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Are wildcard events on infrastructure systems opportunities for transformational change?

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ABSTRACT

Infrastructure systems face a number of pressing challenges relating to demographics, environment, finance and governance pressures. Furthermore, infrastructure mediates the way in which everyday lives are conducted; their form and function creating a persistence of unsustainable practice and behaviour that cannot be changed even if change is desired. There is a need to find means by which this obduracy can be broken so that new, more sustainable futures can be planned. This paper develops a methodology, taking concepts from both engineering and social science. Wild cards, or physical disruptions, are used to 'destructively test' complex infrastructure systems and the multi-level perspective is used as a framework for analysing the resulting data. This methodology was used to examine a number of case studies, and with focus groups consisting of a range of different infrastructure providers and managers, to gain a better understanding of systems' socio-technical characteristics and behaviours. A number of impactful 'intervention points' emerged that offered the opportunity to promote radical changes towards configurations of infrastructure systems that provide for 'less' physical infrastructure. This paper also examines the utility of wild cards as enablers of transition to these 'less' configurations and demonstrates how a 'wild card scenario' can be used to co-design infrastructure adaptation from with both infrastructure providers and users.

1. Introduction and challenges for infrastructure

In many developed countries national infrastructure is reaching a critical condition from physical decay, increasing interdependence, and changing demand and operation. Conversely, in rapidly growing economies, investment in new infrastructure is increasing. However, both developed and developing countries face similar challenges and pressures from population growth, changing demands, financial constraints, technological developments and climate change adaptation and mitigation targets. In the UK, the picture in the developed world has been captured by the Council for Science and Technology (2009, p. 4), who have stated that national infrastructure could not continue on its current trajectory because: '*it is less resilient to systemic failure due to ageing components, greater complexity and interconnectivity between different sectors and due to it approaching maximum capacity as a result of increased social and economic pressures; significant challenges of*

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climate change and socio-demographic change mean there is an urgent need to devise low carbon solutions to meet national reduction targets, infrastructure needs to be future-proofed against extreme natural events and future demographic, social and life style changes; its delivery and governance is highly fragmented i.e. *different sectors are managed in silos, investment is ad hoc, typically at times of crisis, there is no overall vision*'.

Furthermore, to function effectively, society relies on infrastructure networks to provide public services, enhancing quality of life, generating private profits and aiding economic growth (Boin & McConnell, 2007). At the national level, telecommunications, emergency services, energy, finance, food, government, health, transport and water sectors provide these essential services. In each of these sectors, components are described as being 'critical' in that if they were compromised or lost there would be a detrimental effect on the service they provide, which could potentially lead to loss of life, severe economic or social consequences. Often referred to as lifeline services, critical infrastructure typically refers to energy, water, transportation, waste disposal and telecommunication systems (O'Rourke, 2007). Critical infrastructure involves large scale, spatially distributed, complex and multi-dimensional technologies, information, processes and actors, creating a system of systems with both engineering (physical components and technologies) and behavioural properties (behaviour of an infrastructure and properties that emerge from factors such as business processes, decision points, human intervention and information generation, availability and flow (Johansson & Hassel, 2010; Tolone, 2009). Critical infrastructure systems appear to be expanding following technological advances and increasing demand, adding new critical elements, and connectivity of infrastructure components (Egan, 2007).

The challenges facing infrastructure sectors in the coming decades and its current vulnerabilities may also be regarded as intrinsically socio-technical. Over time infrastructure systems have become increasingly interconnected, exhibiting functional, physical, budgetary, market and economic interdependencies (Zhang & Peeta, 2011). To these interdependencies we can add those emerging from the social embeddedness of infrastructure, and their dependency from social perception and cultural practices (Granovetter, 1985). Ageing infrastructure is a common problem which causes both technical issues (e.g. reduced performance of construction materials) and social problems (e.g. demand exceeding capacity) that are likely to become more apparent in the near future. For example, London's sewage and water supply system was designed on the basis of a population several times the London population at the time (CST, 2009). Today 40% of London's water mains are over 100 years old, and 12% are more than 150 years old (Thames Water, 2013) leading to problems of leakage due to the degradation of the lining systems of supply pipes and capacity issues of storm water and waste pipes. Furthermore, the problem of ageing infrastructure is compounded by an inadequate infrastructure supply and unequal access to urban services, particularly in the least developed countries where there are large shortages of infrastructure. Given the long lead time to plan, design and construct new components of infrastructure systems, it is important to ensure that they are adequate for, and resilient to, future societal demands. In addition, given the longevity of physical assets a strategic approach to planning and design is necessary. Lifespans of various infrastructure components vary between 15 and 60 years which indicate the timeframes that should be considered in infrastructure planning. Infrastructure design should be orientated towards meeting future population growth, address the needs of migrant and ageing populations and provide greater choice for people in terms of where they live and work (CST, 2009). Urbanisation may demand new infrastructure which is constrained by and has to function alongside existing infrastructure, providing opportunities to address issues of resilience and redundancy arising from interdependencies (Zhang & Peeta, 2011). Infrastructure will require system-based adaptation that considers interdependencies to maximise capacity and enhance longevity.

The need to adapt is further highlighted by natural disasters and extreme weather events which have severely impacted infrastructure systems. For example, in 2010 the Eyjafjallajökull volcano in Iceland caused significant impact on aviation, with more than 100,000 flights being cancelled, more than $1.7 billion in lost revenues for airlines and more than 10 million stranded passengers (Bolic & Sivcev, 2011); in 2005 Hurricane Katrina destroyed more than 65,300 homes, affected over 200 public water treatment systems in Mississippi, and also affected electricity supply and telecommunications (Levy et al., 2010). Projections of climate change may increase the risks to infrastructure systems (RAEng, 2011; Infrastructure UK, 2011). Systems must be adaptable to long term effects such as sea level rise, and at the same time to extreme weather events such as flooding and heatwaves. Infrastructure also has a major role on greenhouse gas mitigation targets. The energy and transportation sectors are heavily carbon intensive; new technologies and configurations could drastically contribute to mitigation efforts. The provision of infrastructure can also induce changes in demographics and behaviour which may also aid emission reduction targets.

Hence the need to adapt is urgent for many reasons, in addition, in developed nations it is clear that we cannot go on growing our traditional infrastructures as a means of stimulating and supporting economic growth forever due to the constraints of, for example, space, availability of resources such as materials and fuel, environmental degradation and greenhouse gas emissions (e.g. Dawson, 2007). Therefore, there is a need to start thinking differently and at some point we will need to consider less. However, 'less' in this context is both difficult to consider and difficult to achieve due to the inherent obduracy of infrastructure and the built environment in general. We only have to consider the lasting legacy of Roman infrastructure and the way it has shaped our towns and cities to understand how difficult it is to start again, rather than keep adding to what is already present.

These challenges described above highlight several things. Firstly, that infrastructure is inherently a socio-technical system (or system of systems) and as such should be studied from this perspective. Methodologies developed by integrating social science and engineering are required to reconsider the provision and service that infrastructure provides. Furthermore, it is evident that infrastructure systems are not simply components of physical assets, but complex