HM Treasury

Valuing infrastructure spend:

Supplementary guidance to the Green Book

March 2015

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1 Introduction

Overview

1.1 Infrastructure is the generic term for the basic physical structures and assets needed for the operation of our society and economy. In practice, individual structures and assets form part of extensive and interdependent sets of infrastructure networks and systems. Ultimately, it is these infrastructure networks and systems as a whole which underpin the effective operation of our modern economy, and infrastructure spend should be valued and considered within this system-wide context.

1.2 A distinction is sometimes made between different types of infrastructure, for example economic and social infrastructure. Economic infrastructure includes transport, waste management, energy, communications, water and sewerage, flood and coastal erosion management. This supplementary guidance is of particular relevance and makes specific reference to economic infrastructure. However, it could be similarly applied to other sectors within social infrastructure such as schools, prisons, courts, hospitals and regeneration projects more broadly.

1.3 To ensure that the UK's economic infrastructure is able to fulfil its purpose, in facilitating the operation of our society and economy, this document supports effective decision-making in relation to infrastructure spending and interventions that involve the use of public money or have a societal impact. To do so it focuses on characteristics and impacts (or outcomes) that may be of particular relevance to infrastructure in order to maximise value for money.

- Chapter 2 presents important characteristics of infrastructure and key principles to follow in order to account for them.

The subsequent chapters focus on the implications of three of these characteristics and the impacts which may result from, or be affected by, them.

- Chapter 3: Valuing Interdependence and Resilience covers the opportunities and risks which arise due to the interactions between the infrastructure project or asset under consideration and the rest of the national infrastructure system across all sectors. It explains three means of managing interdependence, namely through improving systemic resilience,[1] implementing multi-use assets and joint delivery, and implementing passive provision.[2]
- Chapter 4: Valuing Scale Effects covers the opportunities and risks which arise from the organisation or co-ordination of projects and programmes in such a way that their scale can result in or affect impacts.
- Chapter 5: Valuing Non-Marginal Effects covers the potential for infrastructure to support and enable economic activity and output that may not otherwise have been possible.[3]

[1] The ability of infrastructure to withstand, prevent, adapt to and / or rapidly recover from disruptive challenges, which may occur or be responded to within the same or interdependent sectors, so that the system wide performance returns to an agreed level, within an agreed timeframe.
[2] The inclusion of flexibility within the design and construction of an infrastructure component to allow for the adaptation of its use once better information is available, uncertainty is reduced or it presents better value for money to do so.
[3] In economics a 'network effect' often refers to the tendency for the value of a good or service to become more (or less) valuable as more people use the network. Each of the characteristics explored in chapters three, four and five could be interpreted as a network effect, in the sense that they may relate to a network of assets, suppliers, operators or users.

Application

1.4 This document is a best practice guide for use in central government departments and other government bodies involved in the production and approval of business cases for economic infrastructure projects. The guidance should be understood by all who are either responsible for developing and producing economic infrastructure spending proposals, or for their assessment and approval. This document is also relevant for the regulated economic infrastructure sectors, who will usually consider appraisal from the perspective of the investor and consumer.

1.5 Consideration of the purpose, characteristics and impacts of infrastructure spending is important throughout the application of the 'Five Case Model' (the Strategic, Economic, Commercial, Finance and Management cases, which comprise public sector business cases in line with the Green Book), ROAMEF Framework (the Rationale, Objectives, Appraisal, Monitoring, Evaluation and Feedback stages of the policy cycle) and other decision making tools. This is important to ensure that the entire process, starting with the identification of need and setting of strategic objectives, recognises that individual structures and assets form part of wider networks and systems, which collectively support our economy and society.

1.6 This allows for infrastructure spend to be assessed and valued in terms of the costs and benefits of any impacts both systematically and consistently, through comparability of value for money assessments between projects; and with justification, through clear presentation and communication of the intended and realised impacts. It also provides the most effective way of realising impacts through appropriate commercial, financial and management arrangements.

1.7 The application of this guidance will be case specific, and subject to the existing context and frameworks that are in place for the infrastructure concerned. This document does not provide an exhaustive list of the tools and methods available for valuing spending impacts. In some cases methodologies for quantifying impacts may not be fully developed while in other cases, multiple methodologies may have been developed, none of which can be labelled as being the 'right' one for generic use. It is intended that a programme of work will be put in place to develop the application of this guidance and the content should be adopted into relevant guidance produced by central government departments and other government bodies.

1.8 Recognising that infrastructure projects can take many years to develop and appraise, practical application of this guidance soon after its introduction should be sensitive to the fact that many existing projects and programmes will already be a significant way through the policy appraisal and option selection process.

2 Characteristics of Infrastructure

Chapter overview

2.1 Infrastructure has a combination of characteristics that may be of more relevance than in other areas of spending.[1] This chapter sets out the characteristics which, while their relevance may vary by sector and project, have implications for the impacts of infrastructure projects, programmes and policies. In turn this can affect any decisions made regarding their development, delivery and operation, and their value for money. In practice, these characteristics may overlap making it unnecessary to explicitly account for each one separately. The chapter concludes by presenting key principles to account for the characteristics of infrastructure throughout the application of the Five Case Model and ROAMEF framework.

Long-term

2.2 Infrastructure projects and programmes tend to be of a long-term nature, owing to the time span associated with their construction and / or useful life.

2.3 The long time frame over which infrastructure is usually developed and operated can limit the information that might be available when developing infrastructure projects, owing to uncertainty about future trends. Such uncertainty can arise because various factors may evolve over time regardless of any intervention; technological improvements, economic cycles, demographic changes and climate change are just a few examples. The identification and valuation of the impacts under uncertainty may be a complex task, and the risks associated with such uncertainty may vary for different infrastructure projects.

2.4 Technological redundancy, for example, provides one associated risk. There is a risk of infrastructure becoming outdated or even obsolete as a result of technological developments made during the construction phase of infrastructure, or during its useful life. This risk may be amplified owing to technological lock-in or path-dependency, whereby previous decisions limit future options.

Location specific

2.5 Infrastructure is developed in relation to the geography of an area. For example roads and railways require bridges and tunnels to cross rivers. Infrastructure assets and networks also often remain in fixed geographic locations for long periods of time. It may not be possible to revise decisions on where to locate infrastructure for many years, for example due to the irretrievable costs which have already been incurred in delivering the infrastructure and associated development. This can provide certainty for developers and investors to proceed with other projects and economic activity in the same area. For example, several river crossings and bridges have been in place for centuries and were instrumental in the development of settlements around them.

Interdependent

2.6 The UK's infrastructure has evolved over the centuries through the gradual introduction and development of various structures, assets and networks, leading to the stock of infrastructure

[1] The Green Book presents a wide range of issues which are relevant across all assessments.

around us today. Despite their piecemeal assembly, many assets and networks are highly interconnected and interdependent, and form part of an infrastructure system; each asset and network relies to some extent on one or more of the others to operate efficiently and effectively, for example due to sharing space, customers or inputs.

2.7 Given the interdependence of infrastructure, it is necessary to consider the development of infrastructure from a systemic perspective and recognise that infrastructure components may influence one another, either positively or negatively. From an appraisal perspective, the wide range of potential impacts presents a risk that some impacts may not always be identified. Therefore interdependence needs careful management.

2.8 Chapter 3: Valuing Interdependence and Resilience contains further detail, including how to identify instances of interdependence; potential options for managing interdependence, by improving systemic resilience, implementing joint delivery or implementing passive provision; and how to assess and value the associated impacts.

Scale

2.9 While infrastructure spending is often perceived as relating to large projects, many infrastructure projects are on a relatively small scale, such as road resurfacing, or upgrades to water mains. The scale and type of impacts resulting from smaller individual schemes executed in isolation may differ to those resulting from a major project or programme; one that is on a large scale, such as a new railway line or nuclear power plant, or where a number of smaller projects are co-ordinated and organised into a programme of work, such as flood defence projects across a region. We refer to this as 'scale effects'.

2.10 Scale effects result from the ability of projects and programmes to generate benefits that are greater or more significant than those generated by the sum of their parts subject to their effective organisation and execution, for example by developing the skills base and supply chain. They also relate to the ability of interventions which, because of their role in an infrastructure system or portfolio of projects, generate significant benefits relative to their size.

2.11 Chapter 4: Valuing Scale Effects explores the potential impacts that may arise or be affected. Giving due consideration to such impacts may alter the way in which projects are structured and implemented so as to deliver better value for money.

Non-marginal: supports and enables economic output

2.12 Infrastructure consists of networks that provide goods and services fundamental for economic activity to take place in today's society. As a result, infrastructure has the potential to influence both the level of economic growth as well as the location of such growth. For example it may provide access to or use of land for new housing or development, enabling new economic activity to take place. The ability of infrastructure to support and enable new activity and outcomes that may not have previously been possible is referred to as a 'non-marginal effect'.

