A Systemic, Purposeful, Performance-led and outcome oriented approach to Infrastructure Need Assessment

Dr Tom Dolan
Senior Research Associate, UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC), UCL
Centre Manager and Senior Research Associate, International Centre for Infrastructure Futures (ICIF), UCL

Abstract (max 500 words)

In the absence of a clearly articulated, shared, collaboratively developed and mutually understood PURPOSE (a vision comprising the desired outcomes that we expect infrastructure to enable), it is not possible to fully evaluate system performance and therefore, not possible to undertake a complete assessment of underlying infrastructure system NEED (i.e. identify system performance gaps where actual infrastructure system performance is not sufficiently aligned to expected infrastructure system performance.) The ability to undertake such need assessment is significant for any country/region that aims to cost effectively improve the quality of its infrastructure systems and make fit for purpose infrastructure investments to enable the outcomes society expects from infrastructure systems.

Achieving long-term value for money from infrastructure systems is a question of *'doing the systemically right thing right not the wrong thing better'* [1]. Therefore, it is of paramount importance that need assessment is underpinned by a set of transparent, systemic, structured, interconnected and flexible methodologies that enable a complete assessment of infrastructure need and prioritisation of those investments best aligned to enabling desired outcomes.

The need for such a methodology is particularly significant in the UK, where a pipeline of future infrastructure projects is regularly published, the National Infrastructure Commission (NIC) has a mandate to undertake a National Infrastructure Assessment (NIA) once per parliament and infrastructure was prioritised in a recent Industrial Strategy consultation, because the proposed methodology for NIA does not allow a complete assessment of infrastructure need. It is also significant to any country or region already grappling with these challenges or considering creating their own National Infrastructure Commission. It is also relevant to society groups, infrastructure practitioners, and infrastructure financiers who want to influence decision making, ensure that the infrastructure investments available to them are closely aligned with actual expectations, demonstrably enable a mutual understood vision and are less likely to experience less problems in the planning phase and deliver stable returns for the investments lifecycle.

Commented [u1]: improve

This paper introduces, briefly explains and justifies the importance of a set of principles any methodology to assess future infrastructure needs assessment should seek to embody. These principles build on earlier research undertaken on behalf of Infrastructure UK and the Infrastructure Projects Authority (IPA) on outcome oriented performance indicators to evaluate the alignment between actual and expected system

performance, and research developed in direct response to the launch the National Infrastructure Commission and consultation regarding NIA methodology.

In brief these principles are:

Meaningful decision making requires a clearly articulated systemic vision comprising sector, solution and technology neutral desired outcomes (expectations)
System Health priorities related to system problems must be identified and placed at the core of needs assessment processes
Whole system performance evaluation requires a suite of performance indicators (PI) covering Technical PI, Quantity PI, Outcome Oriented PI, System Health PI
Performance Gaps between expected and actual system performance can diagnose 4 types of infrastructure needs (maintenance/renewal, Quantity of provision, Alignment, System Health PI)
Need requires sector, solution and technology neutral framing. A collaborative system-wide process is needed to identify options to address need (conversion of need into solution is non-trivial)
Options can include intentional change to any component of the dynamic context in which an infrastructure system operates.
Clearly defined outcome-linked selection criteria and system health selection criteria are needed to evaluate the relative merits of different options
Regularly review of desired outcomes underpins the validity of the needs assessment
Needs Assessment Processes must be clearly linked to established plans

Conference Theme: Thinking outside the Silo: system-wide purpose, vision and strategy aligning decisions, performance and needs assessment with system-wide vision of aspirational outcomes

Key Words

Purpose, systemic vision, systemic priorities, performance, expectations, outcomes

Introduction

Achieving long-term value for money from infrastructure systems is a question of *'doing the systemically right thing right not the wrong thing better'*[1]. The process of needs assessment has a significant role to play in enabling this by (i) developing a systemic vision and clearly stating systemic (system health) priorities to underpin the identification of *systemically right things* and (ii) identifying performance gaps (*diagnosing wrong things*). However, the credibility of recommendations made by any needs assessment exercise, is dependent upon the quality, transparency, inclusivity of the methodology used to perform the assessment. Therefore, it is of paramount importance that need assessment is driven by clearly defined set of principles, and underpinned by a set of transparent, systemic, structured, interconnected and flexible methodologies that enable a complete assessment of infrastructure need. Furthermore, any needs assessment process must generate a coherent narrative and audit trail to justify all decisions made during, and recommendations made by, the needs assessment process.

The need for such a methodology is particularly significant in the UK, where a pipeline of future infrastructure projects is regularly published[2,3], the National Infrastructure Commission (NIC) has a mandate to undertake a National Infrastructure Assessment (NIA) once per parliament[4,5] and 'better' infrastructure was prioritised in a recent Industrial Strategy consultation, because the proposed NIA methodology[5,6] is not sufficient to support a complete systemic assessment of infrastructure need.

