



# A Systems Approach to Infrastructure Delivery

A review of how systems thinking can be used to improve the delivery of complex infrastructure projects

# Foreword



**Andrew McNaughton,**  
Chair, Review  
Steering Group

When we think of great infrastructure projects, we often think of amazing feats of civil engineering: tunnels bored under cities, bridges erected over expanses of water, or railway lines criss-crossing the country. In each of these cases, they are of little use without a host of other elements working with them to create an integrated and functioning system – a railway line is of little use without signalling, trains or stations.

Systems, and not structures, provide the mobility, sanitation, energy and all other infrastructure services on which we rely. It is systems, not just structures, that we need to adapt if we are to decarbonise our economy. These systems are increasingly automated, interdependent and reliant on technology that is evolving rapidly. Yet many major infrastructure projects are still dominated by civil and structural engineering alone.

In recent years, a number of these major projects have suffered from severe delays and overrunning costs. Against this backdrop, I was asked to investigate whether a more systems-focused approach could improve project delivery and the effect this would have on how projects are conceived, led, designed, delivered and integrated into an infrastructure owner's existing operations.

My thanks go to the review's steering group for their invaluable advice and to the many colleagues from a wide range of industries who have been so generous with their time and insight. I'd also like to thank the ICE team for all their support.

Reflecting on the evidence we have gathered, it is abundantly clear that continuing as we are is not an option. Big generational challenges such as the UK's commitment to a net-zero carbon economy are adding further layers of complexity to what we do. Technology in areas such as communications, transportation and power generation, distribution and storage is evolving at such a pace that it is forcing a change in how we design, integrate and commission infrastructure systems.

Increasingly, the functionality of infrastructure is sitting in this technology suite and in the digital twin of the physical asset. To me, this presents a huge opportunity to be much more responsive to the changing needs of users. In the future, it seems certain that we will be making different types of interventions into infrastructure systems, with traditional construction projects giving way to the kind of work that may look and feel closer to a software upgrade.

There is a risk that the construction industry will see this as a threat to its current, more dominant position, so it is hugely encouraging that this review aligns so closely with other industry-led change initiatives. I'm delighted that ICE has agreed to support a second phase of work to further develop and test the Systems Approach to Infrastructure Delivery (SAID) model set out in this report.

Phase Two will involve working closely with Project 13, the National Digital Twin Programme and other initiatives led by the Construction Leadership Council (CLC). We will also continue to have a close working relationship with the Infrastructure and Projects Authority (IPA) and its Transforming Infrastructure Performance programme.

One of the recurring themes of this review has been that infrastructure has allowed itself to fall behind other sectors such as oil and gas or aerospace, which face similar project delivery challenges. Now is the time to close that gap and create an industry that is fit for the challenges and opportunities of the 21st century, and to provide the infrastructure services that future generations deserve.

“Big generational challenges such as the UK's commitment to a net-zero carbon economy are adding further layers of complexity to what we do”

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## About the review

In March 2020, ICE asked Andrew McNaughton, Chief Operating Officer of consultancy Systra and former Chief Executive Officer of construction firm Balfour Beatty, to lead a review into the benefits of applying systems thinking to the delivery of complex, major infrastructure projects. The review steering group, made up of key industry thought-leaders, was asked to assess the impact of accelerating technological change and the different approaches taken in adjacent industries to address these changes.

Between April and October 2020, ICE carried out more than 30 interviews with project practitioners from the infrastructure, aerospace, defence, oil and gas, and technology sectors. A detailed literature review was also conducted with the help of Professor Andrew Davies, one of the UK's leading academic specialists in systems integration and complex projects.

ICE has used this insight to create a Systems Approach to Infrastructure Delivery (SAID) that can be used to help deliver better outcomes for infrastructure owners and users. A second phase of the review will develop and test the SAID model. Insight from Phase Two will be gathered by ICE in 2021.

### Steering group members

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Find out more: [ice.org.uk](https://www.ice.org.uk)

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“An increasing number of signature projects are delivered behind schedule, beyond the cost estimate and fail to meet the public’s expectations”

# 01 Executive summary

**New or expanded infrastructure services such as mobility and clean energy are delivered via complex projects that bring together physical assets, technology and digital information in the form of a Building Information Model (BIM) or a digital twin.**

The majority of these assets will need to be integrated into existing networks and services. Asset owners are also seeking a growing range of outcomes from infrastructure including urban regeneration, decarbonisation and wider access to jobs and opportunities. This means that even relatively small construction or refurbishment projects are best seen as interventions into existing complex systems with physical, economic and social characteristics.

The rapid evolution of technology adds to the challenge. In areas such as communications or power distribution and storage, the rate of change is far outstripping developments in structural design or construction methods. In parallel, the possibilities opened up by digital twins to improve delivery and operation of infrastructure are also expanding rapidly. This all points to a future in which physical assets form a platform or ‘box’ for the data and technology that will provide the infrastructure services on which millions of people depend. This technology will go through many cycles of development during the lifetime of the physical structures that surround it.

The dominant leadership and delivery model for infrastructure projects has not evolved to reflect these profound changes. Delivery remains in the hands of traditionally trained engineers working within organisations using long-established construction industry methods. The consequence of this conservatism is an increasing number of signature projects that are delivered behind schedule, beyond the cost estimate and that fail to meet the public’s expectations.

The main output from this review is therefore a new model, a Systems Approach to Infrastructure Delivery (SAID). SAID complements Project 13, also supported by ICE, but has a different focus. Project 13 supports the creation of enterprises, which are long-term commercial arrangements between infrastructure owners and their supply chain. SAID is a model for applying systems thinking to project delivery that has been welcomed enthusiastically by Project 13’s leaders. SAID can be used either in conjunction with or separate from Project 13.

SAID is driven by the needs of users. It places the onus on the owners and operators of infrastructure to translate those needs

into clear outcomes around which assets and networks can be designed, delivered and operated as whole systems.

Systems thinking, systems engineering and systems integration are at the heart of SAID. The review has found that these practices have been extremely effective in other project-based industries such as oil and gas and aerospace. Adopting what works from these sectors can help the infrastructure sector to make rapid progress in the short term. In the medium term, it needs to look at how the technology and software industries have taken advantage of an intense continuous development mindset to help systems adapt to rapidly changing user needs, and the opportunities created by technological change.

The SAID model also stresses the importance of committing resource to the front end of projects to minimise delivery risks. In other sectors, this comes under different names including ‘front-end loading’ and ‘left-shift thinking’. Whatever the term, the hard evidence is clear: projects that commit to being shovel worthy before moving into delivery are much more likely to be successful in terms of budget, delivery date and user satisfaction.

This front-end work does not eliminate all risk. It does, however, identify the sources of risk and allow leaders to design a project model that manages them more effectively. Data oils projects in the SAID model. High-quality, timely data is sometimes described as the golden thread that should run through projects. In the SAID model, this becomes a golden loop as information generated by the project is integrated back into operating systems and forms the basis for future upgrades to services.

Lastly, the model is led by an open, agile leadership style. Evidence submitted to the review made it clear that the heroic leadership style traditionally associated with big infrastructure projects is simply not suitable for complex projects. Borrowing from ideas fostered in the military, SAID requires leaders to be able to define intent, manage the interface with external stakeholders and then step back and let empowered, highly competent teams manage the day-to-day risks to the system. SAID also stresses the importance of diversity within projects and the need for different voices to have prominence at each stage of the lifecycle.

The review is now planning a second stage. Industry must lead the charge for change that will work alongside complementary initiatives such as Project 13 and the National Digital Twin Programme to develop and trial aspects of the SAID model with live and recently completed infrastructure projects.

## 02 Why now?

### The current approach to delivering complex infrastructure projects is facing obsolescence.

The sector is struggling to deal with projects that require complex systems to be planned, delivered and, most importantly, integrated to provide the mobility, energy, sanitation and other infrastructure services on which people depend. In these projects, traditional civil engineering, while still a large capital cost, exists to support a system that is made up of multiple physical, digital and human components. A new tunnel, for example, exists to support a system such as a railway that includes physical trains, stations and track; digital signalling, safety and communications; and human components such as the procedures followed by drivers.

The centrality of the system, rather than the civil engineering, does not only apply to high-profile megaprojects. The use of technology to maintain and operate infrastructure networks means that interconnectedness has grown substantially in recent decades. Today, even relatively small projects are best seen as interventions into existing complex systems that provide the services needed by millions of people. In the future, the increasingly technology-based functionality of infrastructure systems will mean that a different mix of skills will be needed to execute these interventions.

This technical complexity needs to be understood and managed within a delivery environment that is itself increasingly complex. Infrastructure projects face enormous and rapidly shifting pressures from politicians, local communities and many other stakeholders.

### This is a huge opportunity for the infrastructure sector and its customers.

Access to infrastructure services has never been more important. In the short term, it will support economic recovery post-Covid-19. In the longer term, huge investment in infrastructure will be needed to deliver the UN's Sustainable Development Goals and execute the transition to a net-zero carbon economy.<sup>01</sup>

The review highlighted how other sectors have successfully transformed themselves, becoming much more efficient, productive and responsive to customer needs. The review believes that infrastructure can, and must, transform in the same way. In

the immediate term, rapid progress can be made by adopting practices already in use in project-based sectors such as defence systems and oil and gas, which share similar characteristics to construction and infrastructure.

There is also much to learn from sectors that look and feel very different from infrastructure. The technology industry, for example, has adopted ways of working that allow it to cope with rates of change measured in weeks rather than months or years. If infrastructure systems are to fulfil user expectations consistently, as these sectors more habitually do, civil engineers need to establish which of these practices can be used in infrastructure projects.

### This is the moment to transform how infrastructure projects are conceived, planned, delivered and operated.

This transformation will need fundamental changes to be made to project and engineering management so that they are fit for purpose for defining, designing, delivering and integrating infrastructure systems. It will place operations and the services provided to customers at the heart of everything that civil engineers do. It will be data-driven, fully embracing the opportunities created by digital technology. It will understand that the digital deliverables are as important to owners and users as physical structures. And it will mean a fundamental transformation of the leadership, culture and organisation of infrastructure projects.

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

### Why systems...?

**Systems thinking** means embracing the idea that the whole is more important than the sum of its parts. In the simplest terms, it means understanding how all of the component parts of a project work together to meet a common objective. As projects become more complex, it also helps project leaders to understand how individual assets will contribute to the performance of the wider networks in which they sit.

**Systems engineering** is the application of systems thinking to engineering design and management. It helps different teams working on individual components of projects to stay aligned to a common goal.

**Systems integration** is the practical task of bringing together all of these components and taking them into service as a single, fully-functioning system.

**The 'extended system'** refers to the sociopolitical environment in which a project is to be delivered and the many – often hundreds – of stakeholders who can influence it.

<sup>01</sup> In June 2019, the UK Government made a binding commitment to reduce the nation's net greenhouse gas emissions to zero by 2050.

