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Andrew Edkins, The University College London, UK

Vedran Zerjav, The University College London, UK

Proceedings Editors

Paul Chan, The University of Manchester and Robert Leicht, The Pennsylvania State University



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**A POLICY PROGRAM ON INFRASTRUCTURE INTERDEPENDENCIES:
IMPLICATIONS FOR FRONT-END PROJECT MANAGEMENT AND
OPPORTUNITIES FOR RESEARCH**

Andrew Edkins¹ and Vedran Zerjav¹

ABSTRACT

The term ‘infrastructure’ is currently much used by politicians, the business community, the public and the media. Given that there seems to be no universally accepted definition of the term, the primary aim of this paper is to begin unfolding the complex web of interactions that the term infrastructure entails at the levels of policy, businesses, and the general public. To this end, this paper presents some aspects of an ongoing national policy program with the aim to better understand economic, social and engineering types of interdependency and introduce corresponding policies for planning, designing, and managing critical infrastructure in the future. Front-end management of projects is discussed as a particularly important activity in the context of implementing the policy program that addresses both risks and opportunities arising from interdependencies in complex infrastructure networks. The paper concludes with the proposal to acknowledge the rich network of interactions between the diverse technical and non-technical components of infrastructure networks including physical assets, organizations, and institutions.

KEYWORDS: Infrastructure, Interdependencies, Management of Projects, Project Front-end.

¹ The Bartlett School of Construction and Project Management, UCL

1. INTRODUCTION

Mainstream policy documents and consultancy reports understand infrastructure as the backbone for stable operation and future growth prospects across all scales of societies, from smallest local communities to nation-states and supra-national regions such as the European Union. Organizations such as the United Nations, Organization for Economic Co-operation and Development (OECD) and World Economic Forum are reporting on infrastructure provision and performance as key indicators of economic and social development.

Similarly, global and national policies recognize that the role of infrastructure is essential to the wellbeing and prosperity of both individuals and nations (OECD 2006, Ostrom et al. 1993, Calderon et al. 2014, Hill et al. 2012, Cairncross 2013). A lack of adequate infrastructure, as measured through the quantity of infrastructure provided or the quality of it, does harm as it exacerbates poverty, environmental degradation and social divide (Demurger 2001, Giang and Sui Pheng 2011, Lin 2011). The critical role of infrastructure is evidenced by the focus it is given by a range of key international bodies such as the OECD (2006), the World Economic Forum, as well as private sector consultancies such as McKinsey and KPMG (2008). For example, McKinsey reported an estimated global need for infrastructure investment of \$57 trillion by 2030 to simply keep pace with current global rates of GDP growth (McKinsey 2013).

Another indicator of how important infrastructure is for the modern societies is revealed through a search of the term “infrastructure” in the archives of the periodical *The Economist* in the period between 1992 and 2013. This search indicates a steady increase in the number of instances the term is referred to spanning 147 records in 1992 to 310 records in 2013. Despite the increasing pervasiveness of the infrastructure-related discourse across levels of policy, finance, businesses, and engineering, there seems to be no universally-accepted definition of what the term infrastructure, in fact, entails.

There are at least two generic typologies for defining infrastructure: asset-based and provision-based. The asset-based strand would distinguish between, for instance, roads, rail, electricity generation plants, schools, and air and sea ports as different types of infrastructure assets (e.g., OECD 2006, World Economic Forum 2012). The provision-based concept, by contrast, would classify infrastructure in terms of the entity that provides it, in particular institutions of the state as opposed to the free market (Ostrom et al. 1993, Dietz et al. 2003, Esfahani and Ramírez 2003). Apart from the above-mentioned generic typologies of infrastructure, different countries will often also adopt different concepts on the basis that infrastructure discussions are very often related to national politics.

In the UK, for example, there is currently a relatively broad public acceptance of the difference between the classes of so called social infrastructure as opposed to economic infrastructure. This debate refers to social infrastructure as the myriad of physical systems and services which operate and are delivered through significant involvement of the local or national government. These are generally buildings providing some form of accommodation, for example, schools, hospitals, government office buildings, prisons, police and fire stations, etc. Economic infrastructure, by contrast, is increasingly provided, and operated in a commercial and market-driven setting, where private parties can be encouraged to provide and/or operate the infrastructure and bear the risk of demand in return for revenues derived from either the end user or third parties. In extremis this would exclude government bodies (Williamson 1985). Examples of this class of infrastructure in the UK would include sectors such as air transport, energy and water.

