Assessing and Reporting on Systemic Risks and Opportunities in Infrastructure

Infrastructure UK
Engineering and Interdependency Expert Group

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Foreword by Professor Brian Collins, Chief Scientific Adviser, BIS and DfT

The concept of treating risk and opportunities in a systemic way has been around for some time but has not attracted attention because the consequences of not doing so have been small. In the last few decades infrastructure systems and services have become more critical to human and environmental wellbeing and have become deeply interdependent. This has resulted in the consequences of any type of failure or degradation being significant, in failures in one system or service affecting others sometimes with amplified negative effects, and in general reduction of trust in basic services by the general public.

The analysis in this paper highlights with examples some of the classes of failure and their consequences, but also some of the opportunities that could be realised by taking a systemic view throughout their lifecycle of services and their underlying systems. It also brings to the fore the need for better data about systems, at all stages of their development and use, and for a more structured and formalised analytic approach to the use of that data in restoring confidence and trust in infrastructure systems.
A whole systems approach to infrastructure investment is recommended to enlarge the social, economic and environmental value that can be gained from the significant capitalisation that is needed to combat climate change, resource scarcity and changing demographics.

Professor Brian Collins

EXECUTIVE SUMMARY

National Infrastructure: Systemic Risk and Opportunities

Infrastructure UK's Engineering and Interdependency Expert Group (EIEG), has undertaken research to assess the opportunity for deriving enhanced economic, social and environmental value from investments by treating infrastructure in a systemic manner.

The findings of this research show that the networks that constitute the UK national infrastructure for Water, Waste, Energy, ICT and Transport are so tightly integrated and interdependent that it is now not only inappropriate to plan for their improvement or replacement in isolation, it is inefficient economically and very likely to increase the risk of failure when extreme events occur.

These infrastructure networks are potentially at risk of cascade failure arising from poorly understood and managed interdependencies. At the same time, those interdependencies provide opportunities for improved resilience and effectiveness through managed integration, co-location and co-optimisation. There is a continuing risk that the momentum of the existing networks and relationships will deliver us the inevitable failures of a future we are currently heading towards rather than a future that we choose to create.

It is therefore recommended that the improvement or replacement of infrastructure must be addressed using a systemic approach.

There are three principle challenges in these processes;

- infrastructure renewal,
- decarbonising economic and social activity
- infrastructure adaptation to respond to climate change and extreme events.

The research shows that a systemic approach could deliver:

Economic Benefit:

increased value or reduced cost of not less than 10% per annum against current long term investment expectations – around £4bn per annum sustainable over many decades – by better exploitation of the assets and integrated design, procurement and operation. It is considered by some that gains in the order of 20% - 30% could be achieved, equating to some £8bn - £12bn per annum;

reduced direct impact on the economy of infrastructure impairment against historical costs of failure by around £1.5bn per annum, again sustainable over many decades. This can be achieved by designing systemic resilience into all new schemes as a matter of best practice or regulation as appropriate, this gain is sustainable over many years;

greater resilience in the mutually critical relationship between the energy and ICT sectors, the latter of which enables more than 90% of high street purchases (valued at £50bn of consumer purchases per annum) and is depended upon by 98% of businesses and is relied upon to provide the remote control systems for the greater part of the infrastructure networks. Recent experience of a major 'phishing' break-in to a corporate network highlights the importance of this relationship and it is reasonable to suggest that this will increase dramatically over the coming years.

Social Benefit:

reduced indirect impact of infrastructure impairment on society and increased growth arising from greater confidence in the infrastructure. While these impacts are harder to generically quantify in financial terms, we can indicate the scale of social impairment. The severe winter weather experienced for three weeks in December 2010 affected most of the UK population. Specific examples of social disruption were the closure of 7000 schools, an additional 18750 patients treated at NHS hospitals and 34% of rail services cancelled. At one point Heathrow had a backlog of 600,000 people and 4000 flights were cancelled in the period. At least 1.5m people were affected by disruption to water supply in Northern Ireland – just under half the population. The 2006/7 figures (the latest publically available at the time of writing) show that 14 million minutes of passenger delays were incurred for all reasons on the rail network at an estimated cost of £1bn.

The social implications of infrastructure failure and impairment appear not to be fully understood or addressed. However, it is reasonable to state that a multiplier effect acts on every such event. Failure to operate a train amplifies to affect all of the potential passengers which in turn is amplified across the employers of those not able to travel while closure of schools demands that many parents remain at home rather than going to work. Each of these effects has financial and social consequences. It is important that further research is undertaken to explore these aspects more fully.

The 2009 severe winter weather incurred an estimated loss to the economy of £690 million per day, due to people unable to get to work or deliver goods, among other factors. Whilst not all of these losses or impairments could be mitigated by systemic analysis and implementation, it is estimated that at least 20% could be defrayed, amounting to some £150m per day just for one severe winter weather event – about £3bn over the 2010 extreme weather.

The social impacts seem to occur, at least in part, because of the ‘vertical’ or silo organisation of many infrastructure activities. Delivery organisations are focused on the performance of their ‘functional silo’ – the services are not joined up. So, as was seen in London in 2009 – the major routes were cleared of snow but the buses could not run because the short link roads from bus depots to major routes were not seen as strategic and consequently fall under local authority control rather than Mayor of London control. In 2010 this was better ‘joined up’ – but only as a consequence of previous failure – and the structural issue persists. The structural weakness arises because the functions are managed as individual assets rather than in terms of their process enabling contribution (a road is not purposeful in itself – it is an enabler of other purposes.)

Harder to quantify, because it must be expressed in purely speculative terms, are the social benefits that might accrue from more resilient infrastructure with greater capacity. A society confident in the ability of the infrastructure to provide continuity of supply and infrastructure operators to support growth would be expected to be more willing to invest in and support regional economic development activity.

As society and business become increasingly dependent upon applications of Information and Communications Technology, the capability of these systems to continue operation under the most extreme of circumstances will be critical to the maintenance of societal well-being and to economic activity and growth. The benefit of increasing resilience and capacity in these systems will be sustainable over generations.

Critical to realising that benefit is investment in the skills and knowledge required to create and maintain such systems as well as the capacity in both the network of systems and the individuals responsible for them for creative adaptation to emerging issues and challenges.

Environmental Benefit:

arises particularly from co-location of energy generation and consumption assets especially where ‘waste’ heat can be exploited, more effective management of materials supply chains can be achieved, and through localised energy generation through CHP facilities which can also enhance local resilience. Again this is difficult to quantify precisely on a national scale from the limited research so far undertaken as is the reflection that systemic knowledge about supply chains and infrastructure interdependencies would enable the identification of areas and activities where greater efficiency and effectiveness can be realised.

However, the 'Grain' project can be taken as an example in which co-location of energy generation with consumption of waste heat is being implemented. This delivers a thermal efficiency of 72% compared with a best of 55% for stand-alone facilities – a gain of 17% and delivering a reduction in CO2 emissions of 350,000 tonnes. 340MW of 'waste' heat is being utilised at Grain – which would have a production cost of around £27m @ £80/KWh per annum in generation cost for natural gas if that power were being paid for.

Overall efficiency of between 75% and 90% is reported for CHP plants in general – a gain of between 20% and 35% against the best of 55% and 40% against a 'typical' coal fired power station which would be expected to achieve around 36%. The current mix of electricity production is around 25% coal fired, producing 22.5GW at a cost of around £100/KWh – or £10m per GW or £225m/annum. Achieving an improvement to 75% through CHP could deliver sustainable savings of around £100m/annum.

The electricity generation industry anticipates investing some £200Bn over the coming 20 years on replacement or additional power stations. If each of those were to achieve at least 'Grain' levels of thermal efficiency (72%) rather than the 55% current stand-alone norm – a gain of 17% could be achievable. This could potentially both save substantial investment (up to £34Bn) by reducing the number of facilities required or provide additional power at the same cost. These benefits would be further expressed in terms of improved payback on the investments for the owners and/or reduced operating costs. Increased resilience would also be possible because supporting investment in supply chains, access roads, and engineering skills would have greater payback collectively than individually and collaboration between providers could be stimulated. The benefits would be sustainable over the life of the facilities – some 50/60 years. There would in addition be a significant potential CO2 reduction.