2.13 Non-marginal effects can potentially lead to transformational impacts, particularly at a local level. Infrastructure opens up new labour and product markets, facilitating connections between employees and business, between businesses and consumers and amongst businesses, and can result in innovation. For example higher capacity and faster broadband connections, while allowing businesses to operate more efficiently, also enable them to locate at distance from final customers, giving them access to a wider consumer base. This can increase competition, leading to better economic outcomes in terms of lower prices or better products for consumers.

2.14 However, the type and scale of impacts are hard to predict and assess, particularly as outcomes are predicated on other activity taking place, for example a business investing in a new location. The impacts may be positive or negative, and could vary in type or scale during the construction and/or operational life time of infrastructure, which should be considered in order to reach a balanced decision on infrastructure spending. Non-marginal effects may be relevant to other types of impacts, as well as economic impacts, such as environmental and social outcomes.

2.15 Chapter 5 provides more information about the potential approaches available to appraise and evaluate such impacts effectively, and how these may be presented to improve decision making.

Shapes preferences

2.16 While in many cases the provision of infrastructure aims to meet demand, it is also possible for the type of infrastructure provided to affect demand by changing preferences. For example, efficient public transport provision or the laying of good cycling infrastructure may reduce dependency on cars and other road traffic. A reduction in efficiency, for example through limited capacity and congestion, can also result in a change in preferences and behaviour. [2]

2.17 While it is challenging to determine how the provision of infrastructure may influence behaviour, the potential to do so should be given due consideration particularly in the area of policy-making and overall process of infrastructure planning.

Public good characteristics

2.18 Public goods are those that are 'non-rivalrous' and 'non-excludable' to some extent, when used or consumed. Non-rivalrous means that the consumption of the good by one individual does not prevent another individual using that good. Non-excludable means that if a good is made available to one individual, it is effectively made available to everybody, for example due to difficulties in restricting access to the good or charging for its use. These characteristics may not be valid for some types of infrastructure, or may only be valid at certain levels of consumption, for example when a road becomes congested.

2.19 By way of example, once a flood defence is constructed, the protection it provides for a consumer, such as another infrastructure component, commercial or residential property, does not come at the expense of the protection provided to another consumer in the same location; in this sense the flood defence is non-rivalrous. Furthermore, it is difficult to exclude a single consumer in that location from the protection which the flood defence provides; in this sense it is non-excludable. As a result there is limited incentive for any party to reveal their true preference to pay for the project, if there is another individual which may benefit in some form. This makes it difficult to decide whether the project should proceed at all, as well as the level of protection it should provide.

2.20 Non-excludability can result in free riding whereby consumers fail to pay for the provision of goods because they expect others to do so. This means that the market, left to its own devices, will tend to provide less than the socially optimal level of infrastructure. This also makes it difficult to determine the appropriate form and level of public sector spending on some infrastructure projects.

[2] In economics, preferences which are taken as given regardless of the external environment (in this case the infrastructure) are referred to as *exogenous preferences*. Preferences which are affected by individual and internal responses to the external environment are referred to as *endogenous preferences*.

Market power

2.21 It can be both difficult and inefficient for multiple parties to enter into the same market if there are high fixed costs and increasing returns to scale, for example these arise when fixed costs can be spread across a wider customer base. Hence the industry may tend towards a monopolistic structure, creating what may be referred to as a natural monopoly. Some of the most common examples involve utilities such as water, electricity and gas.

2.22 Monopolistic industries are able to determine the price charged for their product or the quantity they supply; this can be economically and socially inefficient. The lack of competition may also result in technical or productive efficiencies not being sought or implemented if the impacts on third parties are not suitably considered. However, monopolies can have a significant profile and reputation with the public, which may provide an incentive to behave efficiently. Due to these considerations many countries opt for some form of market control such as state ownership or regulation, which can ensure effective provision through the market.

Box 2.A: Key Principles

There are several key principles that will be relevant throughout the application of the Five Case Model and ROAMEF Framework for infrastructure spending.

Collaboration

Infrastructure projects often have lots of stakeholders with diverse expertise and perspectives. It is important to collaborate with them throughout the preparation of the Five Case Model, for example to enable appropriate definition of the strategic need for intervention, and reduce the risk of problems being identified late in the process, which may require a change in scope. To collaborate effectively, it may be appropriate to establish and formalise governance procedures, including the identification of roles and responsibilities.

Iteration

Owing to the various sources of uncertainty and complexity in the appraisal of infrastructure projects, it is unlikely that all relevant considerations and impacts are identified and accounted for at the first attempt. It is therefore important that new information is incorporated and the overall position reassessed by iterating any activities as appropriate, to clarify and realise the intended impacts.

Materiality

The characteristics of infrastructure can lead to impacts which vary in type and scale. Taking into account the situations in which an impact is likely to influence a decision, i.e. under what circumstances it could have a material effect on the outcome and why, will help to determine when further investigation into specific impacts and options is warranted.

Proportionality

Infrastructure projects, and the associated impacts, can vary in scale. The scale of investigation into any option and the expected impacts, as well as the resource used in doing so, should reflect the scale of the intervention and its impacts. Combined with the materiality principle above, this will ensure an effective and efficient use of scarce resources.

Communication

Stakeholder engagement is an essential element of successful infrastructure delivery and operation. It is important to communicate the need for infrastructure projects, to give stakeholders a fuller understanding of the intended impacts and appreciation of the realised impacts. Doing so transparently, will better enable the positive impacts to be realised and the negative impacts to be mitigated against. This is enabled through a clear strategy for communicating progress, decisions and appropriate justification for such decisions.

Attribution

Where a party proposing a project cites an impact that will be realised by another party to justify that project, the proposer should provide evidence of how this impact is attributed to the project. The proposer should demonstrate that the impact is real, and that its scale and apportionment has been agreed with the other party (and any relevant third parties such as regulators). This will reduce the risk of double counting of impacts by multiple organisations. An impact, which complies with this principle will generally enable a commercial agreement between the organisations to take place, for example allowing for the possibility of partnership funding.

3 Valuing Interdependence and Resilience

Overview

3.1 The UK's infrastructure has been described as both a *network of networks*[1] and a *system of systems*. The system of systems view states that individual infrastructure assets and networks are dependent upon each other in order to function effectively as part of an infrastructure systems. In turn the infrastructure systems interact with other systems that support our society and economy, such as health, education, justice and defence systems.

3.2 Given the interdependent characteristic of infrastructure, it is essential to consider any project, programme or policy in the context of both the network and wider systems within which it operates, assess the network and system as a whole, and manage interdependencies.

3.3 While interdependence imparts risk on the effective and resilient provision and functionality of infrastructure, it also opens up the opportunity to improve the value of infrastructure spend through enabling the realisation of additional benefits and reducing costs.

3.4 This chapter sets out a toolkit that provides structured analytical approaches to realising and valuing benefits associated with interdependencies, including how to:

- identify and define instances of interdependence and the potential risks and opportunities it may present
- identify the conditions within which interdependence may have a material effect on the impact (outcomes) of an infrastructure project
- identify the options for managing interdependence; at a high level the options explored consist of improving systemic resilience, implementing joint delivery and implementing passive provision; specific actions may involve monitoring, redesigning, introducing and increasing or removing interdependence
- identify and value the resultant impacts, in terms of costs and benefits, to facilitate options selection

3.5 This chapter gathers the latest evidence and approaches on infrastructure interdependency. It, along with other chapters of this document, draws on two reports: the 'Economic evaluation of systems of infrastructure provision'[2] and the 'Development of a Proposed Interdependency Planning and Management Framework'.[3] The second of these reports demonstrates the *Interdependency Planning and Management Framework (IP&MF)*, and shows how this could be integrated within the Green Book ROAMEF cycle.

[1] Council for Science and Technology (2009) A National Infrastructure for the 21st Century. http://webarchive.nationalarchives.gov.uk/+/http://www2.cst.gov.uk/cst/reports/files/national-infrastructure-report.pdf

[2] Brown, A.; Robertson, M (ed.) (2014) Economic evaluation of systems of infrastructure provision: concepts, approaches, methods. iBUILD: Leeds, UK. https://research.ncl.ac.uk/ibuild/outputs/9940_iBuild_report_print_version%20WEB.pdf

[3] Rosenberg, G.; Carhart, N.; Edkins, A.J.; Ward, J. (2014) Development of a Proposed Interdependency Planning and Management Framework. International Centre for Infrastructure Futures: London, UK. http://dx.doi.org/10.14324/20141455020

What is interdependence?

3.6 Interdependence within the infrastructure sectors can be defined as a mutual dependence between two or more assets or networks, which impacts their efficient and effective functioning.

3.7 Interdependence may be relevant at two broad levels: at a **detailed level**, involving specific interactions of individual assets, such as a power source which provides energy to operate a water pump, which in turn cools the power source; or at a **higher level**, such as between organisations or networks, for example relating to the total demand of the energy network upon the water network. In practice interdependence at one level may be best managed through decisions taken at another level or in another part of the system.