This ambiguity the content of the term arguably results in a multiplicity of strategies to propose, provide, and operate infrastructure, which occurs subject to one-off situations and opportunities. Consequently, it is hugely challenging for governments to develop policies and strategies that both ensure and increase the quality and consistency of nation-wide service provision through the infrastructure assets. The economics, politics, financing, management of provision, operation, maintenance and refurbishment, and retirement of infrastructural assets all combine to make this a most complicated and difficult ‘wicked’ challenge (Rittel and Webber 1973). Moreover, these infrastructure projects then go on to have impacts on various economic, social and environmental systems for many years or decades. Some of these impacts will be the *raison d’être* of the project being proposed, but some may not, often only appearing ex-post the completion of the project phase as the ‘unexpected consequences’ of these projects.

To respond to the challenges of infrastructure provision under the above described complexity, the UK Government’s ministry of economics and finance – Her Majesty’s Treasury formed a dedicated body in 2010: Infrastructure UK (IUK). The role of this division is to advise the government on the long-term infrastructure needs of the UK and provide commercial expertise to support major projects and programs. One of the specific areas of concern of IUK is to understand the gamut of economic and engineering interdependencies in the infrastructure space, for which purpose it commissioned two inquiries one, focussed on economic issues, from a UK consultancy practice and one, focussed on engineering interdependencies, from a joint venture between two academic research institutes. These inquiries are expected to inform a series of future policies with a significant impact on the future of infrastructure provision, management, and use. In this paper, we address several aspects of this policy program and begin the discussion of how it might inform future academic research in the areas of infrastructure as a distinct unit of analysis spanning a multitude of technical and non-technical knowledge domains.

To accomplish this, we adopt a working definition of infrastructure that involves a collection of physical, organizational and institutional systems that support the basic functions of societies and economies. We will then use the “management of projects” perspective to extend this technical definition into non-technical domains of policy, finance, and governance. The aim of this approach is to begin constructing a novel concept of infrastructure and the management of its interdependencies that moves beyond the domain of engineering artefacts and includes interactions between actors, organizations and institutions.

The paper is structured as follows. We begin by discussing a range of different interdependencies that are revealed through different cases of cascading failures. We continue with a discussion of how these interdependencies can be tackled both as uncertainties as well as opportunities from the perspective of front-end management of projects. We then discuss the implications of addressing the interdependencies for project management as a profession. Drawing from the discussion on the policy program on infrastructure interdependence, we finally propose a propositional theoretical framework for supporting multi-level planning and management interventions in the space of infrastructure. The paper closes with implications for future research and policy.

2. INTERDEPENDENCY IN INFRASTRUCTURE FAILURES

The UK represents an interesting example of the richness and complexity of infrastructure. As a nation it is relatively old, with some of its current roads being originally built by the Romans substantially more than one thousand years ago (Margary 1973). Despite this

evidence of what can be considered ancient infrastructure, the Victorians (1837-1901) were the true forefathers of the UK's current infrastructure base during the nineteenth century. These pioneers of industry, commerce and engineering created much of the infrastructure backbone that currently supports the UK². This is especially the case with the railway and water networks, which were rapidly expanded in both network coverage and capacity thanks to the skills and technologies that were emerging at the time. From this, the UK has added large networks of initially town (now natural) gas, road networks that span the national and local as well as the widespread generation, transmission and distribution of electricity, fixed line telephony and, most recently, mobile telephony. This infrastructure provision serves both the civilian population as well as the nation's military needs.

In addition, the UK has a rich diversity of social infrastructure as well as increasing provision of intangible infrastructure such as satellite broadcasting, mobile phone and data networks and Wi-Fi access. This rich mix of infrastructure type is reflected in the diversity of provision, with some infrastructure provided and owned by the State, others in mixed ownership and delivery, and much provided by the private sector in either regulated or unregulated mode.

It is due to this richness of complex diversity of the UK's infrastructure that there is concern about its latent or manifest interdependencies. In some cases there is implicit interdependency, as in the case of water supply or railways, where in the former, there is an essential need for electricity to treat and transport water. In the railway sector the switch from independently powered train locomotives, first by use of coal and steam and then to diesel, to now have locomotives drawing electricity from the track, also shows the need for one form of infrastructure (the electricity generation and transmission sectors) to be fed into another (rail). Modern aircraft engines increasingly constantly 'talk' to manufacturer's base stations with telemetry on engine performance³.

However, it has been the emergence of disasters or significant failures that has revealed the true nature of our modern infrastructure's interdependence. This was typified in the UK by the recent incidents of flooding and winter storms of late 2013 and early 2014.

In both 2007 and 2013-14 the UK suffered periods of exceptionally heavy and/or prolonged rainfall. In 2007 there was grave concern for the area around Gloucester following the threat to flooding of the Walham power substation. The threat from this natural disaster threat resulted in the intervention of the British Army who had to protect the electricity sub-station from flooding for fear of the cascade failure that would result and left many thousands of households without both electricity and clean water. In 2013-14 the prolonged period of heavy rainfall and strong winds led to much of the local road network in the Somerset area of south west England being cut off. The storm driven waves also overcame the coastal defense at Dawlish and this led to the main train line from the southwest of England to be washed out completely, resulting in the area being effectively cut off for land transport – see figure 1).

