Infrastructure and Projects Authority

Project Routemap

Setting up projects for success

Systems Integration

UK Module

Interactive document

Requirements	Governance	Systems Integration	Organisational Design & Development	Procurement	Risk Management	Asset Management	Delivery Planning
Rq 01	Gv 02	SI 03	OD 04	Pr 05	RM 06	AM 07	DP 08

Contents

Systems Integration
SI
03

Cover image
A Royal Navy Wildcat helicopter flies above HMS Queen Elizabeth during the aircraft carrier's first entry into her home port of Portsmouth Harbour. A warship requires multiple individual systems to integrate seamlessly so that the platform can float, move and importantly sense, decide, deliver and fight. Final testing was de-risked through advance testing in land-based facilities in parallel with the physical build programme.

Acknowledgements
LPhot Dan Rosenbaum UK MOD © Crown copyright 2020

Preface

Project Routemap is the Infrastructure and Projects Authority's (IPA) support tool for novel or complex major projects. It helps sponsors and clients understand the capabilities needed to set projects up for success, incorporating learning from other major projects and programmes.

The IPA is the centre of expertise for infrastructure and major projects, sitting at the heart of government and reporting to the Cabinet Office and HM Treasury in the UK.

Over the coming years there will be more investment in infrastructure and major projects than ever before, backed by both public and private sectors. This investment will be a catalyst to building back better and stronger. Infrastructure and major projects will play a critical role in fuelling economic growth and improving the lives of people right across the country.

With greater investment comes greater responsibility and we must ensure we have a strong delivery record that demonstrates real value. This means setting projects up for success from the very start, so that they come in on time and budget, and deliver on their promises - to the benefit of the citizens of the UK.

Although setting up projects for success can take more time at the start, this will be repaid many times over in the delivery phase. Projects that focus enough attention on the early stages are much more likely to achieve their intended outcomes later on and display world-class delivery standards.

That's why the IPA developed the Project Routemap ("Routemap") - a support tool that provides practical advice based on learning from other major projects and programmes.

There is no doubt that complex projects can test the limits of organisational capability, but if applied in the most crucial early stages of project development, Routemap will ensure that best practice and learning about the most common causes of project failure and principles for project success are incorporated. This will result in benefits ranging from selection of the most appropriate delivery model, to clearer governance arrangements, proper risk allocation and accelerated decision-making.

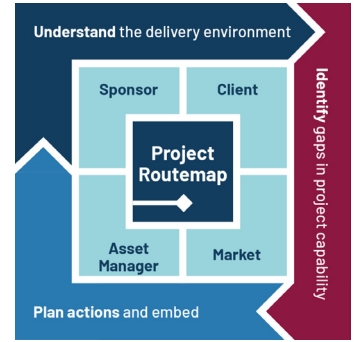
Routemap has been used by many of the UK's biggest, most complex and high-profile projects since its first publication in 2014 and more recently it has also been applied to projects internationally. However, the project delivery system and the way projects are delivered has evolved. That is why the UK Routemap handbook and accompanying modules have been updated to incorporate new and emerging best practice in project delivery and to align with standards, including the Government Functional Standard for Project Delivery and the United Nations Sustainable Development Goals.

Building on its success with economic infrastructure, Routemap has also been expanded to cover social and defence-related infrastructure projects and includes guidance for application to other types of projects.

Applying Routemap to more of our projects will be another step towards realising our ambition of world-class delivery standards. Whatever the project, applying Routemap will give confidence to the people delivering them, those approving them, and those investing in them.

The IPA would like to thank all those organisations and individuals who have contributed to the development, of both the original, and these updated UK Routemap handbook and accompanying modules.

Nick Smallwood
Chief Executive Officer of the Infrastructure and Projects Authority and Head of Government's Project Delivery Function

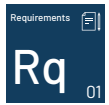


Introduction: What are the Routemap modules?

The Routemap modules provide practical advice to help set up projects for success. The modules have been developed by the UK government in collaboration with industry and academia. They capture best practice and learning from common causes of project failure and success over the past decade from £300bn of capital programmes.

These modules sit alongside the Routemap handbook. The handbook explains how Routemap can be applied to identify gaps in project capability and build an action plan to close those gaps.

There are eight modules, one covering each of the following areas:



Requirements
Delivering strategic project outcomes and realising the benefits.

Procurement
Understanding how the project will buy goods and services.

Governance
Establishing clear accountability and empowering effective decision-making.

Risk Management
Managing uncertainties and opportunities.

Systems Integration
Making multiple systems work as one.

Asset Management
Balancing costs and risks to maximize whole life benefits.

Organisational Design & Development
Organising the project team to deliver successfully.

Delivery Planning
Readying the project for transition into delivery.

The best practice and learning contained in the modules reflect the collective experience of public and privately funded projects from the infrastructure and defence sectors. However, most of the principles apply to all projects, including digital and transformation projects.

These modules are aligned with the government's Project Delivery Capability Framework and help projects comply with the Government Functional Standard for Project Delivery. They also help projects to align with other recognised standards and guidance, including the United Nations Sustainable Development Goals.

They are useful whether you are using the Routemap to undertake a Full Project Review or a Modular Deep Dive, as detailed in the Routemap handbook. They can also be a useful standalone reference to identify potential risks and improvements in project capability development, and relevant good practice from other projects.

The modules are not a complete guide to project development, nor a substitute for business case development. Instead, they provide considerations to challenge your thinking and to launch your project on the path to success. The project team will need to consider their project's individual characteristics and context and identify what will be most helpful to them.

Introduction: How do you use the Routemap modules?

This table summarises how different module sections support the three key stages of the Routemap methodology.

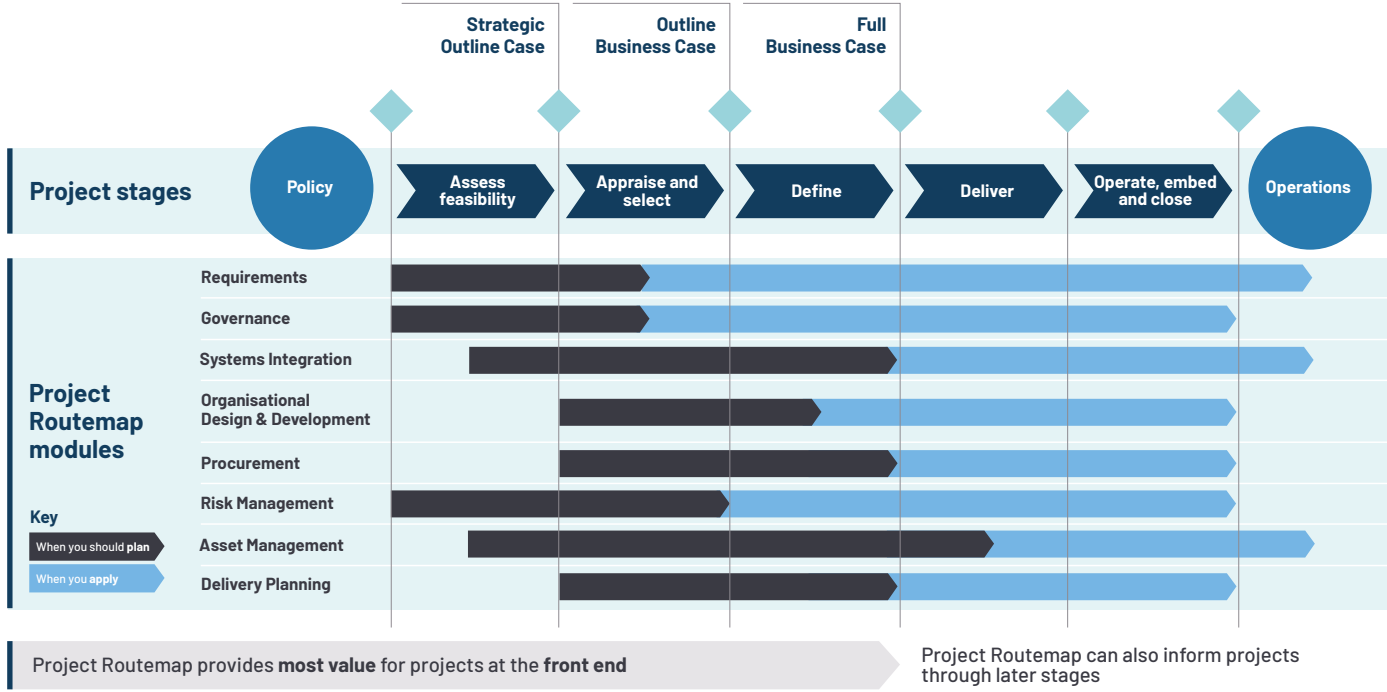
The modules are useful when applying the Full Project Review and Modular Deep Dive approaches, which are described in the Routemap handbook.