This methodological need is also significant to any country or region considering creating their own NIC, and any country already grappling with the challenge of improving systemic infrastructure decision making processes. Furthermore, establishing a complete and credible methodology for needs assessment is of direct interest to all parties involved with infrastructure provision, funding, financing, operation occurs because infrastructure decision making processes closely aligned with the desired outcomes we demand from infrastructure are more likely to identify fit for purpose solutions, which may be less likely to experience delays in the planning phase and are more likely to deliver stable returns over the investment lifecycle.

In response to the above methodological need, this paper proposes a set of transferable principles any methodology to assess future infrastructure need should aim to embody (Table 1), and elaborates further on these principles by proposing a systemic collaborative, transparent, structured and flexible framework for infrastructure need assessment and decision making (Figure 1.)

Background and context

This paper builds on earlier research undertaken on behalf of Infrastructure UK and the Infrastructure Projects Authority (IPA) to develop a process for outcome-oriented performance indicators for infrastructure systems[7–9] and research developed in direct response to the launch of the National Infrastructure Commission[4] and consultations regarding NIA methodology[10,11,5,12,13], and ongoing research to develop approaches to identify desired outcomes[1] and frame desired outcomes as solution, sector and

[1] A forward-looking statement (or set of statements) of the societal level benefits that we expect infrastructure to play a role in enabling.

technology neutral[14,15], and analysis of infrastructure resilience as a system problem[16,17]. The proposed approach is driven in particular by a number of observations which are stated below.

In the absence of a clearly articulated, shared, collaboratively developed and mutually understood purpose (a vision comprising the desired outcomes that we expect infrastructure to enable), it is not possible to fully evaluate system performance and therefore, not possible to undertake a complete assessment of underlying infrastructure system need (i.e. identify system performance gaps where actual infrastructure system performance is not sufficiently aligned to expected infrastructure system performance.)[16,18]

Furthermore, in the absence of strategic vision, there is a tendency to wrongly derive assumptions of infrastructure purpose from, and frame assessments of future infrastructure needs in terms of, the characteristics of the incumbent solutions already in operation. As a consequence, solutions to resolve needs are often assumed to be obvious, and open-ended system-wide processes to enable the identification of common needs that span multiple sectors, and identify opportunities for innovative solutions are rarely undertaken. Consequently, the range of options considered in response to infrastructure need is constrained to an unnecessary extent and innovative systemic approaches are often inhibited.

UK infrastructure is a complex interdependent system of systems, vulnerable to the emergence of system problems (e.g. challenges and resilience, carbon mitigation, flood management, climate change preparedness, sustainability, inclusivity) these problems emerge as a consequence of interdependent interactions between system components (including the political, social and economic context in which their embedded), and are best managed collaboratively. Furthermore, if not prioritised the system problems will jeopardise the achievement of all long-term priorities, therefore infrastructure must be managed as an interdependent system[9,16,19].

Infrastructure interdependence analysis[20–23] has significant explanatory power, and is a substantially broader concept than mere dependence on the immediate inputs infrastructure systems requires to function. Infrastructure systems are also interdependent with the dynamic context (social, political, economic, financial, legal, environmental, regulatory, local, global, spatial and temporal) in which they operate. Therefore, a deep understanding of interdependencies creates an opportunity to improve system performance. Furthermore, if interdependence is well understood, any intentional change any of the above contextual factors can be used as a strategy to improve system performance (i.e. address performance). At present, we tend to favour engineered solutions and overlook the significance of these other options. [19]

The transformative opportunity presented by the requirement for regular national infrastructure assessment (NIA) is in danger of being missed, if we do not develop a systemic collaborative, transparent, structured and flexible toolkit for infrastructure need assessment and decision making (Figure 1.)[10,16,17,19]

Proposed Need Assessment Principles and a Systemic Framework

Table 1 proposes a set of principles for need assessment, and Figure 1 proposes a systemic, collaborative, transparent, structured and flexible toolkit for infrastructure need assessment and decision making. Both

Table 1 and Figure 1 have been refined from similar outputs proposed following a infrastructure practitioners workshop, held as part of research into outcome-oriented performance indicators for Infrastructure UK [7,9].

The motivation in adapting these processes and underpinning this research is the concern that the need assessment methodology proposed and consulted on[6,24] is focused primarily on evaluating need solely from technical performance and quantity of provision perspectives, and does not acknowledge the importance of neutral framing, is primarily sectoral rather than systemic, focuses on solutions closely linked to incumbent infrastructure and lacks a strategic vision for the purpose of infrastructure (i.e. the desired outcomes we aspire to achieve through infrastructure provision) and that the transformative opportunity created by the need for regular National Infrastructure Assessment may be missed [10,19]

The body of this paper is structured using subheadings linked to the 8 framework stages proposed in Figure 1. Each section, makes explicit the connection between the framework stage and one or more principles from Table 1; provides a brief overview of, and justifies the purpose of, the framework stage; presents a tabular summary of a proposed set of steps for each stage, how these steps might be approached and the possible benefits.