3.8 Interdependence between assets or networks can be **direct**, for example the use of a power source to control the flow of water during the production of electricity; or, **indirect**, through an interaction with a third asset, network or organisation, for example the energy and water sectors both rely on the communications network for data collection and real time operation.

Identifying interdependence

Types of interdependence

3.9 Irrespective of the sectors involved, it is possible to distinguish between various types of interdependence. A typology of interdependency is presented in Table 3.A.

3.10 There may be both existing and potential instances of each type of interdependence between two sectors. Existing interdependence may have developed organically or result from planned interactions. Alternatively there may be opportunities to introduce and manage interdependence to realise certain impacts.

Table 3.A: Types of interdependence

Type	Descriptions and examples
Physical interdependence	**A transfer of physical resources**, where the output of one element, either a good or service, becomes the input to another (e.g. electrified rail lines requiring a secure supply of electricity). **A shared physical dependence** between the two elements on a third resource (e.g. both elements consume the same fuel).
Information interdependence	**A transfer of information**, potentially relating to the condition, operation or use of infrastructure and related services; increasingly via telecommunications systems making digital transfer and storage more important (e.g. information about electricity usage by transport systems is required to determine generation needs).
Geographic interdependence	**Resulting from location**, where the components are located in the same place, or within close proximity (e.g. utility connections located under the same road).
Organisational interdependence	**Shared ownership, governance, or oversight** links infrastructure together (e.g. an organisation requires access rights from a third party before developing infrastructure). **Financial mechanisms** link components together (e.g. reliance on the same sources of finance).

Source: (Adapted from) Rinaldi, S.M.; Peerenboom J.P.; Kelly T.K. (2001) Identifying, understanding, and analyzing critical infrastructure interdependencies.

Identification of interdependence

3.11 The benefits of managing interdependencies are most easily identified and realised, and risks to resilience mitigated against, when there is a long-term strategy for infrastructure and spatial development in place. In practice a comprehensive plan is not always available.

3.12 The identification of opportunities and risks relating to interdependencies should be undertaken at an early stage of the project development cycle, when setting strategic objectives. Failing to do so means that potential benefits or risks may be missed, and therefore difficult to manage without subsequent revisions in project scope and additional cost.

3.13 Collaboration with a variety of stakeholders, including organisations across the supply chain such as engineers, operators, regulators, economists and finance specialists, is important from the outset. It is useful to determine complementary, conflicting or shared needs and objectives. Regardless of which organisation identifies the need for an infrastructure intervention, identifying opportunities to add value through interdependencies requires the promoter to work across organisational (e.g. departmental) boundaries. It may be necessary to re-iterate activities throughout the application of the Five Case Model as new information is gathered through the process of engaging with stakeholders, ensuring that any potential for realising benefits or managing risks to resilience through interdependence is re-evaluated.

3.14 The IP&MF can help to facilitate collaboration across organisations and professions because it provides a systematic approach to identifying and managing interdependencies. As part of the IP&MF an interdependence matrix has been developed (see Box 3.A). This helps to organise and guide a search for interdependencies in a structured manner by laying out the components of infrastructure which could potentially involve interdependencies. It may be appropriate to populate the matrix according to the four types of interdependence identified in Table 3.A.

3.15 In order to identify interdependence and populate the interdependence matrix in Box 3.A it is useful to evaluate the existing infrastructure, its purposes, uses and related policy.[4] This could involve insight from existing usage trends; spatial mapping of infrastructure; examples of best practice from other sectors and academic research.

3.16 A forward-looking assessment of future projects and policies can also help to identify interdependencies and populate the matrix. Timelines can be used to identify how interdependence between projects, programmes and policies arise and change through time, for example by determining when changes to demand through time in one sector may require changes to capacity or supply in another.[5]

[4] The Magenta Book provides guidance on designing and realising evaluation of projects, programmes and policies: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220542/magenta_book_combined.pdf

[5] Engineering the Future (2013) Infrastructure Interdependencies Timelines: http://www.engineeringthefuture.co.uk/government/pdf/EtF_Infrastructure_Interdependencies_Report.pdf
DfT, Infrastructure projects timeline: http://assets.dft.gov.uk/infrastructure-projects/timeline/default.html
HM Treasury (2014) Infrastructure Pipeline, National Infrastructure Plan: https://www.gov.uk/government/collections/national-infrastructure-plan

Box 3.A: Interdependence Matrix

The Interdependence Matrix, developed to implement the IP&MF, provides a means of structuring the investigation and reporting of interdependencies. This facilitates collaboration across organisations and disciplines, as well as the presentation and justification of how interdependence has been considered.

The matrix can be applied at many different levels in order to investigate interdependencies. It can be applied at a sector level, for example to identify interactions between a transport sector project with the communications, energy and water sectors; at the sub-sector level to identify interactions between rail and road networks; or, at the project level. It can also be used populated separately to determine opportunities and risks relating to interdependence. The example provided in Figure 1 shows potential interdependence between High Speed 2 (HS2) rail and the water sector; this was populated as part of a cross-organisational workshop during the early development stages of HS2. Not all cells are populated, as only the interactions relevant to the HS2 project are presented.

Figure 1 comprises of a simple matrix with the principal functions or dimensions of the infrastructure populated along the leading diagonal (top left to bottom right), for example the potential for intra-regional transfer of water, and the HS2 Phase 2 rail line and route. The off-diagonal cells are populated with the interdependencies between these functions. These can be conceived as outputs and inputs, such that the cell labelled "F1 → F2" (cell A2) shows the interaction or impact of Function 1 (climate change) on Function 2 (flood protection). The squares in horizontal rows therefore show the output of the function in that row. The squares in the vertical columns show the inputs to the function in that column.

The typology of interdependence can be used to help populate the matrix, by demonstrating the range of forms that interdependence could take. For large or complex projects it may also be necessary to iterate the exercise for different levels of detail with respect to the functions on the diagonal.

Once populated the appraiser can make an initial assessment of the interdependencies, including technical feasibility, potential value, management requirements, and as a result determine which interdependencies warrant further investigation and consideration. Assessments should allow for the degree of uncertainty in the analysis.

Box 3.A. continued

Figure 1: Interdependence matrix for High Speed 2 rail and the water sector

	1	2	3	4	5
A	F1 Climate Change	F1→F2	F1→F3 May result in increased rainfall in North & decreased rainfall in South	F1→F4 May result in increased rainfall in North & decreased rainfall in South	F1→F5
B	F2→F1	F2 Flood Protection	F2→F3	F2→F4	F2→F5 Affects resilience of the railway
C	F3→F1	F3→F2	F3 Intra-Region Transfer	F3→F4	F3→F5
D	F4→F1	F4→F2	F4→F3	F4 Bulk Transfer	F4→F5
E	F5→F1	F5→F2 HS2 embankments provide opportunity for flood detention storage	F5→F3 Provide route for pipeline to strengthen interconnections between water supply zones	F5→F4 Provides route for North-South bulk water transfer pipeline	F5 HS2 Phase 2 Rail Line & Route

3.17 Another approach to identifying interdependencies is to look at the implications of a disruption or failure within the network or system. Increasing interdependence increases the risk to the resilience of our infrastructure systems; disruptions and failures to one asset may in turn cause disruption and failures elsewhere in our infrastructure systems. Table 3.B demonstrates the potential implications and impacts of a single disruption throughout the infrastructure system and economy. The disruption to other assets and networks may involve different time scales, and could be more damaging than the original failure.

Table 3.B: Implications and impacts associated with disruptions and failures

Type of impact	Example
Immediate impact	Assets or networks are disrupted or fail completely causing damage to property, placing the public at risk and disrupting services. For example, bad weather causes an electricity substation to fail.
Cascade impact (within systems)	A failure in one part of a network has a significant impact on the rest of the network. For example, a failure in an electricity substation affects other parts of the electricity network.
Displacement impact (between systems)	A failure in one infrastructure system affects another system. For example, a power failure affecting the transport network. In the short term economic output may be lost or could be displaced. For example, as business may take place through alternate times, locations or activities for the duration of the failure, meaning that there is only a marginal impact.
Non-marginal impact	Disruption may change preferences and behaviour, which can affect the usage of infrastructure, and have a non-marginal impact on economic activity and growth. For example successive failures in the same network or location may result in a business opting to invest or locate abroad to ensure business continuity.
Impact of correlated failures	A disruptive event could be correlated over time with other disruptive events. For example, a storm may result in high winds, which could disrupt electricity transmission, and heavy rain, which could flood and disrupt transport networks. As a consequence there could be landslides which disrupt other networks.