Routemap approach	Setup Determine the scope and timing of the Routemap, which can be project-wide or targeted to specific areas of capability	Diagnosis Gather information and identify where capabilities need to be enhanced	Action planning Collaborative development of practical solutions to enhance capability
Full Project Review	Determine if there is value in using Routemap to support project-wide capability development.	Determine which modules may help.	Apply best practice and learning from the modules and any other major project examples.
Modular Deep Dive	Determine if there is value in using specific Routemap modules to support development of a specific area of capability.	There is likely to be one module in particular that focusses on your selected area of capability. However, there may be value in consulting other interfacing modules too.	Apply best practice and learning from the modules and any other major project examples in the selected area of capability.
Module section			
Key project documents Documents that will help you understand the systems integration arrangements for your project.	You may find it helpful to review these types of project documents, to define the areas of interest in the Routemap scope.	Cross-checking this document list against existing project documents may also help you to identify capability gaps.	You may find that developing or enhancing these types of documents will help to close capability gaps.
Typical findings Indicators that issues might arise during delivery.	If these indicators are apparent even before you start applying Routemap, this should inform the areas of interest in the Routemap scope.	You may find it helpful to review these when identifying issues and articulating your findings.	If your findings contain statements like these, this module could help strengthen capability.
Pillars of effective systems integration Hallmarks of successful project set up.	Comparing your project with these characteristics of good practice may help you to identify areas of interest in the Routemap scope.	*Not applicable to this stage*	Comparing your project with these characteristics of good practice may help you set goals for your action plan.
Considerations Detailed list of questions to understand root causes and suggest improvements.	*Not applicable to this stage*	This section lists a series of questions that can help you to test the effectiveness of existing arrangements.	Working through these questions can help you understand the root causes of the findings and develop solutions.
Good practice examples and suggested reading Context to support your wider understanding.	*Not applicable to this stage*	*Not applicable to this stage*	You may find these good practice examples and suggested reading useful in developing actions to address capability gaps.

Introduction: How do the modules map to the project life cycle?

This diagram maps the Routemap modules to the stages of a project life cycle.

It shows when each of the modules should be used to support planning during project set up. It also suggests the stages when the modules' principles are expected to have been applied.



Project Routemap provides **most value** for projects at the **front end**

Project Routemap can also inform projects through later stages

Cross-cutting themes projects can't ignore

Six cross-cutting themes emerged from our engagement with major projects and industry, which have informed the updated Routemap modules. These place complex demands on project teams and, if overlooked during set up, can create issues during the later stages of the project life cycle.

These themes include the need for focus on behaviours and culture, consideration of wider economic, environmental, and social value and the increasing use of digital systems and tools to enable a systems-focused approach.

Planning ahead for the right skills, experience and capacity to address these themes is key to success.

To help you navigate these themes, we have developed a series of prompts. You can use these prompts to check whether your project is set up to meet the challenges ahead.

Benefits and outcomes focus

adopting a whole life perspective whilst managing the project

- Have you got a clear vision of the target outcomes, which is aligned across the sponsor, client, asset manager and market?
- Have the project outcomes been effectively communicated to key stakeholders and the supply chain?
- Has the project set realistic and transparent targets?
- Are you able to measure the realisation of benefits throughout the whole life cycle? Including any potential early releases?

People and skills

planning ahead for the right skills, experience and capacity to deliver the project

- Have you undertaken activity-based resource planning to ensure you have the people with the right skills, knowledge, experience and behaviours at the right time to deliver the project?
- Are these plans reviewed on an ongoing basis? And do they incorporate skills development and succession planning to ensure continuity in key roles and to meet evolving needs?
- Have you considered the time commitment of your project leaders to ensure they have the right capacity to deliver the project?
- If using delivery partners or third parties, do they have the capacity and expertise to support the project as required?

Behaviour and culture

realising project success with a capable, diverse and integrated team

- Is there a plan for how desired behaviours and values will be cascaded and embedded through the sponsor, client, asset manager organisations and the supply chain?
- How are the desired behaviours and culture promoted in the project?
- Does the project have a culture that empowers constructive challenge and diversity of thought?
- How is the project planning to build relationships and invest in creating the right environment to realise project outcomes?

Economic, environmental and social value

taking in a wider view of the project's impact

- Have you considered how the project will generate economic, environmental, and social value? Has it been hardwired into the business case, with a clear link to the UN Sustainability Development Goals?
- Is your project aspiring to leave a "net positive" impact on the natural environment to combat the impacts of climate change?
- How are you maximising benefits for project affected communities and contributing to levelling up?
- Is there clear accountability for the economic, environmental, and social benefits and outcomes?

Digital and technology

embedding systems and approaches at the front end to maximise project productivity

- Have digital and modern methods been considered at the earliest point in the life cycle to maximise their impact on benefits?
- How has the project assessed and addressed digital capability within the sponsor, client, asset manager and market?
- Has the project considered how information, data and knowledge will be shared across the project, including with the supply chain?
- What consideration has been given to potential changes in technology that may influence benefits realisation?

Transitions

planning for change and developing the required capability before progressing to the next life cycle stage

- Does the project have a clear plan for how they will transition from one life cycle stage to the next?
- Does the plan set out the changes needed to organisational and governance arrangements?
- Does the project have the necessary capability to transition to the new organisational and governance arrangements for the next life cycle stage? Including the change management capability required to embed the changes?
- Is the project clear on how the relevant documents and people will carry knowledge and learning across life cycle stage boundaries?

Systems integration, and why it's important

"Today, even relatively small projects are best seen as interventions into existing complex systems that provide the services needed by millions of people"

A systems approach to infrastructure delivery – Institution of Civil Engineers 2020

"Neither Crossrail Ltd, the sponsors nor the contractors appreciated how complex it would be to bring together all of the separate systems and assets required and assure them as safe and working, or how long it would take."

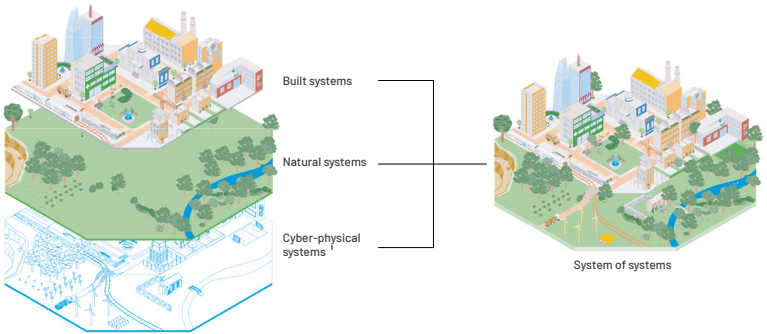
Crossrail – a progress update – National Audit Office 2021

Systems Integration SI 03

Why Systems Integration matters

Systems integration is essential to project success and is one of the most difficult things to get right. If not done well it can be a source of friction and dispute with different system owners blaming each other for failures or incompatibilities. It is a client accountability to ensure that system integration is carried out well, either by a specific dedicated team within the client organisation, or by an external organisation specifically tasked with the role.

As projects become more complex, their success or failure is increasingly determined by the interactions between new and pre-existing natural, built and digital systems, and the critical role of people in making these interactions work. As such, project outputs should not be viewed in isolation but as part of a *system of systems.*

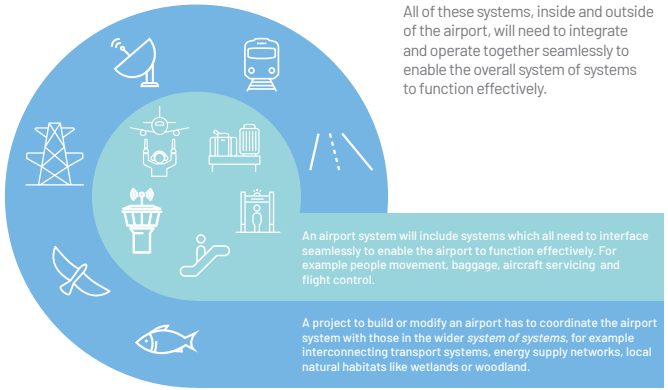


From: http://www.visionforbuiltenvironment.com

Systems integration is the process by which multiple individual systems are successfully combined to function as one all-encompassing system of systems.

The term "system" is widely used, and often in very different contexts. A system - simply defined as an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not - can exist at many different levels.

For example, an airport comprises multiple systems including baggage systems, flight control systems, people movement systems, and also the services that the airport provides to fly people around the world, like border control, catering etc. These systems within the airport boundaries, will interface with systems outside of the airport, including road and rail systems, power systems and the natural environment.



All of these systems, inside and outside of the airport, will need to integrate and operate together seamlessly to enable the overall system of systems to function effectively.

An airport system will include systems which all need to interface seamlessly to enable the airport to function effectively. For example people movement, baggage, aircraft servicing and flight control.

A project to build or modify an airport has to coordinate the airport system with those in the wider *system of systems*, for example interconnecting transport systems, energy supply networks, local natural habitats like wetlands or woodland.

Systems integration, and why it's important

There is increasing emphasis on taking a "whole life" approach to projects, viewing infrastructure projects not just as the creation of assets but as long-term providers of a service. Furthermore, there is increasing recognition that the capital cost of each component system is often disproportionate to the value derived from operation of the overall system of systems.

For example, with a major rail project most of the capital cost is normally in civil engineering related systems. However, the value of the benefits derived from running the railway is driven more by the operational systems (for example, signalling), which also carry the greatest risk in terms of delivery to time and cost. This is why it's critical that project leadership maintains a continual focus on the operational systems, even during the main construction phases.

Techniques and methods to identify, balance and link the systems within and interfacing with a project are important enablers of effective integration. Building information modelling (BIM) is an essential starting point for information integration across systems. Other techniques should also be applied as appropriate.

The application of systems integration must be a constant focus throughout the project life cycle. It should not be started at the beginning of the project and left untouched. As the project progresses through its life cycle, the project leadership should evolve to ensure the right expertise is in place to bring the systems into operation.

For systems integration to be successful, you should consider:

- how systems delivered by the project will interact with other systems outside of the project.
- having a single common plan across all interfacing systems to manage and put into operation the project outputs.
- the whole life of the investment, taking account of obsolescence, periodic renewal of component parts (for example, pumps) and future re-purposing.
- the need to integrate the different organisations delivering individual systems, and
- using progressive assurance and acceptance, and planning well in advance for the approvals that will be needed.

