flooding 5 Airwaves base stations were adversely affected at Cockermouth with 2 still unavailable after 5 days. Given that this was a local incident it would not be meaningful to extrapolate the numbers to the whole system – but it does suggest that an examination of the system from a resilience perspective might be considered beneficial. Such an evaluation should consider the performance and resilience of the system under the extreme weather events anticipated in UKCP09. It is notable for example that whilst significant snowfall impacts on overhead power and communications lines, excess water, either through rainfall or thawing snow and ice, poses a much greater risk through ground based network switches and exchanges.

The operation of the civil infrastructure also increasingly relies on the power and ICT transmission systems to provide energy and connectivity for control and management. Examples of this include traffic management systems (for example, speed, lane and flow control on motorways, signalling systems on the railways, radar and voice communications for Air Traffic Control) but also banking systems (for example ATMs, on line shopping, EFTPOS), water and gas management systems (pumping stations), just-in-time delivery systems for food distribution and other logistics. A critical example is the provision of healthcare for which, in numerous cases, clinical and care data is held in on-line care systems remotely from the site of provision.

It is recommended that these systems, on which the continued operation of society depends, are brought within the envelope of ‘critical communications’ and held to the national standards of resilience proposed in section 5.2 of this report.

The vulnerability of such systems to changing climate should be assessed as a matter of urgency.

5.9: Implementation

It is self-evident that the infrastructure in the UK may be fragile, but it is not yet broken. Every day millions of homes, offices and factories are supplied with gas, water and electricity, goods are delivered and waste of all sorts is taken away. Thousands of rail and air journeys are undertaken and millions of cars are managed through myriad traffic signals observed by hundreds of cameras.

The system works.

However, this reflects ‘business as usual’ – the system coping with the conditions for which is was intended. Expected future conditions (UKCP09) are very different and it is clear that the system will not work so well.

There is a need for action, but this is, not yet, a crisis.

The recommendations in this report do not demand a mass national action, but rather call for a distributed, disseminated but co-ordinated approach with responsibility for each action located where it can deliver most benefit.

The proposed Resilience Assessment (Rec. 3.1) is a task for Local Authority planners, developers and operators. The Resilience Share (Rec. 3.2) on the other hand IS a matter of national interest and national importance, but it interacts with Rec. 3.1, the two things are interdependent – and the product of their interactions should be greater than the sum of their individual impacts.

Modelling for resilience (Rec. 3.3) can again be dealt with as a distributed issue. Given that, as Stafford Beer suggests, “a model is neither true nor false but more or less useful’ the development of the model itself might be for one entity – but the uses to which it could be put (and therefore the mechanism for funding its development) belong to many organisations – both governmental and private. Reflection on the supply chain ownership (Rec. 3.4) can be stimulated at the national level action and should be designed to encourage individuals and businesses to retain or develop strong UK resident capabilities and might encourage or incentivise location of critical elements within these shores.

The development of critical skills in systemic thinking (Rec 3.5) and similarly the ability to properly exploit information technology (Rec 3.6) are both elements which, stimulated by government, need to become the responsibility of Educational Institutions and Professional Bodies to encourage and develop at every level.

Infrastructure Resilience Matters
(Appendices)

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Appendix 1

"An Overview of Systemic Interactions of the UK National Infrastructure"

AEA 2009: Executive Summary

The Chief Scientific Advisor to DfT, BERR and DECC is engaged on a project to explore how to develop a strategy for the modernisation of the National Infrastructure of the UK. In order to gain the highest-level view of the landscape of UK National Infrastructure and to inform further thinking in this area, AEA were engaged to develop a systems map of the major infrastructure components and sub-components.

This project considered five elements of the UK national infrastructure:

- Energy
- ICT
- Transport
- Waste
- Water

The approach was based on an iterative systems mapping, with workshops in which sector experts developed and documented the basic structural components for each sector, from which higher-level maps were developed to reveal key interconnections between components.

The primary theme concerned current and future resilience of the national infrastructure in delivering national demand. The analysis extended beyond the individual components and focussed on interdependencies between the components. The effects of major environmental change, i.e. climate change, on the interdependencies were also considered, as were possible future trends in resilience and the urgency for improvement.

In addition to risks, opportunities presented by the potential renewal of infrastructure were reviewed. This included improvements for better operational efficiencies, for example through better use of ICT, as well as opportunities to respond to potential for mitigation of, and adaptation to, climate change and for supporting the provision of 'green jobs'.

Clearly the process was qualitative. However, it provided useful initial insights and revealed even richer complexity in the interdependencies than perhaps is already acknowledged. This offers both concerns for vulnerabilities and opportunities for building resilience. The maps could be used to consider other potential large-scale trends such as changing demographics, availability of raw materials, and conflict or terrorism.

This initial brief was a first step in further understanding infrastructure interdependencies. The outputs will help guide and prioritise subsequent analyses, which will require more detailed and quantitative modelling and assessment techniques.

However, some initial key findings from the detail and insights recorded in Sections 5, 6 and Appendix 2 are:

1. The elements of the National Infrastructure considered are even more richly interdependent than may already be recognised. Consequently, the risks and vulnerabilities associated with the interdependencies are likely to be poorly understood.

2. There is an absolute dependence on Energy and ICT, as they underpin operations across all of the other sectors.

3. Stress, failure, growth or significant change in any one element will create interdependences that may be different in nature from the better-understood ‘business as usual’ interdependencies. Single Points of Failure can become more important and pronounced in times of stress.

4. The likely ‘business as usual’ trends in these interdependencies, i.e. whether they are on a trajectory to change for the better or for worse, vary for specific types of interdependence within specific infrastructure pairs.

5. Governance emerges as a key issue. Governance responsibilities and oversight are shared and split in a number of ways, for example:

   - Various elements of infrastructure are regulated at a national level by different regulators with their own specific responsibilities, aims, and priorities. There can be institutionalised conflict between the actions of a regulator of one element with actions of another.