Materiality and proportionality

3.18 Investigation of the impacts of and options for managing interdependence will be justified if the interdependence is likely to have a **material effect** upon any impacts or outcomes. This will depend on the context and the type and scale of any impacts, but is most likely if the project involves:

- long-term lifetimes, implications or implementation periods
- decisions with significant irreversible impacts
- implementation across wide geographical areas
- significant investment (or has high value at stake)
- providing for or supporting other national infrastructure, especially critical infrastructure
- contingency planning or business continuity needs

3.19 If it is determined that interdependence is not likely to have a material effect on the impacts or decisions relating to a project then further investigation may not be warranted. The decision not to investigate further should be explicitly stated and justified in the business case.

3.20 The issues of definition, identification, and measurement may vary for different projects and contexts. This means that capturing interdependence within appraisal could have a large burden of data and analysis, which may be difficult to interpret. Any analysis should be **proportionate** to the potential scale of an intervention and its expected impacts.

3.21 Where stakeholders have identified that interdependence may have a material impact on the decisions which they take, it may be appropriate to develop and formalise **governance structures and processes** that can facilitate their consideration and management. A Memorandum of Understanding is one example of this.

Box 3.B: Memorandum of Understanding

The Environment Agency has signed Memoranda of Understanding with Network Rail and the Highways Agency.[6] These documents set out how the parties will work together on interdependent issues. This includes improved communication, identifying opportunities for collaborative working and integrating planning to assist the development and implementation of each other's policies.

Options for managing interdependence

3.22 Once identified, interdependencies can be managed to maximise value through the options and responses considered. Three key responses are now discussed in detail.

- **Improving systemic resilience:** improving the ability of infrastructure to withstand, prevent, adapt to and / or rapidly recover from disruptive challenges, which may occur, or be responded to, within the same or interdependent sectors, so that the system-wide performance returns to an agreed level within an agreed time frame.

  Disruptive challenges may include specific events (e.g. terrorism incidents, extreme weather or operational failures) or changes to the operational context (e.g. demographic, climate, economic, financial or technological change).

- **Implementing multi-use assets and joint delivery:** using an infrastructure component to serve more than one purpose.

- **Implementing passive provision:** the inclusion of flexibility within the design and construction of an infrastructure asset or network to allow for the adaptation of its use once better information is available, uncertainty is reduced, or it presents better value for money to do so.

  Adaptation of use may include expansion, modification, alteration, shared use or abandonment. Various conditions may call for such adaptation including demographic, climate, economic or technological change.[7]

Improving systemic resilience

3.23 Once the interdependencies have been identified, improved systemic resilience can be secured by managing them. It is essential to consider resilience at the level of the system, as opposed to each individual asset, and in terms of the objectives and outcomes which the system is intended to produce. To achieve this requires a **comprehensive analysis of the risks and a strategic plan** with well-defined responses to anticipated disruptive challenges, including both

[6] http://assets.highways.gov.uk/about-us/corporate-documents-memorandum-of-understanding/MoU_Env_Agency.pdf

[7] Passive provision is a similar concept to adaptive investment, and is a common term in literature relating to climate change. Climate change could potentially have a large impact on the UK's national infrastructure, by raising the likelihood of unpredictable and extreme weather and thereby raising the threshold for infrastructure to be resilient. Defra has produced specific guidance on adapting infrastructure to take account of the effects of climate change: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191501/Accounting_for_the_effects_of_climate_change.pdf

disruptive events and changes in operational context. As disruptive challenges may arise over different time periods they may require management in the short, medium or long term.

3.24 The risk assessment and strategic plan should be developed with stakeholders who may either affect and / or be affected by failure of the infrastructure, owing to any identified interdependence, and be common across parties where possible. Sector Resilience Plans for Critical Infrastructure, developed by the Cabinet Office, provide a high-level assessment of vulnerability and propose measures and actions to build resilience.[8]

3.25 Within a strategic plan there are four approaches to improving systemic resilience:

- **resistance:** prevent damage or disruption by strengthening or protecting assets
- **reliability**: design assets to operate under a range of conditions
- **redundancy:** make backup installations or spare capacity available in networks and systems to enable operations to be switched or diverted
- **response and recovery:** understand the weaknesses in networks and systems and have arrangements in place to respond quickly to restore services[9]

3.26 These approaches can then be applied within individual projects and programmes. For example, the introduction of **new** assets or procedures to a network or system, such as the introduction of additional nodes and connections to bypass disruptions; and the management of **existing** assets or procedures, such as changing the design or materials used in an infrastructure component, or, contingency planning to maintain service during disruption.

Implementing multi-use components and joint delivery

3.27 The identification of interdependencies may present opportunities to improve the impact of infrastructure spending by implementing multi-use components and joint delivery. Both existing and new infrastructure could be developed to serve multiple purposes, for example by creating a common corridor or chamber to deliver both electricity and telecommunications links. This can result in cost savings, which in turn could enable a wider range of options to become viable, such as the expansion of a network, upgrade of design components and capabilities, or the introduction of redundancy at low cost to improve systemic resilience.

3.28 Joint delivery and multi-use components may result in impacts including:

- **improved use of redundant land:** in some circumstances land is available around the UK's large infrastructure components, such as the motorway and railway networks, which is used to deliver other infrastructure components
- **cost sharing in delivery:** a significant proportion of the development and delivery cost of infrastructure is often attributable to items such as obtaining planning permission, site preparation work (e.g. moving earth) and civil engineering work; these costs may be reduced, apportioned more widely or avoided by delivering new infrastructure alongside existing infrastructure
- **cost sharing in operation**: having several forms of infrastructure in one place could also reduce the operational and maintenance costs, for example by only monitoring and requiring access to a single location

[8] https://www.gov.uk/resilience-in-society-infrastructure-communities-and-businesses

[9] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61342/natural-hazards-infrastructure.pdf

3.29 Impacts may also accrue to other parties, who may be users of the existing or potential infrastructure. Increased systemic resilience and reduced disruption through faster delivery, or reduced maintenance of infrastructure are examples of such impacts.

Box 3.C: Co-ordinating road works

The City of London Corporation has promoted the use of *Communal Entry Chambers* to enable *Early Installation* of telecoms services into new office developments.[10] The initiative reflects the principles of the National Joint Utilities Group's Vision for Street Works through encouraging greater collaboration between parties such as utility providers and developers.

The benefits of the initiative include faster, more coordinated installation of telecoms services. In turn this reduces disruption to vehicle and pedestrian movement, through less time spent working in the public highway, while also making developments more marketable as services are available more quickly. Throughout 2013, the initiative saved an estimated 396 days working in the public highway.

3.30 However, joint delivery of infrastructure, for example through common corridors may also come with additional costs and risks, for example:

- delays: which can be caused by complexities in the process of obtaining consents and during construction
- operational interference: once built, operational systems may interfere with each other's performance
- decreased resilience: increased cascade and displacement effects, as a disruptive challenge could impact on all of the functions of the infrastructure within a single corridor
- complex maintenance: disruption consequences of maintenance work could be magnified, if separate components within a corridor require maintenance at different times

3.31 These risks can be mitigated through a collaborative effort to create an effective design to increase the resistance of the corridor or multi-use component, which may be more cost effective than increasing the resistance of separate assets individually.

Implementing passive provision

3.32 Passive provision allows for flexibility of future uses of infrastructure components. It can help to avoid irreversible decisions, which may rule out later investment opportunities or alternative use of resources, and avoid the need to develop and deliver future infrastructure as part of an unrelated programme.

3.33 The inclusion of passive provision can increase the range of potential options and responses in the future, with opportunities to lower costs; develop and deliver responses to changes in operation context, to ensure systemic resilience in shorter time frames; and utilise the most relevant technologies at that time to serve the needs when required. As an example, additional capacity could be introduced within electricity networks to allow for future population growth. Similarly, additional space could be introduced alongside the electricity cables, in an infrastructure corridor, to implement infrastructure from other sectors.

[10] http://www.cityoflondon.gov.uk/business/commercial-property/utilities-and-infrastructure-/Pages/telecommunications.aspx

3.34 Owing to the potentially long construction phase and service life of infrastructure, there may be uncertainty around the point at which decisions must be taken due to uncertainty around the operational context, such as demographic, climate, economic or technological conditions. This uncertainty makes anticipating specific needs and planning appropriate responses difficult.

Box 3.D: Passive provision in High Speed 2 (HS2) Phase One Bill

The Bill for HS2 Phase One includes clauses for the laying of a communications network along the route of the railway in the future.[11] This would allow communications infrastructure to be implemented if the anticipated increase in demand is realised, at a lower cost than if it were undertaken as a separate project. This can be achieved by allowing additional space alongside the railway data networks, to allow the inclusion of additional cabling, as well as use of the planned periodic access points.

Passive provision is an appropriate option in this case for several reasons. Firstly, although it is not possible to exactly predict future telecoms needs and design specifications out to 2026, when Phase One of HS2 is anticipated to open, it is highly likely that further investments may be needed to maintain the UK's global competitiveness in a digital world. Secondly, as the rate of technological advance in the telecommunications industry is so high, it is impractical to lay cable immediately that may only service needs over a decade into the future, since the technology would likely be obsolete by the time the railway is completed. Therefore the option of passive provision is preferable as it has the flexibility to react to any demand and technological advances that may emerge in the intervening period. Finally, providing enhanced connections between major business centres also increases resilience to the core network which supports economic activity.