To maximise economic, environmental, and social benefit, effective systems integration establishes a clear and continuous line of sight between individual systems delivered by a project, how these are brought together, and their subsequent incorporation within the overall system of systems to which they contribute.

This module can help to assess whether existing or proposed systems integration arrangements are suitable for the scale and the complexity of your project.

What are the key project documents?

If you are seeking to find out more or to review the existing systems integration arrangements on your project, the typical documents or reports set out below may contain information that will help.

- Target operating model
- Asset management strategy
- Requirements' baseline (including sponsor's, regulatory or statutory, and asset information requirements)
- Configuration baselines
- Governance framework including terms of reference for decision making bodies
- Integrated assurance and approval plan
- Delivery strategy and model
- Systems integration strategy and plan
- Change management plan
- Commissioning and handover plan
- Information management plan
- Assumptions log
- Data (and modelling) to evidence assumptions
- RACI matrix (Responsible, Accountable, Consulted and Informed)
- Record of stakeholder/user consultation
- Risk register
- Interface control documents
- Traceability, verification and validation evidence

Not all projects will have developed all of these documents, particularly in the earliest stages of development.

Typical findings

Primary module
Other relevant modules

Typical findings relating to system integration

This list describes situations that might arise and would indicate that the approach to developing systems integration needs improvement. Other relevant modules may also help you close identified capability gaps.

Relevant modules

Typical findings relating to system integration	Requirements	Governance	Systems integration	Organisational Design & Development	Procurement	Risk Management	Asset Management	Delivery Planning
Responsibility for systems integration is not clear, or there is a lack of rigorous project controls to enable interface and requirements management.		●	●	●				◐
Governance, senior leadership, organisation design and culture are not evolving to reflect the changing priorities of the project with respect to systems integration.		●	●	●	◐		◐	◐
Senior leadership has inconsistent views on the systems integration risks facing the project.		◐	●		◐	●		◐
Allocation of integration risks and responsibilities is not matched by systems integration capability.		◐	●	●	◐	◐		
Upfront consideration of strategic alternatives or different ways of addressing requirements has not occurred, leading to a predetermined view of the solution.	●		●				◐	◐
The project requirements do not define how information will be shared across system interfaces.	●		●				●	◐
The technical requirements have advanced more quickly than the development of the target operating model.	●		●			◐		
There is insufficient planning for systems testing and commissioning before handover, and strict acceptance criteria have not been developed.			●			◐	◐	●
A single common systems integration plan considering existing and adjacent systems has not been developed as part of delivery planning or is applied inconsistently.			●				◐	●
There is insufficient consideration of whole life value, particularly concerning technological obsolescence and the need for periodic renewal of component parts.	◐	◐	●				◐	

Pillars of effective systems integration

The four pillars below summarise the characteristics of systems integration.

Pillar 1: **Establishing system outcomes to maximise value** 1

- Define the systems to be delivered by the project, and how they will be operated together with existing systems within and outside of the asset manager's control.
- Align your project's governance and stakeholders to ensure that they understand the target operating model.
- Establish the role of the systems integrator and ensure there are rigorous project controls to enable interface and requirements management.

Pillar 2: **Setting system requirements** 2

- Convey the vision of success and establish the outputs, outcomes, and benefits of new systems to be delivered by the project and interfacing systems modified by others.
- Assess the impact of systems on the current operating model, and the changes necessary to make the project a success.
- Identify and agree how information will be shared across system interfaces, both new and existing.
- Verify that the systems' functionality and subsequent operation will deliver the intended benefits, which can be measured during operations.
- Ensure, don't assume, different technologies can integrate.

Pillar 3: **Employing a systems integration approach** 3

- Understand the responsibilities for integration across interfaces. If required, bring in external expertise.
- Apply horizon scanning to ensure the systems being delivered by the project will not become obsolete during the project life cycle.
- Consider how change will be managed. If there are any evolving technological requirements, upgrade with as little disruption as possible.
- Use progressive assurance and acceptance. Engage the asset manager during delivery to ensure that the project can handover with no surprises.

Pillar 4: **Enabling capability in the organisation** 4

- Ensure leadership maintains focus on the end state and how systems will need to operate together effectively.
- Clarify the different levels of systems integration to identify the capability required at each level.
- Develop and implement a plan to build and evolve the skill sets and capabilities needed:
  - by the systems integrator
  - within each system
  - at systems' interfaces
- Ensure any necessary enhancements to the asset manager's operational capabilities are part of the project's plans.

These four pillars underpin an effective systems integration framework for projects. If one pillar is missing or out of balance, integration will likely be ineffective or inefficient. The pillars are expanded in the considerations section of this module.

Systems integration arrangements might need to evolve during the project, so you should revisit the considerations at major transition points or approval points, or if plans change.

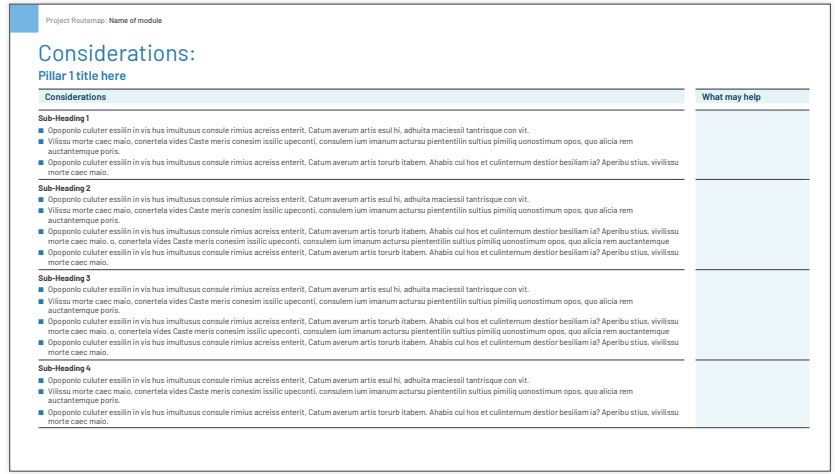
Systems integration arrangements should evolve as:

- more information becomes available to inform the capabilities required to deliver the project
- the project team and their processes develop and embed
- the project progresses through its life cycle, from design and planning, through implementation to operation

Considerations

Module Pillars

The considerations questions help you understand the root causes of the capability gaps and suggest improvements. You may not need to review all the considerations, just use the most relevant ones for your project.


Project Routemap: Name of module

Considerations:

Pillar 1 title here

Considerations	What may help
Sub-Heading 1 ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis esul hi, adhuita maciessil tantrisque con vit. ■ Vilissu morte caec maio, conertela vides Caste meris conesim issilic upeconti, consulem ium imanum actursu piententiiin sultius pimiliq uonostimum opos, quo alicia rem auctantemque poris. ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis torurb itabem. Ahabis cul hos et culinternum destior besiliam ia? Aperibu stius, viviilissu morte caec maio.	
Sub-Heading 2 ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis esul hi, adhuita maciessil tantrisque con vit. ■ Vilissu morte caec maio, conertela vides Caste meris conesim issilic upeconti, consulem ium imanum actursu piententiiin sultius pimiliq uonostimum opos, quo alicia rem auctantemque poris. ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis torurb itabem. Ahabis cul hos et culinternum destior besiliam ia? Aperibu stius, viviilissu morte caec maio. o, conertela vides Caste meris conesim issilic upeconti, consulem ium imanum actursu piententiiin sultius pimiliq uonostimum opos, quo alicia rem auctantemque ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis torurb itabem. Ahabis cul hos et culinternum destior besiliam ia? Aperibu stius, viviilissu morte caec maio.	
Sub-Heading 3 ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis esul hi, adhuita maciessil tantrisque con vit. ■ Vilissu morte caec maio, conertela vides Caste meris conesim issilic upeconti, consulem ium imanum actursu piententiiin sultius pimiliq uonostimum opos, quo alicia rem auctantemque poris. ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis torurb itabem. Ahabis cul hos et culinternum destior besiliam ia? Aperibu stius, viviilissu morte caec maio. o, conertela vides Caste meris conesim issilic upeconti, consulem ium imanum actursu piententiiin sultius pimiliq uonostimum opos, quo alicia rem auctantemque ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis torurb itabem. Ahabis cul hos et culinternum destior besiliam ia? Aperibu stius, viviilissu morte caec maio.	
Sub-Heading 4 ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis esul hi, adhuita maciessil tantrisque con vit. ■ Vilissu morte caec maio, conertela vides Caste meris conesim issilic upeconti, consulem ium imanum actursu piententiiin sultius pimiliq uonostimum opos, quo alicia rem auctantemque poris. ■ Opoponlo culuter essilin in vis hus imultusus consule rimius acreiss enterit, Catum averum artis torurb itabem. Ahabis cul hos et culinternum destior besiliam ia? Aperibu stius, viviilissu morte caec maio.	

Considerations

Each pillar is expanded into a number of consideration questions. These questions will help you:

- to review and validate existing systems integration arrangements
- to target areas for improvement
- to test the design of new systems integration arrangements

What may help

Signposts other related material which you might find helpful. These include other relevant modules with related content, key project documents, good practice examples and suggested further reading.

Routemap uses four primary roles to describe the key areas of responsibility in the early stages of project development. These are sponsor, client, asset manager and market. Before reading through the detailed considerations, you should familiarise yourself with these definitions in the glossary and consider which organisation is fulfilling which role for your project. Sometimes an organisation can fulfil more than one of these roles, for example both the sponsor and client roles. Also, where a project is still at an early stage, a role might not yet be filled by any organisation, for example the market role.