² This era included the work of civil engineers: Isambard Kingdom Brunel and Joseph Bazalgette. For more details, refer to Helm, D. (2013, December 20). Britain Needs to Reclaim its Victorian Vision. *The Financial Times*.

³ See for example Rolls Royce's 'Engine Health Monitoring (EHM)': <http://www.rolls-royce.com/civil/services/corporatecare/>



Figure 1– Collapsed sea wall in Dawlish, UK (Copyright Derek Harper and licensed for reuse under this Creative Commons Licence)

Another form of interdependency was revealed in the major terrorist incidents that took place in both New York/Washington DC and London (the attacks now referred to as “9/11” and “7/7” respectively). In both cases the fear and concern from those caught in the locations targeted led to mobile phone and emergency communication networks in specific areas becoming overloaded as many sought to make or receive calls. This had an impact on the emergency services ability to coordinate and communicate and led to time delays and congestion.

The corollary of these forms of cascade failure interdependency risk is the catalytic boost that infrastructure can and indeed does have. Again, using the UK as the focus, the analysis by Frontier Economics of six case-studies (Frontier Economics 2012) indicated substantial one-off and on-going economic opportunities arising from infrastructure related interdependencies, including the potential to unlock £1-1.5 billion from taking full advantage of the catalytic effect of transport infrastructure interdependency opportunities. These wider economic benefits (Vickerman 2008) may also be considered as impacts. An obvious example would be the multi-layered and broadly spread benefits of providing a robust national network of roads. Such a network would be expected to lead to greater levels of economic activity as goods and knowledge were transported more quickly and hence more efficiently, but such a network has also been shown to provide better social cohesion and inclusion as well as limit further environmental damage by providing efficient flows of road traffic (UK Department of Transport 2003).

It is the recognition of infrastructures’ ability to join and link to many other things that makes it worthy of special consideration. This can lead to a world of ‘unintended consequences’.

For example, it is now many car and truck drivers' experience that widening popular primary roads may only relatively temporarily relieve the congestion that triggered the need for the road widening, with a widely held belief – technically known as induced demand (Cervero 2003) that expanding road capacity seemingly encourages more vehicle use. However, the emergence of perennial road congestion can lead to modal shift as those with alternative options to road travel look to switch. In cases where no alternative mode of travel is available vehicle drivers will seek to avoid congested routes, now aided by the prevalence of satellite navigation with real-time data (traffic) updates or car radios with automatic switching to traffic announcements via the Radio Data System (RDS), resulting in congestion being alleviated, displaced and dispersed. The issue of congestion is not limited to roads, with many major cities now finding all their transport systems under increasing strain as more people move to cities and more of these people commute in. Packing more trains into a given rail network is involving increasingly sophisticated IT based train signalling and train safety systems. In extremis, even civilian air space and corridors can become congested, with now sophisticated stacking and holding systems emerging in 'hot spots' such as the south east of England. Coping with more air traffic again requires increasingly sophisticated IT systems and this interdependency between aircraft, air traffic control experts and complex IT systems involving satellites is a good example of a successful 'system of systems'.

The recognition of the interconnectedness and interrelatedness of these complex networks of infrastructure moves the interest to that of appreciating that systems of systems have been created, in many cases unwittingly, and that there is now a concern for system interdependency as a key element of infrastructure-related discussions. It is, of course, obvious that interdependency is a key feature of any complex system: natural, technical, and social. Rather than observing generic types of interdependencies that exist in complex systems, our aim is to focus on critical events, in which interdependencies unfold themselves through cascading failures that propagate throughout the infrastructure networks with often severe and unforeseen consequences. From this observational interest, the question then becomes one of what can be done to address the various interdependencies through diverse management practices, especially at the point where an intervention is proposed. These interventions are projects. Projects to add new infrastructural assets, alter or expand existing assets, or retire those at end of life, may all have impacts on the existing system. It is clear that whilst we understand some of the consequences of these projects, we do not understand them all. We next turn to this issue by introducing the role of project management in the front end management of infrastructure megaprojects.

