



A Systems Approach to Infrastructure Delivery

Part 2: Putting the principles into practice

“One of the most striking pieces of evidence, we discovered, was work from Independent Project Analysis that showed that, globally, more than two-thirds of mega and major projects disappointed their owners in terms of cost, schedule or a failure to meet desired outcomes”

Foreword



Andrew McNaughton
SAID project lead

In December 2020, the Institution of Civil Engineers (ICE) published A Systems Approach to Infrastructure Delivery (SAID)¹. This report captured the conclusions of a review that I led into improving the delivery of complex infrastructure projects.

I carried out my review in the context of a series of high-profile projects that had ran into serious difficulties. Unfortunately, these problems were not one-offs. One of the most striking pieces of evidence, we discovered, was work from benchmarking consultancy Independent Project Analysis that showed that, globally, more than two-thirds of mega and major projects disappointed their owners in terms of cost, schedule or a failure to meet desired outcomes².

SAID made the case that a wider and more skilful use of systems thinking was needed to reverse this situation. This need will only grow as infrastructure projects are required to deliver a more complex range of outcomes via the integration of diverse technologies alongside traditional civil engineering works.

The first SAID report set out eight principles to help any organisation adopt a Systems Approach to Infrastructure Delivery. The response to the study was overwhelmingly positive and many people contacted me and ICE to ask if we could provide further guidance and, in particular, real-world examples related to the principles.

Therefore, during 2021, with the support of infrastructure engineering software company Bentley Systems, we initiated a series of industry roundtables to explore what the principles meant to the leaders of some of the UK's biggest projects. These discussions, together with a series of extended interviews with these leaders

and others, formed the basis for this second, case study-based, report.

To paint as rich a picture as possible, we selected five projects at various stages of delivery. We examined whether the principles had been applied in part or in whole and, if they hadn't, whether their use would have led to an improved outcome.

In addition to the project case studies, we have included an example of an organisation in the infrastructure supply chain that has looked to develop its capability to support a Systems Approach to Infrastructure Delivery. I am particularly pleased we have been able to include this case study (from Costain) as I believe it is important to dispel the suggestion that the principles of SAID are largely relevant only for asset owners. This is not true. Achieving better outcomes from projects via the SAID principles demands that all organisations working on projects make fundamental changes to how they engage with each other and carry out their work.

Since our first report, the UK Government's Infrastructure and Projects Authority (IPA) has updated its infrastructure investment pipeline, highlighting potential investments with a value of up to £650bn over the next 10 years. The IPA has challenged the industry to take a systems-focused and data-driven approach to delivering this work³.

I strongly believe that the two SAID reports provide a solid foundation for responding to the IPA's challenge and achieving the outcomes from infrastructure investment that the public demands. I would like to thank colleagues from across the industry and beyond who have supported this work over the past two years. I look forward to continuing to work with you to make the changes we so urgently need.

¹ [ice.org.uk/knowledge-and-resources/briefing-sheet/a-systems-approach-to-infrastructure-delivery](https://www.ice.org.uk/knowledge-and-resources/briefing-sheet/a-systems-approach-to-infrastructure-delivery)

² Merrow E (2011) Industrial Megaprojects: Concepts, Strategies and Practices for Success

³ Infrastructure and Projects Authority (2021) Transforming Infrastructure Performance: Roadmap to 2030



About this report

This second Systems Approach to Infrastructure Delivery report is a response to requests from the infrastructure sector for ICE to provide more practical insight into how to deliver a systems approach, wherever possible drawing on real-world project experience.

The bulk of this report therefore consists of a series of deep dives into lessons from five projects and programmes: Tideway, Crossrail, East West Rail, the British Antarctic Survey's Infrastructure Modernisation Programme and Anglian Water's Strategic Pipeline Alliance. It also draws on insight from Costain on the challenges of developing the capability to adopt a systems approach within a large supply-chain business.

We then highlight four themes that run across the deep dives, drawing on a series of ICE roundtable discussions held throughout 2021 on the SAID principles, sponsored by Bentley Systems.

Lastly, we present some recommendations for future actions by ICE to support the implementation of a systems approach.

The project was led by former Balfour Beatty chief executive Andrew McNaughton with the support of

Bentley Systems international director of public policy and advocacy Mark Coates.

They would like to thank the many organisations and individuals who shared their insights during the drafting of this report. Particular thanks are due to the following organisations:

- Anglian Water Strategic Pipeline Alliance
- Arcadis
- Bentley Systems
- British Antarctic Survey
- Centre for Digital Built Britain
- Centre for Systems Engineering and Innovation, Imperial College London
- Costain
- Crossrail
- East West Rail
- EDF
- HS2
- Infrastructure and Projects Authority
- KPMG
- Major Projects Association
- Microsoft
- National Highways
- Project 13 Early Adopters Group
- Science Policy Research Unit, University of Sussex
- Tideway
- Turner and Townsend

Contents

Executive summary p07

Purpose of this report p09

Infographic: Your print-out-and-share summary of SAID p10

Deep Dive case studies

- 01 Tideway p12
- 02 British Antarctic Survey's Infrastructure Modernisation Programme p18
- 03 Crossrail p22
- 04 East West Rail p28
- 05 Anglian Water's Strategic Pipeline Alliance p32
- 06 Costain's systems approach capability p38

Cross-cutting lessons p42

Recommendations p46

Find out more: ice.org.uk

Author: Andrew Crudgington; Lead contributor: Mark Coates;
Editorial manager: Michelle Harbi; Designer: James McCarthy;
Graphics: Anthea Carter, Paul Weston;
P10-11 infographic: Cognitive; Sub-editor: Lucien Howlett



Executive summary

The core of this report consists of six case studies:

- Tideway
- Crossrail
- East West Rail
- British Antarctic Survey's Infrastructure Modernisation Programme
- Anglian Water's Strategic Pipeline Alliance
- Costain's systems approach capability

Each of these case studies provides valuable practical insight into the implementation of the eight SAID principles (see overleaf). In addition, the SAID team has drawn out four cross-cutting themes from the case studies:

Keep the end in mind throughout the entire project

It is not enough to start with the end in mind – it must be there throughout, until the end. Across our case studies, we found that staying focused on the outcomes drove better decision-making and ensured that the consequences of those decisions were tracked, documented and understood by all.

Ensure we are all in this together

Project delivery arrangements need to ensure that we really are all in this together. In our case studies, we found that traditional contractual and organisational structures were not up to the challenges created by modern, complex infrastructure projects. To deliver projects effectively, owners need to create an integrated and collaborative enterprise that embraces all of the key organisations working on a project.

Think hard about leadership

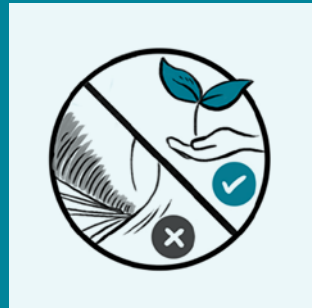
The scale, complexity, duration and range of disciplines involved in delivering a project makes leadership that is aware of its own limitations essential. Good leaders can ensure that a project's vision is shared by delivery partners, stakeholders and external groups. They also have the important task of passing the baton on as a project moves through its lifecycle, ensuring that the right voices and leaders are prominent at the right time.

Do you have to deliver it all at once?

The bigger and more complex a project is, the harder it is to deliver it in one go. Delivering projects with upgrades and obsolescence in mind makes it possible to deliver outcomes in stages. Crossrail's chief executive, Mark Wild, has publicly challenged other megaprojects to identify their minimum viable product (MVP) as part of early-stage development.

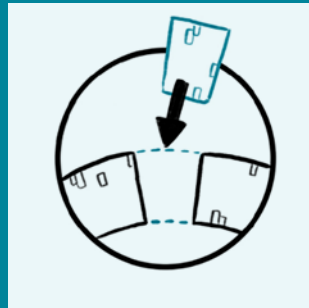
To deliver projects effectively, owners need to create an integrated and collaborative enterprise that embraces all of the key organisations working on a project

The eight SAID principles



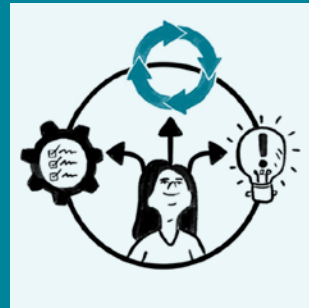
01 THINK OUTCOMES, NOT EDIFICES

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



02 CLOSE THE GAP

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



03 OWNERS MUST OWN PROJECTS

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



04 FUTURE-PROOF PROJECTS

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



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.



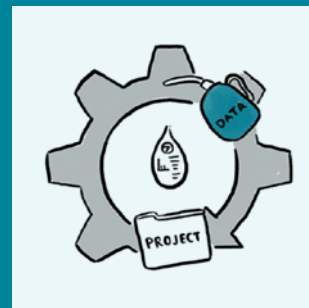
06 BAKE IN SYSTEMS THINKING

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



07 AGILE LEADERSHIP

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.



08 DATA OILS YOUR PROJECT

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 boosts operational performance.

View our animated film explaining the Systems Approach to Infrastructure Delivery at www.bit.ly/icesaid

Purpose of this report

This report:

- Helps professionals involved in infrastructure projects to deepen their understanding of the benefits of adopting a Systems Approach to Infrastructure Delivery
- Provides practical insight on how to realise those benefits

Why we need a Systems Approach to Infrastructure Delivery

Too many projects disappoint their owners and the public

The first SAID report, published in December 2020, was the result of a major review commissioned by ICE against the backdrop of a number of high-profile projects coming in late, over budget and failing to meet the expectations of their owners and users.

Our research found that the infrastructure sector struggled to deal with the complexity of many modern projects. Professionals need to become better at planning, constructing and, most importantly, integrating the complex systems that will deliver a service to users. This service also needs to support the achievement of a much wider set of outcomes than the sector has traditionally dealt with.

For example, asset owners and the public are increasingly expecting infrastructure investments to contribute to the decarbonisation of the UK and the levelling up of its economy. All of this is happening when the rate of change in technology is

accelerating, shifting more of the functionality of infrastructure systems into the digital space.

The review identified eight principles for improving project delivery in this environment (see facing page).

What has happened since the first report?

Systems thinking has moved to the heart of the UK infrastructure programme

The first SAID report points a way forward for infrastructure delivery and complements a raft of industry/government initiatives that are being managed by the Infrastructure and Project Authority. These include the Construction Playbook⁴, Project Routemap⁵ (to whose systems integration model the SAID review team has contributed) and the Transforming Infrastructure Performance: 2030 Roadmap (TIP).

TIP, in particular, is closely aligned with the goals of SAID and is grounded in a system-of-systems model that was developed by the UK Government in partnership with industry. This model takes key societal outcomes as codified in the UN Sustainable Development Goals and links them directly to the built and natural systems that help to deliver them. The IPA and the Construction Leadership Council have committed to using this model to take a systems approach to selecting and delivering interventions that can improve infrastructure performance.



Read the first SAID report at www.bit.ly/icesaid1report

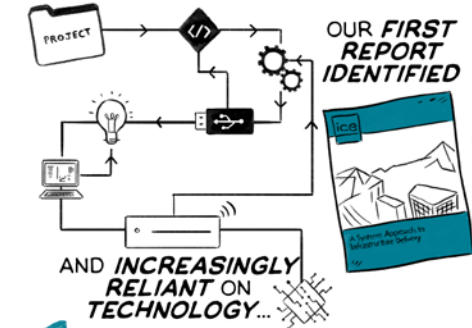
4 www.gov.uk/government/publications/the-construction-playbook

5 www.gov.uk/government/publications/improving-infrastructure-delivery-project-initiation-routemap

Infographic: Your print-out-and-share summary of SAID



MODERN INFRASTRUCTURE PROJECTS ARE COMPLEX...

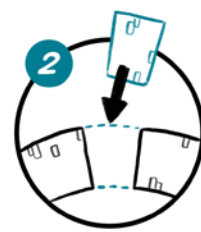


PRINCIPLES...