Considerations:

Pillar 1 Establishing system outcomes to maximise value

Considerations

System definition

- Have all the elements of the systems to be delivered by the project been defined? For example, a project within an airport could include baggage systems, flight control systems, people movement systems etc.
- Have all component parts of the wider system of systems been identified? Including those outside the scope of the project and control of the project team. For example, for a project within an airport, this could include power networks and connecting transport infrastructure.
- Has the target operating model for the systems to be delivered by the project been defined? Does this include how systems delivered by the project will interact with the wider system of systems? Has this been fully communicated to the project team and key stakeholders?
- Are the time constraints for development of each system to be delivered by the project understood?
- Have the requirements for systems to be delivered by the project (for example, data collection, storage, and analysis) and related deliverables at each stage (from project definition to operations), been established?
- Has a whole life perspective been taken when developing the requirements for systems to be delivered by the project?
- Has the asset manager organisation been identified/appointed at the project definition stage, so that the user and operational requirements for systems to be delivered by the project are captured in the project requirements?
- Is each project output and outcome aligned with performance of the wider system of systems? For example, an airport refuelling project must consider operational demands at peak times, and performance of the wider fuel pipeline system.
- Can all outputs for systems to be delivered by the project be linked to planned benefits of the project?

What may help

Requirements Rq 01

Asset Management AM 07

Requirements baseline and asset management strategy

Examples 1 and 8

Suggested reading 1, 2, 4, 6, 10 and 13

Considerations:

Pillar 1 Establishing system outcomes to maximise value

Considerations	What may help

Governance and stakeholders

- Is there top-level support for the project, and what it will take to deliver the outputs and outcomes envisaged?
- Does the leadership and governance model reflect the complexity of the project and influence of the key stakeholders?
- Is project governance clearly established with defined roles and a controlling mind for development and delivery of the end-state?
- Does the client appreciate their accountability for systems integration, and is it clear how they have delegated associated responsibilities?
- How will objective decisions on systems integration be made? Including potential trade-offs. Will it be through independence of an overall systems integrator, or through predetermined leadership changes, at the right phase?
- Does project leadership decision making take into account:
  - the requirements of key stakeholders?
  - the asset manager's risk appetite for innovation in technology?
  - the strategy for technology selection; and future proofing?
- How have lessons learned relating to systems integration been reflected in the project's governance?
- Are the project outcomes and their relationship to the overall system of systems clearly defined and communicated regularly to stakeholders?

Gv 02 | OD 04

Governance framework and record of stakeholder/user consultation

Examples 1 and 7

Suggested reading 4, 7 and 13

Integrating function

- Has the need for a function with responsibility for systems integration (often referred to as the "systems integrator") been clearly articulated at the project definition stage?
- Has the role and scope of the systems integrator been defined?
- Does the client intend to bear the integration risk, or intend to pass this on to an external organisation?
  - Has the need for the systems integrator to be independent of the client team been considered? For example, to ensure an appropriate level of focus has been given to systems integration, which is often lacking compared with other aspects of the project like civil engineering.
  - Has the need for the systems integrator to be independent from provision of the technical aspects of the project been taken into account?
- Has the internal team within the client organisation, or an external organisation who will perform the systems integrator role been identified?
- Does the commercial structure reflect critical interfaces between various systems and allow the client to manage the performance of the systems integrator? For example, commissioning a single integrator who then puts in place the subcontracts and takes the integration risk.

OD 04

Systems integration strategy and plan and delivery strategy model

Example 3

Suggested reading and 6 and 10

Considerations:

Pillar 1 Establishing system outcomes to maximise value

Considerations	What may help

Project control

- Is there a single common plan across all interfacing systems (to be delivered by the project as well as existing) to manage and put into operation the project outputs?
- Are tools used to help manage requirements, interfaces and risks throughout the project life? For example, configuration management databases.
- Is there a decision framework in place to manage change during the project, to preserve the project outcomes?
- Are robust controls and reporting metrics in place to enable effective management of interfaces and requirements?
- Is there a defined process to integrate elements of new and existing systems as design development progresses?
- Has a supplier resilience plan been established for critical elements of the new systems to be delivered by the project?
- Have failure scenarios been identified for the systems to be delivered by the project, and has safety testing been planned?

Delivery strategy and configuration baselines

Example 1

Suggested reading 6, 7, 8 and 10

Considerations:

Pillar 2 Setting system requirements

Considerations	What may help

Alignment with strategic priorities

- Has project success been clearly defined and communicated to the project team and key stakeholders? For example, in a vision statement that establishes the strategic priorities.
- Is project success aligned to national and corporate policy statements and strategies? For example, the UK government's Transforming Infrastructure Performance: Roadmap to 2030.
- Does the project have mandatory requirements which influence system requirements?
- To meet these policy, strategy and mandatory requirements, is it clear what the minimum viable state of the systems being delivered by the project should be?
- How has the project identified and prioritised stakeholders to source requirements for systems that will be delivered by the project? Will this process ensure that requirements driving strategic priorities are fully captured?
- Is it clear how requirements for systems to be delivered by the project will be prioritised against the overall project requirements and strategic priorities?
- How have any differing interpretations of priorities been reconciled? For example, by ensuring those assessing requirements are from diverse backgrounds to ensure appropriate challenge, or the use of independent/external reviews.
- How will the relationship between strategic priorities and requirements for systems to be delivered by the project be documented and tracked?
- Have interdependencies and trade-offs between strategic priorities, project requirements and requirements for systems delivered by the project been examined and determined? Have multiple possible future system scenarios been considered when examining conflicting potential requirements?
- If conflicts arise between changes in project requirements and the systems being delivered, is there a process to resolve these?
- Are existing and new system requirements and associated assumptions tested and challenged at each stage, to ensure alignment with the project business case if this changes?
- Do any of the requirements for systems being delivered by the project enable or hinder any early release of benefits prior to completion?

Requirements Rq 01

Governance framework , record of stakeholder/user consultation and assumptions log

Example 8

Suggested reading 1, 3, 4 and 13

Assessing and changing the current operating model

- Are the impacts of the systems being delivered by the project on the current operating model understood? Has a change impact assessment been carried out?
- Is any business transformation needed to deliver the required overall system of system outcomes?
- Have legacy systems unduly influenced the requirements of new systems to be delivered by the project?
- Have all assumptions about impacts on existing systems including existing physical, natural and digital systems, been tested:
  - with suitably diverse, qualified, and experienced experts?
  - with stakeholders, including representatives for project affected communities?
  - against similar system implementation efforts, current best practices and lessons learned from other projects (internal and external)?
- Have warranties been considered when making changes to interfacing technology (software and hardware)?

Requirements Rq 01 Delivery Planning DP 08

Target operating model, configuration baselines and change management plan

Example 8

Suggested reading 4 and 13

Considerations:

Pillar 2 Setting system requirements

Considerations

Information and data needs

- Is the hierarchy of information needs understood, in terms of the information needed to manage the organisation, manage the assets and/or manage the project?
- Is there a robust plan for information capture, management and subsequent transfer into operation? For example, using a digital twin.
- Has adopting or appropriating external information standards been considered, before developing your own?
- Is there an understanding of the data architecture required for when the systems being delivered by the project will be in operation?
- Have data requirements been defined in relation to the future target operating model processes and/or management protocols?
- Have data requirements been specified such that the data created can be easily used by the asset management organisation after transfer into operation?
- Is a process in place to capture and share across system interfaces (both within and outside of the project) the data necessary to meet operational needs?
- Is it clear what data is required to support decisions? Has this data been clearly specified? Is this clear to the person responsible for providing the data?
- When producing the data requirements, has sufficient consideration been given to how easily the data can be generated?
- Have data storage and transaction costs been considered?
- Is there a need to consider outsourced computing capacity? For example, if the level of data collection, collation and analysis will exceed the computing capacity the asset manager wants to maintain in-house.
- Have all aspects of data security been considered?

Aligning system functionality to intended benefits

- Do all functionality aspects of the systems being delivered by the project lead to benefits? If not, why is this?
- Could any of the project's benefits and outcomes be released early to secure stakeholder support? Will this require changes to when systems are delivered by the project?
- What software and hardware performance is required for operations so that the intended benefits are delivered?
- Are the cause-and-effect relationships between system requirements and project outputs, outcomes and benefits clearly defined and documented?
- Are there appropriate 'tools' to record, track and manage the link between target benefits and project requirements, and to ensure traceability through design, delivery and operation of the new systems?
- Is there a mechanism to obtain external data, to benchmark performance of the new systems and benefits delivered?
- Is there an early understanding of key constraints, dependencies, and risks imposed by the existing system of systems on the benefits of the systems being developed by the project? Does this include any gaps in understanding requiring specific consultation?

What may help

Rq 01 AM 07 DP 08

Information management plan

Examples 5 and 8

Suggested reading 1, 5, 11 and 12

Rq 01 DP 08

Requirements baseline

Examples 4 and 5

Suggested reading 1, 2,6, 8 and 10

Considerations:

Pillar 2 Setting system requirements

Considerations	What may help

Technology integration

- Has a defined system engineering process been adopted for the project?
- How will it be ensured that different technologies can integrate? For example, has prototyping been considered?
- Have integration and interface constraints between existing technologies been considered?
- Do individual system requirements (existing and new) contain all the information necessary to assess how various technologies can be integrated? For example, time constraints or technical information.
- Have security requirements been considered both for individual systems, and across integrations?
- Has it been considered how IT hardware and tools integrate to inform decision making? For example, sensors and software to collect and refine data.
- How has emergent technology, and it's subsequent integration, been considered in the development of systems requirements?
- How does the hardware provider make the transfer of data captured as simple as possible?