Generating energy from waste at Frog Island, whilst less thermally efficient than other means of energy generation at around 25%, is treating 180,000 tonnes of materials per annum drawn from 4 London boroughs removing 120,000 tonnes of material which would otherwise go to landfill. This activity which also reduces subsequent methane and CO2 emissions can only be effective if the upstream and downstream supply chains are managed as part of the whole. This is an example of new infrastructure, based on exploitation of existing waste that will only deliver all of its estimated benefits reliably if interdependence between system components is taken into account at the design and planning stages– a systemic activity.

This facility relies first upon the functioning of the upstream supply chain for waste materials to the site – a supply chain which is vulnerable to disruption of traffic, the supply of road fuel and the source of the materials themselves

– householders. It also requires an electrical feed from the grid both for ‘blackstart’ purposes and for the functioning of the materials processing plant. Downstream, the plant needs to be able to connect to the National Grid and provide a consistent feed of electricity.

More generally, a shift away from coal fired power generation to gas fired delivers a reduction in CO2 emissions from 1000g per kWh to under 200g per kWh – but this requires the maintenance of an international gas supply chain which is beyond the control of the power generators. Again, a systemic approach is required as UK generators anticipate their dependence on imported gas increasing from around 50% of to 75% by 2020. This shift could cause significant social impairment if the supply chain is not managed as much of the gas is used for domestic heating purposes, offers significant environmental benefits in terms of reduced CO2 emissions and, potentially, represents savings of £20/KWh, around £20m/GW per annum for every additional GW delivered from gas rather than coal.

All of these energy generation facilities would benefit from integration and co-location to minimise energy losses, maximise utilisation of ‘waste’ heat and enable greater investment in the supply chains to reduce vulnerabilities such as the single road access to the Grain facility.

These examples show that using a systemic approach to infrastructural investment design, planning, acquisition and operation can save tens of billions of pounds sustained over decades, provide better resilience to extreme events thereby maintain economic activity and economic consequentially lower financial losses and social disruption when they do occur. It must also be recognised that there will be significant challenges to overcome in developing the skills and abilities to develop and implement the necessary changes.

It is recommended that on the basis of this evidence, three lines of activity are carried out in the next six months to achieve a sound basis for developing infrastructure in the UK over the ensuing decades.

They are:

- data collection and analysis of infrastructure assets,
- development and use of full life cycle good practice for infrastructure renewal and modernisation,
- identification and development of critical tools to direct and manage these new and complex processes.

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1 Acknowledgments

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2 Introduction and Background

2.1 Introduction

That the UK national infrastructure (NI) is a 'network of networks' is undeniable. Critically, as a system of complex, dynamic, evolving networks, it is only as effective or resilient as its weakest chain of connectivity – and lack of diversity of pathways through the network implies single points of failure. The identity of those single points of failure is dynamic, a function of the connectivity itself, the expectations, demands, stresses and extreme events imparted to the NI, as well as the condition and performance of the multiplicity of assets that constitute it.

It is not possible to identify one single weakest point and recommend 'fixing it', nor is it possible to define a 'solution' to the whole. What is possible is to accept the systemic nature of the NI and ensure that its challenges are addressed with a systemic mindset supported by adaptive approaches. This means dealing with the challenges of ageing artefacts and connections, carbon emission reduction and climate change from an orientation towards the **outcomes desired** rather than the more conventional focus on input constraints.

The argument presented is that modern infrastructure is a 'network of networks'. It is comprised of many thousands of assets, each of which interacts with one or more others and their performance is a function of their mutuality. These assets exist in interdependent relationships which are continually evolving and each is critical to the continued operation of the others. It is simply not possible to change, repair, renew or replace one asset without the consequences, good or bad, being felt more widely across the system. This implies that there are both risks and opportunities in any modernisation programme.

At a national level there are three clear infrastructure challenges:

- First is the renewal, repair and extension of the established asset base, much of which is ageing and utilised at or beyond its design capacity and life, and whose condition is poorly understood.
- Second is continuing adaptation of the infrastructure to the demands and technical requirements for a low carbon economy and to cope with the exigencies of potential climate change.
- Third is that we must learn to deal with the management and long term development of the NI as an integrated whole, despite an ownership and regulatory structure that at present strongly encourages and rewards each functionally oriented business to focus on its own, relatively short term, interests.

These challenges will demand significant and effective investment. To be able to determine the value propositions for investment there needs to be a deep understanding of purpose of what the NI is for. Those value propositions need to be measured in terms of the value of economic, social and environmental outcomes achieved, not simply the financial cost of inputs provided.

2.2 Background

This research was undertaken on behalf of the Engineering and Interdependency Expert Group (EIEG) supporting Infrastructure UK. The research seeks to demonstrate, through specific examples, the positive impact that an understanding of interdependency can make on the delivery of infrastructure projects.

The research is a response to the 2010 National Infrastructure Plan section 3.41 requirement:

> ‘to assess and report on systemic risks and opportunities in infrastructure’.

In the work programme overview published on 17th November 2010, it was stated that:

> ‘It is essential that complex interdependencies between sectors are understood and managed’

The specific brief, which forms Appendix 1 to this report, requires that the research:

> ‘Study a number of current or recent infrastructure projects and identify where:
>
> > Integration opportunities have been secured or missed
> > Interdependency risks have been managed and/or neglected
>
> Identify a number of issues which must be addressed to obtain benefit or manage/mitigate risk.’

In consequence, ten recent and ongoing infrastructure projects and issues have been reviewed against a standard Resilience Assessment process (appendix 2) and the findings form the final part of this report. An initial list of possible target studies included all five primary infrastructure sectors, water, waste, energy, ICT and transport, however, access to all agreed targets was not possible for commercial reasons. Therefore, in addition to the principal studies, a number of other recently published studies, reports and articles have been taken into consideration in reaching recommendations. These form appendix 3 to the report. Appendix 4 provides a glossary of key terms whilst appendix 5 provides a comprehensive list of sources and appendix 6 the supplementary materials drawn upon.

Prior work on which this report builds include:

An Infrastructure for the 21st Century, CST, June 2009
Modernising National Infrastructure, AEA, April 2009
Infrastructure Resilience Matters, BIS, May 2010

3 Recommendations

The principal findings and recommendations are:

3.1 That new infrastructure schemes and projects which are considered critical to the effectiveness of the national infrastructure be designed according to systemic best practice guidelines which must be developed or through regulation where that is more appropriate, to ensure resilience of infrastructure systems against risk of impairment through extreme events and other sources of failure;

3.2 That systems approaches to recognising, understanding and addressing the interdependency of the UK infrastructure ‘network of networks’ be adopted with an expectation of **sustainably increasing the value derived and resilience improved at a cost 10% lower than would currently be the case** and delivering commensurate environmental and social benefits;

3.3 That government investment in infrastructure be targeted at increasing the effectiveness and resilience of infrastructure across sectors rather than within them where private investment is more appropriate. This could include publication of a ‘good practice book’. This would provide policy development guidelines and indications of resilience requirements. This in turn would encourage investments in projects and assets that focused on enhanced longer-term resilience, sustainability and effectiveness, whilst still achieving shorter term financial performance;

3.4 That the critical interdependency between power generation and ICT systems in which neither can function without the other and on which all other systems (water, waste, transport and secondary infrastructure) depend be formally recognised by government in its regulatory, procurement and infrastructure financing activities and its combined resilience be addressed;

Regulation

3.5 That regulatory regimes be reviewed and realigned to ensure convergence towards inter-sectoral alignment and consistency and be monitored for perverse regulatory outcomes especially around the recognition and management of interdependency risk across industry structures and regulatory boundaries

3.6 That regulation be refocused on delivering effective infrastructure taking account of systemic interrelationships and that ‘total systems cost’ be taken as the economic performance standard rather than the short-term cost efficiency of individual industries and operators

Investment

3.7 That the regulatory economic cycles (which are relatively short term – 5 or 8 years) recognise and respond more effectively to the long-term capital and investment cycles of infrastructure providers which are typically developing assets with a 25-60 year life and in some cases even longer. This may require the development of techniques for valuing inter-generational investment;

3.8 That all investment in infrastructure, whether funded with public or private finance, be guided by the value derived from long term utilisation of infrastructure as well as the short-term cost efficiency in its creation.