Table 1. Need Assessment Principles

Need Assessment Principles
Meaningful decision making requires a clearly articulated systemic vision comprising sector, solution and technology neutral desired outcomes (expectations)
System Health priorities related to system problems must be identified and placed at the core of needs assessment processes
Whole system performance evaluation requires a suite of performance indicators (PI) covering Technical PI, Quantity PI, Outcome Oriented PI, System Health PI
Performance Gaps between expected and actual system performance can diagnose 4 types of infrastructure needs (maintenance/renewal, Quantity of provision, Alignment, System Health PI)
Need requires sector, solution and technology neutral framing. A collaborative system-wide process is needed to identify options to address need (conversion of need into solution is non-trivial)
Options can include intentional change to any component of the dynamic context in which an infrastructure system operates.
Clearly defined outcome-linked selection criteria and system health selection criteria are needed to evaluate the relative merits of different options
Regularly review of desired outcomes underpins the validity of the needs assessment
Needs Assessment Processes must be clearly linked to established plans

Figure 1. Proposal for a systemic, collaborative, transparent, structured and flexible framework for infrastructure need assessment and decision making

Stage 1: Define System Expectations

Define System Expectations addresses the principle: *Meaningful decision making requires a clearly articulated systemic vision comprising sector, solution and technology neutral desired outcomes (statements of expectations).*

The development of a shared, collaborative and mutually understood statement of the desired outcomes the infrastructure system is expected to enable is essential for three main reasons. It provides the basis to articulate a systemic vision. It provides a foundation to enable all subsequent stages of the proposed toolkit for infrastructure need assessment and decision making (fig 1). It creates an aspirational frame of reference against which all subsequent decisions, and evaluations of system performance, can be justified.

Furthermore, there is a notable absence of systemic vision for infrastructure, therefore, a commitment to collaboratively establish and clearly state a systemic vision as the first stage of infrastructure needs assessment, highlights a commitment to establishing a shared sense of purpose and make the decision making process comprehensible and transparent.

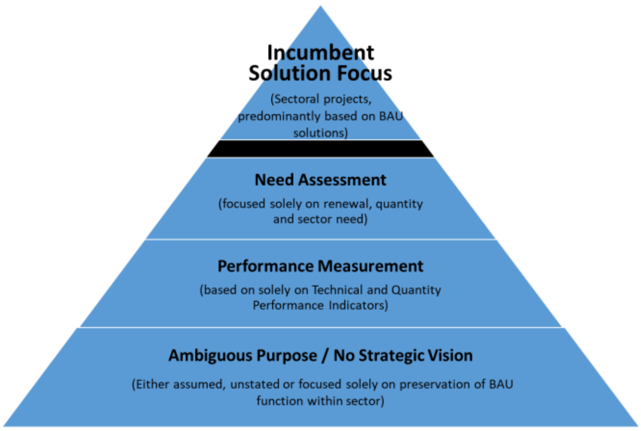
However, a systemic vision requires certain characteristics if it is to perform this function and enable the process proposed in Figure 1. It must be (i) an accurate and inclusive representation of expectations; (ii) Comprised of a set of well structured, unambiguous, mutually understood and mutually accepted desired outcomes; (iii) Objective, Neutral and systemic – framed at the system level, and not biased or anchored toward specific solutions or technologies. Significantly, consensus is not a necessary component of a systemic vision, provided the systemic vision is mutually understood and accepted. Steps 1.1 to 1.4 in Table 2 are proposed to ensure the systemic vision developed has these characteristics.

Table 2. Overview of Steps and Actions to Implementing Stage 1

Steps	Overview of Action Required	Benefit
1.1. Identify Expectations (desired outcomes)	A process to engage citizens, communities, industry, investors, government and other interested parties in identification of the desired outcomes, they expect infrastructure to play a role in enabling	An accurate and inclusive representation of expectations of infrastructure
1.2. Clarify and Structure Expectations (desired outcomes)	A process to enable in-depth discussion, analysis, visualisation and structured mapping of the desired outcomes and to identified through 1.1.	A set of well structured, unambiguous, mutually understood and accepted desired outcomes.
1.3. Frame Expectations (Desired Outcomes)	A process to remove any sector, technology or solution specific terminology from the framing of desired outcomes.	Systemic, unbiased framing not anchored toward specific solutions or technologies
1.4. Set Systemic Vision	A process to convert the above into a shared systemic vision.	An aspirational direction of travel against which all subsequent decisions, and evaluations can be justified.
1.5 Define Outcome-linked Selection Criteria	See 6.1	See 6.1

The significance of objective, neutral and systemic framing is related to the role of systemic vision in driving the process proposed in Figure 1. Any bias or anchoring in the framing of the desired outcomes that comprise the systemic vision will influence decisions made at all later stages of the proposed process. To achieve neutral framing, desired outcomes must be framed in **Solution neutral (**not aligned with any specific solution or mode of delivery) **Sector neutral (**not framed in terms of a specific infrastructure sector) and **Technology neutral** (not aligned with the incumbent or any other technology) terms (This concept is analysed in greater depth in [9,18]). see further analysis of desired outcomes in .