# Infographic: A Systems Approach to Infrastructure Delivery

## START

WE'VE COME A LONG WAY FROM HOW CIVIL ENGINEERS DESIGNED & BUILT THINGS IN THE PAST

TECHNOLOGY DRIVEN

INTERCONNECTED WORLD

HOW WE DELIVER INFRASTRUCTURE PROJECTS

EVERY PROJECT IS A **COMPLEX SYSTEM OF SYSTEMS**

INTERDEPENDENT TECHNOLOGICAL ELEMENTS

EACH OF WHICH IS A **SYSTEM ITSELF**

WE'VE BEEN THINKING HOW TO **IMPROVE**

PLANNING

DESIGN

DELIVERY

USING A **SYSTEMS APPROACH**

## 01

THINK **OUTCOMES**

PROTECT ECOSYSTEM

REDUCE POLLUTION

IMPROVE LOCAL AREA

EMPLOYMENT OPPORTUNITIES

NOT **EDIFICES**

CONSTRUCTION OF TUNNELS

A SEWER PROJECT

SEWAGE TREATMENT WORKS

OWNERS MUST CLEARLY **DEFINE OUTCOMES** SO ENGINEERS & TECHNOLOGY DEVELOPERS **CAN DELIVER FOR THAT USE**

## 05

THINK **SHOVEL WORTHY**

FRONT END DEVELOPMENT

IMPROVES STAKEHOLDER ENGAGEMENT & MANAGEMENT

STABLE DELIVERY ENVIRONMENT

CLEARER PROJECT DEFINITION

FUTURE PROOF PROJECTS

NOT SHOVEL READY

## 04

USE THE **V CYCLE PROCESS**

DEFINE SYSTEMS & PARTS

VERIFY & VALIDATE

TEST & INTEGRATE

IMPLEMENT

ESTABLISH SYSTEMS ARCHITECTURE

MANAGE TECHNOLOGY DEVELOPMENTS

UPGRADE WITH MINIMAL DISRUPTION

GIVE **CLEAR DIRECTION**

## 03

OWNERS MUST **OWN PROJECTS**

FUNCTIONAL REQUIREMENTS

TECHNOLOGY & INNOVATION RISKS

DATA REQUIREMENTS

CLOSE THE **GAP**

INFRASTRUCTURE

SECTORS ADAPTING BETTER TO TECHNOLOGICAL CHANGE

CHERRY PICK **BEST PRACTICES** TO IMPROVE DELIVERY EFFICIENCY

TESTING

PROTOTYPES

## 06

BAKE **SYSTEMS THINKING AND RISK MANAGEMENT** INTO THE **PROJECT DNA**

DESIGN AN **ORGANISATION AND STRUCTURE** THAT MIRRORS HOW YOU'RE GOING TO **MANAGE RISK**

## 07

AGILE LEADERSHIP

ADAPTS TO **MULTIPLE RISKS** IN **COMPLEX SYSTEMS**

SPREAD **AUTHORITY** THROUGH **EMPOWERMENT MODELS**

LISTEN TO THE **RIGHT VOICE** AT THE **CRITICAL MOMENTS**

ENABLE **FRONT LINE** PEOPLE TO **MAKE DECISIONS**

BATON **HANDOVER**

## 08

DEFINE **VITAL DATA**

APPROPRIATE **COLLABORATION MODEL**

SHARE IT THROUGH **THE SUPPLY CHAIN**

**DATA OILS** YOUR PROJECT

COLLABORATING AROUND **SHARED DATA**

INCREASES **PRODUCTIVITY**

ENABLES **INTEGRATION**

IMPROVES **PERFORMANCE**

A **SYSTEMS APPROACH** WILL **TRANSFORM** HOW WE

CONCEIVE

PLAN

DELIVER

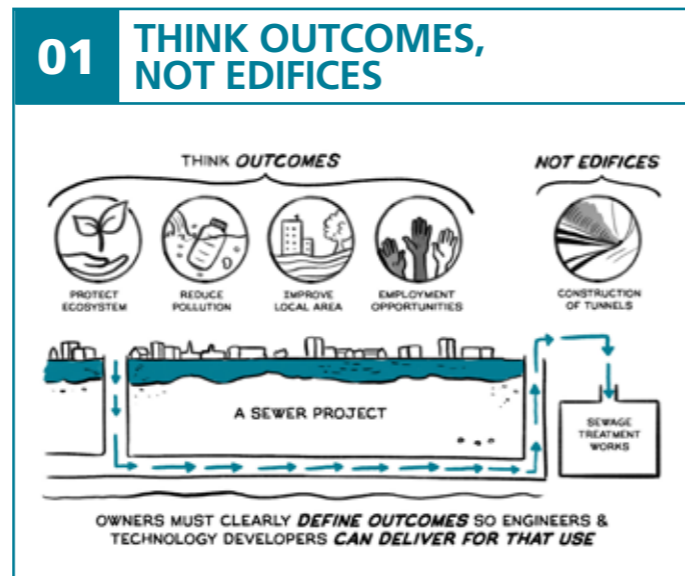
OPERATE

**END**

VISIT [ICE.ORG.UK](http://ICE.ORG.UK) TO WATCH THE SAID ANIMATED FILM

# 03 Doing a better job: a Systems Approach to Infrastructure Delivery (SAID)

The review revealed enormous support for much greater use of systems thinking in how the infrastructure industry delivers complex projects. It heard that a systems approach could provide better outcomes for owners and users and help the sector to make progress with its great strategic challenges, not least its contribution to achieving net-zero carbon emissions by 2050. The review has used these findings to propose a new Systems Approach to Infrastructure Delivery. The SAID model has eight components.

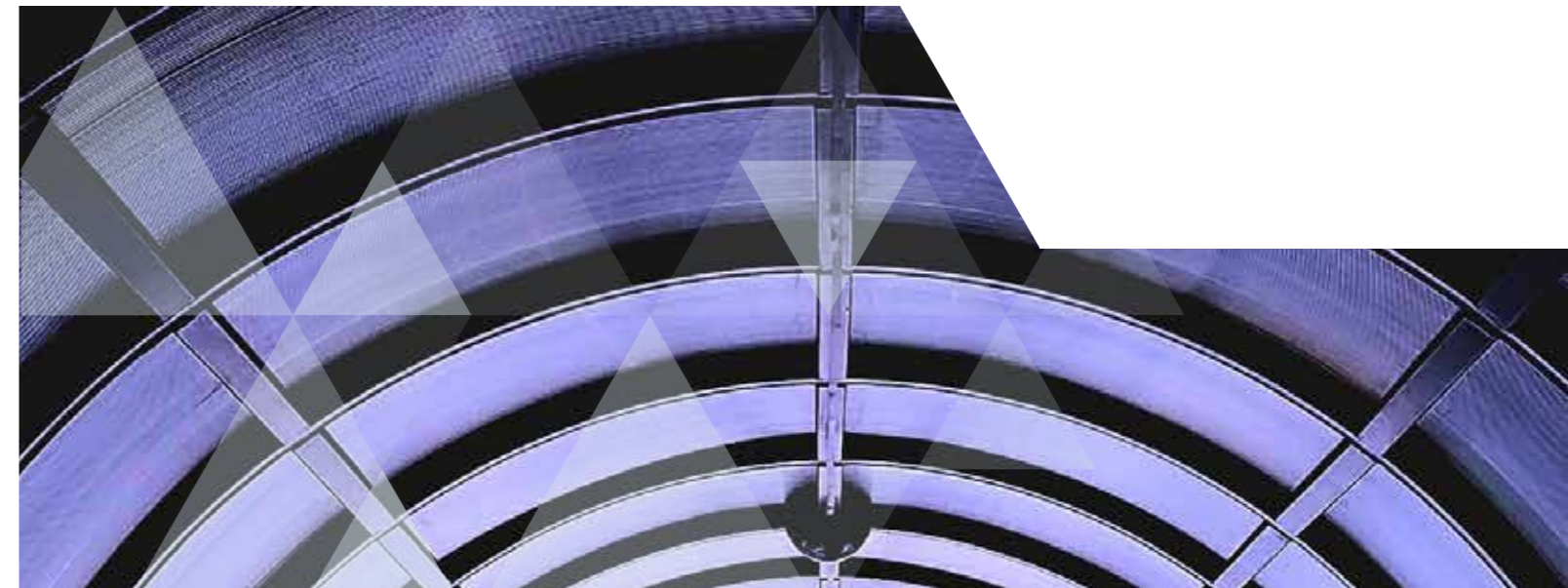


**Owners must clearly define the user outcome, so that engineers and technology developers can deliver for that use.**

- ▶ The purpose of infrastructure projects is to provide a service that meets the needs of their owners and users – not just to deliver a physical structure.

- ▶ Projects can easily go wrong if one aspect dominates. In infrastructure projects, this is often the most expensive element – normally the civil engineering. Finishing the bridge, tunnel or building is the overwhelming priority, right up until the point that it becomes clear that there are serious problems in bringing the system, of which it forms merely one part, into service.

**Set the right project narrative.** The review found that complex infrastructure projects that are seen primarily as exercises in civil engineering excellence are at a higher risk of losing focus on outcomes and failing to allocate enough resources to their systems integration challenges.



## SAID and other improvement initiatives

This review complements a number of other initiatives that are seeking to push the industry in a similar direction. These initiatives, driven by the Infrastructure and Projects Authority and the Construction Leadership Council, are also a rich source of insight, tools and case studies for any organisation looking to implement the SAID model. Here are some of the most relevant.

### Infrastructure and Project Authority

The Project Initiation Routemap was first issued in 2013 and updated in 2016, with a further update in the pipeline. It condenses a large amount of existing best practices into a single tool that helps clients to assess the complexity of their project environment and the capabilities they will need to manage it. Seven Align for Success modules offer detailed guidance on governance, requirements, execution strategy, organisational design and development, procurement, risk management and asset management.

The Transforming Infrastructure Performance programme builds on the IPA's 2017 report of the same name. It aims to ensure that public sector projects are selected, initiated and integrated into the UK's infrastructure

systems in a way that maximises their whole life performance in line with the Government's social, environmental and economic objectives.

The Government is working with the construction industry to create a Construction Playbook to support the delivery of 'faster, better, greener' infrastructure that provides value for money, while supporting a more stable supply chain. The playbook will provide a consistent approach to the procurement of publicly funded projects by bringing together best practice from across the sector. The guidance will cover planning, evaluation, and contract selection and implementation.

### Construction Leadership Council

Project 13 brings together a set of principles based on existing industry best practice to create a new enterprise-based, outcome-focused delivery model. The model is to be put into practice by collaborative teams made up of owners and their main supply chain partners. The Project 13 framework also comprises five pillars (Capable Owner, Governance, Organisation, Integration and Digital Transformation) and a maturity matrix. The principles are currently being put into practice by early adopters including Anglian Water, Heathrow Airport,

Sellafield and Sydney Water. Their experiences are being used to shape new products to aid the wider industry's adoption of Project 13.

The Centre for Digital Built Britain (CDBB) is a partnership between the Department of Business, Energy and Industrial Strategy and the University of Cambridge to understand how the construction and infrastructure sectors could use a digital approach to better design, build, operate and integrate the built environment. The CDBB's National Digital Twin Programme has laid out a path towards creating an information management framework. This framework will offer a consistent, clear structure for sharing and validating data (a Foundation Data Model), a common vocabulary for describing digital elements (a Reference Data Library) and architecture that ensures data is interoperable (Integration Architecture). The Digital Twin Hub brings together practitioners who are creating digital twins to speed up progress through sharing and paving the way towards connected digital twins.

### Links:

[www.gov.uk/government/organisations/infrastructure-and-projects-authority](http://www.gov.uk/government/organisations/infrastructure-and-projects-authority)  
[www.cdbb.cam.ac.uk](http://www.cdbb.cam.ac.uk)  
[www.constructionleadershipcouncil.co.uk](http://www.constructionleadershipcouncil.co.uk)  
[www.p13.org.uk](http://www.p13.org.uk)

## London 2012: Successful organisational structure and systems integration

**The venues and infrastructure for the London 2012 Olympic Games were delivered on time, within the £9.3bn budget announced in Parliament in 2007 and met their project sponsor's outcomes. The Olympics were a success and have left a lasting regeneration legacy in East London.**

The organisational structure that supported this success was arranged in two interacting levels of systems integration to match the complexity and risks of the project.

The Olympic Delivery Authority (ODA) was created in 2006. It was a temporary public sector client organisation responsible for overseeing the design, construction and handover of the Olympic Park, the Games venues, the Olympic Village and Games transport systems.

The ODA's decisions on organisational design were made against a fixed deadline to build and integrate a large, complex system of systems in a densely populated part of a major city. It also knew that it had to manage the relationships with several hundred political, economic, sporting and community stakeholders.

Against this backdrop, the ODA decided to appoint a delivery partner, CLM, to support the overall system of systems integration in the Olympic Park because this would be the quickest and most effective way to attract people with the necessary

experience, skills and knowledge. It decided that the delivery partner should be a new joint-venture organisation, believing that this would bring the mix of capabilities needed to deal with the level of complexity involved.

The ODA and CLM had clearly defined roles in relation to systems integration. The ODA established strategic objectives and goals, worked closely with CLM to plan the overall delivery programme and monitored progress towards those goals. During the programme, the ODA concentrated 'upwards' and provided a single interface between the system of systems and all external stakeholders. CLM, in turn, concentrated 'downwards' and acted as integrator for the overall programme in the Olympic Park, managing interfaces with each project (individual venue).