Use of systemic thinking and systems methods

3.9 That a resilience contribution assessment be undertaken for each infrastructure programme or project as part of the planning and evaluation process. A draft of such an assessment has been applied in developing this research and is presented in appendix 2;

3.10 That the existing Infrastructure Risk Registers be augmented, building on the ‘Black Swan’ work already undertaken by ‘GoScience’, based on the annual audit of the vulnerability of current assets, to include vulnerabilities arising from their interdependency;

3.11 That data which is critical to the design and operational management of national infrastructure be captured using appropriate techniques. All of the studies so far undertaken indicate that performance data collection and availability is a significant current weakness within and across sectors resulting in vulnerabilities in control stability and recovery from shock of all types;

Knowledge and dissemination

3.12 That the systems approach be promoted by government to infrastructure investors, owners and operators and the engineering profession through public dissemination of the findings and recommendations;

3.13 That financial investment be made in the verification and practical application of systemic methods in an infrastructure context, taking these techniques from abstract academic ideas to applied, value generating, engineering solutions. The lessons learned in other sectors about interdependency and the benefits of a systems approach, such as in those manufacturing activities which have adopted them, should be studied and means developed to migrate the learning and techniques to the infrastructure sector;

3.14 We believe there are significant growth and export opportunities to be derived from on UK expertise in this field. We recommend that Infrastructure UK work with colleagues across Government to develop and exploit these opportunities and the skills required;

Strategic leadership

3.15 There is a vast diversity of organisations, both public and private sector leading on or with responsibility for a particular aspect of the national infrastructure. The lack of strategic leadership presents risks and means lost opportunities. We believe that Infrastructure UK could go further in providing unifying strategic oversight of the whole National Infrastructure portfolio and provide advice on infrastructure performance and resilience. I-UK should give guidance to the various economic regulators and other relevant bodies on achieving effectiveness in inter-sectoral resilience and sustainability as well as sectoral economic efficiency;

3.16 On the basis of this evidence, three lines of activity are carried out by Infrastructure UK in the next six months to achieve a sound basis for developing infrastructure in the UK over the ensuing decades. They are

- data collection and analysis of infrastructure assets
- development of full life cycle good practice for infrastructure renewal and modernisation
- identification and development of critical tools to direct and manage these new and complex processes

While this research has a substantial evidence base, it is nonetheless recognised that the findings will require further investigation, verification and testing.

4 Summary Findings

A major challenge in undertaking this research has been the difficulty of obtaining meaningful information about infrastructure projects and data about performance. It is therefore appropriate in declaring these findings to acknowledge an informational uncertainty - “We don’t know what we don’t know!”

Similarly, it is extraordinarily difficult to find evidence of the benefits of the systems approaches to infrastructure programmes and projects when these approaches are not explicitly used. The research therefore, also draws on brief studies of the application of systems thinking to other sectors.

4.1 Overall Consideration

This research suggests that adoption of a systems approach to infrastructure could deliver benefits of not less than 10% in terms of reduced Government expenditure or additional value delivered (of the order of £4bn against current annual spending plans as they are understood). A further £16bn of savings or additional value could be achieved for private sector infrastructure investors over the five years of the current CSR. This could be coupled to additional savings of £1bn - £2bn per annum averaged across the years if investment in infrastructure resilience mitigated or prevented the impact of such events as the extreme weather experienced over the winter of 2010/11 or the Gloucester Floods of 2007. It is suggested that these known (or at least recognised) costs are only a fraction of the true costs which multiply along the supply and value chains.

4.2 Opportunities secured and/or missed

When infrastructure is impaired, the effects can be substantial. Whilst Quarmby (reference 4) estimates the economic impact of the 2010/11 extreme weather at £1.5bn, the social and political impacts should also be seen as significant. Over 1.5 million people were adversely affected by the water leakages in Northern Ireland, while in Scotland the motorways were shut overnight on two occasions with motorists trapped in their vehicles. The European Commission cited as ‘unacceptable’ the closure of Heathrow which generated a passenger backlog of 600,000 people with systemic impacts for every flight source and destination for those people all across the world. Many thousands of others were affected by closures of other transport links throughout the UK.

Public Transport failure (primary infrastructure) impairs ‘services’ (dependent infrastructure) with lack of integration in response planning evident so that minor routes linking major routes are not gritted or cleared of snow. Discussion with Northern Rail revealed that whilst they did not cancel many services due to snow, many of their train operating staff were recorded as having walked 5-6 miles to a depot because the roads were not cleared. As with airlines, each lost train service is amplified in impact by the number of people unable to travel to work on that service, affecting hospitals, schools and businesses.

Typically, projects are focused on the specific outcome desired by the infrastructure owner with dependencies recognised and risk mitigated through agreements with suppliers. It appears however that such mitigation, in some situations, amounts to the attempted transfer or outsourcing of an obligation to a third party through a supply agreement, rather than a substantive reduction in the risk itself. In fact in many cases the accountability for the obligation has not been outsourced with consequential action being taken by those affected.

The Olympic Delivery Authority have successfully capitalised on interdependency between the Olympic Park transport systems and the wider networks with which it is connected, to leverage their investment to great effect and stimulate additional spending. By comparison, the HS2 project has not yet considered the potential exploitation value of its potential right of way beyond the immediate use for the permanent way. Such exploitation might reveal significant additional value from HS2 and enhance the business case – a business case which might be threatened if the overall fall in premium passengers reported by PA Group continues (reference 17).

Considering energy, it is clearly the case that the gap in thermal efficiency between new facilities (72% at Grain) and old (conventional coal at 36%) is substantial. There are multiple possible transitions in this sector. Thermal efficiency gains can most easily be obtained through co-location of facilities such that heat and steam that would be lost in conventional plants can be captured and exploited. These gains can be coupled to a transition from high CO2 emissions fuels (such as coal) towards lower emissions such as gas and renewables. These, in conjunction with development of energy from waste can reduce both emissions and landfill. References 20 through 24 provide the sources for calculating benefits and gains in energy, emissions and finance and it is suggested that the energy industry is addressing these matters at the individual asset level, though not that of the whole system. It is also recognised that the further requirement of increased resilience in energy generation and distribution is dependent upon the integration and management of up and downstream supply chains and of the ICT control systems which enable operation. The energy sector cannot deliver these gains in isolation from the activity of other sectors.

This silo focus of projects may be driven by industry structure, convention and regulation which may be inhibiting innovation. Infrastructure providers in common with their regulators are focused on a single sector; it should be no surprise that they fail to consider opportunities and risks that fall outside their realm of knowledge, influence and control. There is no regulatory ‘meta-structure’ which enables or ensures consistency and coherence of regulation and match to market needs. The Kings Cross Central study shows how the developers ambition to develop and exploit CHP generating capacity on the site is constrained by regulation limiting the amount of power that can be produced. The effect is that the site can only generate power equivalent to one fifth of peak demand – a serious constraint upon performance.

4.3 Interdependency risks managed or neglected

There is no evidence from any of the cases that any formal use is made of systemic thinking, tools or methodologies in the development of infrastructure projects. There is though significant evidence of 'systems engineering' within the boundaries of individual projects. However, while the 'Grain' power station has successfully amplified efficiency, financial performance and reduction in carbon impact by co-location and collaboration, the 'Frog Island' study has revealed that the supply chain of recyclable materials is, in effect, unmanaged although the project has a critical dependence on the materials supply rate.

