ARUP

High Speed 1: Laying the tracks for transformation

Enduring lessons for maximising whole life-cycle value for future high-speed railways

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Foreword

As demand increases for low-carbon modes of transport between cities, high-speed rail represents the most opportune way of achieving this. As a result, governments around the world are investing huge amounts into dedicated infrastructure.

Over the next three years, expenditure on rail projects worldwide is expected to grow by 7% a year, faster than any other infrastructure sector, while the global pipeline of projects in preplanning, planning or construction totals more than US$5.7tn. This will result in an additional 171,500km of completed or improved track by 2025 – 42,500km of which will be high-speed. With growing international pressure to address the impacts of climate change, the modal shift from road and air to rail seems only likely to gather momentum.

At the same time, long-term mega-projects face the challenge of maintaining public and political support as post-pandemic economies struggle with rising debt and soaring energy prices. In a climate of constrained spending, clients may be tempted to focus

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on reducing capital costs to the detriment of long-term operational value and less tangible benefits. To justify investment, the industry needs to devise cost-effective solutions and establish a clear link between spending, performance and sustainability.

The story of High Speed 1 (HS1), the UK's first high-speed rail line, offers many insights into how this can be done. Today, HS1 is one of the best-performing, most reliable railways in the UK. The vast majority of passengers between London, Paris and Brussels use its Eurostar trains rather than airlines. It has also catalysed regeneration, both in London and in communities along the route, and set new environmental standards for major infrastructure projects. The purpose of this report is to explore how all of this was achieved – and how future projects can build on this and use the learnings from HS1 to do even better.

November 2022 marks the 15th anniversary of HS1's full opening, which makes this an interesting time to pause and reflect. The project offers a wealth of knowledge on the funding, organisation, delivery, maintenance and operation of new high-speed railways. All of this will be invaluable for shaping the industry in the critical decades ahead – and for

109km
Length of the HS1 route from London to the Channel Tunnel

26m
Number of international and domestic passengers using HS1 in 2018

1,600
Number of Arup specialists involved in the development of HS1

3
Number of new international stations built as part of HS1

40km
Length of tunnels built on the HS1 route

270km/h
Top speed of Eurostar trains when the line was opened


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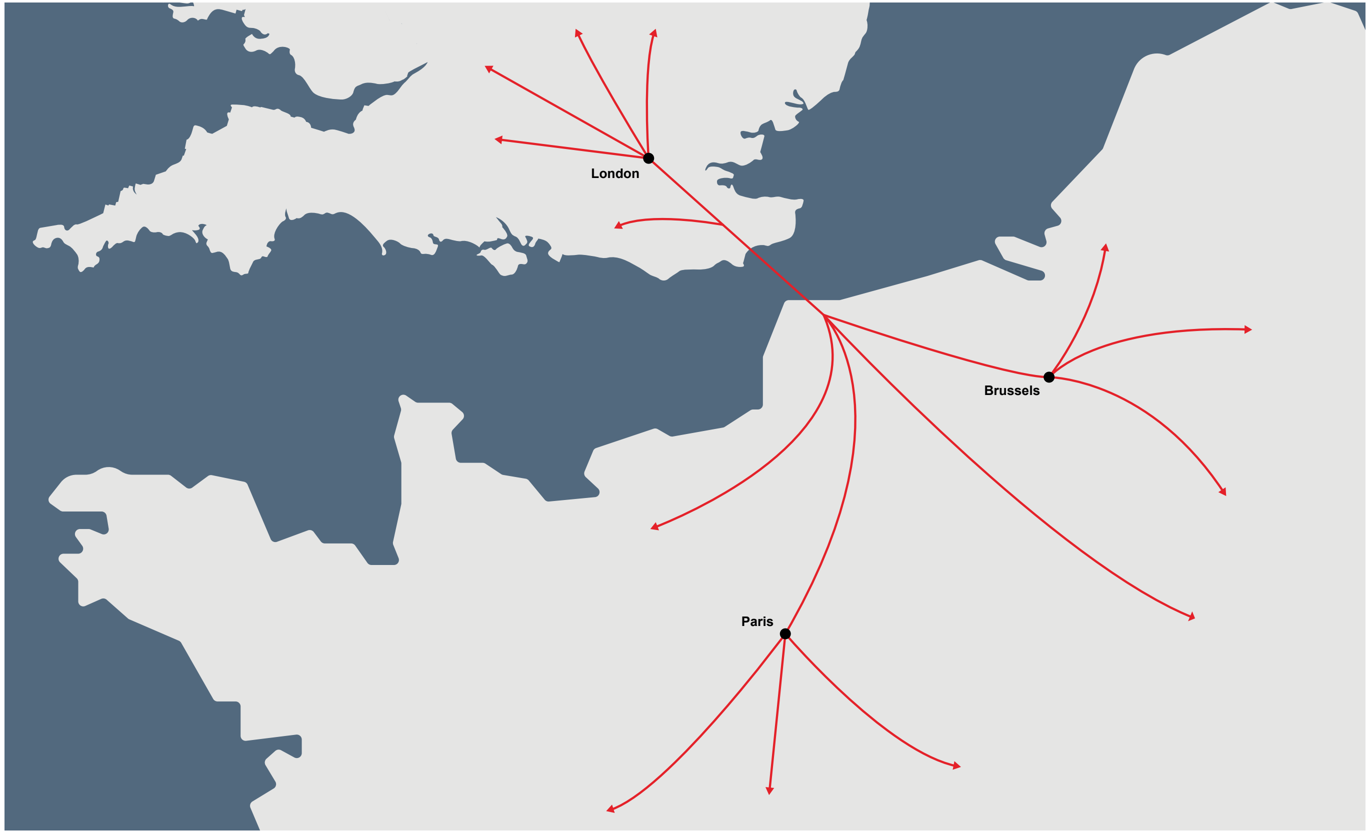
fulfilling our overarching imperative to decarbonise all aspects of train travel. In the near future, successful societies will be defined by sustainability and connectivity. That's our destination: HS1 can help to show us the route.

Executive summary

High Speed 1 (HS1) was the first high-speed railway in the UK. When it opened in 2007, the route from London to the Channel Tunnel was a new gateway to Europe, connecting London with Paris and Brussels in under two hours. In 2018, a total of 26 million passengers used HS1, including 11 million international and 15 million domestic passengers.

Navigating a route through sensitive rural landscapes into a major urban centre, the project delivered 109km of tracks and signalling, three international stations, 152 bridges and 40km of tunnels, on time and on budget. As the first new railway in England for over 100 years, and one of the biggest and most complex infrastructure projects in its history, HS1 was inherently innovative. Everything from its organisational structure to the technologies implemented was new.

Its wider impact and legacy are just as striking. Regeneration and social and environmental value were central to the project from the start. HS1 has been at

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HS1 was the catalyst for the spectacular redevelopment of King's Cross station

the heart of two of Europe's biggest urban renewal projects – the multi-billion-pound King's Cross Central, and Stratford City in east London – and is expected to provide at least £10bn of regeneration benefits over the next 50 years. Its pioneering approach to environmental protection, creating new habitats as well as replacing existing ones, has provided a template for other large-scale infrastructure projects to follow.

The project employed more than 8,000 people over its lifetime, more than 1,600 of whom were Arup specialists brought in for their expertise, from transport consultants and tunnel designers to environmental consultants and bridge engineers. They played a key part in identifying the best route, creating and commissioning the new infrastructure, and planning and designing the stations, including the monumental refurbishment of the terminus at St Pancras. The company has remained closely involved in HS1 since its completion, developing operation and renewals strategies to ensure that it continues to be one of the most reliable railways in the UK.

This report highlights key considerations and learnings for any organisation embarking on a high-speed rail project. Indeed, in a world where sustainability and resilience are becoming ever more urgent priorities, there are wider lessons for anyone engaged in major infrastructure projects of any kind.

Agile working

Any major infrastructure scheme is complex, with a diverse pool of stakeholders and competing interests. Identifying and working with the right organisations from the start will pave the way for a successful whole-life return on the asset.

In the case of HS1, a willingness to embrace new ways of thinking was vital to the project's success. Under an innovative funding model that mixed public and private finance, the contract to build and operate the line was awarded to London & Continental Railways Ltd (LCR). This consortium contained much of the professional expertise needed to design and deliver the scheme, comprising four engineers (including Arup), two transport operators, an energy company and an investment bank. It also had a very lean organisational structure, with fewer than 100 employees. This meant decision-making could be focused, agile and responsive to change.

HS1 established new paradigms in collaborative working with local authorities, communities and contractors – many of which have subsequently become industry best practice. The design and delivery teams were embedded in communities, engaging closely with local groups and forums. The programme was carefully phased to unlock demonstrable value at every stage, helping to maintain public support. These strong connections are essential to creating a sense of shared ownership, while delivering operational goals.

Transformative benefits

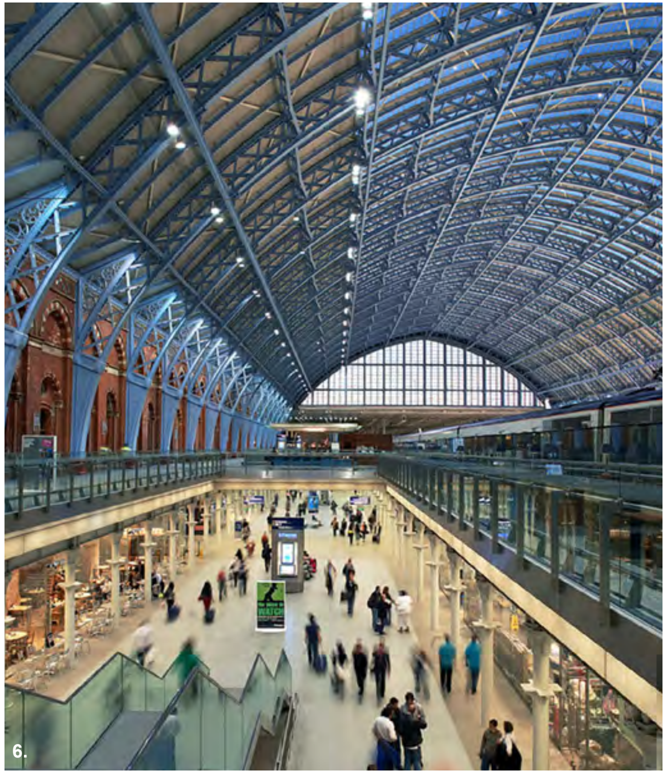
HS1 was one of the first major infrastructure schemes to fully grasp the potential for additional social and economic benefits – and, crucially, to design these in from the earliest stages.

A distinctive element of the rail link was the mix of European and regional services. This posed a number of challenges in terms of scheduling and prioritising high-speed, non-stop trains, but it brought huge opportunities too.

New links between Kent and London brought an economic stimulus to a number of deprived communities along the route. The spectacular redevelopment of St Pancras, meanwhile, showed

The 109km route of HS1 links the English end of the Channel Tunnel to central London

Ebbsfleet International station has sparked plans for thousands of new homes and jobs in the local area



St Pancras station has benefited from an impressive redevelopment and become London's gateway to Europe

how an international 'destination station' could spur the regeneration of a whole swathe of a city. A formerly neglected expanse of rail yards has been transformed into King's Cross Central – a dynamic, sustainable district with more than 1,000 new homes and hundreds of businesses.

One stop down the line, at Stratford in east London, HS1 had a direct bearing on London's successful bid for, and staging of, the 2012 Olympic Games. As with King's Cross, the multi-billion-pound regeneration work around Stratford is ongoing, demonstrating how socio-economic benefits continue to accrue long past the initial delivery of a scheme.