3. THE ROLE OF FRONT-END MANAGEMENT OF PROJECTS

The 'Infrastructure Procurement Routemap' by HM Treasury (2013) notes how the management of infrastructure projects requires clear capacity and capability in the areas of (1) *what* is being sought to be delivered (the project), (2) *who* is seeking the project and will deliver it (the team or coalition comprising sponsor, client, delivery supply chain), and (3) *how* the project is to be arranged and delivered (the funding, financing and procurement solution). This guidance document makes it clear that there is need for proactive and integrated consideration of proposed projects and programs from the very outset of the project lifecycle and that careful and considered thought and planning from the very earliest stages will yield dividends in terms of downstream project performance. The Infrastructure Procurement Routemap follows the UK public sector terminology in terms of key players and parties, identifying two specifically key roles as the Project Sponsor and Project Client. The former has the responsibility for the

proposed project’s business case and for obtaining the decision to invest, whilst the latter has responsibility for ensuring the success of the project as so approved. One can infer that in combination, these two roles will sum to the ‘owner’ of the project. Although not named per se, the expectation is that from the two parties holding these roles will emerge the appointment of individual project managers who will take charge of the project at all levels from highest level to the most detailed, or from the strategic through to the operational.

To address the sensitivity to failure recorded in both historical and contemporary projects (Miller and Lessard 2000, Morris and Hough 1987, Flyvbjerg et al. 2003), the UK government established the Major Projects Authority⁴ (MPA). Amongst the MPA’s objectives and responsibilities is one that is highly relevant to the consideration of interdependencies:

“The MPA is supported by a clear and enforceable mandate and has the authority to: make a starting gate review, or equivalent, mandatory for all new projects/programs to assess deliverability before project delivery gets underway.”

The reference to a ‘starting gate review’ is illustrative of an increasing emphasis on the very early stages of the project lifecycle, referred to as the ‘initiation’ phase (Morris 2006) or the ‘front-end’ of the project (Edkins et al. 2013). This point in the project lifecycle is of fundamental importance in two areas. First, it provides the point where the project’s success or failure will be most heavily influenced. The empirical evidence on this is substantial as illustrated by the work of Miller and Lessard 2000. Second, it is the point where the strategic appreciation of the impact of the project should be fully considered. This will consider the beneficiaries of the project and how these benefits will be known to have occurred. It thus would appear *a priori* to be a key point for understanding the range of interdependencies that the project will or may have.

3.1 When to Tackle Interdependencies?

As noted, there is significant evidence that problems with projects at the latter stages of delivery and transition into operation can be traced back to problems and issues that occurred much earlier in the project lifecycle (Morris and Hough 1987, Miller and Lessard 2000). From this body of work it is argued that there is a need for clear and solid leadership, governance and management of this early and emergent stage. This is not straightforward as the early stage of a project’s lifecycle is where there is very little firm information, much speculation and uncertainty, and the potential for many sources of influence and decision-making (Chapman and Ward 2011, Winch 2010). This current policy program on interdependencies thus potentially adds to this complexity as the consideration of possible interdependencies at the projects’ front-end could lead to not only changes in scope of the project, but also how it is fundamentally considered and understood. For example, in the context of the London’s famous underground metro system, commonly referred to as ‘the tube’, there is an advanced plan to extend one of the lines. The project is known as the Northern Line Extension (NLE). The NLE is clearly understood as a transport project and it will be run by the organization responsible for the tube – London Underground Ltd, which is a wholly owned subsidiary of the major transport authority for London – Transport for London. However, a major extension to an important tube line is in part predicated on the expected catalytic drive for social and economic regeneration in the parts of London affected by the NLE. This economic-related interdependency as an argument for the project will inevitably lead to more engineering-type interdependencies with other forms of

⁴ <https://www.gov.uk/government/policy-teams/major-projects-authority>

infrastructure *on* the project, be they of interdependencies with other elements of economic infrastructure (e.g. impacts on local roads as increased road traffic and possible congestion as a result of more people) or social infrastructure type (e.g. rising population attracted by the NLE will need more doctors surgeries, schools and police).

In the context of this policy program, two important interdependency-linked issues have emerged that relate to: (1) the progression of the project through its lifecycle and; (2) the attributes and competences of the senior management of the project. The first is that the credible seeking of potential interdependencies has to involve a range of parties who would be expected to have a possible interest in the project. The identification of these potential stakeholders and the prior consideration of what their interests is a task that needs to be undertaken both in the correct way and at the right time. Using the front-end management of projects (MoP) lens as well as the more traditional project management (PM) approach we identified two opportunities at different points in the project lifecycle to seek and discuss possible interdependencies.

The first, and most important of these two opportunities arises from a MoP view, is very early on in the project, when the project can be understood and described in principle but without any firm decisions having been made about it, including formal sanctioning that there will be a project. In systems engineering this is when the problem or issue that is seeking a project solution is being understood and is still therefore being explored, but before any single solution is decided upon. In the context of this inquiry, which used real projects as the field data, one of the cases considered demonstrates this point. The project was phase 2 of the major high speed rail project (HS2). This megaproject will connect London to first Birmingham (phase 1) and then from Birmingham to Manchester and Leeds (phase 2). When complete it will form a ‘Y’ set of connections. HS2 phase 2 most closely fitted this of a project in its early lifecycle, with much still being debated about the project. As part of this inquiry, an interdependency exploration workshop was held with a range of high level representatives from other areas of infrastructure to explore how HS2 phase 2 could do more than be just a high speed rail line. Thus, for example, the considerations of what else could be run alongside the rail lines, such as fibre optic cables for future use – so called ‘dark fibre’, together with other piped or similar utilities, or the use of the railway embankments built to offer flood protection were discussed. Such considerations can profoundly affect the project as originally conceived and indeed in the case of HS2 the Act of Parliament that permits the project to proceed was altered to recognise HS2 as both a rail and communications project so that separate telecommunication infrastructure can be provided as part of the project.