Principal contractors were responsible for delivering these projects against time, cost, quality and other strategic objectives such as legacy and sustainability. They also helped to coordinate across the interfaces with adjacent projects.

This division of labour allowed the ODA to provide oversight and assurance for the programme and gave CLM the autonomy needed to manage the programme and projects. The ODA also acted as a buffer, protecting its delivery partner from outside interference that could have made integration more difficult.

CLM simplified the integration process by creating a distinction between relatively self-contained 'vertical' buildings (the permanent and temporary venues) and interconnected 'horizontal' infrastructure (utilities, roads and bridges). This helped to limit the number of interfaces with other systems, allowing principal contractors for the main venues, such as the Velodrome and the Aquatics Centre, to be 'king of their island', focusing on designing and integrating all of the elements of what were, in themselves, large, complex projects.

CLM also created a process to identify how slippages or changes in one venue or connecting infrastructure – for example, water or energy supply – had an impact on others. This included a programme integration group and integration committees to manage the park as a complete system and the interfaces between the 15 to 20 principal contractors working on the programme at any one time. Disciplined flexibility was achieved via a highly structured change control process that could unlock frozen elements of the programme and promote rapid, mutual adaptation between supply-chain organisations as conditions demanded.

Case study based on Davies A, McKenzie I (2014) Project Complexity and System Integration: Constructing the London Olympics and Paralympics, *International Journal of Project Management* 32, 773-790

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Don't let the 'civils' alone drive projects. Projects need to focus very early on on what is critical for the operation and maintenance requirements, performance and safety of the system, and not the biggest chunk of work by value.

Pierre Gosset,  
Chief Technical Officer, Systra

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Many contributors noted that Crossrail's pre-2018 communications centred on the engineering achievements of the project. The BBC series *The 15 Billion Pound Railway*, for example, focused almost entirely on tunnelling and station construction, and not the goal of connecting up engines of economic growth at Heathrow, the City of London and Canary Wharf. At this stage, one can only speculate on the impact such a focus had on decision-making by Crossrail leadership. In its 2019 *Completing Crossrail* report, the National Audit Office also questioned Crossrail's approach to systems integration.

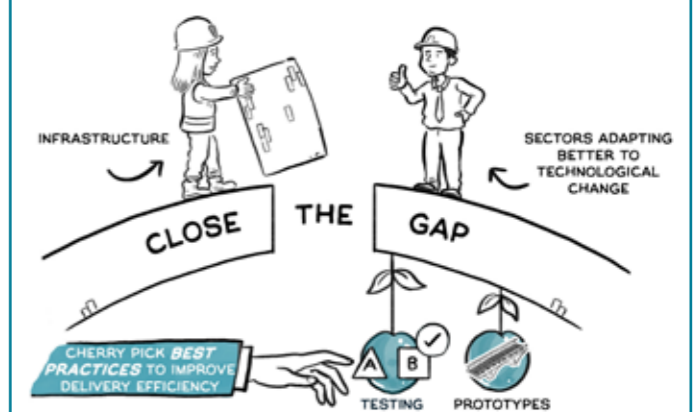
Unfortunately, this is not a new phenomenon. Executives on the Channel Tunnel project in the 1980s and 1990s ran into similar identity issues as they focused too heavily on delivering a tunnel instead of a railway. This eventually required a major, unplanned reorganisation of TransManche Link, the delivery consortium. Two civil engineering organisations had to be merged into a single Anglo-French systems engineering organisation.<sup>02</sup>

There is evidence, however, that lessons are being learnt. Key members of the Thames Tideway project stressed to the review that they had worked hard to reinforce a project identity that focused on the outcome of cleaning up the River Thames and rejuvenating the riverside economy rather than simply building a sewer tunnel. This included a deliberate choice that the project name would not include the word 'tunnel', despite being one of the largest tunnelling schemes in Europe.

**Embed the operator's voice in the project.** Large, complex infrastructure projects are temporary organisations that can sometimes be as big as a FTSE 100 company. It is vital that the organisation is focused on the future use of the asset or system it is constructing. Embedding the voice of the ultimate owner

and operator into the project is vital to achieving this goal. This voice needs to be ever-present at the highest level of decision-making and should be increasingly dominant as the project moves towards commissioning and transitioning to the operations phase. Several contributors told the review that alarm bells should ring if no one can explain to project teams how new infrastructure will be maintained.

## 02 CLOSE THE GAP



**Close the gap between infrastructure and sectors adapting better to technological change. Cherry-pick best practices to improve delivery efficiency.**

► Practices from other sectors can be adopted to help the infrastructure sector make rapid progress.

► The review found a consensus that the infrastructure sector was at least five years behind other project-based sectors in its use of tools, techniques and technologies to manage the design, delivery and commissioning of complex systems. This should be seen as an opportunity to cherry-pick what works and apply it to infrastructure projects.

**Focus first on adjacent industries.** Projects in sectors such as oil and gas and defence equipment have a strong family resemblance to major infrastructure projects in aspects such as lifespan and stakeholder and supply-chain complexity. These similarities, and the long history of professionals transferring successfully between these sectors, provide a firm basis for direct transfer of successful practices.

<sup>02</sup> Winch G (2013) Escalation in Major Projects – Lessons from the Channel Tunnel Fixed Link, *International Journal of Project Management*

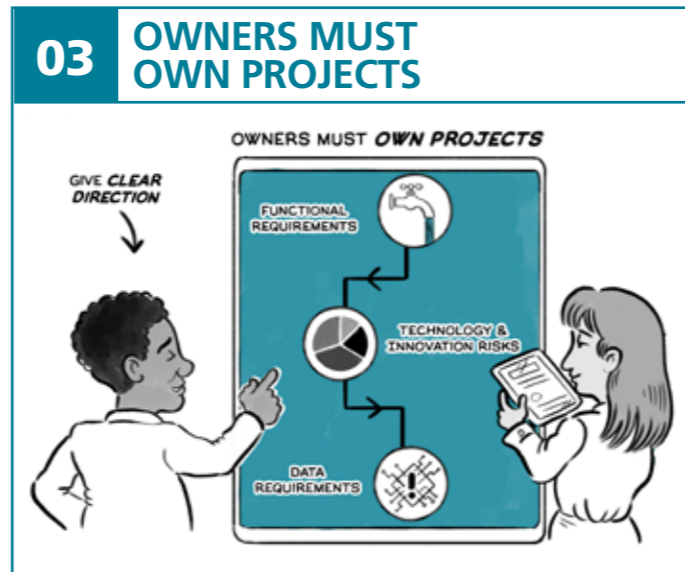


Infrastructure projects should also be open to adopting what works in sectors where the family resemblance is a little more distant. The review found, for example, that the technology industry may be able to help infrastructure businesses to adopt more agile, data-driven practices that are more responsive to changing customer needs.

**Champion all diversity.** Knowledge transfer is often the result of professionals moving between sectors. One contributor suggested auditing project leadership for breadth of expertise. Another noted that, given the size of major project budgets and the fact that a prospective programme director may be committing a third of their career to one role, their preparation could include an extended period shadowing colleagues in other sectors with a view of transferring the experience to the project.

“Preparation could include an extended period shadowing colleagues in other sectors with a view to transferring the experience to the project”

“Owners need to understand the capabilities they need to carry out their role, including which functions they can and cannot delegate to supply-chain partners”

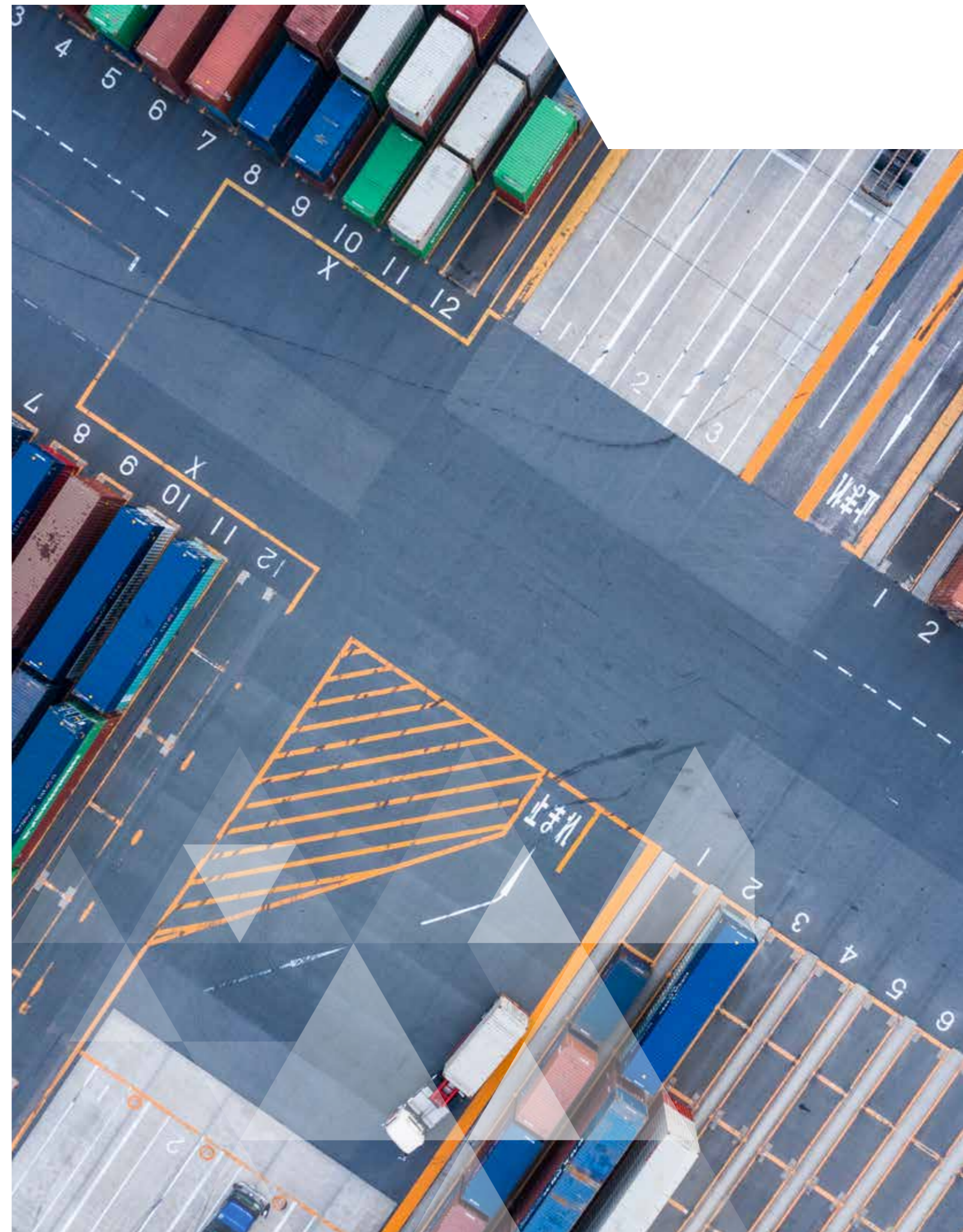


**Owners should give direction on everything, from functional requirements for the operational system to data requirements and acceptable technology and innovation risks.**

- No contractor can do the owner’s work. The owner is much more than a client letting contracts. The owner must have a deep understanding of what the project is trying to achieve for its users and give direction on everything from functional requirements of the system, to data standards and their appetite for technological innovation and risk.

- Projects are often described as temporary organisations created to undertake a unique task. This obscures the fact that infrastructure projects are totally reliant on permanent organisations in the shape of the owners who commission them and the firms in the supply chain who help owners to deliver them. The owner is ultimately responsible for strategic direction, commercial arrangements, governance and integrating the project’s outputs into their operations. Owners need to understand the capabilities they need to carry out their role, including which functions they can and cannot delegate to supply-chain partners. This range of roles means owners need a high capacity for internal and external collaboration.