Overall, HS1 has been the catalyst for more than £8bn of development. In addition, the line supports more than £427m of economic benefits to the UK and continental Europe every year. This does not happen unless social value is addressed from the outset. In planning large-scale infrastructure projects, it is important to think beyond the project itself, and consider the long-term transformation it can bring for communities, economies and, ultimately, the planet.

Focus on the customer

The transformative benefits of high-speed lines are not possible unless they focus relentlessly on fulfilling the needs of their customers. With HS1, the critical customer need was to match the journey time and experience of air travel. By establishing this hard line, the client was able to articulate what it wanted from the designers and contractors, and value could then be added around the more negotiable requirements.

The new model of destination station – as much about shopping, eating and drinking as catching a train – was another key point of differentiation from low-cost air travel, showing that rail can be relaxing and enjoyable as well as fast and convenient. The success of these strategies is evident from the fact that, by 2019, Eurostar accounted for nearly 80% of air and rail travel from London to Paris and Brussels.

Equally, HS1's adoption of domestic services highlights the importance of integrating mega-projects into the wider transport network. Daily passengers want reliability and cohesive communication; their experience depends on the reliability of all the journey segments, irrespective of the train operating company or the infrastructure it runs on.

The line has had to adapt as customer needs and expectations have evolved – the past two decades have seen radical changes, particularly in our use of technology. 4G is now live across the HS1 route, with the associated cabling and power supplies installed in the London tunnels. Passive provision for communications, cabling and utilities is a vital consideration for any future high-speed rail project.

Data is also an increasingly valuable tool in helping to improve the customer experience. A key challenge for the operators and owners of high-speed rail lines is ensuring that data regarding customer journeys, asset information and performance is handled securely.

Pioneering environmental protection

Across the globe, customers are increasingly concerned about climate change and the carbon emissions of their journey. Although rail is more environmentally friendly than road and air travel, major projects must include clear plans to reduce energy consumption. Hybrid rolling stock and hydrogen- and battery-powered trains are being developed, in addition to programmes to electrify tracks, but decarbonisation needs to be at the heart of all aspects of design.

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HS1 was one of the first mega-projects to focus on environmental issues from day one. Even though the UK government had recently tightened environmental regulations, the team went further, adopting a holistic strategy that encompassed everything from biodiversity enhancement and landscape restoration to the reuse of materials. Significantly, it set out to go beyond ‘no net loss’, not only replacing the habitats it disrupted but actively adding to nature, with 255ha of new woodland, 1.2 million trees and shrubs, and whole new landscapes formed from the spoil dug out of the tunnels. The plants and trees were carefully specified, to an extent not previously seen in UK infrastructure projects.

> Within a multi-billion-pound project, the environmental works are extremely small in cost terms, yet the benefits are substantial.

The line has also benefited from using nature-based solutions such as strategic planting and green corridors to solve engineering challenges. As extreme

A railway such as HS1 that has shown adaptability and robustness to a host of new threats, even over a lifespan of little more than 15 years, offers crucial insights to developers of new networks.

weather events become more frequent, more schemes will need to work with nature to manage risks such as flooding and storm damage.

Within a multi-billion-pound project, the environmental works are extremely small in cost terms, yet the advantages are substantial. One of the key lessons from HS1 is that environmental protection needs continuity. Trees and habitats can take many years to mature, so clear protocols should be established to ensure that land owners and managers remain accountable. Objectives and performance metrics should be enshrined in every phase of construction, operations and maintenance.

Capital costs vs whole-life value

The fact that HS1 has run without major faults throughout its operational life is testament to the design, commissioning and testing process. This profited greatly from the integration of proven technologies and standards from an experienced high-speed operator. The close collaboration between that operator's engineering team and their HS1 counterparts, and the integration of these systems into UK operations, was integral to the project's successful delivery.

For any major infrastructure project, it is critical to focus on the whole-life value of the asset, rather than the initial cost. Financial pressures during design and construction can easily see operational costs sidelined, but over the full lifecycle of a railway, this will prove a false economy. A vital factor in the success of HS1 has been the focus on long-term performance – as shown by Arup's groundbreaking 40-year plan for track and civils renewals, and the way in which skills have been maintained throughout the workforce.

For this long-term focus to be successful, detailed information on the expected lifespan of assets and their components must be set out so that mechanisms can be put in place to monitor and assess their condition. New technologies have a huge role to play here. HS1 is increasingly using building information modelling and digital twins, for example, which offer new insights into degradation rates, providing greater cost certainty and enabling renewals planning over a longer timescale.

Building resilience

In increasingly uncertain times, the resilience of our transport infrastructure has never been more important. The transition to renewable energy and decarbonised railways presents a huge challenge – particularly when designing schemes to incorporate technology that may not yet exist. Owners and designers need to consider how much lineside space may be needed in future for the generation or storage of renewable energy.

Capacity constraints are another crucial issue. The change in travel and working patterns driven by the pandemic has created an opportunity to rethink how we approach times of peak demand. Travel demand management, for example, shifts the emphasis from building more to enabling assets to do more, reducing carbon emissions in the process.

The latest digital capabilities can enhance this even further. We are just beginning to exploit the huge potential of agent-based modelling, which seeks to replicate the many interactions of diverse individuals (agents) to understand how complex systems function and evolve, and can be used to examine the impacts of changes in a unified and systematic manner.

Lessons for the future

HS1 has been a true success story, transforming the relationship between London and its continental neighbours and creating the platform for some of the biggest regeneration projects of the past 20 years. Its design depended on new thinking about engineering and the environment, but also on close collaboration with experts on technologies and systems that were already proven overseas. Climate change, Covid-19, terrorism and cybersecurity have presented a range of challenges, both for HS1 and for high-speed rail in general, but through a rigorous, all-encompassing approach to design and delivery, Arup and its partners have built a resilient network, ready for whatever the future may bring.

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A new departure

The first high-speed line in the UK had to create its own template, with a funding structure that would withstand unknown threats and an agile team structure that could bring the ambitious route design to life.

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Key takeaways

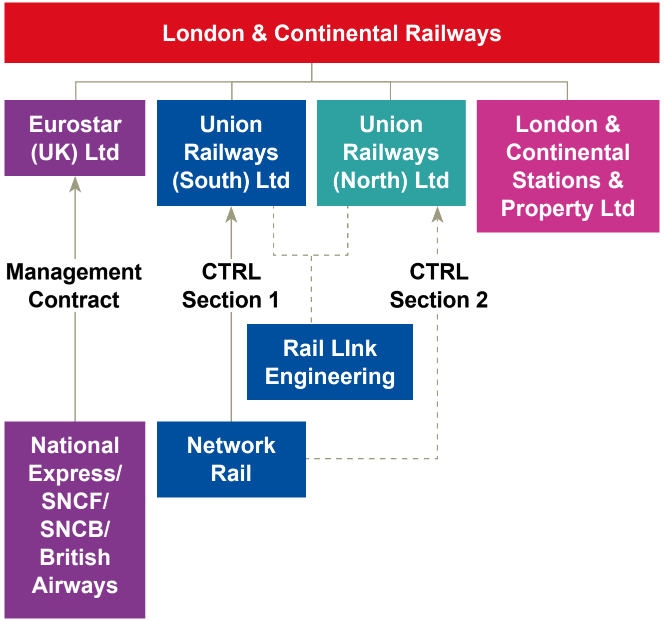
- A lean client structure, supported by a delivery team that encompasses all the expertise needed for delivery, ensures swift decision-making and accountability
- A balance of public and private funding can offer security if revenue expectations are not met
- Publishing route options too early can create unnecessary tension among affected communities
- Routes are likely to go through heavily populated urban areas and protected rural landscapes. These require diverse engineering and environmental solutions, ideally developed with local communities
- Innovative thinking can lead to complementary strategies

A new departure

HS1 was the first new railway in England for over 100 years. It was also the first built to operate at 300km/h. As such, this was a ground-breaking project for the UK – one that would require new approaches to funding and ownership, technologies that had never been used in this country before, and a fundamental rethink of the relationship between rail infrastructure, urban space and the natural environment.

Arup's involvement in the project began in 1989, as the rail tunnel that would carry Eurostar trains between London and mainland Europe was being bored beneath the English Channel. At this time, the UK government and the national rail operator, British Rail, planned to build a high-speed link from the Channel Tunnel to King's Cross station via Kent and south London. Arup pitched an alternative proposal: a route that would travel through the heart of Kent and arrive in London north of the Thames, running through Stratford in east London and into King's Cross's neighbouring station, St Pancras.

This would catalyse the multi-billion-pound regeneration of Stratford, the land around King's Cross and St Pancras, the post-industrial communities of the southern Thames estuary and the disused chalk pits of Kent. It would provide not only a high-speed railway, but also a much-needed high-quality commuter service from Kent to London. Park-and-ride facilities would also encourage the modal shift from road to rail.



London & Continental Railways was set up to bid for the contract to build the Channel Tunnel Rail Link

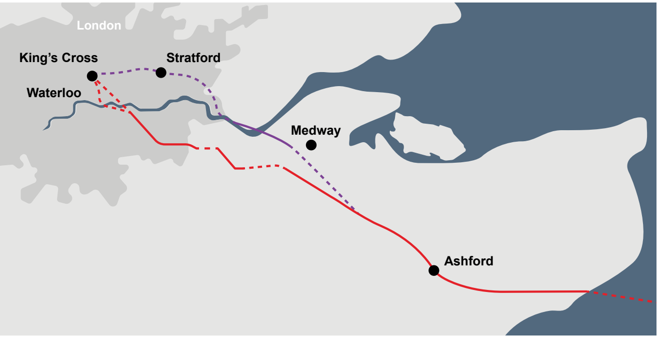
In 1991, Arup's route for the Channel Tunnel Rail Link (CTRL) was given preferred status by the UK government. This came at a time when London's Docklands and Canary Wharf were being radically redeveloped, and there was widespread enthusiasm for regeneration both within the city and across Kent. Three years later, Arup became one of the founding partners of London & Continental Railways Ltd (LCR), which was set up to bid for the contract to build and operate the CTRL. In 1996, the UK parliament passed the CTRL Act, giving the delivery team powers to procure the land and construct the railway. At the same time, the government awarded the contract to LCR.

A model for delivery

The initial funding package was structured as a private finance initiative (PFI) contract – a model of public-private partnership that was driven by the UK government's appetite at the time for harnessing private finance. There was a belief that this would impose greater cost discipline on projects, due to the level of scrutiny from banks and investors.

Under the terms of the 999-year lease, LCR was to finance, construct and operate the CTRL itself, funding the project from income received from the operation

A new departure



of the Eurostar and secured on future revenues. As part of the deal, European Passenger Services (EPS) and Union Railways, companies owned by British Rail, were transferred to LCR ownership, as well as key pieces of infrastructure including St Pancras station and the King's Cross Central development site nearby. LCR also planned to raise additional capital from a partial stock market flotation once the project was under way.

HS1 was the first new railway in England for over 100 years. It was also the first built to operate at 300km/h.