   - Governance of a given sector is sometimes shared between public regulators and planners, and private sector businesses. For example, the resilience of a sector may be dependent on a mixture of a business’s own ICT system and national ICT systems. This means that, firstly, decisions and developments affecting the long-term resilience of each may not be co-ordinated, or even recognised. Secondly, priorities of the private sector may be focused on efficiency and short-term value within that sector/business, rather than maximising the contribution to wider and national objectives.

   In a highly interdependent system this will not lead to optimised risk management.

6. A particularly important aspect of governance is data ownership, which can often be split between different parties. This means that decisions are not, and indeed cannot, be made based on comprehensive information.

7. The five infrastructure elements are not fit for purpose in the context of the expected impacts of climate change. They may not be able to support the operations of UK plc during periods of stress, such as extreme weather events, which may occur more frequently over the coming decades.

8. Rather than just being an issue of risk management, appropriate development of future infrastructure, and in particular better cross-sectoral planning, offers significant opportunities for improved efficiency, effectiveness, and added value. However some legacy systems will need upgrading before full advantage of such thinking (for example more advanced use of ICT) can be realised.

9. While it is recognised that all sectors require enhancement of the skills and knowledge base, which supports them, there is also a need to develop multi-sectoral knowledge, training, and operational research skills.

10. Renewal of national infrastructure should be a key component of planning and action of any national investment to stimulate job creation and economic recovery.

11. Responding to the challenge of infrastructure renewal in a coordinated and timely fashion will require development of efficient policy and planning regimes. A fundamental requirement is therefore a roadmap defining priorities over the next forty to fifty years to support such coordinated decisions on planning, financial investment, development of the appropriate skills base and deployment of new technologies.

Appendix 2:

Resilience Assessment Framework (Indicative)

Section One: The Project Under Consideration

Brief Outline (One paragraph plus links to other planning documentation)

Section Two: Reliance on Existing Infrastructure

The purpose of this section is to make explicit:

the extent to which this project will depend on the availability of existing services;
to evaluate (quantitative and qualitative) the increase in interdependency and/or risk that would arise from its completion;
to quantify the degree of reliance.

Q1: What are the systems on which THIS project depends?

For each, specify the need, quantity, consumption, performance parameters.

Q2: What is the capability of EACH of those systems to meet that need?

For each, specify the current capacity available and the extent to which that capacity would be utilised.

Q3: What characteristics of your project would impose new, or different, demand peaks or troughs on the existing systems?

Q4: What alternative / back up/ failure arrangements will be in place?

Q5: What are the principal infrastructure risks to this project?

Now?
Post-completion?

Section Three: Contribution to Infrastructure Resilience

The purpose of this section is to make explicit:

the ways in which this project will contribute to increasing resilience in the dependent services;
to evaluate (quantitative and qualitative) the decrease in interdependency and/or risk that would arise from its completion;

to quantify the extent of reduction in reliance and/or increase in resilience.

Q6: What other services will become dependent on this project?

Q7: How will supply be guaranteed?

Q8: What will the failure arrangements be?

Q9: How will that contribution be verified?

Q10: How will it be funded?

Q11: How will other users be charged for their reliance on this system?

Section Four: Actions Necessary to Improve Resilience

The purpose of this section is to make explicit:

the actions necessary as a result of this project;
to specify and quantify the risk reduction;
to state the costs of mitigation action.

Q12: What actions will be taken in respect of each element of affected infrastructure?

Q13: What specific risks will be mitigated and to what extent?

Q14: What costs over and above the standard projects costs will be incurred by the mitigation actions?

Q15: What future risk costs are obviated by that investment?

Appendix 3

Infrastructure Australia (IA) Reviewed

Established at the end of 2007, IA consists of three bodies, which are rapidly evolving distinct and separate roles:

Advisory Board:	Chair, Sir Rod Eddington
Executive Agency:	CEO, Michael Deegan
Infrastructure Department:	Executive Director, Carolyn McNally

The timelines for Infrastructure Australia were as follows:

Established end 2007
Michael Deegan, CEO, appointed June 2008
Audit completed by Dec 2008 (economic appraisal)
1st 6 months 2009, refining proposals
2nd 6 months 2009, 'defending' decisions!

The Advisory Board

The Advisory Board, chaired by Sir Rod Eddington, (RE) consists of 6 senior industry figures plus 5 senior civil servants (2 federal, 3 state) and an academic. Their task is to evaluate the infrastructure project proposals put forward. While each State has, perhaps understandably, prioritised its needs according to local rather than Federal requirements, the task of the Advisory Council was to consider:

The business case for the project (on a stand-alone basis) – against the triple bottom line of economic, social and environmental impacts;

The 'fit' to the specific context in which it would be delivered.

Of the original 700 plus proposals, the initially prioritised list of projects was put forward to the Federal Government for funding. A funding pot of around $Aus13bn was reduced to $Aus8bn after commitments had been made to the National Broadband Project (which has a currently estimated total cost of $Aus43bn and, as things stand, is to be entirely funded by the Federation).

The evaluation assessment criteria are provided as appendix 2 to this report but of great importance is that peak oil prices were used throughout this phase having an impact on the outcomes.

It has been suggested that in the initial round, no one had substantially got to grips with the Business Model and, where projects cross sectoral lines, that there was often resistance from other parties as a consequence of not approaching the problems systemically and of dealing with design and integration from a functional perspective. Although Australia has now an Infrastructure Minister, the ministerial remit does not include Energy and Water.

The Executive Agency

The Executive branch is an Independent Agency of the Federal Government, led by Michael Deegan, CEO. It has 10 staff and is funded (about Aus$2bn pa until the budget year ending March 2011) to:

> Develop, where requested, Infrastructure Policy in relation to Water, Energy, Telecommunications and Transport;
>
> Consider funding applications for infrastructure projects in every state;
>
> 'Transform the way Australia works'.

Specifically, IA is required to consider projects from a 'helicopter' perspective, looking at the broad needs and priorities, supplementing the activities of State Governments which are limited by their boundaries.

