Technological Forecasting & Social Change 92 (2015) 40–52

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Towards resource-efficient and service-oriented integrated infrastructure operation

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ARTICLE INFO

Article history:
Received 8 July 2013
Received in revised form 7 July 2014
Accepted 14 November 2014
Available online xxxx

Keywords:
Sustainable infrastructure operation
Performance economy
Energy Service Company (ESCo)
Infrastructure integration
Valuation
Multi-Utility Service Company (MUSCo)

ABSTRACT

Infrastructure is a means to an end: it is built, maintained and expanded in order to enable the functioning of society. Present infrastructure operation is characterised by: governance based on unmanaged growing demand, which is both inefficient and ultimately unsustainable; lack of integration of the end-users, in terms of the variety of their wants, needs and behaviours; separate and parallel delivery of different infrastructure streams prohibiting joint solutions. To achieve long-term sustainability, infrastructure needs to be designed and operated to provide essential service delivery at radically decreased levels of resource use. This new approach will need to: (1) incorporate the end-user, in terms of their wants and behaviours; (2) focus on the service provided; (3) use Information and Communication Technologies more effectively; (4) integrate the operation of different infrastructure systems; (5) be governed in a manner that recognises the complexity and interconnectedness of infrastructure systems; and (6) rethink current infrastructure valuation. Possible configurations incorporating these aspects with the explicit goal of contributing to long-term sustainability could be Multi-Utility Service Companies or "MUSCos". This article presents new insights and ideas generated by considering the challenge of the transition towards a MUSCo infrastructure.

1. Introduction

Infrastructure is a means to an end: it is built, maintained and expanded in order to enable the functioning of society. In turn, however, the technical building blocks of infrastructure and its geographic layout determine, to a large extent, the level and composition of a society's resource demand, leading to long-term locking in of certain types of resource dependency and uses (Unruh, 2000). For example, on average the UK replaces its infrastructure at a rate of 1–2% per year, meaning that the decisions we make today regarding infrastructure will be with us for 50–100 years. Perhaps more surprisingly, physical infrastructure also shapes the institutional and social organisation of a society, through a historical process of change and evolution described as "co-evolution" (Foxon, 2011). This implies that changing infrastructure operation necessarily

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http://dx.doi.org/10.1016/j.techfore.2014.11.008

involves larger social and institutional shifts as well as technical improvements.

Infrastructure is commonly referred to as the physical networks of water and energy supply, communication, transportation, and waste removal and treatment (e.g. Infrastructure UK, 2011), but increasingly incorporates the built environment as well. The present form of infrastructure operation consists of separate supply systems provisioning unconstrained demand: the demand is viewed unquestioningly as the "needs" of society which infrastructure must, somehow, reliably supply. This mode of operation has served industrialised societies well so far. However, defining the mission of infrastructure as the unerring supply of a growing demand is risky and ultimately unsustainable. Unlimited growth in demand means unlimited pressures on ecosystems and natural resources at a time when we are already well beyond our planetary safe operating space (Rockstrom et al., 2009).

From the perspective of societal resilience and security of supply, a system which understands and manages demand is arguably more robust than one of unlimited dependence on external, most often imported, inputs (Foresight, 2008). Achieving this outcome with the current configuration of the infrastructure system presents a number of challenges:

(1) *Governance based on unmanaged growing demand is both inefficient and unsustainable* (e.g. increasing capacity of road transport networks leading to higher road usage and similar congestion known as "induced traffic" (Hills, 1996; Goodwin, 1996; Noland, 2001; Metz, 2008));
(2) *Current design and operation do not integrate the end-users, in terms of the variety of their wants and needs, and behaviours* (e.g. car ownership as unique transport mode) *and their crucial role in selecting and using technological options* (e.g. selection and appropriate operation of energy efficient technologies); *and*
(3) *Separate and parallel delivery of different infrastructure streams prohibits the development of potential joint solutions* (e.g. co-treatment of waste and wastewater), *or even substitutions* (e.g. substitution of electricity with gas through micro-combined heat and power (CHP)), *between infrastructure systems*.

These characteristics of current infrastructure operation act as obstacles to technical innovation and longer term sustainability. To achieve long-term sustainability infrastructure needs to be designed and operated with the goal of providing essential service delivery at radically decreased levels of resource. This requires a new approach to research that goes beyond analysis of individual failures to take a more systemic view of the purpose of infrastructure. This new approach will need to:

- Incorporate the end-user, in terms of their wants, behaviours and technological choices;
- Be focused on the service provided (e.g. thermal comfort) rather than supply of the vector (e.g. gas);
- Use Information and Communication Technologies (ICTs) and data more effectively to connect end-users to infrastructure systems;
- Integrate the operation of different infrastructure systems;
- Be governed in a manner that recognises the complexity and interconnectedness of infrastructure systems; and
- Rethink current infrastructure valuation.

We termed configurations that incorporate most of these aspects with the explicit goal of contributing to long-term sustainability, as Multi-Utility Service Companies or "MUSCos". A MUSCo is an entity which delivers services to end-users, as opposed to electricity, gas, petrol or water. Since the payment to the MUSCo is on the basis of service, the costs of energy, water and material resources required for realising that service are internalised by the MUSCo: the MUSCo doesn't profit from selling energy or other resources, it profits most by saving them, by providing the highest level of service at the lowest level of resource used (Steinberger et al., 2009; Stahel, 2010). The relation between a MUSCo and its customers would be established through performance-based contracts on agreed levels of service delivery, rather than by metering and billing physical resource use. A MUSCo could be a single organisation, or more likely a coalition of several different entities (including local authorities, technology providers and maintenance providers, for instance). A MUSCo would address the interconnectedness of infrastructure, since a single service required by the end-user could potentially be delivered through different technological options, using different mixes and qualities of physical resources. This definition of a MUSCo is clearly inspired by the niche market of Energy Service Companies (Marino et al., 2011; Hannon, 2012), but extends it beyond energy and beyond the usual business-to-business arena with the goal of contributing to massive, systematic economy-wide resource savings of the scale required by climate change mitigation, for example.

This article discusses this novel approach, and presents new insights and ideas generated by considering the challenge of the transition towards MUSCo-like infrastructure configurations. The first part of the article is concerned with the micro-level, starting with an analysis of the infrastructure as though the end-user mattered, including infrastructure services, ownership and control, and service quality, followed by a section on data requirements for enabling action on the user–infrastructure interface. The macro-level is covered in the second part, where the complexity and governance of integrated infrastructure operation are addressed, and the valuation of infrastructure is discussed. We conclude with a discussion of the findings and describe research required to accelerate the transition towards a more resource-efficient and service-oriented infrastructure bridging the gap between the micro- and macro-scale.

2. Infrastructure as though the end-user mattered

2.1. Does the end-user matter?

Society's ultimate requirements of water, energy, communication, transportation and waste removal (in terms of overall volume and peaks of provision) are dictated by the aggregate demand of end-users. Measuring efficiency using the volume of utility products delivered (measured as kWh or passenger kilometre travelled, for instance) as the quantity to optimise, whilst excluding the end-users who set the level of demand, prevents the consideration of some of the most effective measures. Some would argue that demand management