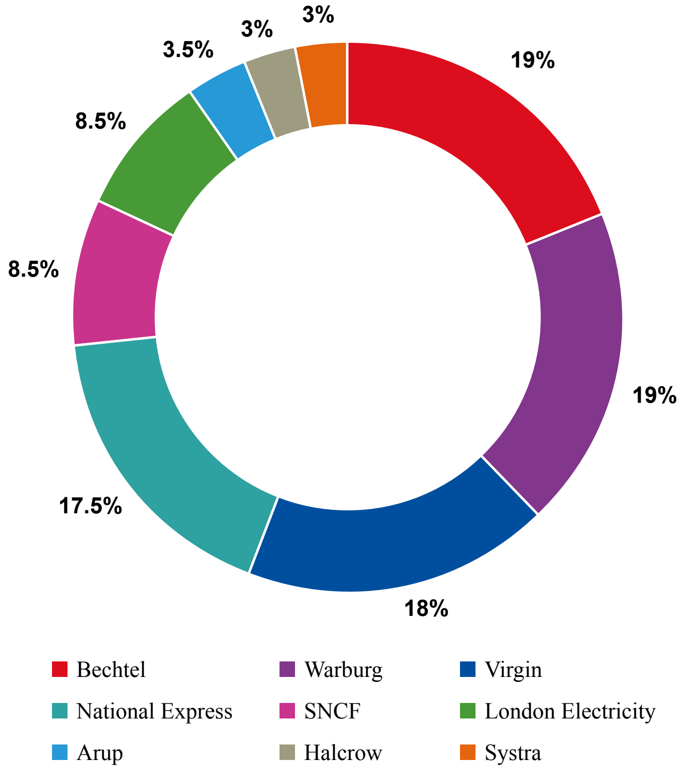
The government agreed to contribute £1.7bn in grants to fund construction of the line and pay for access charges by domestic train services. The funding for the development and subsequent operation of the railway progressed through several restructures over the years that followed (see page 15). This had a number of impacts on the design and delivery of the railway – not least the removal of a dedicated depot and control centre, due to financial pressures during the design stage. However, the combination of public and private funding enabled the project to be delivered. By 2010, after HS1 had been in full operation for three years, its financial position was sufficiently strong for the government to be able to sell the concession for £2.1bn.

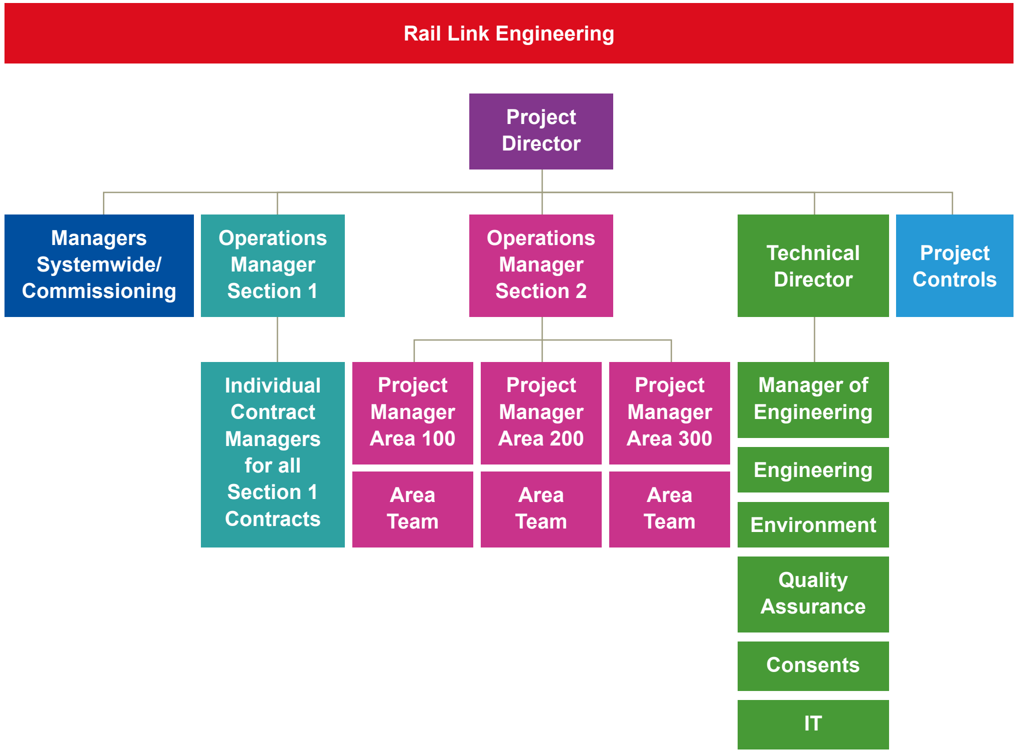
A lean and agile organisation

LCR's organisational structure was incredibly lean, with no more than 90 employees. This encouraged greater personal accountability for delivery and increased the speed of decision-making. Reporting lines were clear, helped by the largely hands-off relationship with government, and the client and delivery partners could maintain direct contact.

The four engineering firms – Arup, Bechtel, Halcrow and Systra – were brought together as a single operational

The original shareholders of LCR





Rail Link Engineering combined four engineering firms into a single operational entity

entity, Rail Link Engineering (RLE). The operational model of RLE ensured that all the specialisms required to design, deliver and operate the railway were embedded into the delivery model. Systra led the track design, Arup and Halcrow focused on the civil engineering elements, Bechtel concentrated on project management, and the environmental and planning teams cut across all the design disciplines. Transport operators National Express and Virgin Airlines were brought on board to inform the yield management and passenger interface solutions of the scheme. Warburg, an investment bank, managed the commercial aspects, and energy expertise was provided by London Electricity.

On the fast track to St Pancras

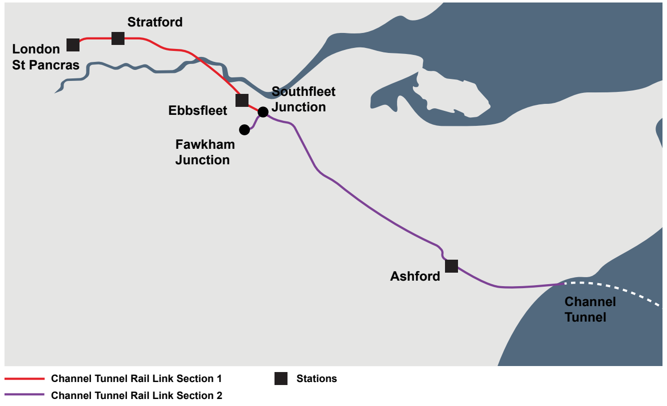
The concept for HS1 was both unique at the time and simple: LCR defined what the railway needed to deliver, focusing on performance rather than physical detail. This established a vision for the scheme – the 'golden thread' – without imposing fixed, and potentially excessive, requirements on the design.

Creating the 109km route, however, was no simple proposition. The route was split into two sections, to be delivered in separate phases. Section one covered 74km from the Channel Tunnel to Fawkham Junction, a few

Can you have too many options?

Route optioneering is one of the most high-risk areas of project development in terms of public scrutiny. A key lesson during the early development of HS1 was that publication of multiple route options can exacerbate tensions and flash points across the proposed routes, leading to protests and local pushback. By publishing all of the options, Union Railways inadvertently created the impression that the project would cause near wholesale blighting of land and property across Kent and south London.

A new departure



The route was delivered in two phased sections, each of which posed its own engineering challenges that had to be solved

miles south of the Thames at Gravesend; it would cross rural Kent, encompassing agricultural land and areas rich in ecological value and archaeological heritage. Traversing the 'Garden Of England', as this part of Kent is known, the main priority would be to minimise the impact on the environment through careful selection of the route, depressing it into the landscape wherever possible, or placing it within false cuttings to limit intrusion. The preservation or replacement of habitats would be paramount. This section of the route would also have to cross the River Medway, requiring one of the longest concrete bridges ever built for the demands of high-speed rail.

Section two, from nearby Southfleet Junction to St Pancras, was equally demanding. On the 19km approach to London, and on through the capital, the line would have to plunge into tunnels running through some of the UK's most heavily populated areas. This posed particular challenges to minimise the construction impact on neighbours and communities.

The route threw up a number of other interesting problems to solve. One of its notable features was the incorporation of domestic as well as international services – which would draw in wider funding streams and bring huge benefits to communities across Kent. However, the inclusion of stopping services and new stations added vast complexity to timetabling and route management, due to the need to accommodate different running, acceleration and deceleration speeds. The movement of trains had to be modelled hour by hour up to 2052, and similar projections were developed for the delivery of assets and required capacity. These highlighted the need to design in passive provision and flexibility.

This, and many other challenges, will be explored in more detail in the chapters that follow. Today, most of the original service plan is in full operation, with the exception of freight services and minor omissions such as a proposed sleeper train. The first section of HS1 opened in 2003 and the second section in 2007. As the first Eurostar drew in to St Pancras station, it ushered in a new era for London: now, high-speed travel was possible across land to France, Belgium and beyond.

(l-r) Secretary of State Alastair Darling, LCR Executive Chairman Rob Holden, Prime Minister Tony Blair and Eurostar Chief Executive Richard Brown mark the opening of Section 1 of the CTRL in September 2003

Changing hands: how the ownership and funding model developed

1994:
Ownership structure established
London & Continental Railways (LCR) is established to bid for the contract to build and operate the Channel Tunnel Rail Link. The original shareholders are engineers Bechtel, Arup, Halcrow and Systra, investment bank Warburg, transport operators Virgin, National Express and SNCF, and energy provider London Electricity.

1998-2003:
Deal restructured
Eurostar revenues prove insufficient to fund construction, partly due to a six-month closure following the 1996 Channel Tunnel fire. The UK government restructures the project and signs a new public-private partnership contract with LCR and rail infrastructure consortium Railtrack. Under the deal, LCR is to finance and build the CTRL, Railtrack is to manage construction and a private consortium will operate Eurostar UK.

The government agrees to another £140m in grants and a separate guarantee agreement to help secure a £3.7bn bond issue by LCR. It also buys a 35% stake in LCR and stipulates that Railtrack become a shareholder and take control of the maintenance of the railway.

1994 | 1996 | 1998-2003 | 2007 | 2010-15

1996:
Initial funding structure agreed
The UK parliament passes the Channel Tunnel Rail Link Act, providing the go-ahead for the high-speed line between London and the Channel Tunnel. The initial funding package is structured as a PFI contract, with LCR to finance, build and operate the CTRL, raising revenue from the operation of the Eurostar. The government agrees to contribute £1.7bn in grants.

2007:
LCR restructured
The government restructures LCR to separate HS1 and Eurostar UK from their past construction liabilities. This enables both HS1 and Eurostar to set a commercial rate for access charges to operators, as opposed to one that is needed to fund the construction, making LCR financially sustainable. The government also separates finance subsidiaries from LCR operations and brings them onto the government balance sheet; this represents £5.2bn in bonds and loan notes.

2010-15:
HS1 and Eurostar UK sold
In 2010, the government sells the 30-year HS1 operations and maintenance concession as part of the restructure of LCR. It is purchased for £2.1bn by Ontario Teachers' Pension Plan and Borealis Infrastructure.
In 2015, the government makes a further sale of its 40% stake in Eurostar UK for £757m.

Economic and social benefits

Regeneration has spread up and down the line, from the transformation of King's Cross to the Olympic quarter in east London to small communities in Kent – who are now plugged into an international network.

Key takeaways

- Thinking carefully about regeneration and social value from the outset is crucial; getting it right will enhance the business case, political support and the whole-life value of the project
- Local stations on high-speed lines can be used to improve social mobility and access to the jobs market
- Stations that serve as destinations in their own right can spur regeneration of a wider area
- High-speed links can bring an international dimension, generating business and tourism opportunities
- Tiered engagement enables delivery partners to build strong links with communities
- Contingent valuation helps to quantify intangible social and community benefits

Economic and social benefits

Regeneration and economic development were vital components of the high-speed link from the start – from the derelict rail yards around St Pancras and King's Cross stations, to economically deprived areas of east London and north Kent and the poorly connected rural areas beyond. The approach to regeneration was all-encompassing, involving new ways of working with local communities, new approaches to placemaking and funding development, and some of the most high-profile restoration projects in recent history.