The importance of prioritising neutral framing and development of systemic vision is illustrated in Figure 2 which illustrates a typical ad hoc approach to decision making where systemic vision is either not clearly stated, assumed or not present. In this situation, decision making process are characterised by the tendencies (i) to infer purpose from properties of incumbent solutions; and (ii) frame infrastructure need in terms of specific of incumbent solutions, sectors and technologies. Figure 2 is therefore a direct contrast to the model proposed in in Figure 1 where strategic vision provides a transparent foundation for all decision making processes.



In short, meaningful decision making requires a clearly articulated systemic vision comprising sector, solution and technology neutral desired outcomes (statements of expectations).

Stage 2: Define Systemic (system health) Priorities

Define Systemic Priorities addresses the principle: System Health priorities related to system problems must be identified and placed at the core of needs assessment processes

UK infrastructure is a complex interdependent system of systems, vulnerable to the emergence of system problems (e.g. challenges and resilience, carbon mitigation, flood management, climate change preparedness, sustainability, inclusivity) these problems emerge as a consequence of interdependent interactions between system components (including the political, social and economic context in which their embedded), and are best managed collaboratively. Furthermore, if not prioritised in decision making processes system problems will jeopardise the achievement of all long-term priorities [9,16,19].

System Problems become Systemic (system health) Priorities when the system as currently configured and/or operated is vulnerable to emergent System problems (e.g. resilience, carbon mitigation, flood management, climate change preparedness, sustainablity, inclusivity) that if not addressed have the potential to jeopardise the long term achievement of all other long-term priorities.

Therefore, any methodology for assessment of infrastructure need, must include processes to improve understanding of and actively address these system problems. Furthermore, it is necessary to evaluate the impact of any recommended change to the infrastructure system on system health problems. Table 3 provides an overview of some actions required. Further research is required to develop and refine the steps proposed in Table 3.

Table 3. Overview of Steps and Actions to Implementing Stage 2

Steps	Overview of Action Required	Benefits
2.1 Identify system Problems	A process to identify current system problems	Greater awareness of system problems
2.2 Analyse interdependent origins of system problems	A process to analyse system interdependencies with a view to understanding the origin of system problems	In-depth understanding of root causes of, and systemic resilience, to system problems
2.3 State Systemic (System Health) Priorities	Based on the above state systemic (system health) priorities that must be addressed or alleviated as part of needs assessment	A clearly framed set of priorities for infrastructure decision making
2.4 Define System Health Priority-Linked selection criteria	See 6.2	See 6.2

Stage 3: Evaluate System Performance

Evaluate System Performance addresses the principle: Whole system performance evaluation requires a suite of performance indicators (PI) covering Technical PI, Quantity PI, Outcome Oriented PI, System Health PI

To fully understand system performance, it is necessary to evaluate performance from a range of perspectives using a suite of Technical, Quantity, Outcome Oriented, System Health performance indicators[9,18]. Each performance indicator type evaluates system performance from a different perspective, and provides information to support different types of decision. As a suite of performance indicators the four performance indicator types complement one another and enable a meaningful assessment of whole system performance. If the indicator types are used in isolation of one another, an assessment of system performance is incomplete, and can lead to erroneous conclusions.

Table 4 proposes 4 steps to put stage 3 into practise and Table 5 provides a brief overview of the purpose of each indicator type, and their advantages and limitations when applied to whole system needs assessment.

Table 4. Overview of Steps and Actions to Implementing Stage 3

Steps	Overview of Action Required	Benefits
3.1. Select Indicators of Technical Performance (Technical PI)	Collaborate with infrastructure operators to identify available which technical PI already in use, can be employed for needs assessment purposes, and which elements of technical performance require additional indicators	A suite of performance indicators to inform analysis of actual system performance related to technical, quantity, alignment and system health. A foundation for the performance gap analysis proposed in stage 4
3.2 Select Indicators of Quantity of Provision (Quantity PI)	Develop a set of Quantity PI for national infrastructure to enable evaluation of whether current provision (supply) is sufficient to meet demand.	
3.3 Develop Outcome-oriented performance indicators (Alignment PI)	Apply the outcome-oriented performance indicator process proposed in [7,9] to develop a set of performance indicators identified in part 1.	
3.4 Develop Indicators of System Health (system health PI)	Refine the process used in 2.3 to create outcome-oriented performance indicators for the systemic (system health) priorities identified in part 1	