Michael Deegan, CEO, suggests that the proper consideration of interactions between the different elements of the infrastructure is constrained by the absence of integrated government. Each State and City is required to submit proposals about the investments they wish to make in transport and other infrastructure systems including telecommunications, energy and water and IA has been considering these in relation to the overall 'fit' to National needs and in the context of other service providers.

The quality of submissions to the initial IA funding round was very variable, with Victoria presenting strong cases and being very successful. During the initial phase of considering project proposals, and after a particularly weak presentation by a state government, the question was asked:

> 'Is there any evidence that people other than IA are thinking systemically?'

Currently, a Long-Term Infrastructure Plan is in development. This is looking at the whole of Australia over the next 50 years and will be submitted to the IA Advisory Council at the end of February 2010. It is anticipated that the plan will be released later in the year.

The Infrastructure Department

Carolyn McNally, Executive Director Nation Building, Department of Infrastructure, Transport and Regional Development states that four initial priorities were seen in the establishment of IA:

Audit the 'national asset';

Determine priorities for investment;

Understand the structural impediments at State level and reduce barriers to entry;

Establish national guidelines for Public–Private Partnerships (these have been based on those already adopted by The State of Victoria).

The initial IA process moved very quickly and Carolyn McNally suggests it might have worked better had a more rigorous approach been taken to the initial round of funding allocations in particular the completion of the asset audit. As it was, funding recommendations were being made ahead of clarity of purpose, brief or standards.

Allocation of funding was primarily to transport projects, partly because this sector was most organised in its approach, being already 'in the game'. Other sectors had to develop rules and guidance. Jim Betts, Secretary for Transport, reported that Victoria had a good experience of IA, obtaining funding for a substantial project after 15 years during which there had been no role for the Federal Government in State transport matters apart from some contribution to Road and Freight Rail. The proportion of the total fund committed to Victoria is 40% - against only 20% of the total population – a significant win. Some 70% of the total money allocated to Urban Public Transport projects was awarded to Victoria.

The Future of IA – Opportunities, Challenges, Limitations

While the IA Independent Agency is seeking to maintain its 'purity' in the planning and policy function it is seeking to move away from reliance on Federal Grant Funding to a market model. The Future Fund (superannuation scheme) is being encouraged to look at IA projects. Michael Deegan suggests that the market will act to make investments worthwhile but that lack of information is currently an obstruction to proper performance and the 'old-fashioned' operation of some elements of the infrastructure will need to be challenged.

The future direction of IA is currently unclear. The 'Department' acts in the role of 'grant managers' – releasing funds against project progress and with responsibility for the return on investment being achieved. The IA executive are in the role of appraisers – providing both evaluation tools and process while the IA Advisory Board are 'experts' appointed by the incumbent government. It is suggested that:

'IA recommends, government decides'

It is notable that there have been, so far, no ‘cross-border’ (inter-state) proposals and the ‘national’ focus has, perhaps, been lost. IA is working to remove barriers to inter-state activity.

The future focus of IA will be on the need for competent and effective planning and surmounting some current challenges. For example, in New South Wales, there are 11 different organisations to talk to about transport plans! IA has not yet won the ‘hearts and minds’ of Government and is seen by some as responding only to the remit of the Ministry for Infrastructure rather than to national needs. There is, so far, no overall ‘strategic oversight’ of water, telecoms or energy nor is there any substantial mapping of the interactions. There is though recognition, for example, of ‘too many water organisations’. CM suggests that there is perhaps a close coupling of the actions of government to ‘what the people want’ as opposed to what the country needs.

With an election due in November 2010, the future of IA will become more interesting and as IA evolves its National Strategies (on for example Freight and Ports) there is the question of how closely funding will be tied to adherence to them.

IA will not follow the ‘Investment Bank’ route. This approach is seen as carrying a risk of ‘funnelling’ all infrastructure investment down a single channel – which may well not be appropriate for some which would be better pursued separately. It was suggested that avoiding that route preserves the freedom of government to not follow the advice of IA which should perhaps set the standards, identify bottlenecks, improve co-ordination, not become the focus of all activity.

Anna-Maria Arabia , FASTS,suggests that

> “the government provides infrastructure ‘just in case’ whereas the private sector provides it ‘just in time’.

In other words, it is the job of government to provide the core.

AA considers that there is a critical issue with the ownership and preservation of Intellectual Property. Recognising that ‘Australia cannot survive just by being the world’s quarry’, AA suggests that with innovation happening on an international basis, Australia needs to own and have access to emerging thinking. She cites the invention of solar power technologies by Australia which they subsequently failed to exploit with implementation technologies now being re-imported.

Appendix 4:

CIPMA – Critical infrastructure Protection Modelling and Analysis

GeoScience Australia

GA is a function within the Attorney-General's Department with a brief to consider the resilience of communities. It has a major security agenda, being concerned with the broad vision of energy management, policy management, e-security and disaster prevention/recovery. It sits under the 'National Security Resilience Division'. CIPMA collaborates with CPNI (Centre for Protection of the National Infrastructure) in the UK.

CIPMA works to support both Government and Private Sector helping them to assess hazards and has the national capability to assist decision makers in a collaborative way. 'Trust' is vital in this operation as CIPMA is holding commercially sensitive data for a wide number of organisations. The project has high level government support and is internationally recognised.

The work being undertaken by CIPMA is to identify vulnerability and resilience with the objective of managing and sustaining the complex infrastructure networks. They explicitly recognise and explore issues of cascade failure, single point of failure and choke points. Some inter-dependency mapping has taken place with an initial examination of impact footprints. It is notable that as with the UK, the 'private sector' stops considering interaction at the boundary of its own particular projects.

The CIPMA policy rationale recognises that there is a lack of meaningful information on sectoral interdependencies and is developing a role for government as 'honest broker' looking strategically at high-impact, low probability events.

All mapping work is undertaken at the level of the individual asset (a building or a power transmission tower) although for the banking sector there is a clear recognition that the 'asset' is the data and its movement – and that a number of essential business functions rely on this AND the physical architecture. This asset-based approach to modelling is believed to be unique. The recognition of the 'data' as the prime asset for banks should perhaps be extended to other organisations.