What may help

DP 08

Systems integration strategy and plan and interface control documents

Examples 4 and 5

Suggested reading 6, 8, 10, 11 and 12

Considerations:

Pillar 3 Employing a systems integration approach

Considerations	What may help

Integration across interfaces

- Have the interfaces been identified within and between existing and new systems, including dependencies between contracts and other projects?
- Has an approach to managing integration across these interfaces been agreed?
- When planning the delivery of project outputs, has a systems-based approach been applied?
- Are appropriate configuration and change management standards and procedures in place?
- Are systems integration responsibilities within the wider project organisation clear? Does everyone use the same terminology in relation to systems integration?
- Are the specific responsibilities of the systems integrator within / across existing and new systems clear?
- Do bespoke processes for systems integration need to be developed to meet the specific needs of the project?
- Is expertise in any domain-specific techniques and technologies required? For example, intergrating railway signalling systems with overhead line electrification systems.

What may help

OD 04 DP 08

Systems integration strategy and plan and interface control documents

Examples 5, 6 and 7

Suggested reading 6, 7, 8, 10 and 12

Whole-life management

- Are road-mapping and horizon scanning techniques used to identify technologies that may emerge beyond the life of the project? Will these techniques be applied to ensure the project delivers systems that will remain viable throughout the whole life of the assets? For example, use of "plug and play" component systems.
- Is the asset manager involved in the development of the systems to be delivered by the project?
- Is there a plan to manage obsolescence, including those parts of a project that may be completed earlier?
- Has outcome-based contracting been considered to drive greater focus on whole-life benefits?
- Have feasibility studies and/or prototyping been undertaken or planned to assess whether different options deliver better whole-life value?
- Is there a process established for adopting better solutions that become available during the life cycle of the project, while maintaining a stable scope and operating environment for the project?
- Have relevant lessons from experience been identified and implemented? Including the lessons of others external to the project.
- Are there processes in place to identify and manage risks related to continuity of service after handover, rather than just those relating to project delivery?

What may help

OD 04 DP 08 AM 07

Asset management strategy, systems integration strategy and plan and risk register

Examples 1 and 4

Suggested reading 1, 2, 3 and 13

Considerations:

Pillar 3 Employing a systems integration approach

Considerations	What may help
Managing change ■ Is the impact of change managed holistically across the system of systems that will include the project outputs? ■ Are technological requirements likely to evolve, either during the project or operational life? If so, how will they be implemented with as little disruption as possible? ■ Is there a recognition that each system may have a unique development and change life cycle? Are these understood and reflected in delivery and asset management plans? ■ Is there an approach established for balancing new stakeholder needs and expectations with what is possible once delivery of the project is underway? For example, using project change controls.	DP 08 Configuration baselines, interface control documents and systems integration strategy and plan Examples 1 and 4 Suggested reading 6, 10, 11 and 12
Assurance and acceptance planning ■ How will the project deliver its outputs into the wider system of systems? For example, can the project deliver in stages or only when finally complete? ■ Is there a plan for testing and commissioning systems delivered by the project in a systematic and progressive manner? Does the plan: – allow progressive de-risking of integration risks? – test how elements of the solution work together at each stage and that the overall outcome works for users? – allow enough time for testing and protect the testing phase from compression? – include enough contingency, for example if early project stages run late against the target in-service date or if testing shows further work is needed before the solution can enter service safely? ■ Are there clear acceptance criteria agreed between the sponsor, client, suppliers, and asset manager for handover to operations? ■ Is it clear what test and evaluation evidence is needed to meet the acceptance criteria for progressive integration and handover? Is there a plan to generate this evidence? ■ Is there a plan for progressive assurance? For example, as part of an integrated assurance and approval plan.	DP 08 Gv 02 Commissioning and handover plan, traceability evidence, verification and validation evidence and integrated assurance and approval plan Examples 2 and 5 Suggested reading 6, 7, 10 and 11

Considerations:

Pillar 4 Enabling capability in the organisation

Considerations

Maintaining focus on the end state

- Does the project delivery leadership have a clear understanding of the intended outcomes and target operating model (end state)? Do they clearly communicate this to everyone involved in the project?
- Is the end state clearly owned by the asset manager, and do they have a role in governance of the project from the start?
- Does project leadership fully appreciate the need to use a system-based approach? Do they have the capability to think forward to the end state?
- Does project leadership seek out and listen to the voice of the systems integrator? Do they follow through on what they hear? Is this evidenced?
- Within project leadership forums (such as board meetings) is there an agenda item on readiness for handover to operations? Does this include monitoring readiness to handover the systems being delivered by the project, from the early project stages?
- Does the assurance approach highlight systems and service readiness, not just delivery to cost and time?

Aligning levels of systems integration

- Has the client considered its approach to building systems integration capability? For example, establishing in-house capability versus outsourcing it.
- How do you organise and structure portfolio, programme and project management in your organisation? Has this been considered when allocating systems integration responsibilities to different parties?
- Has an overall systems integrator (the organisation bringing all the systems, existing and new) been identified?
- Is it clear what systems integration activities will then be delegated to other parties across the portfolio, programme or project? Have these parties been clearly identified as systems integrators?
- Does this delegation align with the product/asset system breakdown across the different parties?

What may help

Governance framework, asset management strategy and delivery strategy and model

Example 6

Suggested reading 4, 10 and 13

Systems integration strategy and plan, delivery strategy and model and RACI matrix

Example 3

Suggested reading 4, 6, 7, 10 and 13

Considerations:

Pillar 4 Enabling capability in the organisation

Considerations	What may help

Defining the organisation and capabilities required

- Is there a clear understanding of the capabilities required to deliver the project outcomes, not just the technical solution?
- Is it necessary to enhance the asset manager's operational capabilities so that they can fully operate the target operating model? Are the actions required to address gaps in the asset manager's operational capabilities part of the project's plans?
- Have the capabilities required to integrate the project outputs with the wider system of systems been identified? For example, psychologists to help understand how to motivate people to adopt new ways of working.
- Have the systems integration interactions and interfaces between the sponsor, client, asset manager and market been agreed in the overall project organisation design?
- How will the organisation maintain stability, yet still have the ability to flex where needed? For example, is there access to additional systems integration capacity if needed to meet emerging future needs?
- Have those systems (existing and new) which are the most complex and uncertain been identified and appropriate systems integration capability and capacity been allocated to them?
- Does the procurement strategy fully consider interfaces between contract packages and integration across these?

What may help

Gv 02 | OD 04 | Pr 05 | RM 06

Systems integration strategy and plan, delivery strategy and model and RACI matrix

Example 2

Suggested reading 1, 6, 7, 9 and 10

Building the required skill sets and capabilities

- Have the skill sets and capabilities needed by the systems integrator and others undertaking systems integration activities been identified?
- Are people's individual objectives aligned with the project outcomes? Has this alignment been tested, and how will it be sustained?
- How will people be encouraged and motivated to become agents of more than one organisation, and do well by both?
- Does the organisation culture, behaviours and skills of the people and teams drive effective systems integration? Including:
  - appointing project leaders who display listening skills and who are curious about the outcome/end game not just the issues created on the way
  - listening to voices of systems integrators looking forward to future issues, as much as the people tackling issues in the here and now
  - seeking people who welcome bad news early, so that it can be dealt with
  - encouraging experimentation, celebrating "fail fast and learn"
  - encouraging 'left shift thinking' and tools and techniques (such as pre-mortems) that promote right to left thinking.

What may help

OD 04 | DP 08

Systems integration strategy and plan and delivery strategy and model

Examples 3 and 6

Suggested reading 4, 6, 7 and 13

Considerations:

Pillar 4 Enabling capability in the organisation

Considerations

Aligning skills and capabilities needed in different phases

- Will the project organisation, or people within the project organisation, need to evolve / transition over the life of the project?
- Has the appropriate timing for project organisation and people changes been identified? Are these aligned with life cycle transitions or have other considerations driven these changes, for example, funding cycles?
- Will transitions be sequential (finish / start relationship), or will they overlap? Is it clear how systems integration responsibilities will be maintained and managed if the transitions overlap?
- Are there mechanisms to ensure lessons learned aren't lost when transitioning from one phase to the next? For example, planning regular lessons learned capture as part of readiness reviews before each transition point?
- How does the project organisation manage knowledge capture and transfer over the full life cycle, especially when different parties and people join and leave?

What may help

Organisational Design & Development OD 04

Delivery Planning DP 08

Systems integration strategy and plan and delivery strategy and model

Example 2

Suggested reading 4, 6, 7 and 13

Good practice examples

Good practice examples	Pillar 1: Establishing system outcomes to maximise value	Pillar 2: Setting system requirements	Pillar 3: Employing a systems integration approach	Pillar 4: Enabling capability in the organisation
It is important to assess how applicable each example is to your specific project, and tailor it as appropriate. This table shows which of the four pillars of good practice are characterised by each example.	1	2	3	4
Example 1 Establishing effective governance and planning flexible whole life use: A Francis Crick Institute case study	●		●	
Example 2 Progressive assurance and acceptance of systems, and enhancing operational capabilities: A Heathrow Terminal 2 case study			●	●
Example 3 Establishing the overall systems integrator and different levels of systems integration: A London 2012 Olympics case study	●			●
Example 4 Establishing long-term operational system functionality and consideration of evolving technology: An HS1 case study		●	●	
Example 5 Ensuring different technologies integrate, and progressive assurance and acceptance of systems: A Type 26 Frigate case study		●	●	
Example 6 Responsibility for systems integration across interfaces and maintaining focus on the end state: A Crossrail 1 case study			●	●
Example 7 Aligning project governance with clarity on responsibility for integration across interfaces: An Oxford Flood Alleviation Scheme case study	●		●	
Example 8 Aligning governance for overall system success: A Nuclear Decommissioning Authority case study	●	●		

Good practice examples

Example 1

Establishing effective governance and planning flexible whole life use: A Francis Crick Institute case study

The Francis Crick Institute is a world-leading centre of biomedical research and innovation in London, dedicated to understanding the fundamental biology underlying health and disease. The new facility was delivered with faultless building operations on day one. The approaches to systems integration, including effective governance, engagement with key stakeholders, incorporating flexibility to deal with future changes and progressive user acceptance have been carried forward to similar projects, as well as other large complex non-science projects.