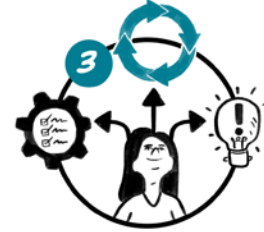
SYSTEMS APPROACH TO INFRASTRUCTURE DELIVERY



1 THINK OUTCOMES NOT EDIFICES



2 CLOSE THE GAP



3 OWNERS MUST OWN PROJECTS



4 FUTURE-PROOF PROJECTS



5 THINK SHOVEL WORTHY NOT SHOVEL READY



6 BAKE IN SYSTEMS THINKING



7 AGILE LEADERSHIP



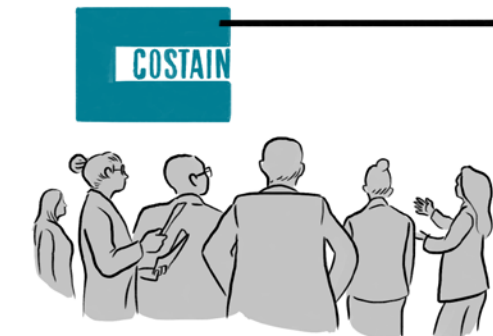
8 DATA OILS YOUR PROJECT

...THAT HELP THE INFRASTRUCTURE SECTOR TO

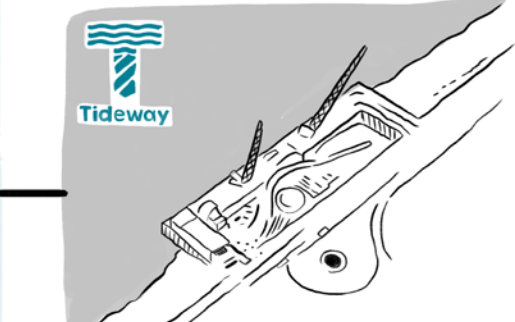
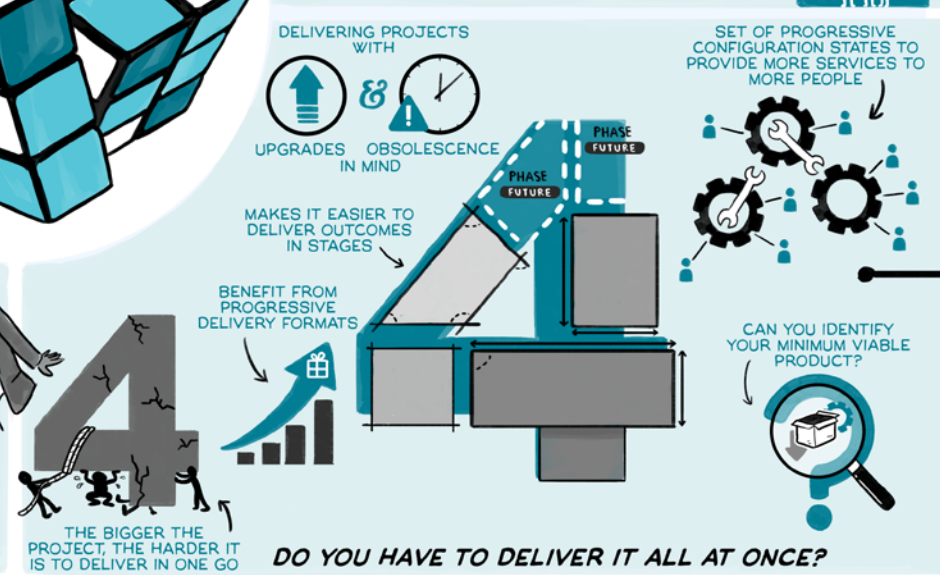
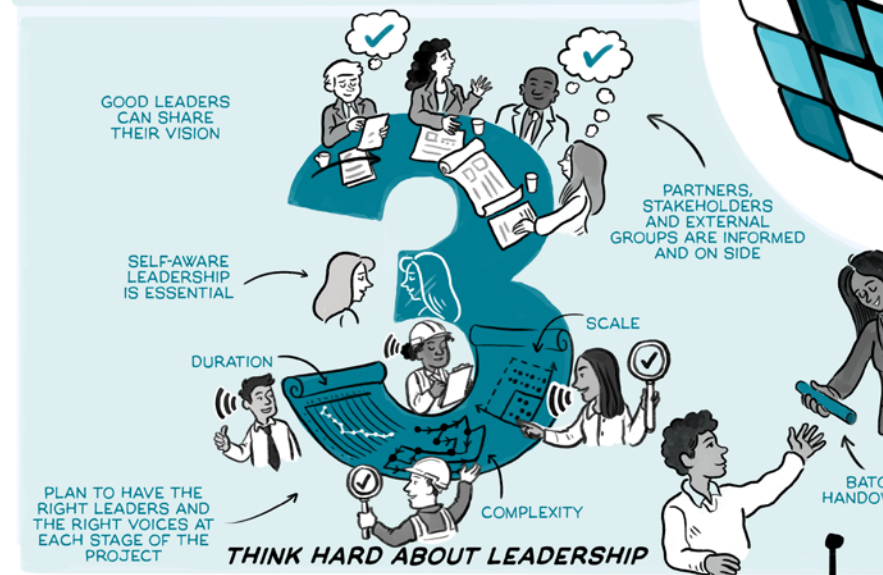
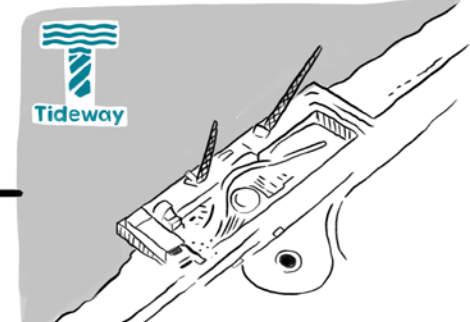
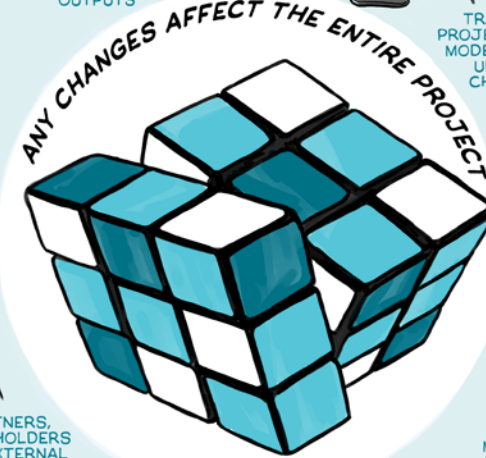
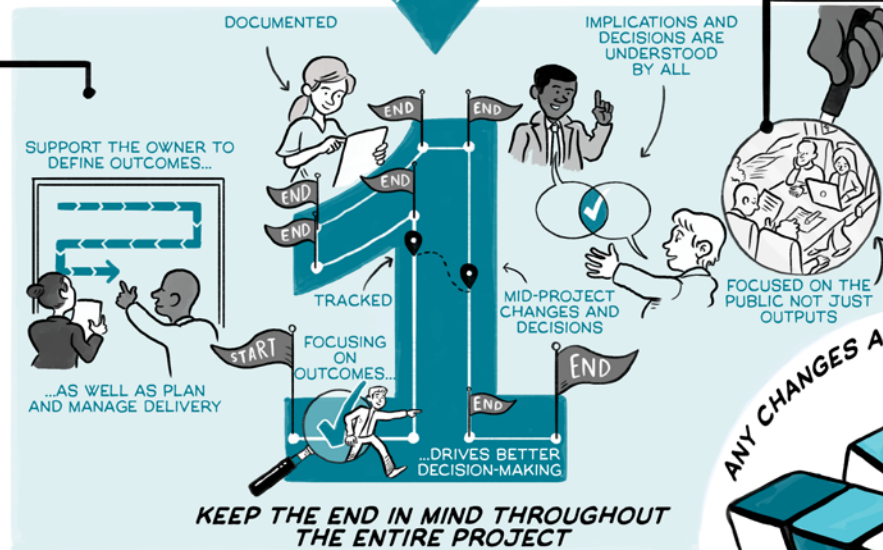
OVERCOME CHALLENGES

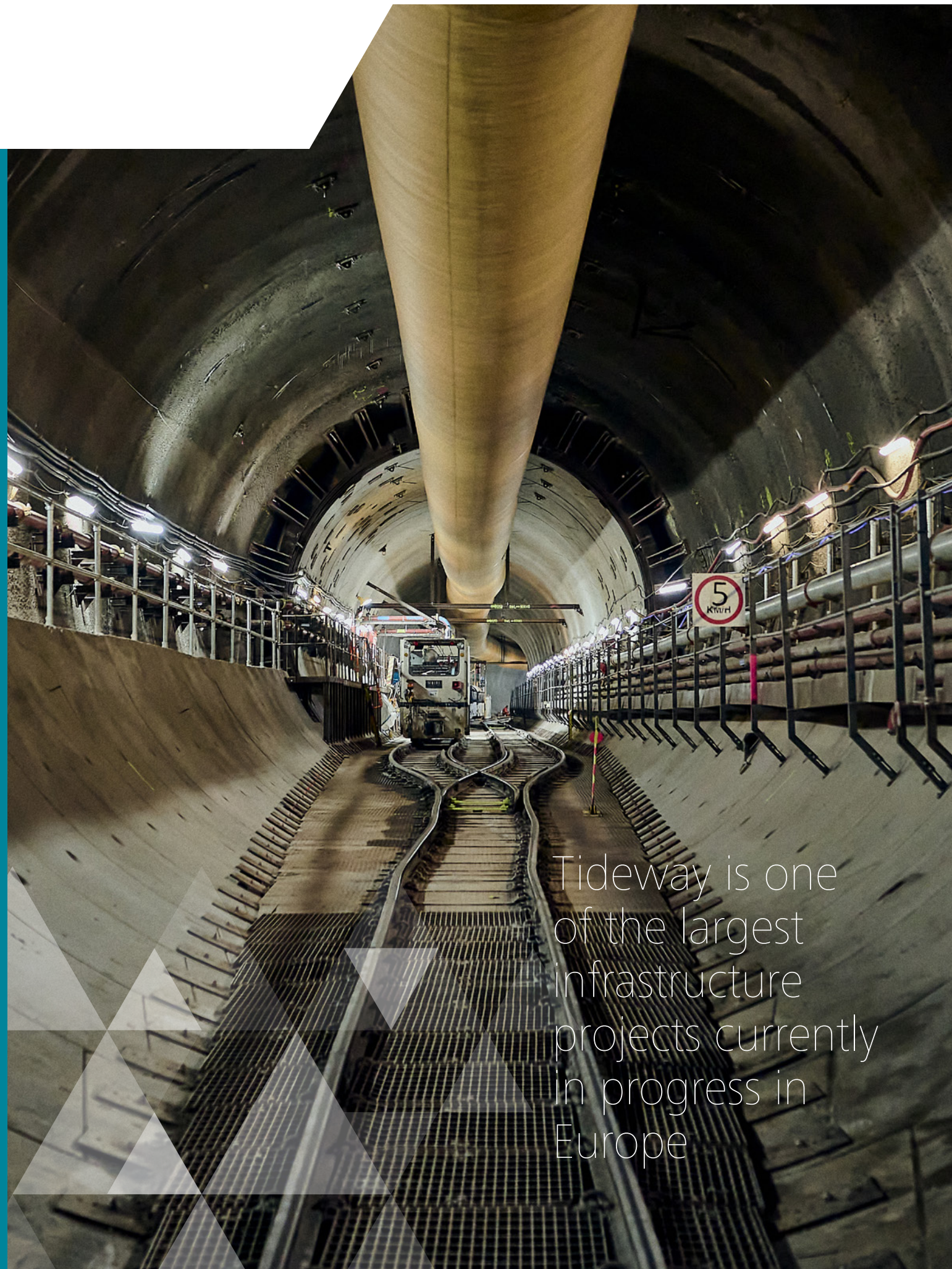
EMBRACE TECHNOLOGY

DELIVER BETTER OUTCOMES



anglianwater
STRATEGIC PIPELINE ALLIANCE





Tideway is one of the largest infrastructure projects currently in progress in Europe

Deep dive

01 Tideway

Front-end planning and the 'owners must own' principle are proving crucial in reconnecting London with the River Thames

Summary of insights

- Identity and narrative matter. Tideway is clear that constructing a tunnel is only a means to an end in reconnecting Londoners to the Thames. This has supported strong relationships with stakeholders and ensured that the civil engineering voice does not dominate within a multidisciplinary project.
- The V-cycle was not just a tool for systems engineers at Tideway – it helped the project organisation to define responsibilities, allocate resources and ultimately focus on bringing an enterprise into operation.
- 'Owners must own' meant committing significant resources to creating a high-quality reference design and delivery schedule that established the 'what' and 'how' of the project. It also meant having an owner with the strength and focus to ensure that the project was delivered to the design with minimal changes.
- Front-end planning between Thames Water and Tideway and a delivery strategy based on three large joint ventures kept interfaces to a manageable level.
- The health and safety of all workers, no matter who their direct employer is, has been seen as a crucial element of the project system. Tideway management took responsibility for standards and their enforcement across the project. Staff working for supply-chain organisations were considered 'its' people.
- Standardisation. Tideway, Thames Water and the joint ventures agreed a common set of mechanical and electrical (M&E) specifications and suppliers. This has considerably reduced risk and complexity, although Tideway does have to be alert to the risk of a key supplier underperforming.

Background

Tideway is one of the largest infrastructure projects currently in progress in Europe. The project is being delivered by Bazalgette Tunnel Limited (BTL), a licensed infrastructure provider created to finance, build, maintain and operate a 25km super-sewer under the Thames (see Fig 1.2, page 17). The project is due to be completed in 2025.

Thames Water's decision to create a separate entity to deliver the project has had an important influence on subsequent events.

Extensive front-end work was needed to package up the project so that it was attractive to equity investors and supply-chain partners. This has delivered benefits right through the project's lifespan.

Identity and narrative matter

BTL is clear that its goal is to reconnect London with the River Thames and not to deliver a set of physical assets. To this end, BTL trades and is known to the public as Tideway. As reported in the first SAID report, the project has worked hard to reinforce this identity in its external and internal communications. Tideway believes this focus has helped it to build constructive relationships with residents and wider stakeholders.