Each infrastructure provider contracts with others to provide the services they require – and in doing so are able to transfer risk from themselves. They are regulated only in regard to matters under their own control. The regulatory frameworks are, understandably, focused on an industry. There is no evidence of meaningful cross-sectoral regulatory interaction to either beneficial or harmful effect. The case studies and other examples show that this lack of interdependency thinking means that extreme events have a much greater impact that they would otherwise have. Interdependency is most commonly taken into account in the development of business continuity plans where, for commercial reasons, businesses need to be able to continue to operate in order to survive or are regulated to do so for safety reasons. So, for example, food distribution businesses have plans that allow them to reschedule deliveries from different distribution centres to deal with blocked roads, whilst businesses dependent on ICT run 'mirror' systems and maintain multiple network connections which are separated both physically and by supplier. National Air Traffic Services runs a multiple resilient back up system with site failover, multiple energy feeds, back up energy generation and UPS support such that absolute failure of the NATS air traffic control system is highly unlikely. But these considerations are not taken into account in the majority of businesses or infrastructural services, leading to the episodes described elsewhere in this report

4.4 Issues to be addressed

Infrastructure is purposeful; that is, infrastructure assets are primarily created for their utility. There is a rationale for their existence, the 'why' that precedes the 'what' and 'how' of their development. The value of infrastructure is embedded in its utilisation, the why, while cost and efficiency are functions of the 'what' and 'how' of the asset being created.

This implies that a 'vision' needs to be developed of the whole infrastructure in terms of the value it must generate to support the economic growth and sustainability of the UK. The design, size, scope and interactions of the various assets can then be aligned to that vision.

This approach would shift infrastructure development from 'producer led' to 'consumption led' and encourage cross-sectoral innovation.

If interdependency is to be addressed and managed, there is a need to avoid reinforcing established prejudices and encourage calculated risk taking in design, supported by research and development. This would imply integrating the research base to avoid repetition and replication, and achieving stronger coordination with designers and implementers.

Questions concerning consistency, coherence and certainty of design and planning will need to be addressed, as will the development of systemically consistent standards and expectations across regulatory boundaries. The 'complex web of planning consents, regulation, process and standards' are also seen to hamper efficiency and effectiveness with increases in time and cost. (Reference 12). Standards of inter-operability across regulators may have to be developed and the relationship between relatively short regulatory cycles and the relatively long life of infrastructure assets will need to be addressed to ensure an approach to pricing principles which encourages and sustains effective investment by, largely, internationally owned, infrastructure providers. The UK is competing with other countries for such investment and must, in both the short and long terms, remain a relatively attractive investment environment.

It may be worthy of consideration for an 'Infrastructure Research Partnership' to be created modelled on the 'Energy Research Partnership' that has successfully operated for five years. It would be a mechanism for bringing together all interested parties from Government, Industry and Academia to ensure a coherent framework for infrastructure thinking. This partnership could also become the lead body for capitalising on the established UK capabilities and skills in this area and the focus for driving the agility of mind required to understand and address the challenges.

Research Councils UK comment as follows:

> The Research Councils are investing in the intellectual capital, innovative solutions and trained people able to address the infrastructure challenges of the future.
>
> The Engineering and Physical Sciences Research Council (EPSRC), as the largest funder of Infrastructure related research in areas as broad as civil engineering and the built environment, water engineering, energy, communications and complexity science, is currently investing over £350M

in projects as diverse as '*Mapping the Underworld*' led by Prof Chris Rogers at University of Birmingham, which intends to develop a tool that is able to map the utilities in the ground in order to avoid the costs and inconvenience of digging up roads unnecessarily and the '*Infrastructure Transitions Research Consortium*' led by Prof Jim Hall at Oxford University, which intends to develop simulation models to inform the planning and design of national infrastructure.

The Economic and Social Research Council (ESRC) supports a range of work linked to infrastructure, such as the public acceptability of infrastructural development, the socio-technical nature of unsustainable practices and the role of urban infrastructure in reducing emissions and enhancing resilience.

Through the Living With Environmental Change cross-council programme, a collaboration of 20 cross-government funding agencies, has identified infrastructure as a challenge, focussing on collaborative activities that '*make infrastructure, the built environment and transport systems resilient to environmental change, less carbon intensive and more socially acceptable*'. Activities funded through this partnership include the 'Adaptation and Resilience to Climate Change' network which brings together a range of research projects which look at the impacts of climate change and possible adaptation options in the built environment and its infrastructure including water resources, transport systems, telecommunications, energy and waste and the 'Collaborative Centre of Excellence in Understanding and Managing Natural and Environmental Risks'.

5 Synthesis of Case Studies

This section of the report looks across the formal case studies and other articles and papers to synthesise themes and ideas that provoke reflection. The synthesis informs the argument for a systemic approach to infrastructure development. The interviews underpinning this synthesis and the case studies themselves were conducted against a standard framework although not all questions were answered in every case. This framework forms Appendix 2 to this report. The case studies themselves form Appendix 3 to this report.

5.1 Infrastructure and Extreme Weather

Between 22nd November 2010 and 2nd January 2011 a minimum of 396 impairments to the infrastructure of the UK were identified from reports in the national press. All arose from the combination of snow (precipitation) and very cold weather with temperatures fluctuating between positive and negative (a freeze-thaw effect) then being experienced. The events vary in impact from very slight (a short airport closure to recover an aircraft which overshot, situation recovered in hours) to very significant (about 1.5m people affected by water restrictions in Northern Ireland, situation recovered over many days). Energy distribution was compromised on a number of days while at the same time record demand was experienced for electricity and gas. The Association of British Insurers estimated a cost of £7m per day following a reported 50% increase in burst pipes. Over 41 days that amounts to around £287m in property damage. Meanwhile the NHS reports an additional 18570 patients admitted to hospital following winter falls.

Transport was further affected with significant airport closures, including all the major airports. Roads became blocked by snow and, subsequently, trapped vehicles, while on some days only 70% of the railways were open with significant cancellations and closures across the network – including international services. Fuel shortages began to be reported, particularly in Scotland where 30% of petrol stations were reported shut due to supply chain problems. Motorists were regularly affected, experiencing severe traffic jams with many trapped overnight in cars. New Civil Engineer (Reference 13), reported that ‘it will be nigh on impossible for councils to make more funds available [for winter resilience] when the overall budget for road maintenance is being cut by £160m’.

Around 25th December, train operators announced that they would scrap timetables for a period, suggesting that snow damage had caused them to run out of trains. One operator reported taking three days to thaw rail vehicles left overnight.

Northern Rail, in an internal report, noted that the majority of services were able to operate throughout this period but that this relied, in a number of cases, on train crew walking between 5 and 6 miles to reach depots along roads blocked with snow and trapped vehicles. Every lost service affects the ability of between about 50 and 200 other people to reach their place of work. In this case and, perhaps with other cases, there needs to be a mechanism which transfers the impact of negative external events, back to those responsible for resolving them. If Northern Rail is unable to run trains because crews are unable to reach depots, the costs and any fine should be paid by the authority responsible for clearing the road, not by Northern Rail. This feedback of negative externalities would drive greater mitigation effort.

It is considered highly likely that most of the people trapped or delayed were travelling to or from their place of work. Due to staff absences, many schools were closed, rubbish was uncollected from in excess of 100,000 properties.

ICT services seemed least badly affected with few reports of significant problems. While land line telephony is able to operate without mains electrical supply for around a week, mobile telephony is much less robust, each cell site having around one hour back up battery supply. In the event that electricity supplies are seriously compromised, mobile telephony, a primary means of communication for many people, suffers quickly.

If climate change projections (UKCP09) are approximately right and an increase is seen in extreme weather events, especially volumes of precipitation and fluctuations in temperature, it is clear that the infrastructure as it is today, lacks the necessary resilience to sustain ‘business as usual’. This may be exacerbated in the short term (15-20 years) by increased reliance on renewable energy sources which may not be available during extreme weather (wind and solar sources in particular) and by the shelving of flood defence schemes following budget reductions. (New Civil Engineer, Reference 14).

The Quarmby report estimated the cost of the disruption to the UK economy at £1.5bn. Investment in greater resilience against such extreme weather would have to be measured against the, increasing, likelihood of such events and the potential impacts.

5.2 Frog Island: Energy from Waste

Frog Island is a site for the manufacture of fuel from waste materials drawn from nearly 1 million residents of East London, treating 180,000 tonnes of household waste and achieving a thermal efficiency of around 25%. The investment was around £45m between East London Waste Authority and Shanks and is the first and largest of its type. The project is dependent upon the waste materials supply chain, a supply chain which has significant uncertainty because volumes and material content are uncontrolled. Energy from waste has the potential to deliver much benefit to reducing landfill including reduced methane emissions, reduced costs and emissions from transporting materials, enhancement of security of energy supply and reduced CO2 emissions.