The government funds most of the modelling and analysis although other work is undertaken on a cost-recovery basis. The value of CIPMA work is potentially huge but is reactive, helping decision makers with the questions they are already asking, rather than driving the agenda.

Simulation and Modelling

An example of the modelling work undertaken is simulation of the impact of a cyclone on the electricity distribution infrastructure in Queensland. This model, using a geo-spatial database overlaid by the ‘National Exposure Information System’ enabled the identification of points of failure (essentially the collapse of electricity pylons), the modelling of the various economic consequences and the simulation of alternative recovery paths and their impacts.

The work is not focused on interaction between infrastructure systems, but on the individual systems themselves in interaction with the changing environment. The particular example examined the future probability of failure of each individual tower (and of chain failure of the whole electricity system) – but did not, for example, consider the impact on water supply, telecommunications or other aspects of the wider infrastructure.

CIPMA is considering modelling of Telecoms, E-commerce, Government Communications, Transport Systems, Liquid Fuel and is continually seeking to build its own capacity.

Climate Change

Climate change is recognised as a key part of potential future vulnerability. One role of CIPMA is to make Australians aware of the risks and to understand the implications for standards. Their task is to provide information to asset owners – but not to provide either funding or remedial support. These asset owners are beginning to ask about the changing risks associated with climate change and the ‘Risk and Impact Analsyis Group’ is thinking about fully integrated modelling of impacts on infrastructure, people and economy.

Appendix 5

Infrastructure Australias' Reform and Investment Framework (the Audit Framework)

Table 1: Infrastructure Australia's Reform and Investment Framework (the Audit Framework)

Stage	Description	Components Required	Rationale
1. Goal Definition	Definition of the fundamental economic, environmental and social goals that Australia seeks to achieve. For example: • sustained economic growth and increased productivity; • lower carbon emissions and pollution; and • greater social amenity and improved quality of life.	• Formalised, comprehensive, and agreed goals, objectives, targets and indicators. • Specific and quantified goals, objectives and targets. • Outline how the initiative fits within existing infrastructure plans. • Outline of how the goals and objectives align with those of other parties (e.g. National – including Infrastructure Australia's Strategic Priorities, State/Territory, Regional, and Local level) and across sectors.	Goals are needed against which problems and solutions can be assessed.
2. Problem Identification	Objective, specific, evidence-based, and data rich identification of problems of infrastructure systems and networks that may hinder the achievement of those economic, environmental and social goals.	• Situation Assessment – a review and analysis of the current status. • Scenario Assessment – a review and analysis of the future status that identifies: – Driver and trends of the current and future situation – Base-case using the current trends (certainties) – Alternative futures using future trends (uncertainties) • A list of Problem Statements that can be accurately defined and quantified.	Specificity regarding inadequacies is essential in order to take targeted and therefore more effective action.
3. Problem Assessment	Objective and quantified appraisal of the economic, environmental and social costs of those deficiencies, so that the most damaging deficiencies can be identified and prioritised.	• Accurate and objective assessment of the economic/environmental/social impacts of those problems. • Priorities identified which reflect the scale of impacts.	Understanding the costs/impact of deficiencies allows the worst problems to be identified and prioritised.
4. Problem Analysis	Objective policy and economic analysis of why these deficiencies exist – i.e. what is the underlying cause (depending on the sector, reasons could include market failure, government failure, capital restrictions, etc). This should include an assessment of non-infrastructure reasons for the problem – e.g. land use patterns, peak demand, or education/business hours.	• For each deficiency, analysis of why those problems have developed. • Covers both immediate and underlying causes (e.g. not just 'lack of investment' but causes of underinvestment, e.g. regulatory environment).	Understanding the causes allows effective and targeted solutions to be created. Infrastructure is often not the only cause of problems.
5. Option Generation	Development of a full range of interventions that address the issue in the domains of: • reform (regulation, legislation, governance); and • investment.	Identify the full range of Options for each problem from the domains of: • reform – e.g. independent pricing, regulation, approvals, coordination; and • investment – e.g. better use through demand management, capacity increases.	Identification of a broad range of options – across reform and investment areas – rather than relying on early judgements or pre-conceived ideas – is more likely to identify the best Solution or package of Solutions.
6. Option Assessment	Strategic analysis and cost-benefit analysis to assess those options. The appraisal should incorporate the full range of economic, environmental and social impacts (including agglomeration and trade impacts, carbon impacts, noise, and social amenity) so that the impact on all goals is measured and understood.	Qualitative and quantitative analysis including: • Strategic analysis – using high-level profiling assessment – to assist in the analysis of a large number of Options; and • Rapid analysis – using a high-level Appraisal assessment – such as a Rapid Cost-Benefit Analysis (CBA) – to assist in the analysis of a smaller of Options.	An understanding of the strategic and economic value along with the risks and uncertainties in delivery – is essential to understand how the Options or package of Options will achieve the fundamental goals outlined in Stage 1.
7. Solution Prioritisation	Identification of policy and investment priorities from the list of solutions, on an objective basis that gives primacy to the Benefit Cost Ratio (BCR) of initiatives, but is balanced by considerations such as strategic fit and deliverability (including risk, affordability).	• A structured and objective evaluation framework – that reflects the primacy of Cost Benefit Analysis along side of the strategic value and deliverability risk – is used to make decisions on the long term infrastructure pipeline. • A review of the Solution is made against the fundamental goals/problem identification.	BCRs provide the best available objective evidence as to how well solutions will impact on the goals outlined in Stage 1 – but is not the whole story.

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Appendix 6: Cases of Systemic Interaction

6.1: The Cockermouth Bridge Failure

Civil Contingencies Secretariat defined this as a 'Regional Incident', one in which Whitehall had only limited involvement, the incident being managed primarily by the Local Authority and the Environment Agency. COBR did not meet for this incident.

A number of issues have emerged.

The vulnerability of the bridges was not understood. Whilst the Rail Industry has very high awareness of 'scour' – including possessing and using a 'scour manual' - this awareness is perceived as lower in the Highways Agency (HA). The HA does have an organised approach to this issue but it is suggested that Local Authorities may be less aware – and that there is a certain lack of clarity in their statutory duties in this regard.