With a mission to translate discoveries into new ways to prevent, diagnose and treat illnesses, the driving principle for The Crick was to increase collaboration between scientists, and pursue discovery without boundaries. Systems integration was therefore both a technical requirement for such a complex biomedical facility, and also an ethos which underpinned the vison for the project.

Integration built into governance arrangements: The project team was structured to facilitate collaboration and alignment of the governance requirements of the five scientific bodies acting as project sponsors. Each partner's requirements were scheduled throughout the project life cycle, so that inputs could be prepared, and the necessary decisions taken to maintain the project schedule. Monthly reports to the project board clearly identified the 3-4 key upcoming decisions to enable quick and well-informed decision making and timely approvals.

Planning for future changes to requirements: The ability to adapt the building cost effectively to provide flexible research facilities was a key project objective. The design was directed to allow rapid reconfigurations for changing research programmes and future scientific requirements. This meant adopting a 'plug and play' solution, where the distribution of centralised services enabled a 'kit-of-parts' approach to laboratory layouts. This allows pre-determined components to be connected into the service spines in combinations, restricted only by total service load constraints.

Delivering technical systems integration: To retain the required flexibility in future use, the project team used several techniques to plan, review and implement the design, manage, stakeholder expectations and ensure successful transition to operations. These methods included:

- **Full-scale mock-up:** Due to the complexity of the facility, full-scale mock-ups proved an effective way of gaining buy-in from stakeholders, resolving interface and user issues, and providing financial certainty.
- **Building information modelling (BIM):** A joint BIM environment across the project team and designers was used to co-ordinate information and clarify whole life costs throughout the design phase. For the pre-construction and construction phases, this was adapted into an assembly model to provide clarity for construction sequencing and scheduling, as well as costing. Post construction, the model was developed to host the client's facilities management and maintenance documents.

Courtesy of Elliot Brown

Pillar 1: **Establishing system outcomes to maximise value** 1

Pillar 2: **Setting system requirements** 2

Pillar 3: **Employing a systems integration approach** 3

Pillar 4: **Enabling capability in the organisation** 4

Good practice examples

Example 2

Progressive assurance and acceptance of systems, and enhancing operational capabilities: A Heathrow Terminal 2 case study

In 2012, Heathrow Airport Limited undertook a £2.5 billion redevelopment of Terminal 2 (T2), extending its capacity from 8 million to 20 million passengers per year. Four years earlier, Terminal 5 (T5) had faced significant challenges when it opened, and while ultimately securing the accolade of 'best airport terminal in the world', Heathrow wanted to use the lessons learned to ensure the opening of T2 was successful.

T2 opened smoothly and successfully on 4th June 2014 receiving positive press coverage. Staff knew where they were going, systems worked, and arriving passengers were surprised that this was T2's first day of operation. In October 2014, a survey of passengers by an independent airport benchmarking group rated T2 'the best terminal in Europe'.

Lessons learned from T5 identified that a robust operational readiness programme was needed, for both technical and people capabilities, in order to achieve seamless integration and open successfully on day one.

Progressive assurance and acceptance of technical systems: the approach to testing and proving trials was based on three principles:

- **Progressive technical capabilities:** The team tested sections of T2 in a logical order upon availability, rather than waiting for completion of whole areas. This was a direct result of learning from T5 and was a more efficient way of working.
- **Risk-based approach:** To retain flexibility to accommodate construction delays, the team developed a risk-based approach. This meant understanding and prioritising the highest risk areas of the terminal - where new systems and processes were being introduced – to ensure these were fully tested before opening day. This ensured the most important trials were undertaken and stakeholder confidence was upheld.
- **Increasing complexity:** Individual process elements were tested first, then inter-connected, sequential processes via 'end-to-end' trials, demonstrating full end-to-end systems integration.

Enhancing people capabilities: combining the gradual and staged acceptance of systems with an integrated programme of staff familiarisation and training meant that operators were fully trained and operational from day one.

Courtesy of Heathrow Airport Holdings Ltd

Pillar 1: Establishing system outcomes to maximise value 1 | Pillar 2: Setting system requirements 2 | Pillar 3: **Employing a systems integration approach** 3 | Pillar 4: **Enabling capability in the organisation** 4

Good practice examples

Example 3

Establishing the overall systems integrator and different levels of systems integration: A London 2012 Olympics case study

The London 2012 Olympics was organised to integrate a large complex "system of systems".

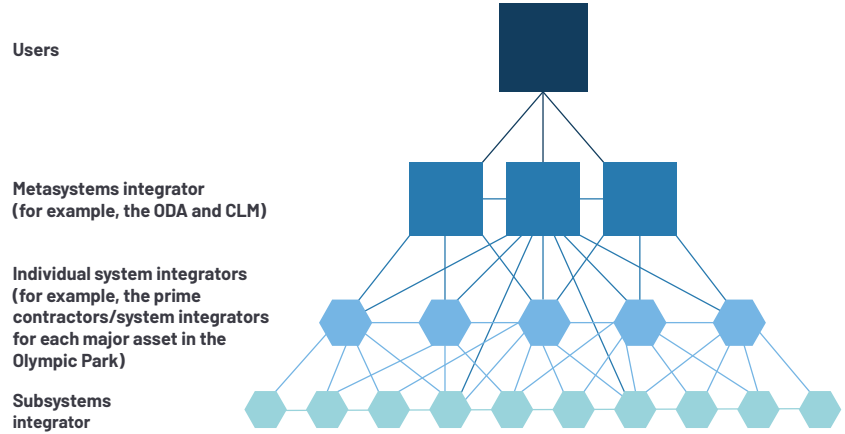
Overall system integration: Sometimes referred to as "meta" systems integration, this depends on the ability to preside over and understand an entire system of systems well enough to make trade-offs and reach decisions in the interest of the overall goals. This task can be performed in-house by a large client, an experienced prime contractor and/or joint-venture delivery partner established on a temporary basis and disbanded on completion of the project.

For the London 2012 Olympics, two temporary organisations were established with the capabilities to understand all the individual systems (all assets located in the Olympic Park), manage external interfaces, and coordinate the integration of the various systems into one overall system of systems. These two organisations jointly performed the role of systems integrator: the Olympic Delivery Authority (ODA) acted as the client and worked with a delivery partner (CLM, a temporary joint venture between CH2MHill, Laing O'Rourke and Mace) to manage the programme.

Different levels of integration:
The ODA managed the external interfaces, acting as a single interface between the project team and users (comprising around 750 stakeholders including the Mayor of London, sporting bodies, LOCOG, Greater London Authority, five London boroughs, International Olympic Committee and British Olympic Association).

Contractors were responsible for building each individual system (for example, the Aquatics Centre and Olympic Stadium projects), creating defined interfaces, and coordinating interdependencies with adjacent systems.

Acting as project manager, CLM was responsible for keeping the ODA fully informed about the progress of the programme, and as the other half of the systems integrator, for coordinating integration of the various individual systems into one system of systems in collaboration with the principal contractor / systems integrator on each individual system project.



Good practice examples

Example 4

Establishing long-term operational system functionality and consideration of evolving technology: A HS1 case study

On railway projects such as High Speed 1 (HS1), 80-85% of the capital expenditure cost is on civil engineering related systems, and 15-20% is on the operating systems. However, in terms of the associated benefits, the return is measured on how the 15-20% spent on operating systems performs.

HS1 comprises a mix of a railway environment (for example, for safety and security) and a high street environment (for example, for heating and ventilation of stations). These systems are integrated to meet safety and reliability requirements, but only within individual systems, for example signalling, and not across other railway or high street environment systems.

Some systems still in use were designed in the 1990s, and HS1 has had to address issues related to living with systems that were leading-edge 30 years ago but are now considered "old technology". There is also a mixture of Smart (incorporating AI and/or machine learning) and Dumb (no AI or machine learning) systems, and intentions to turn appropriate Dumb systems into Smart systems as and when they come up for renewal.

Courtesy of High Speed 1 Ltd

Key learning points from the HS1 experience to date are:

- **Establishing system functionality for long-term operational use:** You need to bring in people early who understand the system, its internal/external interfaces and potential long-term operational changes. Take care not to rely only on designers (for example architects and civil engineers) when defining system functionality, as they may not be best placed to determine how the operational use of the system may need change in the long-term after the project team has disbanded.
- **Consideration of evolving technological requirements:**
  - Consider the legacy issues of proprietary systems. For example, one particular HS1 system with an original capital cost of £2m, had an annual maintenance fee of £0.5m and a callout charge of £10k per visit, which meant its whole-life cost was far more that its capital cost. Learning from this experience, a decision was made by HS1 to move to open system platforms (using common software standards not attached to a particular vendor) where possible. It is now common for projects to use off the shelf systems which have much shorter lifespans, allowing technological enhancements to be brought in while minimising long-term cost commitments, rather than systems with a longer lifespans of 20-30 years.
  - Plan ahead for the funding needed to undertake system renewals. The horizon for renewals is often not fully considered, and as in the case of HS1 signalling systems, can take up to 20 years from the initial point of definition to becoming operational.