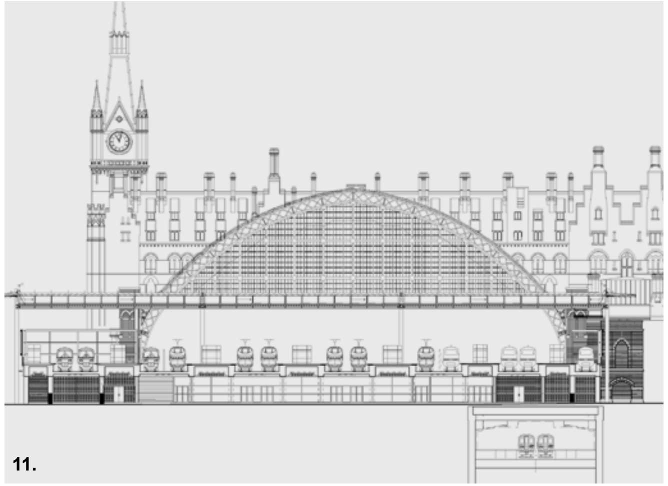
The decision to integrate domestic high-speed services within HS1 was central to this broader perspective. The route entered London from the east through an area of north Kent that, by the 1990s, was blighted by high unemployment, largely due to the decline of heavy industries. This belt of communities had already been identified as a key focus of the Thames Gateway, a multi-billion-pound, government-backed plan for the massive redevelopment of both banks of the Thames east of London.

A station on the HS1 route brought with it the promise of rapid connectivity to London, unlocking the possibility of an influx of commuters, who would need places to live, and new businesses, drawn in by the proximity of the capital in one direction and continental Europe in the other. LCR adopted a novel model whereby local authorities could bid to have one of the two Kent stations. This helped them to understand the drivers within communities and brought factors such as local housing needs, connectivity to jobs and social mobility into the decision-making process. Ultimately, Ashford and Ebbsfleet were selected.

For London, meanwhile, the HS1 project came at an interesting time. Its population was growing for the first time since the post-war decline. A boom in financial services had led to the redevelopment of the Isle of Dogs as Canary Wharf, a second banking quarter in the east of the city. Against a background of rising optimism and economic growth, HS1 stood to become a signature project in London's revitalisation.

The centrepiece of this plan would be the redeveloped St Pancras. Before it was chosen as the HS1 terminus, the station, which originally opened in 1868, had been slated for demolition alongside its neighbour, the Midland Grand Hotel, which had been closed for 70 years. Now both these faded icons of the Victorian age would be revived – the station in an £800m scheme to turn it into a destination in its own right, and the Midland Grand in a £100m project to return it to its Gothic splendour as a hotel and luxury apartments.

This in turn would spearhead the regeneration of 27ha of contaminated railway land and car breakers' yards



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A cross-section of the redeveloped St Pancras trainshed, with St Pancras Chambers in the background

Economic and social benefits

immediately to the north of St Pancras and King's Cross. By bringing an international dimension to the area, turning it into an accessible regional hub for European companies, the St Pancras redevelopment was the ideal springboard for this wider vision.

Revitalising Kent

In the short term, a significant impact of the project was the direct employment it brought to areas around the line. More than 8,000 people worked on the construction of the railway, and HS1 was the biggest community employer in the UK at the height of the works. Local people also benefited from social value initiatives during the delivery programme, and HS1 looked to enhance areas affected by the construction works.

Faster travel

When the line opened, Ebbsfleet rapidly began to transform, largely due to the journey time into London dropping from 40 to 17 minutes. The international station has sparked plans for Ebbsfleet Garden City, which aims to deliver 15,000 sustainable homes and 30,000 jobs by 2035, as well as 1.4 million journeys on HS1 every year. To date, the additional development in the Thames Gateway due to HS1 is estimated to be worth about £500m, and more than 50,000 jobs have been created in east London and the Gateway region.

Further down the line in Ashford, the journey time to St Pancras also halved to 37 minutes. The town's population has expanded by over 20% since 2005, according to developer GRE Assets, while a 2015 report by the Department for Transport noted that the number of businesses within 500m of Ashford station has increased by 4.8%, and within 2km by 6.1%.

In all, over 400,000 more workers in Kent are now within a one-hour train journey of London, enabling more people to benefit from lower house prices outside the capital. The increase in demand has so far resulted in 20,000 new homes being built on brownfield land.

30,000 jobs

15,000 sustainable homes

HS1 also plays a key role in supporting tourism in Kent. A 2017 study by Visit Kent and Destination Research of the tourism and visitor sector, which accounts for 10% of jobs in the county, found that HS1 had generated £73m in 2016 alone, and more than £300m in the decade since 2007.

A focus on the local

As well as the client and project sponsors, complex rail projects have a wide range of stakeholders, including the network operator, regional transport bodies, local government, political representatives and environmental bodies, and ultimately the customers. The more holistic our understanding of transport networks becomes – to incorporate placemaking, regeneration and other local benefits – the wider the pool of stakeholders grows, to include community groups and their representatives.

Economic and social benefits

A strong sense of ownership and inclusion for all stakeholders fosters common goals, helps to break impasses and, ultimately, creates a deliverable scheme. But the likelihood is that these groups will have conflicting priorities that need to be carefully balanced throughout the scheme, from the choice of route through to the way that it is delivered and operated.

Due to the size and nature of the project, a tiered engagement regime was used. Alongside the formal public consultation process, events included small local focus groups as well as mobile engagement booths. In this way, local people gained a real sense of the impact the proposed route would have on their community.

Becoming embedded in the affected communities was crucial. The Rail Link Countryside Initiative, an independent charity, was set up to support local communities, landowners and organisations, with £2m of funding from HS1. The initiative has so far delivered more than 100 environmental initiatives.

Planning, environment and heritage forums were also set up to generate buy-in for the developing designs. The forums comprised representatives from the project delivery teams and technical officers from the local authorities affected by the route.

The forums were regularly attended by the communities relation team (CRT), which managed relations with councils, pressure groups and community groups. CRT members were based on site with the contractors, Rail Link Engineering and Union Railways teams. Their role was to produce easily understandable content for communications, clarify technical aspects of consultations and help to establish consistency in decision-making.

St Pancras and beyond

Together with the redeveloped King's Cross, St Pancras was at the forefront of a complete rethink of London's large stations, turning them into places people actively choose to visit. According to the UK rail regulator, the Office of Rail and Road (ORR), by 2019, one in six of its 50 million annual customers were there purely to shop and use the bars and restaurants. This has helped to stitch St Pancras into the fabric of the wider community, bringing further economic and placemaking benefits for the surrounding area.

The land and infrastructure required for the railway had a catalysing effect on land assembly deals. Landowners

"I remember sharing with a resident that we had an opportunity to cut the journey between Pepper Hill and King's Cross to 15 minutes. At the time it was taking an hour and a quarter. Suddenly, a light went on in people's minds that this project was worthwhile and the mood began to change to one of real positivity. We'd moved away from thinking as engineers, environmentalists and project managers to seeing the impact that the project could deliver to individuals and the community."

Peter Miller, former Environment Manager, Union Railways

Economic and social benefits

Meet me at the station

Rethinking stations to provide more than simply transit links is a cost-effective means of generating value for the community. Many local stations can benefit from multi-use spaces and placemaking elements. Destination stations play a key role in bringing value to a local area through a mix of retail and leisure opportunities. This not only generates local employment, but also pulls visitors to the area. St Pancras has provided the template for other UK stations, such as Grand Central Station in Birmingham.

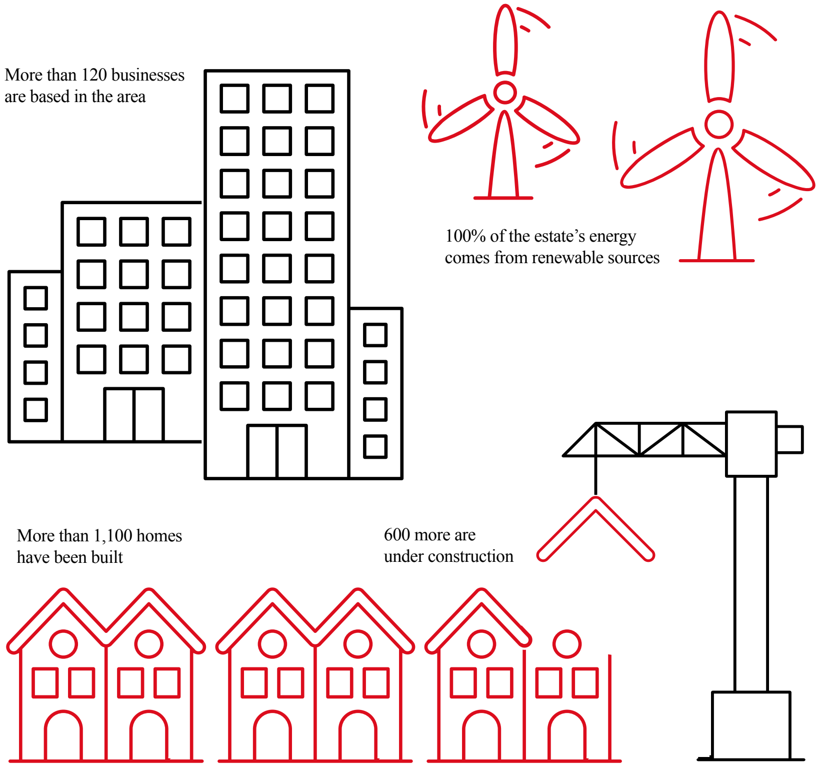
LCR and Exel (now DHL) brought developer Argent on board as delivery partner and plans quickly advanced for what would become one of the largest regeneration projects in Europe, now known as King's Cross Central.

As of December 2020, more than 1,100 homes had been built, with 600 more under construction. More than 120 businesses are based in the area, including the UK operations of Google, Meta, AstraZeneca, Nike and Sony Music. King's Cross is also often held up as a template for sustainable regeneration, with 100% of the estate's energy coming from renewable sources and 40% of the site given over to parks and open spaces.

HS1 also supported a broader narrative that Britain was capable of delivering complex, multi-billion-pound projects on time. This was an important aspect of London's pitch to the International Olympic Committee when the latter was seeking a host for the 2012 Olympics.

The high-speed line was a 'golden thread' that ran through the bid. In practical terms, its domestic services could transport athletes and spectators, as well as all the logistical support needed, from central London to the Olympic Park very quickly through Stratford International Station. The redevelopment

The redevelopment of King's Cross (up to end of 2020)



> "People looking back now realise it was the right thing to build, as it unlocked European travel benefits and catalysed immense social and economic benefits along its route through Stratford and into King's Cross and north Kent."

Andrew Went, Global High Speed Rail Leader, Arup

£8bn catalyst for development

£427m of economic benefits

£10bn of regeneration benefits

work already begun by HS1 also strongly supported London's contention that the infrastructure and assets built for the Olympics could be used to continue the regeneration of east London.

The growth at Stratford since the Olympics has exceeded expectations. Developments in and around the Queen Elizabeth Olympic Park include five new neighbourhoods with 10,000 homes, and the East Bank cultural district. Stratford is now the seventh busiest station in the UK, according to the ORR.

Overall, HS1 has been the catalyst for over £8bn of development. According to a 2020 report commissioned by HS1, the line supports more than £427m of economic benefits to the UK and continental Europe every year. It is expected to provide at least £10bn of regeneration benefits over the next 50 years.

The challenge of demonstrating value

While there are frameworks in place for assessing projects in areas such as time savings, safety and carbon emissions, it is still difficult to quantify the transformative effect of less tangible impacts in an outline business case. A value framework needs to capture everything from land value, connectivity and economic growth to sustainability, resilience and placemaking.