The idea has also been incorporated into the consultation document for HS2 Phase Two, where the question of introducing utilities along the proposed Phase Two route was asked. Further work remains to be completed.

3.35 In order to implement passive provision effectively the promoter should collaborate with relevant stakeholders, who may utilise the passive provision in the future, based on the interdependencies identified. To do so it is important to consider the processes and activities that may be required in order to change the future use or features of the infrastructure component, for example planning permissions. Although specific requirements for future use may not be known, this will help to identify potential future uses and advisable features that may facilitate them, such as:

- size
- positioning and access requirements
- materials
- safety requirements
- operational considerations

3.36 Once it has been decided to incorporate passive provision, it is important to **actively manage any future options** associated with its use or non-use. The governance of any decisions

[11] http://www.publications.parliament.uk/pa/bills/cbill/2014-2015/0002/15002.pdf

relating to the use or non-use of passive provision should be clearly determined. This will be necessary to realise the optimal benefits from the infrastructure. The risk of the passive provision being unused should also be determined and managed, and taken account of in the investment decision. The Orange Book[12] should be referred to for information on risk management.

Box 3.E: Heat networks

Heat networks can supply cheap, green and locally-produced heat and hot water to local buildings from a wide range of energy sources. A scheme introduced in Islington in 2012 supplies heat to over 850 homes and two leisure centres.

The first phase of the Islington network is heated by efficient combined generation of heat and power (CHP). This interdependence between energy needs justified the project as it uses less primary energy than separate generation of electricity (in centralised power stations) and heat (in individual gas boilers). The high efficiency means heat is affordable for residents, generates revenue for the local authority and reduces carbon emissions.

The network pipes were oversized to allow for expansion and adaptation through the incorporation of more users and alternative sources of heat (such as the heat generated by electricity sub-stations or the London Underground's excess heat). This is a form of passive provision; pipe oversizing means additional cost in phase one, but creates opportunities for greater value in the future.

Other European cities have found that large heat networks are more efficient, in economic and environmental terms, than smaller systems; it is therefore important to consider the wider potential when planning a scheme.[13]

3.37 The inclusion of passive provision will not be suitable in all cases. It may result in additional carrying costs for the operator, such as ensuring that it is maintained until such time as it might be used. Both additional benefits and costs associated with passive provision must be clearly stated and justified.

Valuing the impacts of interdependence

3.38 This section presents methods to value the opportunities and risks, in terms of the associated benefits and costs, relating to infrastructure interdependence. It builds on the methods presented in the Green Book relating to non-market valuation, uncertainty and flexibility, by providing examples of when and how to apply them. The suitability of specific methods in practice will depend on the circumstances and may differ on a case-by-case basis owing to factors such as the materiality and proportionality of the impacts that are being valued; timing; uncertainty; available information; and the opportunity for new information to become available.

Measuring non-market effects

3.39 To appraise the impacts of spending public money on interdependent infrastructure from a society-wide perspective, it is important to include impacts relating to the party promoting the business case, as well as third parties or other sectors to which benefits or costs may accrue.

[12] https://www.gov.uk/government/publications/orange-book

[13] Bale, C. S. E., Bush, R. E., Hawkey, D. & Webb, J. (2014) Chapter 5: Valuation of passive provision for heat network investments. In: Brown, A. and Robertson, M. (ed.) Economic evaluation of systems of infrastructure provision: concepts, approaches, methods. Leeds: iBUILD. https://research.ncl.ac.uk/ibuild/outputs/9940_iBuild_report_print_version%20WEB.pdf

The effects on third parties as a result of interdependence may arise due to externalities which are not directly captured within markets. As a result the full value of such impacts cannot always be inferred directly from market prices but should still be valued and appraised wherever feasible.

3.40 The Green Book provides guidance on estimating the value of non-market impacts.[14] This can be based upon willingness to pay, to derive the maximum amount of money an individual is willing to give up in order to receive a good, or willingness to accept, to derive the minimum amount of money they would need to be compensated to forego or give up a good. This can be achieved (using either published values or bespoke values) through:

- revealed preference (preferred): inferring the implicit price placed on a good by consumers by examining their behaviour in a similar or related market; hedonic pricing is an example of this approach, for example by examining the relationship between the distance from a railway station and house prices
- stated preference: using specially constructed questionnaires which describe a hypothetical choice within a hypothetical market in order to elicit values associated with an impact; when using stated preferences the main choice is between contingent valuation, with direct questions about a specific outcome, or choice modelling, with questions about preferences within a series of alternatives; stated preference is often used in order to value specific attributes of a good, rather than the good as a whole, for example examining the effect of a change in the reliability of service on the price of a train ticket

Measuring risk and uncertainty

3.41 The presence of interdependence, in combination with the long time frames associated with infrastructure projects, introduces various factors which can result in risks and uncertainty when valuing impacts. The Green Book provides guidance on the valuation of risk and uncertainty,[15] through the use of the following techniques:

- expected values
- sensitivity analysis
- scenario analysis
- Monte Carlo analysis

3.42 When uncertainty is present, these techniques can be used to determine if the infrastructure under consideration will be able to function and fulfil its purpose, by identifying the situations and conditions under which it would not be able to function as intended, or will be sufficiently flexible, in terms of its ability adjust to new information or conditions to fulfil its purpose.

3.43 Appraisers should refer to the Green Book and Orange Book for guidance on risk management, and supplementary guidance on the estimation of early financial cost estimates. These documents advocate the presentation of ranges, as opposed to point estimates, in the presence of uncertainty. In appraisals, there is always likely to be some difference between what is expected, and what eventually happens, because of biases unwittingly inherent in the appraisal, and risks and uncertainties that materialise.

[14] It should be noted that where infrastructure lasts longer than the life of the subjects to revealed preference and stated preference techniques, both will suffer inaccuracies at inferring societal willingness to pay.

[15] The Green Book identifies other approaches which may complement such analysis including the life satisfaction approach, which uses econometrics to estimate the life satisfaction provided by certain non-market goods, and determines a monetary value by combining it with an estimate of the effect of income on life satisfaction; or, making reference to the costs of preventing the loss of, or replacing, a non-marketed good.

Measuring flexibility

3.44 It is important to incorporate the value of flexibility (for example flexibility provided by passive provision) which may allow for adaptation to changes in operational context.

3.45 Real options analysis is one way of incorporating flexibility into the valuation of a project, to determine whether the cost of additional flexibility represents value for money. A real option is the opportunity to make a choice or take an action in future, based on the prevailing circumstances, for example whether flexibility was incorporated into the design.

3.46 Real options analysis is most likely to provide a materially different value to a net present value which does not account for flexibility, under the following conditions:

- uncertainty: there must be a significant element of uncertainty; this may relate to the potential use of the equipment and time available before a decision must be made
- opportunity to learn: new information may become available during the asset lifetime, which could indicate that an alternative use of the infrastructure is preferred
- flexibility: there must be an opportunity to respond to the new information; if there is no flexibility and the initial spending is completely irreversible then the same outcome will be derived as for the net present value approach; alternatively, if the spending decision is completely reversible and costs are recoverable then there will be no value in waiting to obtain new information; therefore partial irreversibility is required for the approach to add value

3.47 Real options analysis is based around several parameters, namely the:

- investment expenditure: the cost of implementing passive provision
- present value of a project's cash flow: consisting of the expected returns from the option as well as the costs of maintaining the option
- time: the period over which a decision may be deferred
- time value of money: to reflect the opportunity cost
- riskiness of a project's cash flows: to reflect uncertainty regarding whether the option will be realised[16]

3.48 Several models are available to value the expected benefit offered by real options.[17] These techniques can also be utilised to determine which options become available or are limited by a decision, even if the decisions are taken together, for example when designing a transport route.

- Qualitative approach: outlining the basic criteria for comparing options. This cannot provide a value for money recommendation or a quantitative measure of the option value and should be used with caution.
- Black and Scholes: a mathematical solution to a narrowly defined set of financial options problems. Whilst it is relatively simple to use, it is also the model with the strictest assumptions. The most restrictive of these is the assumption that there is a fixed date on

[16] https://www.ofgem.gov.uk/ofgem-publications/48227/realoptionsinvestmentdecisionmaking.pdf

[17] Accounting for the effects of climate change:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191501/Accounting_for_the_effects_of_climate_change.pdf
Ministry of Defence, JSP 507, Investment Appraisal and Evaluation Guidance:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/275550/JSP507_Part_2_U.pdf

which the option can be exercised and that the price of doing so (Strike Price) and volatility are both known and constant over time.