**Understand what it means to be capable.** The Infrastructure Client Group’s Project 13 initiative was launched in 2017 and has taken a similar path of drawing on practice in other sectors. The Project 13 model may not be suitable for all projects but its

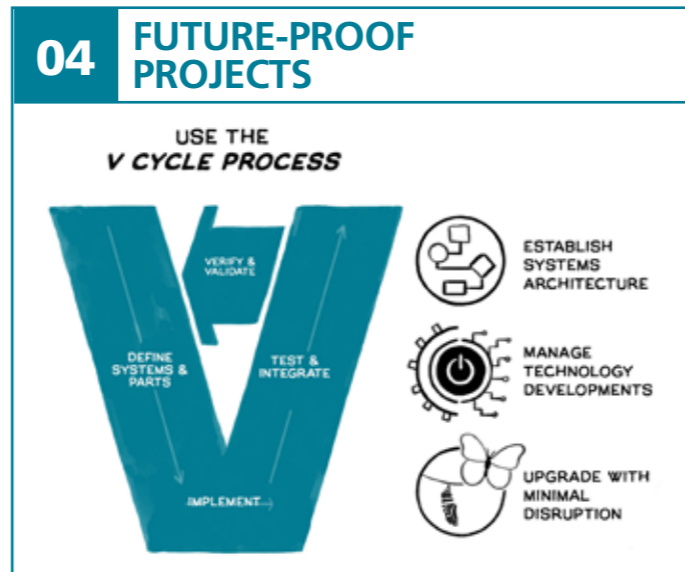


six key characteristics of a capable owner (see Table 1, page 19) are an excellent starting point for any organisation wanting to develop its capabilities.

**Develop a wide concept of value that embraces net-zero emissions and other strategic challenges.** The owner has the fundamental task of defining the outcomes needed from a project and translating them into a set of functional requirements for an operational system. This cannot be reduced to a narrow economic cost-benefit analysis. For example, owners of major projects must be able to articulate how they contribute to relevant UN Sustainable Development Goals and national strategic challenges including the UK’s target for reaching net-zero greenhouse gas emissions by 2050.

**Define the appetite for technology risk and innovation.** Outcomes and requirements should drive the choice of the technologies that will be specified within the project. In advance of this detailed work, there is an important role for the owner in giving strategic direction on their overall attitude to technology risk and innovation. As an example, one contributor told the review of owner organisations explaining that they wanted a “five-year-old railway” – that is, no technology less than five years old – as shorthand for their appetite for innovation.

“Where new technology is needed, the process of breaking the project down into sub-systems will help leaders to identify, isolate and manage this risk”



**Use the V-cycle process to establish systems architecture, manage technology development and upgrade it with minimal disruption.**

Infrastructure projects exist to meet people’s needs. They do this by bringing fully integrated systems safely into use. Systems engineering is a mature process that has been shown to support this outcome for complex projects, but is still underused in the infrastructure sector.

The review found wide support for incorporating the discipline of systems engineering into the future delivery model. Systems engineering is a structured approach to designing and delivering an integrated set of engineered assets. In very simple terms, it forces engineers to work backwards from the end state they are being asked to achieve – a fully functioning airport, for example.

A set of requirements for how the system should perform is created based on an analysis of user needs. A ‘system architecture’ is then established that describes how the asset will meet these requirements. The architecture is broken down (decomposed) into a series of sub-systems.

In the case of an airport, this would include the terminal structures, air traffic control facilities and baggage handling system. Different teams can then get on with the detailed design of the sub-systems, their construction and subsequent integration and testing in the context of a shared understanding of how the whole system needs to function.



Definition of a capable owner	
Role	Description
Articulating the voice of the customer	Ability of the owner organisation to understand who the customer is, engage with them, obtain and analyse customer feedback, translate and articulate it into an outcome, flow the voice of the customer up and down the organisation and sustain the activity. Ability of the organisation to balance and align customers’ views and expectations with the organisation’s values and strategic goals.
Value-driven mindset	Ability to focus on value delivery rather than asset delivery. Value defined in terms of outcomes for customers and hence value to the business rather than net present value of the investment. Ability to provide and present a broader view of the value in the business case. Ability to manage both the revenue and capital side of the business plan.
Articulating the voice of operations	Ensuring programme managers, asset operators and asset maintainers have clarity of the business objectives and the service offered to the customer and are able to plan for the operations and maintenance upfront.
Relating to the ecosystem	Ability of the owner organisation to modify, create or develop new commercial models that facilitate early engagement and alignment between customers’ needs and the supply chain and other stakeholders.
Creating and maintaining complex systems	Bringing together the appropriate technology, structures and processes and infuse a common understanding of what is to be achieved and the ability to manage change.
Recruiting, maintaining and building talent	Ability to attract, build and retain the right talent i.e. individuals who are professionally qualified, knowledgeable, experienced, competent, innovative thinkers, with the right skills, who can challenge and who can deal with ambiguity. Talent more akin to a business manager profile rather than a project manager, and people who can be advocates of the business case.

Table 1: Taken from Project 13’s What is a Capable Owner?

The systems engineering process is often captured in a V-cycle process diagram (see Figure 1, page 21). In a modern infrastructure project, this process will deliver both the physical assets and their digital twin.

**Owners should define and communicate a limited number of fundamental requirements and explain how they intend to operate the completed system.** The requirements creation process needs to be managed carefully. The review was cautioned that, in large projects, requirements definition can become siloed and divorced from the day-to-day life of the project. The review was also told that for longer, more complex projects, it is not always possible to define an exhaustive set of requirements from day one.

High-level requirements should therefore be limited to about 10 fundamental needs, accompanied by a clear explanation of how the system will be operated. This can be in the form of simple stories describing how different groups will use the system. In whatever form the requirements are captured, it is important that they allow the owner to communicate effectively with external stakeholders and provide a shared focus for project participants while any more detailed tiers of requirements are developed.

**The allocation of time and resources to different elements of the project – including civil engineering – must be guided by the requirements of the system.** Traditional civil engineering projects tend to concentrate attention and resource on the design and construction of structures. This stores up problems as the project tries to move towards commissioning the whole system. One contributor described this as “too many people focusing only on the base of the V diagram”.

Establish clear responsibility and accountability for key tasks in the V process. Three basic roles need to be established:

- The systems architect is responsible for defining the overall system, breaking it down into component parts and identifying the most important interfaces between them.
- The systems engineer works backwards from the desired system end state to produce an engineering plan that describes how work will be accepted as complete and fit for purpose.
- The programme manager takes the engineering plan and aligns it to a credible delivery schedule and cost estimate.

**Isolate any components of the systems architecture that rely on technology that does not yet exist.** The V process can

make a significant contribution to improving the management of technology and innovation within projects. An emerging technology or innovation that is not needed to deliver the functional requirements of the system should not find its way into the systems architecture.

Where new technology is needed, the process of breaking the project down into sub-systems will help leaders to identify, isolate and manage this risk with less disruption to the overall project. A contributor from outside the infrastructure sector advised that technology development of this kind should, wherever possible, be decoupled from the core programme and managed as a standalone project. If this project is successful, the innovation can be reinserted at a lower level of risk.

At the system of systems level, project leaders will need to adopt a stance of disciplined flexibility. As an example, sub-systems containing the more innovative elements of the systems architecture can be targeted for a later design freeze.

**Design the infrastructure system to support regular updates of the technology that will be used to operate it.** Physical infrastructure such as a road, tunnel, rail corridor or bridge will normally have a design life running into decades. The technology that allows infrastructure systems to operate efficiently will run through multiple cycles of obsolescence in this period. If more infrastructure services are delivered through technology, it should be possible to update it more quickly to respond to changing needs. The V process, therefore, needs to be geared towards delivering a mix of physical and digital assets that can be updated with minimal disruption to users.

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It's better to use test cases to assess how multiple requirements work together to deliver the functionality you need to meet stakeholders' outcomes.

**Marcel van de Ven,**  
Co-Chair,  
Infrastructure Working Group,  
International Council  
on Systems Engineering

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# V-cycle diagram

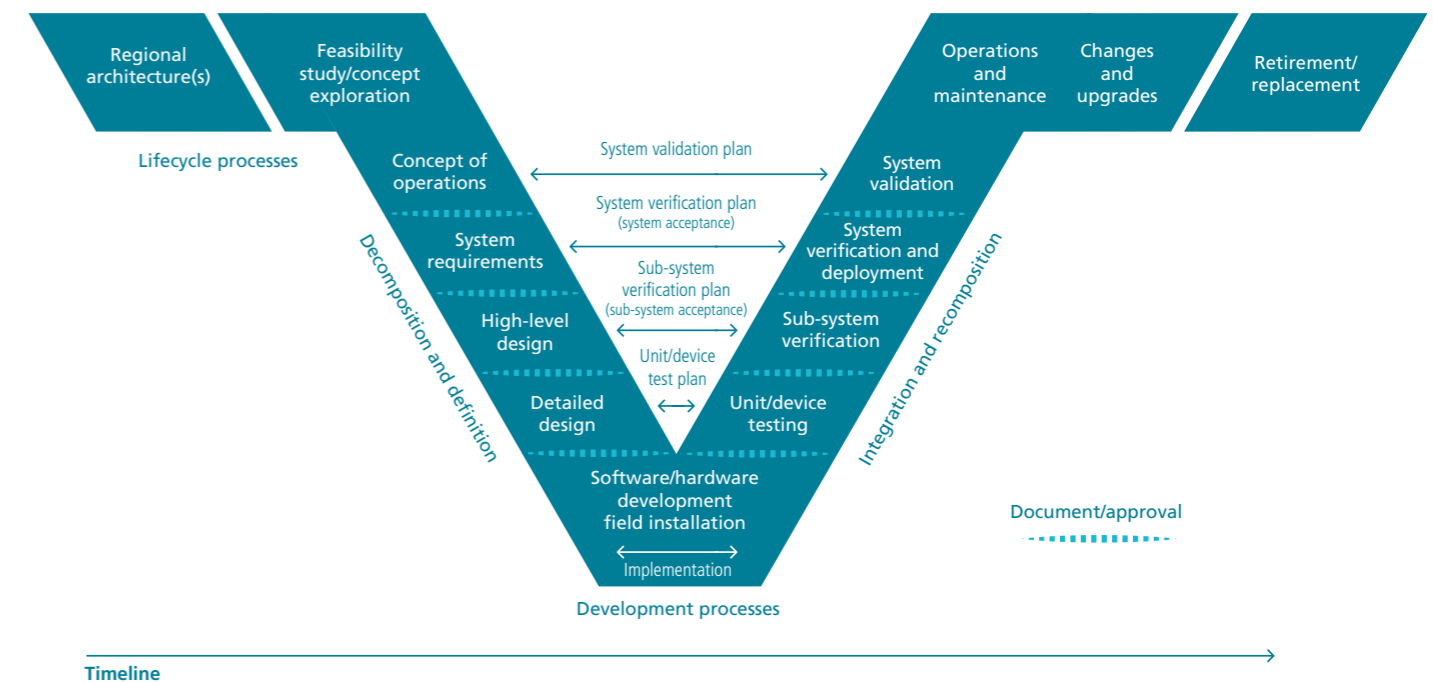
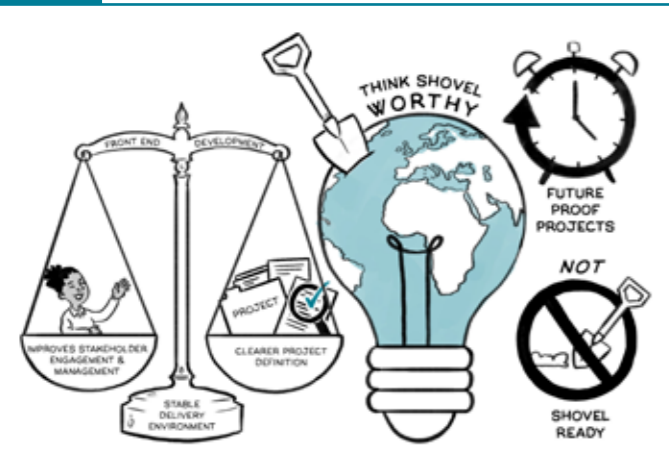


Figure 1: An example of a V-cycle diagram taken from US Department of Transportation, Federal Highways Administration, Office of Operations



## 05 THINK SHOVEL WORTHY, NOT SHOVEL READY



**Front-end project development gives clearer project definition, creates a more stable delivery environment and improves stakeholder engagement and management.**

► The evidence is clear. Projects are significantly more successful if there has been rigorous planning and rehearsal before spades go into the ground.