Good practice examples

Example 5

Ensuring different technologies integrate, and progressive assurance and acceptance of systems: A Type 26 Frigate case study

A warship is an incredibly complex system of systems, integrating seamlessly so that the platform can float, move and importantly sense, decide, deliver and fight.

The Type 26 Anti-Submarine Warfare frigate is a highly capable and versatile multi-mission warship, optimised to undertake Anti-Submarine Warfare, but with inherent air defence and general-purpose operation capabilities for deployment anywhere on the world's oceans.

The design and delivery into service of these new ships involves over 2000 BAE Systems employees, working across 10 sites in the UK, collaborating with over 100 suppliers of equipment and systems in the UK and around the world, in partnership with the Defence Equipment & Support within the Ministry of Defence and the Royal Navy.

Don't assume different technologies can integrate: Unlike the aircraft industry where prototypes are common, warship creators have to specify technologies and equipment that will only be brought together for the first time as an overall system during the build of the first warship and therefore face a choice; either integrate, prove and test complex systems on board during the test of the first ship, or conduct advanced testing in land-based facilities in parallel with the build programme, before testing the physical ship.

With multiple technologies and systems converging for the first time in a new platform, the choice was made to "left shift" systems integration testing for Type 26 into a land-based facility – building on successful experience of having done so for the Type 45 Destroyer Class and the Queen Elizabeth Class aircraft carrier amongst others. Such a left shift approach has also been applied for Crossrail 1 and is illustrated in Example 6 within this module.

The Maritime Integration and Support Centre (MISC) provides a land-based integration and proving environment for Royal Navy surface ship combat systems.

Pillar 1: Establishing system outcomes to maximise value 1

Pillar 2: **Setting system requirements** 2

Pillar 3: **Employing a systems integration approach** 3

Pillar 4: Enabling capability in the organisation 4

Progressive assurance and acceptance of systems: The capability at the MISC includes shared computing environments, flexi-labs which can simulate any mission system and platform configuration needed, and more recently the introduction of the App Locker which takes advantage of the 'sandbox' facility in Royal Navy's Shared Infrastructure private cloud solution. Mission systems capability providers can operate in a secure 'locked-down' environment at a security classification appropriate to their development, accessing a range of mission systems expertise resident on site.

As a consequence of left shifting and the collaboration across systems and suppliers made possible at the MISC, the first version of the Combat Management System (CMS) software for Type 26 had its first factory acceptance test several years ahead of the first in class going to sea.

Development of the CMS at the MISC will also optimise the planned sea trials of the physical warship. Without this, sea trial durations would be significantly longer, and the cost of rework due to systems integration issues discovered late would be significantly higher.

Courtesy of BAE Systems

Good practice examples

Example 6

Responsibility for systems integration across interfaces and maintaining focus on the end state: A Crossrail 1 case study

For complex projects like Crossrail 1 (CRL1), it is important to understand the wider delivery environment, including all the necessary operational interfaces. The CRL1 signalling system needs to integrate with around 7 separate signalling systems used by trains scheduled to run on its track (as illustrated in the diagram to the right).

The boundaries for these signalling systems are at geographically different points on different lines which created logistical and safety issues. Stakeholder engagement was key and required weekly stakeholder meetings and continuous communication.

CRL1 was very successful in breaking down the overall project requirements into requirements for each of the individual systems the project was to deliver, but the process of validating those systems and keeping interface and integration issues in view of the delivery team was less successful.

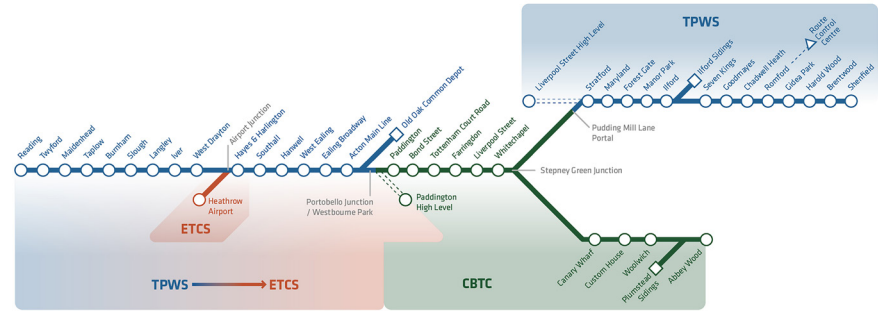
Clarity on responsibility for systems integration across interfaces: CRL1 envisaged a light touch approach to systems on the basis that the contractors would naturally integrate. As a result, those working on different systems at the beginning of CRL1 were not fully integrated from the outset, the major focus instead being on civil engineering. Key associated lessons are:

- Be clear about the environment you are delivering in (CRL 1 links into old railway signalling systems too).
- Understand what the systems are and the interfaces between them.
- Determine when in the project life cycle to bring systems and sub-systems together and develop the organisational structure to achieve this well in advance.
- Engage the users early. This is how you'll understand the functionality needed and how success of the service of the overall system will be measured.

Maintaining focus on the end state: The division and disconnect between the delivery and systems functions meant that while the physical asset looked finished, the testing and systems validation had not yet been carried out. At a late stage in the construction, there were fundamental questions still to be answered around how CRL1 would integrate the systems between various contracts (for example station systems and trackside systems). Key associated lessons are:

- Evolve the leadership team as the project progresses through life cycle stages.
- Ensure the leadership team has core domain knowledge of the systems is being integrated.

Signalling across the Elizabeth Line



Courtesy of Crossrail Ltd

Pillar 1: **Establishing system outcomes to maximise value** 1
Pillar 2: **Setting system requirements** 2
Pillar 3: **Employing a systems integration approach** 3
Pillar 4: **Enabling capability in the organisation** 4

Good practice examples

Example 7

Aligning project governance with clarity on responsibility for integration across interfaces: An Oxford Flood Alleviation Scheme case study

Oxford has a long history of flooding. In recent decades significant floods have damaged homes and businesses, closed the main railway line and major roads. The Environment Agency maintains rivers and streams in and around Oxford. The Oxford Flood Alleviation Scheme (OFAS) is designed to allow for climate change impacts and manage flood risk in Oxford over the next 100 years.

The main outcome of OFAS is a much-reduced flooding risk to nearby homes, businesses, and infrastructure over the next 100 years. Subsidiary benefits include:

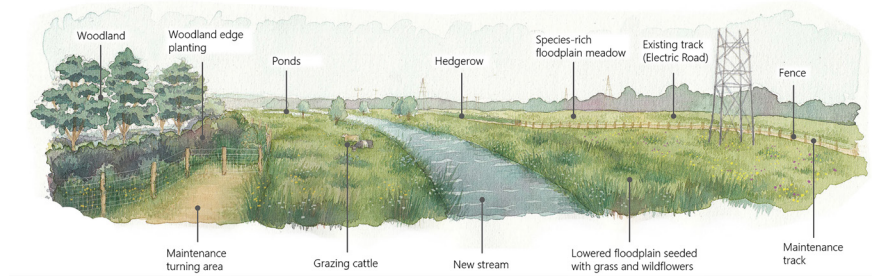
- Environmental improvements for people living locally throughout the duration of the scheme.
- A scheme whereby all partners and stakeholders benefit.
- A scheme which balances long-term social, economic, and environmental needs. A partner is currently being sought to maintain the scheme over its 100-year design life.

Aligning project governance and stakeholders: The scheme partners include a number of national, regional and local organisations:

- Environment Agency (EA)
- Highways England
- Oxford City Council
- Oxfordshire County Council
- Oxfordshire Flood Alliance
- Oxfordshire Local Enterprise partnership
- Thames Regional Flood and Coastal Committee
- Thames Water
- University of Oxford
- Vale of White Horse District Council

Almost all of the partners were co-funders of OFAS. This multi-partner and funder arrangement was reflected, not only in the scope of the scheme, but also in the governance arrangements which ensured key decisions were mutually beneficial to all partners.

Clarity on responsibility for integration across interfaces: With so many active stakeholders being part of the decision-making process it was important to align and integrate working practices and financial processes. This allowed robust consideration of technical interfaces, given that all main services (rail, road, electricity, sewers) ran through a narrow land corridor impacted by flooding. The strength of this partnering approach was demonstrated by the way it enabled Oxfordshire County Council to take advantage of works done by others to bring forward the replacement of a major bridge and so alleviate traffic congestion.



Courtesy of The Environment Agency

Pillar 1: **Establishing system outcomes to maximise value** 1
Pillar 2: Setting system requirements 2
Pillar 3: **Employing a systems integration approach** 3
Pillar 4: Enabling capability in the organisation 4

Good practice examples

Example 8

Aligning governance with overall system success: A Nuclear Decommissioning Authority case study

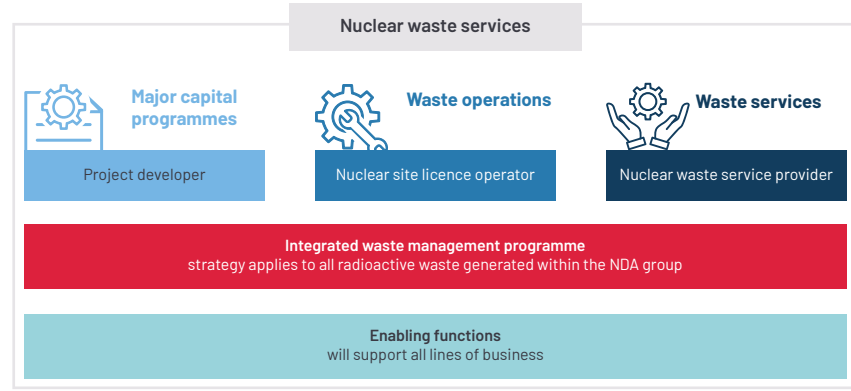
The 2016 Nuclear Decommissioning Authority (NDA) Strategy made a commitment to develop a single radioactive waste strategy for the NDA group which would apply to all radioactive waste generated within the NDA estate. Nuclear Waste Services (NWS) has been created within NDA to support delivery of this strategy, with the vision:

"A sustainable future by providing integrated, through-life radioactive waste management solutions in safe, cost-effective ways that protect people and the environment."