It does, however, rely upon a supportive planning and investment regime and the integration of waste management policies across, at least, the four boroughs which it serves. It treats 180k/tonnes of material from 850,000 properties diverting two-thirds of material from potential landfill. There is a fundamental dependency on the supply rate of recyclable materials, with storage capacity on site for only one week. Any prolonged disruption to supply, or significant alteration in the composition of supplied material, would have a profound effect. Blackstart for Frog Island takes 3-4 days. The supply chain for this project is also completely dependent upon local and regional transport infrastructure, particularly the roads network, and it requires electrical connectivity to enable materials processing as well as discharge of generated electricity to the National Grid. For anaerobic processes (bio-mass use), electrical connectivity must be continuous – a 'blackstart' for bio-mass would impose a 3 month service break.

Resilience in this case could be improved through longer-term materials contracts (input and output), rail as well as road links and multiple grid connections. Equally, enhanced thermal efficiency and economic gain might be created if the site included a CHP plant making use of waste heat on site. This would obviate the need for transportation in the downstream supply chain.

This project is completely reliant on water, waste supply and electrical connection.

5.3 Grain Combined Heat and Power (CHP) Power Station

This is a very positive study. Co-location of the EON CHP plant with a National Grid Liquefied Natural Gas (LNG) plant has delivered a system which is up to 72% thermally efficient. This compares very favourably with 25% at Frog Island. It uses 340MW waste heat (in the form of hot water) from the 1275MW £500m CHP plant, enabling a reduction of 350,000 tonnes of carbon dioxide emissions from the LNG plant. Blackstart may be a problem for this site when the nearby Kingsnorth power station closes in 2015.

Each plant continues to be able to operate independently of the other if necessary, reducing inter-dependence. There continues to be reliance on natural gas supplies for input, connection to the National Grid for outputs, river water for cooling and sea water for the water treatment plant.

Staff access and deliveries are reliant upon a single access road, imparting a potential vulnerability to the site. Operating and staffing processes are designed to ensure that critical staff and materials are on site during difficult weather conditions. While EON normally design to cope with 1/1000 year events it is currently unclear what level of flood risk Grain is resistant to or whether that level has been achieved.

Assessment of the project risks was essentially financial once the strategic fit was understood. Other key issues raised by the study include planning and regulation, the market value of the project, which is affected by the prices of gas, carbon and electricity, and overall market volatility. It is suggested that further co-location of such facilities could deliver benefits in simplification of connectivity and defensibility as well as the thermal efficiency benefits of co-location already recognised.

The uncertainty surrounding investment in energy generation was highlighted in a Daily Telegraph report (Reference 9). Scottish and Southern Energy announced a minimum two year deferral in the construction of a reportedly ‘greener’ 870mw gas turbine power station at Abernedd, suggesting it might reduce the scale to 450mw or scrap the project altogether. The driver behind the announcement was uncertainty surrounding the likely reform of the electricity market and the increasing difficulty of the market for smaller gas-fired generation.

5.4 EON Central Networks DNO Operations

This case was considered from a ‘business as usual’ perspective, examining how the DNO interacts with other infrastructure assets and utilities and considering challenges likely to arise. The DNO network itself is highly resilient being designed to run in parallel down to the level of the last sub-station. There is also a very high degree of network switching available, a feature established pre-privatisation which would be difficult and expensive to develop today in a purely commercial market. The water companies do not have such a national system and the development cost would be likely to be prohibitive. This means that control centre operators have great flexibility to route electricity around problem areas and minimise both the duration of service outages and numbers of consumers affected. This DNO covers two distinct network areas with very different historic levels of redundancy. The ‘east’ network has higher levels of interconnectivity (and therefore redundancy) than the west, however, because efficiency in the sector is measured in terms of assets, it is seen as a less efficient network which imparts a financial penalty. Redundancy, which is good for resilience, is then bad for business.

A bizarre, or at least unintended, regulatory outcome may thereby be achieved in which the pursuit of efficiency reduces the effectiveness of the infrastructure.

EON recognise a number of potential issues that may affect their service capability. These include the number of interdependencies with and on other infrastructure assets, e.g. road access to flooded sites, availability of clean water supplies and impacts on telecoms from lost electricity. Current upgrades and refurbishments to the network are building in potential vulnerabilities from more sophisticated, less robust, shorter working life components and, in some cases, the use of mobile telephony for control systems.

Looking to the future, they anticipate that, as an internationally owned business, they will be in competition for investment funding from their parent company. Also, as serious moves commence towards a ‘smart grid’ and ‘embedded generation’ they recognise that the impact on the network and its operation are not understood and may generate additional interdependencies. Finally, they express concern about the continued availability of the engineering skills required to support and manage the network.

5.5 Gloucester Floods Retrospective

This review was undertaken to determine whether there were any key questions or issues that had not been addressed in earlier studies. It is noted that the impact of the flooding on drinking water supply through the loss of the Mythe Water Treatment Works was greater than that on electricity distribution. In summary, the floods compromised electricity and water supply as well as closure of strategic and arterial road routes affecting thousands of drivers. The cost of the damage, as estimated by the ABI is £3bn with 48,000 customers immediately affected and 420,000 people without drinking water for a week. Recovery of services to re-establish water as ‘safe to drink’ took 16 days.

Since the floods at Castle Meads a flood defence system has been installed to reduce risk, while security surveillance has been established through the use of CCTV at that site and Port Ham – introducing a potential alternative vulnerability. Operating procedures have been amended at the sites to look for evidence of water ingress prior to work commencing. All substation sites have been topographically mapped to identify flooding risk (1 in 1,000 year events) and possible flood depths are currently being assessed with a view to understanding risk to customer supply and making protection investments where required. Costs for such protection are estimated at between £130m and £400m.

It should also be noted that there are significant differences in resilience of assets in different locations. Whilst major sub-stations have been or are being made flood resistant, it is important to note that where power is supplied to areas at risk of flood, e.g. housing or industrial facilities on flood plains, it is likely that the sub-station will be as vulnerable as the buildings it supplies. This generates a potential risk around communications technology in particular where the recent experience of Japan suggests that disruption of power and other supplies tends to increase demand on ICT for information dissemination. Assets, such as hospitals, built on a floodplain will require continuity of supply of water and energy.

It would appear that past experience is being taken seriously, with actions in hand at the DNO level to maintain the very high level of supply reliability to which consumers are accustomed. What this does not, and within the limitations of the industry, cannot address, are supply risk from the National Grid and other future suppliers. Equally, transport and site access risk to operators and engineers are system dependencies over which the DNO has no influence.

5.6 Kings Cross Central

The case study highlights several major findings. First is the risk to the whole development from uncertainty over funding and planning consents. This, in this case, is coupled to an expectation by government that private landowners would provide forward funding for major infrastructure work which will serve a much wider area than this development alone. Uncertainty over technical expectations and standards might also be barriers to fast, effective development.

The Kings Cross regeneration project is the first study that considers the dependent infrastructure. In this case, commerce, education, healthcare and civil administration, create a combined value proposition that draws on the primary infrastructure (water, waste, energy, ICT, transport) demanding that the whole must be dealt with as an integrated system. Covering 67 acres just north of Kings Cross Station, the project is to regenerate a site directly linked to 'Europe's largest rail hub' and connects with 11 London Underground lines. The project has been a long time in gestation. Perhaps somewhat speculative in nature at the outset, its progress was accelerated by the winning bid for the Olympics in 2012, by the completion of the Eurostar move to St. Pancras from Waterloo and by the attraction of a major education provider to a building on the site. The site comprises 50 new and 20 historic buildings, 10 new public open spaces, 3.4million sq. ft. of office space, 500,000 sq. ft. of retail space and 2,000 new homes.

While the developers were keen to take an integrated, holistic, view of the site it is apparent that there is a need for government to support such a perspective. This might extend, in particular, to the use of innovative approaches to energy and water extraction.