Table 5. Overview of the Four Performance Indicator types identified in stage 3

Indicators of Technical	**Technical PI** have the purpose of measuring and providing insight into real time performance, and are typically used at a tactical or operational level by infrastructure

Performance (Technical PI)	operators to inform real-time and short-term operating decisions and ensure an asset, component or process operates as efficiently (and effectively) as possible. Technical PI for a system component are typically fixed in line with technical specifications (typically those expected and/or designed for when the system component was commissioned) and remain constant, over the lifecycle of an infrastructure asset or system component. Advantages: Technical PI can assess whether a system component is operating within, at the edge of, or outside an expected / acceptable range. Information from Technical PI can diagnose situations where maintenance, renewal or replacement action is required to return performance back to the expected range. Technical PI focus on asset, component or process performance and preventing component failure. Although not systemic, technical PI if used in combination with knowledge of system interdependence (Rinaldi et al., 2001; Rosenberg et al., 2014; Carhart and Rosenberg, 2016) and criticality (Egan, 2007) can be used to proactively mitigate the risk of *interdependence-related disruptions* initiated by component failure, and by ensuring actual and expected operational performance indirectly reduce the risk of a failure event **cascading** or **escalating** through a system. Or by implemented to detect changes to technical performance that might be indicative of common cause failures. Limitations: Information from Technical PI, provides little (if any) insight into the root cause of poor performance, or the specific maintenance, renewal or replacement actions required to address the performance issue identified. Technical PI provide little (if any) insight into outcome oriented or alignment need. Technical PI at best provide a snapshot of system purpose at a specific point in time (i.e. when the component was commissioned). Additionally, it is possible for all system components to be performing in line with Technical PI, but for performance of the system itself to be no longer aligned with expectations (fit for purpose). This is because in any large technical system (LTS) (Hughes, 1987) or socio technical system (STS) or complex adaptive system (Oughton, and Tyler., 2013) such as infrastructure systems, system purpose often changes more rapidly than the underlying technical components of the system (ref NC, KL and SH),
Indicators of Quantity of Provision (Quantity PI)	**Quantity PI,** focus mainly on measuring either inputs or output. Quantity PI enable evaluation of whether current provision (supply) is sufficient to meet demand. Additionally, Quantity PI can be combined with projects of future scenario, to assess whether infrastructure supply will be sufficient to meet future demand. Advantages: Quantity PI can provide strategic insight into infrastructure capacity, access, availability, utilisation; in order to facilitate strategic planning for current and future infrastructure provision under a range of plausible scenarios. Limitations: Quantity PI offer little (if any) insight into how to respond to, or the root cause of, under or over supply. Neither do they offer insight into the extent to which actual system performance is aligned with societal expectations of expected performance.

Outcome-oriented performance indicators (OO PI)	OO PI are a form of strategic performance indicator directly aligned with one or more 'desired outcome' that infrastructure is expected to enable. Advantages: OO PI[2] aim to make it possible to *regularly and meaningfully evaluate : (a) the extent to which infrastructure enables the desired outcomes expected of it and therefore its 'fitness for purpose'; (b) infrastructure performance at the whole-system level, and (c) whether changes to infrastructure strategy are needed to ensure that infrastructure performance remains fit for purpose in the face of future challenges* Limitations: OO PI are not a direct measure of the performance of an infrastructure system, rather they evaluate alignment between *expected* and *actual* outcomes and provide information complementary to Technical PI and Quantity PI
Indicators of systemic (system health) priorities	Systemic (system health) priorities PI are a form of OO PI aligned not with desired outcomes but with system health priorities. Advantages: systemic (system health) priorities PI aim to make it possible to regularly and meaningfully evaluate: (a) the extent to which the infrastructure system as currently configured and /or operated is vulnerable toemergent system problems; (b) the impact on system heaqlth of changes to the system, and (c) whether changes to infrastructure strategy are needed to improve system health. Limitations: They are untested and further work is required to develop a process for designing system health PI

Stage 4: Assess Performance Gaps (identify needs)

Assess Performance Gaps addresses the principle: Performance Gaps between expected and actual system performance can diagnose 4 types of infrastructure needs (maintenance/renewal, Quantity of provision, Alignment, System Health PI)

In this paper, the term infrastructure need is used to refer to any situation where there is a performance gap of any form. A performance gap exists where there is an observable gap between actual and expected system performance. Analysis of performance gaps, can be used to identify four different types of Infrastructure Need. Based on the 4 indicator types from stage 3, it follows that a complete needs assessment requires evaluation of 4 types of infrastructure need, each of which are linked to different performance:

Renewal or Maintenance Need (technical performance gap) – This need type arises where one or more component of an infrastructure asset or system is no longer performing in line with the initial technical specification of the component.