Using the V-cycle to bake systems thinking into a project organisation

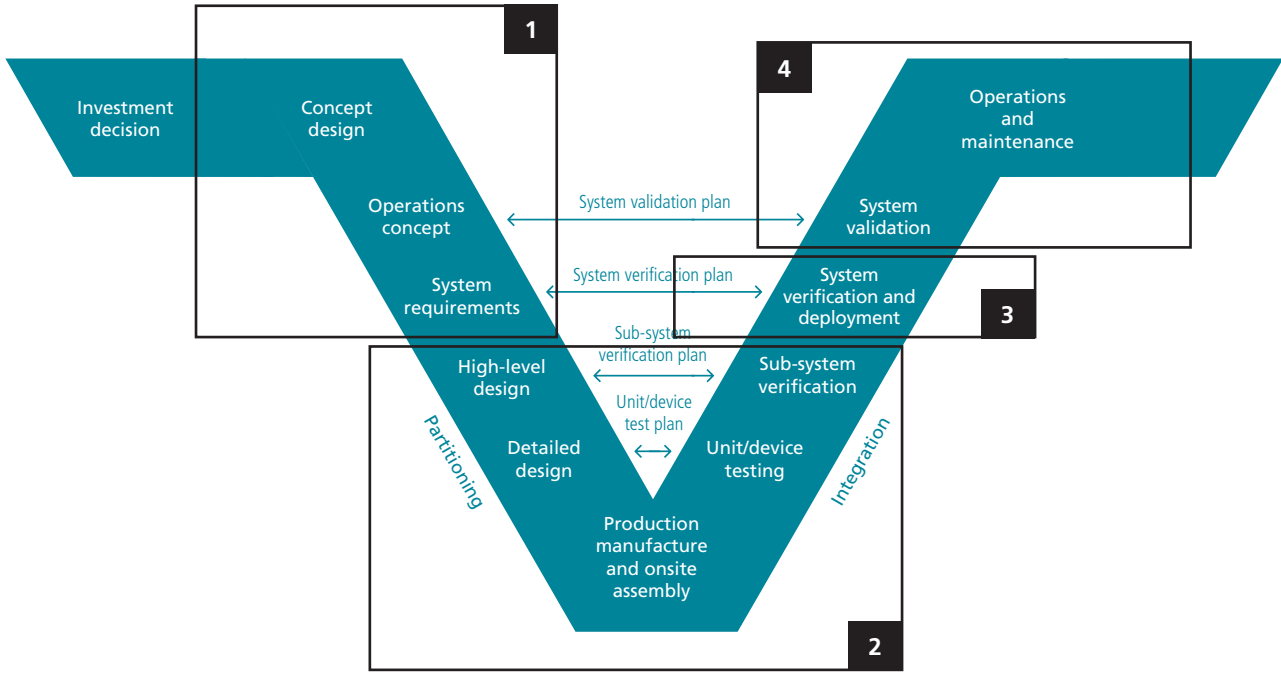
At Tideway, the processes encapsulated in the V-cycle have been helpful not just as a systems engineering tool but also as a way of baking this outcome-based thinking into the project DNA (see Fig 1.1, overleaf).

At the next level of detail, Tideway is clear that this outcome will be achieved by bringing into operation the services that will be supported by the infrastructure delivered by the project. The V-cycle process requires the owner to deliver a very high-quality specification on the left-hand side of the V and then commit to a high standard of quality and risk management through the base and right-hand side.

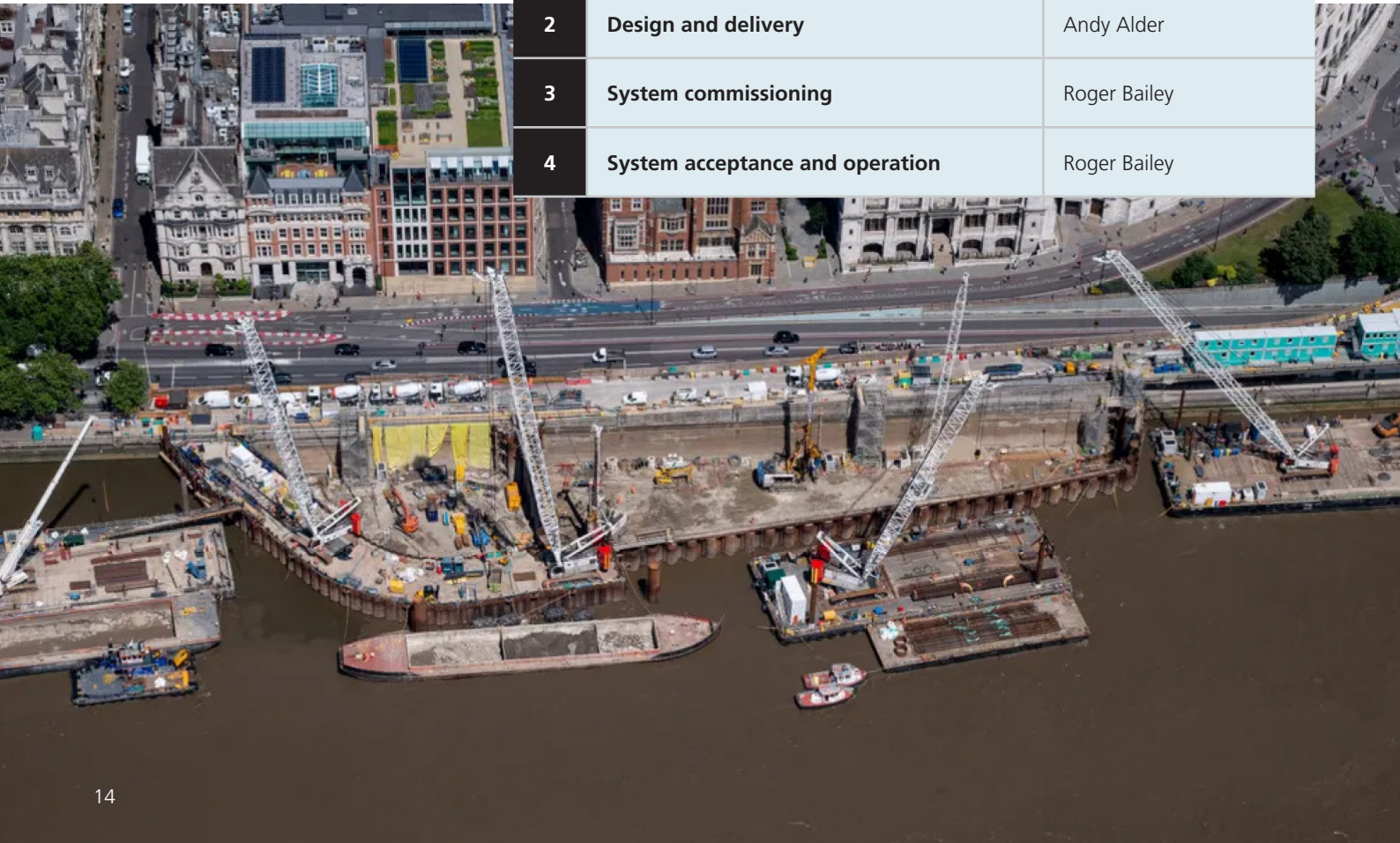
This process has helped Tideway to ensure that key processes and roles were clearly defined at an early stage, allowing resources to be allocated and key staff to feel empowered. It also helped to establish responsibility for integration at different levels, for example between civil engineering sub-systems, with the existing 'classic' sewer network and with the control system.

Senior team responsibilities and handover points are mapped on the V-cycle. Tideway has planned for how different voices should rise and fall during the lifecycle, balanced against the benefits of continuity.

Fig 1.1: Tideway’s systems engineering V-cycle



	Stage	Director
1	System design and requirements	Roger Bailey
2	Design and delivery	Andy Alder
3	System commissioning	Roger Bailey
4	System acceptance and operation	Roger Bailey



As an example, Tideway chief technical officer Roger Bailey has been closely involved at points 1, 3 and 4 in Fig 1.1, essentially acting as an ‘owner within the owner’. This means that the same person has been involved in establishing outcomes before moving on to drive the creation of the detailed systems requirements. Meanwhile, Andy Alder, the programme director, has led delivery at the base of the V, during which time Bailey has been preparing to receive the assets and bring them into service.

Similarly, at the inter-organisational level, Tideway and Thames Water worked hard at an early stage to clarify roles and minimise interfaces between the two organisations. Thames was also heavily involved as promoter and ultimate operator in the specification of the assets Tideway is delivering. Post-completion of its enabling activity, Thames Water stepped back slightly and concentrated on work it needed to carry out on the remainder of its network to be able to accept the new infrastructure, leaving Tideway to focus on its construction and integration.

The role of consultancy Jacobs as delivery partner has also been crucial. As a one-off project, Tideway does not have access to the human resources of a serial client so has used Jacobs to rotate the necessary expertise through the project at key times.

All of this has kept Tideway focused on creating an operational enterprise and not simply a set of assets. As the project team told us: “Someone is always thinking about turning it on.”

Owning the what and how of the project

The ‘owners must own’ theme of SAID resonates with the Tideway leadership. This has manifested itself in several important ways. Significant resources were committed to establishing a strong reference design. As part of this process, Tideway leadership communicated its appetite for innovation to the design community and was open to putting time and resource into investigating and testing alternative solutions at the concept stage.

An example is the vortex design being utilised for sewage shafts. Tested in 1:10 physical models, the solution replaced less durable conventional cascade designs, making an important contribution to achieving one of Tideway’s outcomes: that the system can operate with minimal maintenance.

The design was subject to extensive legal and technical review and was tested using digital simulation and scale models. This

allowed Tideway to go to the market for delivery contractors with a design that was overall approximately 30% complete, and 100% complete for the system design and hydraulics. Tideway was clear that it did not want the joint-venture delivery partners unpicking the design so put in place strong change control procedures, limiting significant design changes to single figures during the 10-year project, which has operated on more than 20 sites across 14 London boroughs.

Tideway was equally keen to provide strong leadership on the project’s schedule. A six-month period of optimised contractor involvement was used to tease out innovation on how the project was to be delivered, allowing progress in key areas such as standardisation of M&E equipment. Tideway also worked with Ofwat, its economic regulator, to create a highly credible programme and budget that was grounded in an extensive risk register.

Once the budget and programme were set, the project’s leadership was wary of any significant reopening. In part this is because the project’s development control order places significant constraints on areas such as noise and environmental impact, so well-meaning changes – for example, reversing the direction of a tunnel drive – could have been extremely disruptive to the overall schedule.

Front-end planning

Tideway procured its construction partners slightly ahead of identifying its financing partners. This allowed it to go to the market for investors with both a budget and transparency on contractors’ prices.

Risk management was baked into the organisation design for construction delivery via splitting the project into three joint ventures⁶, reflecting different technology and ground conditions in different parts of the scheme, and a desire to avoid the risks associated with a single ‘Godzilla’ joint venture. Amey is leading a fourth contract to support systems integration and a fifth contract with Jacobs provides project and programme management support.

At a more tactical level, the quality control role found in the ‘Supervisor’ in the NEC Engineering and Construction Contract has been extremely important. Quality is vital at Tideway. The tunnel needs to operate for more than 100 years without major maintenance – if one section needs to close for repairs, it could take the whole system out of service for months. The NEC supervisor function has thus been key to driving this quality across the joint ventures.

⁶ The construction in the west region is being delivered by a joint venture of BAM Nuttall, Morgan Sindall and Balfour Beatty Group. This contract is known as Tideway West, with work taking place from Acton to Fulham. Construction in the central region is being delivered by a joint venture of Ferrovial Agroman and Laing O’Rourke Construction. This contract is known as Tideway Central, with work taking place from Fulham to Blackfriars. Construction in the east region is being delivered by a joint venture of Costain, Vinci Construction Grands Projets and Bachy Soletanche. This contract is known as Tideway East, with work taking place from Bermondsey to Stratford.

One lesson from the project is that this role needs a high degree of independence and should not be subsumed into the project management function. A Jacobs employee delivers this role for Tideway, avoiding adding another organisation to the project, and they report directly to Tideway's chief technical officer.

Standardisation

Tideway, Thames Water and the joint-venture contractors work to an agreed common set of M&E specifications and suppliers. This has considerably reduced risk and complexity compared with peer projects, although Tideway does have to be alert to the concentration of risk in a smaller supply-chain group.

Driving health and safety across the whole project system

Tideway took an early decision to seek a transformational level of health and safety performance. This was based on an assessment that the project represented 5% of UK annual construction activity – roughly 19,000 person years – which meant that ‘normal’ performance would generate 3,000 trips to A&E, 200-plus life-changing health impacts, 150 serious injuries and two fatalities. While not an entirely scientific estimate, the leadership team had a clear understanding of levels of fatalities and injuries on peer projects and a shared commitment to improve on that performance.

Contractors in the supply chain backed Tideway defining and driving a higher standard, but were clear that it must be policed. An owner asking for high standards and then accepting lower bids from organisations with poor safety records would destroy confidence.

A major innovation (and cost) was called EPIC – the Employer Project Induction Centre. Tideway wanted to cut through the multiple tiers of the supply chain and took the view that everyone entering the site would be one of ‘its’ people. All subcontractor staff received a full-day induction at the project’s expense, over and above any induction and training provided by their direct employer.