Looking at this in terms of infrastructure engineering, it raises some interesting issues. In effect, the developers are working as if this were an 'island' site. While its physical boundaries are porous and open to all, its infrastructure boundaries are planned to be discrete. A narrow, common, point of entry is being established for all major services (water, electricity, gas, ICT) in conjunction with an on-site CHP capability which will provide a district hot water system. This common entry point is seen as a potential vulnerability for the whole development. On site electricity generation will only meet one fifth of peak requirements for the whole site and the original plan for an 'inset grid' is understood to have been prevented by a regulatory limit of 1MW beyond which a supply license is required. This regulatory limit may be appropriate for single building development, but clearly does not lend itself to the sort of larger scale development being undertaken in this instance. This could have been overcome by the creation of an Energy Services Company (ESCO), but the cost of so doing would have outweighed the benefits of the power generated. While the CHP system can be expected to provide high overall site efficiency, there is a significant risk around the resilience of that system. In common with the single point of entry for services, this presents as a possible ‘single point of failure’ which could affect the habitability of the whole site. Water will be provisioned to the site by Thames Water, but once within the boundary will be managed and distributed by the developers.

While ‘value’ will ultimately be generated in the sale/lease of buildings and facilities, cost is being generated and, where possible, minimised in the functional silos of the primary infrastructure. This has potential as a model for understanding how these themes link.

5.7 High Speed 2

In its final development, High Speed 2 is expected to treble north-south capacity on the rail network and create the potential for economic regeneration of, at least, the West Midlands. With a total cost of about £34bn (£16.8 plus £2bn rolling stock for Phase One and a similar amount for Phase Two) it is suggested that the total economic payback over around 50 years will be twice as much.

HS2 will be absolutely dependent upon electricity fed into the overhead lines from four high voltage substations – lines which may become vulnerable to the impact of higher speed winds as the UK climate evolves. Backup power supply sufficient to move the trains cannot be provided; HS2 will rely upon at least 3 of its 4 connections being live at all times. It is therefore likely that, as with high speed rail in China, it will be necessary to maintain a number of appropriately equipped diesel powered ‘rescue’ locomotives in order to sustain services in the event of a power failure. Similarly, it has been suggested that slightly lower top speeds with 5 minute longer journey times would minimise power consumption. This is believed to be the approach taken with the TGV in France which often runs at 150mph compared with a theoretical top speed of 186mph. This may have implications for the design and cost of HS2.

Movement authority for rail vehicles on HS2 will be delivered via radio telecommunications which, currently, do not have the bandwidth to support full speed running. HS2 will integrate in London with existing transport services and interchanges but does have a dependency on the delivery of Crossrail and on certain other transport upgrade projects. A key vulnerability for HS2 is the availability of appropriately skilled civil engineers. HS2 is in competition for these individuals with other infrastructure organisations.

The completion of HS2 will increase the interaction with the dependent infrastructure at all stopping points along the route(s), demanding additional capacity in some locations. While the railway will have increased capacity, and arguably resilience, the effects on other infrastructure have not been factored in to the business case.

Similarly, the potential for exploiting the HS2 ‘right of way’ for other infrastructure purposes has not been explored. For example, it might be used for the deployment of a water storage and distribution system, for broadband internet cable or, and this has been considered briefly, electricity distribution. HS2 will draw on the existing resources of the energy generators for its electricity. It might be considered that, given its absolute, dependency on this, consideration should be given to a dedicated power generation facility with excess energy fed to the grid. No work has been undertaken within the scope of this research to evaluate these possibilities in either engineering or economic terms.

HS2 is a massive project with implications across the UK and it faces a number of legal hurdles before construction can commence – including its own Act of Parliament. A major project such as this, regardless of the merits of the basic business case, must also be assessed in the light of the potential/probable impacts across the country. To be successful, HS2 must cannibalise some long haul passenger traffic from short-haul air traffic and existing long-haul rail. In doing so it will reduce the competitiveness of those services, possibly generating a monopoly (or practical monopoly) position and thereby reducing throughput traffic in the locations currently served. It is unclear what the infrastructure impacts will be of such a migration or the impact on the local economies adjacent to the stations currently served by long haul rail.

The objectives and actions perhaps need to be challenged in the case of HS2. At present, the argument is being presented that ‘HS2 will enable the regeneration of the West Midlands which, speculatively, is worth £40bn thereby generating twice as much value as cost’. If the argument were presented the other way round ‘the regeneration of the West Midlands will generate value of £40bn of which £17bn will be invested in a high speed rail link between London and Birmingham’ it would put value generation at the heart of the infrastructure development, and would imply a higher order regeneration project of which infrastructure is one key part.

5.8 ODA: Transport Infrastructure

As with Kings Cross Central, the Olympic Park transport infrastructure is being delivered to support purposeful dependent infrastructure – there is a clear and beneficial purpose to the Olympic Park. This clarity of purpose brings great focus and provides a value proposition against which the necessary ‘cost-efficiency’ arguments can be debated. If the primary infrastructure is not ‘fit for purpose’ then the dependent infrastructure will, very publicly, fail to perform. The Olympic Park is being built as a 'whole system' and the primary infrastructure that underpins it reflects that whole system view.

The project has benefitted from the fixed delivery date, special planning status and clarity of funding. Taken together these represent a substantial risk reduction compared with conventional infrastructure development – whether replacement or upgrade. The special planning status of the site delivers benefits most particularly in terms of reduced room for dispute – the site has been designed and developed as a whole – and in terms of speed of decision making, with all under one authority.

Similarly, though for very different reasons, in Queensland, Australia, a Reconstruction Authority has been established to oversee rebuilding work following the recent floods including £1bn damage to the road network (Reference 16). New Civil Engineer (Reference 10) reported that this authority will be given 'legal powers to override bureaucracy in order to implement disaster recovery recommendations.

Working systemically, and being in the very unusual position of leaving a legacy behind which is 'gifted' to the beneficiaries, the ODA have used their £800m of funding as leverage to bring forward, or accelerate the delivery of, transport upgrade projects from other providers. This demonstrates a multiplier effect from such investment which exploits the existing transport infrastructure – a key reason for the choice of site. These other operators include the Docklands Light Railway, Transport for London and the relevant train operating companies. It is considered unlikely that a number of the transport projects would have proceeded, and certainly not in this timescale, had they not been stimulated by the Olympic funding. Preparations for the 2014 Winter Olympics in Sochi, Russia are following a similar approach, with a £4.7bn integrated road and rail pathway being developed for transport of materials and people to and from the site. (Reference 15).

The Games must proceed so the definition of resilience adopted by the ODA is:

> 'the ability to keep going even if bad things happen'

and that has been designed into the solutions.

5.9 Literature Review

A comprehensive literature review has been undertaken and condensed for inclusion in this report. This review confirms our belief that substantial modelling and analysis work is being undertaken both nationally and internationally. Work in this area is known to be undertaken in, at least, Australia, Canada, USA, Germany, Sweden and Holland. While much of this work by other nations is aimed at response to adverse events (weather, terrorism), the techniques being adopted will, in some cases, lend themselves to wider application. What is clear from this area so far is that the UK has a substantial lead in tackling the problems of interdependency of infrastructure at a national level and across a full spectrum of infrastructure investment and protection challenges.

The challenges for this work include:

> The recognition that what is being examined are not 'simple' infrastructure assets and projects but socio-technical-political systems that have organisational, economic and behavioural/cultural dependencies and impacts;
>
> The challenge of understanding what we seek to achieve by systemic risk analysis. Funding is already provided to several such initiatives but these are focused on modelling for process rather than modelling for outcome;
>
> The lack of measurement and telemetry on current infrastructure assets, coupled to the need (or desire for) commercial confidentiality limit availability of data to support meaningful modelling and risk assessment;
>
> The complexity and scale of the UK infrastructure coupled to its dynamics and inherent evolution and uncertain connectivity;
>
> Modelling for 'all hazards' has traditionally been considered very difficult and while failure of one or more components and the potential for cascade failure can be modelled, some might wonder whether anything can be done to prevent it and/or what the nature of a contingency recovery model might be;
>
> Developing meaningful models from which useful extrapolations can be made and what the role of different modelling approaches might be in this regard;
>
> The impact of the model upon the subject of the modelling must also be considered. It is recognised that there is often a social or behavioural adaptation as an immediate response to a characteristic being measured. Thus modelling can, sometimes, shift the dynamics of the whole system being studied.