► Upfront planning is needed to ensure that major infrastructure projects are politically sustainable, practically deliverable and economically affordable. Better planning also enables owners to halt projects that are not viable. Projects need to embrace ‘left-shift thinking’, whereby more activity and resources from the delivery phase is pulled from the later stages (right-hand side) of the schedule to the front (left-hand side).

The most popular approach to achieving this shift among contributors was ‘front-end loading’, developed by Independent Project Analysis (IPA) and its founder, Ed Merrow. IPA’s database of more than 20,000 projects shows that those with the best-quality front-end loading have 20% lower costs and are delivered 10-15% faster than average projects.

**Plan around facts.** Front-end loading highlights the risk of setting deadlines, project scope, deliverables and budget without regard to hard facts. The review heard that the infrastructure sector was behind adjacent sectors in the quality of the basic data used to make these decisions. This prevents projects from being managed against a credible baseline and increases the risk of time and cost overruns.

**Manage all external stakeholders who can influence the project.** Projects must understand the perspectives of all external stakeholders who can influence it or make a claim to the value it generates. Managing these demands early helps to create a simpler, more stable environment in which to deliver the project. However, the review heard that over-commitment to external stakeholders also runs the risk of making the project economically unviable for the owner or undeliverable by the project team.

**Judge project readiness against a pre-agreed set of criteria.** Infrastructure projects should carry out the best practical project definition and planning before starting to build. The nuclear power generation sector has recently identified 14 criteria (see Table 2, page 23) against which projects should be able to demonstrate adequate progress before they receive the green light to start the delivery phase. Nuclear sector leaders told the review that they believed these criteria could be applied to any major infrastructure project. They also argued that such consistency and objectivity could help to unlock the resources needed to carry out high-quality project definition.

**Test the delivery plan and test it again.** Advances in digital technology mean it is now possible to ‘build it twice’, first inside a digital model and then in the real world. Once again, the review was told that infrastructure was behind other sectors in using these technologies to resolve design and delivery problems. As with other aspects of left-shift thinking, this kind of testing needs a commercial arrangement that allows all key supply-chain partners to be involved in the project at an early stage.

66 The infrastructure sector needs to improve the quality of the data collected and collated to support project definition, demonstrate as-built quality, testing, commissioning and handover into operation.

Ailie MacAdam,  
Senior Vice President,  
Bechtel Infrastructure

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# 📋 Risk reduction enablers

**01 Financing**  
Is the financing model secure; are stakeholders aligned and is HMG (Her Majesty’s Government) committed and aligned?

**02 Regulation**  
Are regulation and permitting requirements understood?

**03 Governance**  
Is the governance defined and fit for purpose: the roles of owner and delivery team defined and distinct, with a strong multidisciplinary owner’s team?

**04 Site data**  
Is the site-specific data understood and taken into account?

**05 Technology data**  
Is the data on processes and components accurate enough, and are innovations under control?

**06 Design**  
Is the design mature?

**07 Estimates**  
Are costs and schedule estimates realistic, integrating robust risk assessment?

**08 Contractual interfaces**  
Are interfaces identified, understood and managed at each level of the project?

**09 Project management**  
Is the management of the project strong enough, with a robust organisation and processes and an effective and experienced project team?

**10 Data system**  
Is the data structure access and related systems strategy consistent with the project context?

**11 Construction preparation**  
Is the construction executive plan fit for purpose? Are [nuclear safety and construction] special requirements taken into account, including management of quality and defects?

**12 Supply chain**  
Are the procurement and contracting strategies defined and fit for purpose? Are suppliers incentivised to deliver the best for the project?

**13 Skills**  
Are the critical skills identified and managed, with particular attention to safety and quality culture?

**14 Operations preparation**  
Is the transition to operations planned, with operation staff embedded in the project early?

Table 2: Project readiness criteria taken from Nuclear Sector Deal Cost Reduction Working Group (2020) Nuclear New Build Cost Reduction

## Deepwater Project: Front-end project development

The Deepwater Project was initiated to develop a deepwater, offshore, world-scale oil and gas field. The project scope comprised four multibillion-pound sub-projects, offshore facilities, marine and subsea installations, an onshore terminal, and the construction of wells.

The project was in a country with limited infrastructure and an unstable regulatory regime. There were multiple equity stakeholders. Technical challenges included extreme seasonal cold temperatures, deepwater, high-pressure and high-temperature reservoirs, and seismic events.

The technical challenges also drove organisational complexity. Two major contractors were engaged for front-end engineering design (FEED) and engineering, procurement, construction and installation (EPCI). The owner procured key technical-scope items direct from four primary vendors. Integration between the owner, the two EPCI firms and vendors was necessary throughout the project lifecycle.

Based on its size and complexity, the Deepwater Project was a megaproject. Data from management consultancy Independent Project Analysis shows that two-thirds of megaprojects are failures, experiencing large cost overruns, many months or years of delay, and poor-to-mediocre functionality.

However, the Deepwater Project performed well. It came in on budget with minimal schedule slip and achieved the owner's desired functional performance. Independent Project Analysis benchmarks also indicate that the project costs were within industry norms on most criteria, while the schedule was slightly slower. What's more, project safety was exceptional, with no fatalities in the five-plus years of execution and low lost time and recordable incident rates.

The Deepwater Project achieved this performance through planning

and organisation that recognised the different kinds of work needed and the highly interdependent nature of the work.

**Clarity of objectives:** Driven by the project leadership team, objectives were clear, well communicated and aligned across the project participants at all times.

**Strong, integrated team:** The project team was organised as a strong and integrated asset team, enabling effective decision-making. Before starting onsite, team members raised concerns that key negotiations were yet to be finalised and that equity stakeholder involvement was uncertain. The project leadership overcame this challenge by actively engaging the sponsor company's leadership to gain the attention of the host government and other stakeholders when needed.

**Active integration:** A strategic role of 'project manager for integration' was created, with equivalent authority in the organisational hierarchy to the sub-project project managers. This supported a holistic view of the overall priorities at all times and was essential for taking strategic decisions that preserved the project's value. A strong focus on integration at the asset level, across the production value chain and with the stakeholders responsible for government and partner relationships ensured there were no blind spots that could cause issues for delivery.

**Realistic targets:** The Independent Project Analysis research shows that megaprojects that set aggressive schedule targets end with poor outcomes. The Deepwater Project was able to balance cost and reliable performance by not pushing for an aggressive delivery schedule. The project had realistic targets that were generally met. In addition, the targets were underpinned by

'best practical' project definition, including robust execution plans and well-framed contracting and procurement plans.

**Commitment to safety:** The project team introduced mechanisms to influence the contractor safety culture. The team required fabrication contractors to carry out a safety performance analysis six months into construction. The exercise revealed that incidents were driven by inconsistent adherence to procedures. Addressing these gaps helped to improve productivity, which the contractors appreciated. Site safety leaders were assigned to each contractor site and helped to drive a better safety culture across the board. The project team encouraged an open reporting culture and recognised safe behaviours.

**Continuity:** The project developed an organisation plan that outlined the staffing requirements at different stages, including succession planning. The execution period of five-plus years meant that some team member transitions were unavoidable; the majority were planned and the team followed a detailed handover process. Strict management of change procedures also curtailed changes owing to turnover of staff. Project director continuity was maintained from mid-FEED to completion, which was important as a single point of authority for the project's vision.

**Owner project control:** Solid project control plans were carried through into execution. A team was set up to monitor and manage the contractor's performance. This started from the very beginning and progress was updated frequently. Such a hands-on approach drove high productivity and prevented unnecessary delays. The sponsor's presence at the fabrication yard – including for quality, safety and control management – helped to provide oversight and prevent delays.



## 06 BAKE IN SYSTEMS THINKING



**Bake systems thinking and risk management into the project DNA. Design an organisation and structure that mirrors how you're going to manage risk.**

► The project needs to be designed to ensure that systems integration runs through its organisation and activities at all stages of its lifecycle.

► Systems integration is a core organisational capability needed to manage interdependency, uncertainty and change in complex infrastructure projects. Successful projects have an organisation, governance arrangement and commercial model that keeps participants focused on the elements of the project and the interfaces between them that pose the most significant risks to the delivery of the whole system. Creating the right project organisation and planning for its evolution during its lifecycle is essential.

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We organised the carrier programme around how we managed risk. It was vital that we invested upfront in analysing the characteristics of each sub-system and the system of systems. We had to understand where risk to delivering the system lay and establish mitigation strategies.

**Sir Simon Lister, Managing Director,  
Aircraft Carrier Alliance**

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**Design the organisation and any systems integrator role around the specific needs of the project and understand:**

The hierarchy of systems to be integrated:

- The components making up a larger system (e.g. IT services)
- The single systems or sub-systems (e.g. air traffic control facilities at an airport)
- The system of systems bringing together multiple systems (e.g. all of the systems making up an airport)

The types of interdependence that the integration process needs to manage:

- Pooled interdependence, where individual sub-systems are developed with a high level of independence and brought together towards the end of the project
- Sequential interdependence, where one sub-system's output is another's input
- Mutually adjusted interdependence, where collaboration is needed in real time to deal with emerging challenges

The level of innovation and uncertainty in the system (see Boeing Dreamliner case study and Table 3, pages 28-29):

- The novelty of the project, since it is completely new to the owner or supply chain, new to the sector or even new to the world
- New technology is embedded in the systems architecture
- The complexity of the project owing to many interfaces and intense interaction between sub-systems
- The pace of the project if delivery is focused on a fixed deadline or to avert a crisis

The basic project characteristics:

- The client can be an experienced client or a one-off organisation
- The level of risk for the owner's business
- The stakeholders and whether they have consistent and coherent views
- The project environment, which can be completely new (e.g. a hospital on a greenfield site) or making an intervention into an operational system (e.g. a project to expand road or rail capacity)

**There is no one-size-fits-all model for project organisation.**

As projects become more complex and uncertain, the importance grows for an integrator at the system of systems level, along with the formality of implementing systems integration processes. The review found that this system of systems integrator role had been successfully carried out by the owner, a supply chain delivery partner and various forms of joint venture. In all cases, the review heard that it was vital that

## BAE Systems: Left Shift Thinking

**"The concept of Left Shift Thinking or front-end loading was the most profound learning for me. Far too often I have observed projects fail or obtain a suboptimal outcome because the planning and preparation had not been completed at the very start"**  
– Delegate, BAE Systems, Leading Complex Projects, Programmes and Portfolios (LCP3) course.

BAE Systems is one of the world's largest providers of advanced, technology-led defence, security, aerospace and security solutions. The business operates as a prime contractor and integrates the work of a complex supply chain to deliver military capabilities, protect national security and keep critical information and infrastructure secure. Current projects in the UK include the Type 26 frigate, Astute and Dreadnought submarines, Typhoon fighter jet, cyber technology programmes and a variety of support programmes across air, land and sea.

The business's projects and programmes can last for more than a decade, which means the truism that 'projects don't go wrong, they start wrong' can have serious consequences. BAE Systems has developed the concept of Left Shift Thinking (LST) to tackle this risk. Left Shift is grounded in management consultancy Independent

Project Analysis' work on front-end loading but also recognises that prime contractors play a vital role in the project ecosystem. To implement LST, BAE Systems works intensively with the supply chain on project definition and planning to achieve higher levels of project maturity earlier in the lifecycle and to increase operational excellence.

The business's leadership believes that the right mindset and behaviour are central to the successful execution of LST. To develop this mindset business-wide, more than 500 members of the firm's leadership community have taken part in an intensive Leading Complex Projects, Programmes and Portfolios (LCP3) course launched in 2016 in collaboration with Alliance Manchester Business School.

Participants on LCP3 are invited to reflect honestly on their own and their team's behaviour and its impact on project delivery. Five crucial questions highlight the importance of behaviour to successful LST:

1. Are we planning around facts?
2. Is the project sponsor providing support?
3. Are we faithful to the process?
4. Are we honestly assessing our progress and risks?
5. Are team members pulling their weight?

The questions can help to flush out behavioural issues related to the following concerns:

- Are leaders working around formal processes and making commitments to stakeholders that are near impossible to meet?
- Are budgets and schedules being set with regard to hard facts?
- Do teams feel able to admit to problems while there is still time to make changes before the project moves into execution?