The development of contingent valuation (CV) to account for and monetise benefits related to social and community goods offers a possible solution for rail schemes. This calculates monetary values for non-market assets by asking people about their willingness to pay or to accept compensation for a particular change. CV was used to quantify the total net benefit of the A303 enhancement scheme, which proposed a tunnel beneath the Stonehenge and Avebury World Heritage Site for the busy trunk road – one of the main routes between London and the south-west. This approach valued the project at £1.5bn, compared with £500,000 had cultural heritage impacts not been taken into account.

Demonstrating value at every stage of a long-term scheme is essential to retaining local support and investment, especially if the political or social climate changes. Phased delivery helps to balance long-term objectives with more immediate gains.

Customer experience

This was the key consideration that underpinned all aspects of the design: how could high-speed rail provide passengers with a better alternative to air travel?

Key takeaways

- Providing a viable alternative to air travel was key to HS1's success – the overriding need for quicker journey times and greater reliability informed all design decisions
- Concerns about climate change have also changed attitudes to car use, and HS1 provided local benefits in encouraging the modal shift from road to rail
- The station and onboard facilities were opportunities to differentiate rail travel from flying as an enjoyable, relaxing experience in its own right
- Internet technology has transformed customer expectations in ways that were not anticipated during the design of HS1
- Operators and infrastructure owners need to be able to share and handle data regarding customer journeys, asset information and performance in a secure way
- System thinking needs to extend beyond a single mega-project

Customer experience

Customer experience was always going to be central to the success of HS1 – even technical aspects of delivery were framed around delivering speed, reliability and comfort. Rail had traditionally been seen in terms of a network for domestic and local services, but the arrival of high-speed rail in the UK brought with it an international dimension, with the opportunity to travel directly to Paris, Brussels and, more recently, Amsterdam. Its main competitor in this new market was air travel. The ambition was to combine the speed of flying with the romance and convenience of train journeys, to offer an unrivalled end-to-end experience.

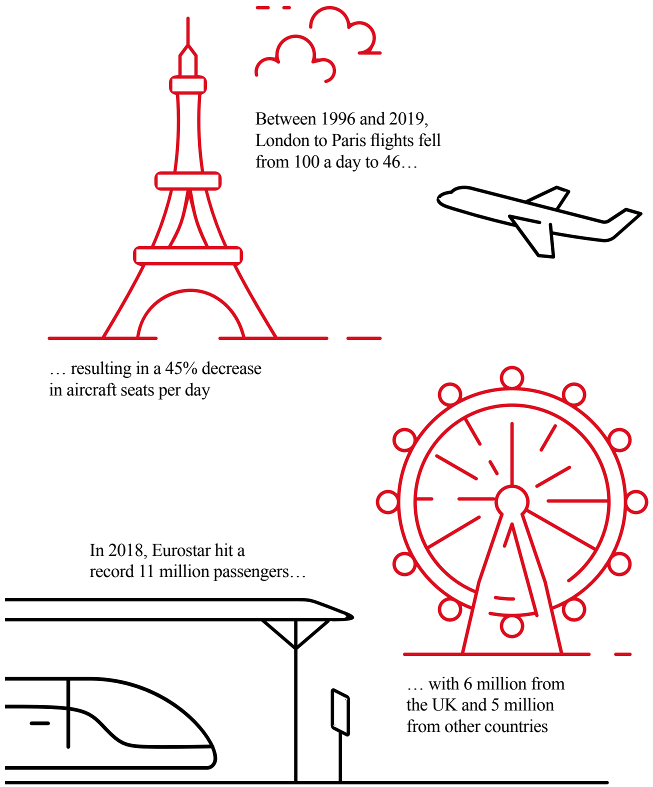
Designing for speed and reliability

With the opening of phase two of HS1 in November 2007, the journey time between London and Paris was cut to two hours 16 minutes, a saving of 33 minutes on the original route to and from Waterloo station.

This was not only down to the high-performing Eurostar class E300 trains, capable of running at 300km/h. The overriding need for speed and reliability informed everything from route development to tunnel design to passenger movement. Route planning focused on the need to separate international and domestic services so that priority could always be given to the high-speed trains. This required the development of secondary lines, to enable stopping services to divert into stations without congesting the main line. A complex timetabling model was also created to show daily train movements up to 2052, thereby demonstrating how a flexible two-speed system could accommodate ten international trains and eight domestic trains per hour.

To date, this has helped to provide a reliable, high-performing service, with delays measured in seconds rather than minutes, and the flexibility to cope with periods of operational strain, such as the 2012 Olympics. Nearly 90% of Eurostar trains arrive within 15 minutes of their scheduled time, compared with around 75% on EasyJet, Air France and British Airways.

In 2018, Eurostar carried a record 11 million passengers, including 6 million from the UK and 5 million from other countries. According to air travel data analyst OAG, the number of daily flights between London and Paris fell from 100 in 1996 to 46 in 2019. Although some of this can be attributed to larger capacity on aircraft, the overall number of aircraft seats per day still decreased by almost 45%.



Customer experience

The station as destination

If speed and reliability were essential requirements for competing with air travel, the station and onboard experience would be what set high-speed rail apart. Following its redevelopment, London St Pancras became the first true destination station in the UK, designed to provide more than simply an international terminus for 50 daily Eurostar services and a link to the Tube and regional rail network. It was intended as a social place for people to shop, rest, eat and meet one another. This was partly in response to the sudden emergence of budget airlines: rail had to both replicate the various retail and leisure attractions of airports and differentiate itself as a more relaxed alternative.

The design of the station, which has a capacity of 3,000 people, presented complex challenges in terms of passenger flow. Multiple train companies operate within the station boundaries, running discrete systems and physical areas of the station. A passenger getting on at Sheffield, for example, is a Network Rail passenger, and it is not until they step onto the St Pancras platform that they pass into an HS1-controlled space.

The HS1 team benefited from the inclusion of two rail operators, Virgin and National Express, with vast

12.

experience in moving and managing passengers. Their ability to articulate the customer experience had a huge influence on the station design in terms of passenger flow management, security and border control, and the intelligent segregation of international and domestic services: while the Eurostar trains arrive in a secure, controlled area, fast domestic services are allocated platforms on a deck extension leading directly to the station concourse. Specific branding and communications for different customer types has proved useful, both to improve wayfinding and to provide a more clearly delineated experience between international and commuter services. In 2020, St Pancras International was named the top-performing station in the UK, with a passenger satisfaction score of 96%.

Since HS1 opened, rail operators have developed a more holistic understanding of customer expectations. A greater focus on accessibility has led to advances such as step-free boarding, clearer signposting and improved access to toilets and other onboard facilities. In 2016, the launch of a new fleet of Eurostar trains, with stylish interiors by Italian design company Pinanfarina, free WiFi and onboard entertainment, led to the brand becoming one of the top travel companies in KPMG’s Customer Experience Excellence survey.

Customer experience

Integrating new technology

The area in which customer expectations have transformed most radically over the past two decades is undoubtedly technology. When CTRL was in its design phase 25 years ago, mobile phones were still relatively rare. Today there is an expectation of personalisation and 24/7 connectivity, with the ability to communicate, work and stream content, all through handheld devices.

Trains in all three Eurostar classes have been fitted with WiFi hardware, as well as USB charging points and standard electrical sockets. 4G is now live across the CTRL route, with 4G cabling and the associated hardware and power supplies having been installed in the London tunnels. This supplements the free WiFi available throughout St Pancras station.

The advent of mobile devices has also drastically altered the way customers expect to find journey information. Passengers make decisions while in transit, based on live departure boards on their phones, rather than waiting to look at displays in stations. They have already made decisions and found the platform for their connection before they disembark from the train.

Data is an increasingly valuable tool in helping to improve the customer experience, but the rail industry faces challenges in keeping pace with how it is used by passengers. Rail operators and infrastructure owners all own and hold silos of data regarding customer journeys, asset information and performance, but the sector lacks a body where all interested parties and owners can share and handle this data in a secure way. A holistic approach, in compliance with the EU General Data Protection Regulation and other governance protocols, could only enhance the customer experience further.

Changing customer expectations

The reasons for choosing different transport modes are also changing, which will have implications for the design of new high-speed links. At the turn of the century, the main question for high-speed rail was how to compete with the speed of air travel. Since then, terrorist attacks, such as 9/11 in New York and the 7/7 bombings in London, have had a huge impact on security and on passenger perceptions of risk in relation to transport mode. Stations have to be managed to provide reassurance without negatively impacting the customer experience. At the same time, quicker security and passport controls than those at airports make international rail travel a more appealing option for some travellers.

Passengers at St Pancras can now take advantage of free WiFi while they wait for their train

Customer experience

The development of hydrogen-powered trains will help to reduce carbon emissions from rail travel

Customers are also increasingly concerned about climate change and the carbon emissions of their journey. Where mass transit is concerned, rail is more environmentally friendly than road and air travel – although the industry still needs to reduce its energy consumption; in the UK, for example, it uses 7 million litres of carbon-based fuel every year. Hybrid rolling stock and hydrogen- and battery-powered trains are being developed, in addition to programmes to electrify track infrastructure.

> The pandemic has highlighted the fact that learning about customer expectations and concerns is a continuous process.

Conversely, Covid-19 has pushed some travellers back into personal vehicles. This was an unforeseen challenge, just as the introduction of low-cost air travel posed an unanticipated threat to high-speed rail decades ago. The pandemic has highlighted the fact that learning about customer expectations and concerns is a continuous process, requiring constant close engagement to understand how people interact with transport infrastructure.

At the same time, designers are becoming more nuanced in their understanding of customer needs. In 2019, Arup and the Rail Safety and Standards Board (RSSB) published a study on seat comfort. This included an assessment tool that uses anthropometric data on UK rail passenger profiles to help train operators to rate the comfort of seats. The analysis from this study is informing how existing fleets are refurbished and new fleets are developed.

Designing for future connectivity

The retrofitting for 4G – in both trains and tunnels – has posed challenges. Passive provision for communications, cabling and utilities was largely overlooked during the initial design of HS1 but should be an important consideration in any future high-speed rail project.

Likewise, the initial route design should be flexible enough to adapt to the changing long-term needs of passengers. There is an emerging business case for CTRL to provide a domestic service direct to Dover. This proposed link could provide customers with a

High-speed rail shows the benefits of a closed system – one that is cohesive and largely seamless, with slick connectivity from the heart of one city directly to another. However, it also illuminates the challenges faced by a wider, more fragmented network.

convenient service with a journey time of less than an hour, but it would require additional crossovers at the southern end of the CTRL network, at great expense – a problem that would have been averted by providing connective nodes from the outset. This has implications for future mega-projects: there are many towns close to Birmingham and Manchester, for example, that would benefit immensely from domestic service links to HS2. For a smaller investment upfront, future connectivity to the high-speed network for surrounding conurbations could be greatly enhanced.

This is why end-to-end or total system thinking needs to extend beyond a single mega-project. Domestic passengers want reliability and cohesive communication; their experience depends on the reliability of all the journey segments, irrespective of the train operating company or the infrastructure it runs on. High-speed rail shows the benefits of a closed system – one that is cohesive and largely seamless, with slick connectivity from the heart of one city directly to another. However, it also illuminates the challenges faced by a wider, more fragmented network: for the domestic services using CTRL infrastructure, the customer journey is more complex and open to greater influence from elements beyond HS1's control.

Managing diverse objectives

For the best long-term investment, schemes should be driven by customer needs – this is the core requirement or 'golden thread' that runs through the scheme. But if requirements management is too rigid, and driven in a top-down process, there can be little room for discussion or flexibility during the development phase. This in turn can lead to an unaffordable scheme that fails to deliver on the main drivers. All too often, requirements are developed in isolation, which results in integration issues and conflicting goals.