- Lattice or decision tree approach: this requires a decision tree, or cone of uncertainty, in which the potential paths of the underlying asset use and associated value are mapped out. It is based on the assumption that between any two points in time the likelihood of an option being realised, and therefore the asset value, can either rise with probability (p) or fall with probability (1-p). This approach can be used with continuous time, to allow options to be taken during a range of time, and can be relatively easy to understand and explain through visualisations.
- Monte Carlo simulation: this is a variant of the lattice approach, as it is known that the asset will follow one of the paths laid out but it is unknown which one. This can be useful where two interchangeable options have uncertainty associated with them. A disadvantage of this approach is that it is technically challenging and information intensive.

Valuing systemic resilience

3.49 Systemic resilience has been defined as the ability of infrastructure to withstand, prevent, adapt to and / or rapidly recover from disruptive challenges. Therefore impacts associated with systemic resilience should be based upon the value of reducing or mitigating against disruption owing to resilience measures.[18]

3.50 The impact associated with improved systemic resilience is difficult to derive directly from a market valuation, as it may be incorporated within the price of other goods. Therefore the techniques for valuing non-market impacts may be relevant, provided that the appropriate information about how the resilience, or lack thereof, impacts all members of society and the economy have been considered (refer to Table 3.B for the implications and impacts of disruptive events).

3.51 Use of the willingness to pay and accept approaches should be framed appropriately and compared with the counterfactual, i.e. the do-nothing or do-minimum scenario. As an example, an intervention may be intended to protect against disruption due to a specific disruptive event, such as a severe winter storm, and should consider the following parameters:

- probability of a disruption: incorporating both the probability of the disruptive event occurring and the probability of it causing disruption to infrastructure components; the latter may be affected by the severity of the disruptive event, for example the severity of the storm, and the resilience measures in place
- depth of the failure: the effects at each level should be considered (see Table 3.B for the implications and impacts of disruptive events, such as direct, cascade and displacement effects)
- timing and duration of the failure: the impact of disruption will vary through times, for example, a resultant electricity blackout could affect less economic activity if occurring at night; any displacement effects in other networks may persist after the initial failure has been rectified

3.52 Market prices or behaviour may provide relevant information to facilitate a revealed preference approach, for example owing to past events and trends. This could include

[18] For further discussion and examples see: Wardman, M., P.J. Mackie and A. Gillies-Smith. (2014) Chapter 2: Valuing systemic transport resilience: methods and evidence. In: Brown, A. and Robertson, M. (ed.) Economic evaluation of systems of infrastructure provision: concepts, approaches, methods. Leeds: iBUILD. https://research.ncl.ac.uk/ibuild/outputs/9940_iBuild_report_print_version%20WEB.pdf

compensation or insurance payments; changes to the price of goods directly or indirectly associated with disruptive challenges, for example changes to house prices following incidences of disruption or intervention; or, the value or cost of previous interventions to improve resilience. It may be necessary to evaluate how a previous intervention has affected resilience against disruption, to determine if the costs represented the value of the intervention.

3.53 Stated preference may provide an indication of the absolute or relative value of different options. Questions should be appropriately framed with relevant information to allow for informed decisions. If the same group of individuals is affected by a combination of projects or interventions, owing to interdependence, a value of the combined impact should be sought (see Box 3.F).

Box 3.F: Valuing resilience benefits from an integrated grid

The development of an integrated water supply grid by Wessex Water is intended to improve protection against catastrophic failures of standalone sources in their operational area, alongside other benefits. At the commencement of the project in 2010, 21% of customers in the area were served by standalone sources. The catastrophic failures which these sources were at risk from include those deriving from major flooding of a site or structural failure of water treatment works.

To value the resilience benefits of the development of the existing water supply network, from a trunk and branch structure into an integrated grid, Wessex Water used willingness to pay data gathered via stated preference techniques. This was based on questions framed around the outcome of the entire grid project, as opposed to details of specific elements.

When customers were asked how much they would pay to reduce the number of households experiencing an interruption to supply of two week duration from 400,000 to 200,000 households and from 400,000 to zero households, they gave mean values of £73.02 and £76.90 a year respectively. Building the grid is anticipated to reduce the risk for 260,000 people, and so the benefits were derived as £37.37 million per year. The sensitivity of the estimates to risk scenarios was then tested by Monte Carlo analysis.

In combination with other evidence, Ofwat was satisfied that the project represented value for money and offered the best value solution to delivering the capacity, water quality, environmental and resilience benefits intended from the integrated grid.

3.54 In order to value the non-marginal effect of resilience, or disruption, it may be necessary to look at economic loss associated with lost or displaced output. Further information on non-marginal impacts is provided in chapter 5.

Box 3.G: Displacement of economic activity – resilience to extreme winter weather

Following the severe weather during the winter of 2010, the Department for Transport estimated that the average daily cost of transport disruption caused by severe weather in England was £280 million (in 2010 prices).[19] In addition to 'hard' costs to the economy (e.g. lost output), this included 'welfare' costs to individuals which do not directly impact GDP (e.g. delays to personal travel).

Displacement and behavioural responses may affecting valuation in such situations. Firstly, some economic activity may be delayed until future periods, for example by working overtime. This means that some of the initial loss from disruption may subsequently be made up, but this will come at the expense of other activities and productivity. Secondly, other firms and sectors may gain, for example online business activity may increase, if the ability to travel to shops is restricted by bad weather.

More generally, changes in GDP may not correspond to changes in welfare. For example, if infrastructure is damaged by some event, this can result in reduced output and lower welfare. Any subsequent expenditure to replace or repair the damaged infrastructure will count towards GDP but would represent an opportunity cost from a welfare perspective (assuming the relevant inputs are economically scarce).

3.55 There may be great uncertainty regarding the probability and impact of the occurrence of infrastructure failure, and therefore the benefit associated with improving systemic resilience. Care should be taken in using past data to infer probabilities and risks over the long time horizons relevant for infrastructure investments; for example, some of the risks related to climate change, such as more extreme weather events, reflect the potential occurrence of events that have not been frequent in recent years.

Valuing joint delivery impacts

3.56 Joint delivery and multi-use components may affect the direct costs and benefits to the project promoters as compared with delivering and operating separate components (see paragraphs 3.28 to 3.30). It may be possible to derive market prices for many of these impacts, for example through engagement with contractors or from existing contracts.

Box 3.H: Multi-use assets – Channel Tunnel Electricity Interconnector

A proposed 1GW electricity interconnector (ElecLink) may be built using the service tunnel in the Channel Tunnel increasing cross channel capacity to France by a third, from 2GW to 3GW. The additional interconnector has the capability of powering up to 3 million homes. The 75km link will require an investment of around €400 million. On the basis of industry norms it is expected that to deliver an interconnector of a similar length would cost from around £525 million (including grid connection costs). In addition, ongoing maintenance costs would also be lower.

[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/4557/an-assessment-of-the-case-for-additional-investment.pdf

3.57 The full value of impacts associated with joint delivery and multi-use assets should be valued where possible, for example if it alters the amount of disruption to third parties during construction or operation phases. In order to value such costs the techniques associated with non-market effects may be useful. For example, the impact of additional days working in public highways has a cost to businesses and individuals who do, or otherwise would, continue to use the highway. This may include impacts associated with scale effects and non-marginal effects (see chapters 4 and 5 respectively).

3.58 Sharing factors can be used to agree the **attribution** of the impacts associated with joint delivery and multi-use infrastructure, and related costs and benefits, to different organisations.[20]

Valuing passive provision impacts

3.59 The inclusion of passive provision in infrastructure offers flexibility, by providing an option relating to the use of the infrastructure in the future. The value of such flexibility should be captured appropriately in analysis for decision making, for example by using real options analysis.

3.60 Passive provision can result in the reduction of costs, or the avoidance of duplicated costs, as is the case with joint delivery and multi-use assets. Such cost savings should be reflected in the valuation relative to other options. The value of the use of passive provision should be clearly separated within the analysis, to reflect the risks of it not coming into use.

3.61 Techniques associated with risk and uncertainty should be employed to assess the likelihood of any option being realised. The risk and uncertainty associated with a real option will be affected by the future management of the option, for example the actions taken to evaluate when and how the option can be realised.

[20] https://www.ofgem.gov.uk/ofgem-publications/83708/jrgsubgroupinfrastructuresharedusereportversionsep2013.pdf

4 Valuing Scale Effects

Overview

4.1 This chapter aims to highlight some of the scale effects that can result from large projects as well as the co-ordination of smaller schemes into programmes, collectively referred to here as 'major projects and programmes'. This is owing to their ability to generate impacts that are greater or more significant than those generated by the sum of their parts subject to their effective organisation and execution, for example by developing the skills base and supply chain. It also refers to the ability of interventions which, because they are part of a larger infrastructure system or portfolio of projects, are able to generate significant benefits relative to their size.

4.2 This chapter promotes the consideration and valuation of scale effects and related impacts where possible. In practice, this may alter the way in which projects are structured and implemented so as to deliver better value for money.