On the basis of 'if it is not a statutory duty, it isn't likely to happen' it might be that scour monitoring work is inhibited by cost factors in some instances. It might be that the potential for bridge collapse under flood conditions was unknown.

The bridge was carrying electricity, water, sewerage and telecommunications and the key disruption statistics are:

Bridges:	6 bridges lost, 1600 checked for damage
Telecommunications:	3500 homes disconnected
Electricity Supply:	1200 homes disconnected
Rail Transport:	unharmed, but temporary station built
Road Transport:	local and trunk roads closed
Ports:	120,000 tons of flood deposits to clear
Flooding:	1300 homes
People:	3 fatalities, 1 person missing

Of 5 'Airwave' sites affected by the flooding, 2 were not functioning 5 days after the event. These carry Category One responder communications. Although mitigation was achieved through the use of temporary sites, failure of elements of the critical communications system at the moment of maximum need should be a concern.

The Environment Agency and Local Authority will investigate this incident through the local resilience forum which falls under the Police Authority. It is suggested that the minimal loss of life in this instance may inhibit the inquiry process.

The rebuilding of the bridges will be at the cost of the Local Authority although the Bellwin Scheme will pay for the immediate costs of the event in excess of £1m. The ABI estimate total recovery costs at between £50m and £100m.

Reflecting on this event, a number of questions arise:

> Might any rebuilding simply recreate the same vulnerabilities as previously existed?
>
> If ‘temporary’ services are maintained in place might they increase the resilience in the area?
>
> To what extent will the resilience be understood locally, the consequences, in this instance, of the loss of the bridge were small;
>
> Will it be considered ‘worth’ the time and effort to map out the interdependencies when a relatively small number of people were involved or affected and the economic impact might be thought of as low?
>
> Would a ‘local’ resilience plan perhaps rely on hotels and rentals to close any accommodation gaps?

Looking more broadly:

> At what point does an emergency become an emergency?
>
> In terms of National Infrastructure, how do we define what is critical?
>
> How detailed should we be in understanding resilience and dependencies?
>
> Each Local Authority uses ‘constraint maps’ as the basis of local planning decisions, could these be developed and used as the basis of mapping the key elements of Critical National Infrastructure and, perhaps using digitised maps and common conventions (if not already established) a GIS (Geographical Information System) could be used to identify vulnerable geographic interaction points and vulnerabilities.

6.2: Water in the Gas Supply

On the 21st December 2009 it was reported that a burst water main had leaked into a gas pipeline in Barnet, North London cutting off the supply to around 700 homes.

At the time, despite drafting in Engineers from the Midlands to work on resolving the problem, there was uncertainty about whether or not the supply could be restored before Christmas. It is notable that the ‘spokesman’ interviewed about this problem was from the National Grid, an organisation more frequently associated with electricity supply than either gas or water.

Residents had been supplied with fan heaters and electric boiling rings to provide some measure of comfort during very cold weather.

This event highlights, at a very local and specific level, the tight interaction between these vital systems. The physical proximity of the water and gas supply lines was clearly a critical factor.

6.3 Rail and Energy - Interaction and Risk

6.3.1: East Coast Main Line - Current Operations

The complexity of the Intercity East Coast Franchise timetable and its interaction both with other operators and other elements of infrastructure ‘eats capacity’ on the ECML.

The ECML could, if not appropriately managed (scheduling of services) draw power (electricity) in such a manner that it could knock out the local National Grid (NG) feed. Equally, the ability to supply sufficient power is such that the National Grid could knock out the ECML. Because of electricity supply limitations, diesel trains must be run on the southern sections of the ECML.

In other words, ECML is already using more power than the ‘theoretical capacity’ of the infrastructure and is forced to use fossil fuels directly to compensate for the lack of power;

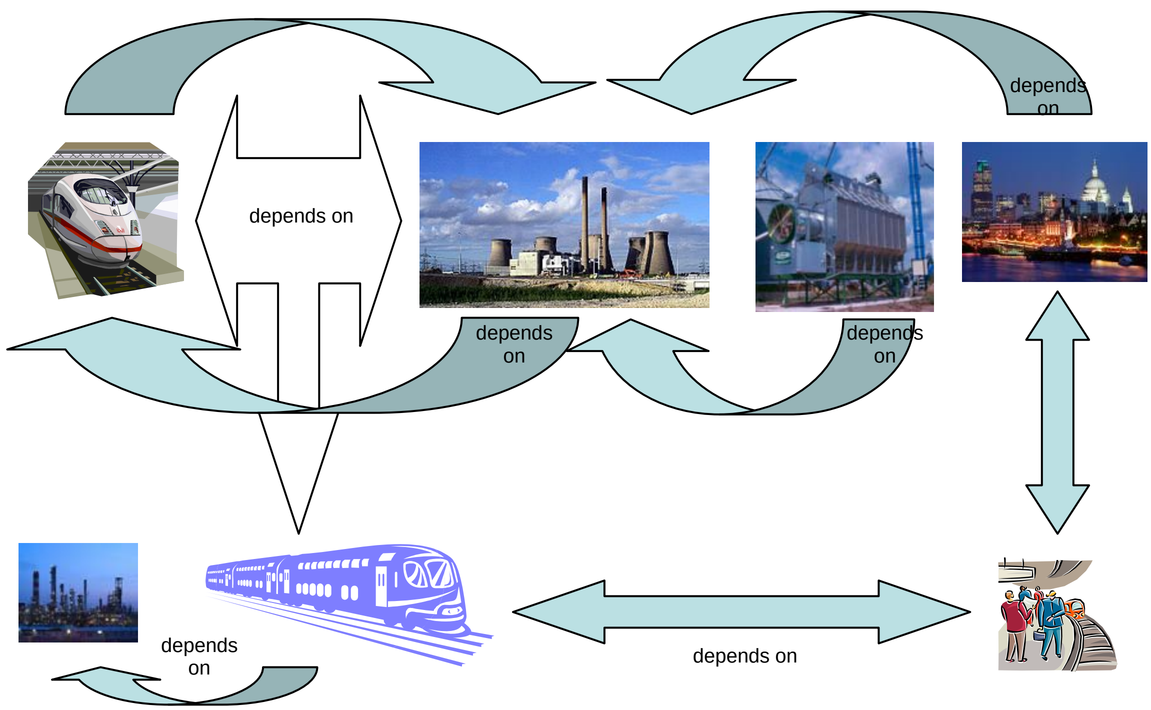
Overall, National Grid limits ECML but ECML also limits National Grid. The dependency of these two systems upon each other appears both absolute and fragile, offering a potential ‘single point of failure’.