With HS1, the critical customer need was the ambition to match the journey time and experience of air travel. By establishing this hard line and focusing on it relentlessly, the client was able to articulate what it wanted from the designers and contractors. Value could then be added around the more negotiable requirements.

Typically, 10% of requirements are set by legislation, 10-15% by customers and stakeholder non-negotiables, and the remainder by the client. Adopting a whole-system approach, with designers and contractors working with the client to release value at every stage of the project, can help to reduce costs. It can also provide greater programme certainty and meet other, less tangible, goals in areas such as future resilience and sustainability.

Environmental strategy

HS1 was in the vanguard of a new approach to environmental protection – something that has become ever more important in the ensuing years, given the urgent global focus on tackling climate change.

Key takeaways

- Transport is the source of a quarter of global carbon emissions, so major infrastructure projects need to be planned from the outset with clear plans to drive decarbonisation
- Assets need to be multifunctional in terms of enhancing/protecting agricultural land, mitigating noise and contributing to the natural environment
- Great design and delivery embeds infrastructure into the existing landscape, with assets that maximise benefits to people and the natural environment
- Do more than achieve 'no net loss'. Areas and communities should be provided with an enhanced environment
- Environmental protection needs continuity. Clear objectives and performance metrics should be enshrined in every phase of construction, operations and maintenance


13.

Environmental strategy

The development and subsequent operation of HS1 provides a wealth of knowledge on designing infrastructure that not only protects the environment but enhances it, leaving a legacy for future generations. HS1 took a pioneering approach to environment in its widest sense: preserving and restoring historic buildings, enhancing understanding of our roots through archaeological studies, providing momentum for investment in regeneration, and adding new habitats as well as replacing existing ones. The lessons learned are continuing to shape the way that mega-projects approach environmental planning, working with the landscape for the long-term benefit of nature and people – a goal that has added urgency in light of global efforts to achieve net zero and mitigate the effects of climate change.

A successful strategy… but what does success look like?

The landscape and agricultural restoration parcels on HS1 have performed well against the expectations set for the first 10-15 years. However, key risks can arise from a lack of accountability and measurement to drive maintenance. It is important to continue to manage trees and other soft assets, which often take 10 years or more to reach maturity.

A lot of the sites around the HS1 route are no longer controlled by the line's owners, which poses a substantial challenge in terms of maintaining and measuring the success of environmental interventions. Establishing documented ownership and accountability with clear maintenance protocols is crucial to ensuring that soft assets continue to perform their desired function. For HS1, a substantial maintenance manual was compiled, detailing all of the natural vegetation classifications, maps and specifications for the land parcels.

The maintenance plan also needs to strike a balance between aesthetic landscaping and ecology. For example, if a tree dies, landscaping would dictate that it should be replaced. However, from an ecological perspective, the loss may be part of the lifecycle of a natural space, creating room for other plants to thrive.

Tracking the success of environmental work is crucial to planning future interventions. Metrics generate a greater understanding of the factors influencing natural assets and their subsequent ability to perform well against their desired functional requirements.

But qualifying success is complex. It needs to be about more than simply counting soft assets, but rather about

> "East West Rail is taking this philosophy one step further and embedding it within the standards. So it's tangible, measurable and must be delivered. It ensures commitment – 'Yes, we will do this'. The strength of the environmental policies is substantial and considerably better than anything I've ever seen to date."
>
> Nick Mitchard, Director (Planning – Major Infrastructure Projects), Arup

measuring specific characteristics, such as intrusion of noise, effectiveness of screening or erosion of banks. Projects need to set out clear environmental objectives and include these in design standards from the outset. This establishes a framework for assessment that can be referred back to, even decades later.

Value-based policies such as biodiversity net gain are particularly difficult to measure. There has been an increase in guidance in this area and a standardised approach is beginning to emerge. The East West Rail project between Oxford and Cambridge – on which an Arup consortium is leading the early works – is one of the first to establish a robust framework to quantify and deliver its target of 10% biodiversity net gain.

The way forward

The scale of mega-projects brings a substantial opportunity to positively influence the environment, both locally and nationally. Within a multi-billion-pound project, the environmental works are extremely small in cost terms, yet the benefits are substantial. Protection and enhancement measures help to achieve the necessary consents and unlock substantial value by integrating sustainability and resilience into the heart of the design.


14.

In North London, the HS1 tunnel runs under a densely populated area, following the route of the North London Line

There has been a clear shift towards multidisciplinary thinking, as issues such as climate change, social cohesion, health and wellbeing and the protection of nature have come to the fore. Consultants can have a substantial influence through bringing knowledge and experience from other countries and sectors. It is important that this happens in the feasibility and early design stages, as the pace of major projects provides little space for critical thinking once work is under way.

A new approach to environmental impact

Prior to the development of HS1, the guiding framework for environmental protection in the UK was the Control of Pollution Act 1972, which concentrated on air quality, emissions and noise. During the 1980s, attitudes began to shift across the Western world, with a groundswell of local protests against transport projects and growing support for laws to protect the environment. In the UK, the EEC's Directive 85/337 was implemented, introducing the requirement for environmental impact assessments (EIAs).

For the emerging HS1 route, this prompted a step change from a traditional rail business case, with environment and engineering addressed in tandem. This began to mitigate the concerns raised by the affected London boroughs and address the wider consequences for local communities.

The parliamentary bill for the proposed route defined minimum requirements covering landscape, ecological and heritage objectives, the control of noise and dust, minimisation of waste, protection of water and construction practices. Design and construction arrangements were then set out in the CTRL Development Agreement, which stipulated that the environmental impact of the scheme would be 'not environmentally worse than' (NEWT) the parameters set out in the bill. A code of construction practice (COCP) set out in more detail the measures that would be undertaken. This approach was groundbreaking and continues to inform development practice on UK mega-projects today.

Throughout the construction process, contractors were charged with delivering these environmental and social goals. Contract documents and the COCP compelled them to produce detailed local plans to address issues such as noise, air quality and traffic control. Every contractor was required to employ a full-time environmental manager and team – something that was unheard of at the time.

Environmental strategy

The environmental team had a huge amount of work to do up front to control environmental risks related to the programme. In all, the project required over 2,000 planning and environmental consent submissions and more than 200 ecological surveys. The key areas of focus are detailed below.

Archaeology

The archaeological programme for the scheme was the largest of its kind ever undertaken in the UK, with over 45 sites investigated. The teams were successful in working around any sites of importance that were discovered, enabling the preservation and removal of artefacts while ensuring the construction works could progress as efficiently as possible.

There were many interesting finds, such as an unusual Anglo-Saxon horizontal water mill at Ebbsfleet, a Roman cemetery nearby, and Anglo-Saxon burial grounds at the Singlewell and Medway Viaduct sites, where jewellery and buttons were discovered that are now on display in the British Museum.

Heritage

As with many large-scale infrastructure projects, the HS1 scheme affected heritage sites and buildings. The

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(above) Excavations for HS1 uncovered an Anglo-Saxon mill at Ebbsfleet
(right) A 7th-century Anglo-Saxon brooch found during excavations at Saltford

Key landscaping and ecology achievements

The scale of the environmental measures delivered was unprecedented:

- 7,900,000m^3 of excavated material reused in landscape mitigation and adjacent projects
- 1.2 million native trees planted
- 230ha of woodland created
- 25ha of new woodland translocated on ancient woodland soils
- 370ha of grassland created
- 80ha of wildflower meadow created
- 40km of hedgerows planted
- Three land bridges built to act as wildlife corridors
- Seven ponds and two wetlands created
- 200ha of temporary sites restored to agricultural use.

most substantial was St Pancras station, the largest grade I-listed building on the route, which required protection, refurbishment and enhancement to become the HS1 terminus. Other historic buildings that were protected included:

- The grade II-listed, 17th-century Bridge House in Mersham, which was transplanted to a site 80m away using a slide technique
- The grade I-listed Midland Grand Hotel, which was refurbished and converted into St Pancras Chambers – a hotel and luxury flats
- The grade II-listed 2 Boys Hall Road in Willesborough, which was dismantled and taken into storage

Landscape

With section one of the route passing through Kent's rolling countryside, landscaping played a crucial role in minimising the visual and physical impact of the line. The landscape design was as naturalistic as possible, with a far more fluid form than standardised embankments.

Interventions included lowering the route in some places and creating undulating embankments to mimic the surrounding area. Three land bridges were also constructed to provide wildlife corridors and further integrate the scheme visually into the landscape.

Ecology and biodiversity

The project teams went beyond the NEWT principles by creating additional woodland, wetlands, ponds and grasslands of a greater value than that removed during construction. The relocation of affected areas was time-sensitive and had to be carefully managed so that flora and fauna could establish themselves successfully once reinstated.

The plants and trees were carefully specified, to an extent not previously seen in the UK. This involved using native species to protect the local ecosystems. Every area, down to less than an acre in size, had a planting strategy, with species assigned to satisfy specific objectives for the particular plot.

Protection and reinstatement of land

Virtually all of the temporary land-take, including more than 200ha of versatile, high-grade agricultural land, had to be returned to its original use – and quality. This was a strictly controlled process involving the removal of topsoil and subsoils from

The historic Bridge House in Mersham, which stood on the HS1 route, was slid 80m to a new location

100 parcels of farmland, the separate storage of the soils, and then the careful replacement of the soil structures once the temporary construction areas and access routes had gone.

The land reinstatement also included woodland (some of which was designated ancient), grassland and other sites of natural significance. To reinstate and translocate ancient woodland, the team needed to protect the soils; they did not move and replant every tree, but instead recreated the environment in which the woodland could re-establish itself.

Acoustic fences were installed along the route to provide noise mitigation

Noise

Noise and vibration were among the most significant environmental risks to the project. Protecting communities, both during construction and from the operation of trains and fixed equipment, was a complex challenge and no off-the-shelf solutions were available.

Using the environmental statement as a baseline, RLE assessed the noise impact on communities and proposed mitigation works where appropriate in the form of noise bunds, or earthworks, using surplus spoil.

The main challenge was in the design of acoustic barriers. Two types were developed:

- Wayside timber barriers. Up to 5m high, these comprise machined tongue-and-groove softwood planks, 35mm thick, nailed to vertical supports. In places an absorbent lining, secured by perforated steel panels, further enhanced the acoustic performance of these reflective barriers.
- Low-level barriers. These 1.4m-high galvanised steel panels have absorbent linings and are protected by profiled perforated covers. They were installed closer to the wheel-rail interface and used exclusively on structures, mounted on the track ballast retention kerb. Acoustically sealed gates were installed at intervals to allow emergency egress.

Waste management and reuse of materials

Tunnelling comprised 25% of the HS1 route, but huge efforts were made to minimise waste and spoil movement from site. Some 7,900,000m^3 of surplus excavated material was reused in landscape mitigation schemes. These included:

- Chalk from the North Downs tunnel was used in the construction of the concurrent M2 motorway widening project, providing benefit to both projects
- Surplus material from cuttings and tunnelling formed platforms for regeneration. For example, the site of the Olympic Village and Stratford City in east London is underlaid by spoil from HS1
- Various chalk and limestone quarries in the Medway area have been infilled.

Local reuse of materials avoided tens of thousands of lorry movements to remote locations.

Operations and maintenance

HS1 seamlessly integrated French systems and standards into a UK system for the first time. Fifteen years on, the railway continues to explore new ways of understanding and improving whole-life performance.

Key takeaways

- Instil flexibility and shared expertise in the team. Maintain the competency of the workforce and encourage them to drive innovation of maintenance and renewals practices
- Balance core expertise with fresh ideas from other sectors
- Plan and design for the full lifecycle. Add value at every stage, from operations to maintenance to renewal
- Understanding the factors that influence degradation helps maintenance specialists to build in greater cost certainty
- Operating costs need to be considered alongside capital costs. The financial pressures of acquiring land mean that provision for renewals is often sacrificed in the design stage
- Harness as much accurate data as possible about degradation rates, and use it to develop long-term renewals strategies

19.