Major projects and programmes

4.3 Major projects and programmes can result in impacts which differ to those realised by a series of smaller projects planned in isolation, potentially offering better value for money. In some instances it may only be feasible to carry out a large-scale project or programme of work as small projects may have limited impact on the functionality of the network. In many situations there may be economies of scale to be gained, improved procurement terms, and more efficient use of plant and the labour force through the adoption of "production line" techniques. Conversely, major projects may result in negative impacts, such as integration problems, particularly in the initial stages, for example if a consortia of firms are formed to work together for the first time.

4.4 The creation of a pipeline of work also allows for benefits to be realised over time as successor projects executed as part of a managed project pipeline are able to benefit from the knowledge gained from prior projects. This can reduce uncertainty, enable cost efficiencies and facilitate the scheduling of work (see Box 4.A).

Box 4.A: Creating a pipeline of work

Transport for Greater Manchester (TfGM) opened the Metrolink line to Wythenshawe and Manchester Airport in 2014, over 12 months ahead of schedule. Several major purpose-built structures have been built as part of the programme to complete the 14.5km route, including a viaduct over the Mersey Valley, two new bridges over the M60 and M56, and the Ringway Road dual carriageway and underpass at Manchester Airport.

TfGM had delivered a number of other lines within their pipeline of works ahead of schedule, which allowed them to move resources onto the airport line earlier. Lessons TfGM learnt during the early phases of the Metrolink expansion drove efficiencies across work areas. By working closely with local authorities, utility firms, their principal contractor, stakeholders and the operator, TfGM have created efficiencies that are leading to early delivery of infrastructure.

Potential impacts associated with scale effects

4.5 This section outlines some of the **impacts which may be more relevant for major projects and programmes** than smaller projects planned in isolation. However, stating the impacts as part of the strategic objectives and including them within analysis does not in itself ensure they will be realised during the construction and operation of the infrastructure. If these impacts are used to justify a project then a plan should be in place to maximise value by actively managing such impacts to **realise benefits as well as reduce costs**. This could be the role of the sponsors, who can incorporate requirements and incentives into public procurement contracts, or the role of the developers, who engage with industry to incentivise sustainable and more efficient ways of working.

Functionality of the network

4.6 Major projects and programmes may have a more significant effect on the way in which an infrastructure network is designed and operated, as well as the way in which people interact with the network and wider infrastructure system, for example through changing user preferences. It is important to consider and model how a project or programme may affect, or be affected by, existing or related infrastructure to ensure that it has the intended impact.

Developing the supply chain in the UK

4.7 Major projects and programmes may have a more than proportional impact on the development of the supply chain. For example they often require specialist skills, tools and products on a larger scale than smaller or more standard projects. Similarly sponsors of such projects may have better knowledge and certainty relating to their requirements for skills, tools and products through time. This will allow time to engage with industry, who in turn can adjust to the requirements and organise responses, for example allowing industry to identify possible skills shortages and training apprentices in response.

4.8 The development of the supply chain may cover a wide geographical area, providing benefits across the UK as well as the immediate location of that project. It may also be necessary for skills and technology to be imported; this can provide an opportunity to improve the capability of the local workforce and production techniques, for example through skills transfer.

Spill-over benefits across projects and sectors

4.9 Given that the technical expertise deployed in a major project tends to be wide ranging, such knowledge is likely to be transferable to projects across a range of infrastructure sectors. Opportunities to do so may be identified owing to the interaction and interdependence between major projects and projects in a variety of infrastructure sub-sectors (see Box 4.B).

Box 4.B: Scale effects relating to Crossrail

Projects of a certain scale are able to unlock technological and practical advances and innovation. Crossrail provides a number of examples of this:

- the application of Building Information Modelling (BIM) to this large-scale project, has helped the UK to take a lead in this field; BIM provides a digital asset database of Crossrail including a digital representation of the railway, comprehensive historical data and other information, which can be used to manage and maintain the asset
- an innovation programme and sustainability strategy which are setting new standards for the UK and potentially globally
- the development of a system to measure and benchmark supplier performance, enabled by the fact that the Crossrail programme has 12 similar projects running in parallel; this system demonstrated how a methodical and sustained programme of measurement and feedback can drive continuous improvement and efficiency across the supply chain

Demonstrating the UK's capability

4.10 The successful delivery of large scale infrastructure projects can help to promote the UK internationally, in terms of its businesses and delivery capabilities, as well as governance structures. This brings with it positive impacts such as improving the reputation and competitiveness of UK industry, resulting in more trade (see Box 4.C). Similarly, effective delivery of major projects can make the UK more attractive to investors as it demonstrates good risk management, thus reducing the cost of capital. Conversely, failure to deliver reflects adversely on the UK.

Box 4.C: Reputational impact of London 2012 Olympic and Paralympic Games

The delivery of London 2012 led to nations turning to the UK to help deliver their own events, creating large supply chain opportunities.

The UK economy is estimated to have received a £14.2 billion boost within the two years since UKTI's British Business Embassy hosted the largest programme of business events ever held in Britain, during the London 2012 games. This boost was a result of businesses securing contract wins, additional sales and new foreign investment.[1]

Affecting input prices

4.11 It may be the case that multiple major projects and programmes pursue the same resources for their delivery or operation, particularly where interdependencies exist. These resources might include technical products, materials or skills. Major projects may be able to utilise economies of scale and efficiency to reduce the price of inputs in the short term. However, if a project or policy leads to a demand for such inputs that is greater than their supply, the resultant scarcity could lead to price increases in the short term (see Box 4.D).

[1] https://www.gov.uk/government/news/turning-the-games-into-gold-economic-boost-from-london-2012-has-passed-14-billion

Box 4.D: Security and scarcity of critical materials

Certain materials and inputs may be in limited supply, and may be critical for the completion of a project. As a result it is important to avoid path dependency which may result in becoming locked-in to a technology or resource. This might be achieved by retaining 'techno-diversity' in an infrastructure programme or system, avoiding the temptation to rely on a single technology to deliver a given goal because it is marginally more efficient.[2]

To help address this, Defra has developed a Resource Security Action Plan to make the most out of valuable materials.[3] This highlighted several risks, including increasing competition for resources and a lack of viable alternatives in key applications, which may affect infrastructure projects. It suggests strategies to secure supply of materials, for example through recycling. Also, the Highways Agency has commissioned research that maps each of its core functions onto the materials it consumes, highlighting which functions might be exposed to potential disruptions in critical materials supply.[4]

Non-marginal and transformational impacts

4.12 Major projects and programmes can be more likely to have non-marginal and transformational effects over a large geographical area, in addition to impacting local areas. For example, they may reduce deprivation and make urban areas more attractive. Chapter 5 provides more information on non-marginal impacts.

Valuing impacts associated with scale effects

4.13 The impacts mentioned in this chapter are not necessarily benefits in and of themselves that can easily be attributed to a project, but might under certain circumstances lead to benefits or costs or contribute towards wider objectives. For example, a more highly-skilled labour market results in a more productive economy and higher GDP.

4.14 Major projects and programmes, due to factors such as long time frames, large scales, transformational nature and (relative) uniqueness, can raise a number of appraisal challenges. This is in part a result of the higher level of uncertainty over factors such as demand, project life and residual values and the need to quantify 'non-standard' impacts. Furthermore scale effects may be non-linear.

4.15 The extent to which the costs and benefits associated with these impacts can be monetised and included in a Cost Benefit Analysis (CBA) will depend on how developed the methodologies for doing so are. Furthermore, some impacts will already be included as part of a welfare-based CBA, through the measurement of other parameters, and are not to be double counted. The process and methodology for monetising impacts is explained in the Green Book, and guidance prepared by Government Departments.

[2] For further discussion and examples see: Busch, J.; Dawson, D.; Purnell, P.; Roelich, K.; and J. Steinberger. (2014) Chapter 6: Accounting for critical materials in sustainable energy provision: maintaining systemic resilience. In: Brown, A. and M. Robertson (ed.) Economic evaluation of systems of infrastructure provision: concepts, approaches, methods. Leeds: iBUILD.
https://research.ncl.ac.uk/ibuild/outputs/9940_iBuild_report_print_version%20WEB.pdf

[3] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69511/pb13719-resource-security-action-plan.pdf

[4] http://www.highways.gov.uk/knowledge/publications/infrastructure-and-material-criticality-project-findings-report/

5 Valuing Non-Marginal Effects

Overview

5.1 Infrastructure consists of networks that provide goods and services fundamental for economic activity to take place in today's society. As a result, infrastructure has the potential to influence both the level of economic growth as well as the location of such growth. For example, it may provide access to or use of land for new housing or development, enabling new economic activity to take place. The ability of infrastructure to support and enable new activity and outcomes that may not have previously been possible is referred to as a 'non-marginal effect'. This chapter identifies some of these impacts, and demonstrates the potential for valuing and presenting such impacts.