The EPIC training included a project simulation delivered by actors in which one character who had recently had a child suffered a fatal injury. The scenario then moved on to the impact of the death, encompassing a boardroom, a police interrogation and other settings. It included a powerful scene set 21 years later where the dead worker’s daughter talked about the consequences of losing her father when she was only weeks old. Earlier scenes were then replayed with the actors playing out a scenario in which safety was prioritised and the worker survived, leaving attendees with the feeling of having saved a life.

EPIC was helpful in clarifying the outcome and ethos Tideway was demanding. It made clear that for health and safety, the ‘norm’ was not acceptable, that onsite everyone was part of a single team and that no one could hide behind the ‘corporate veil’ of their contract or subcontract to evade responsibility. A member of the senior leadership team attended wash-up sessions at the end of the day to hear feedback from team members and an 0800 telephone number was provided to report any concerns. In the region of 100 ‘valid’ calls have been received, highlighting 30-40 issues. Each is investigated by internal auditors who report to the Tideway board.

Three different EPICs have been created – for construction, logistics and marine workers – to ensure that the sessions are relevant to participants. A particular concern was the quality and safety record of the existing logistics workforce on the River Thames. Tideway was keen to maximise use of the river, but research showed that 85% of boat master tests were failed, in part because the sector was dominated by small players who struggled to invest in training and development. Tideway developed its own code of practice and put all of its river-borne logistics subcontractors through a four-day course on a simulator at specialist water consultancy HR Wallingford’s research centre.

Tideway also visited key plant and materials suppliers to impress upon them that health and safety was a core value that should drive their decisions. They were also asked to provide 3D models of the new TBMs to facilitate pre-construction rehearsals.

Innovation

Much of the innovation on Tideway took place pre-construction. For example, the use of a regulated asset base model to finance the project made it more investable and reduced costs by encouraging competition. Some aspects of technical design, while not first of a kind, were also leading-edge. As noted above, however, Tideway froze the reference design and did not want contractors making isolated changes that could affect the wider system. This shifted the focus in the pre-construction dialogue phase to how the work would be delivered and away from what would be built.

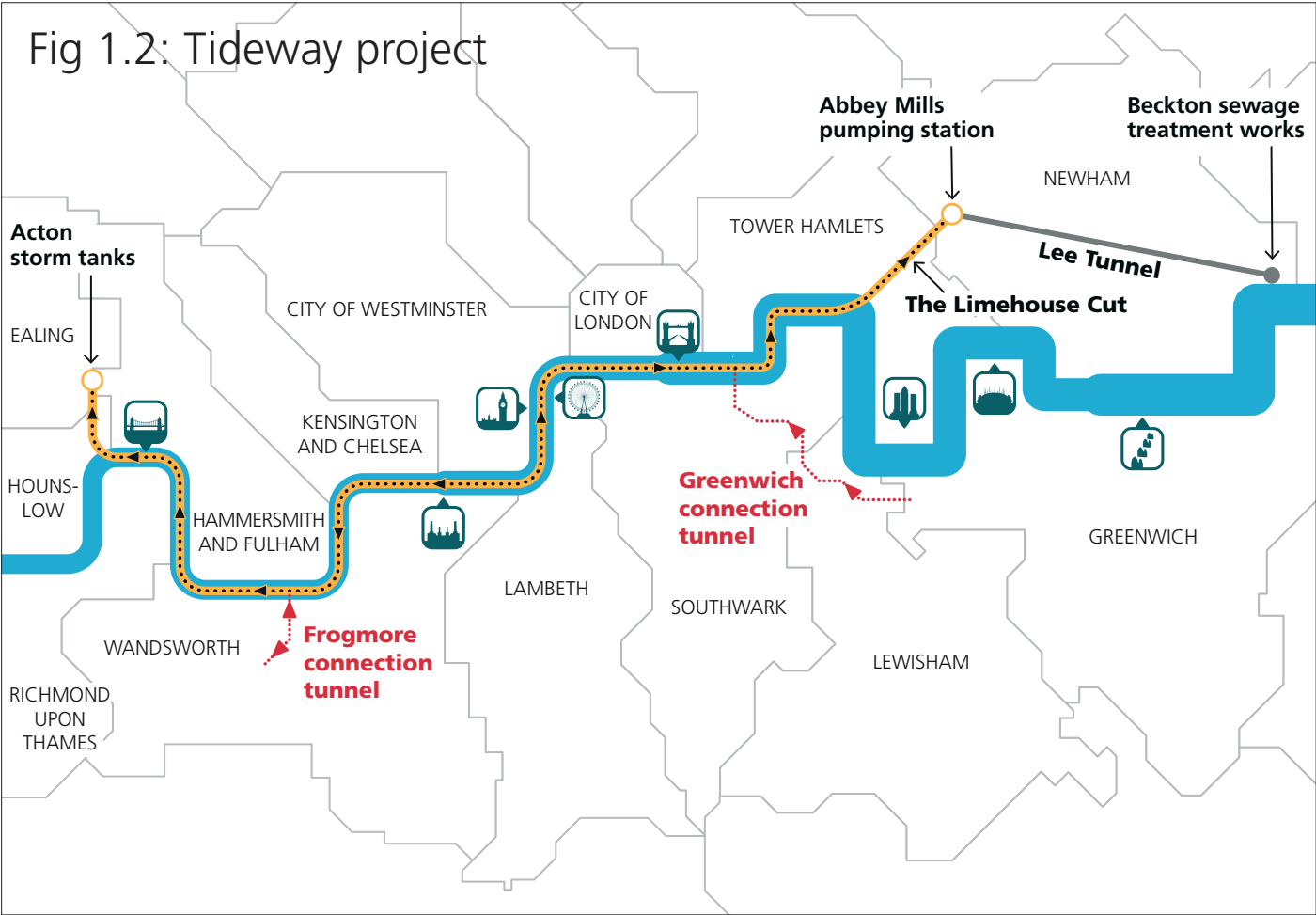
I3P – Industry Innovation Platform

Tideway created an Innovation Forum that allowed the project to take ownership of ideas emerging from all levels of the organisation and absorb the initial cost of developing a business case or trial. Innovations emerging from this process include PPE for Muslim women and a 3D virtual cube to allow steel fixers to rehearse activity.

Not all investments were successful: efforts to develop a precast secondary lining did not reach a sufficient level of maturity to fit with the schedule. This highlights a key challenge for the infrastructure sector: risk aversion is understandable in relation to the failure of physical assets. As a result, innovations need to be developed, proved and only then deployed, which, as the secondary lining example shows, is difficult within the timelines of a project.

Tideway is one of the creators of the I3P industry innovation platform, which seeks to collectivise this process by allowing groups of projects and owners to jointly fund innovation to meet common needs and then test and deploy programmatically across their activities.

One lesson from the project is that the NEC supervisor role needs a high degree of independence and should not be subsumed into the project management function



Deep dive

02 British Antarctic Survey

Resisting pressure to just get going, BAS, with its partners BAM and Ramboll, rebuilt its wharf at Rothera Research Station on time and under budget

Summary of insights

■ 'Owners must own' has been an important concept behind the success of the British Antarctic Survey (BAS) – but ownership has had to be dispersed to deliver a facility as complex as the Rothera Research Station's Discovery Building within the narrow Antarctic construction window.

■ Pressure to just get going needed to be resisted. Site investigation work revealed that a project to upgrade the wharf at Rothera carried significant risk. Delay meant the facility would not be available for the launch of the RRS Sir David Attenborough research vessel, but it was crucial to the project's success that it did not become fixated on that end date.

■ Extensive front-end loading was focused on redesign, modularisation, and digital and physical rehearsals, which resulted in the wharf project coming in on time and under budget, with health, safety, quality and environmental performance all uniformly excellent.

Background

The British Antarctic Survey has a permanent physical presence in Antarctica and a visiting presence in the Arctic. BAS is currently delivering its Antarctic Infrastructure Modernisation Programme, which includes two projects at its Rothera Research Station (see Fig 2.1 overleaf), a rebuilt wharf and the new Discovery Building. BAS's purpose is to support the safe delivery of world-class science and research.

Delivering the owners' role through the 'Magnificent Seven'

BAS's experience suggests some important nuances for organisations looking to implement the SAID principle of 'owners must own'.

NERC (the Natural Environment Research Council) is the ultimate owner of the UK's Antarctic infrastructure but day-to-day operation is in the hands of BAS. In the harsh conditions of the Antarctic, it is potentially disastrous if a user finds that what has been delivered via a construction programme does not work for them in practice. It has therefore been vital to dedicate time to achieving alignment between the owner, users and the infrastructure delivery team.

On projects such as the upgrade of the Rothera station's wharf, this proved relatively simple as there was no real complexity of need. The Discovery Building has been altogether more challenging: the project aims to replace six obsolete structures with a single multi-function building incorporating science and medical facilities, workshops, a plant room, garages, stores and offices.

The multi-use nature of the facility means that the works affect nearly every member of the station community. In a climate where construction is possible only during five to six months of the year, decision-making has needed to be efficient and delegated downwards wherever possible. This has been achieved by creating a 'Magnificent Seven' group of owners responsible for overseeing the design, development, delivery and handover to operations of each distinct function of the building to an agreed scope. This arrangement also provides a single point of contact for

In a climate where construction is possible only during five to six months of the year, decision-making has had to be efficient and delegated downwards wherever possible

resolving any conflict between areas of the building, enables smoother succession planning where required, and ensures that within the programme there is a clear understanding of the history of decisions and assumptions.

The challenges and benefits of investing in a shovel-worthy project

Projects in Antarctica progress only when BAS has a comprehensive understanding of the risks and is confident that works can be delivered to programme. Prior to the Discovery Building project, the first stage of the modernisation of the Rothera station was to rebuild and extend its wharf. The project had operational, environmental and political drivers, not least the high-profile launch of the new Royal Research Ship Sir David Attenborough.

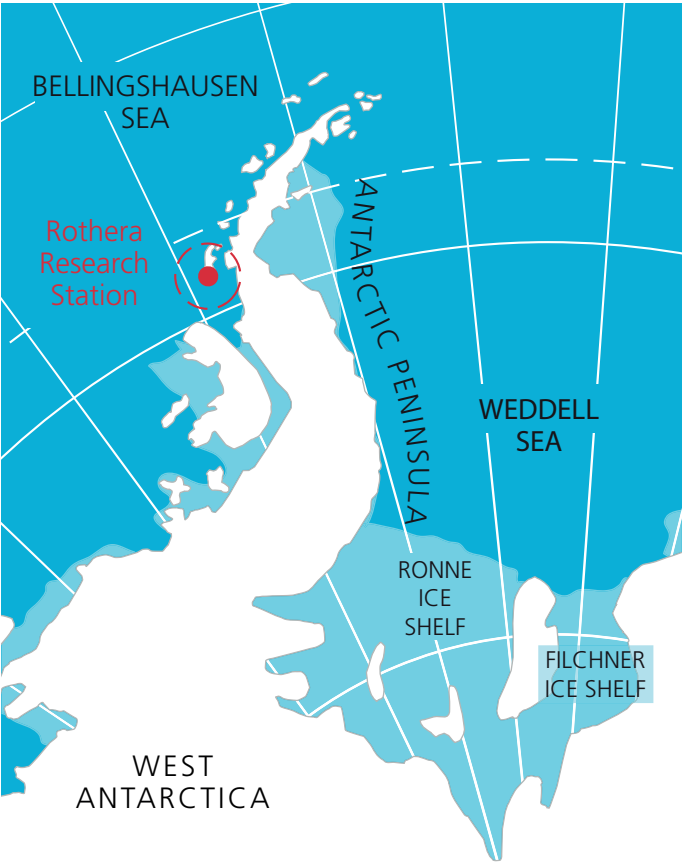
Extensive site investigation revealed that the original proposed design solution carried an estimated £20m of client risk against a construction contract value of about £35m, set within an overall project budget of only £40m. The programme leadership concluded that this was unacceptable. The project’s senior responsible owner (its sponsor) supported a year-long pause to rethink delivery, despite some stakeholder pressure to ‘just get going’.

BAS took steps to fully exploit the time available and co-located its team with its delivery partner, BAM, to work through the new solution. Every aspect of the build was examined with both the design team and the construction manager and foreman. Full digital and physical rehearsals were carried out, first using a digital model and then in the factory. The full team walked through every page of the method statement pre-deployment to the Antarctic and BAM even developed an app to allow excavator operators to practice digging out the rockfill from the existing wharf.