The operational phase covers most of a railway's lifecycle, so poorly designed systems or badly planned maintenance regimes can have severe long-term consequences. For a pioneering project such as HS1, which included assets and systems that had never been used in the UK before, the stakes were incredibly high. The fact that, 15 years into operation, it remains a high-performing, reliable railway is testament to well-planned protocols, an agile team structure and the successful integration of proven high-speed technologies and standards into UK systems.

Building the team

By 2003, a five-strong operations and maintenance management team was in place. Adopting lessons from the Channel Tunnel project, they sought to instil flexibility and shared expertise throughout their team.

To build the expertise of the new maintenance and operations staff, SNCF training schools, standards and practices were implemented. All of the base systems and much of the design thinking were taken from the high-speed lines for the TGV Méditerranée and TGV Nord. The team developed cross-acceptance regimes for the systems and equipment and defined maintenance protocols for the HS2 Rule Book, which was based on the SNCF manual. Tackling differences in terminology was key, as was the cultural aspect of introducing French methodology to UK staff.

To ensure that safety standards were met, Rail Link Engineering developed the Train Accident Risk Model. This assessed the risks to passengers, operators, maintainers and persons adjacent to the railway under operation, as well as maintenance and critical incidents/failures.

The CTRL team also introduced a Compliance Review Group (CRG) – a group of technical experts and professional heads from the UK rail infrastructure consortium Railtrack (later Network Rail). The CRG reviewed the developing designs to assess the impact on the existing network and confirm that the proposed works and new infrastructure interfaces were safe, deliverable and reliable through compliance with the existing UK rail standards.

The commissioning was incredibly pressured. Work continued until the very last minute on the first signalling room boundary, from the Channel Tunnel to the CTRL infrastructure, in order to accept the first Eurostar train on time.

Into the maintenance phase

The innovative team structure, balancing specialisms with flexibility, has proved effective. The delivery teams are able to mobilise rapidly in response to major incidents and to support other teams where required. Following the completion of section one, they built a

The dangers of systems overload

The number one risk to a rail scheme entering into service on time is systems integration. Too many schemes underestimate the complexity of this process, and subsequently try to squeeze it into the end of the programme. This can be due to the design running late, or to the build and testing runs being conducted in isolation of one another. This then leads to a lack of end-to-end testing of the system as a whole.

Integration requires more time as the complexity of the system increases. Third-party systems, owner systems, revenue systems, data and analytics all need to be part of an overriding structure, which needs to be considered from the optioneering stage of development onwards. Systems integration should then be phased throughout the delivery of the project.

relationship with the installers on section two, passing on their knowledge and experience. In this way, the multidisciplinary focus provided a robust, railway-wide approach to the delivery of the second section.

The standards and Rule Book have evolved, adapting to the UK context. Over time, a risk-based approach has been adopted, based on data collected over agreed periods. Detailed standards have been developed, and data modelling and risk analysis are used to show that the risks identified have been mitigated to as low a level as is reasonably practical.

Overall, the majority of assets are performing well. The overhead line equipment, which has a different design to standard UK gantries, is in good condition, with the wire showing fewer signs of wear than anticipated. The ballasted track, which makes up most of the route, is also performing well – although HS1 will begin replacement and rerailing in the next five years – and the signalling system has proved reliable.

Why early engagement is crucial

Rail schemes need to optimise the balance between capital and operating expenditure, which means thinking about maintenance from the start of the process. By working collaboratively with the future operator and maintenance engineers throughout the feasibility and design phases, rail designers can create a service that is not only cost-efficient during design and build, but throughout its lifetime.

Many of the biggest challenges on HS1 derived from the feasibility and design stages, before the operations

The impact of new rolling stock

As a single fleet operator, HS1 has been able to observe the effect that new trains have on the condition of the rails, particularly since the introduction of the Javelin in 2007, with its lighter suspension and bogies. The imminent arrival of the heavier Siemens high-speed train, the Velaro, is likely to have a considerable impact on track longevity, potentially reducing the lifespan from 25 years to 20.

There is an emerging requirement to understand wear and degradation, to inform both renewal planning and rolling stock choices. This in turn could affect access charging and provide the potential to incentivise more track-friendly rolling stocks. HS1 is now assessing how to balance this particular risk with the associated maintenance and renewal costs.

and maintenance function had even been established. An example of this was the decision to remove the dedicated HS1 depot and control centre, instead relying on sharing existing Network Rail depots and the Channel Tunnel control centre. The absence of a depot posed problems during section one of the project by increasing the time it took to move people and equipment to site locations.

The new Velaro train is heavier than the model it will soon replace, which will affect track longevity

Following the successful commissioning of section one, a dedicated depot at Singlewell came online during the operational phase. The new depot enabled the purchase of multipurpose modular maintenance machines, paving the way for a fully operational maintenance function within two years of the opening of section one.

Access to specific site locations remains a concern, however. Although the depot is well situated at the centre of the route, the reliance on a single site is a constraint for rapid deployment. The railway would benefit from a hub and spoke depot arrangement, with the main depot providing permanent housing of large plant and staff, and outer hubs used to temporarily house plant and materials during maintenance and renewals activities.

Getting to grips with degradation data

In an innovative approach, the HS1 maintenance team has created a 40-year plan for track and civils renewals. Through a greater understanding of the factors that influence degradation, maintenance specialists can build in greater cost certainty over a longer period. This in turn helps to incentivise international operators by ensuring that access charges can remain both competitive and transparent.

> “We’ve had to pull together a more detailed 40-year plan, and that has provided us with forward visibility of peaks in our renewals work bank. That really draws the eye to the big-ticket items that we have to deliver – and also to where extra consideration could perhaps have been taken to make sure those things were easy to do.”

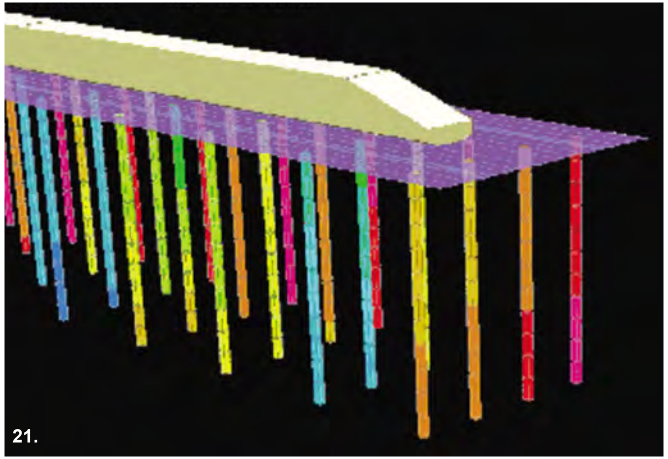
Robert Dean, Head of Route Engineering and Operations, HS1 Ltd

Operations and maintenance

Detailed information on the expected lifespan of assets and their components needs to be set out in the operations and maintenance regimes from day one, so that mechanisms can be put in place to monitor and assess their condition. A simple degradation curve, with concise details of how assets perform over time and in different environmental conditions, is a powerful tool for maintenance engineers – particularly if it is overlaid with live data on usage and wear. For HS1, most of the assets were cherry-picked from continental high-speed lines where they had been operating for 15 years, but operational data can reveal the impact of local factors such as rainfall and wind speed.

Technology is providing new ways of harnessing data to provide a 'live' representation of assets. Remote condition monitoring (RCM) is increasingly used beyond the construction phase to monitor the whole of the railway's lifecycle. HS1 is in talks with Network Rail to take LiDAR scans across the route and create a 3D model of the entire operating system. And building information management (BIM) software is being used to develop a holistic understanding of assets from cradle to grave. A BIM virtual model contains comprehensive data on everything from construction materials to lifecycle performance of an individual component, as well as how it connects to wider systems.

Today, digital twins take the BIM virtual model even further. As yet, there is no fully developed live model of a digital twin for railways. However, in practice, when developed in a targeted way to suit the unique operational requirements of a railway, digital twins can support its performance over its lifetime. The benefits will increase over the asset lifecycle.



The use of BIM software offers efficiency gains in the planning of new projects, but also in the maintenance of soft assets

The cost of retrospectively building up such datasets is a major consideration. For new mega-projects, the use of BIM, from feasibility through to operation for the entire route, offers efficiency gains. But for existing linear assets, where changes are made on average every 25 years, the benefits may not be immediately apparent.

However, BIM and digital twins have a clear role to play in the maintenance of soft assets, particularly as the focus on environmental protection intensifies. Soft assets are not linear or static – they continually change, grow or die back, affecting their ability to perform their function. Maintenance crews can benefit greatly from information regarding woodland and planting; for example, to stabilise banks or reduce runoff. Geospatial information about plants or habitats of special significance can be recorded and any replacement species or alterations can be updated in the live models, placing granular information in the hands of the onsite teams.

When to use innovation – and when not to

Research and development is an industry-wide challenge. High-speed rail is being designed and delivered across

BIM and digital twins have a clear role to play in the maintenance of soft assets, particularly as the focus on environmental protection intensifies. … Geospatial information about plants or habitats of special significance can be recorded and any replacement species or alterations can be updated in the live models.

the globe, and there is a clear requirement for all developers to play their part in managing innovations. One of the key areas of innovation within operations and maintenance is automation.

A lot of inspection data is binary – ascertaining whether or not an asset or piece of equipment is there – and requires no subjective human interpretation. This can be captured by remote sensors or drone-based image recognition software. Human-led inspections can then be less frequent and focus on areas such as degradation issues, where a more subjective approach is required.

The use of intelligent infrastructure is also increasing, and HS2 is reviewing various RCM solutions for reliability and whole-life costs. In particular, the sensitivity of the systems, and their potential to produce false positives, need to be carefully evaluated.

The use of cutting-edge technology is tempered by managing the associated risk. The need to protect mission-critical systems is paramount. Understanding risk profiles across systems in terms of health and safety, cybersecurity, performance, reliability and customer experience can inform decisions about where and how to use innovation. This has driven a move to bring in technology from sectors and geographies with similar risk profiles, such as aviation. In an environment such as a control centre, which requires hundreds of sub-systems to be integrated into a single complex system, it would be unwise to introduce the levels of risk associated with hosting multiple new technologies.

To manage the risks associated with innovation, there are four core strategies:

- Innovation labs and testing facilities. For example, advances in 3D design and computational fluid dynamics mean that detailed models can be used in areas such as tunnel design. Testing the acoustic impacts of the trains in this way has informed the design of porous portals

- Live operational test beds. HS1 is being used to assess acoustic barrier designs for HS2, allowing the options to be tested in a controlled environment in advance of the wholesale rollout. Testing needs careful risk management on a live railway, requiring a full understanding of who owns and manages that risk

- Progressive design, with careful management and phased rollout to enable real-world testing

- Global sharing of knowledge. For example, Spanish infrastructure owner Adif has a laboratory train that runs once a month and reports on works carried out, providing a light-touch assurance solution rather than physical inspection checks. The short length of the HS1 route currently makes having a similar inspection train cost-prohibitive, but as the high-speed network increases across the UK, this may become more attractive financially and in terms of efficiency.

Managing obsolescence

The market's appetite for proven technology creates a number of challenges when systems eventually become obsolete. This is the situation facing HS1's TVM 430 signalling system, which is being superseded by the international standard system, ETCS. HS1 is facing the challenge of managing the obsolescence of the current equipment and switching to the new system in the next ten to 15 years.