A common thread through all of these questions is transparency, honesty and a willingness to be brave and speak truth to power.

BAE Systems is already realising the benefits of implementing LCP3 and is seeing increased confidence, motivation and leadership capability from its project and programme managers. It has also experienced greater consistency in management approach and more effective stakeholder engagement (both internal and external). LST is driving improved contract capture and increased revenue generation owing to better decision-making and process management concerning factors such as schedule, cost, technical trade-off decisions, risk management and change control.



## Boeing Dreamliner: Risk management and project design using the Diamond model

Aaron Shenhar and Dov Dvir, two leading management academics, have developed a useful framework to support the upfront analysis of the level of innovation in a project and how the risks created by innovation can most effectively be managed. The model is grounded in evidence from more than 600 projects from different sectors. It consists of four project dimensions, each of which has four categories or levels. The analysis generates a diamond shape when plotted on a graph.

In 2016, Shenhar co-authored a study that included a retrospective application of the Diamond model to Boeing's project to design, build and bring into service its new B787 Dreamliner. The first Dreamliner was delivered 40 months late and the project was reported as coming in at over twice its original budget.

Shenhar's analysis suggested that Boeing treated the B787 as a system project to provide the next generation of an existing product when, in fact, it was closer to an 'array' or system of systems and was therefore creating something that was new to market. Boeing opted for a level of outsourcing of design and development that was new to the company and supply chain. This created greater systems integration and supply chain coordination challenges than anticipated.

Similarly, Boeing initially behaved as if it was dealing with medium technology on Shenhar's criteria, but many of the materials and technologies in the systems architecture were completely new to commercial aviation, presenting challenges common to high-technology projects.

When the project began to run into trouble, Boeing had to introduce

multiple, unplanned development and testing cycles for key technologies. It also had to retrofit a complex management system to coordinate the supply chain and ensure quality. Resources were needed for education, training and verification of competency of supply-chain partners.

Shenhar and his colleagues contend that many of these risks and problems could have been mitigated by committing more time and resources to the design and testing of the project model and a more realistic assessment of the time required to establish a mature, integrated design.

Case study based on Shenhar A, Holzman V, Melamed B, Zhao Y (2016) The Challenge of Innovation in Highly Complex Projects: What Can We Learn from Boeing's Dreamliner Experience?, Project Management Journal 417, 2, 62-98

## Diamond of innovation (summary)

Category	Levels and description	Implications
Novelty	<p><b>Derivative:</b> Improvement to existing product</p> <p><b>Platform:</b> A new generation of an existing product line</p> <p><b>New to market:</b> Adapting a product from one market to another</p> <p><b>New to world:</b> A product that no one has seen before</p>	Higher levels of novelty need more time and effort to define market and customer requirements. Design freeze may also need to be delayed.
Technology	<p><b>Low:</b> No new technology</p> <p><b>Medium:</b> Some new technology</p> <p><b>High:</b> Technology that is new to the organisation, but already exists</p> <p><b>Super-high:</b> Critical technologies do not exist</p>	Higher levels of technology demand more resources and capabilities for design, development and testing. Additional design and testing cycles inevitably result in later design freeze.
Complexity	<p><b>Component/material:</b> The product is a discrete component or material</p> <p><b>Assembly:</b> A sub-system performing a single function e.g. a communications system</p> <p><b>System:</b> Collection of sub-systems performing multiple functions: e.g. a metro station</p> <p><b>Array:</b> A widely dispersed collection of sub-systems with a common objective e.g. a city's metro system</p>	Higher levels of complexity create demands for systems integration and greater coordination to manage the project effectively.
Pace	<p><b>Regular:</b> Delays are not critical</p> <p><b>Fast-competitive:</b> Time to market is important for the business or owner</p> <p><b>Time-critical:</b> Completion time is crucial for success e.g. London 2012 Olympic Park</p> <p><b>Blitz:</b> A crisis project, immediate solution is necessary e.g. new critical care temporary 'Nightingale' hospitals built during the Covid-19 pandemic in the UK</p>	Urgency (or otherwise) will affect the time management and autonomy of the project management team.

Table 3: Taken from Shenhar A, Holzman V, Melamed B, Zhao Y (2016) The Challenge of Innovation in Highly Complex Projects: What Can We Learn from Boeing's Dreamliner Experience?

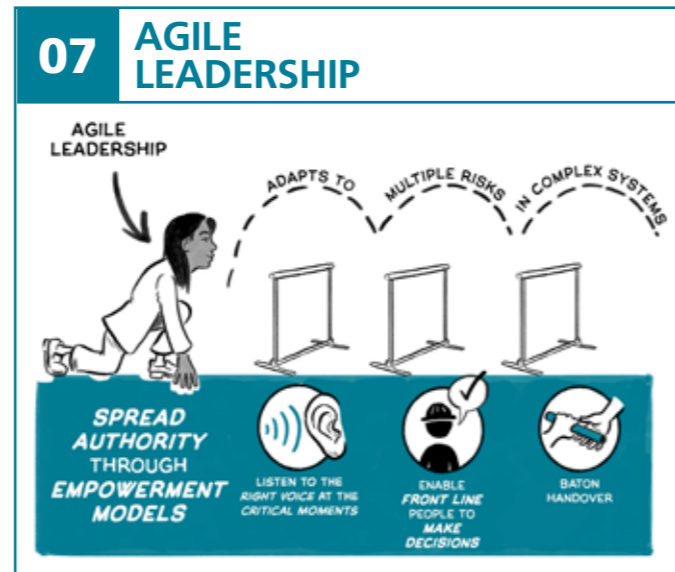


the integrator had the authority and capability to fulfil the role. This pointed to the need for the integrator to have political and consensus-building skills, coupled with the ability to understand the systems architecture at a technical level and deep programme management capabilities.

**Create governance, monitoring and accountability mechanisms that focus on the most significant risks to the project's success.** A project that has designed its organisation around a realistic assessment of its integration risks will be able to put in place sound governance, monitoring and accountability mechanisms. At higher levels of complexity, the project will be making greater use of decomposition – that is, breaking down the overall programme into more manageable sub-projects and sub-systems. The definition of the interfaces between sub-systems and absolute clarity on responsibility for their management is vital. If projects are making greater use of emerging technology, some sub-projects will need freedom to run multiple development cycles and freeze design at a later stage. Clarity on how and where this targeted flexibility operates is crucial. At the system of systems level, the project needs to be able to give its key decision-makers a credible quantitative account of progress at the whole-system level and keep them aware of any residual risks.

**Create procurement and commercial arrangements that promote collaboration and systems integration.** Higher levels of project complexity generate more risks and a greater need for project partners to collaborate to manage them. Projects need a contractual model that supports such collaboration, rewards collective performance and includes incentives for identifying and dealing with risks. Many different models can work, but they must support the creation of an integrated team, allow the owner and their main suppliers to collaborate on early project development, and align their interests.

“In normal conditions, the leader’s role is not to project-manage via detailed processes”



**Agile leadership adapts to multiple risks in complex systems. Spread authority through empowerment models that listen to the right voices at critical moments, enable skilled front-line people to make decisions and support baton handovers.**

➤ The increasing size, complexity and duration of infrastructure projects demands a project culture and leadership style that is different from the one typically used on smaller, simpler projects.

➤ Contributors repeatedly emphasised the need for adaptable and agile leadership for complex projects. As projects become more complex, so does the level of uncertainty and risk. In this environment, a hierarchical, transactional style in which project teams are driven to deliver a tightly prescribed list of activities by a ‘heroic’ leader is suitable only in moments of crisis. In normal conditions, the leader’s role is not to project-manage via detailed processes, but to cultivate the right environment and manage upwards to keep sponsors and external stakeholders on board. Nurturing an environment in which the whole project team is working together to identify and drive out the risks is much more important than being the person at the top of the hill raising a flag.

**Plan for changing leadership needs through the project lifecycle.** Project leaders need to deal with several levels of systems integration as they move through the lifecycle. They also need to manage multiple specialist disciplines, technology development, different stakeholder interests and a host of other

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There must be clarity on who is responsible for integration at the tiers [levels] of the systems architecture – underpinned by a contract strategy and project culture that supports collaboration. What you must not have is a series of contracts that will give you a door, hinges and frame but with no one responsible for ensuring it opens and closes properly.

Nadia Savage,  
Type 26 Programme Director,  
BAE Systems

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## Sydney Water: Systems integration using Partnering for Success

Sydney Water’s Partnering for Success (P4S) model views integration as a key capability shared across a collaborative enterprise.

P4S came into operation in 2020 and is based on a 10-year agreement to create three regional delivery consortia for the full design, construction, maintenance and operation lifecycle of Sydney Water’s A\$1.3bn annual investment programme. Sydney Water itself is a member of each consortium and all three of them are supported by consultancy Arup acting as strategic planning partner. The consortia also draw on a common pool of 588 specialist suppliers.

P4S has led to a big intellectual and cultural shift away from trying to tackle engineering challenges on a series of projects in isolation. The partners are incentivised to collaborate across an integrated programme to solve process and production problems that enable

more effective delivery via much higher levels of replication, standardisation and continuous improvement.

Sydney Water has spent more than five years bringing its supply chain on board with this change of philosophy and organisation. It has taken care to ensure its partners really believe in it, including a big investment in behavioural-based assessment methodologies. The business has also invested heavily in its own capabilities as a client and owner, with a particular focus on leadership, commercial expertise and project management.

P4S has a strong digital spine. Mark Simister, the Head of Programme Delivery, describes his challenge as being similar to establishing the kind of collaboration experienced on popular web-based video games such as Minecraft, with all parties sharing the same collaborative tools to guide decision-making.





## Shell: Mission Command thinking



Oil company Shell is one of a number of organisations consulted in adjacent industries in this review. It explained how it had overhauled its approach to leadership of complex projects by drawing on the Mission Command doctrine developed by the US and British military.

Shell concluded that its project delivery framework had become overly prescriptive and assurance-heavy. The focus on project outcomes had unintentionally become diluted because of a growth in information demands and a proliferation of prescriptive instructions and checklists.

Shell took inspiration from Mission Command, which requires senior leadership to define

intent. This includes a strong narrative explaining why an objective is being pursued. Detailed delivery is then delegated to empowered, highly competent people and collaborative teams, operating within clear constraints. Two key factors for successfully implementing this approach are:

**Competence:** Assurance and process cannot replace individual competence. The business invested in the Shell Project Academy to develop confident and competent individuals.

**Behaviour and environment:** Individuals must feel able to identify and act on risk to the mission. This must include acknowledging where they lack specific competence and need further support.

factors. To deal with this complexity, leaders must plan for the right specialist voices to be loudest at the right stages of projects. There is also a strong case for thinking about planned baton handovers to cope with changing demands. As an example, the advocacy, galvanisation and upwards management so vital in the early phase of projects may need to give way to more detailed delivery and integration expertise as the project moves towards commissioning.

**Value all forms of diversity.** Complex modern infrastructure projects need a workforce from a much wider range of backgrounds and professional disciplines to identify the different risks that can arise through the project lifecycle. Leaders need to be highly visible champions of diversity at all levels of an organisation and ensure that less extrovert yet vital voices are heard.

**Be brave, step back, take stock.** The review heard that leaders of a number of major infrastructure projects regretted that they had not been brave enough to tell the owner that they needed to stop and take stock of the condition of the project. This is a cultural issue and speaks to the need for a project environment in which bad news is actively welcomed. Commissioning and transitioning to operations can, however, be particularly challenging and the review heard that projects could benefit greatly from bringing the project team, operators and external stakeholders together at key milestones. Stakeholders can then identify outstanding risks by working backwards from the asset coming into operation and walking through the remaining work and the interdependencies between key activities.