6.3.2 Inter City Express – Replacement Rolling Stock

When considering replacement rolling stock, the challenges increase. New rail vehicles currently being specified and designed, whilst drawing the same ‘headline’ power from the National Grid, draw it very differently. The power draw increase on existing vehicles is gradual whilst that on new vehicles is more peaky, that is, when they demand power they demand all of it instantly. This is characterised as a ‘square wave’. The impact of this difference in characteristic was apparently evident during the "south of the Thames" MKI rolling stock replacement which led to the "southern power supply upgrade" project.

A key constraint on the deployment of Inter City Express Procurement Project (IEP) Sets is the availability of overhead power lines. Future vehicles will draw additional power from the Grid in the North East of England – an area which is already short of power.

ECML Inter-Relationships



For example, when farmers run grain dryers during the autumn this limits the amount of spare capacity and has the potential to disrupt the power supply that runs the signalling system. Vehicles being procured under IEP will be 'bi-mode' – and will seek to draw power from overhead lines wherever they are available. This will potentially cause further problems in this area.

The IEP timetable projects delivery of the first vehicle into the UK in 2012. The potential problems become real at that time.

This same power supply to fleet interaction is hugely evident in the plans to deploy IEP Sets on the Great Western route. This is currently only electrified to support Heathrow Express services at the west end of the route. National Grid connections are a significant cost and time constraint on the overall project.

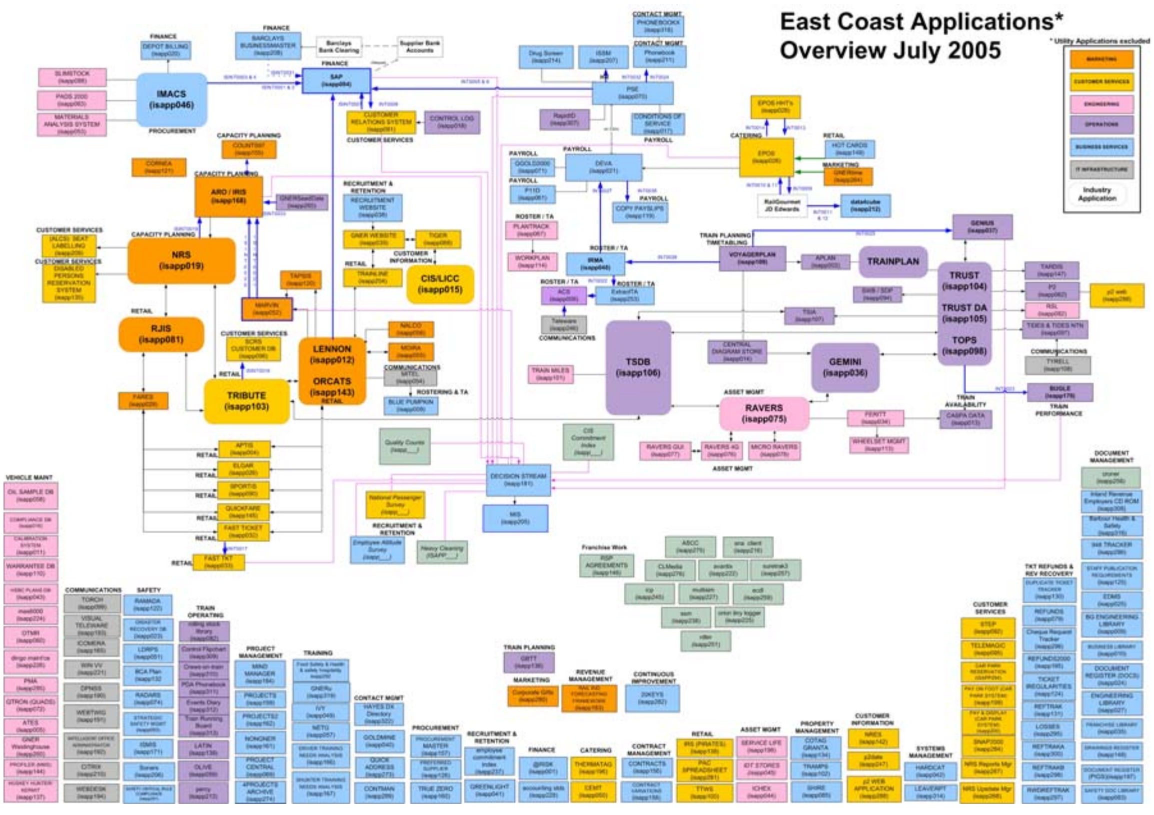
However, the availability of electric traction supplies is a key dependency in determining which type of train to procure.

It is also notable that the permanent way in the North East is vulnerable to both flooding and subsidence during times of harsh or extreme weather. This already causes frequent service disruption and further reflects the need for the infrastructure to be more resilient than is currently the case.

6.3.3 Railways and ICT

In general, this is a very complex area of railway operation, a typical Train Operating Company (TOC) is running around 70 'industry' applications to support the safe operation of the rail system – from scheduling and rostering of people to maintenance, scheduling and management of vehicles and stations – and a number of these systems are 'required' under the terms of either Franchise Agreements or by force of law.

However, these information systems are purely 'operational' at the level of the TOC not the railway system.