There is not a vast range of choice when it comes to products and services for use with a new system. Procurement is through long-term frameworks lasting between five and ten years, and the largest suppliers control most of the market. Moreover, if the system being designed is not a closed one, this limits the choice of technology further due to the difficulties of integrating it with the existing network. The compatibility of the technology with interfacing systems is probably more important than the technology itself.

For a signalling system, there is a clear business case to reduce the operating costs through having fewer control points. This results in larger signalling areas, which are generally supplied by a technology provider, so the scheme's control system is almost predetermined.

There is not a vast range of choice when it comes to products and services for use with a new system. … The compatibility of the technology with interfacing systems is probably more important than the technology itself.

Safety-critical elements such as interlocking are also usually provided by the same supplier.

The limited number of suppliers able to purchase and maintain signalling equipment means that changes are expensive, and this in turn affects obsolescence management. There is a fine balance to be struck in maintaining levels of spare equipment, which complicates planning for maintenance and future upgrades.


22.

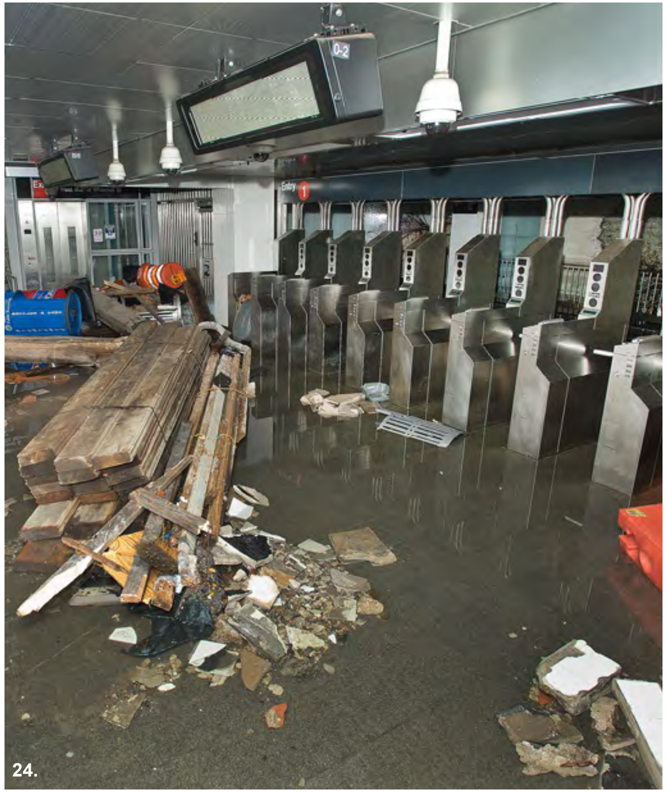
Sustainability and resilience

The world has changed radically since HS1 was built, but through embracing nature-based solutions, renewable energy and new approaches to passenger demand and digital security, it is prepared for whatever the future holds.

Key takeaways

- Schemes and enhancements need to appreciate the wider interfaces with domestic networks and the natural environment
- The inherent uncertainty and risks caused by climate change demand an industry-wide response
- A risk-based approach generates pragmatic solutions in areas such as flood protection and power distribution
- Future schemes will need to factor in provision for the transition to renewable energy and decarbonised railways
- Bringing a security specialist into the development team from the start ensures security is designed into every aspect
- Silos are a barrier to resilience

23.


24.

South Ferry subway station in New York was flooded during Hurricane Sandy

We rely on transport networks to maintain our economy and our way of life, through the movement of goods and people. Equitable and successful societies need a resilient public transport network to prosper and to foster social mobility, and high-speed rail has an increasingly important role to play in that.

The focus on resilience has increased over the past two decades, in the face of a number of known and emerging risks. The terrorist threat has become part of the rhythm of daily life in major cities in the wake of the 9/11 attacks on the US. Climate change has led to more frequent incidents related to weather extremes, such as flooding and landslips, causing major disruption to communities – a risk that will continue to increase over time. And the Covid-19 pandemic has created long-term disruption for transport networks, with public transport systems having to rethink travel demand. Resilience must address both shocks (emergency events) and stresses (more chronic, long-term issues) to the system.

On a high-speed railway project, resilience needs to be viewed in the context of the wider transport network. The connectivity of rail systems and the many interfaces with wider domestic services and infrastructure creates incredible complexity. The system is not just track, stations and operational technology, but also the natural environment and less tangible elements such as political and social structures. Passengers, visitors, and operations and maintenance staff are all human facets of the system. Designers, owners and operators need to consider all of this to plan properly for an increasingly uncertain future.

How HS1 approached resilience

During the design phase of HS1, all of the assets, systems and sub-components were assigned a risk level and failure factors. They were then scored to ascertain what resilience measures were required. This risk-based approach enabled the team to drive down cost, while maintaining the required levels of operational resilience. Key areas of focus included:

Energy: The route required three £12m electrification units. The SNCF standards dictated that each of these units needed a backup to mitigate disruption due to power failure, increasing the provision to six units with a total cost of £72m. Through the application of a risk-based approach, the team modelled the risk of more than one of the three units failing at any one time, and calculated that it was near zero. This resulted in reducing the proposed backup to one mobile unit.

Environmental measures: The main environmental risk in terms of resilience was flooding of the tunnels. The Thames Flood Prevention Scheme included barriers, bunds and sluice gates, but there was evidence that it would not withstand a 100-year storm event at the point where the CTRL tunnel passed under the Thames. Should the bunds be breached, this would in turn flood the tunnel. The team explored various flood protection measures and modelled the 100-year storm scenario in terms of disruption to services and the cost of pumping out the tunnels and repairing them. This enabled them to understand the implications of a storm event and apply a risk-based approach to the design development.

Emergency preparedness: CTRL sought advice from other bodies with similar levels of technical and operational complexity, including the Royal Navy. The main focus of emergency preparedness on submarines, for example, was repeatedly drilling teams in various scenarios to embed an automatic response. CTRL has adopted a similar approach so that the protocols become second nature. There is an overriding rule to act on any detector triggered in the system, which activates the emergency procedures and a simultaneous investigation into the cause of the alert. This enables the team to prepare for shutdown, while identifying false alarms and minimising disruptive full shutdown incidents.

25.

The CTRL tunnel passed under the Thames, necessitating the development of measures to prevent flooding

Control centres: The decision to house a single operations system within the Ashford control centre introduced a resilience risk. This is partly managed by separating systems to allow them to have discrete cybersecurity and fire screening.

In the face of new and emerging threats, HS1's approach to sustainability and resilience has evolved. Key areas of focus include climate change, nature-based solutions, cybersecurity measures and the developing field of travel demand management.

Climate adaptation and mitigation

Climate change has had little direct impact on the HS1 infrastructure to date, but the wider UK rail system has suffered closures due to soaring temperatures and storm damage. Design assumptions based on a 50- or 100-year event need to be revisited. The HS1 drainage is performing well but, alongside the risk of runoff, this is an area where an updated approach may be necessary. Rail temperatures are being managed through tactical interventions, such as painting critical areas white to reflect heat and prevent buckling.

26.

HS1 benefited from being embedded in the environment and using nature-based solutions, such as strategic planting and green corridors, to solve engineering challenges like the risks posed by flooding and runoff. New infrastructure needs to further develop this approach.

In terms of mitigating climate change, substantial megawatt hours of energy could be saved by turning off equipment out of operational hours. This is complicated by the way power distribution is owned and managed on HS1. The energy is paid for by the train operator, but all the assets, such as feeder stations and autotransformer sites, are owned, operated and maintained by UK Power Networks under a 50-year concession. Therefore, the risk of equipment failing to restart when the service resumes rests with the power supplier.

Renewable energy presents another challenge. Fundamentally, rail has to decouple its reliance on fossil fuels to power the network. Owners and designers need to consider how much lineside space may be needed for the future provision of energy development, such as solar photovoltaics for buildings and battery energy storage. The transition to renewable energy and decarbonised railways will require the industry to form close partnerships with other sectors, such as energy and technology.

Data and security

The security landscape has changed dramatically over the past 15 years. New threats have emerged and the nature of assets has changed completely, with a far greater reliance on internet-enabled systems and data. In terms of physical security, the changing role of stations presents new challenges. As designers seek to balance functional requirements with retail and leisure facilities, people tend to dwell for longer. Concourses are designed to be enjoyed, which means security measures, fire and evacuation strategies need to be as unobtrusive as possible.

The non-physical world is perhaps harder to protect. As we continue to generate, hold and use more data, we create more potential for cybercrime. The increased adoption of BIM, for example, creates both opportunities and threats; with the increased availability of detailed designs comes the risk of that information falling into the wrong hands. Work continues on finding the best ways to control and protect this data.

Sustainability and resilience

On HS1, a fully auditable process of threat and risk assessments was adopted, and this is being replicated on HS2. Having a security specialist embedded within the development team from the start ensures that security is designed into every aspect of the scheme.

Digital technology can also be used to enhance resilience. The risk associated with the single control centre has been managed through the use of cloud-based services, which enable teams to work from secure hubs and a backup control room in emergency situations.

Covid-19 – preparing for the unexpected

The Covid-19 pandemic has highlighted the need for capacity risk scenario planning. The operations teams had to plan for the reopening and smooth running of stations and public places in accordance with social distancing requirements. These stipulated that HS1 trains and stations could run at a maximum of 35% capacity. Operations within St Pancras were a particular challenge, with the Eurostar reduced from 50 services a day to just four. At peak times, the demand from passengers was greater than this reduced capacity.

This highlighted a number of issues around operational resilience: space for queuing in stations and seating capacity in trains were both limited. At St Pancras, the queue often stretched out into the retail area. Timetabling pressures and lack of rolling stock prevented the expansion of services to cater for more, socially distanced passengers.

In light of changing travel demand and behaviours – whether due to the pandemic or policy interventions around climate change and congestion – we can now use agent-based modelling. This simulates the actions and interactions of diverse individuals (agents) to better understand and predict travel patterns across towns, cities and or countries. Doing this enables us to better plan for future integrated transport systems.

Capacity constraints and managing demand

There is still untapped capacity on the HS1 network, and there is an opportunity to provide more and faster services to the eastern side of Kent and east London. High-value and lightweight freight provision is being explored, due to the demand for same-day deliveries driven by online retailers.

The main operational constraint is at the stations. St Pancras in particular is heavily constrained: the three domestic platforms are at capacity at peak times,

Covid-19 created unforeseen problems for Eurostar and highlighted issues around operational resilience creating a bottleneck on the line. Some services are overcrowded, making seat provision from Ebbsfleet North a challenge. Extending the footprint of the station would be expensive, and the rolling stock also limits any increase to passenger numbers. However, there is potential for expanding the footprint and size of Stratford station.

Prime Minister Tony Blair officially opens Section 1 of the CTRL at Waterloo station on 28 September 2003

The change in travel and working patterns driven by the pandemic has created an opportunity to rethink how we approach transport resilience more widely. Travel demand management (TDM), for example, shifts the emphasis from building more to enabling assets to do more, reducing carbon emissions in the process. By collecting and analysing user data, rail companies can begin to direct passengers towards periods of lower demand through strategies such as discounted tickets or marketing campaigns. The rise in home working and flexible working patterns ushered in by the pandemic could help to smooth peak commuter times, but TDM requires wider buy-in to influence travellers.

The short history of HS1 shows not only how transformational a rail project can be – to passengers, communities, businesses, even entire cities – but also how uncertain the future is. Since 2007, the world has faced energy and financial crises, terrorist threats, a global pandemic and an intensifying climate crisis. If operators and infrastructure owners can bring lasting resilience to railway networks, and show customers that trains are a reliable, enjoyable and sustainable way to travel, the modal shift from road to rail could become a reality.

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