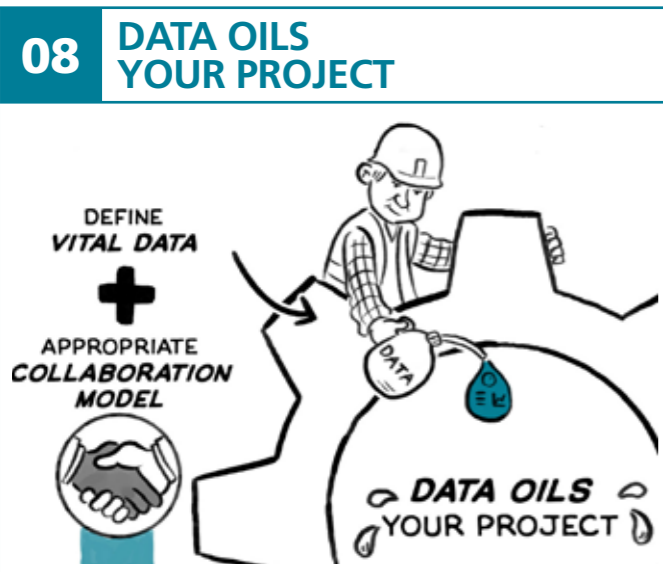
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Traditional professional development can create a deep vertical skill-set resulting in leaders overly focused on a narrow set of problems to the detriment of the wider project. We need to encourage people to evolve from hedgehogs, with one defining world-view, to foxes, who can draw on a much wider range of experiences.

Atif Ansar,  
Saïd Business School,  
University of Oxford

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Owners should define the vital data for delivering the service, the appropriate collaboration model and share it through the supply chain. Collaborating around shared data increases productivity, enables integration and improves operational performance.

Infrastructure lags many industry sectors in its use of data and technology to transform how projects are conceived, designed, delivered and integrated into existing services.

Data is the lifeblood of projects. The V-cycle process demands that multiple project participants have access to consistent, timely and reliable information. In addition, modern infrastructure projects create a collection of physical and digital outputs that together allow the owner to deliver services. The digital elements of this cyber-physical asset, in the form of a BIM process or digital twin, is the basis for designing and testing a robust delivery and commissioning plan. A project's digital outputs can also become the basis for maintaining and upgrading the operational assets, creating a 'golden loop' of information as described in the report Flourishing Systems – Re-envisioning Infrastructure as a Platform for Human Flourishing, published in 2020 by the Cambridge Centre for Smart Infrastructure and Construction and the Centre for Digital Built Britain (see Figure 2, page 35).

**Define data needs and fix the data plumbing.** The sheer volume of data generated by modern projects means that owners must take responsibility for defining which information is of value for project delivery and for operating the final assets. Owners

must also be satisfied that the project's data plumbing is converting the raw data into timely, meaningful information around which the project team can collaborate and make better decisions. The owner will need to set project-wide standards to shape the collection, storage and exchange of data by all members of the team.

**Automate, automate, automate.** Contributors expressed frustration that the flow of data through infrastructure projects remains very slow. This is a barrier to identifying and dealing with risks before they crystallise. Projects must look for every opportunity to automate data collection, collation and basic analysis.

**Support lower tiers of the supply chain.** A lack of resource and expertise at lower tiers of the construction supply chain is a significant barrier to exploiting the full potential of data. Owners and Tier 1 supply-chain partners need to provide support to these organisations to get them up to speed.

**Adopt a continuous development mindset to be more responsive to changing user needs.** Technology businesses such as Microsoft have moved from a model where a new version of, say, Windows is released every two to three years to a platform model with hundreds of updates and new features released every month. As more and more of the functionality of infrastructure systems is embedded in the technology sitting on top of the physical asset, infrastructure owners should be able to adopt more elements of this continuous development mindset and respond much more quickly to changing user needs.

“A lack of resource and expertise at lower tiers of the construction supply chain is a significant barrier to exploiting the full potential of data”

## The 'use' of infrastructure is at the centre of everything

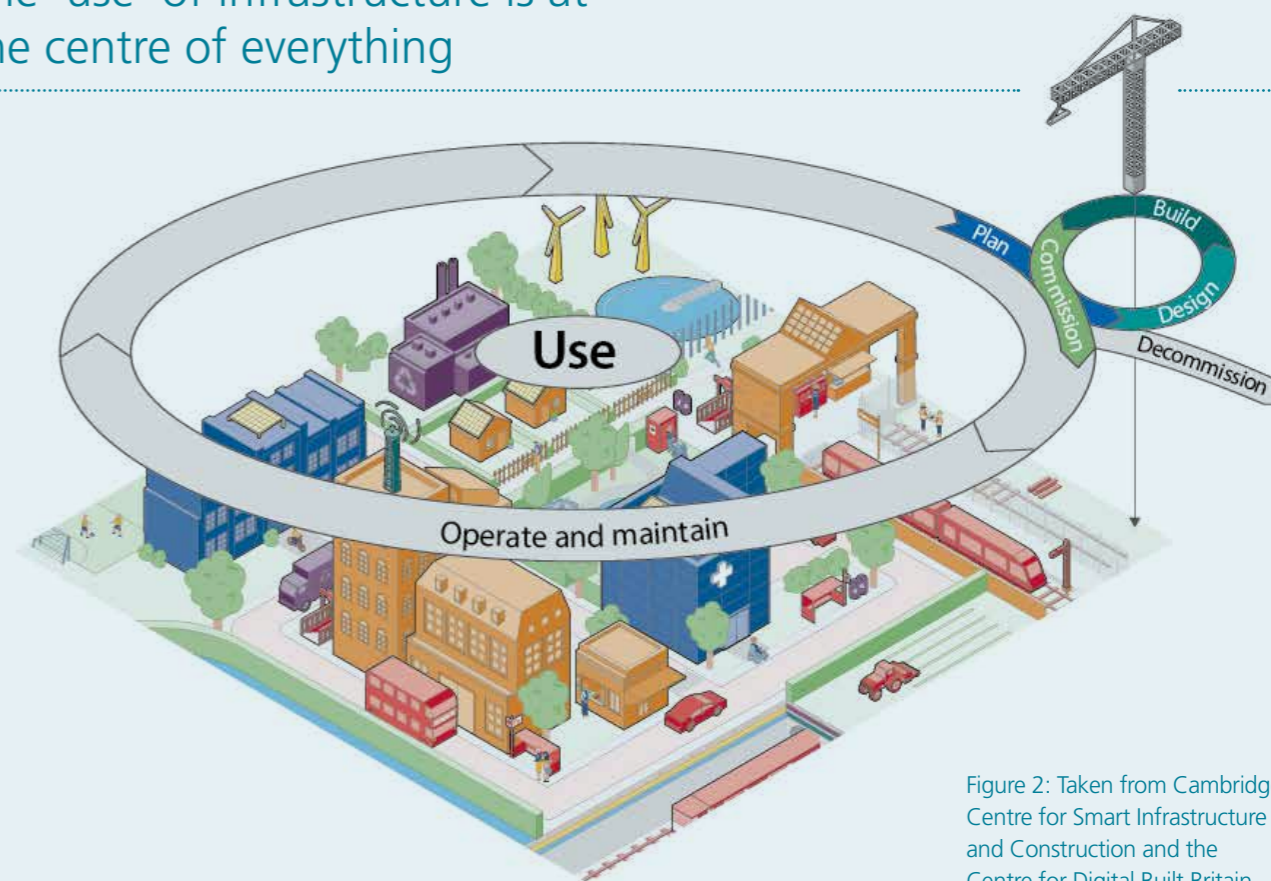


Figure 2: Taken from Cambridge Centre for Smart Infrastructure and Construction and the Centre for Digital Built Britain (2020) Flourishing Systems

## Bank-Monument London Underground station: Collaborating in a common data environment

Bank-Monument London Underground station is one of the most complex subterranean railway stations in the UK and is used by more than 52 million passengers each year. In 2013, an upgrade project was initiated to improve passenger access, circulation and interchange, with the goal of providing an additional 45% capacity during peak hours. The project is due to be completed in 2022. The project team faced a complex design challenge owing to the station's intricate network of tunnels, shafts and galleries. This was exacerbated by its location in the heart of the City of London and a requirement to keep the station open during construction.

More than 30 organisations are involved, including the design team, contractors and a range of other stakeholders. Project owner London Underground and its main contractor, Dragados, have worked with engineering software specialist Bentley Systems to establish a 'connected data environment' (based on Bentley's Projectwise software). This functions as a single source of truth for the project and a focus for collaboration. By working in such a way, Dragados and London Underground have streamlined workflows and collaboration, leading to 92% of clashes in the detailed design being resolved in only four days.



# 04 Conclusions and next steps

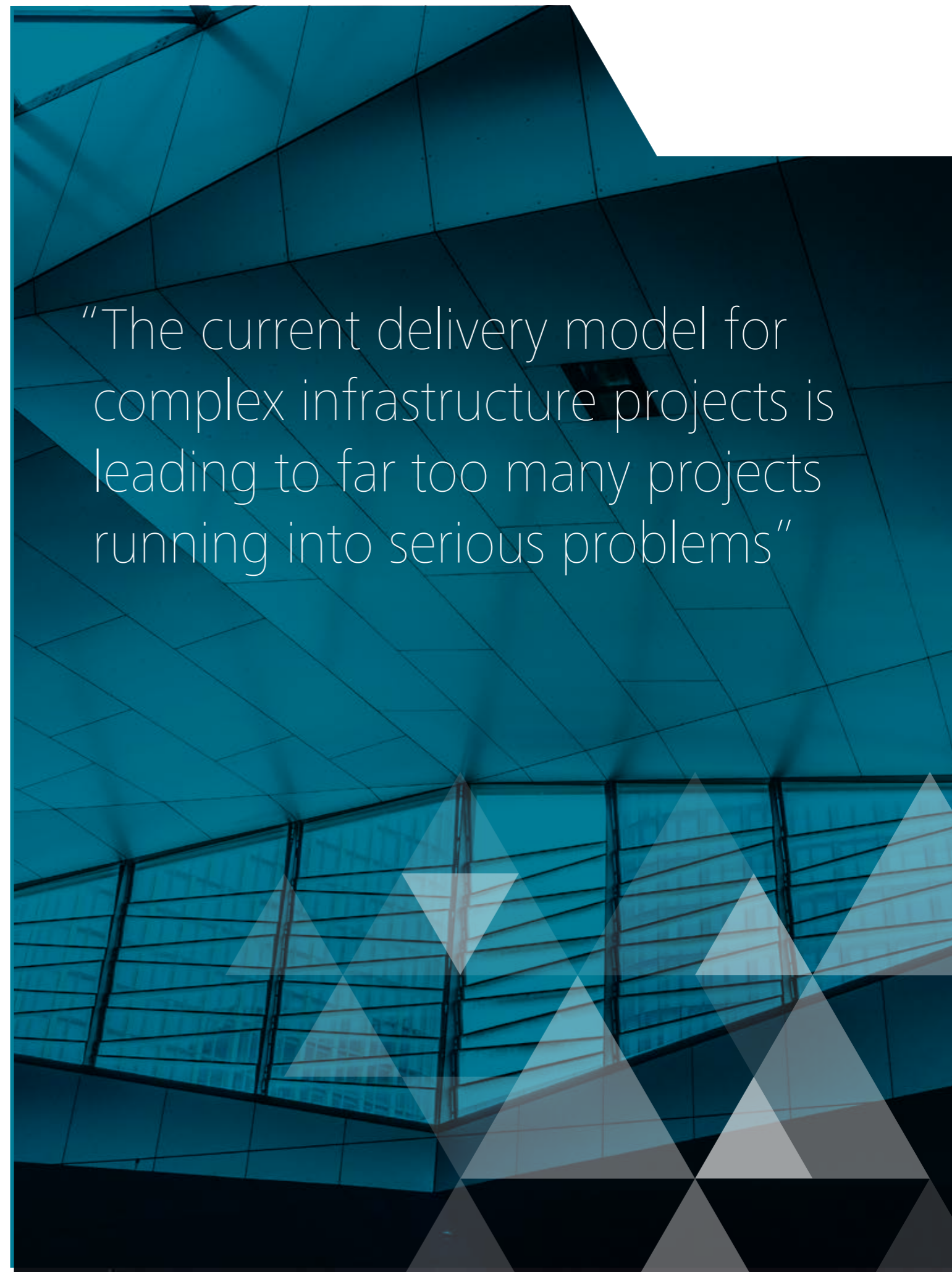
**The current delivery model for complex infrastructure projects is leading to far too many projects running into serious problems. This can be avoided if the sector embraces systems thinking, adopts successful practices common in other sectors, and builds on the experience of the best-executed infrastructure projects of the past decade, such as London 2012.**

The UK Government has put infrastructure at the heart of both its short-term plans to build back from Covid-19 and its long-term strategy to level up opportunity and transition to a decarbonised economy. The private sector has made it clear that billions of pounds are available for investment in the right projects, delivered effectively. There is a huge opportunity for the industry and the public we serve.