Quantity of Provision Need (quantity performance gap) – This type of need arises where the demand (expectation) for an output or service supplied by the infrastructure system is greater than the supply capacity of the system (actual) for that output or service. Quantity Need can take two forms (i) Current -

where current demand is greater than supply or (ii) Predicted Future - where future demand is predicted to exceed supply capacity in the future.

Outcome-oriented or alignment need – This need type emerges where *actual* system performance is no longer aligned with the desired outcomes *expected* by society. In these cases, expected outcomes are not 100% satisfied because the infrastructure is not capable/designed to meet the desired outcomes as currently expressed.

System Health Need – where the system as currently configured and/or operated system is vulnerable to System problems (e.g. resilience, carbon mitigation, flood management, climate change preparedness, sustainablity, inclusivity) that need to be addressed.

An Infrastructure system is 'fit for purpose' when it enables all desired outcomes expected of it, and operates without performance gaps.

Table 6. Overview of Steps and Actions to Implementing Stage 4

Steps	**Overview of Action Required**
4.1 Identify Technical Performance Gaps	A process to identify components of an infrastructure asset or system that are not performing to the technical specifications they were designed to meet or to the technical specification expected by the operator (Technical Performance Gaps)
4.2 Identify Current Quantity Performance Gaps	A process to identify any situation where the demand (expectation) for an output or service supplied by the infrastructure system is currently greater than the supply capacity of the system (actual) for that output or service.
4.3 Identify Projected Future Quantity Performance Gaps	As above, but based on scenarios linked to drivers of changing demand, drivers of changes to current supply capacity, to identify under under what plausible future scenarios the demand (expectation) for an output or service supplied by the infrastructure system is projected to be greater than the supply capacity of the system (actual) for that output or service.
4.4 Identify Outcome Oriented Performance Gaps	A process to identify any situation where actual system performance is no longer aligned with the desired outcomes expected by society. (Outcome-oriented performance gaps).
4.5 Identify System Health Performance Gaps	A process in three parts to i) identify where the system as currently configured and/or operated system is vulnerable to System problems (e.g. resilience, carbon mitigation, flood management, climate change preparedness, sustainablity, inclusivity) ii) Assess whether system problems identified in the previous assessment have changed in status iii) assess whether system problems or vulnerabilities will emerge as a consequence of planned changes to current patterns of system use, or change to external context (i.e. what system needs must we address if system failure is not to jeopardise the long term realisation of the outcomes we expect?

4.6 Frame Performance Gaps identified as option, sector, technology neutral needs	A process to collate performance gaps and ensure framing is sector, solution and technology neutral terms, and reframe need wherever necessary	Framing need in neutral terms enables (i) the identification of common needs that span multiple sectors, and (ii) the opportunity for innovative solutions to be considered
4.7 Root Cause Analysis	A process to analyse and identify the root causes of the performance gaps that have been identified whether multiple 'symptoms' share a common cause.	Develop deeper understanding of the causes of performance gaps

Stage 5: Invite Options (publish infrastructure needs pipeline)

Invite Options (publish infrastructure needs pipeline) addresses the principles: Need requires sector, solution and technology neutral framing. A collaborative system-wide process is needed to identify options to address need (conversion of need into solution is non-trivial); and Options can include any intentional change to any component of the dynamic context in which an infrastructure system operates.

In an interdependent context, any intentional change to any of the contextual factors that characterise the broader STS in which infrastructure is embedded (i.e. social, political, economic ,regulatory, financial, legal, environmental, local, global, spatial and temporal) can be used as a strategy to improve system performance (i.e. address a performance gap)[19]. However, conventional approaches often focus primarily on implementing tried and tested sector level technical fixes (typically engineered solutions) in response to performance gaps observed at the sector level, with little reference to the possible systemic root causes of the performance gap observed.

It follows, little if any attention is given to (i) understanding the performance gap as a symptom of a broader problem (ii) the identification of common needs that span multiple sectors, or (iii) the opportunity for innovative solutions to be sourced from outside of sector. Therefore, it is important to break the implicit connection between need and solution assumed in many conventional approaches to infrastructure decision making (Figure 2) and significantly broaden the option space in recognition that options can be based on: a portfolio of responses; targeted actions in other Infrastructure sectors; targeted change to any interdependent element of the broader system; adopting best practice approaches from elsewhere in the infrastructure system, or from outside the infrastructure system; innovative business models that deliver services in non-traditional ways; innovative solutions enabled by digital technologies, or problem avoidance based on understanding the root cause of the observed problem. Stage 5 builds on the principle of neutral framing of desired outcomes and needs by explicitly broadening the option space considered in response to statements of infrastructure need.