After this first ‘golden’ and early opportunity to seek interdependencies has passed, the project will move through stages of the lifecycle that refine and elaborate its scope and specification and, in the UK as an example, as part of this will enter into the formal submission stage for statutory permission to proceed. This requires that these projects will be considered by those who are recognized to be potentially affected by the project, typically involving neighbours, utility providers, and others with pertinent jurisdictions or proximities. This statutory consultation period is often driven by considerations of disrupted impact, risk of localized cascade failure or need for interface working, so often identifies negative interdependencies. However, if a second multi-party interdependency exercise were to be arranged towards the end of this consultation period (prior to final statutory approvals) then there is the potential for positive interdependencies to emerge. An example of this is given below (The Environment Agency 2001):

“The Ravensbourne, at Brookmill Park, downstream of Lewisham [south London] used to flow through a concrete flood channel and provided negligible environmental or social value. The extension of the Docklands Light Railway (DLR) to Lewisham provided the perfect opportunity to restore this section of river. This is because the flood channel actually provided the most direct route for the DLR to Lewisham and using it would have minimal environmental and visual impact on the park and surrounding area. The Ravensbourne could then be diverted into a new natural channel in the park to create a quality river environment for both wildlife and people to enjoy. This scheme was financed by DLR Ltd., CGL Rail and LRG Contractors as part of the planning conditions for the DLR extension.”

3.2 Implications of Interdependencies for Managerial Decision-making

Having identified the two key points in the project lifecycle where the search for interdependencies can be conducted, it is also important to consider the implications of such additional activities on those who manage such projects or programs. These will be considered at the three traditional military and management levels: strategic, tactical, and operational (Ackoff 1992).

3.2.1 Interdependencies at the strategic level project and program management

The project sponsor and those providing the investment funds operate at this most superior level of consideration. The project sponsor is expected to be able to hold a clear vision of why a proposed project/program is needed and be able to articulate clear answers to the questions of how/when/where/who is associated with the benefits that are expected to flow from the completed project/program over its foreseeable operating life. The level of investment in the skills and capabilities of the players in this space has been recognized as needing improvement and the creation of the Major Project Authority which has established a Project Leadership Academy, in conjunction with the publication and updating of the National Infrastructure Plan is in part designed to provide a better sponsor role.

This policy program has clearly sought to address the requirement to seek out possible interdependencies and for the project sponsor this will impact on two critical areas. The first area is the appreciation of why the project is needed. As possible strategic level interdependencies are introduced by a wider range of interested parties, so a previously conceived clearly defined and bounded project may ‘morph’ from being seen as solely a solution to a single department’s problem (e.g. road widening to relieve to road traffic congestion) to also include alleviation of possible flooding (i.e. some technically complementary flood defense work is added to the road widening). The issue here is that the UK system is set up to encourage sector specific consideration and ‘tight’ ownership of the project sponsor role. This is partly explained by the current thinking about the ‘what’ the project is. Using the hypothetical road example: the initial project proposal would be for a road widening project for the responsibly party: the UK’s Department for Transport and by its national road agency - The Highways Agency. The latter would be a jointly sponsored road and flood alleviation project by the Highways Agency and Environment Agency. Whilst the latter may be ultimately cost effective and value maximizing, it would present itself as more complex in terms of current arrangements for governance, funding and management.

To cope with this, the strategic project/program leaders will need to have the breadth of vision and knowledge to willingly accept scope, ownership and governance changes that allow the project to span the boundaries between the traditional roles.

3.2.2 Tactical level project and program management

Having considered strategic level interdependencies and agreed on both what the project is and why it is needed, it will fall to the client of the project to drive it forward and seek its successful delivery. This involves a critical set of decisions as to the parties to be involved and the form of procurement to be used. Again the Infrastructure Procurement Routemap (2013) provides clear guidance on the parameters to consider. However, introducing possible interdependencies at the strategic level will open the project/program to possible scope creep and changes to the definitions of success. This was observed with the London 2012 Olympics and Paralympics where at one level the project had to be a sporting success (and was) whereas at another level it must act as a catalyst for economic and social regeneration of east London (not yet capable of being assessed, but there are many who remain sceptical this will be achieved). Those acting as project clients must therefore understand that fluidity in the early stages of the infrastructure project or program's lifecycle will be expected as those sponsoring the project are identified and then set about agreeing a set of metrics and timescales against which to measure the project or program's success.