Overview of IT Systems: East Coast Main Line

It was discovered during the review that:

> there is no central control capability for the UK mainline network;
>
> there is no visualisation tool that represents the whole 'machine' (the real-time operating railway) that everyone is trying to operate;
>
> the railway is controlled as a series of parts rather than as a network.

Bizarrely, in the short term, much of the rail industry IT could be turned off and many of the trains would continue to function and run.

However:

> all 'live' operating problems happen at a distance on the railway, and they cannot be solved without, at least, the use of telephones;
>
> resilience is 'OK' in the unstressed 'Business as Usual' situation – the operators get away with the lack of a command and control network view – but when the system is stressed or broken it is managed through
>
>> 'lots of paper and a few intelligent people who understand the system' – ' the railway freaks'

There is then, no capability to make the 'best' decisions and to regulate the system and there is no mechanism for deciding what 'best' means! And, as both volume and complexity increase, the number of interdependencies and interactions (potential and actual) increases and the, paper based, response to perturbation is too slow.

Perhaps using the NATS (National Air Traffic System) as a model, an urgent need is to be able to consider the system as a whole and thereby manage overall performance.

It was suggested by Richard McClean that the UK rail network is the most complex due to its mixed traffic and speed, high levels of utilisation, multiple power supplies, different loading gauges and signalling systems. Whilst the German system is nearly as complex, they have resolved the 'High-Speed Network' issue in a different way (building high-speed bypasses at key points), whereas the French have, in effect, built a whole new railway. Rather than 'solving' the network management problem, both appear to have gone round it!

The complexity of interaction in the railways is high – and such control systems as exist, or are planned, are focused on safety (stop the trains) rather than performance (optimise train running). These two key systems are:

ERTMS: European Rail Traffic Management Systems
ETCS: European Train Control System (Signalling)

It is unclear how ‘complex’ a system might be coped with from a modelling/performance management perspective – and at what point it might be appropriate to ‘intervene’ to improve performance. Current interventions are for safety and necessarily limit the capacity of the system AND increase the use of energy (because the necessary default is to stop trains at red signals and then restart them.) No information system currently exists which would obviate this need.

It is proposed that, given appropriate information about train positioning AND the fact that trains only move in one plane (so that speed up/slow down are the only relevant instructions) it would not take much intervention to ensure that trains always miss each other.

Under British Rail, ‘headcodes’ used to be the basis of regulation of rail traffic – giving priority to fast/long haul traffic over slow/short haul traffic. This system of prioritisation was lost at the outset of the current franchising system with all operators having ‘equal right of access’. In effect, once a TOC has a ‘train path’ established it holds and retains the rights to that path – regardless of the inefficiency elsewhere in the railway system that the path may generate!

It is suggested that while regulating decisions should seek to minimise overall delays the decision making information is not available to support such a judgement. However, a system of prioritisation for both train planning AND live operations would probably improve the performance of the industry in relation to:

Energy consumption;
Delays;
Revenue.

6.4 Food Distribution – Interaction Points of Failure

When it snowed across London in early 2009, the bus service largely ceased because, although the major routes had been cleared, buses were unable to exit from depots across short stretches of minor roads linking them to major routes. The salting of major and minor roads falls under the responsibility of different authorities. Each authority fulfils its obligations to clear the priority roads – neither is responsible for ensuring the buses can run.

Food delivery to UK supermarkets depends on an almost ‘just-in-time’ system based on supermarket owned high throughput distribution centres. Deliveries in and out are tightly timed and controlled with perishable goods (fruit, fresh meat, dairy products and vegetables) passing through very rapidly. For example, mushrooms typically move from farm to distribution centre to store in less than 24 hours – often being consumed within a further 24 hours.

This system is capable of operating under a wide range of normal operating conditions (accommodating routine weather variations, road traffic delays and so on).

In early 2010 there was significant snow lying across much of England. One of these centres experienced a situation where goods could neither be delivered nor despatched because although the adjacent motorway and the distribution centre yard were rapidly cleared of snow, the short, sloping, link roads between the centre itself and the motorway were not cleared. It was not the responsibility of either the Highways Agency or the supermarket and not a priority route for the Local Authority.

Further issues arose because the delivery trucks were automatic (giving improved fuel efficiency) but, giving the drivers only minimal control of power delivery to the driven wheels.

Although there is an evident fragility in this set up – and 'just-in-time' systems generally have a massive susceptibility to unmanaged delay, the supermarkets build in a degree of resilience. They were able, in this instance, to shift store supply arrangements so that those which could not be supplied from the original centre were able to be supplied by rerouting vehicles from other centres, providing around 60% coverage to the exposed supermarkets. It is unknown for how long, or for what area of the country these arrangements could be sustained.

6.5 Shared Infrastructure – Hidden Fragility in ICT

A train operating company suffered the loss of over one million emails when a hidden fragility in its telecommunication systems was revealed.

Recognising the business critical nature of its email system and its persistent need to move data between multiple offices, the IT Director ensured that each office was provisioned with dual broadband capability, sourced from different providers.

A 50mbps connection was contracted from each of two suppliers, providing 100% failover resilience – the loss of one of these fibre optic cables leaving the business fully capable of functioning.

Nearby road works caused damage to a cable causing complete loss of internet and inter-office connectivity.

On investigation, it was determined that the physical connection was only provisioned through a single cable. The first supplier (a major supplier of physical infrastructure) had installed a 100mbps capable cable 'throttled back' to supply only 50mbps. The second supplier, a secondary provider, was selling 'bundled bandwidth', purchasing 'bulk' capacity from a primary provider and reselling it on a 'service only' basis. Following the loss of connectivity, it was determined that the secondary provider was purchasing bandwidth from the primary provider – who were selling the 'spare' capacity from their throttled back 100mbps cable.

The fragility of the system was hidden in the secondary market arrangement.

This situation is not unusual. A further recent instance in the care sector found that whilst a service was being purchased from one supplier the physical cable provision is through the BT Network. This 'secondary' market creates an illusion of system resilience which is not actually present at the level of the physical network.

6.6 Eurostar

The Eurostar failures being very recent (17th – 20th December 2009), these were discussed based on the available 3rd party reports.