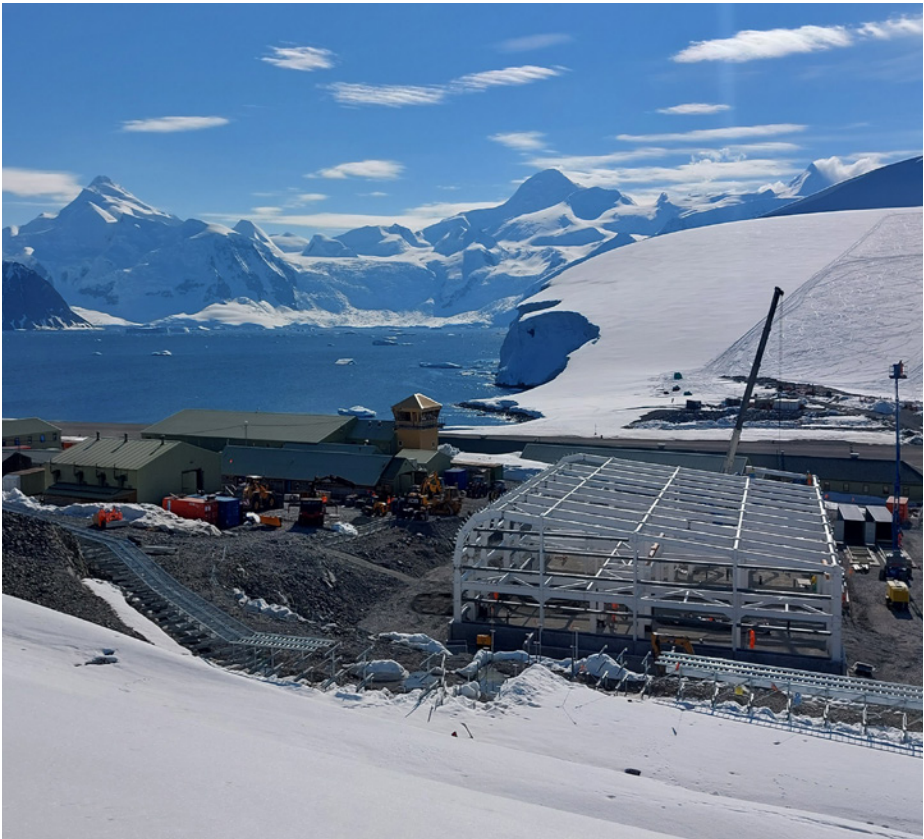
Construction began in November 2018 and was completed a week ahead of schedule in April 2020. The construction budget for the revised solution was £29m, a saving of £6m on the original, with client risks assessed at circa £5m. Some risks did materialise (including as a result of the Covid-19 pandemic) and the project risk pot was used for further mitigation measures: for example, buying additional plant to reduce the risk of a single point of failure. The project also realised some opportunities, with the net effect being that the construction contract final account was approximately £0.5m under the final adjusted target cost of £30.5m, realising a modest gain share for both parties.

The wharf project’s health, safety, quality and environmental performance was uniformly excellent. The owner is very satisfied with the project and the RRS Sir David Attenborough berthed at Rothera for the first time on 16 December 2021.

Fig 2.1: BAS’s Rothera Research Station location



BAS took steps to fully exploit the time available and co-located its team with its delivery partner, BAM, to work through the new solution



Left and below: At Rothera Research Station, BAS is replacing six obsolete structures with the single multi-functional Discovery Building, incorporating science and medical facilities, workshops, a plant room, garages, stores and offices



Deep dive

03 Crossrail

A procurement strategy that passed much of the integration risk to supply-chain partners contributed to Crossrail's problems

Summary of insights

- Crossrail Ltd committed significant resources to creating the Crossrail Programme Functional Requirement (CPFR), which formed the basis for a robust reference design. The clarity of this intent, however, was undermined by a procurement strategy that gave 37 lead contractors a high degree of freedom to alter the reference design without a sufficiently strong central authority to analyse and manage the consequences for the system.
- The Crossrail experience reinforces the view in the first SAID report that the strategic risks around integrating, assuring and commissioning a functioning railway (or any other system) should be held and proactively managed by the owner. In its latter stages, Crossrail has had to dedicate significant resources to reassembling the systems integration capability and evidence to enable it to assure the system against the CPFR and establish safety cases that can satisfy regulators.
- A retrospective review of Crossrail supports the case for planning for baton handovers to ensure that leadership has the right skills and experience to deal with the very different risks that need to be managed at different stages of a project. Simply planning for a handover between a civils team and a systems team would not, however, have avoided all of the problems encountered by Crossrail. Systems integration considerations need to be baked into a project leadership's priorities from day one. The challenge for project sponsors is to ensure that all relevant voices are heard throughout the project lifecycle and that their prominence rises and falls with the changing risk profile.
- Crossrail's chief executive, Mark Wild, has challenged future megaprojects to embrace the concept of defining a minimum viable product (MVP) that reduces complexity and can be built upon to progressively deliver greater benefits. The benefits of such an approach and the barriers and enablers to its adoption warrant further exploration.

Background

The current incarnation of Crossrail began in 1999, although earlier versions of the scheme date back to the 1980s. It is a very large, complex programme to run new, direct rail services between Reading and Heathrow Airport at the western end of

the railway, to Shenfield in Essex and Abbey Wood in south-east London. It will be integrated into Transport for London (TfL)'s rail and underground network as the Elizabeth line.

In the summer of 2018, it was announced that it would miss a planned opening date of 9 December 2018 and would need significant additional funds. TfL now plans to open the Elizabeth line in the first half of 2022: the final cost of the scheme is estimated at £18.9bn, against an original budget of £14.8bn.

The National Audit Office has published a number of studies into the problems encountered on the scheme and ICE has published a paper entitled Systems Integration on Major Projects: Seven Lessons from Crossrail⁷. Key findings from this work are summarised in Table 3.1 (overleaf).

This report does not set out to duplicate this detailed analysis. It does, however, benefit from a series of interviews and discussions

TfL now plans to open the Elizabeth line in the first half of 2022: the final cost of the scheme is estimated at £18.9bn, against an original budget of £14.8bn

⁷ ICE Proceedings – Management, Procurement and Law (2022): www.icevirtuallibrary.com/doi/10.1680/jmapl.21.00014

Table 3.1: Seven lessons from Crossrail		
	Lesson	Evidence from the case
01	Manage programme delivery as an integration activity	This change in mindset was adopted only from early 2019 onwards. There is evidence from the case that managing delivery through contracts, budgets and schedules does not work well in the case of complex projects.
02	Actively manage systems integration	In parts of the programme, it was assumed that two competent subcontractors would manage the integration between them. This changed from early 2019 when the client team took control. It was found that interfaces needed owners to give them specific attention.
03	Ensure authority to make decisions	Crossrail introduced a railway integration authority, chaired by the programme director, to ensure that integration decisions were made at the right level at the right time. This authority was crucial to decision-making.
04	Maintain configuration control	This required (a) the resources and leadership to understand and implement the required configuration control; and (b) comprehensive configuration control systems and processes with the correct historical and real-time records.
05	Plan for a lengthy testing and commissioning phase	Over the course of a long programme, the testing and commissioning phase was squeezed by overruns in construction. The lesson is that the opposite was required – to increase the testing and commission phase to deal with the volume and complexity of digital systems.
06	Appreciate supply-chain products may be part of unaligned global R&D and development programmes	It was not fully understood that a manufacturer's products would only become available in accordance with the development/production programme set out by the parent company. The Crossrail programme had assumed that products would be available when needed.
07	Final integration only when there is something to integrate	Design integration can take place early in the programme, but the integration of physical products and systems can only take place when they exist and are installed.

Source: ICE's Systems Integration on Major Projects: Seven Lessons from Crossrail

with current and past participants in the project that have allowed it to draw out lessons that have deepened its understanding of the eight SAID principles. Discussions yielded the following conclusions.

Front-end work to establish a robust systems architecture is vital, but Crossrail shows the importance of aligning systems engineering to a project's commercial and procurement strategy

In the project's early stages, Crossrail Ltd committed significant resources to developing the Crossrail Programme Functional Requirement, which set out in detail what the system must do. The CPFR flowed into the reference design for the new railway. At this point in the process, Crossrail could be said to have been closely following a classic systems engineering V-cycle process (see Fig 3.1, overleaf).

A commercial and procurement strategy was then developed for the project, which, although pursued for robust reasons, in hindsight had the effect of undermining this clarity of intent. The project was broken up on a geographical basis into 37 main contracts and the lead (tier 1) contractor for each package was given a high degree of freedom to alter the reference design. Contractors were obliged to work together closely on areas such as communications and signalling, but this did not extend to civil engineering, stations, or mechanical and electrical engineering.

The responsibility of Crossrail's programme delivery partner (PDP) for managing these risks and understanding their implication for the integrity of the system was removed when the PDP contract was renegotiated in 2010. Crossrail Ltd did not sufficiently rebuild its internal systems engineering capability and responsibility for high-level systems integration became muddled.

The concepts of 'right team, right time' and leadership baton handovers should not be at the expense of planning for systems integration from day one

In practice, Crossrail could be said to have broken its system 'V' and post-2018 it has needed to commit significant resource to reintroduce a system integration function in the organisation. This has allowed it to define an MVP that will allow it to open the scheme and plan the staging of delivery of the remaining functionality. Time and resource has also had to be dedicated to reassembling evidence to reassure that what has been undertaken will enable delivery of the original functional requirement (the right-hand side of the V).

This integration, testing and assurance challenge has been exacerbated by Crossrail's limited use of standardisation and modularisation across its 37 individual delivery contracts. The project is characterised by high volumes of bespoke design with multiple versions of many components, from pumps and building management systems through to doors. This has added complexity that has hampered assurance and commissioning.

Managing systems integration risk is high on the list of activities that owners must own

The importance of owners having a clear-eyed view of the activity that only they can carry out – and thus the risks that they should hold on to and manage – has been a recurring theme of both of the SAID studies. Crossrail's procurement strategy looked to pass much of the integration risk to its supply-chain partners. In retrospect, this looks to have been a mistake and reinforces the view that the strategic risk of assuring and commissioning a functioning railway (or any other system) must be held and proactively managed by the owner.

Crossrail has now taken this stance but, as noted, has had to commit significant resources to rebuilding in-house capabilities to reassemble the evidence needed to assure the system against the CPFR and create the evidence to support safety cases that will satisfy regulators.

The concepts of 'right team, right time' and leadership baton handovers are useful, but should not be at the expense of planning for systems integration from day one

The issues highlighted above support the view that during the project's early years, Crossrail Ltd did not give sufficient attention to systems integration. This is understandable given the huge expenditure and perceived risk associated with a civil engineering project to drive tunnels under London. In retrospect, however, it is clear that the scale and complexity of creating a functioning railway to operate in that space presented the larger risk.

Simply planning to hand over from a civil engineering to a systems engineering leadership at some point around 2013 seems unlikely

to have, in itself, prevented the difficulties encountered given that systems integration, assurance, testing and commissioning have very long lead times and preparatory work needs to run in parallel with heavy civils activity.

One Crossrail manager suggested that we should think of two projects running in parallel, each with a highly experienced and skilled leadership, with the civils project finishing years before its systems counterpart. That, in turn, could facilitate a planned rise and fall of the prominence of voices within the overall programme, while ensuring that all key voices are heard throughout the lifecycle.

This line of thinking is appealing. To execute this idea successfully on a multi-year megaproject would demand that care is taken to preserve corporate memory and pass learning forward. There is also likely to be a psychological challenge in convincing a successful leadership team to allow other colleagues to take prominence in the project. These challenges suggest that sponsors

The role of Crossrail’s reassembled systems engineering capability includes defining a minimum viable product for the railway’s opening and a plan for staging the delivery of the remaining functionality

need to give greater attention to setting up projects to facilitate smoother leadership transitions.

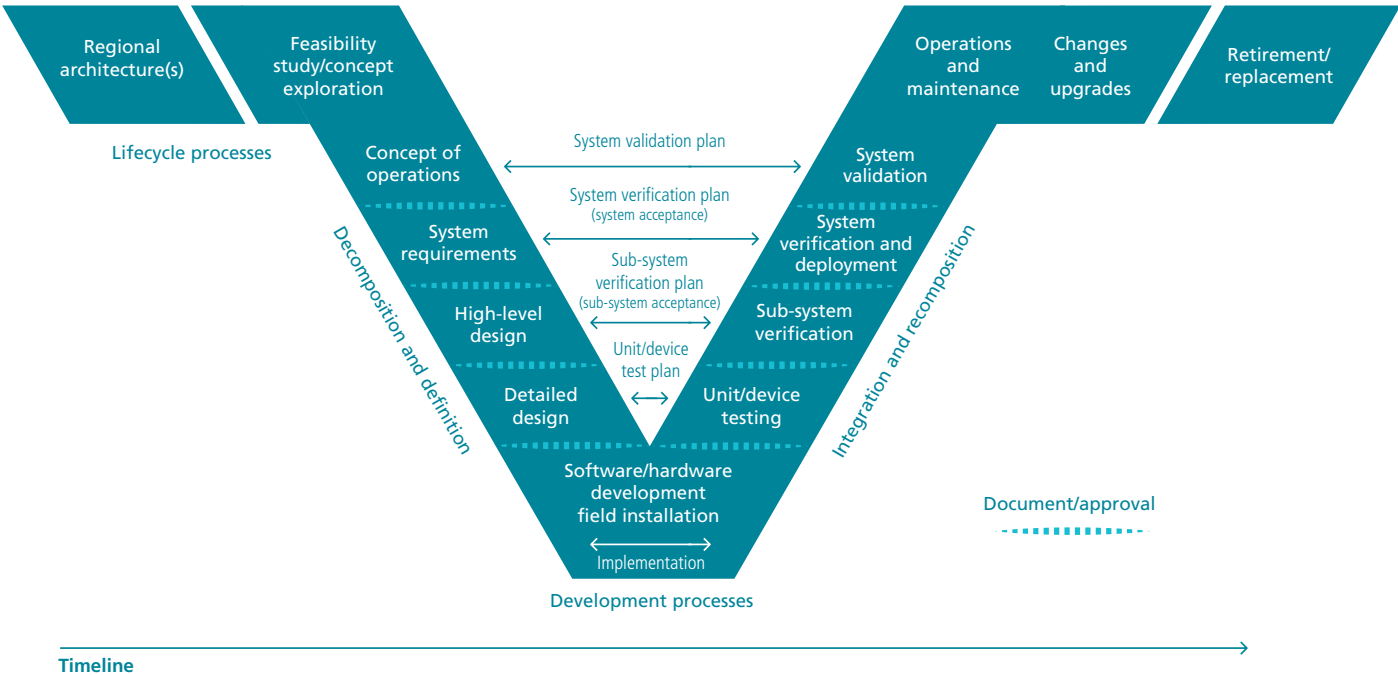
Can megaprojects identify an MVP that can be built on?
Crossrail’s Mark Wild has made a concerted effort to share his insights on lessons from the project, including at a roundtable session facilitated by ICE. His suggestion that future megaprojects should make more use of the concept of an MVP and a staged delivery of benefits raised much interest, particularly when set against Crossrail’s pre-2018 efforts to deliver a highly complex, high-frequency, digital railway in one ‘big bang’.