Table 7. Overview of Steps and Actions to Implementing Stage 5

Steps	**Overview of Action Required**	**Benefit**
5.1 Publish Infrastructure Needs Pipeline (based on 4.6)	Regularly publish and update an infrastructure need pipeline, to create transparency, signal the challenges in need of resolution, open the option identification process to non-traditional actors and invite cross sectoral solutions signal the areas of need	Broadening the option space, creates a marketplace to engage with possible solution providers, greatly increasing the potential for innovative options to be identified
5.2 Cross Sectoral and Public Engagement	The pipeline proposed in 5.1 changes the terms of engagement for how options to address infrastructure need are identified. A Suite of processes to publicise this, and invite option proposals are required.	

Stage 6: Define and Apply Selection Criteria

Define and Apply Selection Criteria addresses the principle: Clearly defined outcome-linked selection criteria and system health selection criteria are needed to evaluate the relative merits of different options

Successful implementation of stage 5 will increase the number and diversity of options proposed to address any infrastructure need. A transparent set of methodologies to consistently evaluate the relative merits of different options in terms of the desired outcomes and systemic (system health) priorities identified in stages 1 and 2 is therefore required. It is proposed that to do this outcome-linked selection criteria are developed from the desired outcomes comprising the systemic vision (Table 2 steps 1.4 and 1.5) and systemic (system health) priority linked selection criteria are developed from the system health priorities identified in Table 3. Table 8 offers an overview of what is envisaged.

Table 8. Overview of Steps and Actions to Implementing Stage 6

<table>
<tr><th>Steps</th><th>Overview of Action Required</th><th>Benefits</th></tr>
<tr><td>6.1. Define Outcome-linked Selection Criteria</td><td>A process to convert the desired outcomes identified in 1.3 into a set of sector, solution, technology neutral outcome-linked selection criteria, suitable as i) guidance for those proposing options in stage 4 and ii) for evaluation of Options in order to select a solution from options proposed or identified in stage 4</td><td rowspan="3">Establishing a clear link between the systemic vision, system priorities and decisions making processes in this way enables transparent defensible decision making to enable expectations and manage systemic priorities.

It also provides Needs Assessment recommendations with credibility</td></tr>
<tr><td>6.2 Define System Health Priority-Linked selection criteria</td><td>A process to convert the systemic (system health) priorities identified at stage 2 into a set of system health linked selection criteria and therefore place systemic priorities at the core of the decision making processes</td></tr>
<tr><td>5.3 Apply Selection Criteria</td><td>A process to apply the selection criteria identified in 6.1 and 6.2 to evaluate which of the options identified in stage 4 are most fit for purpose.</td></tr>
</table>

Stage 7: Publish to Infrastructure Project Pipeline

Publish to Infrastructure Project Pipeline addresses the principle**:** Needs Assessment Processes must be clearly linked to established plans. Table 9 provides an overview of what this involves.

Table 9. Overview of Steps and Actions to Implementing Stage 7

Steps	Overview of Action Required	Benefit

7.1 Publish decisions made in 6.3 into the project pipeline	A process to link needs assessment recommendations to the established project pipeline and National Infrastructure Delivery Plan Process	Create certainty for investors and other infrastructure practitioners

Stage 8: Fitness for Purpose Review

Fitness for Purpose Review addresses the principle: Regular review of desired outcomes underpins the validity of the needs assessment

Table 10. Overview of Steps and Actions to Implementing Stage 7

Steps	Overview of Action Required	Benefits
8.1 Repeat stages 1-7 every 5 years	Follow stages 1-7 of this process for every subsequent National Infrastructure Assessment (NIA). Do not skip steps 1 or 2	Regular review ensures the credibility of recommendations from the need assessment process. Regular review of pipeline needs and pipeline projects is needed to ensure that need and projects remain fit for purpose in the period between recommendation and implementation.
8.2 Review Needs Pipeline every 5 years	A process to review whether a Need put into the pipeline 4.1 at the previous NIA remains fit for purpose	
8.3 Review Projects in Pipeline every 10 years	A process to review whether a project added to the project pipeline over 10 years ago remains fit for purpose.	

Conclusions and Recommendations

Table 1 proposes need assessment principles that should be embodied by any process to evaluate infrastructure need. The body of the paper elaborate on and explains the significance of these principles by proposing Figure 1 as a possible framework for infrastructure need assessment and decision making. It is recommended that the that content of this paper be used in 1 of 3 ways

I. Apply the principles in Table 1 to critically evaluate and review any established need assessment process with a view to incorporating these principles
OR

II. Adopt, and tailor Table 1 and Figure 1 as the basis for developing a new needs assessment process
OR

III. Use the paper as a whole to identify important areas of process and research that require further action to enable meaningful evaluation of infrastructure need.