These tactical project/program managers will need to accept that initial views of the project and systems for managing the project may need to alter to reflect strategic changes. This will lead to consideration of the need for inherent flexibility and this will drive the selection of procurement paths, governance and control systems, and the players and parties appointed. These issues are covered well in systems engineering as noted and more recently in agile project management (Highsmith 2009).

3.2.3 Operational level project and program management

Whilst some of the most important and influential considerations and decisions for projects and programs are made very early on and by those most senior on the project/program, it would be foolhardy in the extreme to assume that everything outside and downstream of these key initial stages was straightforward. It is not, and those involved in the operational management of projects and programs are essential to the success of the project as they plan, monitor, control and communicate much on and within the project/program.

As previously elaborated upon, at least two opportunities exist to embrace the potential for interdependencies. The first is very early on when the project/program is still forming as a proposed idea. As noted, the consideration of interdependencies will be led by the project sponsor and project client. However, when the project progresses to the downstream point of seeking statutory approval (i.e. seeking the necessary legal authorizations or regulatory permissions) then, as part of the required consultation period, it will be possible to invite possible beneficial interdependencies to be proposed (see the earlier example of the DLR Lewisham Extension). Embracing the search for such interdependencies is something that traditionally schooled project managers may be expected to protest about, as it could jeopardize delivering the project to its previously agreed 'iron triangle' objectives (Atkinson 1999). But if those in positions of strategic leadership and oversight are fully involved and engaged, then they will be able to provide the reassurance to the operational project managers that such changes to the project's scope, schedule and budget are acceptable prices to pay for a set of enhanced project/program outputs and outcomes. All this suggests that the management of contingency will become far more important (Howell et al. 2010).

3.3. Implications of Interdependencies for the Project Manager Practitioner

Whether considered at the level of project sponsor, project client, or those managing the delivery of the project, all these roles are drawing on skills associated with being a manager of projects. Although the term is subject to loose application, true project managers are specialists in managing complex challenges and they increasingly operate on a pseudo or quasi-professional level, with membership organizations, formalized bodies of both practitioner and academic knowledge, and internationally recognized practitioner qualifications.

For the majority of practicing project managers there are some ‘givens’ that have emerged over time. An example of this is the mantra that will often be heard of what project management is – it’s about the delivery of the project to time (schedule), to cost (budget), quality (scope and specification). This is telling as it raises very important points for future research on the seeking of interdependencies. The first is that if the project manager is in charge of the delivery of the project only then who is it (if it isn’t the project manager) who sets these essential parameters and constraints? In the case of UK infrastructure, the answer to this second question is in the Infrastructure Procurement Routemap. Here it clearly makes it the responsibility of the project sponsor and project client. This area is associated with project strategy and during the early initiation stages is an area of academic interest since the late 1980s (Morris and Hough 1987). The main concern of this stream of thought is the need to distinguish between the traditional view of ‘Project Management’ as an execution-focused activity - on the one hand - and ‘The Management of Projects’ which is both more strategic and holistic, on the other (e.g., Morris and Hough 1987, Edkins et al. 2013, Davies and Hobday 2005).

The distinction between sponsor of the project, the party set up as the client, and delivery orientated project manager is therefore clearly supportive of the differing roles as the view of the project is very different for those taking these roles of project sponsor, client and deliverer. The early stages of a project (pre formal sanction to proceed) are most simply described as vague, complex and messy. Unlike the latter stages of a project where there is clarity of what the project is, how much it will cost and how long it will take are all calculated and known, the early stage of the project’s front-end are where ideas abound, fundamental options arise (.e.g. abandon, delay, accelerate, fundamentally alter) and where power and influence can come from many sources, including politics at all levels and from high status individuals and organizations. Strategic interdependencies arise in the world of the project sponsor and it is expected to be closely tied to their areas of normal operation.

Project sponsors who are so minded will need to draw on the skills and experience of initially project clients who will bring insight into the best way to shape and steer the project so that it will be capable of successful delivery. This will then cascade on to the project managers charged with day-to-day delivery of the projects, both tactically and operationally. The best of project managers embrace these challenges and work on the project from the outset. To do so, they need a very different skillset from the traditional execution-orientated project manager. They will need better skills associated with diplomacy, politics, strategic visioning, leadership, estimating, team building and communication (Edkins et al, 2013). Critically, they must accept that projects in the early stages of their life will change. It is this last aspect that the proactive search for interdependencies will involve as, by definition, if interdependencies are found they should be expected to change the pre-existing project parameters – potentially fundamentally. There is thus a potential tension as a balance is sought between making progress and not seeking to rush into a ‘locked in’ project solution too early. It is vital that those in positions to influence and direct the future of project management recognize this need to move project management

into the early stages of the project lifecycle. The players involved are those such as the major project management organizations, bodies such as the Major Projects Authority and academic and similar institutions and organizations that deliver project management education and training.