Post-2018, the role of Crossrail’s reassembled systems engineering capability includes the definition of an MVP for the railway’s opening and a plan for staging the delivery of the remaining functionality. Inevitably, at this late stage of the project, this exercise has limitations and the bulk of the benefits will only accrue if the new line is able to move quickly to a full service.

Crossrail did have a complex evolution in the 1990s and 2000s: it was at one point conceived as a standard mainline rail scheme (an east-west version of the north-south Thameslink project) and at another as a standalone metro system. The scheme that emerged through a long process of political and industry debate is a more complex hybrid, a complexity that has fed through into requirements for key areas such as trains and signalling.

The idea of an MVP is tied to another of Wild’s observations: that modern infrastructure projects are effectively technology businesses. The tech industry is at the forefront of the MVP approach, following a model in which it creates a product that is continually upgraded. There are challenges to bringing this approach to infrastructure projects, but as noted in the first SAID report, the infrastructure sector needs to understand better what practices can be transferred from other industries. More work on the benefits of this approach and the barriers and enablers to its implementation would be welcome.

Fig 3.1: An example of a V-cycle diagram



Taken from the US Department of Transportation, Federal Highways Administration, Office of Operations



The delivery of specific benefits – and levels of service – is being aligned to a series of connection stages, each tied to the entry into service of different sections of the line



Deep dive

04 East West Rail

The East West Railway Company has placed enterprise architecture at the heart of its approach to delivering its new route

Summary of insights

- The East West Rail project is being organised around a systems approach to designing, constructing and operating a railway. It has borrowed the concept of enterprise architecture (EA) from the IT sector to allow it to define a clear scope of physical infrastructure delivery, while retaining flexibility to evolve its services to meet rapidly changing customer needs.
- The approach is creating a common language for different professions to collaborate to identify the best way to achieve outcomes, thus preventing civil engineering or any other single disciplinary voice from dominating options for development.
- A systems approach is helping the East West Railway Company (EWR Co) to understand the impact of its decisions on the cost and benefits of the railway on a whole-life basis, avoiding the risks that can be created by a value engineering exercise that is focused narrowly on capital cost.
- It is also allowing EWR Co to shift its thinking from managing its structures via whole-life asset management to managing its capabilities and services via whole-life functional management. This is facilitated by moving more of the functionality of the railway into digital systems that can be upgraded rapidly.
- The approach is helping EWR Co to understand how it contributes to the goals of a wider transport system, offering opportunities to cut out costly duplication and provide customers with an improved, integrated service across the whole network.

Background

East West Rail is intended to create a new direct connection between Oxford and Cambridge (see Fig 4.1, overleaf). Serving communities across the area, it aims to speed up journey times and reduce transport costs, as well as ease pressure on local roads.

The project is planned to be delivered in three connection stages:

- Stage 1: Oxford to Bletchley and Milton Keynes
- Stage 2: Oxford to Bedford
- Stage 3: Oxford to Cambridge

The East West Railway Company was created by the Department for Transport (DfT) in 2018. It is currently acting as

DfT's co-sponsor, with Network Rail, of a construction alliance to deliver Connection Stage 1.

EWR Co is also developing the route to enable services to run to Cambridge via Bedford and plans to seek statutory powers under the Planning Act 2008, following a period of extensive consultation.

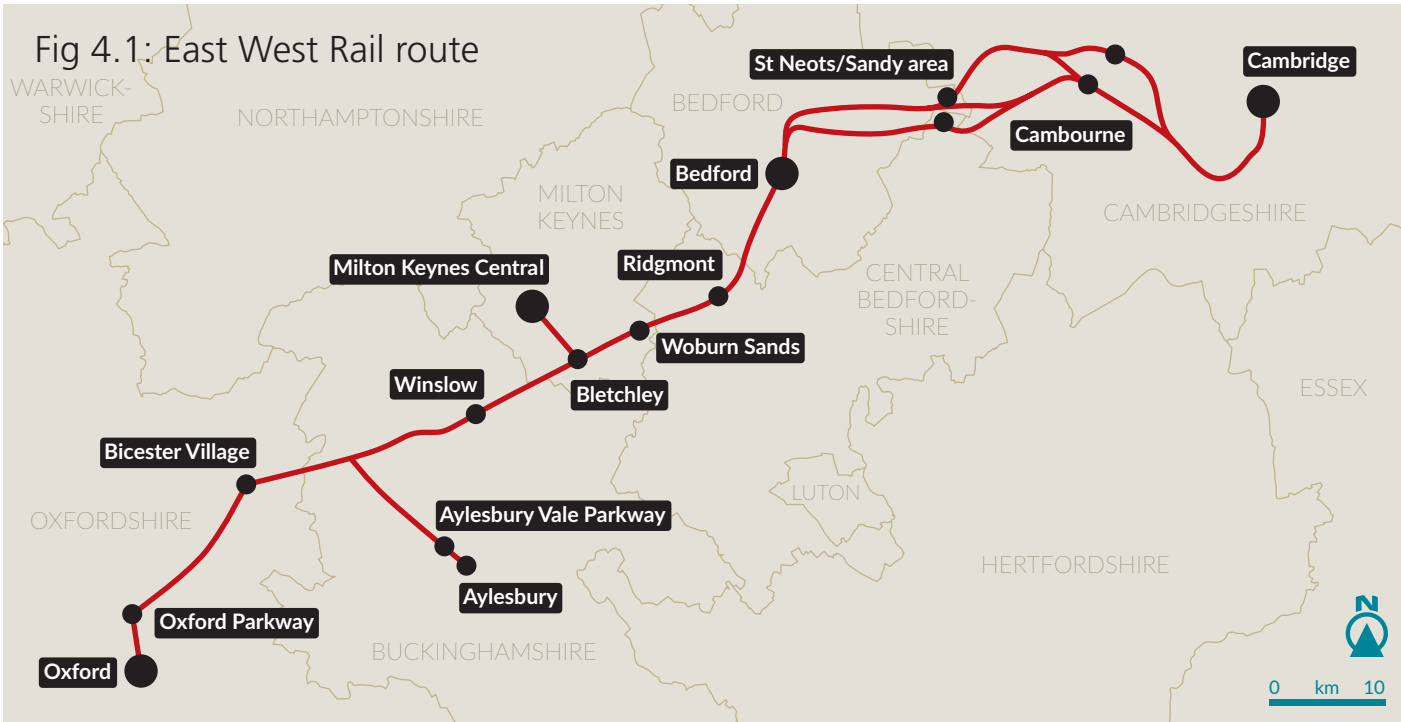
In its early-stage work, EWR Co is attempting to embrace many of the SAID principles. The following discussion captures the organisation's current thinking and how it differs from more traditional approaches to major projects.

Baking systems thinking into the organisation: enterprise architecture

EWR Co is taking advantage of its position as the developer of a new rail link to organise itself around a systems approach to developing and operating a railway. Enterprise architecture, a concept borrowed from the IT industry, is at the heart of this effort. EA is a way of modelling the connections and interrelationships between an organisation's capabilities, its physical and digital assets and the strategic outcomes it is trying to achieve. This generates a single visual representation that helps EWR Co to understand the interrelationships between its desired outcomes and the capabilities and systems that will be needed to deliver them.

The EWR Co team use the analogy of a Rubik's Cube to describe the benefits of the model. Each element of the system, for example civil engineering or security, is represented by a face of the cube. The impact of changes made to one element of the project is immediately visible and can be analysed across all of the others.

EWR Co reports that this has had the advantage of creating a common language for all of the disciplines working on the project. In particular, it has helped to remove the problem identified in the first SAID report of the civil engineering voice becoming overly dominant in infrastructure projects, to the



detriment of the full system. The EA model facilitates challenge and dialogue against agreed outcomes and helps to stop the organisation from jumping to hasty sub-optimal solutions. It would, for example, shift the conversation towards the best way to stop collisions, and away from defaulting to specifying a series of level crossings.

Working to a series of connection stages

EWR's sponsors have set the business an outcome-based remit that is based on transforming journeys and unlocking growth in the Oxford-Cambridge corridor. EWR Co's primary focus, therefore, is to secure these benefits, delivering a railway that is safer, better, cheaper, greener and delivered quicker as a means to that end.

The delivery of specific benefits (and levels of service) is being aligned to a series of connection stages, each tied to the entry into service of different sections of the line. The enterprise architecture approach identifies the capabilities needed for each stage, allowing EWR Co to develop options for what is needed rather than starting from a predetermined solution.

EWR Co's approach also helps it to explore affordability in a more sophisticated way than traditional value engineering. The model shows the impact of decisions on the whole-life benefits generated (or not) by the railway: like a heat map showing where whole-life cost and value is being baked into a design.

From whole-life asset management to whole-life functional management

EWR Co hopes that using enterprise architecture, systems thinking and configuration states will create a disciplined way of encouraging agility and divergent thinking about possible futures while still allowing this to crystallise into a series of deliverable programmes of work.

The analogy of a software upgrade is useful in understanding how EWR Co hopes that working to the connection stages will deliver benefits. Versions 2.0, 3.0 and so on mark step-changes to the functionality being made available to users, with smaller improvements delivered continuously as versions 2.1, 2.2, etc.

A simple example can illustrate how this is meant to work. EWR Co's customer service and engineering teams need to plan how they will design a system that meets user expectations for onboard connectivity, while also recognising that this is changing rapidly. In the short term, the only option may be to construct wifi masts, but it is also clear that over the next 10-20 years, new technologies that demand much less physical infrastructure

have a high probability of reaching maturity. The programme delivery team can work to deliver a clear scope for Connection Stage 1 that includes the wifi masts, but with a design life of only five years. In parallel, preparatory work can begin that will give EWR Co the flexibility to drop in upgrades at Connection Stages 2 or 3 should the technology mature.

More broadly, systems thinking, with its focus on modularity, defining sub-system boundaries and standard interfaces, brings the opportunity for smaller 2.1, 2.2 etc upgrades in between the 'big bangs' of each configuration state.

This supports a shift in thinking away from whole-life asset management to whole-life functional management, which EWR Co describes as the difference between "we need a building with a design life of 100 years" and "we need a station to be in this location at Connection Stage 2 to deliver our benefits". The movement of ever more functionality into the digital sphere brings the prospect of the life of some functionality being very short, with upgrades delivered overnight.

EWR Co recognises that on a railway, much functionality will continue to be delivered via buildings and structures. However, it hopes that its approach will provide a platform for an evolving service that is able to respond rapidly to changing customer and technological developments such as the mass use of autonomous vehicles.

East West Rail and the wider transport system

EWR Co is aware that its railway will form part of a wider transport network that needs to meet the mobility needs of customers across the Oxford-Cambridge corridor. That system of systems will include the existing road network, buses, taxis and potential new infrastructure such as the Cambridge Metro. The EA model is being designed to help EWR Co to understand the interface between its 'block' of the transport system and these other modes.

This has practical implications for establishing the scope of work and functionality to be delivered at each of the connection stages. As an example, the Cambridge Metro may remove the need for some EWR stations by providing a more effective means of linking up intermediary locations.

This approach also focuses attention on the need to define and manage the interface between the EWR sub-system and other parts of the networks. This generates a need for functionality at the network level, for example common journey information for customers and the data-sharing protocols that underpin it.



What is Project 13?

Project 13 is a partnership initiative of ICE.

It seeks to develop a new business model – based on an enterprise, not on traditional transactional arrangements – to boost certainty and productivity in delivery, improve whole-life outcomes in operation and support a more sustainable, innovative, highly skilled industry.

www.project13.info

Deep dive

05 Anglian Water

The water company’s Strategic Pipeline Alliance has achieved success by building strong, positive relationships with suppliers

Summary of insights

- The Strategic Pipeline Alliance (SPA) is a collaborative enterprise designed to deliver outcomes not scope. This is supported by a commercial model that incentivises collaboration and outperformance (shared risk and reward).
- Suppliers critical to the delivery of the programme have been invited to become full strategic partners and be involved in solution development. This can be challenging for some suppliers, both large and small, and time is needed to build confidence and understanding.
- SPA’s embrace of the principle of ‘shovel worthy not shovel ready’ is tied to a commitment of faster end-to-end delivery of the programme. Resources have been frontloaded into system optimisation and programme planning. Production management and digital rehearsal were core competencies sought when procuring partners for the enterprise.
- Anglian Water’s senior leadership team, led by its chief executive, has played an active role in building supply-chain trust in the SPA enterprise model. This is vital if partners are to be asked to move away from traditional transactional commercial relationships.