5.10 The Earthquake at Fukushima

Although not a UK event, it was considered appropriate to undertake a very high level study of the events in Japan following the earthquake and tsunami of 11th March. This study is based purely on published material.

Clearly a massive event with disruption of both the primary and secondary infrastructures, there are some issues of particular note.

First, the nuclear power stations would have been considered, by all normal expectations to be resilient – the cooling pumps were supplied with electricity, with back up generation (which tripped in immediately) and 'battery backup' giving a ten hour timeframe (beyond the failure of the back-up generators when overwhelmed by the tsunami) to reconnect mains supply. It is not known what the risk profile for these facilities was – but clearly the event fell outside any 'normal' risk distribution. It should be considered how systemic scenario modelling might have projected this risk on the basis of the surrounding geological conditions.

Second, whilst initial problems arose with the damage to roads, it quickly became apparent that the ability to distribute fuel and food and collect waste is a bigger issue – with some degree of panic-buying both aggravating shortages and increasing pressure on other forms of transport and on ICT.

Third, and a real revelation, has been the resilience of the ICT systems and their continuing operation despite energy shortages and disruptions to the ICT infrastructure. Citizens have made extensive use of social media to share news, maintain (or re-establish) contact with relatives and others and to trace the missing. The resilience and dynamic capability embedded in the ICT should act as a model not just for ICT in the UK but, perhaps, as setting a standard for other infrastructure operators.

6 The Argument for a Systemic Approach to Infrastructure Investment

That the UK National Infrastructure is now made up of a ‘network of networks’ is indisputable. According to Ordnance Survey figures, (References 1 and 2), there are, by way of example:

20	Ports
90	Airports
402	Refineries
6,617	Telecom Masts
2,399	Energy Production Sites
187,719	Electricity Sub Stations
11,368	Reservoirs
31,688	Water Pumping Stations
65,000,000	Consumers (approx.)

That is around 240,000 individual asset sites – the number of individual assets will be a multiple of these numbers and every one of these will be in some way dependent upon at least one other – and in most cases four others. However, we continue to own and regulate these networks as if they were made up of independent, individual assets.

The supplementary materials show the fragility of these networks whether at the local level, such as the ‘Thatcham Flooding Forum’ (Reference 3) being unable to identify through either the Local Authority or the Water Company where the underground pipes are in the local area, or the regional level. A break in at a Vodafone server centre saw the theft of a number of network switches disrupting service to thousands of subscribers for nearly 24 hours. Sir John Beddington, Chief Scientific Adviser, reporting on Food Security matters (Reference 11), suggest that whilst security and management of water supply will be the start point, this can only be resolved if measures to address energy prices and transport infrastructure are also addressed, a systemic argument.

The argument for a systemic approach is rooted in the evident absence of a coherent understanding of the structures that bind the disparate elements of the infrastructure into a network. There is currently no coherent meta-system for observing or managing this infrastructural eco-system. The truth is that no part of the primary infrastructure will continue to operate for more than a very short period of time without the continued operation of all the systems to which it is connected and on which it depends, absolutely, for its operation.

The five primary infrastructure sectors are driven, partly by regulation and partly because of their business models, to optimise their individual performance and to export risk to other providers, rather than to work with those others to address

systemic challenges and opportunities. It is also the case that in the UK there is less vertical integration, for example in power generation and distribution, than is commonly the case in other countries. This approach also drives a risk avoidance approach to problems, potentially discouraging innovation. Are they perhaps driven not to do the right thing right but to do the wrong thing better?
HS2 is a very good, indeed, perhaps the only, answer to a particular question – but is it only a good answer to that question and not to any other?

When considering the case studies and reflecting on the systemic paradigm, the idea of ‘purposefulness’ is dominant. The project that appears most effective and apparently most resilient is the Olympic Park transport infrastructure, arguably followed by the Kings Cross Regeneration study. These apparently purposeful projects are closely tied in to an understanding of their potential value, their legacy, – perhaps an expression of a higher order purpose measured in terms of societal rather than purely economic benefit. Dependent infrastructure provides services that are, one way or another, value generating – but they generate that value through the exploitation of infrastructure assets which are managed through ‘cost-efficiency’ driven regulatory frameworks. The regulators seek to protect the ‘consumer’ by regulating prices and performance within their industry. This drives each utility to minimise its own costs and increase its efficiency within the control period of 5 to 8 years, whereas the life of its assets may be 25 – 60 years. A good response to regulation in any given control period may be to defer cost into subsequent periods – when, perhaps, it will be someone else’s problem.

One purposeful and critical dependent infrastructure system, is the network of ICT networks that carry the data for around 94% of commercial transactions in the UK; a figure incorporated in a report to DEFRA (Reference 25) in 2010 on ICT resilience to climate change. Whilst the cost of that network is directly calculable and represented in the balance sheets of its owners, from a value perspective it is perhaps priceless. That value rests entirely in the exploitation of the network. The vulnerability of such networks was highlighted on April 4th 2011 when the Guardian reported that a woman in Georgia, stealing copper for sale as scrap put her spade through the fibre-optic cable cutting off 90% of Armenia’s 3.2 million internet users (reference 8). Satellite dependent ICT, and the satellite navigation systems now being very widely exploited, whilst not owned as part of the UK infrastructure, introduce another vulnerability. The Royal Academy of Engineering suggesting that a system failure could “just conceivably cause loss of life”. (Reference 6). The report, cited in the Daily Telegraph on 8th March 2011, (Reference 7) suggests that a ‘synchronous collapse in the banking system, mobile telephony in disarray, chaos in public transport, suspension of search-and–rescue services, anarchy in weather forecasting, loss of critical data for aviation and marine navigation’ would all be possible if the Global Navigation and Satellite System were to fail.

There is continuing growth in demand for the ‘Digital Economy’ with ongoing development of high speed data networks across the country and a generational shift in reliance on it. It is critical to the growth of the UK economy that continued investment in these networks is an attractive proposition to its owners. The Japanese experience at Fukushima has shown how resilient ICT networks can support a country in a time of crisis. Resilience in these networks and a real appreciation of their contribution to economic and social well-being is vital.

Clarity of purpose, the value to be delivered, also permits the leveraging of investment. Cost is incurred in building an asset, value is enabled through its consumption or use, if the value enabling potential of an asset can be more fully understood then more appropriate guidance for investment in it can be promulgated.

A typical challenge for this is that ‘repex’ (expenditure on replacement infrastructure assets) is not as clearly ‘purposeful’ as new ‘capex’ (expenditure on new capital assets that add capacity). ‘Repex’, like ‘revex’ in ‘motivational’ terms is a hygiene factor – it is not something we want to do, but something we are obliged to do to maintain a given level of service. We will be penalised if we fail – but will not be rewarded when we succeed – even though the ‘value’ enabled may be the same.

It is also important to consider the type and nature of the project instigator, the ‘who’ that goes with the ‘why’ of any project and to understand how their interest is served and, critically, how the interests of citizens and consumers are served by the particular project.

These projects also highlight the value of simplified planning. Whereas the Olympic Park enjoys special status in relation to planning, as will HS2 assuming the relevant bill goes through Parliament, ‘ordinary’ projects are subject to lengthy and expensive local planning processes. An application for a nuclear power station may take nine years, and cost £500m, before building work commences. This cost imparts huge risk to the energy generator and parent company. That is not special pleading for dedicated planning zones or exemptions but a recognition that planning is a major cost in terms of cash and time for any infrastructure provider. A systemic focus on ‘purpose’ might be the key to developing greater understanding of the proposals and the value that can be generated as opposed to the costs to be incurred. Planning is also a consideration where, as with the Frog Island example, the project involves multiple local authority areas with consent or support required from each of them.