The performance of the Construction Leadership Council during the Covid-19 crisis has demonstrated that the traditionally fragmented UK construction sector is capable of coordinated action to deal with common challenges. Initiatives such as the Infrastructure Client Group's Project 13 programme demonstrate that both clients and the supply chain know that change needs to come.

We must seize this moment. Leadership needs to come from the infrastructure industry, from clients and supply chain businesses. Government, professional bodies and universities can all help to create an environment conducive to SAID. Still, it is the industry that has fallen behind, and it has the responsibility to catch up and provide the infrastructure that the public deserve.

This review will play its part. ICE will work through the practicalities of implementing the SAID model and will share outputs from this work throughout 2021. The institution welcomes input from organisations interested in taking part.



“The current delivery model for complex infrastructure projects is leading to far too many projects running into serious problems”

# 05 Recommendations

**To help create an environment in which the infrastructure sector can deliver a Systems Approach to Infrastructure Delivery, the review has identified actions for the Government, the Construction Leadership Council and ICE in the following areas.**

## Construction readiness

The Infrastructure and Project Authority's (IPA)'s July 2020 guidance, Principles for Project Success, pushes public sector projects to focus on outcomes and invest time and resources in thorough upfront planning to improve the timely delivery and quality of projects. It is vital that the implementation of the government's Project Speed initiative to accelerate the delivery of infrastructure projects fully embraces the IPA guidance.

High-quality planning does not inevitably mean delaying project start dates, but it does mean making significant resources available for upfront work and focusing on the aspects of project development that have the greatest impact on outcomes. We welcome the commitments in the new National Infrastructure Strategy to increase the use of the Project Initiation Routemap and to introduce a Project Initiation Framework with clear standards to be met at each stage of the project before it proceeds.

We recommend that the IPA ensures that these initiatives incorporate a systems view and include an assessment of the maturity of the design and delivery plan for the whole system and not simply the physical assets. The routemap and framework should also be usable across the breadth of public and private infrastructure projects.

We also welcome the Government's commitment to create a new cost benchmarking hub and recommend that the IPA, with the support of the Construction Leadership Council, prioritises the collection of benchmark data that helps owner organisations to assess how much resource to commit to the front end of projects.

## Future leaders

The infrastructure sector needs to develop a pipeline of leaders with the breadth and adaptability to thrive in an ever more complex, technology-driven project environment. Leaders of these projects need capabilities that are over and above those gained through formation in any one of the individual professions that make up the UK infrastructure workforce.

This review recommends that the Institution of Civil Engineers leads on engaging with other relevant professions to develop a career development pathway for leaders of complex infrastructure projects. This must be targeted at talented individuals from all professional backgrounds. We also recommend that the CLC acts as a critical friend for its development and implementation. ICE should also seek to collaborate with those in Her Majesty's Government who are leading the creation of the new Government Projects Academy promised in the National Infrastructure Strategy.

The benefits of transferring people and practices from adjacent industries is a strong theme of the review. The Covid-19 economic downturn means that sectors such as aeronautics and oil and gas that have a strong track record in systems integration have been shedding experienced project leaders. This review recommends that the IPA and the CLC investigate opportunities to attract and retrain project leaders from outside of civil engineering to work on the future infrastructure pipeline.

## Data-driven planning, project delivery and asset management

A 'golden loop' of high-quality digital information flowing through the asset lifecycle and back into future planning underpins the implementation of the findings of this review. There is a risk that every asset owner and major supply-chain business expends considerable time and resources in developing their own unique approach to delivering this information flow. A common approach to the collection, storage and exchange of data will accelerate digital literacy in the supply chain, provide a common platform for innovation and open up opportunities for linking digital twins to provide greater system of systems-level insight.

This review recommends that the IPA, in consultation with the CLC, identifies how to give further support to the National Digital Twin Programme's efforts to establish a common approach to data management that supports design, delivery, systems integration, asset management and future planning.

The review found that infrastructure has much to learn from working practices that are commonplace in the digital sector and that infrastructure and digital businesses can struggle to collaborate owing to a lack of mutual understanding. To begin to tackle this problem, this review recommends that ICE invites digital businesses to take an active role in the next phase of the review.



“The infrastructure sector needs to develop a pipeline of leaders with the breadth and adaptability to thrive in an ever more complex, technology-driven project environment”

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# 07 References

## **Association for Project Management (2019) Leadership: Responding to Complexity**

Association for Project Management (2019) Project Management for Large, Complex Projects – An Expert Report for the Edinburgh Tram Inquiry

## **Bakhshi J, Ireland V, Corral de Zubielqui G (2015) Exploring Project Complexities: A Critical Review of the Literature, AIPM 2015 Conference Proceedings**

Brady T, Davies A (2014) Managing Structural and Dynamic Complexity: A Tale of Two Projects, Project Management Journal, August/September 2014, 21-38

## **Bungay S (2010) The Art of Action: How Leaders Close the Gaps Between Plans, Actions and Results**

Cambridge Centre for Smart Infrastructure and Construction and Centre for Digital Built Britain (2020) Flourishing Systems – Re-envisioning Infrastructure as a Platform for Human Flourishing

## **Centre for Digital Built Britain (2018) The Gemini Principles**

Department for Transport and Infrastructure and Projects Authority (2019) Lessons from Transport for the Sponsorship of Major Projects

## **Davies A, Brady T, Hobday M (2006) Charting a Path Toward Integrated Solutions, MIT Sloan Management Review 47, 3, 39-48**

Davies A, Gann D, Douglas T (2009) Innovation in Megaprojects: Systems Integration at London Heathrow Terminal 5, California Management Review 51, 2, 101-125

## **Davies A, Mackenzie I (2014) Project Complexity and Systems Integration: Constructing the London 2012 Olympics and Paralympics, International Journal of Project Management 32, 773-790**

Denicol J, Davies A, Krystallis I (2020) What are the Causes and Cures of Poor Megaproject Performance? A Systematic Literature Review and Research Agenda, Project Management Journal

## **Dvir D, Shenhar A (2011) What Great Projects Have in Common, MIT Sloan Management Review 52, 3, 18-21**

Edmondson A (2012) Teamwork on the Fly: How to Master the New Art of Teaming, Harvard Business Review, April 2012

## **Get it Right Initiative/University College London (2019) Barriers to the Adoption of Future Digital Engineering Technology**

Gil N, Tether B (2011) Project Risk Management and Design Flexibility: Analysing a Case and Conditions of Complementarity, Research Policy 40, 415-428

## **House of Commons Public Accounts Committee (2020)**

### **High Speed 2: Spring 2020 Update**

Infrastructure Client Group and Institution of Civil Engineers (2020) Project 13 Framework

## **Infrastructure and Projects Authority (2017) Transforming Infrastructure Performance**

Infrastructure and Projects Authority (2020) Principles for Project Success

## **London 2012 Learning Legacy (2011) Systems Integration: A Programme-Wide Legacy**

Merrow, EW (2011) Industrial Megaprojects: Concepts, Strategies, and Practices for Success

## **National Audit Office (2019) Completing Crossrail**

Nuclear Sector Deal Cost Reduction Working Group (2020) Nuclear Sector Deal: Nuclear New Build Cost Reduction

## **Shenhar A (1993) From Low- to High-Tech Project Management, R&D Management 23, 3, 199-214**

Shenhar A, Holzmann V, Melamed B, Zhao Y (2016) The Challenge of Innovation in Highly Complex Projects: What Can We Learn from Boeing's Dreamliner Experience?, Project Management Journal 417, 2, 62-98

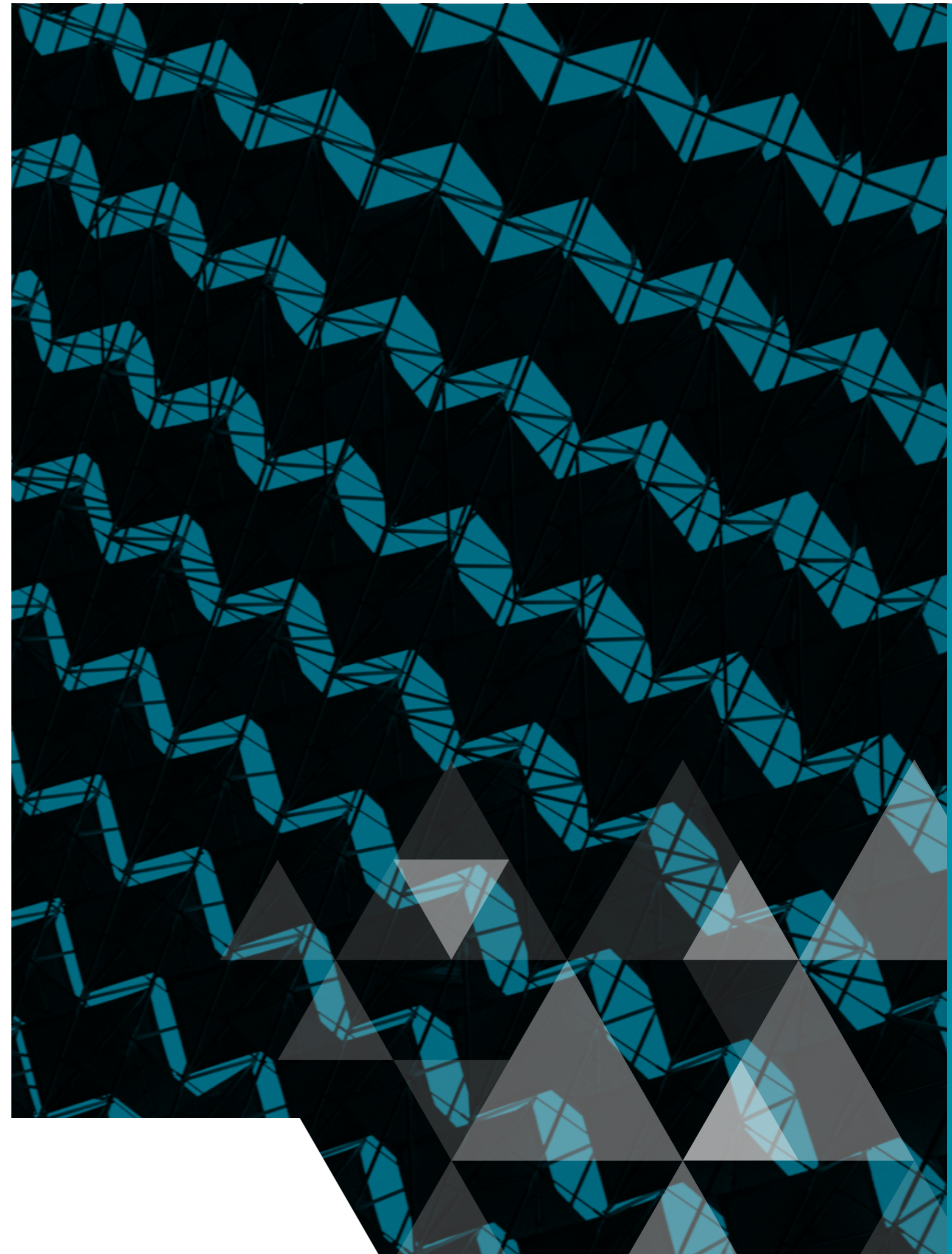
## **Whyte J (2019) How Digital Information Transforms Project Delivery Models, Project Management Journal 50, 2, 1-18**

Winch G (2014) Three Domains of Project Organising, International Journal of Project Management 32, 721-731

## **Winch G, Leiringer R (2016) Owner Project Capabilities for Infrastructure Development: A Review and Development of the 'Strong Owner' Concept, International Journal of Project Management 34, 271-281**

Winch G, Maytorena-Sanchez E, Sergeeva N (2018) No Project is an Island, Project, Autumn 2018

## **Zerjav V, Edkins A, Davies A (2018) Project Capabilities for Operational Outcomes in Inter-Organisational Settings: The Case of London Heathrow Terminal 2, International Journal of Project Management, 36, 444-489**



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