4. TOWARDS A FRAMEWORK FOR INFRASTRUCTURE INTERDEPENDENCY RESEARCH AND POLICY

The above described developments in policy and practice of infrastructure provision clearly present a major opportunity for research institutions wishing to engage in high social impact interdisciplinary research that transcends the boundaries of traditional disciplinary domains. This section aims to propose a propositional theoretical framework for supporting multi-level planning and management interventions in the space of infrastructure.

To accomplish this goal, we draw from the recent debates in the field of social science that call for interpretive approaches to understand organizational behaviour. Nightingale (2008), for example, describes this as a development in which the foundational assumptions of the bulk of 20th century social science are being gradually abandoned in a shift away from the focus on determinism, reductionism, and essences in theory building. This shift is illustrated through the emergence of different theories of the firm that gradually drift away from the classical utility maximization and optimization paradigm that assumes all knowledge is generated by moving from empirical variety towards the essences picked up in formal mathematical models. As examples of this gradual paradigm shift in arguing the firm, Nightingale (2008) mentions the development from neo-classical economics, through transaction-based approaches, resource-based view towards the knowledge-based view and dynamic capabilities, and finally empiricist political economy and business history approaches. In this trajectory, each successive concept departs to a greater extent from the determinism, reductionism and essences of the so called traditional scientific paradigm.

In organisation studies, a similar development is visible in discussions that argue for the adoption of so called non-representational approaches for describing the world and organizations that exist in it (e.g., Vaara 2002, Lorino et al. 2011). The non-representational approach focuses on different forms of enacted agency to understand organizations as opposed to representations of structures that are assumed to exist “out there in the world”. Actor-network theory (ANT) is one of these emerging theoretical concepts that are congruent with the non-representational and interpretive paradigm (e.g., Latour 1987, Latour 2010). Using the main conceptual ideas from ANT, we next derive a propositional framework concerning infrastructure interdependency that should be tested in future research.

Along these lines, infrastructure can be plausibly conceived as a complex web of interactions between non sentient artefacts and human actors. The above theoretical proposition makes sense when it is contrasted with the traditional interpretation in which infrastructure is separately referred to in terms of engineering artefacts, government investment and maintenance policies, construction projects, business models, and public opinion. We would argue that infrastructure does indeed include all of the above, however not as their sum in a simple hierarchical structure, but as a complex network of interactions. The outcome of these interactions is then the object of infrastructure taken both as a social construct as well as a tangible set of assets.

This actor-network concept represents a socio-technical assemblage of physical things (i.e. roads, buildings, all the artefacts used in design and construction processes, etc.) in the

context of abstract concepts (i.e. models of public or private service provision), communities of practice (e.g., professions involved in planning, delivery, and operations of infrastructure), individual end-users of services provided, etc. This list could go on, but the idea that we are trying to convey is that infrastructure only comes about as the result of the interactions in this complex socio-technical assemblage, and should not be viewed purely as a thing that exists out there in the world irrespective of all the above mentioned elements that give it its meaning.

The actor-network conceptualization of infrastructure, of course, has implications for research methods as well. Whilst the traditional engineering research methods are valuable to study the physical artefacts of infrastructure, such methods clearly have limitations in addressing the complexities that arise from social, financial, power, and other kinds of relations between different human actors and organizations that enact the web of infrastructure phenomena.

If such a view is accepted then such a comprehensive approach will eventually lead to a multifaceted knowledge framework that will be comprehensive enough to:

1. Identify the opportunities presented by the integration of infrastructure development over the long term, within a framework that balances current socio-economic and fiscal needs with longer term ecological sustainability and asset value;
2. Define planning policies and investment priorities which are sufficiently flexible and responsive to changes in technologies, socio-economic policy and the natural environments;
3. Support local and national government departments, regulators and commercial enterprises in developing their capacity to create and manage interdependencies successfully.

Whilst part of the framework would comprise a tool that could be used to negotiate interdependencies through the use of multi-stakeholder workshops, the framework also has the potential to initiate a change in the current mind-sets of principal players involved in infrastructure policy. This change involves a move towards the stewardship of infrastructure across a dynamic and evolving continuum and the integration of the knowledge acquired through this framework throughout the project lifecycle, but particularly in the early strategic stages.