NWS's role is to bring together, and to provide a focal point for, the management of radioactive waste from across the various parties engaged in the UK nuclear industry. NWS will provide 90% of the UK's radioactive waste management services, provide both geological and near-surface disposal capabilities, and deliver committed savings of £2.3bn with £50m by 2023.

Successful implementation of the NWS vision requires an integrated system-wide approach, in particular through aligned governance and operational arrangements:

- A group wide commitment to work to an integrated plan, with all business cases associated with waste checked for alignment.
- Governance of the integrated plan delegated to NWS and overseen by the Integrated Waste Management Programme.
- Establishing one overall operational group by bringing together decommissioning planning, inventory management treatment, conditioning facilities, and disposal facilities, so that a holistic approach is taken across the entire waste management life cycle.
- A commitment to improve the quality and reduce inherent uncertainty within key data sets and to effectively share information across all parts of the NDA group, and to develop an integrated information management system which will allow single users in the industry rapidly to run future scenarios informed by common datasets.



Pillar 1: **Establishing system outcomes to maximise value** 1
Pillar 2: **Setting system requirements** 2
Pillar 3: **Employing a systems integration approach** 3
Pillar 4: **Enabling capability in the organisation** 4

Suggested further reading

	Reference	Use
1	**Guidance** Transforming infrastructure performance: Roadmap to 2030 - Infrastructure and Projects Authority 2021	Transforming Infrastructure Performance is the IPA's flagship programme to lead system change in the built environment. Its purpose is to transform how the government and industry decide to intervene in the built environment, to drive a step change in infrastructure performance.
2	**Report** Our vision for the built environment - Centre for Digital Built Britain 2021 www.visionforbuiltenvironment.com	A vision to secure better outcomes from the built environment for the long-term devised by 45 cross-industry figures and 75 industry leaders, published in 2021.
3	**Guidance** The futures toolkit: tools for futures thinking and foresight across UK Government- Cabinet Office 2018	A set of tools to help embed long-term strategic thinking within the policy process. It is intended for policy officials and analysts across government.
4	**Guidance** Principles for project success – Infrastructure and Projects Authority 2020	A quick guide for practitioners on things to get right for any project to succeed.
5	**Report** The gemini principles - Centre for Digital Built Britain 2018	This report was published to enable alignment on the approach to information management across the built environment, including definitions and principles to make it easier to share data in the future.
6	**Report** A systems approach to infrastructure delivery – Institution of Civil Engineers 2020	A review of how systems thinking can be used to improve the delivery of complex infrastructure projects.
7	**Report** Crossrail – a progress update – National Audit Office 2021	This report makes recommendations for Crossrail Ltd and the sponsors as the programme nears completion.
8	**Report** Innovation in megaprojects: systems integration at London Heathrow terminal 5	This report presents the findings of research on design and production of London's Heathrow Airport Terminal 5 (T5). The findings were used to develop a conceptual framework— a systems integration model—to identify the project and operational processes that contribute to success in delivering megaprojects.
9	**Guidance** INCOSE SE Competency Framework	A set of competencies for systems engineering within a framework that provides guidance on the knowledge, skills, abilities, and behaviours important to systems engineering effectiveness.

Suggested further reading

Reference	Use
10 **Report** Whyte J, Davies A. 2021. "Reframing Systems Integration: A Process Perspective on Projects"	This report highlights the concept of systems integration, with a focus on the importance of systems that projects deliver as they become more complex and face significant uncertainty.
11 **Guidance** Guide for the Application of Systems Engineering in Large Infrastructure Projects - INCOSE Infrastructure Working Group 2012	The purpose of this guide is to reposition traditional systems engineering practices, as they have been successfully developed and applied in the defence, aerospace, manufacturing, and telecommunications industries, into the context of the construction industry.
12 **Guidance** Guideline for Systems Engineering within the Dutch civil engineering sector	This guidance outlines the current situation of systems engineering in the civil engineering sector and the challenges for the future.
13 **Report** Lessons from transport for the sponsorship of major projects – Department for Transport 2019	Identifies 24 lessons learned from transport to improve controlled delivery of major projects by government departments.

Glossary

Accountability
The accountable person is the individual who is ultimately answerable for an activity or decision. This includes 'yes' or 'no' authority and veto power. Only one accountable person can be held to account. An accountable person has to be accountable to someone for something. Accountability cannot be delegated or shared.

The responsible person is the individual who actually undertakes the task: in other words, they manage the action/implementation. Responsibility can be shared. The degree of responsibility is determined by the individual with the accountability.

Asset
Anything tangible or intangible that is owned or controlled with the expectation of present or future benefit.

Benefits
In the context of project delivery, benefit is the measurable value or other positive impact resulting from an outcome perceived as an advantage by one or more stakeholders, and which contributes towards one or more objectives.

Capability
In the context of Routemap, capability describes the ability of the sponsor, client, asset manager and market to organise for effective and efficient delivery. It refers to the capability of all or part of an organisation, and not that of the individual.

Client
In the context of Routemap, the client is the organisation that is responsible for undertaking the work to fulfil the sponsor's requirements. The client translates the requirements from the sponsor and manages the delivery. The client selects the most appropriate suppliers. In some contexts, the sponsor and client could be from the same organisation.

Complexity
In the context of Routemap, project complexity is a measure of the inherent difficulty of delivering a project. This is assessed on factors such as the stability of the wider delivery environment, the level of innovation required, and the number of stakeholders involved.

Governance
Governance defines relationships and the distribution of rights and responsibilities among those who work with and in the organisation. It determines the rules and procedures through which the organisation's objectives are set and provides the means of attaining those objectives and monitoring performance.

Market
In the context of Routemap, the market comprises organisations which integrate and compete to deliver goods or services to one or more clients. This includes

- the players, for example, sellers/buyers/partner
- the rules, for example, regulation, legislation
- processes, for example, procurement, delivery
- structure, for example, relationships between buyers, sellers, partners

Outcomes
The result of change, normally affecting real-world behaviour or circumstances. Outcomes are desired when a change is conceived. Outcomes are achieved as a result of the activities undertaken to effect the change; they are the manifestation of part or all of the new state conceived in the target operating model.

Outputs
A specialist product (the tangible or intangible artefact) that is produced, constructed or created as a result of a planned activity and handed over to users.

Requirements
Requirements are the project stakeholders' wants and needs, clearly defined and with acceptance criteria.

Glossary

Risk
The effect of uncertainty on objectives. Risk is usually expressed in terms of causes, potential events, and their consequences.

- a cause is an element which alone or in combination has the potential to give rise to risk
- an event is an occurrence or change of a set of circumstances and can be something that is expected which does not happen or something that is not expected which does happen.
- the consequences are the outcomes of an event affecting objectives, which can be certain or uncertain, can have positive or negative direct or indirect effects on objectives, can be expressed qualitatively or quantitatively.

Sponsor
In the context of Routemap, the sponsor is an organisation that secures the funding, oversees the business case and is responsible for specifying the requirements to the client. In some contexts, the sponsor and client could be the same organisations.

Stakeholders
Any individual, group or organisation that can affect or be affected by or perceive itself to be affected by an initiative (programme, project, activity or risk).

Systems integration
The process by which multiple individual systems are successfully combined to function seamlessly together.

Systems integrator
An organisation responsible for systems integration. The systems integrator may be part of the client organisation or a separate organisation specifically procured for this purpose.

Systems-of-systems
This term describes the many different and interconnected assets and networks of the built environment, alongside their digital representations, the services they provide and the natural world.

Target operating model
The target operating model refers to how the asset or change will be funded, owned, operated and maintained once the project has closed.

Acknowledgements

The IPA would like to thank the following organisations and individuals that contributed time and expertise to the development of the Project Routemap.

Anglian Water
Arup
Arnab Banerjee
Asset Management Consulting Ltd (AMCL)
Association of Project Management
BAE Systems
Babcock
Becky Ivers
Crossrail
Crossrail 2
Crossrail International
Department for Transport
Heathrow Airport Ltd
High Speed 2
Mott MacDonald
Highways England
Office of Government Property
Imperial College
International Council on Systems Engineering (INCOSE, UK)
International Project Management Association
Major Projects Association
Martin Buck
Martin Samphire
Ministry of Defence
Philip Wilbraham
PricewaterhouseCoopers (PwC)
Routemap Ltd
Sellafield Ltd
Systra Group
Thames Water
Transport for London
Turner & Townsend
University College London
University of Sussex
Wendy Cartwright

Infrastructure and Projects Authority

Contact IPA

www.gov.uk/IPA
IPA@ipa.gov.uk
@ipagov

Cabinet Office
Correspondence team
70 Whitehall
London
SW1A 2AS

publiccorrespondence@cabinetoffice.gov.uk

General enquiries: 020 7276 1234

HM Treasury
Correspondence team
1 Horse Guards Road
London
SW1A 2HQ

public.enquiries@hmtreasury.gsi.gov.uk

General enquiries: 020 7270 5000

Produced by the Infrastructure and Projects Authority