Background

Anglian Water’s SPA is delivering a programme of work to provide continued security of water supply and resilience to customers across the East of England. The provision of water supplies is under pressure from significant population growth, regulatory changes and the impact of climate change. The SPA’s solution will involve up to 500km of new, interconnecting transmission pipelines to move water from north Lincolnshire to the south and east of the region.

The SPA has adopted the principles of the Infrastructure Client Group’s Project 13 model (see box, facing page) and functions as a collaborative, integrated enterprise comprising Anglian and four strategic partners: Costain, Jacobs, Farrans and Mott MacDonald Bentley. The core enterprise is supported by an ecosystem of key advisors and suppliers. Fig 5.2 (overleaf) shows the capabilities identified by Anglian that the SPA needs to secure its outcomes. Work onsite began in summer 2021 and is due for completion by March 2025.

Delivering outcomes not scope

The SPA has been established to deliver a defined set of strategic outcomes (see Fig 5.1 overleaf) that are aligned to Anglian’s business plan and customer outcomes.

This ‘outcomes not scope’ approach is underpinned by a commercial model based on incentivising all of the partners to collaborate to beat a target price that is affordable to Anglian as the owner and its customers. Incentivising outcomes and focusing on a systems optimisation approach has already led to the removal of 30% of scope from the physical works.

Baking a systems approach into the delivery organisation

Anglian recognises the importance of the SAID principle of baking systems thinking and risk management into an organisation’s DNA.

The design of the SPA therefore reflects Anglian’s recognition that it is operating in a complex, highly uncertain environment, which means access to expertise, backed by strong, positive relationships with suppliers, is vital for success.

To achieve this, the SPA enterprise and a supporting ecosystem of suppliers is built around an analysis of the nature and depth of the relationships needed between different parties. This is summarised in Fig 5.3 (see page 36).

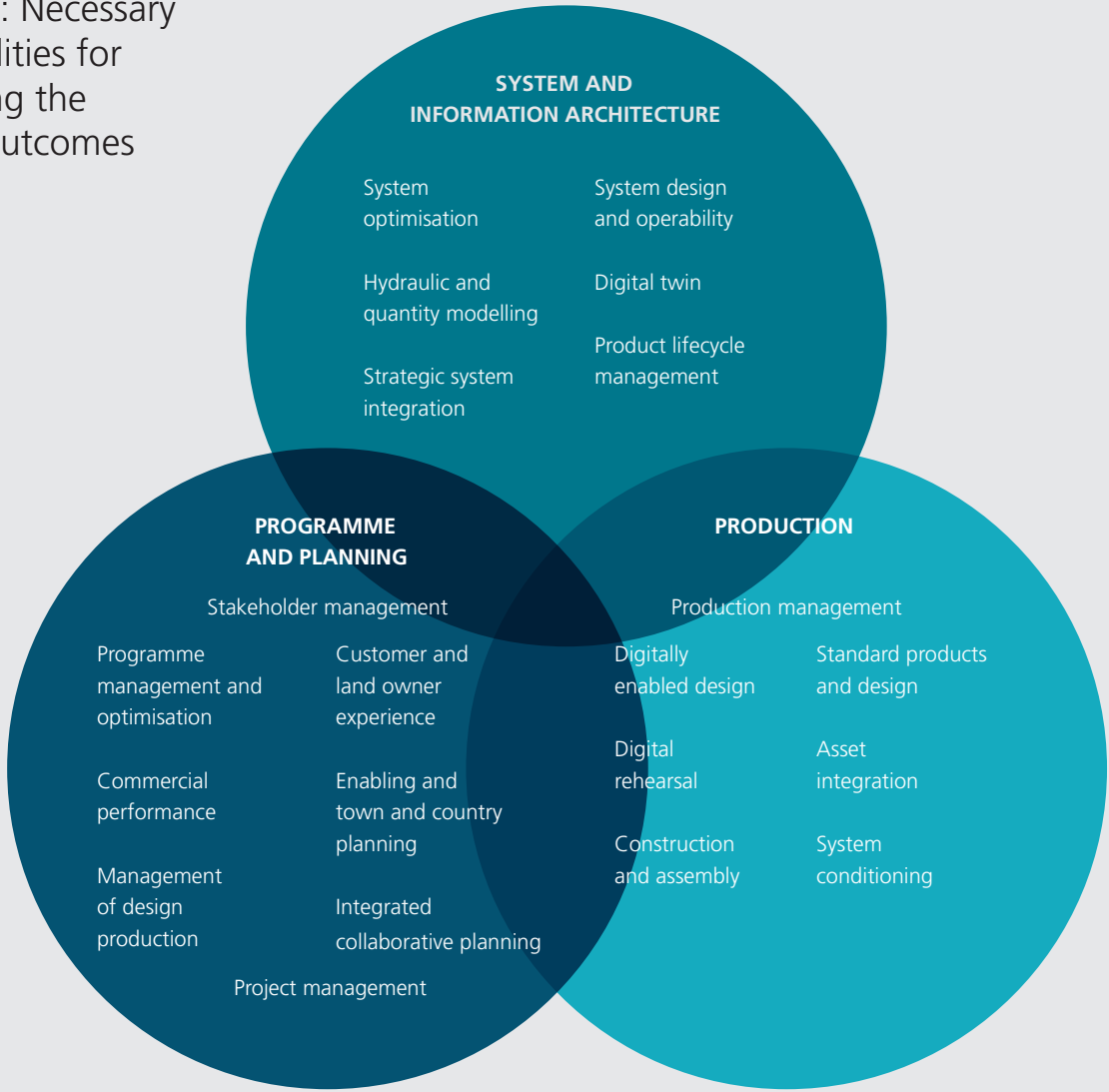
A key lesson has been the time and effort needed for Anglian to build these relationships. This goes well beyond good practices such as onboarding and relationship management: the SPA model demands that all suppliers with a critical dependency for programme success are integrated into the enterprise as strategic partners and incentivised to take part in solution development.

This can be challenging for smaller organisations such as pipework suppliers that are used to joining projects with a more well-developed scope. For example, many suppliers commonly incorporate high levels of risk into their pricing, with the result that prices risked falling outside Anglian’s assessment of

Fig 5.1: Strategic Pipeline Alliance outcomes



Fig 5.2: Necessary capabilities for securing the SPA's outcomes



affordability. Anglian had to convince key suppliers that they could price for positive outcomes based on what the enterprise could deliver collaboratively and that they would not face punitive measures in the event of an overspend. This, in turn, requires contracts and risk allocation that reflect the spirit of the enterprise.

Speed not haste
The SPA is equally invested in the SAID principle of 'shovel worthy not shovel ready' but stresses that this does not run counter to accelerating end-to-end delivery. The enterprise is targeting both a 50% faster end-to-end process and 50% faster delivery onsite.

To achieve these goals, resources have been shifted to the front end of the programme. The SPA has also sought to shift its mindset to allow it to see the ambiguity of the early stages of the programme as an opportunity and not a threat – allowing it to avoid closing down too early options that could have the potential to achieve its outcomes more effectively and efficiently.

As part of this front-end work, the whole programme has been mapped in detail, from securing planning permissions through

to the sequencing of commissioning. Anglian is clear that in the delivery phase individual activities will not be accelerated without an understanding of their impact on the whole system.

The SPA also intends to make extensive use of production management techniques and drive the construction-to-production ethos which, as Fig 5.2 shows, is one of the key capabilities designed into the enterprise. The enterprise is embracing high levels of standardisation at the asset and component level and a digital platform is also being used to bring design information and data into procurement schedules.

Asset and component data can also be transposed directly into digital models that will underpin digital rehearsals at key milestones in the programme. Physical rehearsals are also being used to establish the most effective techniques and suppliers for key processes, including welding, pipeline installation and logistics. These will then be rolled out across the enterprise.

The enterprise has adopted 'Deliberately delivering differently' as a guiding principle and is making extensive use of drones

Fig 5.3: Nature and depth of relationships needed between SPA parties

	NATURE OF RELATIONSHIP	COMMERCIAL ALIGNMENT	LEVEL OF INTEGRATION	STAGE OF INVOLVEMENT
INFLUENCE ON SPA OUTCOMES	STRATEGIC	Incentivised model where: ■ Reward is linked to overall reduction in programme cost ■ Risks/opportunities are collaboratively managed	■ Key people are embedded and co-located with the SPA ■ Supplier is involved in key processes through solution development, product development, production and assembly ■ Full access to relevant demand and supply information ■ Supplier may be digitally integrated ■ Supplier-to-supplier relationships are supported and facilitated by the SPA	■ Early involvement during solution development ■ Supplier likely to be formally engaged and compensated
	COLLABORATIVE	Incentivised model where: ■ Reward is linked to overall reduction in programme cost or package cost ■ Risks/opportunities are collaboratively managed	■ Key people may be embedded and co-located with the SPA ■ Supplier is involved in key processes through solution development, product development, production and assembly ■ Full access to relevant demand and supply information ■ Supplier may be digitally integrated ■ Supplier-to-supplier relationships may be supported and facilitated by the SPA	■ Early, pre-assembly, involvement ■ Supplier likely to be formally engaged and compensated
	IMPORTANT	Incentivised model where: ■ Reward is linked to overall reduction in package cost ■ Risks/opportunities may be collaboratively managed	■ Key people may be embedded and co-located with the SPA ■ Supplier may be involved in key processes through solution development, product development, production and assembly ■ Supplier is provided access to relevant demand information	■ Early, pre-assembly, involvement if required ■ Supplier may be formally engaged and compensated
	TACTICAL	Cost-based model where: ■ Risks/opportunities may be collaboratively managed	■ Supplier may be involved in key processes through solution development, product development, production and assembly ■ Supplier is provided access to relevant demand information	■ May be involved early, pre-assembly, if required

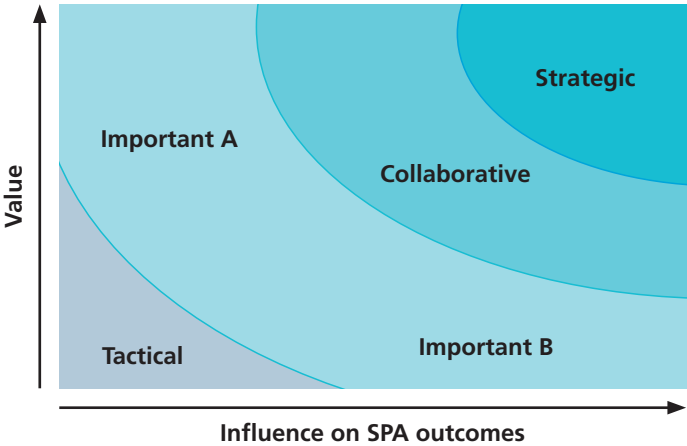
and similar technology to identify opportunities for further efficiency. One example is its waterless commissioning strategy, which is identifying ways to reduce the very large volumes of water traditionally needed in the final testing processes used to commission new assets into full operation.

‘Deliberately delivering differently’ is intended to extend into operations – for example, the programme is focused on operating efficiency (cost and carbon) and using real-time data to learn and drive better system decision-making. This will ultimately incorporate data on abstraction and electricity tariffs, digital control systems to support demand measurement and delivery, and near real-time modelling of hydraulic systems into a single

digital twin. The enterprise recognises the rapid evolution of technology and has adopted a digital transformation roadmap to help it to plan the delivery of key functionality.

Senior leadership commitment

The SPA approach demands a high level of confidence and trust between participants. Anglian has needed the courage to make large upfront financial commitments to the SPA in the belief that the approach will deliver value and that its partners will collaborate as a single enterprise and not revert to more traditional behaviours. Likewise, the supply-chain partners have to believe that Anglian will hold to the model and that the whole enterprise will win together.



As part of the front-end work, the programme has been mapped in detail, from securing planning permissions to the sequencing of commissioning



Deep dive

06 Costain

Developing its systems approach capability has enabled the company to deliver real value to its clients and end users

Summary of insights

- The Infrastructure and Projects Authority's Transforming Infrastructure Performance route map exemplifies the growing client and regulator demand for a systems approach to infrastructure that can deliver a complex set of outcomes while meeting cost and time expectations. This is helping to establish the need to develop capability within supply-chain organisations.
- Costain's route to developing a systems approach capability is based on four pillars: systems thinking; systems engineering; systems assurance; and systems integration. Deployed collectively, they help the business to plan, develop, build, integrate and deliver outcomes and value to clients and users.
- People working in supply-chain organisations need to be able to relate the abstract concept of a systems approach to what happens onsite and in the design office. Costain has benefited by using the four pillars to establish a set of principles, methods, processes and tools that can be used to support a Systems Approach to Infrastructure Delivery (see Fig 6.1, overleaf).
- A shared language is vital. Costain has benefited from establishing a common language to explain the concepts and practices underpinning a systems approach in a way that is understandable for technical and non-technical colleagues.