The key points of the discussion were:

> Eurostar's emergency and recovery processes did not appear to address the issues arising from their operational role of moving large numbers of passengers over long distances;
>
> In particular, Eurostar appears to have no effective 'recovery' plan in place to enable either the completion of commenced passenger journeys OR the completion of the day's diagrams;
>
> > (Noted that UK TOCs have processes in place to use rescue locomotives and vehicles from other TOCs to enable delivery of services to stranded passengers and to ensure as far as possible that passengers who have started a 'round trip' get to complete it).
>
> Eurostar appears to have developed only limited relationships with other TOCs operating on the same or adjacent networks.
>
> Eurostar appears not to have fully developed arrangements with the Channel Tunnel Infrastructure Manager (Eurotunnel)

With regard to interdependencies, it was noted that:

Eurostar and Eurotunnel services are absolutely dependent on the provision of electricity via the National Grids of UK, France and Belgium;

The Channel Tunnel is cooled by the pumping of chilled water through pipes in the tunnel. It is not known whether this is fresh or sea water, nor how long the Channel Tunnel can continue to operate, or at what level of traffic without the cooling system. However, the critical implication is the:

further demand for power;
seemingly critical dependency for safe and effective operation on the water supply to cool the tunnel.

Elements of the rail vehicles themselves are extensively operated by compressed air (for example doors and toilets) meaning that not only does the movement of the rail vehicle depend on the electricity supply, but the general well-being and safety of all passengers and train crew is dependent upon continuation of the air-supply – which is itself dependent on the electricity supply. The train air conditioning shuts down as soon as the main power is lost, lighting lasts only 20 minutes.

6.7 National Air Traffic Services – a Resilient System

The Air Traffic Management Centres are at Swanwick and Prestwick and are physically separate from all the airports they control. With the new facility at Prestwick, there is believed to be 85% failover resilience in terms of coverage both at that site and at Swanwick. Either site is believed able to absorb part of the others operation if necessary. The ‘Corporate and Technical Centre’ (CTC) provide systems resilience through duplicated systems and communications which is capable of providing both a training and a ‘live’ environment. They constitute a ‘virtual’ third site.

Each facility is equipped with dual conventional power supplies which are geographically separated, coming in to the AT Centres via different routes and from different power stations. Each facility is equipped with dual generators, again physically separated and operable, capable of supporting all the power requirements of the centre with seven days fuel supply. In the event of loss of both standard and generator supplied power, UPS systems are capable of supporting each ATC for up to 48 hours.

In the event that standard, generator power and UPS systems are exhausted or fail altogether, the centres use ‘Manual Reversion’ a voice-only system with 24 hours supply which will enable the safe landing of all air traffic existing at the time of the failure.

Each Control Room is also able to withstand an external fire for up to two hours.

In terms of system development, risk assessment is paramount with a complete and strict separation of operational and non-operational systems. All contingencies are tested and re-tested to ensure that any aircraft in the air at the time of failure can be landed safely.

Maintenance of all systems (IT, Radar, Radio) is rigorous and condition based. There remains however a vulnerability to the competence of individual maintenance engineers. ATC trains both AT Controllers and AT Engineers (who are highly specialised) at its own centre at Hurn.

Radar and Radio transmission sites are widely spread across the UK. Each has back-up generators rather than dual power supply (due to the remote locations), but radar coverage is overlapping so that resilience is embedded in that. Radio communication with aircraft operates on both ‘line of sight’ VHF frequencies and ‘non-line of sight’ HF frequencies, bouncing signals off the ionosphere.

In the AT Centres themselves (the Control Rooms of which are Faraday Cages), the AT Controller is supported by an Assistant who provides the ATC with updated flight information. Whilst the AT Controller is only concerned with the particular sector under consideration, these sectors can be dynamically split or joined depending on traffic volume, and the Watch Manager has an overview of the whole situation.

The resilience of the overall ATC system is substantially greater than has been found in other sectors reviewed. The costs of this resilience have not yet been identified nor have the measure of extreme events (weather or otherwise) under which it can continue to operate.

There are potential vulnerabilities.

A potential point of weakness arises here which is much broader than simply Air Traffic. The Swanwick centre operates on IBM system applications, whilst the Prestwick Centre uses Spanish sourced system applications. Both hardware and software are sourced overseas. They are therefore vulnerable to the continuing availability of overseas sourced intellectual and physical property.

This overseas sourcing applies increasingly to all aspects of ICT. This generates a vulnerability to the whole sector – and consequently to all others if, for any reason, there is an interruption to supply. Given the increasing prevalence of ‘just-in-time’ supply chain management in multiple industries, there may be an ‘interaction’ vulnerability emerging the impact of which could be substantial. A good example is the availability of the transport system (rail and road networks) to deliver food, coal, fuels, machinery and components.

The Air Traffic Management system runs on the ‘Da Vinci’ network which is jointly managed by NATS and BT and is, at least partly, private circuits. It is currently unclear to what extent this generates a significant risk to voice and data traffic between AT Centres, Radar and Radio stations. However, the use of public exchanges/switching centres is clearly an area of potential risk.

The provision of systems (of all types) from overseas sources gives rise to a question of long-term resilience for those systems and, importantly, the ability of NATS to develop and enhance their provision.

NATS is believed to be aiming for a ‘fully-outsourced’ strategy, in which it will operate AT Services on an infrastructure in which it has no asset ownership. Its approach will be ‘pay as you go’ with the assets owned by other organisations. Whilst, from NATS perspective, this obviates the need to raise large sums of capital, the loss of control and, potential, shift in culture, attitudes and behaviour that often ensue from an outsourcing strategy must be regarded as a cause for concern.

NATS is believed to be in discussion with ATOS about providing all the ‘Business Systems’ support to NATS, i.e. the Local and Wide Area Networks and Hardware. ATOS is a core supplier to the Rail Industry.

An integrated European Air Traffic Control System is being developed with a target date of 2020. The impacts of this are unknown. However, all other AT Services in Europe are owned and operated by Governments.

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