This requires a shift away from the present individual discrete project and ‘siloes’ mentality (at least in the UK) towards a recognition of an integrated infrastructural asset creation and management philosophy that would have inherent interdependency issues. The move to the principle of stewardship requires a wide range of institutions and enterprises to collaborate in developing a coherent framework of policies, plans, processes and institutions to guide infrastructure investment and planning against some long-term vision. The proposed stewardship role would have a critical impact in determining how infrastructure interdependencies will be framed and assessed during the project appraisal process, and in promoting the collaborative approach needed to identify beneficial interdependencies across government, regulators and industrial sectors. The proposal is bold, but it is felt that without this, there will be no similar ‘burning platform’ to catalyse a change in thinking and consideration. Such views are being expressed elsewhere (Armitt 2013, Estache and Philippe 2012).

5. CONCLUSION, RECOMMENDATIONS AND IMPLICATIONS

The emergence of most important infrastructure has been sporadic and often lacking any long-term overarching strategy. This is illustrated in the context of the UK, where in 2011, IUK published its second National Infrastructure Plan (HM Treasury 2011) in which it characterizes

the UK's approach to the development of infrastructure of national importance as having been "*fragmented and reactive*", noting that "*opportunities to maximise infrastructure's potential as a system of networks have not been exploited*" (p5). Despite this, National Infrastructure remains "*a major determinant of growth and productivity*" (p5), and an instrument for geographically rebalancing the economy. This is a view held internationally as expressed by the OECD: "*Infrastructures are the very foundation of modern economies and societies. Energy, transport, water, telecommunications, all will continue to be essential to future development and growth.*" (OECD 2006).

This paper described an ongoing policy development inquiry on behalf of a division within the UK's ministry of economics and finance – Infrastructure UK. This policy inquiry is focused on economic and engineering interdependencies occurring on infrastructure projects. The two commissioned inquiries were undertaken in one case by two leading academic research institutions and in the other by consultancy practice and both showed the potential for much economic and social benefit arising from such infrastructure projects that was not formally evaluated as part of the current project appraisal approach.

Whereas much is appreciated about the negative interdependencies that can result in cascading and escalating failures, there is growing appreciation of how specific projects can have wider impacts. This allows the project sponsors, clients and project delivery teams the opportunity to accommodate internal and external socio-economic, natural and technical interactions in the planning, appraisal and design processes of these infrastructure projects to achieve maximum benefit. This registers the potential for a wider spread of consequences for infrastructure and points to the importance of effective and early engagement with a broad set of key stakeholders and the explicit appreciation of the role that policy has in shaping and influencing the way that these projects emerge and progress.

The wider set of consequences and interested parties in a proposed infrastructure project can become a critical factor in the specification, planning, and appraisal of infrastructure and for the identification of immediate and downstream interdependencies. Similarly, defining and justifying proposed infrastructure development solely in terms of narrowly framed monetary costs and monetized benefits was found to unduly constrain the processes of infrastructure planning, appraisal and design. Such an approach to development limits efforts to identify a more complete set of potential interdependencies and seek benefit through their exploitation. 'Soft' factors such as governance structures, regulatory regimes, policy frameworks, institutions and organizational learning, were also found to be highly important determinants of the likely overall success of infrastructure development.

The discussion of front-end project management concludes that two distinct points of the project lifecycle are particularly well suited to identify the interdependencies and utilize the opportunities they create. They occur at the early strategic stage when the project is embryonic and more fluid, and later, when the project is subject to formal consultation as part of the statutory approval exercise. The latter point is noted as being in the context of the UK, where this is a legal requirement to consult stakeholders, however, it is felt that many nations and States have a similar arrangement. Different people, with different considerations will take part in both of these discussions and there is the potential for these discussions to be tense. This then raises the second primary finding, that of the implications of the search for such interdependencies on those managing these types of projects. Three separate project management roles were considered: strategic, tactical, and operational. All three were found to be affected by, and

capable of influencing these interdependencies and the skills and attitudes of these individuals needs to be considered carefully if interdependencies are to be valuably included.

Moreover, consideration has been given to the more general impact of seeking interdependencies on the world of project management. This revealed a direct and significant link to first the arguments for challenging traditional notions of project management being dominated by an ‘execution-orientated’ mindset, as is done by those arguing for the ‘management of projects’. Second, such arguments for widening the remit of project management have been dwelling on the role of the ‘front-end’ of projects. This research has found that the biggest opportunity for considering and capturing interdependencies is indeed during the project’s front-end and whilst this may not be easy, there exists the potential for substantial improvements to the stream of benefits that will flow over long timescales that result from these infrastructure projects.

Finally, we used the findings from the policy inquiry to derive a propositional theoretical framework for research and policy in infrastructure interdependency. The goal of the propositional framework is to construct a sensemaking basis in the space of infrastructure that would account for a myriad of interactive phenomena that is attributed to different levels of the infrastructure discourse - policy, finance, business, and engineering.

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