1. Beckford, J. *Systems Engineering: Necessary but not sufficient for 21st Century Infrastructure*. Review (Beckford Consulting, 2013).
2. IPA. National Infrastructure Pipeline 2016 - Publications - GOV.UK. *National Infrastructure Pipeline* (2016). Available at: https://www.gov.uk/government/publications/national-infrastructure-pipeline-2016. (Accessed: 26th August 2016)
3. IPA. *National Infrastructure Delivery Plan 2016 to 2021*. (HM Treasury, Infrastructure and Projects Authority, 2016).
4. UK Government. National Infrastructure Commission Website. (2016). Available at: https://www.gov.uk/government/organisations/national-infrastructure-commission. (Accessed: 26th August 2016)
5. International centre for Infrastructure Futures. ICIF Response to National Infrastructure Assessment Consultation. (2016).
6. ICE. *National Needs Assessment*. (Institute of Civil Engineers, 2016).
7. Carhart, N. J., Bouch, C., Walsh, C. L. & Dolan, T. Applying a new concept for strategic performance indicators. *Infrastruct. Asset Manag.* **3,** 143–153 (2016).
8. Carhart, N., Bouch, C., Walsh, C. & Dolan, T. *A Critique of Current Infrastructure Performance Indicators: Towards Best Practise*. 31 (ICIF and iBUILD, 2015).
9. Dolan, T., Walsh, C. L., Bouch, C. & Carhart, N. J. A conceptual approach to strategic performance indicators. *Infrastruct. Asset Manag.* **3,** 132–142 (2016).
10. Dolan, T. Infrastructure Commission: what are the opportunities and how should it work? *Infrastructure Commission: what are the opportunities and how should it work?* (2015).
11. Dolan, T. *The National Infrastructure Commission: opportunities and principles to improve UK infrastructure*. 4 (CIRIA, 2016).
12. International Centre for Infrastructure Futures. ICIF Response to National Infrastructure Commission Consultation. (2016).
13. HM Treasury. *National Infrastructure Commission: consultation*. (2016).
14. *Understanding Infrastructure: Need, Value and Purpose*. (Palgrave MacMillan, In Press).
15. *Visions of Infrastructure*. (Palgrave MacMillan, In Press).
16. Dolan, T. & Cosgrave, E. Aligning systemic infrastructure decisions with social outcomes. *Proc. Inst. Civ. Eng. - Civ. Eng.* **169,** 147–147 (2016).
17. Dolan, T. ICE Thinks - Infrastructure Transformation. *Bringing infrastructure to life in the public imagination* (2015).
18. Making the Case for Solution, Sector and Technology Neutral Framing of Systemic Infrastructure Need and Purpose. in *Understanding Infrastructure: Need, Value and Purpose* (eds. Hiteva, R., Dolan, T., Carhart, N. & Lovell, K.) (Palgrave MacMillan, In Press).
19. Dolan, T. & Hiteva, R. Policy Brief: The National Infrastructure Assessment – A Transformative Opportunity For UK Infrastructure. (2017).
20. Rinaldi, S. M., Peerenboom, J. P. & Kelly, T. K. Identifying, understanding, and analyzing critical infrastructure interdependencies. *IEEE Control Syst. Mag.* **21,** 11–25 (2001).
21. Carhart, N. & Rosenberg, G. Towards a Common Language of Infrastructure Interdependency. *Int. J. Complex. Appl. Sci. Technol.* **1,** 35–60 (2016).
22. Rosenberg, G., Carhart, N., Edkins, A. J. & Ward, J. *Development of a Proposed Interdependency Planning and Management Framework*. (International Centre for Infrastructure Futures, 2014).

23. Boin, A. & McConnell, A. Preparing for critical infrastructure breakdowns: The limits of crisis management and the need for resilience. *J. Contingencies Crisis Manag.* **15,** 50–59 (2007).
24. The National Infrastructure Commission. THE NATIONAL INFRASTRUCTURE ASSESSMENT: PROCESS AND METHODOLOGY - A CONSULTATION. (2016).
25. Egan, M. J. Anticipating future vulnerability: Defining characteristics of increasingly critical infrastructure-like systems. *J. Contingencies Crisis Manag.* **15,** 4–17 (2007).
26. Hughes, T. P. The Evolution of Large Technological Systems. in *The Social Construction of Technological Systems: New Directions in the History and Sociology of Technology* 1–82. (MIT Press, 1987).
27. Oughton, E. & Tyler, P. Infrastructure as a Complex Adaptive System. (2013).

INTERNATIONAL SYMPOSIA FOR
NEXT GENERATION
INFRASTRUCTURE

INTERNATIONAL SYMPOSIA FOR
NEXT GENERATION
INFRASTRUCTURE

INTERNATIONAL SYMPOSIUM FOR
NEXT GENERATION
INFRASTRUCTURE
LONDON, 11-13 SEPTEMBER 2017