Background

Costain describes itself as a smart infrastructure solutions company and offers a range of services that span the traditional contractor/consultancy divide. Founded in 1865, it is one of the larger players in the UK infrastructure market with turnover in 2020 of £1,070m. It has about 3,000 staff operating in the rail, highways, aviation, water, energy and defence sectors.

The following insights were gathered from interviews with Costain group head of systems approach capability Paul Eastwood, who established the systems discipline at Costain in 2015. He is also the industry co-chair of the Ministry of Defence Multi-Domain Integration Working Group led by Team Defence Information. The capability within Costain has now grown to more than 30 people delivering systems thinking, engineering, assurance and integration services to clients.

This deep dive looks at some of the practical issues encountered by a large supply-chain business in developing and deploying a systems approach and the benefits it has delivered to its clients.

Why the business chose to develop a systems approach capability

Major clients, for example HS2, are increasingly expecting the use of a systems approach from their supply chains. Similarly, Ofwat, the economic regulator for water utilities in the UK, via its 'Resilience in the Round' initiative, is pushing for greater use of systems thinking in the face of complex challenges such as those being tackled by Anglian Water's Strategic Pipeline Alliance, discussed earlier in this report.

This shift is exemplified by the IPA's Transforming Infrastructure Performance: Roadmap to 2030 (2021), which uses the word 'system' more than 100 times in its description of how the Government expects publicly supported projects to be delivered.

Against this backdrop, Costain has developed and deployed a systems approach capability to:

- Help capture and agree with clients a sound understanding of the problem being tackled and the outcomes to be realised by a project. This includes establishing where and how to intervene in the system and creating a structure to develop, measure and deliver the outcomes and value clients and users want from the system.
- Provide the agility and control to respond effectively to the presence of ambiguity, new information and changes in scope within a complex and dynamic project environment. A systems approach also provides the methods and timelines for the progressive testing of the developing solution against the detailed requirements and intended outcomes.
- Enhance the ability to understand and predict the impact of change on a project within hours not weeks. This improves decision-making processes and ensures that projects are not adversely affected by change.
- Ensure that the final design fulfils the desired outcome when it is built and integrated. A systems approach improves the

business’s understanding of how components, sub-systems and whole systems have been designed to work together and how new technologies can be integrated into the system as they are developed over the life of the assets. This facilitates robust assurance against the desired outcome at every stage of integration and commissioning into service and operation.

Explaining what a systems approach means for the business

To help the business to understand how a systems approach differs from traditional infrastructure delivery, Costain has developed an infographic (see Fig 6.1) based on four pillars: systems thinking, systems engineering, systems assurance and systems integration. The principles, methods, processes and tools in each of the four pillars help the business to deliver a systems approach at strategic, tactical and operational levels, embracing both the technical and non-technical issues that arise in infrastructure projects.

An important lesson is that the four pillars in the model are part of a whole and have a greater positive influence on outcomes

and value when they are delivered together and at all stages of the life of the project.

Language is vital

The importance of language for making a systems approach work in practice is another key lesson. Costain has developed a common systems approach language for its work on infrastructure projects. To achieve this, systems engineers have had to display a level of humility and pragmatism and adapt their specialist language to that commonly used by other professionals in infrastructure projects.

One simple example has been the use of the words ‘inspection’ and ‘testing’ in place of the more common systems engineering terms of ‘verification’ and ‘validation’. This has also helped to make a link between traditional engineering work products and those needed for systems engineering, reducing duplication of activity where modification of an existing product will be sufficient.



Major clients, like HS2, are increasingly expecting the use of a systems approach from their supply chains

Fig 6.1: Costain’s systems approach



Cross-cutting lessons

01 Keep the end in mind throughout the project

Key questions for projects:

- How will you track the implications of decisions in one part of the project on the performance of the system? How will you know if political, value engineering, procurement or other decisions are selling forward risks to achieving outcomes?
- What are your assurance arrangements? How will the project demonstrate that the outputs it delivers work together as a system that safely delivers the owner's desired outcomes?

Starting with the end in mind, although vital, is not enough. Owners need to set up projects so that outcomes are driving decisions right through the lifecycle.

Our case studies demonstrate different ways this can be achieved. East West Rail is being organised around an enterprise architecture model that provides a dynamic, integrated and systematic view of all of the capabilities and physical and digital assets that will be needed to deliver outcomes. Anglian Water's Strategic Pipeline Alliance is underpinned by a commercial model that incentivises all parties to meet outcomes affordably. Tideway has effectively created a 'client within the client', which has helped to keep the project focused on how the system will be operated as it has moved from planning to delivery to preparations for commissioning.

Our deep dive into Crossrail, meanwhile, shows how a focus on ends can be lost if the implications of decisions are not fully understood and tracked. It highlights the danger of allowing responsibility for systems integration to become ambiguous. Crossrail's issues also illustrate the important truth that projects don't just need to be able to deliver and integrate a set of assets that leaders believe will deliver outcomes – they also need to demonstrate via assurance that the system they have created is safe and fit for purpose. Assurance is a serious undertaking and needs serious planning and resourcing.

02 Ensure we really are all in this together

Key questions for projects:

- How will the project organisation and commercial model ensure that owners can access the real sources of innovation and expertise they will need to deliver their outcomes?

- How will the project organisation and commercial model ensure that participants are collaborating to achieve the outcome – and not just delivering 'their' outputs?

The project owner is much more than a client letting and managing a series of contracts. Major infrastructure projects and programmes are hugely complex and subject to high levels of uncertainty. To manage the risks this creates, projects should be set up so that the insight and expertise from many organisations and specialists can be accessed when and where they are needed. As one contributor put it, owners need to be able to have their 'own handshake' – a direct relationship – with organisations much further down the supply chain than has traditionally been the case in the UK construction industry.

To achieve this goal, owners must be able to align all partners to a shared outcome. The partners also need a shared understanding of what has to happen to achieve the outcome, and that must include how individual assets will be integrated to create the system.

During phase two of the SAID project, we heard from owners that had achieved alignment around outcomes with their Tier 1 contractors, only to find that these partners were defaulting to traditional transactional relationships with their own subcontractors.

This behaviour was, in part, driven by the historic operating models and risk management processes inside those Tier 1 organisations. Similarly, some lower-tier operators admitted that their traditional business model was based on being a vendor, focused more on sales volumes than on value-added outcomes.

The case study of Anglian Water's Strategic Pipeline Alliance is an example of the radical change that is needed to overcome such problems. The SPA's delivery model is an integrated enterprise in which the most important members of the supply chain are full partners, whatever their position in the traditional construction industry hierarchy.

The enterprise is set up to deliver a set of outcomes and the strategic partners are rewarded for their contribution to their delivery within a pre-agreed price that is affordable to Anglian.

All partners have a voice in solutions development, which includes extensive use of digital modelling and rehearsal. They also share a broader commitment to continually bring forward new ideas to allow the programme to align with the Government’s Delivering Differently initiative to improve public services.

Shifting to this type of model demands a significant change in how construction companies do business, generate profit and relate to other organisations in the supply chain. For senior leaders, this will mean taking a risk on new commercial arrangements.

More important, it also means that a key element of leadership in both owner and supply-chain businesses is developing the empathy and trust to generate confidence that the collaborative model will not be abandoned and that the whole enterprise will win together.

03 Think hard about leadership

Key questions for projects:

- How will you select a leadership team that matches the scale and complexity of the project? What characteristics will leaders need to shape this specific project environment?
- How will you manage the changing demands on leaders over the project lifespan? What arrangements are in place for planned (and unplanned) baton handovers?

Scale matters. The larger and more complex a project, the less likely it is that it can be successfully led by a ‘warrior’ leader who can manage crises by force of will, or by a super-project manager who is focused overwhelmingly on process and deliverables.

In phase two of the SAID project, we heard that leaders needed to be resilient and possess subject-matter expertise, and that they also needed to deliver in a project environment that was multidisciplinary, culturally diverse, geographically dispersed and sat within a complex web of stakeholders.

Success in such an environment is delivered by leaders who are selected for their awareness of the limits of their personal capabilities and experience. Such leaders need to be able to select,

motivate and integrate groups of individuals into a single united team that is focused on delivering the project outcome.

These leaders will need to take ownership of that outcome and set a clear direction to their colleagues. Alongside harder project management skills, they will need to be able to mentor, coach, negotiate and influence at a high level.

Faced with this need, owners should not default to drawing on a pool of traditional project managers or engineers to lead their most complex projects. They should take time to define the broad attributes required to lead in their specific environment and be open-minded about where they might find these people.

There is also a need to analyse how the demands placed on leaders will change through the life of the project. A theme running through the case studies is the need to balance the value of continuity against the value of changing leadership to deal with the different risks and opportunities that will dominate the varying stages of projects with lifespans of a decade or more.

04 Do you have to deliver it all at once?

Key questions for projects:

- Can you establish a minimum viable product as part of project initiation? What can be done to reduce complexity and risk and deliver some benefits earlier?
- How will you take advantage of more functionality moving into the digital sphere to better meet users’ needs – and how will you manage the risk of accelerating technological obsolescence?

Very often, a whole system does not need to be delivered to start producing outcomes. In fact, given the increasing cost, scale and duration of projects, the concept of delivering outcomes progressively offers real opportunities to reduce complexity and risk while ensuring owners and users receive some benefits much earlier.

Crossrail’s chief executive, Mark Wild, said that in retrospect the project might have benefited from establishing an MVP that could be built upon, instead of seeking to deliver a high-frequency, digitally advanced metro that was fully integrated with National Rail and London Underground in one ‘big bang’.

As programmes grow in size and duration and infrastructure networks become more dependent on technology, understanding what represents a major project’s MVP and how that relates to overall outcomes seems likely to become an increasingly important element of project delivery. The infrastructure industry will need to draw on expertise from other sectors, such as software development, where this concept is common practice.

More projects may also need to follow East West Rail’s example and align possible service upgrades to a series of future ‘configuration states’. Under this approach, physical interventions into the network are bundled together with the wider capabilities the business needs to deliver defined outcomes.

The East West Railway Company believes that this will allow it to balance the need to define a scope of work to be delivered via construction programmes with the flexibility to plan for different ways to meet the future needs of its customers. Its use of digital models and deep understanding of its own enterprise architecture also opens up the possibility of regular, smaller and faster upgrades between each configuration state, taking advantage of the shift of more and more functionality of the railway into the digital realm.

The concept of delivering outcomes progressively offers real opportunities to reduce complexity and risk while ensuring owners and users receive some benefits much earlier

Recommendations

Recommendations for future action by ICE

This is the second report from the Systems Approach to Infrastructure Delivery project. It is heartening that many of the eight principles identified in December 2020 are now embedded in the IPA's Transforming Infrastructure Performance: Roadmap to 2030. SAID project lead Andrew McNaughton and report author Andrew Crudgington were also invited to contribute to a new systems integration module that forms part of the IPA's Project Routemap suite of guidance.

Phase 2 of SAID calls on ICE to continue to work closely with the IPA to support the further development and rollout of its guidance on project initiation and delivery.

Leadership was a recurring theme across all of the case study interviews and roundtable sessions that made up the second phase of the review. Construction's traditional, 'heroic' style of leadership is not fit for purpose for modern infrastructure projects, but the solution is not to introduce swathes of new controls and processes either.

Instead, the sector needs to adopt leadership models that spread authority and empower highly competent individuals to take the key decisions in their areas of a project, while ensuring that everyone involved is focused on maintaining the integrity of the system to deliver the outcome demanded by its users and owners.

The UK has a pipeline of infrastructure projects valued at approximately £650bn over the next 10 years and urgent action is needed to ensure that the sector has access to a cadre of leaders that can deliver projects effectively.

Civil engineers who develop the necessary skills and experience can form part of this cadre. The infrastructure sector does, however, need to be much more open-minded about the professional background of its top teams and should seek to attract highly skilled programme leaders from across industry.

Phase 2 of SAID also calls on ICE to work with the Infrastructure Client Group and other interested parties to set up a project to identify the competencies and experience required by leaders of future infrastructure projects and to explore how individuals could be supported to acquire these, and how excellent programme leaders from other industries could be attracted into the infrastructure sector.

Construction's traditional, 'heroic' style of leadership is not fit for purpose for modern projects – the sector needs to adopt leadership models that spread authority and empower highly competent individuals

Established in 1818 and with more than 95,000 members worldwide, the Institution of Civil Engineers exists to deliver insights on infrastructure for societal benefit, using the professional engineering knowledge of our global membership.



Follow us on Twitter
@ICE_engineers

and LinkedIn:
bit.ly/FollowICELinkedIn

An animated film explaining
A Systems Approach to
Infrastructure Delivery is
available at **ice.org.uk**



Institution of Civil Engineers is a Registered
Charity in England & Wales (no 210252) and
Scotland (SC038629).



By using Carbon Balanced Paper for this publication, ICE has helped to protect 9m² of critically threatened forest and balanced through World Land Trust the equivalent of 50kg of carbon dioxide.

ICE
One Great George Street
Westminster
London SW1P 3AA
UK

Get in touch
For more information, please contact:
ICE Knowledge
E: **knowledge@ice.org.uk**
W: **ice.org.uk**