Interdependency of the performance of one asset on those with which it interacts is poorly understood, much is hidden, unknown or regulated in a different silo. Whilst each utility can be penalised or rewarded by its own regulator for its own performance, it cannot be so penalised or rewarded for the performance of others. So, whilst it is in the interests of the infrastructure provider to meet the needs of its customer, this is only so to the point where meeting the customer’s needs costs as much as, or more than, the penalty for failure.

This reduces the amount of resilience that a utility can build into its assets to a simple commercial calculation expressed purely in terms of cost/benefit to the business. The investment/payback relationship is distorted by the limited penalties that can be imposed for service failure. There may well also be, realistic, practical limits to resilience. The electricity distribution network is 100% redundant down to the last sub-station and gives a 99.98% uptime to consumers, a very high level of performance. Increasing that performance would almost certainly require a disproportionate level of additional investment. Understanding where this investment breakpoint lies needs an understanding of the value enabled by the operation of the system – not just the cost of improvement.

Increasingly, infrastructural elements are becoming integrated with each other so that it is difficult to describe them and their performance separately. Whilst this is evident in the Grain case study, where the co-location of power generation with use of waste heat will deliver significant benefits, the risk of integration has been recognised and the systems designed to also operate independently. Alternatively with Frog Island the waste supply chain is now integrated with the electricity supply chain contributing to the whole but creating a potential weakness because of the chain of dependencies. If waste cannot be collected in East London boroughs, due to extreme weather, industrial action or even the elimination of waste at source by consumers, then the whole supply chain may breakdown. Similarly, the use of both land line and mobile networks to enable remote control and management of infrastructure assets, which serves to reduce ongoing operating costs, integrates those telephony solutions as a key part of the infrastructure – yet the vulnerability of the mobile networks has already been highlighted.

ICT is then a critical partner to energy in the operation of both the primary and dependent infrastructures. Electricity generation and distribution relies increasingly on ICT – and ICT relies absolutely on electricity. Neither can function without the other and, increasingly, none of the other primary infrastructure networks can operate without both. Trains, traffic signals, ports, airports and aircraft all function through electricity and ICT and the dependent infrastructure increasingly relies upon it. Every meaningful business in the country and the vast majority of commercial transactions rely upon the infrastructural artefacts of the 'Digital Economy' for their continued operation. The costs of failure are enormous.

The evidence suggests that risks are conventionally defined both through focus on the financial and engineering risks of the project under consideration – but not on the consequential risks external to it. The 'interface' with the world beyond the project is recognised and managed - but no more than that. There is no evidence to suggest that the assumptions about the outside world are ever made explicit or tested. As shown by the Kings Cross Central project, the intention to build a complete 'inset grid' and generate all the power for the site was stopped not by any practical or engineering reason but by regulation. The developers had assumed they could do this but had not tested or validated that assumption.

If consideration of the argument for a systemic approach moves beyond the infrastructure sector, where it is not habitually applied to other sectors where it is, greater understanding of its potential value can be identified (Reference 18). The systems body of knowledge has been in existence for around 90 years and its models and approaches have been applied widely in industry. Perhaps the most widely known approach is the 'Toyota Production System (implemented in the 1960s) and interpreted in many economies as 'Lean Manufacturing'. This approach, rooted in the quality movement and building on the work of Feigenbaum and Ishikawa in particular, adopts a focus on purposefulness (the meeting of customer expectations from the product or service) and on minimising 'the loss imparted to society by the failure of the product' (Taguchi's Quadratic Loss Function). Notwithstanding some challenges in 2010, Toyota is the world's largest and most successful vehicle manufacturer – and notably had never itself reported financial losses until 2010. It has thrived in a world in which many motor manufacturers around the globe have disappeared. Toyota's cost of manufacturing has been significantly lower than that of most of its competitors for many years. The success of this approach has been such that it is now adopted, almost as a matter of routine, not only in motor manufacturing but in many other areas as well – including the management of public sector services.

Experience across many sectors in the UK has shown that adoption of systems methodologies can deliver substantial gains in both performance and costs to those organisations that adopt it. Companies where systemic thinking has been adopted in at least part of the organisation include HSBC, Royal Bank of Scotland, GNER, Northern Rail, Parcelforce, Arena Housing Group, and St Regis Paper amongst others. A train operating business adopted an organisational form, focused on customer service and based on managerial cybernetics. It achieved a 50% reduction in Senior Management numbers, delivering £5m of benefit against an overhead spend of around £50m, a 10% overall saving. A logistics business adopted an information system based on a similar understanding and architecture and achieved a £4m reduction in cost against a £20m budget, a saving of 20% achieved in around six months. Adopting a systems approach it solved a substantial organisational problem, which had been declared by the industry experts as 'too difficult'. A major bank hierarchy was redesigned to focus on customers and delivered a 30% improvement in bottom line with no additional headcount by dealing with its organisation and processes systemically. A Registered Social Landlord adopted a systems approach to underpin a change programme, reducing headcount over one year by 15% and adding a net £1m to its surplus for reinvestment in social housing. The same organisation took the same approach to its asset management and maintenance system and delivered cost savings of £1m on a £3m budget – a saving of around 30%.

These organisations, by gaining a systemic understanding of their relationships and the interdependencies in their operations, delivered gains of between 10% and 30% coupled to performance gains and substantial improvements in customer focus. Recognising that these form part of the dependent infrastructure rather than the primary infrastructure, it is nonetheless reasonable to extrapolate the results of these interventions to the interactions of water, waste, energy, ICT and transport.

A reasonable approach is to assume realisable benefits, cautiously, at the lower end of the range quoted. Doing so, it seems fair to suggest that a cost/performance gain of around 10% on infrastructure investment should be achievable through the development and adoption of a systemic understanding of interdependency in the 'network of networks' and to set that as an achievable target. With planned government investment of £40bn that delivers either a saving of £4bn or an additional £4bn of value – or some combination of the two. Extending that to include private sector investment of a further £160bn a saving of £16bn might be achieved on investment – or £16bn of additional value might be obtained. Together, these could almost fund the development cost of Phase One of HS2. Operational savings achieved would be sustainable across the life of the assets.

This requires a radical approach – not doing the wrong thing better, but learning to do the right thing right. There are two prevailing schools of thought in relation to infrastructure investment. The one (similar to Singapore, Hong Kong, Dubai) voices the notion that a vision of the desired infrastructure can and should be created and that investment decisions are made in order to 'fill the gap' between the present and the desired future. The second school of thought, perhaps dominant in the UK, suggests accepting that the infrastructure has a dynamic of its own, it is a 'supertanker' and all that can be achieved is to seek to steer it towards a more favourable, or preferred, destination.

The relatively cautious incrementalism of 'steering the supertanker' seems to embed an assumption that tomorrows markets and commercial environment will be much the same as today but with an incrementally different weather pattern. A more visionary approach allows for the possibility of creating the future rather than (merely) responding to the recent past and the present. It is the difference between navigating using headlights and using a map.

This reflection is given additional impetus when the very rapidly emerging integration of mobile phones with 'near-field communications' technology enabling the phone to become the 'credit card' is considered. Such convergence of technology (which is now inevitable) has a number of possible consequences These are listed for ease of understanding:

- Increase in the increase in reliance on the mobile phone networks (which it is established are likely to be reducing in resilience for 'cost-efficiency' reasons);

- Shift in 'ownership' of the means of payment from banks to mobile phone manufacturers, service providers and writers of 'apps';

- Reduction in levels of resilience of the individual due to likely reduction in the diversity of payment methods and systems.

The ‘emergent’ changes could well represent a ‘black swan’ event in relation to living in society. It is likely that what is required is to be both visionary and incremental. We must articulate a vision of the future that is desired. That may be constrained by current known limits to technology but can inspire appropriate research. We can also describe the future we will have if we steer the supertanker and seek to avoid its pitfalls. The gap between them is the basis for action.

Incrementalism has allowed continuous improvement whilst, perhaps, inhibiting more radical innovation. A slightly, cheaper, quicker, more efficient version of ‘today’ is likely to be lower risk than substantial innovation – but it is highly unlikely to deliver the infrastructure and performance needed.

A bold, holistic and systemically informed approach will enable both to be delivered.