5.2 The Benefit Cost Ratio (BCR) remains the summary metric used for the purposes of comparing the value for money of projects across all measures of spend, and should be used when projects involve Central Government funding. Supplementary analysis for the purposes of prioritising projects should be used where relevant; for example, where there are non-marginal impacts, which cannot be included in the BCR due to the potential for double counting or the potential for displacement rather than additionality. Various organisations have developed supplementary analysis and presentation techniques to allow such information to be considered as part the decision making process.

Welfare-based appraisal

5.3 Green Book assessment is firmly grounded in welfare-based appraisal as it aims to capture all benefits and costs to society. Such impacts are derived and monetised using a number of monetisation methodologies such as 'market value', 'shadow pricing', 'stated preferences' and 'revealed preferences'. In addition, to ensure inter-regional fairness, 'equity' values are widely used for the purposes of monetising benefits. These are standard nationwide assumptions applied irrespective of the geographical location of the project.

Supplementary analysis

5.4 There may be instances where the underlying assumptions used in an appraisal process preclude the recognition of certain impacts. This is particularly relevant for projects which have transformational impacts. For example, government might influence the population trajectory of a city though its decisions about public investment. There is some evidence that high levels of public expenditure may have played a major part in securing the resurgence of some of the larger cities outside of South East England. Similarly, various future investment decisions in large projects (e.g. HS2 and house building and planning policies) might have important implications for some areas.[1] Where possible the assumptions used in an appraisal should reflect the impact that the infrastructure being considered may have on demographic, economic or welfare outcomes at a localised level or on aggregate.

5.5 A number of project promoters have found it helpful to present an alternative analysis of benefits (see Box 5.A). Some of these have focussed on measuring the return to one or more of the four factors of production, namely rents (land), wages (labour), interest (capital) and profits (entrepreneurship). The application of such approaches aims to capture what are known as the

[1] https://www.gov.uk/government/publications/future-cities-people-in-cities-the-numbers

'real economy' impacts of projects, but is only partial and will not in itself be able to capture the total costs and benefits to society. Supplementary analysis could account for localised or project specific measures and parameters, introducing additional information, which could be useful in the appraisal and decision-making process.

Box 5.A: Presentation of supplementary analysis

Transport for London (TfL), are aiming to demonstrate more transparently how their projects contribute to strategic objectives. For this they have produced a mechanism which allows them to score the performance of a project in relation to each objective, which is presented along-side the BCR. A visual representation of these scores is also produced through a colour-coded ranking.

Greater Manchester (GM), in addition to producing BCRs, have produced an internal ranking of their schemes based on the ratio of each scheme's contribution to Gross Value Added (net at the GM level) per pound of whole life cost. Criteria relating to social and environmental benefits were also set at a programme level.

5.6 Supplementary analysis could also be used to identify the beneficiaries of a project, as well as the extent of such benefits. To the extent that such benefits are real, attributable and realisable, they could facilitate the identification of funding sources for a project (see Box 5.B).

Box 5.B: Land value changes

The construction of infrastructure may have significant impacts on land values in an area, these changes may be net positive or net negative. The latter case may occur when the project causes activity to be displaced, or where some parts of the projects lead to less desirable outcomes in specific locations or at points in time (for example crime is at times reported to increase in the immediate vicinity of rail stations).

Measuring land value changes would give an indication of the potential net cost of the scheme. The net impact on property value is a net benefit or cost to society and should already be captured in Cost Benefit Analysis (CBA). Yet there is also a real financial gain which would be realised via increased rents (or capital value) of the land / property in question. In a hypothetical scenario where land value changes could impact infrastructure costs, through some form of land value capture mechanism, the net cost of the scheme could be reduced. This may impact the financial case as well as the economic case for the scheme, and hence the BCR.

Given that, in the case of a transport project, land or property values effectively capitalise part of the estimate of the value of time savings and the benefits from better connectivity (most of which are usually captured in standard CBA) one would be double counting the benefits if both were to be included in a single value for money measure. For this reason, such analysis would have to be presented as supplementary to the standard CBA.

Localised impacts

5.7 Non-marginal effects and transformational impacts can occur to varying geographical extents. In some cases they may be localised, for example an improved rail station could enable regeneration in its immediate surroundings, resulting in improved urban realm and

opportunities for local businesses, increasing competition and productivity. In others instances, such as the introduction of a new railway line, the impact can be more widespread, influencing commuting patterns and opening up markets to each other, increasing competition and productivity further (see Box 5.C).

Box 5.C: King's Cross Redevelopment

King's Cross Central is a 67 acre site to the north of King's Cross and St Pancras International stations in central London. Once completed it is expected to contain 3.4 million square feet of office space, 500,000 square feet of retail space and 2,000 homes. The development of King's Cross Central is expected to cost £2 billion of which £300 million is accounted for by its infrastructure development. The expected end value of the site is expected to be around £3.5 billion. Where infrastructure is a constraint, interventions can play a key role in facilitating specific developments. Two infrastructure projects that helped facilitate the King's Cross Central development are:

- routing of the Channel Tunnel Rail Link: the decision was made to route the link through East London terminating at King's Cross St Pancras Station. The approach of the line was pushed as far north as possible to allow maximum land space for the development of King's Cross Central
- upgrade of King's Cross underground station: significant upgrade work was carried out to increase capacity. This was a key factor in facilitating planning permission for the development of King's Cross Central

5.8 A well-planned and implemented piece of infrastructure can deliver benefits to the local economy and, under the right circumstances, help facilitate greater economic output on aggregate. Alternatively, infrastructure could have a more negative impact on the local region, but may be important to the national economy, such as a power plant that has localised environmental impacts or harms local tourism.

5.9 In some instances, infrastructure projects may result in displacement or redistribution of economic benefits across an area. Therefore the overall net impact of projects should be sought across geographical areas. Information on who the winners and losers are, either in economic, financial, social or environmental terms, could then allow policy makers to put measures in place to help mitigate against any localised negative impacts.

A Further Information

Acknowledgements

A.1.1 The authors gratefully acknowledge the work which has been referred to and identified for further information within this guidance, notably the report 'Economic Evaluation of Systems of Infrastructure Provision' edited by Andrew Brown and Mary Robertson (iBUILD and University of Leeds), as well as the 'Development of a Proposed Interdependency Planning and Management Framework' by Ges Rosenberg, Neil Carhart (University of Bristol and ICIF), Andrew Edkins and John Ward (UCL and ICIF). The continued support and work in this field by ICIF, iBUILD and ITRC has been essential in developing the content of this guidance.

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Sources of further information

Infrastructure UK

https://www.gov.uk/government/organisations/infrastructure-uk

Infrastructure Business models, valuation and Innovation for Local Delivery (iBUILD)

https://research.ncl.ac.uk/ibuild/

International Centre for Infrastructure Futures (ICIF)

http://www.icif.ac.uk/index.html

UK Infrastructure Transitions Research Consortium (ITRC)

http://www.itrc.org.uk/

UK Regulators Network

http://www.ukrn.org.uk/

Interdependency Planning and Management Framework; ICIF

Rosenberg, G.; Carhart, N.; Edkins, A.J.; Ward, J. (2014) Development of a Proposed Interdependency Planning and Management Framework. International Centre for Infrastructure Futures: London, UK. http://dx.doi.org/10.14324/20141455020

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Economic evaluation of systems of infrastructure provision: concepts, approaches, methods

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Systemic Risks and Opportunities in UK infrastructure; Frontier Economics

http://www.frontier-economics.com/documents/2013/10/frontier-report-systemic-risk-and-opportunities-in-uk-infrastructure-2.pdf

Resilience in Society, Infrastructure, Communities and Businesses; Cabinet Office

https://www.gov.uk/resilience-in-society-infrastructure-communities-and-businesses

Infrastructure Cost Review; Infrastructure UK

https://www.gov.uk/government/publications/infrastructure-cost-review

Early Cost Estimates

https://www.gov.uk/government/publications/green-book-supplementary-guidance-valuing-infrastructure-spend/early-financial-cost-estimates-of-infrastructure-programmes-and-projects-and-the-treatment-of-uncertainty-and-risk

Green Book: Appraisal and Evaluation

https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-govervent

Orange Book: Management of risk – Principles and Concepts

https://www.gov.uk/government/publications/orange-book

Magenta Book: Evaluation

https://www.gov.uk/government/publications/the-magenta-book

Green Book Supplementary Guidance

https://www.gov.uk/government/collections/the-green-book-supplementary-guidance

Sector Specific Appraisal Guidance

Transport analysis guidance: WebTAG; Department for Transport

https://www.gov.uk/transport-analysis-guidance-webtag

Flooding and coastal change guidance for practitioners; Defra

https://www.gov.uk/flooding-and-coastal-change-guidance-for-practitioners

Accounting for the Effects of Climate Change; Defra and HM Treasury

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191501/Accounting_for_the_effects_of_climate_change.pdf

Assessing the Impacts of Spatial Interventions; Office of the Deputy Prime Minister

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191509/Regeneration__renewal_and_regional_deveopment.pdf

HM Treasury contacts

This document can be downloaded from www.gov.uk

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